

Physicochemical Properties of Jujube Powder from Air, Vacuum, and Freeze Drying and Their Correlations

Su Hwan Kim · Young Jin Choi · Hanna Lee · Sang-Hwa Lee · Jun-Bae Ahn · Bong-Soo Noh · Sea Cheol Min

Received: 6 December 2011 / Accepted: 2 February 2012 / Published Online: 30 April 2012
© The Korean Society for Applied Biological Chemistry and Springer 2012

Abstract Physical and chemical properties of jujube powder with different powder sizes prepared by different drying methods were determined, and correlations of the properties were statistically analyzed. Air-, vacuum-, and freeze-dried (AD, VD, and FD, respectively) jujube were milled and sieved to produce powders. Powder size, morphological characteristics, color, volatile profile, moisture sorption isotherm, water solubility, rehydration, total sugar content, and polyphenol content of the powder were determined. Hunter L , a , and b , degree of browning, and volatile profile varied depending on drying methods. Moisture sorption isotherms exhibited typical Type II sigmoidal shape. Polyphenol content was highest in AD powder (2.6 ± 0.1 mg/g). Powder size, morphology, water solubility, and total sugar content were not different by different drying methods. Correlations identified among the properties indicate rehydration of the powder could be maximized by controlling particle size and water activity of the powder. Rehydration and powder size of AD, VD, and FD powder were significantly correlated ($p < 0.001$) ($R^2 = 0.92, 0.88, \text{ and } 0.94$, respectively). Property correlations determined could be useful in customizing properties of jujube powder and increasing commercial uses of the powder.

Keywords drying · jujube · particle size · physicochemical properties · property correlation

Introduction

Jujube (*Zizyphus Jujuba* Miller) has a long history in its use as a food ingredient and is consumed more than 30 countries in the world (Fang et al., 2009). Dried or half-dried jujube is a most popular form of jujube for food application and mostly prepared by sun drying in Asia countries, including China, Korea, and Japan (Li et al., 2009; Sun et al., 2009). Sun drying, the most economical way of drying, is usually made in the field of harvesting or a greenhouse before shipment. Dried jujube is used in sliced or powdered form in foods and characterized by high concentrations of sugars, ascorbic acid, and polyphenols (Kim and Joo, 2005; Zhu et al., 2010). Dried jujube has been also known to have medicinal functionalities and used as Asian-traditional anticancer, refrigerant, sedative, stomachic, stytic, and tonic medicines (Crawford, 2002; Sun et al., 2009). Interest in the use of dried jujube has been increasing in Asia countries due to its high nutritional and functional properties. Irrespective of well-known wholesome properties of the dried jujube, its preparation for efficient mass production, especially production of powder, has not been systematically investigated. Further drying of sun-dried jujube was done for quality control of raw material and powder obtained from the dried jujube. Thus, the effect of different drying methods on the physical and chemical properties of the powder must be investigated for developing industrial production of the powder.

Determining the properties of jujube powder, including powder size, morphological characteristics, color, flavor, water solubility, rehydration, total sugar content, and polyphenol content, is important for its applications to instant convenience food products

H. Lee · B.-S. Noh · S. C. Min (✉)
Department of Food Science and Technology, Seoul Women's University,
621 Hwarangro, Nowon-gu, Seoul, 139-774, Republic of Korea
E-mail: smin@swu.ac.kr

S. H. Kim · Y. J. Choi
Department of Agricultural Biotechnology and Center for Agricultural
Biomaterials, Seoul National University, 599 Gwanangno Gwanakgu,
Seoul, 151-742, Republic of Korea

S.-H. Lee
Department of Food and Nutrition, Seowon University, 231 Mochung-
dong, Heungduk-gu, Cheongju, Chungbuk, 361-742, Republic of Korea

J.-B. Ahn
Department of Food Service Industry, Seowon University, 231 Mochung-
dong, Heungduk-gu, Cheongju, Chungbuk, 361-742, Republic of Korea

(Zhang et al., 2005; Lee et al., 2008; Fang et al., 2009). Pearson correlation, multiple linear regression, and response surface analysis (RSA) are used to determine relationships among the properties (Schmidt et al., 1979). Pearson correlation and regression analysis measure the strength of linear dependence between variables (Pearson, 1920; Breiman and Friedman, 1985). RSA is a method for studying geometric relationships among response variables, which are generated by mathematical models (Myung et al., 2000).

Identifying correlations of the properties of jujube powder may allow preparation of the powder that possesses a desired property by manipulating other properties of the powder that significantly affect the property of interest. Thus, the objectives of the present study were to determine physical and chemical properties of jujube powder obtained from hot-air oven drying, vacuum drying, and freeze drying, including powder size, morphological characteristics, color, volatile profile, moisture sorption isotherm, water solubility, rehydration, total sugar content, and polyphenol content and to study correlations among the properties using Pearson correlation, multiple linear regression, and RSA.

Materials and Methods

Materials. Jujube was harvested from an orchard (Boeun, Korea) in 2009 at a mature stage and sun-dried in a clean greenhouse for 20 days. Sun-dried jujube was transported to the laboratory in a packaging box and kept in cold storage at 4°C. The fruit without physical injuries or apparent decay was selected for study. The moisture content of dried jujube was 40.8 g/100 g jujube (dry basis), determined at Korea Food Research Institute (Sungnam, Korea). Chemicals, trichloroacetic acid, lithium chloride (LiCl), potassium acetate (CH₃COOK), magnesium chloride (MgCl₂), potassium carbonate (K₂CO₃), magnesium nitrate (MgNO₃), sodium chloride (NaCl), potassium chloride (KCl), phenol, sulfuric acid, methanol, folin-ciocalteu, sucrose, tannic acid, and sodium carbonate (Na₂CO₃) were purchased from Sigma-Aldrich (St. Louis, MO).

Jujube drying. Sun-dried jujube was pitted, sliced, and dried. Drying was conducted in an hot-air oven dryer (VS-1202D2, Vision Scientific Co., Ltd., Bucheon, Korea) at 80°C for 48 h, a vacuum dryer (OV-11, Jeio Tech Co., Ltd., Seoul, Korea) at 50°C and 5 kPa for 24 h, and a freeze dryer (FD 5505, Ilshin Lab Co., Ltd., Yangju, Korea) at -45°C and 1.3 Pa for 72 h to reduce the moisture content of the jujube (40.8 g/100 g; dry basis) to less than 20 g/100 g, which is considered most appropriate for food application of the powder (Kim and Joo, 2005). Moisture contents of hot-air-, vacuum-, and freeze-dried (AD, VD, and FD, respectively) powder were 19±2 g/100 g, 19±2 g/100 g, and 18±2 g/100 g (dry basis), respectively.

Jujube powder preparation. Dried jujube was milled using an analytical mill (M20, IKA[®], Staufen, Germany) with different mesh-sized sieves (32, 32–53, 53–100, 100–150 μm) to obtain

powder with different particle sizes. The powder was equilibrated to 11, 15, and 23% relative humidity (RH), corresponding to water activity of 0.11, 0.15, and 0.23, respectively, in desiccators at 25°C before testing. The water activity was measured with a water activity meter (AquaLab pawkit, Decagon Devices, Pullman, WA).

Powder size. The average size and the distribution of the sizes of powder dispersed in 10 mL of distilled water were determined using a particle size analyzer (Analysette 22 MicroTec plus, Fritsch GmbH, Idar-Oberstein, Germany).

Morphological characteristics. The shape of the powder was examined by a vacuum scanning electron microscope (SEM) (JSM 5410LV, JEOL Ltd., Tokyo, Japan). The dried powder was attached to SEM-stubs using a double-sided carbon tape coated with gold.

Color and degree of browning. The color of the powder was measured using a colorimeter (CR-300, Minolta Co., Ltd., Osaka, Japan) and expressed as Hunter *L* (brightness), *a* (red-green component), *b* (yellow-blue component) values. The degree of browning was spectrophotometrically determined. One gram powder was added to the mixture of 40 mL distilled water and 10 mL of 10% trichloroacetic acid solution. The powder solution was kept at 23±3°C for 2 h and then filtered through a filter paper (Whatman No. 2, Whatman Ltd., Maidston, UK). The absorbance of the filtrate at 420 nm measured by a spectrometer (Optizen 2021UV, Mecasys Co., Ltd.) was recorded as the degree of browning (Lee et al., 2003; Kim et al., 2007).

Volatile profiles. Volatile profiles of jujube powder were analyzed by the method of Noh et al. (2005) using an electronic nose system (SMart Nose300, SMart Nose[®], Marin-Epagnier, Switzerland) installed with an automatic headspace sampler (SMart Nose[®] Autosampler, SMart Nose) and a mass spectrometer (Quadrupole Mass Spectrometer, Balzers Instruments, Marin-Epagnier, Switzerland). The number of channels of the electronic nose system was 191 (bargraph mode, 10–200 amu). The flow rate of 99.999% nitrogen purge gas was 230 mL/min. Powder samples (2 g) were incubated for 15 min at 70°C with an agitation at 30 rpm. Selected 20–30 ion fragments peaks were analyzed by discriminant function analysis (DFA) using statistics software (SMart Nose).

Moisture sorption isotherm characteristics. Moisture equilibrium data were obtained by the static gravimetric method using different saturated salt solutions (Spiess and Wolf, 1987). Triplicate samples (2 g each) in 57-mm disposable dishes without lids were placed inside desiccators (24 cm diameter) containing saturated salt solutions with water activity ranging from 0.11 to 0.84 (LiCl, CH₃COOK, MgCl₂, K₂CO₃, MgNO₃, NaCl, KCl). The desiccators were placed in an incubator (VS-1203P3N, Vision Scientific Co., Ltd) at 30°C. The moisture content of powder was determined by following the Association of Official Analytical Chemists method (1998) and expressed on a dry basis. Samples were weighed every 24 h until the difference in two consecutive weight measurements was less than 0.0005 g.

Water solubility. Water solubility was determined by the method

of Schoch (1964). Initial solid content of powder was determined by an oven drying method using a hot-air oven dryer (VS-1202D2, Vision Scientific Co., Ltd.) at 105°C for 24 h. The powder (0.1 g) was suspended in 10 mL of distilled water with stirring at 120 rpm for 5 min. The suspension was placed in a refrigerator at 5°C for 30 min and then centrifuged at $500 \times g$ and 4°C for 30 min. The supernatant was poured into a test tube and dried in the hot-air oven dryer at 105°C for 24 h. The solid content was measured to determine the water-soluble solid content. The solubility (%) was defined as the ratio of the water-soluble solid content to initial solid content ($\times 100$).

Rehydration. Rehydration was determined by the method of Medcarf and Gilles (1956). One gram powder was added to 20 mL distilled water and left standing at 25°C for 1 h. The mixture was centrifuged at $2,000 \times g$ for 15 min. The weight of precipitate was measured as the weight of rehydrated powder. The degree of rehydration was determined using the following equation;

$$\text{Degree of rehydration} = \frac{\text{Weight of rehydrated powder (g)} - \text{Initial dried powder weight (g)}}{\text{Initial dried powder weight (g)}} \times 100$$

Total sugar content. Total sugar content was determined by following the method of Sohn et al. (2002). The dried jujube powder (1 g) was dispersed in 10-mL distilled water. One milliliter dispersed solution was added to the mixture of a 1-mL phenol solute in 5 mL H₂SO₄. The absorbance of the solution was measured at 480 nm using a spectrophotometer (Optizen 2021UV, Mecasys Co., Ltd.), and the sugar content was determined from a calibration curve that was generated with sucrose solutions.

Polyphenol content. The amount of total polyphenols was determined using the method of Swain et al. (1959). Nine milliliters of extract from 10 g of the powder was mixed with 1 mL of 0.2 N Folin-Ciocalteu solution. One milliliter of 40% Na₂CO₃ solution was mixed with the extract solution for 1 h at 23±3°C. The absorbance of the final solution was measured using a spectrophotometer (Optizen 2021UV, Mecasys Co., Ltd.) at 720 nm.

Statistical analysis. All experiments were performed in triplicate. An ANOVA test (Duncan's multiple range tests) was carried out using SAS (SAS[®] version 9.2, SAS Institute Inc., Raleigh, NC) to estimate the significant difference ($\alpha=0.05$). Pearson correlation coefficient, multiple linear regression, and RSA were conducted using SAS. A face-centered cube design (FCD) was used in RSA to measure effects of two individual variables (average powder size and water activity) on dependent variables (water content, water solubility, rehydration, total sugar content, and polyphenol content) of the powder. The complete design consisted of 11 experimental points including three replications of the center points. Regression equations are described in a polynomial expression (Koch, 2005).

Results and Discussion

Powder size. Average sizes of dried jujube powder are summarized in Table 1. The sizes ranged from 16.0 to 148.8 μm . A normal size distribution was exhibited from all the powder samples (data not shown). Powder size was not different depending on different drying methods (Table 1). The average powder size was closer to the sieve maximum size than the minimum size (Table 1). This may be related to the shape of the powder (Fig. 1). More powders with shorter dimensions could pass the sieve during the shaking operation of sieving.

Morphological characteristics. Micrographs of the powder are exhibited in Fig. 1. Dried jujube powder had amorphous structures with some porosity. Milling induced during powder preparation could form biomaterials with an amorphous structure (Zhao, 2009). Morphologies of the powder obtained from different drying methods were not distinguishable (Fig. 1).

Color and degree of browning. The values of Hunter L , a , and b and degree of browning of the jujube powder are displayed in Table 2. The lightness (L value) increased as the size of jujube powder decreased. This phenomenon was also observed in distiller-dried grains with solubles (DDGS), a mix of particulate materials processed from yellow corn, with L varying from 44.9 to 59.6 (Liu, 2008). The powder from 100–150 μm sieve had the highest values of a and degree of browning. The L values of AD and VD powder were higher than those of FD powder (Table 2). The values of a , b , and degree of browning were highest (4.23, 19.78, and 0.23, respectively) in AD powder, probably because AD powder was exposed to more heat energy compared to VD powder or FD powder. Non-enzymatic browning which took place between reducing sugars and amino acids in the powder during heat-induced air-drying could have contributed to the color change of AD powder.

Volatile profiles. A DFA plot of the results from the volatile analysis of jujube powder prepared by different drying methods is illustrated in Fig. 2. The result of DFA could be grouped according to the drying methods. The direction of arrow indicates decrease in the amount of volatiles. More volatiles were detected from VD and FD powders. This might be due to less loss of volatiles by the drying methods conducted at relatively low drying temperatures with vacuum processing. The quantity of volatile components was dependent upon the particle size of jujube samples (Fig. 2). The smaller the powder size was, the less volatile components were detected, possibly due to more loss of volatiles of smaller powder owing to its larger surface area to volume ratio.

Moisture sorption isotherms. The moisture sorption isotherms plotted with experimental data at the a_w range of 0.11–0.84 are shown in Fig. 3. The moisture sorption isotherms exhibited a typical Type II sigmoidal shape, which is common in many food materials, including *Chaga* mushroom, *Agaricus bisporus*,

Table 1. Physical and chemical properties of jujube powder with different powder sizes produced by different drying methods^A

Sample ¹⁾		Property						
Drying method	Sieve size (μm)	Water activity	Average powder size (μm)	Water solubility (%)	Rehydration (%)	Total sugar content (mg/mL)	Polyphenol content (mg/g, dry basis)	
Air-drying	100–150	0.11	147.2 ^a	78.6 ^a	531.6 ^b	8.0 ^{cd}	2.6 ^{ab}	
		0.15	147.2 ^a	76.0 ^a	544.2 ^b	8.1 ^{bcd}	2.7 ^a	
		0.23	147.2 ^a	78.8 ^a	615.5 ^a	7.6 ^d	2.7 ^{ab}	
	53–100	0.11	90.3 ^b	66.8 ^a	465.1 ^c	8.6 ^{abcd}	2.6 ^{ab}	
		0.15	90.3 ^b	79.5 ^a	482.0 ^d	8.4 ^{abcd}	2.6 ^{ab}	
		0.23	90.3 ^b	81.4 ^a	515.1 ^c	8.2 ^{bcd}	2.7 ^{ab}	
	32–53	0.11	38.9 ^c	38.9 ^c	79.5 ^a	330.5 ^h	8.8 ^{abc}	2.6 ^{ab}
		0.15	38.9 ^c	38.9 ^c	84.2 ^a	349.8 ^g	8.6 ^{abcd}	2.5 ^b
		0.23	38.9 ^c	38.9 ^c	80.1 ^a	381.9 ^f	9.3 ^a	2.6 ^{ab}
	≤32	0.11	16.0 ^d	16.0 ^d	76.1 ^a	297.7 ⁱ	8.9 ^{abc}	2.6 ^{ab}
		0.15	16.0 ^d	16.0 ^d	81.4 ^a	280.7 ^j	8.7 ^{abc}	2.6 ^{ab}
		0.23	16.0 ^d	16.0 ^d	93.4 ^a	342.3 ^{gh}	9.2 ^{ab}	2.6 ^{ab}
Vacuum-drying	100–150	0.11	145.7 ^a	73.7 ^a	500.0 ^{ab}	8.0 ^d	2.2 ^g	
		0.15	145.7 ^a	74.8 ^a	489.7 ^{bc}	9.0 ^{abc}	2.3 ^f	
		0.23	145.7 ^a	76.5 ^a	508.7 ^a	8.9 ^{abc}	2.5 ^{abc}	
	53–100	0.11	92.1 ^b	92.1 ^b	75.1 ^a	481.8 ^c	8.1 ^{cd}	2.3 ^{ef}
		0.15	92.1 ^b	92.1 ^b	76.6 ^a	459.7 ^d	8.7 ^{bcd}	2.3 ^{ef}
		0.23	92.1 ^b	92.1 ^b	78.6 ^a	458.0 ^d	9.3 ^{ab}	2.6 ^a
	32–53	0.11	48.9 ^c	48.9 ^c	74.7 ^a	391.4 ^c	8.4 ^{bcd}	2.5 ^{bcd}
		0.15	48.9 ^c	48.9 ^c	78.4 ^a	334.4 ^f	8.9 ^{abc}	2.4 ^{de}
		0.23	48.9 ^c	48.9 ^c	78.5 ^a	319.1 ^f	9.1 ^{ab}	2.6 ^{ab}
	≤32	0.11	18.1 ^d	18.1 ^d	73.8 ^a	264.3 ^g	9.8 ^a	2.5 ^{bcd}
		0.15	18.1 ^d	18.1 ^d	74.8 ^a	249.0 ^{gh}	8.4 ^{bcd}	2.5 ^{cd}
		0.23	18.1 ^d	18.1 ^d	76.8 ^a	241.5 ^h	8.9 ^{abcd}	2.6 ^{abc}
Freeze-drying	100–150	0.11	148.8 ^a	76.2 ^c	407.9 ^d	8.0 ^b	2.5 ^{ab}	
		0.15	148.8 ^a	76.9 ^c	527.4 ^a	9.1 ^{ab}	2.0 ^e	
		0.23	148.8 ^a	78.2 ^{de}	449.3 ^c	8.6 ^b	2.5 ^{ab}	
	53–100	0.11	92.7 ^b	92.7 ^b	80.8 ^{abcd}	388.2 ^e	8.6 ^b	2.5 ^{ab}
		0.15	92.7 ^b	92.7 ^b	81.1 ^{abcd}	475.1 ^b	9.9 ^a	2.3 ^d
		0.23	92.7 ^b	92.7 ^b	82.5 ^{ab}	388.8 ^e	8.5 ^b	2.6 ^a
	32–53	0.11	45.6 ^c	45.6 ^c	79.3 ^{bcde}	319.7 ^g	8.2 ^b	2.4 ^{bc}
		0.15	45.6 ^c	45.6 ^c	84.7 ^a	358.3 ^f	9.9 ^a	2.3 ^d
		0.23	45.6 ^c	45.6 ^c	81.1 ^{abcd}	364.1 ^f	8.5 ^b	2.3 ^{cd}
	≤32	0.11	17.6 ^d	17.6 ^d	78.7 ^{cde}	239.1 ⁱ	8.8 ^b	2.6 ^a
		0.15	17.6 ^d	17.6 ^d	80.7 ^{abcd}	270.8 ^h	8.7 ^b	2.6 ^a
		0.23	17.6 ^d	17.6 ^d	81.9 ^{abc}	245.9 ⁱ	8.8 ^b	2.4 ^{bc}

^{a–j}Values followed by the same alphabet in the same column are not significantly different ($p > 0.05$).

Pleurotus florida, tapioca, and fufu (Sanni et al., 1997; Shivhare et al., 2004; Lee and Lee, 2007). Similar moisture contents were obtained among the powders at the same level of water activity regardless of powder size (Fig. 3). This phenomenon was exhibited in AD, VD, and FD powders.

Water solubility. The water solubility values of the jujube powder obtained by different drying methods are exhibited in Table 1. The solubility of the powder ranged from 66.8 to 93.4%, similar to the reported values of onion powder (Kim et al., 2007). The solubility of the jujube powder was not significantly affected by different

drying methods or powder sizes ($p > 0.05$). The water solubility is one of the most important properties characterizing instant powder foods (Picesky, 1986; Shittu and Lawal, 2007). The water solubility of jujube powder (Table 1), which is comparable to that of cocoa powder (44.2–76.6%) (Shittu and Lawal, 2007), showed that the powder could be used in tea or beverage products. Although the solubility was thought to be correlated to the content of sugar, highly soluble in water, but no significant influence was observed (Table 1), which is consistent with the results observed with cocoa powder (Shittu and Lawal, 2007).

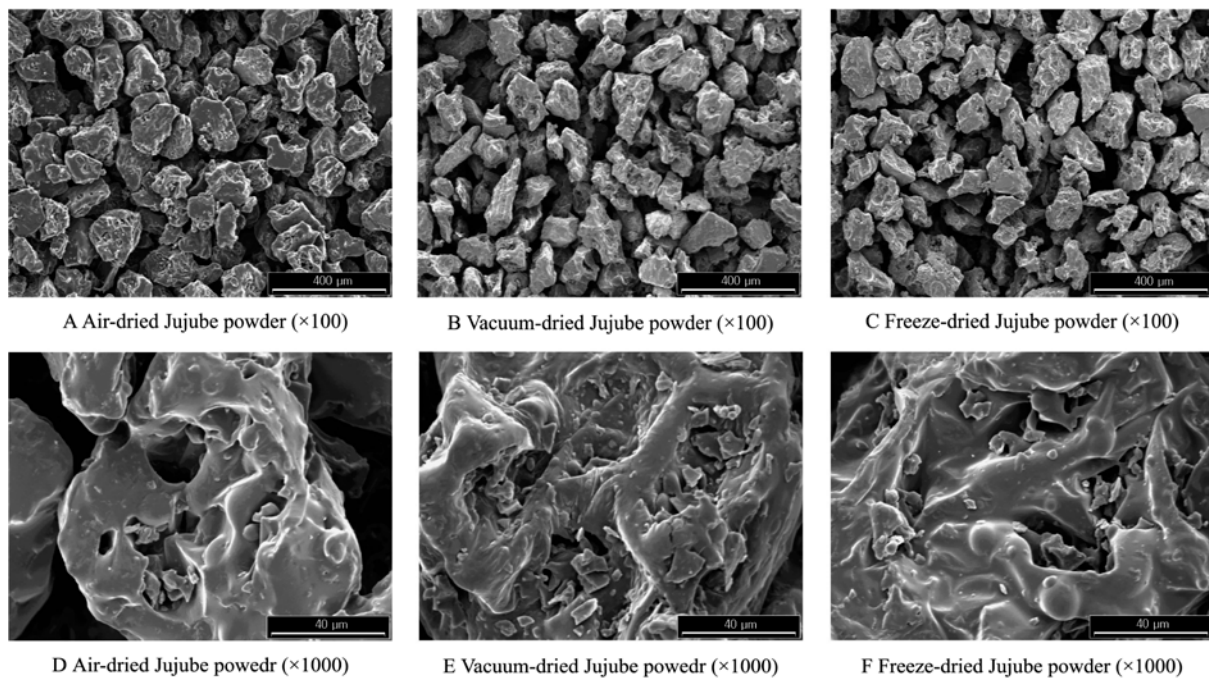


Fig. 1 Scanning electron micrographs of jujube powder obtained from the sieve of 100–150 µm mesh after air-, vacuum-, and freeze-drying.

Table 2. Color properties of dried jujube powder with different sizes produced by different drying methods^{A, B}

Sieve size	L	Air-drying	Vacuum-drying	Freeze-drying	DGM
100–150 µm		44.92±0.83	46.38±1.20	45.76±0.26	45.69 ^d
53–100 µm		50.90±1.19	52.71±1.49	49.72±1.05	51.11 ^c
32–53 µm		55.63±0.41	54.75±1.04	52.85±0.61	54.41 ^b
≤32 µm		59.39±0.58	57.49±2.03	53.75±0.69	56.88 ^a
DGM ^C		52.71 ^a	52.83 ^a	50.52 ^b	
	a	Air-drying	Vacuum-drying	Freeze-drying	DGM
100–150 µm		4.70±0.25	3.82±0.18	4.37±0.21	4.30 ^a
53–100 µm		4.24±0.27	3.36±0.26	3.59±0.17	3.73 ^b
32–53 µm		4.15±0.02	3.33±0.25	3.19±0.06	3.56 ^b
≤32 µm		3.82±0.09	3.07±0.15	3.94±0.35	3.61 ^b
DGM		4.23 ^a	3.40 ^c	3.77 ^b	
	b	Air-drying	Vacuum-drying	Freeze-drying	DGM
100–150 µm		17.90±0.44	17.99±0.43	18.71±0.14	18.20 ^b
53–100 µm		19.88±0.65	19.82±0.68	19.23±0.35	19.64 ^a
32–53 µm		20.96±0.47	19.51±0.49	19.49±0.25	19.99 ^a
≤32 µm		20.38±0.19	19.33±0.41	19.15±0.57	19.62 ^a
DGM		19.78 ^a	19.16 ^b	19.14 ^b	
	Degree of browning	Air-drying	Vacuum-drying	Freeze-drying	DGM
100–150 µm		0.23±0	0.22±0	0.20±0	0.22 ^{e,f}
53–100 µm		0.24±0	0.22±0	0.20±0	0.22 ^c
32–53 µm		0.23±0	0.21±0	0.20±0	0.22 ^{e,f}
≤32 µm		0.22±0	0.21±0	0.20±0	0.20 ^f
DGM		0.23 ^f	0.22 ^f	0.19 ^e	

^{a-d}Values followed by the same alphabet in the same column or row are not significantly different ($p > 0.01$) by Duncan’s two-way ANOVA test.

^{e-f}Values followed by the same alphabet in the same column or row are not significantly different ($p > 0.05$) by Duncan’s two-way ANOVA test. DGM, Duncan grouping mean.

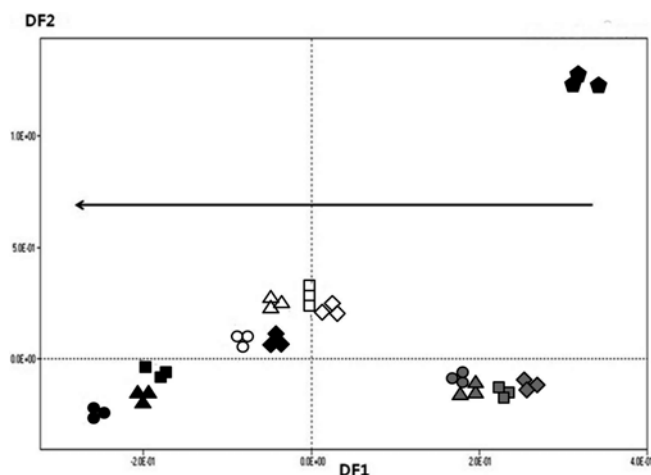


Fig. 2 A discriminant function analysis (DFA) plot of the results from the jujube powder analysis using the mass spectrometer-based electronic nose. ●: air-dried jujube powder passed through the sieve of 32 μm mesh, ▲: air-dried jujube powder passed through the sieve of 32–53 μm mesh, ■: air-dried jujube powder passed through the sieve of 53–100 μm mesh, ◆: air-dried jujube powder passed through the sieve of 100–150 μm mesh, ○: vacuum-dried jujube powder passed through the sieve of 32 μm mesh, △: vacuum-dried jujube powder passed through the sieve of 32–53 μm mesh, □: vacuum-dried jujube powder passed through the sieve of 53–100 μm mesh, ◇: vacuum-dried jujube powder passed through the sieve of 100–150 μm mesh, ◐: freeze-dried jujube powder through the sieve of 32 μm mesh, ◑: freeze-dried jujube powder through the sieve of 32–53 μm mesh, ◒: freeze-dried jujube powder passed through the sieve of 53–100 μm mesh, ◓: freeze-dried jujube powder passed through the sieve of 100–150 μm mesh, ◔: air.

Rehydration. The results from the rehydration of powder obtained by different drying methods are shown in Table 1. Larger-sized powder had higher values of rehydration at each level of water activity, irrespective of the drying method used ($p < 0.05$). The rehydration values of AD powder were higher (280.7–615.5%) than those of VD (241.5–508.7%) and FD (239.1–527.4) powders. This is consistent with the result observed with onion powder in that AD onion powder had a higher value for rehydration than VD and FD onion powders (Kim et al., 2007). However, the order of the drying methods resulting in a higher rehydration was not the same and appeared to differ depending on food sample (Ratti, 2001). This discrepancy could be because rehydration is influenced by many factors, including porosity, capillaries, cavities (air), amorphous-crystalline state, dryness, and pH of soaking water (Lewicki, 1998; Rahman and Perera, 1999).

Total sugar content. The range of total sugar content of all kinds of jujube powder was 8.0–9.9 mg/mL (Table 1). The total sugar content did not differ by different drying methods, water activities, and powder sizes.

Polyphenol content. The content of polyphenol of the powder is shown in Table 1. The polyphenol content was not significantly affected by average powder size and water activity ($p > 0.05$), but was affected by drying method ($p < 0.05$). The polyphenol

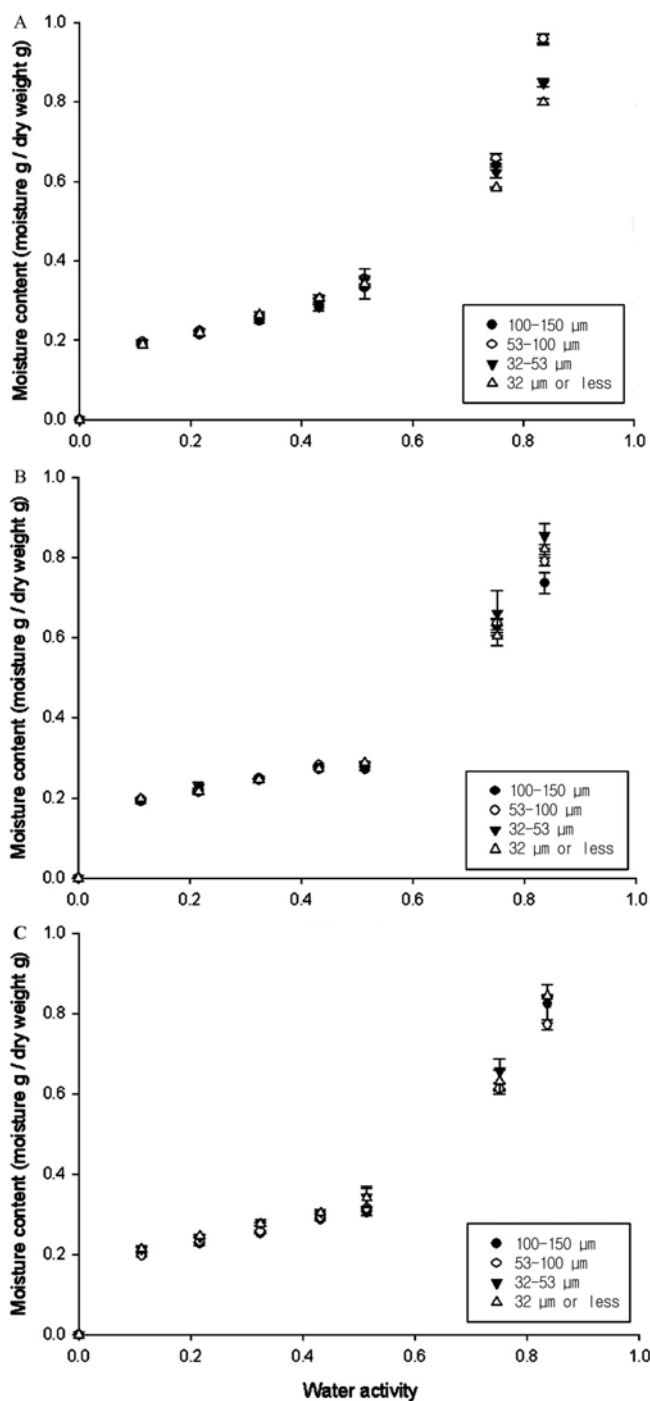


Fig. 3 Moisture sorption isotherms of air- (A), vacuum- (B), and freeze- (C) dried jujube powder obtained through sieves of different mesh sizes.

contents of AD, VD, and FD powders were 2.5–2.7, 2.2–2.6, and 2.0–2.6 mg/g, respectively. The AD powder had the highest polyphenol content ($p < 0.05$), possibly because heating process could break down covalent bonds of polyphenols, thereby liberating smaller molecules of polyphenols and forming more

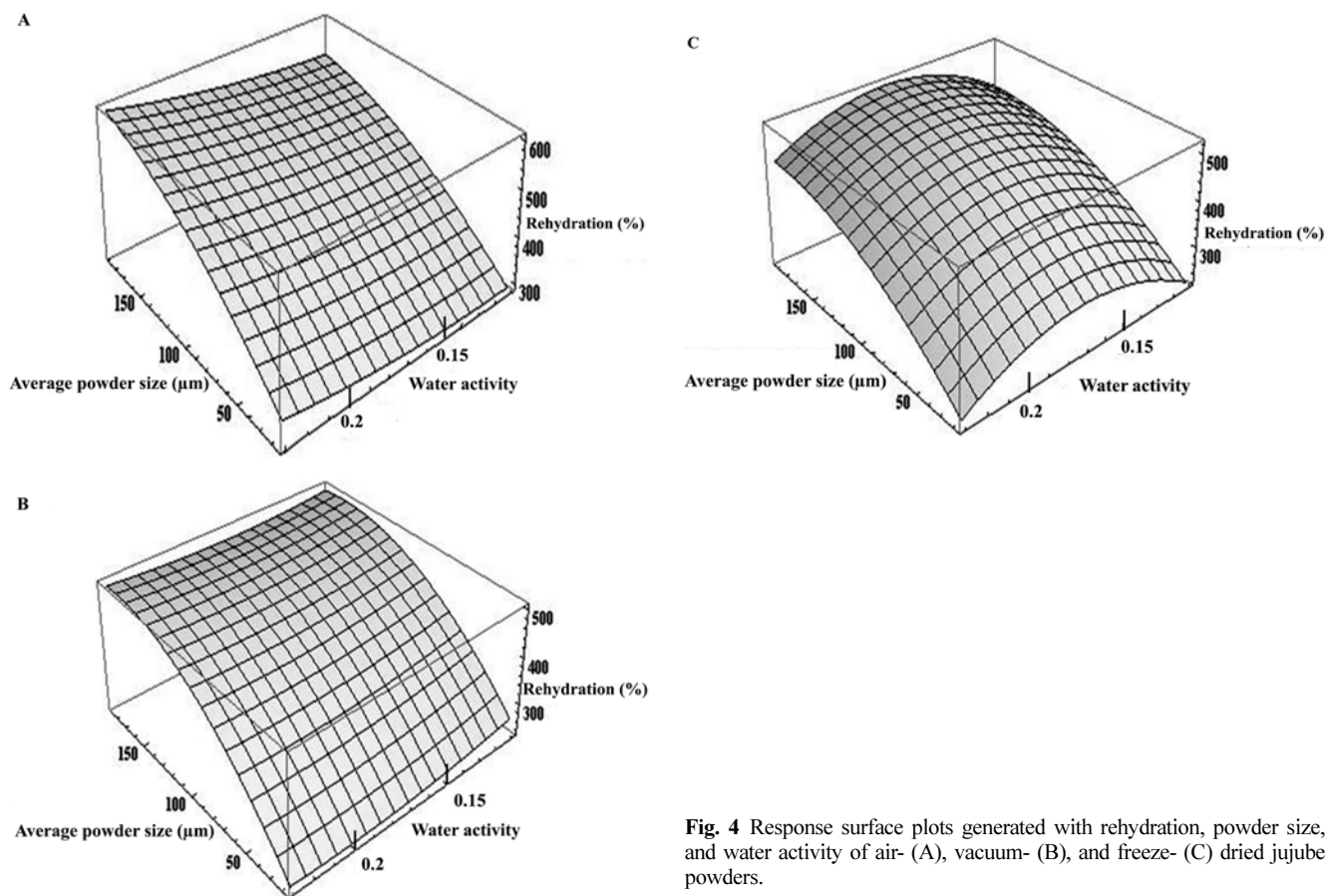


Fig. 4 Response surface plots generated with rehydration, powder size, and water activity of air- (A), vacuum- (B), and freeze- (C) dried jujube powders.

Table 3 Pearson correlation coefficients between the physicochemical properties of jujube powder

Drying method	Property	Average powder size (μm)	Water solubility (%)	Rehydration (%)	Total sugar content (mg/mL)	Polyphenol content (mg/g)
Air-drying	Average powder size (μm)	1.000				
	Water solubility (%)	-0.403	1.000			
	Rehydration (%)	0.954 ^B	-0.317	1.000		
	Total sugar content (mg/mL)	-0.874 ^B	0.282	-0.828 ^C	1.000	
	Polyphenol content (mg/g)	0.698 ^A	-0.286	0.680 ^A	-0.518	1.000
Vacuum-drying	Average powder size (μm)	1.000				
	Water solubility (%)	-0.125	1.000			
	Rehydration (%)	0.933 ^B	-0.082	1.000		
	Total sugar content (mg/mL)	-0.276	0.362	-0.334	1.000	
	Polyphenol content (mg/g)	-0.541	0.568	-0.505	0.613 ^A	1.000
Freeze-drying	Average powder size (im)	1.000				
	Water solubility (%)	-0.592 ^A	1.000			
	Rehydration (%)	0.871 ^B	-0.325	1.000		
	Total sugar content (mg/mL)	-0.126	0.498	0.236	1.000	
	Polyphenol content (mg/g)	-0.285	0.067	-0.608 ^A	-0.533	1.000

^ACorrelation significant at $p < 0.05$.

^BCorrelation significant at $p < 0.001$.

Table 4 Multiple linear regression models predicting the physicochemical properties of jujube powder

Drying method	Properties	Independent variables	Coefficient	R ²
Air-drying	Water solubility	Constant	98.82	0.92 ^A
		Average powder size	-0.12	
		Rehydration	0.04	
		Total sugar content	-4.14	
	Rehydration	Polyphenol content	3.28	
		Constant	-27.93	
		Average powder size	1.55 ^A	
		Water solubility	1.53	
		Total sugar content	9.34	
		Polyphenol content	46.69	
Vacuum-drying	Water solubility	Constant	51.35 ^A	0.88 ^A
		Average powder size	-0.00	
		Rehydration	0.01	
		Total sugar content	0.13	
	Rehydration	Polyphenol content	8.85	
		Constant	151.90	
		Average powder size	1.48 ^A	
		Water solubility	3.22	
		Total sugar content	-25.06	
		Polyphenol content	31.16	
Freeze-drying	Water solubility	Constant	42.36	0.65
		Average powder size	-0.04	
		Rehydration	0.03	
		Total sugar content	1.45	
	Rehydration	Polyphenol content	7.98	
		Constant	8.43	
		Average powder size	1.19 ^A	
		Water solubility	7.18	
		Total sugar content	13.62	
		Polyphenol content	-184.74	

^ARegression significant at $p < 0.001$.

moles of polyphenols (Jeong et al., 2004). Phenolic compounds formed by non-enzymatic browning in AD also could increase the polyphenol content, because the polyphenol-determining method using the Folin-Ciocalteu reagent can response to phenolic compounds (Hong et al., 2011). Similar results of polyphenol content were observed from drying studies with tangerine epicarp and onion (Jeong et al., 2004; Kim et al., 2007).

Correlations among the properties. Pearson correlation, multiple linear regression, and response surface analysis were applied to the property data to obtain correlations among the properties. The results from Pearson correlation coefficient analysis indicated that the level of rehydration and the average powder sizes had positive correlations (AD: $r=0.954$, $p < 0.001$; VD: $r=0.933$, $p < 0.001$; FD: $r=0.871$, $p < 0.001$) (Table 3).

Multiple linear regression analysis was conducted to determine which variables (water solubility, total sugar content, and polyphenol content) are significantly affected by water solubility or rehydration. Results from the multiple linear regression analysis are summarized in Table 4. In AD powder, rehydration was more

strongly related to the other properties ($R^2=0.92$) than water solubility ($R^2=0.24$) (Table 4). A fairly strong correlation between rehydration and average powder size was shown with VD powder ($R^2=0.88$). Water solubility was not significantly related to any of the properties of VD powder ($p > 0.05$) (Table 4). In FD powder, both water solubility and rehydration showed correlations with the other properties ($R^2=0.65$ and 0.94 , respectively) (Table 4). Furthermore, rehydration showed significant correlation to average powder size in AD, VD, and FD powders ($p < 0.001$).

The models obtained from RSA for AD, VD, and FD powders with respect to rehydration (y) were $y=311.000329+2.425031x_1-9.46587x_2-0.005886x_1x_1+0.016618x_2x_1+0.373288x_2x_2$, $y=329.140722+3.458194x_1-15.221496x_2-0.010959x_1x_1+0.015569x_2x_1+0.368428x_2x_2$, $y=-438.154407+2.586081x_1+82.547066x_2-0.007215x_1x_1+0.007834x_2x_1-2.412708x_2x_2$, respectively. Rehydration was highly correlated with the independent variables of average powder size (x_1) and water activity (x_2). The rehydration, average particles size, and water activity were well explained by the models ($R^2=0.98-0.99$, $p < 0.001$). Response surfaces generated

with rehydration, powder size, and water activity of air-, vacuum-, and freeze-dried jujube powders are illustrated in Fig. 4. The correlations among the properties indicate rehydration of the powder could be maximized by controlling particle size and water activity of the powder. The correlations determined herein could be used to improve the property of interest by controlling other properties that significantly affect the property of interest.

Acknowledgment This study was supported by Boeun Jujube Industry Support Center of the Ministry for Food, Agriculture, Forestry and Fisheries in Republic of Korea.

References

- AOAC (1998) Official Methods of Analysis (16th ed.), Association of Official Analytical Chemists, Arlington, VA.
- Breiman L and Friedman JH (1985) Estimating optimal transformations for multiple regression and correlation. *J Am Stat Assoc* **80**, 580–598.
- Crawford M (2002) The jujube: *Ziziphus Jujuba*. *West Australian Nut and Tree Crop Association* **26**, 37–42.
- Fang S, Wang Z, Hu X, and Datta AK (2009) Hot-air drying of whole fruit Chinese jujube (*Ziziphus jujube* Miller): Physicochemical properties of dried products. *Int J Food Sci Tech* **44**, 1415–1421.
- Hong JI, Kim HJ, and Kim JY (2011) Factors affecting reactivity of various phenolic compounds with the Folin-Ciocalteu reagent. *J Korean Soc Food Sci Nutr* **20**, 205–213.
- Jeong SM, Kim SY, Kim DR, Jo SC, Nam KC, Ahn DU et al. (2004) Effect of heat treatment on the antioxidant activity of extract from citrus peels. *J Agr Food Chem* **52**, 3389–3393.
- Kim HK and Joo KJ (2005) Antioxidative capacity and total phenolic compounds of methanol extract from jujube. *J Korean Soc Food Sci Nutr* **34**, 750–754.
- Kim HR, Seog EJ, Lee JH, and Rhim JW (2007) Physicochemical properties of onion powder as influenced by drying methods. *J Korean Soc Food Sci Nutr* **36**, 342–347.
- Koch HJ, Gürtler K, and Szecey A (2005) Correlation of Mini-Mental-State-Examination (MMSE), Syndrom-Kurztest (SKT) and Clock test (CT) scores in patients with cognitive impairment assessed by means of multiple regression and response surface analysis. *Arch Gerontol Geriatr* **40**, 7–14.
- Lee JE, Jun JY, Kang WS, Lim JD, Kim DE, Lee KY et al. (2008) Effect of particle size on the solubility and dispersibility of endosperm, bran and husk powder of rice. *Food Sci Biotechnol* **17**, 833–888.
- Lee KS, Park KH, Lee SH, Choe EO, and Lee HG (2003) The quality properties of dried carrot as affected by blanching and drying methods during storage. *Korean J Food Sci Technol* **35**, 1086–1092.
- Lee MJ and Lee JH (2007) Moisture sorption isotherm characteristics of chaga mushroom powder as influenced by particle size. *Food Sci Biotechnol* **16**, 154–158.
- Lewicki PP (1998) Effect of pre-drying treatment, drying and rehydration on plant tissue properties: A review. *Int J Food Prop* **1**, 1–22.
- Li H, Li F, Wang L, Sheng J, Xin Z, Zhao L et al. (2009) Effect of nanopacking on preservation quality of Chinese jujube (*Ziziphus jujube* Mill. var. *inermis* (Bunge) Rehd). *Food Chem* **114**, 547–552.
- Liu K (2008) Particle size distribution of distillers dried grains with solubles (DDGS) and relationships to compositional and color properties. *Bioresour Technol* **99**, 8421–8428.
- Medcalf DG and Gilles KA (1956) Comparison of physicochemical properties. *Cereal Chem* **42**, 558–568.
- Myung IJ, Kim C, and Pitt MA (2000) Toward an explanation of the power law artifact: Insights from response surface analysis. *Mem Cogn* **28**, 832–840.
- Noh BS, Youn AR, and Lee NY (2005) Application of mass spectrometer-based electronic nose for discrimination of *Angelicae gigantis radix*. *Food Sci Biotechnol* **14**, 537–539.
- Pearson K (1920) Notes on the history of correlation. *Biometrika* **13**, 25–45.
- Picesky J (1986) Standard specification and test methods for dry milk product. In *Concentration and Drying of Foods*, pp. 203–220, Elsevier Applied Science, London, UK.
- Rahman MS and Perera CO (1999) Drying and food preservation. In *Handbook of Food Preservation*, pp. 173–216, Marcel Dekke, New York, NY.
- Ratti C (2001) Hot air and freeze-drying of high-value foods: A review. *J Food Eng* **49**, 311–319.
- Sanni LO, Arere C, and Kuye A (1997) Moisture sorption isotherms of fufu and tapioca at different temperatures. *J Food Eng* **34**, 203–212.
- Schmidt RH, Illingworth BL, Deng JC, and Cornell JA (1979) Multiple regression and response surface analysis of the effects of calcium chloride and cysteine on heat-induced whey protein gelation. *J Agr Food Chem* **27**, 529–532.
- Schoch TJ (1964) Swelling power and solubility of granular starches. In *Methods in Carbohydrate Chemistry*, pp. 106–108, Academic press, New York, NY.
- Shittu TA and Lawal MO (2007) Factors affecting instant properties of powdered cocoa beverage. *Food Chem* **100**, 91–98.
- Shivhare US, Arora S, Ahmed J, and Raghavan GSV (2004) Moisture adsorption isotherms for mushroom. *LWT-Food Sci Technol* **37**, 133–137.
- Sohn KS, Lee JH, and Ha YS (2002) Clarification of mixed fruit and vegetable juices using enzyme treatment. *Food Eng Prog* **6**, 241–247.
- Spies WEL and Wolf WR (1987) Critical evaluation of methods to determine moisture sorption isotherms. In *Water Activity: Theory and Applications to Food*, pp. 215–33, Marcel Dekke, New York, NY.
- Sun HF, Meng YP, Cao QF, Wada M, and Liang AH (2009) Molecular cloning and expression analysis of a SQUA/API homologue in Chinese jujube (*Ziziphus jujube* Mill.). *Plant Mol Biol Rep* **27**, 534–541.
- Swain T, Hillis WE, and Oritega M (1959) The phenolic constituents of *Prunus domestica*. I. - The quantitative analysis of phenolic constituents. *J Sci Food Agr* **10**, 83–88.
- Zhang MC, Zhang J, and Shrestha S (2005) Study on the preparation technology of superfine ground powder of *Agrocybe chaxingu* Huang. *J Food Eng* **67**, 333–337.
- Zhao XY, Yang ZB, Gai GS, and Yang YF (2009) Effect of superfine grinding on properties of ginger powder. *J Food Eng* **91**, 217–222.
- Zhu Z, Zhang Z, Qin G, and Tian S (2010) Effects of brassinosteroids on postharvest disease and senescence of jujube fruit in storage. *Postharvest Biol Technol* **56**, 50–55.