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ORIGINAL PAPER

Comparative analyses of phenolic compounds and antioxidant properties of Chinese jujube as affected by geographical region and drying methods (Puff-drying and convective hot air-drying systems)

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Abstract

This work was aimed to investigate the effect of geographical regions and drying methods on phenolics, flavonoids, antioxidant properties, sugars, and acid content of Chinese jujube. The results revealed significant differences in the antioxidant properties and phenolics content of jujube as affected by geographical origin (Hebei, Shandong, Shanxi, Xinjiang, and Henan province) and drying method (puff-drying and convective hot air-drying). The highest concentrations of DPPH (90.01 ± 0.48% DW), FRAP (0.76 ± 0.05 mM TEAC/g DW), TAC (187.16 ± 2.66 mg AEAC /100 g DW), TFC (3.03 ± 0.09 g REAC /100 g DW), TA (1.15 ± 1.10 g CA /100 g DW) and TS (75.10 ± 1.35 g GE /100 g DW) were recorded in the puff dried jujube samples from Xinjiang province. However, samples from Hebei had highest concentration of TPC (2.82 ± 0.13 g GAAC /100 g DW), TANC (46.47 ± 1.64 mg anthocyanin /100 g DW) and TCC (4.27 ± 0.88 mg β-carotene /g DW), while most ABTS (54.45 ± 0.72 μM TEAC/g DW) was recorded in the jujube samples from Henan. Likewise, jujube from Shandong demonstrated highest ferrous chelating activity (89.17 ± 0.52% DW). Similarly, puff dried jujube from Xinjiang had the highest concentration of gallic acid (29.52 ± 0.15 μg/g DW), phloridzin (16.73 ± 0.45 μg/g DW) and cianidanol (60.87 ± 0.71 μg/g DW), whereas, higher concentrations of L-epicatechin (143.59 ± 0.69 μg/g DW) and rutin (10.94 ± 0.78 μg/g DW) were recorded in Hebei, and caffeic acid (66.21 ± 0.88 μg/g DW) in Shanxi province. Conclusively, the bioactive profile of Chinese jujube varies depending upon their geographical origin or drying method used, with puff-drying being a better option to retain the bioactivity.

Keywords Antioxidant properties · Chinese jujube · Drying methods · HPLC-DAD · Phenolic compounds

Introduction

The Chinese jujube (*Ziziphus jujuba* Mill.), belongs to family Rhamnaceae and is native to China with a history of more than 4000 years. It is widely distributed in tropical and subtropical regions of America and Asia [1]. Moreover, since last few years it is being cultivated in Italy, Spain, Malta, and Southeastern Europe. The Chinese jujube is well known for its functional and nutritional properties, including high content of polysaccharides, sugars, minerals, vitamin C, organic acid, polyphenols and other antioxidants [2]. The immature fruit possesses smooth green color, tastes like an apple, and contains a single hard pit. However, when ripened, the color of fruit changes to purplish black or brown, and peel becomes wrinkled [3]. The Chinese jujube is used in several foods accompanied by diverse processing i.e. frying, boiling, fermentation, drying, and steaming [4]. Additionally, it is used in traditional Chinese medicine for its functional properties including antibechic, palliative, and analeptic effects [5].

The climatic conditions, source of irrigation, and soil type are the key factors responsible for the quality of Chinese jujube in a given geographical location. Resultantly, the

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environmental differences may affect the accumulation of antioxidants and phenolics in Chinese jujube. Geographically, Xinjiang is in Northwest of China and exhibits higher differences in day and night temperatures. The region has a longer period of intense sunshine with low annual precipitation and is less humid [6]. Hebei is a coastal province in Northern China with a continental monsoon climate, higher annual precipitation, hot and humid summers followed by cold dry winters [7]. Likewise, Shandong is also a coastal province located in the East China region with a temperate climate, transitioning between humid continental and humid subtropical zones with four distinct seasons. The vast majority of annual precipitation occurs during summer monsoon [8]. Shanxi, a landlocked province situated in the North of China exhibits four distinct seasons with sufficient sunshine and synchronous heat and rain [9]. Similarly, Henan is also a landlocked province located in the central part of the country with temperate climate. It has distinct seasonal climate characterized by the dry winter and hot humid summer attributed to East Asian monsoon [10].

Generally, the Chinese jujube is harvested in autumn, with a postharvest shelf life of about 10 days under normal storage conditions [11]. Thus, it has become imperative to look for preservation methods to increase the postharvest shelf life of the fruit. Until now, dehydration is the most used method to preserve the fruit. Apart from shelf life extension, dehydration decreases weight and volume of the fruit leading to cost reduction in transport and storage. Among different drying techniques, sun drying is most commonly used. Albeit direct exposure to sun light, the drying parameters are not controlled, leading to heterogeneity in the quality characteristics of the final product [12]. Now-a-days, puff-drying is readily available as a fast and commercially viable alternate for dehydration of vegetables and fruits. The puff-drying is performed in a superheated steam at elevated pressure. It rapidly brings the internal fruit water temperature above its atmospheric boiling point, immediately leading to flash steam. The process results in the development of porous structure of the finished product. Various fruits including apples, blueberries, and potatoes have been successfully dried using puff-drying [13–15]. Previous work also reported higher amount of total phenolic compounds, carotenoids, and flavonoids in puff-dried seedless grapes when compared to air-dried samples. The puff-dried samples also exhibited better acceptability and organoleptic properties [16]. In another study, puff-dried yellow-fleshed peach crisps exhibited higher concentrations of carotenoids and DPPH radical scavenging ability when compared to hot-air dried samples. Moreover, puff-dried peach crisps were crispier than vacuum freeze-dried samples [17]. Likewise, another study has revealed that freeze-drying pre-treatment coupled with puff-drying increased the retention of ascorbic acid, total phenolics, total carotenoids, and total flavonoids in mango, pitaya and papaya chips [18]. The favorable characteristics of the puff dried products are visible in the form of ambient temperature storage, fast rehydration, and low transportation or storage costs. Moreover, the consumers preferences for puff dried products are mostly attributed to their unique flavor, attractive appearance, and soft crunchy texture [19].

Previously, sixteen types of fully ripened and air-cured jujube samples were investigated for their flavonoids, phenolics, and antioxidant activities. Among different jujube cultivars, large variations in total flavonoids and phenolics, along with individual phenolic compounds were observed [20]. Likewise, two jujube cultivars were analyzed for pigments, phenolics, and antioxidant activities over six stages of fruit development. Reduction in chlorophylls, anthocyanins, β-carotene, and antioxidant activity was witnessed throughout the fruit development, while lutein content decreased during first stage and subsequently increased to maximum level at last stage of development [21]. The comparison of different drying methods i.e. vacuum-microwave drying, convective drying, freeze drying, and a combination of convective pre-drying and vacuum microwave finish drying on bioactive content and sensory properties of jujube was also made. The result revealed significant differences among different cultivars and drying methods [22]. The geographical region owing to variation in soil type, source of irrigation and climate condition may alter the quality of Chinese jujube. Though some work has been have carried out on few drying methods, the aforementioned studies did not investigate the effects of geographical regions in combination with drying methods on the phytochemical profiles of jujube. Therefore, current work was designed to explore the impact of puff-drying and convective hot air-drying systems on phenolics, flavonoids, antioxidant properties, total sugars and acid contents of Chinese jujube from different geographical origin. Moreover, it would be interesting to understand the concentration of bioactive compounds in the puff dried fruits to increase their consumption and bring improvements in puff-drying technology. Thus, the instant study was planned to investigate the impact of geographical origin and drying methods on the major bioactives of Chinese jujube.

Materials and methods

Chemicals and reagents

Hydrochloric acid, formic acid, ferric chloride, sodium acetate, acetic acid, monosodium phosphate, disodium phosphate, 2,2-diphenyl-1-picrylhydrazyl radical (DPPH), 2,4,6-tris (2-pyridyl)-s-triazine (TPTZ), 2,2′-azino-bis (3-ethylbenzothiazoline-6 sulfonate) diammonium salt

(ABTS), potassium persulfate, sodium sulfate, sodium nitrite, aluminium trichloride, sodium hydroxide, rutin hydrate, potassium chloride, ferrous chloride, ferrozine, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), glucose, sulfuric acid, phenolphthalein, and ascorbic acid were of analytical grade and purchased from Sigma-Aldrich (St. Louis, MO, USA). The phenolic standards; cianidanol, rutin, phloridzin, L-epicatechin, hydroxycinnamic acid, gallic acid, ferulic acid, chlorogenic acid, caffeic acid, and catechol were acquired from the Sinopharm Group Co. Ltd. China. The water used for HPLC analyses was obtained from Milli-Q purification system (Millipore Corp., Billerica, MA, USA).

Sample collection

Fresh Lang Chinese jujube samples were harvested at optimal ripeness in August 2018 from five different provinces of P.R. China; Hebei (39° N 116° E), Shandong (35° N, 117° E), Shanxi (37° N, 111° E), Xinjiang (41° N, 85° E), and Henan (34° N, 113° E). Approximately, 5 kg fruits from randomly selected trees (15–20 fruits per tree) were collected and posted via fast courier to School of Food and Biological Engineering. The samples were received at the research laboratories within 24 h.

Drying of Chinese jujube

This study was designed to compare antioxidant properties and phenolic content of Chinese jujube as affected by drying methods (convective hot air drying and puff-drying) and geographical regions. Fresh Chinese jujube was used as a reference to compare the drying methods. Prior to drying, approximately 5 kg sample from each province was pitted and cut into small pieces. The convective hot air drying was performed at School of Food and Biological Engineering, while, puff-drying was carried out at Jiangsu Kaiyi Intelligent Technology Co., Ltd. Yanqiao Industrial Park, Wuxi, Jiangsu, China.

The convective hot air dryer was equipped with temperature and humidity controllers. The temperature modulation was achieved through an electrical heating system coupled with an axial and turbulent flow fans to blow the hot air uniformly inside the drying chamber. The temperature of the dryer was controlled by a proportional-integral-derivative system (Omron, E5CN model, Tokyo, Japan). The relative humidity was maintained through humidification solenoid valve. The air velocity within the drying chamber was measured by an anemograph (XY1000-1F, XieYa, Beijing, China). The temperature, air velocity, and relative humidity of convective hot air dryer were maintained at 65 °C, 2.0 m/s, and 60%, respectively [23, 24]. After convective hot air drying, the final moisture content of the samples approached 6%.

The semi-commercial puff-drying system (Fig. 1) was used for drying of Chinese jujube. Purposely, each batch of fruit flesh was placed inside the vessel of puff dryer. The flesh was vacuumed and puffed at 0.03 MPa for 12 minutes. In puff dryer; the first, second, third, fourth, fifth, and sixth temperature–time sequence followed were: 86 °C for 30 min, 85 °C for 30 min, 83 °C for 30 min, 80 °C for 30 min, 76 °C for 30 min, and 73 °C for 30 min, respectively. The final

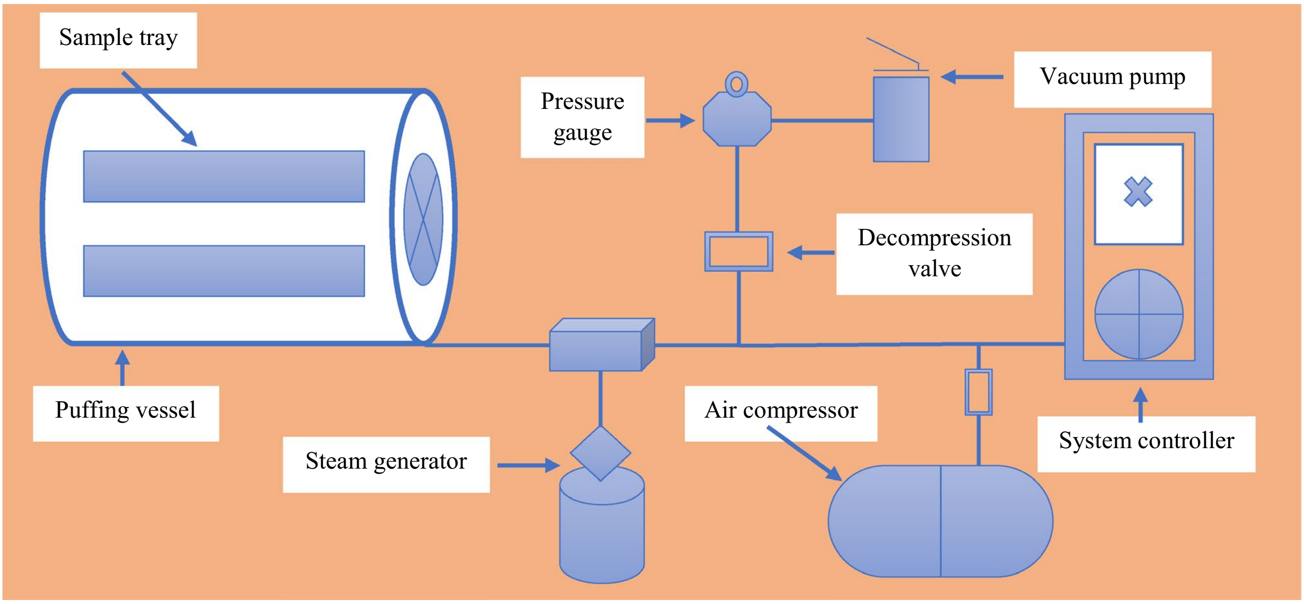

Fig. 1 Schematic diagram of puff-drying system

moisture content of the fruit approached 5% after puff-drying. The dried samples were ground to fine powder in a small electric grinder (QE-100, Zhejiang YiLi Tool Co., Ltd, China) by passing through 500 μm mesh. Three batches were prepared for each drying system.

Reference chemical analyses

The Chinese jujube sample (fresh = 5 g, dried = 0.2 g) was extracted for phytochemical analyses using 20 mL methanol (80%) in an ultrasonic bath (continuous, 20 kHz, 25 ℃ and 30 min). It is pertinent to mention that aqueous methanol provides better extraction yield with strong antioxidant properties [25, 26]. The extraction mixture was centrifuged for 10 min at 3000 rpm followed by filtration through Whatman No. 1 filter paper. The residue was collected and re-extracted according to the procedure described above. The two extracts were combined, diluted with 80% methanol up to the mark and stored at 4 ℃ in an airtight container before use.

The DPPH radical scavenging assay and total antioxidant capacity (TAC) of Chinese jujube extract were measured according to the previously reported protocols [27]. The standard solutions of ascorbic acid (0–12 μg/mL) were used to create the calibration curve. The results for DPPH and TAC were expressed as inhibition % dry weight (DW), and milligrams (mg) of ascorbic acid equivalent antioxidant content (AEAC)/100 g DW, respectively. The total polyphenol content (TPC) of the extracts was measured through standard colourimetric assay with Folin-Ciocalteu reagent, while, the results were presented as gram (g) of gallic acid equivalent antioxidant capacity (GAAC)/100 g DW [28].

The ferric reducing antioxidant power (FRAP) assay of jujube extracts was carried out according to the previously reported method [29]. The Trolox standard solution (0.1-1 mM/mL) was used to draw the calibration curve. The results were reported as millimole (mM) of Trolox equivalent antioxidant capacity (TEAC)/g DW. Likewise, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS) free radical scavenging capacity of extracts was determined using the previously reported protocol [30]. The standard curve was generated using 70% ethanolic solution of Trolox (0-500 μM/mL). The results were expressed as micromole (μM) of TEAC/g DW. The ferrous chelating capacity of jujube extract was determined according to the previously reported methods [31, 32]. The acquired results were presented as percent chelation capacity DW.

The total flavonoid content (TFC) of jujube extract was quantified using spectrophotometric method [33]. The standard solution of rutin (10–300 μg/mL) was used to draw the calibration curve, while, the results were expressed as g of rutin equivalent antioxidant content (REAC)/100 g DW. The total anthocyanin content (TANC) of jujube extract was quantified by mean of pH-differential [34]. The reported results were expressed as mg of anthocyanin/100 g DW. The total carotenoid content (TCC) of extract was measured through an earlier reported method [35]. The acquired results were presented as mg of β-carotene/g DW.

The total sugars (TS) were quantified using phenol-sulfuric acid method [36]. The reported results were expressed as g of glucose equivalent (GE)/100 g DW. Likewise, total acid (TA) in jujube extract was analyzed according to the method of Chinese Pharmacopeia [37]. The acquired results were reported as g of citric acid (CA)/100 g DW. All the results presented are average of three replicates. The interested readers can also refer to other sources for full coverage of analytical methods [38–42].

Quantification of individual phenolic compounds

The extraction of phenolic compounds was carried out by following the previously reported method [43] with slight modifications. The Chinese jujube sample (fresh 10 g; dried 5 g) was mixed with 200 mL of methanol followed by sonication for 30 min at 25 °C. The resultant mixture was centrifuged for 10 min at 3000 rpm. Thereafter, the vacuum filtration was performed, supernatant was collected in a flask specifically designed for vacuum filtration, while, the residue was re-extracted. The two filtrates were combined and evaporated through rotary evaporator (45 °C) to bring the final weight down to < 15% of the original filtrate. The concentrated extract was passed through 0.45 μm membrane filter and transferred to a vial prior to injection into HPLC-DAD system. The standard solutions of phenolic compounds (2000 μg/mL) were prepared in HPLC grade methanol. The stock solutions were diluted to prepare the working standards of 0.1, 2.5, 5, 50, 100, and 1000 μg/mL. The dark bottles were used to store the working standards at 4 °C prior to injection into HPLC-DAD system.

The Shimadzu system (LC 20A, Tokyo, Japan), equipped with autoinjector (SIL-20AC), autosampler (SIL-20 AC), a binary pump (LC-20AD), degasser (DGU-20A3), communication bus module (CBM 20A), column oven (CTO-20AC), and DAD detector (SPDM20A) was used for analyses of phenolic compounds. The reversed phase Zorbax SB-C18 column (Agilent Technologies, particle size = 5 μm, 250 mm 149 × 4.6 mm) was used for the separation of phenolics and flavonoids. The mobile phase A and B comprised of 0.1% formic acid and 100% methanol, respectively. The following gradient profile was set: 0.0–5.0 min linear gradient 0–10% eluent B; 5.0–20.0 min linear gradient 40% eluent B; 20.0–32.0 min linear gradient 45% eluent B; 32.0–45.0 min linear gradient 50% eluent B; 45.0–70.0 min linear gradient 80% eluent B; 70.0–75.0 min linear gradient 5% eluent B. The injection volume for all the working standards and samples was 5 µL, and the flow rate was maintained at 0.2 mL/min [41]. The spectra of chromatographic peaks were observed between 210 and 500 nm. The results were expressed in microgram per gram (µg/g) DW.

Statistical analyses

The statistical analyses was carried out using Statistix software version 10 (Tallahassee, USA). The acquired data for each parameter was subjected to two-factor factorial in randomized complete block design to determine the level of significance ($p < 0.05$) followed by Tukey's test for separation of means [44]. The principal components analyses (PCA) was carried out using Soft Statistica version 13.1 (TIBCO Software, USA), and Minitab version 19.1 (Pennsylvania, USA).

Results and discussion

Antioxidant capacities assays

The antioxidant activities of Chinese jujube were affected by both drying methods and geographical origin. The effects of drying methods on antioxidant activities have been summarized in Table 1. The DPPH radical scavenging activity of fresh, convective hot air dried, and puff dried jujube was in the range of 58.59 ± 1.34–72.17 ± 0.62, 60.28 ± 1.07–81.87 ± 1.47 and 75.88 ± 1.54–90.01 ± 0.48%, respectively. The highest DPPH activity was recorded in puff dried jujube from Xinjiang province, whereas samples from Shandong exhibited lowest activity. The samples acquired from Shandong exhibited lower DPPH activity after convective hot air drying as compared to fresh jujube. Likewise, highest DPPH activity for convective hot air-dried jujube was observed for Xinjiang. In addition, fresh jujube procured from Henan and Xinjiang reported lowest and highest DPPH activity, respectively. The FRAP contents of Chinese jujube harvested from five regions were in the range of 0.25 ± 0.02–0.42 ± 0.01, 0.41 ± 0.02–0.63 ± 0.02,

Table 1 The influence of drying methods and geographical regions on antioxidant capacities; DPPH (% DW), FRAP (mM TEAC/g DW), ABTS (µM TEAC/g DW) and ferrous chelating activity (% DW) of Chinese jujube

Provinces	Parameters	DPPH	FRAP	ABTS	Ferrous activity
Hebei	Fresh (control)	66.63 ± 1.67^{fA}	0.25 ± 0.02^{i}	17.11 ± 2.20^{j}	60.42 ± 2.04^{fg}
	Hot air drying	71.45 ± 0.58^{e}	0.48 ± 0.03^{f}	21.95 ± 1.20^{hi}	67.96 ± 1.17^{de}
	Puff drying	82.72 ± 0.94^{b}	0.66 ± 0.03^{bc}	28.82 ± 0.64^{fg}	82.82 ± 1.51^{b}
Shandong	Fresh (control)	63.63 ± 0.84^{fg}	0.34 ± 0.04^{gh}	24.61 ± 1.67^{gh}	62.64 ± 2.08^{efg}
	Hot air drying	60.28 ± 1.07^{gh}	0.49 ± 0.02^{ef}	19.28 ± 0.84^{ij}	76.09 ± 1.14^{c}
	Puff drying	77.01 ± 0.54^{cd}	0.71 ± 0.03^{ab}	32.61 ± 0.15^{ef}	89.17 ± 0.52^{a}
Shanxi	Fresh (control)	68.43 ± 0.99^{f}	0.26 ± 0.02^{hi}	28.07 ± 1.32^{g}	64.06 ± 1.32^{ef}
	Hot air drying	72.76 ± 1.29^{de}	0.41 ± 0.02^{fg}	37.31 ± 1.76^{d}	57.39 ± 1.03^{g}
	Puff drying	81.52 ± 0.60^{bc}	0.56 ± 0.01^{de}	49.70 ± 0.49^{b}	72.54 ± 2.11^{cd}
Xinjiang	Fresh (control)	72.17 ± 0.62^{e}	0.42 ± 0.01^{fg}	25.73 ± 1.23^{gh}	48.44 ± 1.21^{h}
	Hot air drying	81.87 ± 1.47^{b}	0.63 ± 0.02^{cd}	33.39 ± 1.32^{de}	57.73 ± 1.85^{g}
	Puff drying	90.01 ± 0.48^{a}	0.76 ± 0.05^{a}	48.09 ± 0.93^{b}	65.70 ± 1.54^{ef}
Henan	Fresh (control)	58.59 ± 1.34^{h}	0.39 ± 0.02^{g}	43.53 ± 1.66^{c}	47.75 ± 1.85^{h}
	Hot air drying	65.12 ± 1.49^{f}	0.56 ± 0.05^{de}	33.53 ± 1.66^{de}	67.38 ± 0.58^{de}
	Puff drying	75.88 ± 1.54^{de}	0.72 ± 0.01^{ab}	54.45 ± 0.72^{a}	77.29 ± 0.85^{bc}
Drying method	Fresh (control)	65.89 ± 5.11^{cA}	0.33 ± 0.07^{c}	27.81 ± 9.69^{b}	56.66 ± 7.93^{c}
	Hot air drying	70.29 ± 8.19^{b}	0.51 ± 0.08^{b}	29.09 ± 7.95^{b}	65.31 ± 7.86^{b}
	Puff drying	81.42 ± 5.60^{a}	0.68 ± 0.07^{a}	42.73 ± 11.29^{a}	77.50 ± 9.06^{a}
Provinces	Hebei	73.60 ± 8.25^{bA}	0.46 ± 0.20^{d}	22.62 ± 5.88^{e}	70.40 ± 11.39^{b}
	Shandong	66.97 ± 8.85^{c}	0.51 ± 0.18^{c}	25.50 ± 6.70^{d}	75.96 ± 13.26^{a}
	Shanxi	74.23 ± 6.66^{b}	0.41 ± 0.15^{e}	38.36 ± 10.85^{b}	64.66 ± 7.59^{c}
	Xinjiang	81.35 ± 8.93^{a}	0.60 ± 0.17^{a}	35.73 ± 11.36^{c}	57.29 ± 8.63^{d}
	Henan	66.53 ± 8.73^{c}	0.55 ± 0.16^{b}	43.83 ± 10.46^{a}	64.14 ± 15.03^{c}

[A] Mean value in a column sharing different letter are statistically different at $p < 0.05$

DPPH 2,2 diphenyl-1-picrylhydrazyl radical, *FRAP* ferric reducing antioxidant power, *ABTS* 2,2′-azino-bis (3-ethylbenzothiazoline-6 sulfonate) diammonium salt, *TEAC* trolox equivalent antioxidant capacity and 0.56 ± 0.01–0.76 ± 0.05 mM TEAC/g for fresh, hot-air dried, and puff dried samples, respectively. The puff dried jujube from all geographical locations exhibited higher FRAP contents when compared to hot air-dried jujube. The FRAP concentration of puff dried jujube from Xinjiang and Shanxi exhibited highest and lowest antioxidant capacities, respectively. Similarly, fresh and convective hot air-dried jujube from Xinjiang reported highest FRAP concentration, however, the lowest content was observed in samples obtained from Shanxi.

The ABTS assay values for fresh, convective hot air dried and puff dried jujube were in the range of 17.11 ± 2.20–43.53 ± 1.66, 19.28 ± 0.84–37.31 ± 1.76, and 28.82 ± 0.64–54.45 ± 0.72 µM TEAC/g, respectively. Similarly, ferrous chelating activity varied between 47.75 ± 1.85–64.06 ± 1.32, 57.39 ± 1.03–76.09 ± 1.14, and 65.70 ± 1.54–89.17 ± 0.52% for fresh, convective hot air dried, and puff dried jujube, respectively. The higher values for ABTS and ferrous chelating activity of puff dried jujube were observed for Henan and Shandong provinces, respectively, whereas Hebei and Xinjiang recorded comparatively lower values. Likewise, the hot air-dried jujube from Shandong and Henan revealed lower values of ABTS assay as compared to fresh samples, while, hot air-dried jujube from Shanxi exhibited lower ferrous chelating activity (57.39 ± 1.03%) when compared to fresh fruit (64.06 ± 1.32%).

In comparison, puff-dried Chinese jujube revealed better results for DPPH, FRAP, ABTS and ferrous chelating activity as compared to those dried under hot air. The comparison of provinces explicated highest values of DPPH and FRAP in samples obtained from Xinjiang, ABTS from Henan and ferrous chelating activity from Shandong. Similar trends have also been observed in previous studies [43, 45]. The high content of DPPH and FRAP in Xinjiang province might be attributed to higher intensity of sunshine and low annual precipitation. In addition, Henan and Shandong have hot, humid summer and higher annual precipitation owing to monsoonal influences, affecting ABTS and ferrous chelating activity of Chinese jujube.

Phytochemical screening

The TAC for fresh, convective hot air dried and puff dried jujube was in the range of 116.33 ± 1.90–163.89 ± 1.52, 134.36 ± 2.63–146.12 ± 2.05, and 166.68 ± 1.27–187.16 ± 2.66 mg AEAC /100 g, respectively (Table 2). The highest content of TAC for puff dried samples was observed for Xinjiang (187.16 ± 2.66 mg AEAC 100/g) followed by Shandong, Hebei, Shanxi, and Henan. The most TAC for hot air-dried jujube was recorded from Shanxi province. However, hot air-dried jujube from Shandong and Xinjiang exhibited lower TAC as compared to fresh samples. This may be due to direct exposure of fruit to the heat that led to loss of antioxidant properties. The TPC of Chinese jujube harvested from five regions were in the range of 0.98 ± 0.06–1.42 ± 0.03, 1.51 ± 0.05–2.15 ± 0.02, and 2.41 ± 0.15–2.82 ± 0.13 g GAAC 100/g for fresh, convective hot-air dried, and puff dried samples, respectively. The highest and lowest TPC was recorded for Hebei and Shanxi for puff dried and convective hot air-dried jujube, respectively. Similarly, fresh jujube had highest TPC for Xinjiang, and lowest for Shanxi.

The TFC for fresh, convective hot air-dried and puff dried jujube from all the geographical locations were in the range of 0.85 ± 0.03–1.43 ± 0.05, 1.10 ± 0.05–2.15 ± 0.03 and 1.38 ± 0.03–3.03 ± 0.09 g REAC 100/g, respectively. The highest TFC value was observed for puff dried jujube from Xinjiang followed by Henan, Shanxi, Hebei, and Shandong. The jujube samples from Hebei and dried through hot air recorded lowest TFC value, while highest was observed for Xinjiang. Likewise, fresh jujube from Xinjiang and Hebei contained highest and lowest TFC, respectively. The TANC for fresh, convective hot air dried and puff dried jujube was in the range of 22.54 ± 2.58–33.06 ± 1.94, 20.48 ± 2.51–40.06 ± 1.44, and 31.62 ± 1.69–46.47 ± 1.64 mg anthocyanin/100 g, respectively. Higher TANC values for puff dried jujube was observed in samples from Hebei followed by Xinjiang, Shanxi, Shandong, and Henan, respectively. The hot air-dried jujube from Shandong, Shanxi, and Henan contained lower TANC values as compared to fresh jujube. The TCC of fresh, convective hot-air dried, and puff dried jujube from all the locations ranged between 1.88 ± 0.08–2.62 ± 0.20, 1.87 ± 0.06–3.01 ± 0.14, and 2.80 ± 0.27–4.27 ± 0.88 mg β-carotene/g, respectively. In puff dried jujube, highest TCC was recorded for Hebei and lowest for Henan. Likewise, the convective hot-air dried jujube from Hebei and Xinjiang recorded lower TCC as compared to fresh jujube. In addition, fresh jujube presented highest TCC for Shandong and lowest for Henan.

The mean comparison test performed for fresh, hot air and puff-drying system indicated the superiority of puff-drying in terms of retaining higher antioxidant properties. Likewise, the mean comparison among provinces revealed higher values of TAC and TCC from Shandong, TANC from Hebei, TPC and TFC in samples from Xinjiang. The higher contents of TPC and TFC in Xinjiang province might be due to environmental conditions and soil properties of the region. The results for antioxidant properties of Chinese jujube are in agreement to the previous studies [1, 46, 47].

Acid and sugar content

The quality of fruit in the market is variable owing to its geographical origin, agronomic practices and type of cultivar.

Table 2 The influence of drying methods and geographical regions on total antioxidant assays; TAC (mg AEAC /100 g DW), TPC (g GAAC /100 g DW), TFC (g REAC /100 g DW), TANC (mg anthocyanin /100 g DW) and TCC (mg β-carotene /g DW) of Chinese jujube

Provinces	Parameters	TAC	TPC	TFC	TANC	TCC
Hebei	Fresh (control)	127.01 ± 1.61^{iA}	1.21 ± 0.03^{hi}	0.85 ± 0.03^{k}	33.06 ± 1.94^{cd}	2.16 ± 0.03^{de}
	Hot air drying	141.60 ± 3.16^{fgh}	2.15 ± 0.02^{de}	1.10 ± 0.05^{ij}	40.06 ± 1.44^{b}	1.87 ± 0.06^{e}
	Puff drying	175.05 ± 1.32^{bc}	2.82 ± 0.13^{a}	1.47 ± 0.02^{f}	46.47 ± 1.64^{a}	4.27 ± 0.88^{a}
Shandong	Fresh (control)	163.89 ± 1.52^{de}	1.22 ± 0.04^{hi}	1.02 ± 0.08^{j}	23.87 ± 1.26^{ef}	2.62 ± 0.20^{cde}
	Hot air drying	143.89 ± 1.58^{fg}	1.75 ± 0.01^{fg}	1.24 ± 0.03^{ghi}	20.48 ± 2.51^{f}	3.01 ± 0.14^{bcd}
	Puff drying	181.02 ± 1.05^{ab}	2.74 ± 0.25^{abc}	1.38 ± 0.03^{fg}	31.95 ± 1.58^{cd}	4.00 ± 0.44^{a}
Shanxi	Fresh (control)	116.33 ± 1.90^{j}	0.98 ± 0.06^{i}	1.21 ± 0.01^{hi}	31.59 ± 1.10^{cd}	2.16 ± 0.04^{de}
	Hot air drying	146.12 ± 2.05^{f}	1.51 ± 0.05^{gh}	1.71 ± 0.10^{e}	27.62 ± 1.87^{de}	2.45 ± 0.08^{de}
	Puff drying	174.96 ± 1.65^{bc}	2.41 ± 0.15^{cde}	2.21 ± 0.44^{c}	40.16 ± 0.70^{b}	3.54 ± 0.27^{abc}
Xinjiang	Fresh (control)	155.42 ± 2.59^{e}	1.42 ± 0.03^{gh}	1.43 ± 0.05^{f}	25.40 ± 2.09^{ef}	2.55 ± 0.09^{de}
	Hot air drying	136.08 ± 1.83^{gh}	2.09 ± 0.04^{ef}	2.15 ± 0.03^{c}	34.07 ± 1.34^{c}	2.19 ± 0.08^{de}
	Puff drying	187.16 ± 2.66^{a}	2.76 ± 0.24^{ab}	3.03 ± 0.09^{a}	42.06 ± 2.12^{ab}	3.91 ± 0.69^{ab}
Henan	Fresh (control)	118.25 ± 1.62^{j}	1.18 ± 0.02^{hi}	1.32 ± 0.06^{fgh}	22.54 ± 2.58^{ef}	1.88 ± 0.08^{e}
	Hot air drying	134.36 ± 2.63^{hi}	1.59 ± 0.05^{g}	1.90 ± 0.12^{d}	21.65 ± 1.13^{f}	2.33 ± 0.18^{de}
	Puff drying	166.68 ± 1.27^{cd}	2.44 ± 0.09^{bcd}	2.54 ± 0.04^{b}	31.62 ± 1.69^{cd}	2.80 ± 0.27^{cde}
Drying method	Fresh (control)	136.18 ± 22.00^{cA}	1.20 ± 0.15^{c}	1.16 ± 0.23^{c}	27.29 ± 4.73^{b}	2.27 ± 0.30^{b}
	Hot air drying	140.41 ± 5.03^{b}	1.81 ± 0.28^{b}	1.62 ± 0.44^{b}	28.77 ± 8.31^{b}	2.37 ± 0.41^{b}
	Puff drying	176.97 ± 7.64^{a}	2.63 ± 0.19^{a}	2.12 ± 0.70^{a}	38.45 ± 6.50^{a}	3.70 ± 0.56^{a}
Provinces	Hebei	147.89 ± 24.62^{bA}	2.06 ± 0.80^{a}	1.14 ± 0.31^{e}	39.86 ± 6.70^{a}	2.77 ± 1.30^{bc}
	Shandong	162.93 ± 18.58^{a}	1.90 ± 0.77^{b}	1.21 ± 0.18^{d}	25.43 ± 5.89^{c}	3.21 ± 0.71^{a}
	Shanxi	145.80 ± 29.31^{b}	1.63 ± 0.72^{c}	1.71 ± 0.50^{c}	33.12 ± 6.40^{b}	2.72 ± 0.72^{bc}
	Xinjiang	159.55 ± 25.78^{a}	2.09 ± 0.67^{a}	2.20 ± 0.80^{a}	33.84 ± 8.33^{b}	2.88 ± 0.90^{ab}
	Henan	139.76 ± 24.66^{c}	1.74 ± 0.64^{c}	1.92 ± 0.61^{b}	25.27 ± 5.51^{c}	2.33 ± 0.46^{c}

[A] Mean value in a column sharing different letter are statistically different at $p < 0.05$

TAC total antioxidant capacity, *TPC* total phenolic content, *TFC* total flavonoid content, *TANC* total anthocyanin content, *TCC* total carotenoid content, *AEAC* ascorbic acid equivalent antioxidant capacity, *GAAC* gallic acid equivalent antioxidant capacity, *REAC* rutin equivalent antioxidant capacity

The sugar and organic acid contents of the fruit are important determinants of flavor and sensory characteristics. The TA content of fresh, convective hot air dried and puff dried jujube were in the range of 0.57 ± 0.02–0.78 ± 0.02, 0.66 ± 0.06–0.88 ± 0.07, and 0.79 ± 0.05–1.15 ± 1.10 g CA/100 g, respectively. Likewise, TS content ranged between 47.25 ± 1.74–63.61 ± 1.65, 52.30 ± 1.12–71.13 ± 1.22, and 66.97 ± 0.46–75.10 ± 1.35 g GE/100 g for fresh, convective hot-air dried, and puff dried jujube, respectively (Table 3). The highest TA and TS values were recorded in puff dried jujube from Xinjiang, whereas, Hebei and Shanxi exhibited lowest contents of TA and TS, respectively. The hot air-dried jujube from Shanxi delivered the lowest TA values, while highest were observed for Xinjiang. Likewise, hot air-dried jujube from Shandong recorded lower content of TS as compared to fresh jujube.

The mean comparison test for drying methods revealed that puff dried jujube had the most quantity of TA (0.97 ± 0.13 g CA/100 g) and TS (69.80 ± 3.56 g GE/100 g) as compared to convective hot air dried. The mean comparison for five provinces revealed that Xinjiang samples contained the highest content of TA and TS. Previously, it had been reported that the drying method may significantly affect the organic acid and sugar contents of the jujube samples [43]. The higher amounts of sugars and acids present in jujube from Xinjiang might be due to greater difference in day to night temperatures, longer period of high intensity sunshine coupled with low annual precipitation and dry air.

Individual phenolic compounds

The HPLC parameters optimized in this study resulted in appropriate separation of phenolic compounds. The phenolic compounds have been reported to account for antioxidant properties of Chinese jujube [48–50]. Generally, the phenolic compounds are categorized into three classes: phenolic acids, flavonoids, and tannins. These compounds are known to exhibit in vitro and in vivo antioxidant properties, decreasing the risk of various health disorders [51].

The phenolic acids in Chinese jujube originating from different regions varied in terms of their concentrations (Table 3). Gallic and caffeic acid were detected in all the samples except hot-air dried ones from Shandong. The ferulic, hydroxycinnamic and chlorogenic acids were not detected in any of the samples.

The gallic acid values for fresh, convective hot air dried and puff dried samples were in the range of 10.34 ± 0.81–15.34 ± 1.14, 7.32 ± 1.12–14.18 ± 1.03, and 20.02 ± 0.52–29.52 ± 0.15 μg/g, respectively. The

Table 3 The influence of drying methods and geographical regions on phenolic acids (μg/g DW), flavonoid compounds (μg/g DW), TA (g CA /100 g DW) and TS (g GE /100 g DW) of Chinese jujube

Provinces	Parameters	Gallic acid	Caffeic acid	L-epicatechin	Phloridzin	Cianidanol	Rutin	TA	TS
Hebei	Fresh (control)	13.22 ± 0.55^{cdA}	23.84 ± 0.16^{e}	99.06 ± 0.73^{cA}	7.57 ± 0.45^{ef}	18.95 ± 0.77^{i}	6.83 ± 0.16^{c}	0.57 ± 0.02^{iA}	47.25 ± 1.74^{g}
	Hot air drying	8.18 ± 1.22^{ef}	28.23 ± 0.10^{d}	112.53 ± 0.38^{b}	n.d.^{h}	26.04 ± 0.35^{f}	n.d.^{e}	0.69 ± 0.03^{fghi}	52.30 ± 1.12^{fg}
	Puff drying	27.21 ± 0.64^{a}	48.06 ± 0.50^{b}	143.59 ± 0.69^{a}	10.60 ± 0.47^{d}	42.51 ± 0.39^{c}	10.94 ± 0.78^{a}	0.79 ± 0.05^{defg}	66.84 ± 1.63^{bcd}
Shandong	Fresh (control)	15.34 ± 1.14^{c}	15.68 ± 0.71^{g}	21.52 ± 0.33^{j}	5.51 ± 0.34^{g}	14.11 ± 0.13^{k}	7.63 ± 0.23^{bc}	0.64 ± 0.03^{hi}	64.17 ± 1.76^{cd}
	Hot air drying	11.95 ± 1.24^{cde}	n.d.^{i}	26.67 ± 0.38^{i}	n.d.^{h}	9.43 ± 0.48^{m}	n.d.^{e}	0.74 ± 0.08^{efgh}	53.96 ± 1.72^{efg}
	Puff drying	29.33 ± 0.32^{a}	24.39 ± 0.24^{e}	33.29 ± 0.67^{h}	12.68 ± 0.49^{bc}	21.42 ± 0.39^{h}	8.77 ± 0.21^{b}	0.92 ± 0.02^{cd}	68.33 ± 1.05^{abc}
Shanxi	Fresh (control)	10.34 ± 0.81^{def}	35.85 ± 0.71^{c}	75.99 ± 0.77^{d}	n.d.^{h}	23.55 ± 0.38^{g}	n.d.^{e}	0.76 ± 0.12^{efgh}	53.15 ± 1.25^{fg}
	Hot air drying	7.32 ± 1.12^{f}	21.23 ± 0.11^{ef}	52.66 ± 0.43^{f}	6.73 ± 0.13^{f}	12.43 ± 0.27^{l}	n.d.^{e}	0.66 ± 0.06^{ghi}	60.19 ± 1.31^{de}
	Puff drying	20.02 ± 0.52^{b}	66.21 ± 0.88^{a}	101.89 ± 0.81^{c}	9.70 ± 0.35^{d}	35.01 ± 0.18^{e}	3.95 ± 0.49^{d}	0.94 ± 0.24^{bc}	66.97 ± 0.46^{bcd}
Xinjiang	Fresh (control)	10.54 ± 2.05^{def}	14.84 ± 0.67^{gh}	45.59 ± 0.38^{g}	11.67 ± 0.49^{c}	37.04 ± 0.36^{d}	n.d.^{e}	0.73 ± 0.05^{fgh}	63.61 ± 1.65^{cd}
	Hot air drying	14.18 ± 1.03^{cd}	22.18 ± 0.68^{ef}	56.22 ± 0.13^{f}	8.52 ± 0.31^{e}	49.51 ± 0.37^{b}	n.d.^{e}	0.88 ± 0.07^{cde}	71.13 ± 1.22^{ab}
	Puff drying	29.52 ± 0.15^{a}	30.16 ± 1.70^{d}	65.74 ± 0.74^{e}	16.73 ± 0.45^{a}	60.87 ± 0.71^{a}	5.20 ± 0.25^{d}	1.15 ± 1.10^{a}	75.10 ± 1.35^{a}
Henan	Fresh (control)	14.41 ± 0.18^{cd}	19.93 ± 0.71^{f}	33.28 ± 0.73^{h}	10.58 ± 0.28^{d}	26.27 ± 0.35^{f}	n.d.^{e}	0.78 ± 0.02^{defgh}	54.29 ± 1.59^{ef}
	Hot air drying	13.72 ± 0.49^{cd}	11.35 ± 0.17^{h}	19.35 ± 0.46^{j}	7.42 ± 0.40^{f}	16.45 ± 0.43^{j}	4.36 ± 0.15^{d}	0.82 ± 0.05^{cdef}	65.17 ± 2.25^{bcd}
	Puff drying	25.68 ± 0.56^{a}	34.93 ± 0.73^{c}	42.57 ± 0.16^{g}	13.09 ± 0.11^{b}	34.55 ± 0.40^{e}	n.d.^{e}	1.07 ± 0.08^{ab}	71.76 ± 1.58^{ab}
Drying method	Fresh (control)	12.77 ± 2.25^{bA}	22.02 ± 8.52^{b}	55.08 ± 31.87^{bA}	7.06 ± 4.64^{b}	23.98 ± 8.64^{b}	2.89 ± 3.97^{b}	0.69 ± 0.08^{cA}	56.49 ± 7.26^{c}
	Hot air drying	11.07 ± 3.15^{c}	16.59 ± 11.07^{c}	53.48 ± 36.66^{c}	4.53 ± 4.18^{c}	22.77 ± 16.20^{c}	0.87 ± 1.94^{c}	0.75 ± 0.09^{b}	60.55 ± 7.82^{b}
	Puff drying	26.35 ± 3.87^{a}	40.75 ± 16.69^{a}	77.41 ± 45.48^{a}	12.56 ± 2.72^{a}	38.87 ± 14.45^{a}	5.77 ± 4.26^{a}	0.97 ± 0.13^{a}	69.80 ± 3.56^{a}
Provinces	Hebei	16.20 ± 9.85^{bA}	33.38 ± 12.90^{b}	118.39 ± 22.83^{aA}	6.05 ± 5.45^{c}	29.17 ± 12.08^{b}	5.92 ± 5.52^{a}	0.68 ± 0.11^{cA}	55.46 ± 10.17^{d}
	Shandong	18.87 ± 9.21^{a}	13.35 ± 12.35^{d}	27.16 ± 5.90^{e}	6.06 ± 6.35^{c}	14.99 ± 6.04^{e}	5.46 ± 4.76^{a}	0.77 ± 0.14^{b}	62.15 ± 7.39^{bc}
	Shanxi	12.56 ± 6.63^{c}	41.10 ± 22.94^{a}	76.84 ± 24.62^{b}	5.47 ± 4.96^{d}	23.66 ± 11.29^{d}	1.31 ± 2.28^{b}	0.78 ± 0.14^{b}	60.10 ± 6.91^{c}
	Xinjiang	18.08 ± 10.07^{ab}	22.39 ± 7.66^{c}	55.85 ± 10.08^{c}	12.31 ± 4.14^{a}	49.14 ± 11.91^{a}	1.73 ± 3.00^{b}	0.92 ± 0.21^{a}	69.95 ± 5.83^{a}
	Henan	17.94 ± 6.71^{ab}	22.07 ± 11.93^{c}	31.73 ± 11.68^{d}	10.36 ± 2.84^{b}	25.75 ± 9.06^{c}	1.45 ± 2.51^{b}	0.89 ± 0.15^{a}	63.74 ± 8.82^{b}

[A] Mean value in a column sharing different letter are statistically different at $p < 0.05$; total acid, TA; total sugar, TS, CA, citric acid, GE; glucose equivalent, not detected, n.d highest values were observed in puff dried samples from Xinjiang. The hot-air dried samples from Hebei, Shandong, Shanxi, and Henan depicted lower values of gallic acid as compared to fresh samples. The caffeic acid in fresh, hot-air dried and puff dried jujube was in the range of 14.84 ± 0.67–35.85 ± 0.71, 11.35 ± 0.17–28.23 ± 0.10, and 24.39 ± 0.24–66.21 ± 0.88 µg/g, respectively. The highest caffeic acid was recorded in Shanxi followed by Hebei, Henan, Xinjiang, and Shandong for jujube dried by means of puff-drying system. The highest and lowest caffeic acid in convective hot-air dried jujube was observed for Hebei and Henan provinces, respectively. Furthermore, highest content for fresh jujube was observed for Shanxi and lowest for Xinjiang.

In comparison, puff dried jujube presented higher contents of gallic and caffeic acids as compared to hot-air dried jujube. Similarly, mean comparison test for provinces indicated that gallic acid and caffeic acid were higher in Shandong and Shanxi samples, respectively. The total phenolics contents for fresh, convective hot-air dried, and puff dried sample were 34.79 µg/g, 27.66 µg/g, and 67.10 µg/g, respectively. However, among provinces the total phenolics contents were; Shanxi (53.66 µg/g), Hebei (49.58 µg/g), Xinjiang (40.47 µg/g), Henan (40.01 µg/g) and Shandong (32.22 µg/g).

It is well documented that flavonoids exhibit antioxidant and chelation properties [52]. Epidemiological studies indicated that their consumption is directly associated with a decreased risk of cardiovascular disease [53, 54] and cancer [55, 56]. Previous literature has also reported the presence of rutin, quercetin, catechin, epicatechin in fresh and dried Chinese jujube [57, 58]. The flavonoids of Chinese jujube have been presented in Table 3. This is first instance that cianidanol and phloridzin have been analyzed in Chinese jujube harvested from different orchards of China. The L-epicatechin, phloridzin and cianidanol concentrations of puff dried samples were in the range of 33.29 ± 0.67-143.59 ± 0.69, 9.70 ± 0.35–16.73 ± 0.45, and 21.42 ± 0.39–60.87 ± 0.71 µg/g DW, respectively; higher than that of fresh and hot-air dried samples. The highest content of L-epicatechin was observed in puff dried jujube from Hebei followed by Shanxi, Xinjiang, Henan, and Shandong provinces. The hot air-dried jujube from Shanxi and Henan had lower amounts of L-epicatechin as compared to fresh jujube. The fresh jujube from Hebei exhibited highest L-epicatechin concentration, while the least was recorded in samples from Shandong. Likewise, for phloridzin and Cianidanol, jujube from Xinjiang recorded highest values in puff dried and convective hot-air dried samples when compared to other provinces. The phloridzin was not detected in fresh jujube from Shanxi and hot-air dried jujube from Hebei and Shandong. The highest rutin content was observed in puff dried jujube obtained from Hebei followed by Shandong, Xinjiang, and Shanxi. The rutin was not detected in puff dried samples acquired from Henan. Among hot-air dried samples, rutin was only recorded in Henan, while, in fresh jujube it was observed for Hebei and Shandong.

The mean comparison of drying methods revealed that puff-drying outperformed hot-air drying in retaining the L-epicatechin, phloridzin, cianidanol and rutin. Likewise, mean comparison for different provinces indicated highest values of L-epicatechin and rutin in Hebei, whereas phloridzin and cianidanol were most abundant in Xinjiang samples. The total weight of flavonoids in fresh, convective hot-air dried, and puff dried jujube were 89.01 µg/g, 81.65 µg/g and 134.61 µg/g, respectively. However, among provinces the total weight of flavonoids followed the following order; Hebei (159.53 µg/g) > Xinjiang (119.03 µg/g) > Shanxi (107.28 µg/g) > Henan (69.29 µg/g) > Shandong (53.67 µg/g).

The literature survey clearly indicates the impact of drying methods on chemical composition of jujube, yam flours and sweat potatoes [22, 59, 60]. The puff-dried samples retained the highest antioxidant properties, phenolics compounds, total acids and sugar content. This probably could be due to better heat and mass transfer, lower puffing pressure, reduced thermal exposure, rapid dehydration and little contact with air [16–18].

Principal component analysis

To analyze the effect of geographical locations and drying methods on the quality characteristics of Chinese jujube, principal component analysis (PCA) was performed using antioxidants, total sugar, total acid and phenolic compounds as the variables (Fig. 2). The first three principal components (PCs) accounted for more than 83% of total variance. In detail, PC1 explained about 54% of total variance and

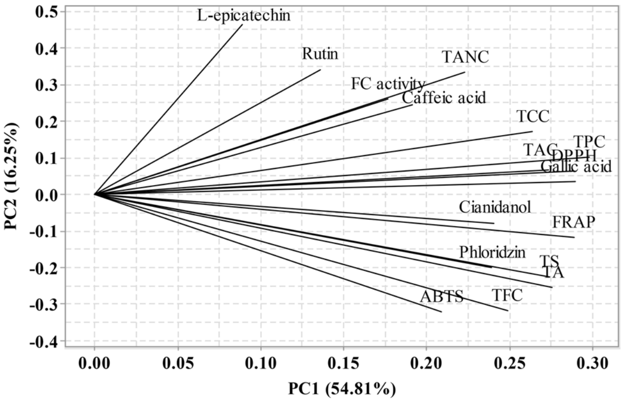

Fig. 2 Loading diagram of principal component analysis for antioxidants, total sugar, total acid, and phenolic compounds

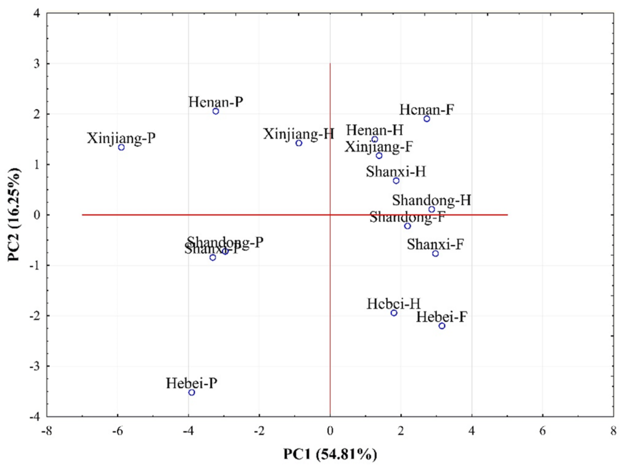

Fig. 3 Loading matrix of principal components for provinces and drying methods. Fresh, F; Hot-air dried, H; Puff dried, P

primarily comprised of DPPH, FRAP, ABTS, TAC, TPC, TFC, TCC, TA, TS, gallic acid, and phloridzin. Similarly, PC2 represented about 16% of the total variance and was significantly affected by the ferrous chelating activity, L-epicatechin and rutin. The PC3 mainly comprised of TANC, caffeic acid, and cianidanol and accounted for about 12% of the total variance.

The differences in the antioxidant properties, total sugars, total acid, and phenolic compounds of the Chinese jujube cultivated in different provinces and dried by means of convective hot air drying and puff-drying system are presented in Fig. 3. It was observed that geographical locations and drying methods played prime role in the determination of Chinese jujube quality. For instance, fresh jujube and hot-air dried jujube from Hebei, Shandong and Shanxi province were placed together at the positive scale of the of the PC1. This grouping was mainly attributed to the closer concentration of DPPH, FRAP, ferrous chelating activity, TAC, TANC, TCC, TA, TS, gallic acid, phloridzin, and rutin. Likewise, fresh, hot-air dried, and puff dried jujube from Henan and Xinjiang province were aggregated on the positive scale of the PC2. Their closer association on the plot was due to presence of higher concentrations of DPPH, FRAP, ABTS, TFC, TA, TS, gallic acid, phloridzin and cianidanol. In addition, puff dried jujube from Shandong and Shanxi province lied near the negative scale of PC2. This grouping on the plot was due to the presence of similar concentrations of TAC, TPC, TCC, TS, DPPH, ferrous chelating activity and phloridzin. The puff dried jujube from Hebei province placed near the negative scale of PC1 was mainly attributed to concentration of L-epicatechin and rutin.

Conclusions

The acquired results revealed that puff dried jujube samples were rich in antioxidant properties and phenolics such as gallic acid, caffeic acid, phloridzin, rutin, cianidanol and L-epicatechin. The traditional convective hot-air drying resulted in the decline of antioxidant properties. Among the provinces, Xinjiang had highest contents of DPPH, FRAP, TPC, TFC, TA, TS, and phenolics such as phloridzin and cianidanol, thereby yielding superior quality fruits. Conclusively, the environment friendly and commercially viable puff-drying offers greater prospects for industrial processing of Chinese jujube leading to considerably reduced drying time, yielding end products enriched with phenolics and antioxidants. Moreover, the results are of interest for consumer and nutritionist to opt from healthy products enriched with bioactive compounds varying in their place of origin and method of drying.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study does not involve human or animals subjects, therefore does not entail ethical considerations.

Informed consent Informed consent is not applicable for the nature of this study.

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