Color, bioactive compounds and morphological characteristics of encapsulated Asian pear juice powder during spray drying

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Abstract Encapsulated Asian pear juice powder was produced through spray drying using three maltodextrin levels (15, 20, and 25% w/v) and three inlet air temperatures (130, 150, and 170 °C). The impact of maltodextrin concentrations and inlet air temperatures on color, bioactive compounds, and morphological characteristics of encapsulated Asian pear juice powder were investigated. Maltodextrin concentrations and inlet air temperatures significantly influenced L^* and b^* values of encapsulated Asian pear juice powder. Increasing inlet air temperatures increased total phenolic content, whereas the vitamin C content decreased. Vitamin C content was strongly correlated with particle size, inlet air temperature, and maltodextrin concentration. ABTS⁺ radical-scavenging activity was highly correlated with total phenol content while DPPH radical-scavenging activity was highly correlated with vitamin C content. Encapsulated powders made with higher inlet air temperature and higher maltodextrin concentration had lowest median particle diameter with a smoother, more regular and rounded outer surface than those of encapsulated powders produced with

lower inlet air temperature and lower maltodextrin concentration. Therefore, the results demonstrate that high-quality encapsulated Asian pear juice powder could be manufactured by adding 15% (w/v) maltodextrin and spray-drying at 170 °C.

Keywords Asian pear · Maltodextrin · Drying temperature · Bioactive compounds · Antioxidant activity

Introduction

In Korea, Asian pear (*P. pyrifolia* Nakai) fruit is abundantly produced and accounts for 11.5% of total fruit production (Zhang et al. 2003). Fresh Asian pear fruit and juice are the most common commodities consumed in Korea. Pears contain anti-cancer, anti-inflammatory and antioxidant compounds such as vitamin C, flavonoids and polyphenol-like chlorogenic acid, rutin, procyanidins, catechin, epicatechin, and arbutin (4-hydroxyphenyl- β -D-glucopyranoside) (Zhang et al. 2003). Recently, pear orchards have suffered high economic losses because of low stability in terms of quality deterioration and decaying of pear during storage. Pear fruits are quickly affected by core browning or brown heart due to fermentive and antioxidant enzyme during controlled atmosphere storage (Larrigaudière et al. 2004). Long-term cold storage could be used to preserve the pear fruit. However, preservation by cold storage is costly and also could be formed core browning or brown heart. Processing fruit into value-added products include juice, wine, vinegar, and snacks would stabilize the price. However, expensive shipping and storage are required for those products owing to their liquid and solid state. Therefore, alternative shelf-stable pear products should be pursued.

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Juice powder could be made from pear using drying techniques. Reduced packaging, easy transport and longer shelf life are the main advantages of the juice powder (Mishra et al. 2014). Among different drying methods, spray drying is superior for maintaining heat sensitive compounds, product quality and yield. Drying temperatures, drying air, feed flow rate, encapsulating agents and contact between the hot air and juice droplets in the main chamber are the crucial factors for final product quality during spray drying (Goula et al. 2004).

Spray drying and various encapsulating agents like gum Arabic, modified starch capsules, maltodextrin, whey protein isolate, chitosan, and gelatin were used in the manufacture of fruit juice powders, such as amla (Mishra et al. 2014); cashew apple (Bastos et al. 2012); bayberry (Fang and Bhandari 2012); gac (Kha et al. 2010); pomegranate (Santiago et al. 2016); and cactus pear (Castro-Munoz et al. 2015). Maltodextrin concentration of 5–7% could be used to produce good quality blackberry powder by spray drying (Ferrari et al. 2012). Tomato powder (Goula et al. 2004); watermelon powder (Quek et al. 2007); guava powder (Chopda and Barrett 2001) and buckthorn fruit juice powder (Selvamuthukumaran and Khanum 2014) was also made using different concentration of maltodextrin through spray drying. Different encapsulating materials protect different polyphenols during drying. Polyphenols compounds are sensitive to high temperature, pH, moisture, oxygen and light. Among different encapsulating agents, low cost and commercially available dextrose equivalents of maltodextrin are often used during spray drying. There are no reports available on the stability of bioactive compounds and morphology of pear juice powder using maltodextrin with spray drying. Therefore, this study aimed to evaluate the color, bioactive compounds, antioxidant activities, and morphological characteristics of Asian pear juice powder with different concentrations of maltodextrin added and spray-dried at different inlet air temperatures.

Materials and methods

Materials

Asian pears (*P. pyrifolia* Nakai cv. Niitaka) were obtained from a local farm in Naju, Korea, and stored at 4 °C until used (not more than one week). Maltodextrin (Corn Products, Daesang, Seoul, Korea) with 10 dextrose equivalents (DE) was used as a carrier agent and purchased from a local market in Gwangju, Korea.

Juice preparation

The pears were washed and cut with a knife into eight equal parts, placed into filter cloth and then pressed using a

juice extractor (JRC001, Koryeo Industry, Seoul, Korea) at a pressure of 1325 kgf/cm² for 3 min. Extracted juice was filtered through a 0.45-μm filter paper (MFE4500-hs, Rover Pompe, Polverara, Italy) using a press filter (MFS0010, Rover Pompe, Polverara, Italy). The filtered juice was stored at −80 °C in polyester (PET) bottles (Polinati et al. 2010).

Preparation of encapsulation solution

Different concentrations of maltodextrin (15, 20 and 25% w/v) were added to the juice and homogenized using a blender (HR1372, Philips, Eindhoven, Netherlands) until completely dissolved.

Spray drying

Prior to spray drying, frozen juice was thawed at 4 °C for 12 h. Various concentrations of maltodextrins were added to the juice before spray drying. Treated juice was dried using a pilot-scale spray dryer (MH-8, Mehyun Engineering, Seoul, Korea), with rotary disc atomizer under the following conditions: atomizer speed 9860 RPM, feed rate 12 mL/min, compressor air pressure 0.74 MPa and inlet air temperatures/outlet air temperatures 130 °C/82 °C, 150 °C/85 °C and 170 °C/88 °C. Lower concentration than 15% of maltodextrin was not sufficient to produce pear juice powder due to stickiness as well as yield was also lower as compared to pear juice made with higher concentration of maltodextrin.

Analysis of methods

Color measurement

A colorimeter (CR-400, Minolta, Tokyo, Japan) was used to the determination of color of Asian pear juice powder. The results were expressed as lightness (L^*), redness and greenness (a^*), yellowness and blueness (b^*). The colorimeter was calibrated using a white color tile ($L^* = 86.90$, $a^* = 0.3170$ and $b^* = 0.3240$).

Vitamin C content

The Doner and Hickts (1981) method with slight modifications was used to analyze the Vitamin C content. A volume of 50 mL of 5% metaphosphoric acid solution was added into 1 g of Asian pear juice powder and stirred for 30 min at room temperature. The solution was centrifuged at 2016 RCF (g) for 15 min and the supernatant filtered through a 0.45-μm PVDF syringe and then injected to the High performance liquid chromatography columns (HPLC;

1200 Series, Agilent Technologies, Santa Clara, CA, USA). Samples of 20 μL at wave length 254 nm and Sep-pak C_{18} column (4.6 mm I.D $\times$ 250 mm L, Alltech Co., China) with a mobile phase of acetonitrile: 0.05 M KH_2PO_4 (60:40 v/v) (A) and water (B) at a flow rate of 1 mL/min was employed to separate the vitamin C from the supernatant. The 1 mg/mL of ascorbic acid was used as external standard and dissolved in 5% metaphosphoric acid solution. Working standard solution was also prepared at concentration of 0.1–3.0 $\mu\text{g}/\text{mL}$ and mixed in 5% metaphosphoric acid solution. Sample retention time and working standard retention time was compared to quantify the amount of vitamin C of samples and calculated from standard curve (correlation coefficient of 0.989) and results were expressed as mg/100 g.

Total phenol content

The Folin–Ciocalteu reagent was used to determine the total phenol content of Asian pear juice powder (Eghdami and Sadeghi 2010). First, 9 mL of 80% methanol solution was mixed with 1 g of Asian pear juice powder at 40 °C for 24 h and cooled at room temperature. The solution was centrifuged at 2016 RCF (g) for 15 min and then filtered through filter paper. A volume of 200 μL of sample extract, 800 μL of Folin–Ciocalteu reagent and 2 mL of 7.5% sodium carbonate were incorporated and distilled water added for a total volume of 7 mL. The solution was kept in the dark for 1 h. The absorbance at 765 nm of the sample mixture was measured using a UV spectrophotometer (Optizen 2120UV, Mecasys, Seoul, Korea). Gallic acid was used as standard and expressed as mg gallic acid equivalents (GAE)/100 g.

DPPH radical-scavenging activity

The Blois (1958) method with modification was followed for the analysis of DPPH radical-scavenging activity of Asian pear juice powder. Juice powder (0.1 g) was mixed with 10 mL of ethanol for 3 min and filtered. An aliquot of 20 μL of the pear juice solution was added to 80 μL of 0.1 mM ethanolic solution of DPPH and shaken for 1 min. The solution was incubated in the dark for 30 min and absorbance was measured at 517 nm by a microplate spectrophotometer (Synergy Neo2, Biotek, Winooski, VT, USA). The following formula was used to calculate the DPPH radical-scavenging activity:

$$\text{Scavenging activity (\%)} = (1 - A_1/A_0) \times 100$$

A_0 = the absorbance of control solution (20 μL ethanol in 80 μL of DPPH solution); A_1 = the absorbance of the

0.1% pear juice powder solution in DPPH solution after 30 min incubation.

ABTS⁺ radical-scavenging activity

Spectrophotometric method (Re et al. 1999) with some modifications was employed to determine of the ABTS⁺ radical-scavenging activity. Pear juice powder (0.1 g) was extracted with 10 mL of ethanol and filtered. An aliquot of 10 μL of the filtered sample was mixed with 90 μL of 7 mM ABTS⁺ and vortexed for 1 min. The solution was incubated in the dark for 10 min at room temperature. The absorbance at 732 nm was measured using a microplate spectrophotometer (Synergy Neo2, Biotek, Washington, USA) and the following formula was used to estimate the ABTS⁺ radical-scavenging activity:

$$\text{Scavenging activity (\%)} = (1 - A_1/A_0) \times 100$$

A_0 = the absorbance of control solution (10 μL ethanol in 90 μL of ABTS⁺ solution); A_1 = the absorbance of the 0.1% pear juice powder solution in ABTS⁺ solution after 10 min incubation.

Particle size distribution of encapsulated Asian pear juice powder

Particle size determination was accomplished using a laser diffraction RODOS/VIBRI (Sympatec GmbH, Clausthal-Zellerfeld, Germany). De-agglomeration was performed using a HELOS laser sensor and a RODOS dry-powder air-dispersion system at 3 bar pressure (Rehman et al. 2004). A small sample was used to analyze the particle size.

Particle morphology of encapsulated Asian pear juice powder

Powder morphology of pear juice powder was observed using a scanning electron microscope (JSM-IT300LV, JEOL, Tokyo, Japan). Powders were coated with platinum by sputtering the voltage was 20 kV with magnifications of 500 $\times$.

Statistical analysis

All experiments were conducted twice and all measurements were performed in triplicate to calculate the mean $\pm$ standard deviation. One-way Analysis of Variance (ANOVA) followed by Duncan's multiple-range test (SPSS 18.0 software) was used to obtain the significance of the data. A value of $p < 0.05$ was considered statistically significant.

Results and discussion

Effects of maltodextrin concentrations and spray-drying temperatures on the color values of encapsulated Asian pear juice powder

Color plays an important role in determining the quality of dried powders and is an essential factor for consumer acceptability of the finished products (Quek et al. 2007). Color values of spray-dried Asian pear juice powder are shown in Table 1. Maltodextrin concentrations and inlet air temperatures significantly ($p < 0.05$) influenced L^* and b^* values of Asian pear juice powder. An increase in maltodextrin concentration led to an increase in L^* values whereas a decrease was seen for b^* values. On the other hand, increasing drying temperatures negatively influenced L^* values while b^* values were positively influenced. However a^* values were dependent on maltodextrin concentrations and drying temperature. Maltodextrin concentrations were the main reason for enhanced powder lightness as maltodextrin is usually white. The variation of a^* and b^* was probably related with phenolic content. Ahmed et al. (2010) showed redness and yellowness were correlated with total phenol content of maltodextrin treated spray-dried sweet potato powder. The L^* and b^* values were also influenced by caramelization and Millard reactions that occurred in the presence of sugars at high temperature during drying. In this study, we found L^* and b^* values were highly correlated with total phenolic content while a^* values were less so (data not shown). L^* , a^* and b^* values of spray-dried Asian pear juice powder were similar to the values found by other researchers such as in spray-dried sweet potato flour (Ahmed et al. 2010), spray-dried gac powder (Kha et al. 2010), spray-dried water melon

powder (Quek et al. 2007), and spray-dried guava powder (Chopda and Barrett 2001).

Effects of spray drying conditions on bioactive compounds of encapsulated Asian pear juice powder

Vitamin C content

The vitamin C content of Asian pear juice powder varied from 126.31 to 223.02 mg/100 g (Fig. 1a). Vitamin C values in Asian pear juice powder were much higher than that found in different pear cultivar (Table 2), spray-dried guava powder made with maltodextrin 580 (114.79 mg/100 g, Chopda and Barrett 2001) and spray-dried pomegranate juice powder made with maltodextrin 20 (11.52–31.56 mg/100 g, Muzaffar et al. 2016). However, Asian pear juice powder contained less vitamin C than spray-dried guava juice powder made with maltodextrin 500 (309.45 mg/100 g, Chopda and Barrett 2001) and spray-dried sea buckthorn fruit juice powder with maltodextrin 10 (336.2–406.9 mg/100 g, Selvamuthukumaran and Khanum 2014). These variations may be the result of different sample types and processing methods. Vitamin C content decreased as the concentration of maltodextrin increased because the overall solid content of the sample increased. Similar results were found for sea buckthorn fruit juice powder (Selvamuthukumaran and Khanum 2014) and spray-dried guava juice powder (Patil et al. 2014). Highest (25%) maltodextrin concentration showed significantly ($p < 0.05$) higher loss of vitamin C (31–44%, data not shown) than those of lowest (15%) maltodextrin concentration (2.69–22%, data not shown).

Vitamin C content significantly ($p < 0.05$) decreased as inlet air temperature increased. Similar observations were

Table 1 Color of encapsulated Asian pear juice powder prepared with three concentrations of maltodextrin and spray-dried at three inlet air temperatures

	Inlet air temperature (°C)	Maltodextrin concentrations (w/v)		
		15%	20%	25%
L^*	130	^C 93.30 ± 0.06 ^a	^B 94.17 ± 0.03 ^a	^A 94.48 ± 0.01 ^a
	150	^C 92.54 ± 0.03 ^b	^B 93.68 ± 0.08 ^b	^A 94.19 ± 0.02 ^b
	170	^C 88.18 ± 0.02 ^c	^B 91.51 ± 0.03 ^c	^A 92.27 ± 0.02 ^c
a^*	130	− ^A 3.16 ± 0.01 ^a	− ^B 3.43 ± 0.02 ^b	− ^C 3.94 ± 0.04 ^c
	150	− ^A 3.17 ± 0.02 ^a	− ^B 3.50 ± 0.02 ^b	− ^B 3.48 ± 0.02 ^b
	170	− ^A 1.33 ± 0.02 ^a	− ^B 1.89 ± 0.02 ^b	− ^C 2.59 ± 0.04 ^c
b^*	130	^A 13.39 ± 0.08 ^c	^B 11.01 ± 0.03 ^c	^C 10.29 ± 0.02 ^c
	150	^A 14.46 ± 0.07 ^b	^B 13.02 ± 0.06 ^b	^C 11.87 ± 0.02 ^b
	170	^A 20.86 ± 0.03 ^a	^B 14.14 ± 0.03 ^a	^C 13.64 ± 0.07 ^a

Values represent mean ± standard deviation

^{A–C} Means followed by different letters in each row are significantly different ($p < 0.05$)

^{a–c} Means followed by different letters in each column are significantly different ($p < 0.05$)

Fig. 1 **a** Vitamin C content of encapsulated Asian pear juice powder prepared with three concentrations (w/v) of maltodextrin and spray-dried at three inlet air temperatures. **b** Total phenol content of encapsulated Asian pear juice powder prepared with three concentrations (w/v) of maltodextrin and spray-dried at three inlet air temperatures. **c** DPPH radical-scavenging activity of encapsulated Asian pear juice powder prepared with three concentrations (w/v) of

maltodextrin and spray-dried at three inlet air temperatures. **d** ABTS⁺ radical-scavenging activity of encapsulated Asian pear juice powder prepared with three concentrations (w/v) of maltodextrin and spray-dried at three inlet air temperatures. ^{a–h}Means followed by different letters in each temperature are significantly different among maltodextrin concentrations ($p < 0.05$)

found by Patil et al. (2014) for spray-dried guava juice powder; by Muzaffar et al. (2016) for spray-dried pomegranate juice powder and by Rodríguez-Hernández et al. (2005) spray-dried cactus pear juice powder. High percentage of maltodextrin with high temperature had lower amount of vitamin C as compared to lower percentage of maltodextrin with lower temperature. These might be related to oxidize of vitamin C or particle size. Vitamin C is very sensitive to temperature and heat (Rodríguez-Hernández et al. 2005) as evidenced by the decrease in vitamin C content as inlet air temperature increased.

Particle size also influenced the degradation of vitamin C during drying. Rodríguez-Hernández et al. (2005) showed that the larger surface area to volume of smaller particles reduced the vitamin C content during drying.

Lowest particle size was obtained when Asian pear juice powder made with high concentration of maltodextrin and high inlet temperature than those of Asian pear juice powder produced with lower concentration of maltodextrin and lower inlet temperature (Table 4).

Total phenol content

It has already been proven that phenolics have antioxidative properties. Figure 1b shows the total phenol content (50.44–223.54 mg GAE/100 g) of Asian pear juice powder prepared with three maltodextrin concentrations and spray-dried at three inlet air temperatures. The total phenol content in spray-dried Asian pear juice powder was consistent with other pear varieties (Table 2) but greater than

Table 2 Bioactive compounds and antioxidant activity of different pear cultivars

Species	Cultivars	Origins	Total phenolics (mg/100 g FW)	Total phenols	Vitamin C	DPPH	ABTS	Source
<i>Pyrus communis</i> L.	Kirmizi	Turkey	–	216.8 (mg/100 g DW)	7.6 (mg/100 g DW)	50%	–	Abac et al. (2016)
	Limon	Turkey		230.5 (mg/100 g DW)	10.1 (mg/100 g DW)	34.5%	–	Abac et al. (2016)
	Red D' Anjou	Chile	200.5	40.7 (mg/serving)	7.2 (mg/serving)	37.7 (ascorbic acid equivalent)	–	Galvis-sanchez et al. (2003)
	Bose	Chile	166.5	32.8 (mg/serving)	5.4 (mg/serving)	48.6 (ascorbic acid equivalent)	–	Galvis-sanchez et al. (2003)
<i>Pyrus salicifolia</i>	Banda	Turkey		220.1 (mg/100 g DW)	10 (mg/100 g DW)	42.3%		Abac et al. (2016)
<i>Xoconostle</i>	Cuaresmeno	Mexico		128–986 (mg/100 g DW)	7.6–229.2 (mg/100 g DW)	–	–	Salvador et al. (2010)
<i>Pyrus bretschneideri</i>	Yali	China		210 (mg/100 g DW)	–	45%	94%	Yim and Nam (2016)
<i>Pyrus pyrifolia</i>	Niitaka	South Korea		240 (mg/100 g DW)	–	50%	88%	Yim and Nam (2016)
	Chuwang	South Korea		180 (mg/100 g DW)	–	35%	62%	Yim and Nam (2016)

FW fresh weight, DW dry weight

spray-dried pineapple fruit juice powder (40.5 mg/100 g, Selvamuthukumaran and Khanum 2014) and spray-dried grape fruit juice powder (46.9 mg/100 g, Selvamuthukumaran and Khanum 2014). Current values of spray-dried Asian pear juice total phenolic content were lower than spray-dried sea buckthorn fruit juice powder (453.6 mg/100 g) reported by (Selvamuthukumaran and Khanum 2014) and spray-dried bayberry juice powder (294.82 mg/100 g) reported by Fang and Bhandari (2011). These variations could be related to differences in raw sample types and encapsulating agents used. The total phenolic content in Asian pear juice powder significantly ($p < 0.05$) decreased as maltodextrin increased whereas temperature had a positive correlation with total phenolic content. Similar results were observed by Mishra et al. (2014) for spray-dried amla juice powder and by Wariyah and Riyanto (2016) for spray-dried aloe vera juice powder. Total soluble solid content tends to increase with increasing maltodextrin concentrations as the reacting molecules are located closely together and this arrangement influences the phenolic content (Ahmed et al. 2010; Kirca et al. 2007). Total phenol content in Asian pear juice powder increased with increasing inlet air temperature as a result of polyphenol synthesis. Mishra et al. (2014) showed that total phenol content increased in amla powder when temperature increased from 125 to 175 °C after which phenolic content

decreased. Ho et al. (2015) noted that phenolic content was reduced in spray-dried sim juice powder when drying temperature exceeded 180 °C. Therefore, it can be concluded that drying temperature is the crucial factor for phenolic content and 170 °C is the optimum temperature for Asian pear juice powder.

Antioxidant activity of encapsulated Asian pear juice powder

At least two methods are essential to estimate in vitro antioxidant activity (Bermudez-Soto and Tomas-Barberan 2005). Therefore, in this study we used two similar methods, DPPH radical-scavenging activity and ABTS⁺ radical-scavenging activity, to estimate the antioxidant activity in spray-dried Asian pear juice powder. Asian pear juice powder prepared with different concentrations of maltodextrin and spray-dried at different inlet air temperatures showed 26.50–65.28% DPPH radical-scavenging activity (Fig. 1c). These values were consistent with Kuck and Noreña (2016) who found 45.4–59.1% antioxidant activity determined by DPPH in microencapsulated grape skin prepared by using gum Arabic, polydextrose and partially hydrolyzed guar gum through spray- and freeze-drying. DPPH radical-scavenging activity of Asian pear juice powder decreased as maltodextrin concentrations and inlet

air temperatures increased. Mishra et al. (2014) showed similar trends for DPPH radical scavenging activity in spray-dried amla juice powder. However, no significant differences in DPPH radical scavenging activity were found between 15% (w/v) and 20% (w/v) maltodextrin concentrations. The DPPH radical-scavenging activity was strongly correlated with vitamin C content of Asian juice pear powder.

ABTS⁺ radical-scavenging activity was observed from 46.71 to 73.70% in Asian pear juice powder (Fig. 1d). These values were higher than those found by Ho et al. (2015) who observed 42.38–61.04% retention of antioxidant activity in spray-dried sim juice powder produced using different concentrations of maltodextrin. ABTS⁺ radical-scavenging activity of Asian juice pear powder decreased with increasing maltodextrin concentration, and increased with increasing inlet air temperature. These results might be correlated with total phenolic content. ABTS⁺ radical-scavenging activity was higher than DPPH radical-scavenging activity in our study. Bermudez-Soto and Tomas-Barberan (2005) and Horszwald et al. (2013) found greater ABTS⁺ radical-scavenging than DPPH radical scavenging in commercial red fruit juice and aronia powder, respectively. Wang et al. (1998) reported scavenging is dependent on the types of polyphenol compounds and mentioned that ABTS⁺ acts as a scavenger but that DPPH radicals did not scavenge. Therefore, the opposite result could be derived between ABTS⁺ radical-scavenging activity and DPPH radical-scavenging activity.

Correlation between antioxidant activity and bioactive compounds of spray-dried Asian pear juice powder

In this study, we found strong correlations between antioxidant activity and vitamin C content ($R^2 = 0.987$ – 0.998) and between antioxidant activity and total phenolic content ($R^2 = 0.989$ – 1.0) (Table 3). There was correlation between DPPH radical-scavenging activity and vitamin C at 15% maltodextrin concentration ($r = 0.998$, $p < 0.05$); 20% maltodextrin concentration ($r = 0.998$, $p > 0.05$) and 25% maltodextrin concentration

($r = 0.998$, $p < 0.05$). On the other hand higher maltodextrin concentration showed higher correlation (at 25% maltodextrin concentration $r = 1.0$, $p < 0.01$) and 20% maltodextrin concentration $r = 1.0$, $p < 0.01$) followed by 15% maltodextrin concentration ($r = 0.994$, $p < 0.05$) between ABTS⁺ radical-scavenging activity and total phenolic content. Many researchers found correlation between antioxidant activity and concentration of phenolic compounds as well as some who found a relationship between antioxidant activity and non-phenolic compounds. Horszwald et al. (2013) found no relation between phenolic compounds and antioxidant activity measured by DPPH and ABTS⁺ in spray dried aronia powders. However, this research group found positive correlation between monomeric anthocyanin and antioxidant activity determined by DPPH and ABTS⁺. Bermudez-Soto and Tomas-Barberan (2005) reported that antioxidant activity was correlated with total phenolic, anthocyanin and flavonol content in commercial red fruit juice. Kha et al. (2010) found a strong correlation between antioxidant activity and total carotenoid content in spray dried gac fruit powder.

Particle size distribution of encapsulated Asian pear juice powder

The particle size distribution of Asian pear juice powder ranged from 1.50 to 398.47 μm with a median diameter from about 55.29–62.38 μm (Fig. 2A and Table 4, respectively). Significantly ($p < 0.05$) lower particle size was observed with increasing temperature and increasing the maltodextrin concentration. Particle size distribution of Asian pear juice powder was monomodal. The distribution of particle size was similar with spray-dried sim juice powder (0.1–400 μm) reported by Ho et al. (2015), but particle diameter was higher than that of spray-dried blackberry juice powder (12.52–34.18 μm) obtained by Ferrari et al. (2012). Ho et al. (2015) observed monomodal and bimodal distribution of sim juice powder particle size. The variations of particle size pattern and particle diameter might be related to the types and concentrations of the encapsulating agents used. The highest inlet air temperature and highest maltodextrin concentration resulted in the

Table 3 Pearson's correlation coefficients among all antioxidant attributes of spray-dried Asian pear juice powder

	Concentrations (w/v) of maltodextrin					
	15%		20%		25%	
	Vitamin C	Total phenol	Vitamin C	Total phenol	Vitamin C	Total phenol
DPPH	0.997*	–	0.987 ^{NS}	–	0.998*	–
ABTS ⁺	–	0.989*	–	1.00**	–	1.00**

NS non-significant

*, ** significant at $p < 0.05$ and $p < 0.01$ respectively

Fig. 2 A Particle size distribution of encapsulated Asian pear juice powder prepared with three concentrations (w/v) of maltodextrin and spray-dried at three inlet air temperature. **a** Dried at 130 °C after treated with 15, 20, 25% maltodextrin. **b** Dried at 150 °C after treated with 15, 20, 25% maltodextrin. **c** Dried at 170 °C after treated with 15, 20, 25% maltodextrin. **B** Scanning electron micrographs of encapsulated Asian pear juice powder prepared with three concentrations (w/v) of maltodextrin and spray-dried at three inlet temperature. **a–c** Dried at 130 °C after treated with 15, 20, 25% maltodextrin, respectively. **d–f** Dried at 150 °C after treated with 15, 20, 25% maltodextrin, respectively. **g–i** Dried at 170 °C after treated with 15, 20, 25% maltodextrin, respectively

lowest median diameter (55.29 μm) as compared to the lowest inlet air temperature and lowest concentration of maltodextrin (62.38 μm). High moisture content prompts

the agglomeration of particles because of hydrogen bonds forming between maltodextrin and water molecules (Ho et al. 2015). In this study, we found that the moisture content of Asian pear juice powder prepared at higher inlet temperature and higher maltodextrin concentration was lower when compared to the moisture content of Asian pear juice powder made at lower temperature and lower maltodextrin concentration (data not shown). Ferrari et al. (2012) showed that particle size increased with increase the carrier agents. On the other hand, Ho et al. (2015) found that lower concentrations of carrier agents had larger particle size than higher concentration of carrier agents. In our study, we observed that particle size decreased as

B

Fig. 2 continued

Table 4 Particle size of encapsulated Asian pear juice powder prepared with three concentrations of maltodextrin and spray-dried at three inlet air temperature

Concentrations (w/v) of maltodextrin	Drying temperature (°C)		
	130	150	170
15%	^c 62.38 ± 0.13 ^C	^c 60.71 ± 0.33 ^B	^c 59.23 ± 0.22 ^A
20%	^b 61.13 ± 0.40 ^C	^b 59.16 ± 0.12 ^B	^b 58.05 ± 0.12 ^A
25%	^a 58.56 ± 0.24 ^C	^a 56.58 ± 0.33 ^B	^a 55.29 ± 0.11 ^A

Values represent mean ± standard deviation

^{a–c} Means followed by different letters in each column are significantly different ($p < 0.05$)

^{A–C} Means followed by different letters in each row are significantly different ($p < 0.05$)

maltodextrin concentrations increased. Particle size not only depends on moisture content but is influence by various factors such as juice droplet size, atomizer type, and the concentration and physical properties of the feed solution (Goula and Adamopoulos 2004).

Particles morphology of encapsulated Asian pear juice powder

Figure 2B show the scanning electron micrographs of Asian pear juice powder at three inlet air temperatures and three concentrations (w/v) of maltodextrin. Lower maltodextrin concentrations produced particles were strongly attached and more aggregated whereas the highest concentration of maltodextrin produced particles that were dented Fig. 2B. These differences might be related to higher moisture content causing particle stickiness. Similar results were obtained by Fazaeli et al. (2012) for spray-dried mulberry juice powder; Ferrari et al. (2012) for blackberry powder. However, as in let air temperatures increased particles were smoother, more regular and with rounded outer surfaces Fig. 2B (g–i) as compared to lower drying temperatures Fig. 2B (a–c) and (d–f). Fazaeli et al. (2012) found that higher drying temperatures produced smoother mulberry juice powder particles. Particle structures are influenced by drying rate and diffusion of water (Fazaeli et al. 2012). Usually slower diffusion of water leads to particle shrinkage and collapse and creates deformed particles (Fazaeli et al. 2012). Water diffusion varies with factors such as drying temperature, concentration and particle size (Fazaeli et al. 2012).

Conclusion

The effects of maltodextrin concentrations and inlet air temperature on color, bioactive compounds, antioxidant activities, particle size and morphology of pear juice powder were studied. Higher inlet air temperature causes a decrease in particle size, vitamin C content and DPPH

radical-scavenging activity, yet leads to increases in total phenol content and ABTS⁺ radical-scavenging activity. Increasing maltodextrin concentration causes a decrease in particle size, vitamin C content, total phenol content and DPPH radical-scavenging activity, yet leads to an increase in ABTS⁺ radical-scavenging activity. Thus, the results indicated that Asian pear juice powder could be prepared using spray dryer at 170 °C with 15% (w/v) maltodextrin that would be used to produce different foods and nutraceutical products.

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