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Influence of spray drying on water solubility index, apparent density, and anthocyanin content of pomegranate juice powder

Seid Mahdi Jafari [a,*], Malihe Ghalegi Ghalenoei [a], Danial Dehnad [b]

[a] Department of Food Materials and Process Design Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran
[b] Young Researchers and Elites club, Gorgan Branch, Islamic Azad University, Gorgan, Iran

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ABSTRACT

Pomegranates, originally cultivated in Iran and a valuable medicinal and nutritional fruit, could be converted into pomegranate juice powder to be accessible in other seasons and used as a valuable ingredient in other food and pharmaceutical products. In this research, pomegranate juice was spray dried at three maltodextrin levels (25, 35 and 45% w/w) and two inlet air temperatures (124 and 143 °C) and physicochemical and nutritional characteristics of the powder were surveyed. The experiments were carried out to measure drying yield, water solubility index, apparent density, color values, anthocyanin content, and morphological properties of the pomegranate juice powders. Inlet air temperature just could affect density of the powder while maltodextrin level could influence anthocyanin content of the final powder as well. Higher maltodextrin levels and temperatures lowered a* values of the powder, due to the lower anthocyanin content remained in the product at these situations. SEM analysis revealed that lower maltodextrin levels and higher inlet air temperatures resulted in smaller but smoother particles. In conclusion, pomegranate juice powders produced at 25% maltodextrin level and 124 °C, with high water solubility index of 95%, high density of 0.889 g cm^{-3}, and anthocyanin content of 8 mg L^{-1}, are suitable and nutritionally-rich choices for industrial production.

1. Introduction

Pomegranate (*Punica granatum* L.) is originally cultivated in many tropical and subtropical regions of the world and is a valuable medicinal and nutritional fruit mainly due to its antioxidant, antitumor, antihepatotoxic, antilipoperoxidative and antibacterial properties. Pomegranate juice has strong antioxidant activity, attributable to a diverse group of polyphenols including ellagitannins, gallotannins, ellagic acid, and flavonoids such as anthocyanins [5,37]. Fruits and vegetables contain high moisture content (80%), resulting in their classification as highly perishable produces [19]. There are several drying techniques for production of food powders to hamper the relevant loss of food products: hot air, vacuum, freeze, fluidized bed [15,16], Refractance-Windows [15,18], osmotic [4] and spray drying among which the latter is the simplest and commercially used method for transforming a wide variety of liquid food products into powder form. The drying process is very short, thus enabling us to prepare dried fruit powder without heat degradation even at comparatively high air temperatures [8].

Usually, fruit juices have low T_g points due to their high content of sucrose (62 °C), Fructose (5 °C) and glucose (32 °C). They might stick to the dryer chamber wall during drying, leading to low product yield and operational problems [25]. In process-based modifications, stickiness could be avoided by keeping the outlet temperature of the air below 50 °C or even at ambient temperature although the obtained powders usually have high residual moisture contents and water activity values, negatively impacting their subsequent storage [21]. To overcome these problems, drying aids, e.g. isolated protein, maltodextrin with different dextrose equivalent, and food grade anticaking agents are added. The most conventional carrier agents used in the spray drying of fruit juices are maltodextrins and gum Arabic, mainly due to their high solubility and low viscosity [2]. These carrier agents, which have high molecular weight, are also useful for increasing the product's glass transition temperature, aiming at avoiding spray drying operational problems such as stickiness to the dryer chamber wall, as well as structural transformations such as collapse and crystallization, during food processing and storage, especially important in the case of sugar- rich products such as fruit juices [34]. The addition of maltodextrin before spray drying has been reported to be effective in preserving carotenoids such as b-carotene; carrot carotenes; blackcurrant, apricot and raspberry juices and guava juice [22].

Yousefi et al. [40,41] compared effects of a combination of maltodextrin, Arabic gum, and waxy starch at different levels (8% and 12% w/w) as the drying aid and various concentrations (0, 1.5, 3, and 4.5%) of microcrystalline cellulose on spray drying of pomegranate juice. They concluded that as cellulose concentration increased in solution, the

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* Corresponding author.
E-mail address: smjafari@gau.ac.ir (S.M. Jafari).

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solubility of the final product decreased, and adding a carrier could increase T_g of the powder and its storage stability considerably; they also suggested the selected Artificial Neural Network model (3-10-8-5) was more efficient than the RSM model to predict drying behavior of the product. Muzaffar et al. [26] optimized spray drying conditions for production of pomegranate juice powder. Their spray drying operating conditions included inlet air temperatures of 170–190 °C, feed flow rate of 18–30 mL/min and blower speed of 2000–2400 rpm; they concluded that optimum quality was obtained at 171 °C, 30 mL/min and 2400 rpm. In a similar study, Muzaffar et al. [27] determined production efficiency, color, glass transition, and sticky point temperature of spray dried pomegranate juice powder. In that research, they focused more on the changes in temperature when different levels of maltodextrin were added at temperatures of 170–190 °C and reported increases of T_g from 38 to 72 °C and sticky point temperatures from 57 to 89 °C after a raise in maltodextrin concentration from 5 to 25%. In another study, Horuz et al. [14] spray dried unclarified pomegranate juice, and different inlet air temperature (110–140 °C), maltodextrin percentage (39.08–64.12%), and feed mixture concentration (19.61–44.11°Brix) were chosen as the independent variables; they drew a conclusion that high drying yield (86%) and antioxidant activity (77%) could be obtained. Finally, and most relevantly, Vardin and Yasar optimized spray drying of pomegranate juice treated with 0.5, 0.75 and 1 ratios of juice to maltodextrin at 110, 140 and 170 °C and concluded that the optimized temperatures would be between 125 and 145 °C as we deployed in our research although different ratios of juice to maltodextrin were applied.

Iran is one of the main producers of pomegranate in the world; a high volume of this product are produced in a short period, which could be converted into pomegranate juice powder to be accessible in other seasons and also be used as a valuable ingredient in other food and pharmaceutical products. Besides, transportation, packaging, and storage costs of the product could be reduced in this way. So, we decided to evaluate physicochemical and nutritional contents of pomegranate juice powder and assess the influence of different inlet temperatures of spray drier and maltodextrin concentrations on those properties of the final powder to represent an optimal condition for this product at our own spray drying operational parameters.

2. Materials and methods

Hydrochloric acid, ethanol 96%, $CH_3CO_2Na \cdot 3H_2O$, KCl, sodium carbonate, and methanol 96% were purchased from Merck Company, Germany, and maltodextrin DE = 18–20 from Foodchem International Corporation, China.

2.1. Spray drying of pomegranate juice

Pomegranates were purchased from a local market in Hamedan, Iran. Only sweet, mature fruits were selected for these tests. The skin was removed and fruit juice extracted from the fleshy sacs using a hand-operated domestic press. The juice was stored at 4 °C overnight to allow the suspended particles to settle. The fresh juice was then clarified using a spiral ultrafiltration system with a molecular weight-cut off of 40 KD (Osmonic, USA). Before dehydration, the juice was diluted and standardized with distilled water to 12°Brix TSS. Pomegranate juice, mixed with different maltodextrin percentage of 25, 35 and 45%, was dried by a spray drier (Jahad Keshavarzi Fars, Iran) with rotary disc atomizer nozzles working at a fixed speed of 11,300 rpm into a 3.5 m high drying chamber (Fig. 1). The air flow type was concurrent, and inlet and outlet air temperatures were 124–143 and 48–76 °C. The liquid feed rate was kept between 0.5 and 1.5 kg h^{-1} and drying air flow (aspirator) rate at 4500 m^3 h^{-1}. In this project, concentration of maltodextrin and temperature of inlet air were our variables. The final product was vacuum sealed in polyethylene bags. The bags were then stored in a desiccator containing silica gel before quality evaluation.

2.2. Drying yield

The weight of the dry material in the powder and juice was used to determine the spray-drying yield. This factor was calculated from the following eq. [41]:

$$Yield = \frac{P \times S_P}{L \times S_F}$$

where P is the rate of powder production (g/min), S_P is the percent of total solids of the powder, L is the feed flow rate (g/min), and S_F is the percent of total solids of the feed.

2.3. Water solubility index (WSI)

WSI was determined as described by Anderson et al. [3] with modifications. To determine WSI, 2.5 g of powder was suspended in 30 mL of distilled water at ambient temperature in a tared centrifuge tube. The

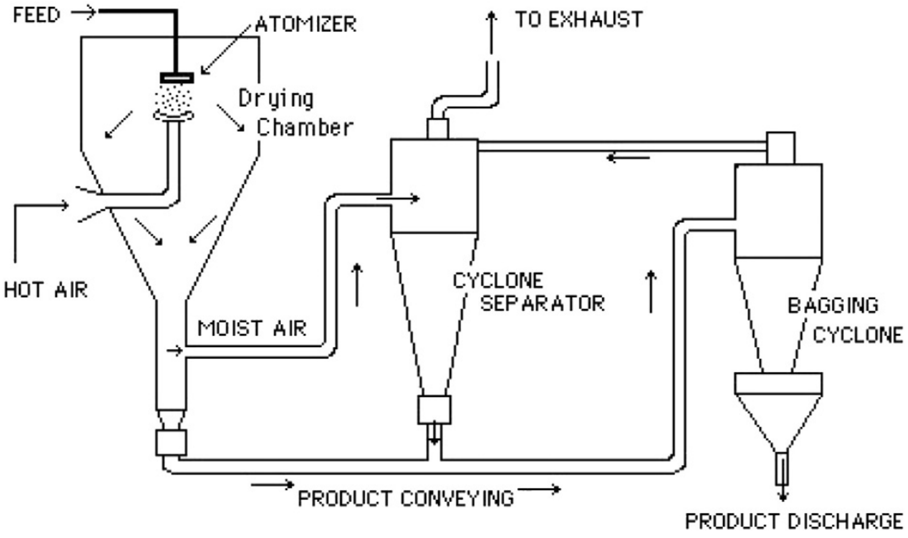

Fig. 1. Spray drying equipment used in this research.

suspension was stirred in a vortex mixer for 1 min, place in a water bath (Fater Electric, Iran) at 37 °C for 30 min, and then centrifuged in a Dragon centrifuge (Dragon Laboratory, China) at 3500 rpm and 4 °C for 20 min. The liquid supernatant was poured into a pre-weighed dish and dried at 105 °C to a constant weight. WSI was calculated by:

$$WSI\ (\%) = \frac{Dried\ supernatant\ weight}{Initial\ sample\ weight} \times 100$$

2.4. Density

2 g of powder was transferred into a 10 mL graduated cylinder and vibrated by a vibrator (Dragon Laboratory, China) for 1 min [2]. The bulk density was calculated by dividing the mass (g) of the powder by the volume occupied in the cylinder.

2.5. Color properties

Color properties of pomegranate juice powder were determined by Image J software and differences between color values of the dried samples were clarified in terms of L^* (lightness), a^* (redness, greenness) and b^* value (yellowness, blueness) [18].

2.6. Determination of total anthocyanin

Monomeric anthocyanin pigments change color with a change in pH reversibly; the colored oxonium form exists at pH 1.0, and the colorless hemiketal form predominates at pH 4.5. The difference in the absorbance of the pigments at 520 nm is proportional to the pigment concentration. Results are expressed on a cyanidin-3-glucoside basis. Degraded anthocyanins in the polymeric form are resistant to color change regardless of pH and are not included in the measurements because they are absorbed at pH 4.5 as well as pH 1.0.

2.6.1. Anthocyanin isolation

1 g powder was extracted exhaustively by maceration with 9 mL acidic methanol (1:10, w/v) containing 1% 0.1 M HCl over 24 h at room temperature and the extract was filtered through a sintered glass funnel [20].

2.6.2. Buffer preparation

pH 1.0 buffer (potassium chloride, 0.025 M): 1.86 g KCl was weighed into a beaker and distilled water was added to ca 980 mL. pH was measured and adjusted to 1.0 with HCl (ca 6.3 mL). It was transferred to a 1 L volumetric flask and diluted to the volume with distilled water [23].

pH 4.5 buffer (sodium acetate, 0.4 M): 54.43 g $CH_3CO_2Na \cdot 3H_2O$ was weighed into a beaker and distilled water was added to ca 960 mL. pH was measured and adjusted to 4.5 with HCl (ca 20 mL). It was transferred to a 1 L volumetric flask and diluted to volume with distilled water [23].

2.6.3. Anthocyanin measurement

5 mL of the extract was mixed with 20 mL pH 1.0 buffer and diluted to 50 mL volume with distilled water and was left for 20–45 min in a dark place and its absorption was read at 520 and 700 nm by a spectrophotometer (UNICO, USA) (sample to buffer ratio of 1 to 4).

5 mL of the extract was mixed with 20 mL pH 4.5 buffer and diluted to 50 mL volume with distilled water and was left for 20–45 min in a dark place and its absorption was read at 520 and 700 nm by a spectrophotometer (sample to buffer ratio of 1 to 4).

Now, the difference in absorbance between the two buffer solutions is due to the monomeric anthocyanin pigments. Polymerized anthocyanin pigments and nonenzymic browning pigments do not exhibit reversible behavior with pH, and are thus excluded from the absorbance calculation [39]:

$$\text{Total Anthocynins}\left(\text{mg L}^{-1}\right) = \left(A \times MW \times DF \times\ 10^3\right)/(\mathcal{E} \times L)$$

$$\text{A} = [\text{A}_{520\ \text{nm}} - \text{A}_{700\ \text{nm}}]_{\text{pH}=1} - [\text{A}_{520\ \text{nm}} - \text{A}_{700\ \text{nm}}]_{\text{pH}=4.5}$$

MW (molecular weight) = 449.2 g mol^{-1} for cyanidin-3-glucoside (cyd-3-glu); DF = dilution factor; L = path length (1 cm); $\mathcal{E}$ = 26.900 M extinction coefficient, in L mol^{-1} cm^{-1}, for cyd-3-glu; and 10^3 = factor for conversion from g to mg.

2.7. SEM

The specimens were examined by a SEM (TESCAN, Czech Republic) equipment at an accelerating voltage of 15 kV and magnificence of × 1400 and × 220 [17].

2.8. Statistical analysis

All experiments were conducted in duplicate and an analysis of variance was performed. For the design of experiments, full factorial design was used. The least significant difference at $p < 0.05$ was calculated using the Duncan Multiple Range Test by SAS 9.1 software. To depict figures, Excel 2010 software was used.

3. Results and discussion

As it could be seen in the Table 1, maltodextrin percentage was more effective on pomegranate juice powder than temperature rate, discussed in detail below.

3.1. Production yield

Production yield of pomegranate juice powder was between 17 and 25%, with higher maltodextrin rates and temperatures leading to higher yields (Fig. 2). Although this yield rate was low, it is in agreement with the research of Chegini and Ghobadian [7] on orange juice powder, who obtained 18–35% production yield by using maltodextrin as drying aid and applying inlet air temperature of 130–50 °C and mentioned that without drying carrier, no powder obtained and a hard glass film shaped on walls. However, higher temperature had a reverse relationship with the drying yield of orange powder, in apparent contrast with the results of this research. They justified that increasing the inlet air temperature caused melting and more adhesion to wall, so the amount of powder production and yield reduced. Also, because of creating a dried layer at the droplet surface, water could not influence the inner surface of particles when they were dissolved in the water. Nevertheless, Fazaeli et al. [11] confirmed our result and attributed higher yield at greater temperatures to the greater efficiency of heat and mass transfer

Table 1
Analysis of variance for the effect of maltodextrin and temperature on physicochemical and nutritional characteristics of pomegranate juice powder.

Mean square				
Source	DF	Density	WSI	Anthocyanin
Maltodextrin	2	0.009**	8493^{ns}	3.626**
Inlet air temperature	1	0.003*	22.41^{ns}	0.221^{ns}
Interaction of maltodextrin and temperature	2	0.001^{ns}	0.173^{ns}	0.041^{ns}
Error	6	0.00035	5.29	0.275
CV		2.342	2.427	7.589

** Means significantly different at 0.01 probability level.
^{ns} Means with no significant difference at 0.05 probability level.
* Means significantly different at 0.05 probability level.

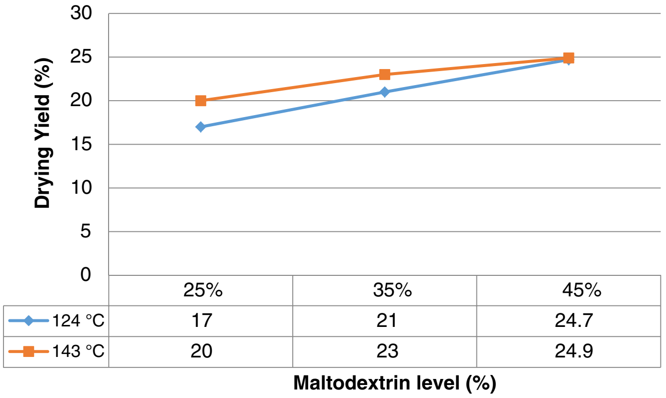

Fig. 2. Production yield of pomegranate juice powder by spray drying.

processes and lower probability of hitting the falling particles to the drying chamber wall.

Considering the effect of maltodextrin, Fazaeli et al. [11] approved that increasing carrier agent concentration in black mulberry juice significantly increased the process yield, because of increasing T_g values of the amorphous fractions in the mixtures. Nonetheless, Tonon et al. [33] showed that increasing maltodextrin concentration decreased the process yield due to increasing the mixture viscosity which results in more pasting of solids to the main chamber wall.

3.2. Apparent density

It is shown in Table 2 that there is a significant difference between density of samples with 25 and 35% maltodextrin levels and higher maltodextrin reduced density of the final product, probably due to a decrease in its moisture content or the higher air trapped in the particles as maltodextrin is a skin-forming material [11]. Similar results were observed by Goula and Adamopoulos [12] and Abadio et al. [1] when tomato and pineapple pulp were dried using maltodextrin as the carrier in a spray dryer. As far as the effect of temperature on density is concerned, increasing temperature decreased the density since it accelerates the rate of evaporation, creating a more porous and fragmented product.

3.3. Water solubility index (WSI)

WSI is a crucial representative of product behavior in an aqueous phase and a general criterion for determining reconstitution quality of the powder. For consumers, quick and complete reconstitution of powdered products is one of the main quality indicators. Solubility of powders can be affected by many parameters such as initial compositions of the raw material to be spray-dried, the carrier agents, compressed air flow rates, and low feed rates [22]. For example, a superior water solubility property of spray-dried cashew apple juice powder could be obtained by using cashew tree gum as the drying aid agent [10]. Influences of maltodextrin and temperature levels on this index were not considerable (Fig. 3). Kha et al. [22] reported the similar result after investigating into spray drying of sumac extract powder with different maltodextrin and temperature quantities. There was no significant difference between samples with various maltodextrin levels in this research but augmenting maltodextrin level lowered the index a bit although maltodextrin has a high solubility in water [11] This result is consistent with the results obtained by Moreira et al. [25] who reported water solubility of acerola pomace extract powders was negatively affected by maltodextrin although solubility remained above 90% in powders of all the treatments.

Table 2
Comparison of mean values for the effects of maltodextrin and temperature on density of pomegranate juice powder.

Treatment	Density (gr/cm^3)
MD25-T124[1]	0.889^{a,*}
MD25-T143	0.816^{a}
MD35-T124	0.795^{b}
MD35-T143	0.784^{ab}
MD45-T124	0.769^{b}
MD45-T143	0.747^{b}

[1] MD and T call for maltodextrin (%) and temperature (°C), respectively.

[*] Mean values with different letters show significant difference at 0.05 probability level.

Increasing temperature caused a little raise in WSI but not substantial statistically. This might be the result of lower density as a consequence of higher temperature and that larger particles sink in water rapidly while smaller particles float on the surface of water, causing a problem for reconstitution of the powder [11,12]. However, Chegini and Ghobadian [7], and Quek et al. [30] reported that increasing inlet air temperature diminished solubility of orange and watermelon juice powder, respectively. They explained that at very high inlet air temperature, a hard surface layer might be formed on the powder particle which could prevent water molecules from diffusing through the particle, dwindle the wettability of the particle and reduce the dissolution of the powder.

3.4. Color

Color of powders is a crucial factor in their acceptance by consumers and representative of the original food product for them. Even if the food powder is applicable a lot (in other products) and brings considerable advantages for consumers' health but lacks attractive eyesight aspects, it might fail to appeals to patrons. Table 3 represents color values of pomegranate juice powder obtained by different treatments. Intensifying temperatures increased L* value of the pomegranate juice powders. Similarly, Sousa et al. [31] found that the highest value of lightness of spray-dried tomato powders was observed at the highest inlet drying temperature, indicating less darkness due to the pigment oxidation. In contrast, the lightness of water melon powders reduced when inlet drying temperature increased, attributed to its high content of sugar causing browning of powders [30]. Increasing maltodextrin rate from 35% to 45% lowered a* and b* values of the samples substantially. In this study, lower a* color values at higher maltodextrin concentrations and temperatures could be ascribed to lower anthocyanin amounts remained at those situations - anthocyanin rate will be discussed as following - since there is a direct relationship between a* value and anthocyanin content as established by Mahdavee Khazaei et al. [24]. Besides, according to Desobry et al. [9], conditions favoring

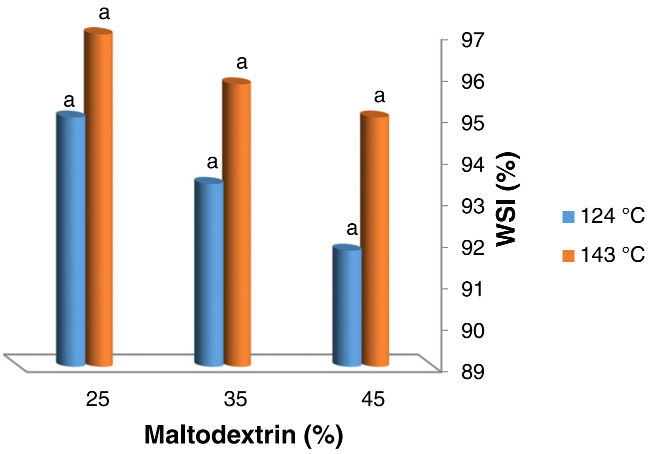

Fig. 3. Effects of maltodextrin and temperature on Water Solubility Index of pomegranate juice powder.

Table 3
Comparison of mean values for the effects of maltodextrin and temperatures on color values of pomegranate juice powder.

Treatment	L* Value	a* Value	b* Value
25% Maltodextrin*	46.836^{a,1}	30.024^{b}	−2.707^{a}
35% Maltodextrin*	47.500^{a}	31.533^{a}	−3.440^{b}
45% Maltodextrin*	46.880^{c}	27.367^{c}	−3.872^{c}
Temperature-124 °C*	45.328^{b}	30.715^{a}	−3.825^{a}
Temperature-143 °C*	48.819^{a}	28.568^{a}	−2.852^{a}

* Mean values of all treatments having this fixed parameter.

[1] Values with different letters show significant difference at 0.05 probability level.

a high surface/volume ratio or a larger number of smaller particles tend to favor pigment oxidation and, in the case of spray drying, these conditions are intensified by high temperatures and atomization speeds. Cano-Chauca et al. [6], who studied microstructure of mango powder produced by spray drying, reported the similar relationship between temperature of drying air and a* value of the product. Spray drying conditions at high temperatures resulted in a considerable loss of red color due to thermal degradation of pigments. As known, during thermal processing, anthocyanins readily degrade and form colorless or undesirable brown-colored polymeric pigments. Goula and Adamopoulos [12] indicated that a higher loss of lycopene content in tomato powder was observed by increasing the air inlet temperature, too. Likewise, Kha et al. [22] reported loss of samples redness, resulting in low a*/b* value and high hue angle, increased when elevating temperatures from 120 °C to 200 °C although there was no statistical difference in the values of a*/b* and hue angle among the sample temperatures of 120, 140 and 160 °C, or between them at 180 and 200 °C. The lesser redness of powders at higher concentration of maltodextrin used in the spray-drying process was in accordance with the previous findings by Grabowski et al. [13] and Kha et al. [22].

3.5. Anthocyanin

Anthocyanins are very sensitive compounds and unstable during processing and storage. Of course, the role of internal properties (pH, chemical structure, and anthocyanin concentration) of the product, available enzymes and other color inducing substances, ionic metals, sugars, and processing conditions (intensity and duration of heating procedure, storage time and temperature, oxygen and light) is effective on their stability too [37]. Raising maltodextrin level declined anthocyanin rate of the product although this reduction was not significant between 35 and 45%-maltodextrin treatments (Table 4). Mahdavee Khazaei et al. [24] reported this decrease too, stating that in these cases, the juice was not really encapsulated and the carrier agent acted merely as an aid for facilitating the drying process, which is probably a reason for the lower anthocyanin content when this agent was used. The same phenomenon was reported by Tonon et al. [34] who used different carrier agents including maltodextrin for spray drying of acai juice.

Table 4
Effects of temperature and maltodextrin on the anthocyanin content of pomegranate juice powder.

Treatment	Anthocyanin (mg L^{-1})
MD25-T124[1]	8.015^{a,*}
MD25-T143	7.880^{a}
MD35-T124	7.000^{ab}
MD35-T143	6.945^{ab}
MD45-T124	6.160^{b}
MD45-T143	5.980^{b}

[1] MD and T call for maltodextrin (%) and temperature (°C), respectively.

* Values with different letters show significant difference at 0.05 probability level.

Higher temperatures resulted in lower anthocyanin rates in final products, which could be due to thermal degradation and oxidation [22]. The underlying reason is that powders produced at lower inlet air temperatures own higher moisture content, and, as a result, a greater degree of aggregation occurs because of the natural stickiness of the product, leading to lower oxygen exposure and lower lycopene loss [22].

The better operating spray drying conditions and processing parameters led to greater anthocyanin maintenance in our final powder than those achieved by Vardin and Yasar [36] at about 0.6–1.2 mg L^{-1} or Horuz et al. [14] at about 2–2.5 mg cyanidin-3-glucoside/g.

3.6. Microstructure

The particles showed spherical shape of various sizes, typical of materials produced by spray drying. As it is clear in the Fig. 4, consumption of higher maltodextrin levels caused particle sizes to become larger. Cano-Chauca et al. [6] and Tonon et al. [33] reported that viscosity of the feed flow of spray drying enlarged with increasing maltodextrin levels, meaning that particle size of liquids establishes direct relationship with viscosity of liquids at a constant speed of atomizer. Higher liquid viscosities culminate in larger particles in atomizers and larger particles in spray drying chamber. SEM photographs revealed that elevated maltodextrin levels caused shrunken surfaces in particles since maltodextrin tends to migrate toward the surface from inside areas as surface coating materials and weakens powder strength as contact between particles at shrunken surfaces is less than that of smooth ones.

As Fig. 4 illustrates, greater temperatures led to larger particle sizes. Results of studies carried out by Walton [38] and Tonon et al. [33] confirm this finding; they concluded that hotter inlet air made particles expand more, stay shorter inside the spray drying chamber and avoid forming particles with lower diameters since using lower inlet air temperatures induces more contraction and produces particles with smaller diameters. Similarly, Phisut [29] stated that the use of higher inlet air temperature led to the production of larger particles and caused higher swelling; in detail, he reasoned that drying at higher temperatures results in faster drying rates, leading to the early formation of a structure which avoids the particles to shrink during drying.

As morphological photographs of the particles (Fig. 4) display, more intense temperatures brought about smoother particle surfaces. In fact, when the inlet air temperature was low, most of the particles showed a shriveled surface, while increasing drying temperatures resulted in a larger number of particles with smooth surface. Results of researches by Tonon et al. [34] approve this finding, and suggest this difference is relevant to the drying rates. Indeed, higher temperatures speed up water evaporation and form smoother and harder crusts; thus, diverse surface morphologies, either pliable and collapsed (at low or medium inlet air temperatures) or porous and rigid (at high air temperatures), are related to miscellaneous temperatures applied in the drying procedure. Nijdam and Langrish [28] also verified this explanation and reported that, in spray drying of milk, when the drying temperature was sufficiently high, moisture evaporated very quickly and the skin became dry and hard, so that the hollow particle could not deflate when vapour condensed within the vacuole as the particle moved into cooler regions of the dryer. In contrast, when the drying temperature was lower, the skin remained moist and flexible, so that the hollow particle could deflate and shrivel when moving toward cooler sections. However, Solval et al. [32], who surveyed production of cantaloupe juice powders using spray drying technology, reached another result, and reported that the powder produced at 170 °C had smoother surface and a more spherical shape than those powders produced at 180 and 190 °C, attributed to moisture transport during the falling rate period. In fact, they concluded that the particles could inflate and break when evaporation occurred at higher temperatures during the falling rate period of juice drying. Likewise, Tze et al. [35] reported that low spray drying temperature led to

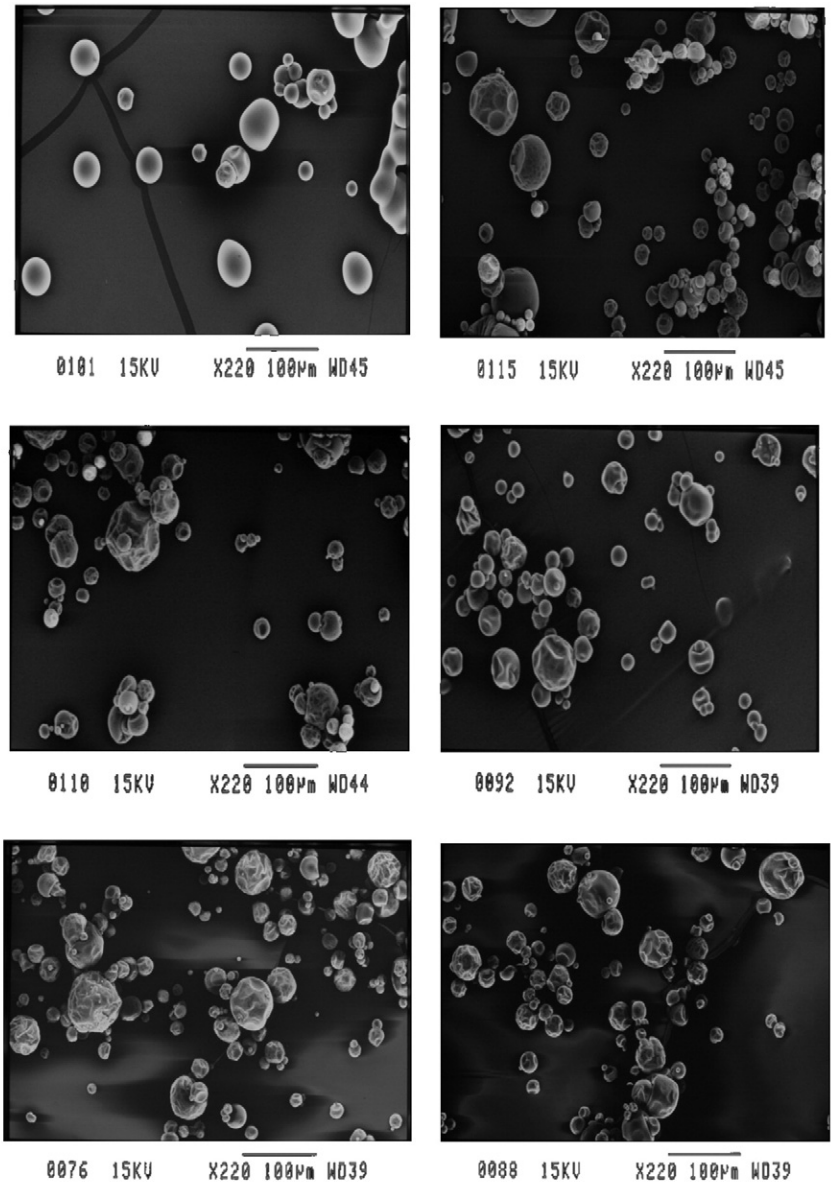

Fig. 4. SEM analysis of pomegranate juice powder from above left to below right: MD25-T124; MD25-T143; MD35-T124; MD35-T143; MD45-T124; MD45-T143 (MD and T call for maltodextrin (%) and temperature (°C), respectively.

smooth surface particle in comparison with that of high temperature, attributed to an increase in crust shrinkage in the latter case.

4. Conclusion

The effects of different drying air temperatures on density, and L* and a* values were significant whereas maltodextrin level could affect density, anthocyanin, a* and b* values. Water solubility index was not affected by either air temperature or maltodextrin addition and ranged from around 92 to 97%. Apparent density of the powder was high and in the range of 0.75–0.89 g cm^{-3}. Anthocyanin rates of pomegranate juice powders were between 6 and 8 mg L^{-1}, with higher maltodextrin and temperature rates leading to lower anthocyanin contents. SEM analysis displayed that greater temperatures and maltodextrin levels resulted in larger particles due to higher heat transfer and higher viscosity rates at these situations, respectively. Optimum pomegranate juice powders should have higher water solubility index, density, anthocyanin content and a* values all of which could obtain at lower maltodextrin levels (20%) and temperatures (124 °C).

References

[1] F.D.B. Abadio, A.M. Domingues, S.V. Borges, V.M. Oliveira, Physical properties of powdered pineapple (*Ananas comosus*) juice-effect of malt dextrin concentration and atomization speed, J. Food Eng. 64 (3) (2004) 285–287.

[2] S. Akhavan Mahdavi, S.M. Jafari, E. Assadpoor, D. Dehnad, Microencapsulation optimization of natural anthocyanins with maltodextrin, gum Arabic and gelatin, Int. J. Biol. Macromol. 85 (2016) 379–385.

[3] R.A. Anderson, H.F. Conway, V.F. Pfeifer, E.L. Griffin, Gelatinization of corn grits by roll- and extrusion-cooking, Cer. Sci. Today 14 (1969) 4–9.

[4] A. Bahmani, S.M. Jafari, S.A. Shahidi, D. Dehnad, Mass transfer kinetics of eggplant during osmotic dehydration by neural networks, J. Food Process. Preserv. 40 (5) (2016) 815–827.

[5] D. Bopitiya, T. Madhujith, Antioxidant potential of pomegranate (*Punica granatum* L.) cultivars grown in Sri Lanka, Trop. Agric. Res. 24 (1) (2012) 71–81.

[6] M. Cano-Chauca, P.C. Stringheta, A.M. Ramos, J. Cal-Vidal, Effect of the carriers on the microstructure of mango powder obtained by spray drying and its functional characterization, Innovative Food Sci. Emerg. Technol. 6 (4) (2005) 420–428.

[7] G.R. Chegini, B. Ghobadian, Effect of spray-drying condition on physical properties of orange juice powder, Dry. Technol. 23 (2005) 657–668.

[8] D. Dehnad, S.M. Jafari, M. Afrasiabi, Influence of drying on functional properties of food biopolymers: from traditional to novel dehydration techniques, Trends Food Sci. Technol. 57 (2016) 116–131.

[9] S.A. Desobry, F.A. Netto, T.P. Labuza, Comparison of spray drying, drum-drying, and freeze drying for b-carotene encapsulation and preservation, J. Food Sci. 62 (6) (1997) 1158–1162.

[10] M.A. De Oliveira, G.A. Maia, R.W. De Figueiredo, A.C.R. De Souza, E.S. De Brito, H.M.C. De Azeredo, Addition of cashew tree gum to maltodextrin-based carriers for spray drying of cashew apple juice, Int. J. Food Sci. Technol. 44 (3) (2009) 641–645.

[11] M. Fazaeli, Z. Emam-Djomeh, A. Kalbasi Ashtari, M. Omid, Effect of spray drying conditions and feed composition on the physical properties of black mulberry juice powder, Food Bioprod. Process. 90 (4) (2012) 667–675.

[12] A.M. Goula, K.G. Adamopoulos, Spray drying of tomato pulp in dehumidified air: II. The effect on powder properties, J. Food Eng. 66 (1) (2005) 35–42.

[13] J.A. Grabowski, V.D. Truong, C.R. Daubert, Spray-drying of amylase hydroluzed sweet potato puree and physicochemical properties of powder, J. Food Sci. 71 (5) (2006) 209–217.

[14] E. Horuz, A. Altan, M. Maskan, Spray drying and process optimization of unclarified pomegranate (*Punica granatum*) juice, Dry. Technol. 30 (7) (2012) 787–798.

[15] S.M. Jafari, D. Azizi, H. Mirzaei, D. Dehnad, Comparing quality characteristics of oven-dried and refractance window-dried kiwifruits, J. Food Process. Preserv. 40 (3) (2016) 362–372.

[16] S.M. Jafari, M. Ganje, D. Dehnad, V. Ghanbari, Mathematical, fuzzy logic and artificial neural network modeling techniques to predict drying kinetics of onion, J. Food Process. Preserv. 40 (2) (2016) 329–339.

[17] S.M. Jafari, V. Ghanbari, M. Ganje, D. Dehnad, Modeling the drying kinetics of green bell pepper in a heat pump assisted fluidized bed dryer, J. Food Qual. 39 (2) (2016) 98–108.

[18] S.M. Jafari, S.S. Jabari, D. Dehnad, S.A. Shahidi, Heat transfer enhancement in thermal processing of tomato juice by application of nanofluids, Food Bioprocess Technol. 10 (2) (2017) 307–316, http://dx.doi.org/10.1007/s11947-016-1816-9.

[19] S.M. Jafari, D. Azizi, D. Dehnad, H. Mirzaei, The influence of refractance window drying on qualitative properties of kiwifruit slices, Int. J. Food Eng. (2017), http://dx.doi.org/10.1515/ijfe-2016-0201 (accepted manuscript).

[20] V. Jaiswal, A. Der Marderosian, J.R. Porter, Anthocyanins and polyphenol oxidase from dried arils of pomegranate (*Punica granatum* L.), Food Chem. 118 (1) (2010) 11–16.

[21] M. Jayasundera, B. Adhikari, T. Howes, P. Aldred, Surface protein coverage and its implications on spray-drying of model sugar-rich foods: solubility, powder production and characterization, Food Chem. 128 (4) (2011) 1003–1016.

[22] T.C. Kha, M.H. Nguyen, P.D. Roach, Effects of spray drying conditions on the physicochemical and antioxidant properties of the Gac (*Momordica cochinchinensis*) fruit aril powder, J. Food Eng. 98 (3) (2010) 385–392.

[23] J. Lee, R.W. Durst, E. Wrolstad, Determination of total monomeric anthocyanin pigment content of fruit juices, beverages, natural colorants, and wines by the pH differential method: collaborative study, J. AOAC Int. 88 (5) (2005) 1269–1278.

[24] K. Mahdavee Khazaei, S.M. Jafari, M. Ghorbani, A. Hemmati Kakhki, Application of maltodextrin and gum arabic in microencapsulation of saffron petal's anthocyanins and evaluating their storage stability and color, Carbohydr. Polym. 105 (2014) 57–62.

[25] G.E.G. Moreira, M.G. Maia Costa, A.C.R.D. Souza, E.S.D. Brito, M.D.F.D.D. Medeiros, H.M.C.D. Azeredo, Physical properties of spray dried acerola pomace extract as affected by temperature and drying aids, LWT Food Sci. Technol. 42 (2) (2009) 641–645.

[26] K. Muzaffar, B.V. Dinkarrao, P. Kumar, F. Yildiz, Optimization of spray drying conditions for production of quality pomegranate juice powder, Cogent Food Agric. 2 (1) (2016) 1127583.

[27] K. Muzaffar, S.A. Wani, B.V. Dinkarrao, P. Kumar, F. Yildiz, Determination of production efficiency, color, glass transition, and sticky point temperature of spray-dried pomegranate juice powder, Cogent Food Agric. 2 (1) (2016) 1144444.

[28] J.J. Nijdam, T.A.J. Langrish, The effect of surface composition on the functional properties of milk powders, J. Food Eng. 77 (2006) 919–925.

[29] N. Phisut, Spray drying technique of fruit juice powder: some factors influencing the properties of product, Int. Food Res. J. 19 (4) (2012) 1297–1306.

[30] S.Y. Quek, N.K. Chok, P. Swedlund, The physicochemical properties of spray-dried watermelon powder, Chem. Eng. Process. Process Intensif. 46 (5) (2007) 386–392.

[31] A.S.D. Sousa, S.V. Borges, N.F. Magalhaes, H.V. Ricardo, A.D. Azevedo, Spray-dried tomato powder: reconstitution properties and colour, Braz. Arch. Biol. Technol. 51 (4) (2008) 607–614.

[32] K.M. Solval, S. Sundararajan, L. Alfaro, S. Sathivel, Development of cantaloupe (*Cucumis melo*) juice powders using spray drying technology, LWT Food Sci. Technol. 46 (1) (2012) 287–293.

[33] R.V. Tonon, C. Brabet, M.D. Hubinger, Influence of process conditions on the physicochemical properties of acai (Euterpeoleraceae Mart.) powder produced by spray drying, J. Food Eng. 88 (2008) 411–418.

[34] R.V. Tonon, C. Brabet, M.D. Hubinger, Anthocyanin stability and antioxidant activity of spray-dried acai (*Euterpe oleracea* Mart.) juice produced with different carrier agents, Food Res. Int. 43 (3) (2010) 907–914.

[35] N.L. Tze, C.P. Han, Y.A. Yusof, C.N. Ling, R.A. Talib, F.S. Taip, M.G. Aziz, Physicochemical and nutritional properties of spray-dried pitaya fruit powder as natural colorant, Food Sci. Biotechnol. 21 (3) (2012) 675–682.

[36] H. Vardin, M. Yasar, Optimisation of pomegranate (*Punica granatum* L.) juice spray-drying as affected by temperature and maltodextrin content, Int. J. Food Sci. Technol. 47 (1) (2012) 167–176.

[37] S. Vegara, N. Marti, P. Mena, D. Saura, M. Valero, Effect of pasteurization process and storage on color and shelf-life of pomegranate juices, LWT Food Sci. Technol. 54 (2) (2013) 592–596.

[38] D.E. Walton, The morphology of spray-dried particles a qualitative view, Dry. Technol. 18 (9) (2000) 1943–1986.

[39] R.E. Wrolstad, R.W. Durst, J. Lee, Tracking color and pigment changes in anthocyanin products, Trends Food Sci. Technol. 16 (2005) 423–428.

[40] S. Youssefi, Z. Emam-Djomeh, S.M. Mousavi, Comparison of artificial neural network (ANN) and response surface methodology (RSM) in the prediction of quality parameters of spray-dried pomegranate juice, Dry. Technol. 27 (2009) 910–917.

[41] S. Yousefi, Z. Emam-Djomeh, S.M. Mousavi, Effect of carrier type and spray drying on the physicochemical properties of powdered and reconstituted pomegranate juice (*Punica granatum* L.), J. Food Sci. Technol. 48 (6) (2011) 677–684.