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ORIGINAL ARTICLE

Effect of different carriers on microstructure and physical characteristics of spray dried apple juice concentrate

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Abstract Adhesion is the most important factor in product loss in the spray drying of syrups and juices. The main solution to reduce adhesion is using drying aids. The aim of this study was to evaluate effect of maltodextrin (MD) and gum Arabic as drying aids, and pectin and whey protein concentrate (WPC) as complementary drying aid on the powder yield, physical, functional and microstructural properties of spray dried apple juice concentrate. The studied variables and composition of the carriers were used. The inlet air temperature, atomizer rotational speed, feed flow rate, feed temperature and atomizer pressure were kept constant at 160 °C, 18,000 rpm, 15 ml/min, 25 ± 1 °C and 4.2 ± 0.1 bar, respectively. The results of powder production yield indicated that WPC was more effective than pectin as complementary drying aid. The bulk and tapped density of powders significantly decreased with an increase in WPC ratio. Moisture content, solubility, wettability, hygroscopicity and color parameters of the powders were also influenced by the carriers' type and their combinations. The microstructure of spray dried powders showed various particle sizes with spherical and irregular shapes (with shrinkages and dents on the surface). Taking into account all the parameters, 10% WPC in combination with MD was used which showed the best results in the economic production of powder with the highest yield (60.85%) and appropriate physical, flowability and functionality properties.

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Introduction

Fruit and vegetables are seasonal and perishable products with a short shelf life. Thus, different methods such as drying can be used to increase their storage time. Among the methods for drying of food, spray drying is the most common way to convert liquid products (such as extract, syrup, fruit juices and concentrates) for powders with high chemical and biological stability (Oliveira et al. 2006). The spray drying of concentrated syrup and juice rich with low molecular weight sugars (such as fructose, glucose and sucrose), and organic acids (citric, tartaric and malic) lead to the low glass transition temperature and adhesion of these products makes it very difficult to dry in normal conditions (Cano-Chauca et al. 2005). The most common solution to reduce the adhesion of these products, is the use of high molecular weight drying aid compounds such as Gum Arabic, and a variety of starch and its derivatives such as maltodextrin (Quek et al. 2007; Goula and Adamopoulos 2012). Each of these carriers show advantages and disadvantages in terms of cost, process efficiency and effect on the characteristics of the final product. Disadvantages can be noted as low glass transition temperature (Bae and Lee 2008) and amorphous nature of maltodextrin at the storage conditions with high relative humidity become sticky by moisture absorption (Wang et al. 2013). Also lack of emulsifying activity is the factor that limits its application (Carneiro et al. 2013).

Gum Arabic (GA), a natural plant polysaccharide exudate of acacia, is a well-known and effective wall material, which has been used for many years and it is still a good choice because of its high solubility and low viscosity at high concentrate. It contains small amounts of protein in its composition, therefore it shows the emulsifying activity. Also, it is edible and has E number E414. These characteristics led to widespread use as a wall material for spray drying of different components (Idham et al. 2012). For example, Idham et al. (2012) investigated the effect of maltodextrin, Arabic gum and their combination on the encapsulation of Roselle anthocyanins using spray drying. They reported that the combination of two carriers had the best effect on the anthocyanin stability compared to non-encapsulated samples. Also, GA shows better performance than maltodextrin due to higher glass transition temperature, but its high cost compared to maltodextrin is an disadvantage (Righetto and Netto 2006). This problem has led numerous studies to be done to replace all or part of these carriers together, or with other compounds. The aim of these studies were to modify the surface structure or production of semi-crystalline particles, reducing the hygroscopicity, degree of caking, the adhesion and increase of powder production yield. Among these studies combination of maltodextrin and cashew tree gums in the production of Acerola pulp extract powder (Moreira et al. 2009), and MCC and waxy starch in the production of relatively crystalline mango juice powder (Cano-Chauca et al. 2005) can be noted. But each of these complementary drying aids also showed disadvantages and limitations. For instance, substitution of maltodextrin with cellulose and starch caused a significant decrease in the water solubility of mango powder (Cano-Chauca et al. 2005). Also, insolublty of cellulose and starch inhibits the formation of uniform and smooth crust caused formation of cavities and pores in the surface of particles (Wang and Zhou 2015).

In recent years application of proteins as an alternative or supplement of maltodextrin has been noticed in the spray drying of various products. Proteins are very effective carriers that have been used for the microencapsulation of flavor compounds and oils at low concentrates alone or in combination with carbohydrates (Frascareli et al. 2012; Botrel et al. 2014) and for spray drying of syrups and sugar rich concentrate (Jayasundera et al. 2011; Fang and Bhandari 2012; Wang et al. 2013). The mechanism of their function is due to good surface activity, preferential migration to particle surface, in which the protein molecules link together by hydrophobic interaction and show low lateral mobility and cohesion film forming with low hygroscopicity (Jayasundera et al. 2011; Fang and Bhandari 2012).

Whey proteins are main byproducts of dairy industries which have good emulsifying properties and high-speed film formation (with low adhesion and hygroscopicity) that increase powder production yield at low concentrate (Bhusari et al. 2014). In various researches the mechanism and efficiency of whey protein in increasing the production yield and physicochemical properties of soy sauce powder (Wang et al. 2013), honey powder (Adhikari et al. 2007) and cherry juice concentrate powder (Sarabandi et al. 2017) were investigated. The results show the advantage of whey proteins in reducing the adhesion and increasing the production efficiency of sticky products.

Pectin is a structural component of the cell wall of many plants. It is a heterogeneous polysaccharide consisting linear bonds of α (1 → 4) D-Galacturonic acid. This component is a dietary fiber used as a gelling, bulking and thickening agent in various food products (Zaidel et al. 2017). Pectin can be used in drug encapsulation, colloidal delivery systems and as a carrier in spray drying of sticky plant extract (Sansone et al. 2011). So far, there have been no studies available on the effect of different carriers (MD and GA) and partial substitution of them with WPC and pectin in the spray drying of apple juice concentrate. Hence, the purpose of present study was to investigate the effect of different carriers (MD and GA) and their replacement with WPC and pectin on the production yield, flowability index, functionality and microstructure of spray dried apple juice concentrate powder.

Materials and methods

Preparation of feed solution

In this study, initial trial was carried out to determine the minimum concentrate of carrier required to produce powder. Accordingly, each carrier of MD or GA was used with a ratio of 50% based on wet weight of apple juice concentrate (BX = 63) (Behnoosh, Shirvan Branch, Iran). Also, the apple pectin (in a ratio of 1, 2, 3 and 5%) and WPC (in a ratio of 5, 10, 15 and 20%) were used as supplement with MD or GA for feed production. The carrier was completly solubilized in distilled water (approximately with 17.66% concentration) using a magnetic stirrer (L-81, Labinco B.V, Netherlands) and then mixed with apple juice concentrate. Finally, for all the samples, feed solution with solid content of 30% was used in the spray drying process.

Spray drying

A pilot-scale spray dryer (Maham Sanat, Neyshabur, Iran) fitted with a 5 cm diameter rotary atomizer rotating by compressed air was used. Based on previous experiments, inlet air temperature, atomizer rotational speed, feed flow rate, feed temperature and atomizer pressure were kept constant at 160 °C, 18,000 rpm, 15 ml/min, 25 ± 1 °C and 4.2 ± 0.1 bar, respectively. Inlet air as co-current with feed was applied for drying process. The collected powder was placed in the desiccator to achieve a constant temperature and preventing humidity change and then was kept in dark glasses away from light until the time of the experiment. The remaining powder on the internal wall of dryer also was discarded due to heat damage (Sarabandi et al. 2017).

Powder production yield

The production yield was calculated as the ratio of the mass of solids collected after spray-drying to the amount of solids in the feed solutions (dry basis). In this study, powder collected in glass collector as the main product was used in order to calculate the processing yield and for final tests on powder.

Moisture content

About 2 g of powder were placed in a petri dish in an air drier oven for 2–3 h at a temperature of 105 ± 2 °C. Finally the samples were taken from the oven, cooled in desiccators and weighed. Drying process was continued until sample achieved to a constant weight. The moisture content was calculated by percentage of weight difference between samples before and after oven drying (Turchiuli et al. 2014).

Bulk density and tapped density

Bulk density (g/ml) was determined by gently adding 2 g of powder into a 10 ml empty graduated cylinder and, the ratio of mass of the powder and the volume occupied in the cylinder was determined as the bulk density value. Then by using tapped densitometer, continuous beats were applied to the cylinder (an average of 400 beats), as long as the volume changes of powder stop and tapped density is obtained (Jangam and Thorat 2010).

Flowability (static angle of repose, Hausner ratio and compressibility)

The amount of 10 g of powder was dumped on a flat horizontal surface from a fixed height through a funnel with 12 mm outlet diameter, to obtain a cone. Angle formed between the side surface and the base of a cone was measured and represented as repose angle (Bhandari et al. 1998). The cohesiveness of the powders was evaluated by the Hausner ratio (HR) mentioned in Eq. 1.

$$\mathrm{HR} = \mathrm{TD}/\mathrm{BD} \tag{1}$$

In this equation HR is the Hausner ratio, TD is the tapped density and BD is the bulk density (Jinapong et al. 2008).

The amount of empirical relationship between flowability characteristics of the powders and the results of two parameter of repose angle and Hausner ratio tests according to the Jinapong et al. (2008) was expressed by the amount of 25–30 and 1–1.11 for the excellent flowability and more than 66 and 1.6 for very bad flowability (lack of free flow), respectively .

For compressibility index (Eq. 2), empirical values between 0.05 and 0.15 indicate very good flow behavior with coarse granular powder type and the values higher than 0.4 indicate lack of flow due to high adhesion of powders.

$$\mathrm{CI} = 1 - (1/\mathrm{HR}) \tag{2}$$

Hygroscopicity

5 g of each spray dried sample was placed in a desiccator containing saturated NaCl solution (relative humidity 75%). Samples were kept at ambient temperature for 7 days. The Hygroscopicity of powders was determined as gram of adsorbed moisture per 100 g dry powder (Cai and Corke 2000).

Solubility and wettability

The solubility of the powders was evaluated according to the method proposed by Cano-Chauca et al. (2005) with some modifications. 1 g of powder was added carefully to 100 ml distilled water under stirring condition with a magnetic stirrer in 200 g for 4 min. The resulting solution was centrifuged at 3000 g for 4 min. 25 ml of the supernatant was transferred to a pre weighted petri dish and dried in an oven at 105 °C for 5 h. Weight of dried solid matter as percentage of the initial powder was used in order to determine the solubility in water.

Wettability of the powders was determined using the method of Fuchs et al. (2006) with some modifications. 0.2 g of powder was poured on 100 ml of distilled water at room temperature without any agitation. The time taken for powder particles submerge so that no particles left on the surface was recorded as wettability index.

Color

The color characteristics of manufactured powder was evaluated by L*, a* and b* indexes. Imaging of samples was done by Canon digital camera (Powershot A3400) with sensitivity of 16 megapixel in a chamber designed for photography in stationary condition. Each of powder samples were separately photographed and the photos were saved in the JPEG format. Analysis of the samples was performed using Image J software. The hue angle and chroma were calculated as follows:

$$\text{Hue} = \tan^{-1}(b^*/a^*) \tag{3}$$

$$\text{Chroma} = \left[(a^*)^2 + (b^*)^2\right]^{1/2} \tag{4}$$

Scanning electron microscopy (SEM)

The structure of the powder particles was evaluated using a scanning electron microscope (HITACHI PS-230, Japan). The samples were placed separately on an aluminum plate using two-sided adhesive tape. Then the particles were coated with a thin layer of gold (10 nm) using a desk sputter coater DST1 system with a magnetron cathode under vacuum. Finally coated samples were transferred under the microscope at an accelerating voltage of 3 kV with magnifications of 300× and surface structure of particles were observed (Santhalakshmy et al. 2015).

Statistical analysis

All the tests were carried out in triplicate and the results were reported as the mean values ± standard deviation except for color analysis. Analysis of variance (ANOVA) was performed by SPSS statistical software (Version 19.0). Effect of carriers and their combinations on means values of responses was evaluated by Duncan's multiple range test with 95% confidence.

Results and discussion

Powder production yield

The powder yield is the main indicator for evaluating economic and performance aspect of process. The use of 1 and 2% pectin concentration in combination with MD and GA increased powder production yield (Fig. 1a). While, with increasing concentrations of pectin over 2%, powder yield reduced significantly ($P < 0.05$). This finding can be attributed to the capability of wall forming ability and particle coating in low concentrations. But use of higher pectin ratios reduced the production yield. Increasing the viscosity and the possibility of gel formation in the feed are the factors that can reduce the powder recovery (Sansone et al. 2011). The use of whey protein concentrates in combination with both carriers (MD and GA) resulted in a significant increase in the powder production yield. Using 5 and 10% WPC in combination with MD increased production yield from 31.3 to 45.18 and 60.85%, respectively. Also, 5% WPC in combination with GA increased production yield from 29.64 to 56.1%. But, higher concentration of WPC did not show any effect on the increase of production yield ($P < 0.05$).

These results are in agreement with research of Adhikari et al. (2007) that studied the effect of WPI as drying aid supplement of MD in the production of spray dried honey. Fang and Bhandari (2012), compared the performance of whey protein isolate and MD (DE10) in the spray drying of bayberry juice. Results showed that the effect of 1% protein on production yield was higher than 50% MD. Bhusari et al. (2014) investigated the effect of MD, GA and WPC as carriers on the physicochemical characteristics of spray dried tamarind pulp powder. Among different carriers, the highest yield (76.23%) in the production of powder was obtained using 30% WPC. The major role of common carriers such as MD and GA is reducing adhesion and increasing powder production yield by increasing the glass transition temperature of the product. But the results of various studies imply the role of proteins in increasing the powder production yield through preferential migration to the particle surface and formation of non-adherent film (Jayasundera et al. 2011).

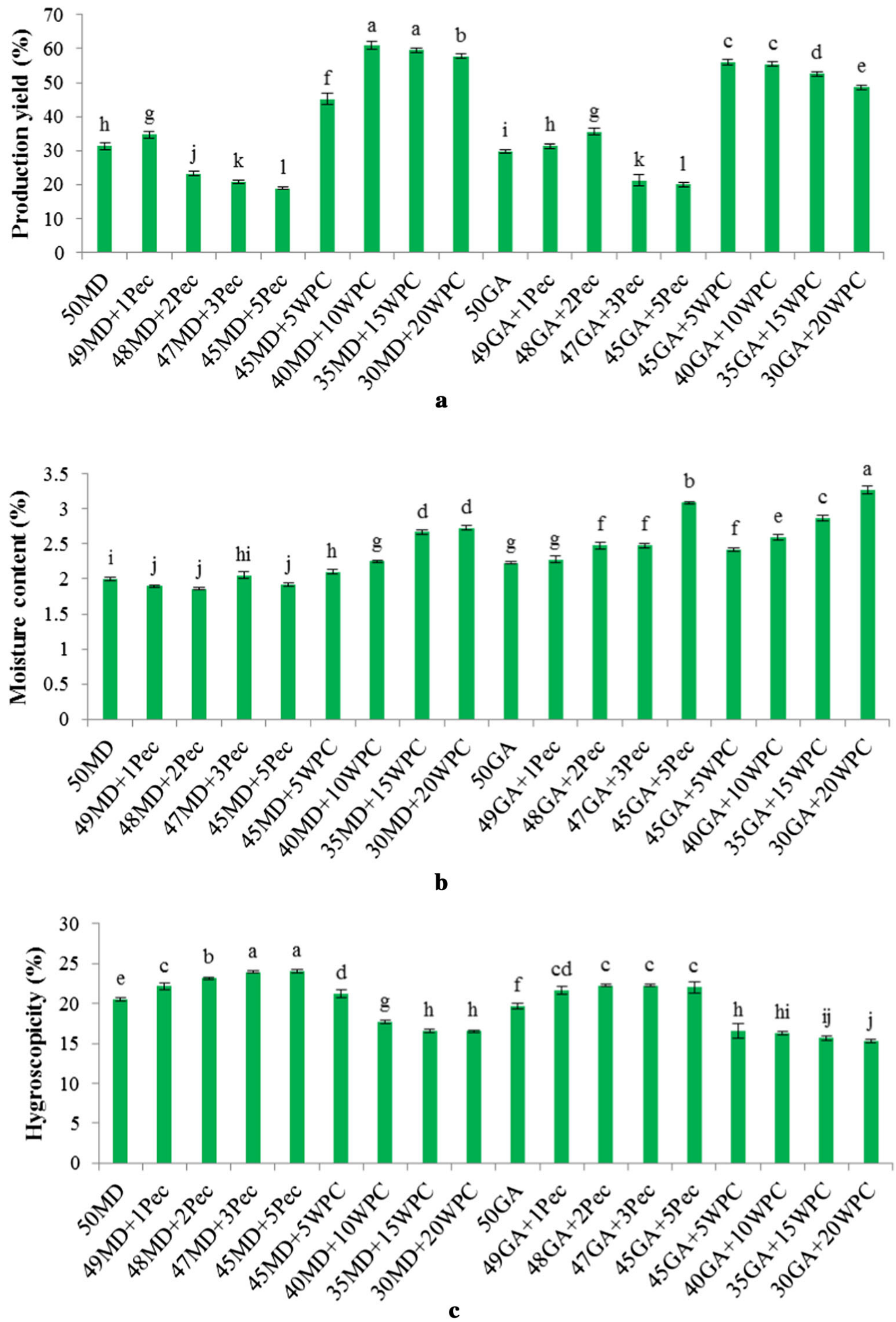
Moisture content

Figure 1b. shows the effect of different carriers on the moisture content of apple juice concentrate powders. The moisture content of spray dried apple juice concentrate powder was in the range of 1.86–3.27%. Among the produced samples, treatments which contain GA as a carrier showed higher moisture content compared to the samples produced with MD. This can be due to higher water retention capacity of hydrocolloids compared to starch derivatives. Also, powders obtained with WPC combination with the MD and GA showed an increase in the moisture content by increaseing WPC content. This can be attributed to the high water retention capability of whey protein in the amorphous state (Bazaria and Kumar 2016). The moisture content of apple juice concentrates powder was close to the amounts reported by Cai and Corke (2000), Santhalakshmy et al. (2015) and Bazaria and Kumar (2016) that they studied the effect of temperature and different carriers on spray dried Amaranthus betacyanin pigments (1.9–4.5%), jamun fruit juice (3.22–4.18%) and beet root juice concentrate (2.81–4.37%), respectively.

Bulk density and tapped density

The bulk and tapped density of apple juice concentrate powder was in the range of 0.37–0.84 and 0.46–0.91 g/ml, respectively (Table 1). In general, samples produced by MD and GA showed the highest and the lowest bulk

Fig. 1 Effect of different carrier combination on **a** production yield, **b** moisture content and **c** hygroscopicity of spray dried apple juice powders



density and tapped density, respectively. Use of 2% pectin in combination with these carriers (MD and GA) caused a significant decrease in density of the samples. But the application and increasing concentration of WPC in combination with the MD and GA decreased the density of spray dried apple juice concentrate powder significantly ($P < 0.05$).

The above results are due to the lower viscosity of the feed produced with MD compared to other carriers. Higher feed viscosity by increasing the droplets size produced during atomization causes reduction in bulk and tapped density of powders (Bhusari et al. 2014). Also, increasing the concentration of WPC especially in combination with the GA reduces the density of spray dried powders. The

Table 1 Physical properties of spray dried apple juice concentrate powder

Treatments	Bulk density (g/ml)	Tapped density (g/ml)	Solubility (%)	Wettability (s)
50MD	0.737 ± 0.01^{a}	0.906 ± 0.01^{a}	98.696 ± 1.03^{a}	1.901 ± 0.43^{i}
49MD + 1Pec	0.731 ± 0.01^{a}	0.896 ± 0.01^{a}	97.026 ± 1.07^{b}	2.080 ± 0.59^{i}
48MD + 2Pec	0.706 ± 0.01^{b}	0.876 ± 0.01^{b}	95.263 ± 1.89^{cd}	1.966 ± 0.61^{i}
47MD + 3Pec	0.706 ± 0.02^{b}	0.866 ± 0.01^{bc}	95.030 ± 0.77^{de}	2.166 ± 0.42^{i}
45MD + 5Pec	0.700 ± 0.01^{b}	0.856 ± 0.02^{c}	94.233 ± 0.51^{def}	2.302 ± 0.36^{i}
45MD + 5WPC	0.556 ± 0.01^{d}	0.676 ± 0.01^{de}	96.693 ± 1.43^{b}	4.196 ± 0.19^{h}
40MD + 10WPC	0.533 ± 0.01^{e}	0.643 ± 0.01^{g}	94.890 ± 0.64^{de}	7.573 ± 0.48^{f}
35MD + 15WPC	0.487 ± 0.01^{g}	0.583 ± 0.01^{i}	93.990 ± 0.75^{def}	12.386 ± 1.67^{e}
30MD + 20WPC	0.473 ± 0.01^{h}	0.573 ± 0.01^{i}	92.973 ± 1.12^{f}	16.633 ± 2.28^{d}
50GA	0.570 ± 0.02^{c}	0.680 ± 0.02^{d}	96.606 ± 0.51^{bc}	6.202 ± 0.71^{g}
49GA + 1Pec	0.533 ± 0.01^{c}	0.673 ± 0.01^{de}	93.656 ± 0.58^{ef}	8.576 ± 0.29^{f}
48GA + 2Pec	0.516 ± 0.01^{f}	0.666 ± 0.01^{ef}	93.387 ± 1.01^{f}	8.863 ± 0.35^{f}
47GA + 3Pec	0.513 ± 0.01^{f}	0.673 ± 0.01^{de}	93.060 ± 0.57^{f}	8.360 ± 0.14^{f}
45GA + 5Pec	0.506 ± 0.01^{f}	0.656 ± 0.02^{f}	91.336 ± 1.31^{g}	8.966 ± 0.42^{f}
45GA + 5WPC	0.482 ± 0.01^{gh}	0.616 ± 0.01^{h}	92.743 ± 1.03^{f}	12.446 ± 2.66^{e}
40GA + 10WPC	0.416 ± 0.01^{i}	0.503 ± 0.01^{j}	93.076 ± 0.71^{f}	18.583 ± 1.48^{c}
35GA + 15WPC	0.393 ± 0.01^{j}	0.466 ± 0.01^{k}	92.796 ± 1.23^{f}	22.576 ± 3.15^{b}
30GA + 20WPC	0.373 ± 0.02^{k}	0.456 ± 0.01^{k}	90.666 ± 0.81^{g}	28.813 ± 1.45^{a}

Data represent mean value of three replicates ± standard deviations

Different letters in the same column indicate statistical significant differences ($P < 0.05$)

reason of this finding can be attributed to the higher film formation capability of WPC, the reduction of adhesion, and the higher air retention of particles in comparison to GA. In addition, increasing the viscosity of the feed as a result of increasing the WPC ratio raises the particle size and decreases the density. These results are consistent with the findings of Bazaria and Kumar (2016), who reported a reduce in the density of spray dried beetroot juice concentrate as a result of increasing WPC concentrations. In this study, the bulk density values of samples were close to the bulk density of 0.52–0.64 g/ml for Amaranthus betacyanin pigment powder (Cai and Corke 2000), 0.64 g/ml for pineapple juice (Abadio et al. 2004), 0.54–0.61 g/ml for Guava concentrate (Mahendran 2011) and 0.482–0.588 g/ml for beetroot juice concentrate (Bazaria and Kumar 2016).

Solubility and wettability

Depending on the type and combination of carriers, solubility of powders ranged from 90.67 to 98.69% (Table 1). Among the produced samples, powders containing MD showed higher solubility than the powders containing GA as a carrier. Also, use of pectin and WPC in combination with MD and GA was reduced solubility of the powders ($P < 0.05$). In this study, solubility of apple juice powders was similar to the solubility of Jamun fruit juice that was in the range of 87.67–99.67% (Santhalakshmy et al. 2015). This result is in agreement with the results of Cano-Chauca et al. (2005) that studied the effect of different carriers on the solubility of mango juice powders. On the other hand, due to the high initial solubility of MD, replacing it with other carriers reduced the solubility of produced powders.

Similar to solubility results, wettability of apple juice concentrate powder was influenced by the type and combination of carriers ($P < 0.05$). In this way, the MD-produced powders had the least wettability time. Among different drying aid supplements, pectin did not show any effect on the hygroscopicity of the particles. However, increasing the WPC ratio in combination with carriers (MD and GA) increased the wettability time due to a more complex structure and lower water solubility. Also, wettability of powders depends on the type of carrier and encapsulated compound, presence of hydrophilic groups on the particle surfaces and the interaction of these groups with water. When a similar carrier is used, the time of wettability depends on particle size. So that larger particles due to presence of higher spaces are between the particles and higher porosity, penetrate faster into the water (Santhalakshmy et al. 2015). In another study, substitution of WPI with MD and inulin reduced wettability time of powder containing fish oil from 226 to 130 and 112 s, respectively (Botrel et al. 2014). It was believed that reduction in wettability time was due to an increase in the hydrophilic groups and reduction of the oil on the surface of particles.

Flowability

Table 2 shows cohesiveness, compressibility and angle of repose in spray dried apple juice concentrate powders under the influence of type and combination of carriers. The cohesiveness and compressibility of spray dried apple juice concentrate powders varied depending on type and combination of the carriers. The powder produced with MD alone showed higher cohesiveness and compressibility compared to the samples derived from the GA. Flowability of particles was affected by surface properties (smooth and globular, or rough surface with dents), size and particle size distribution (Lumay et al. 2012), the chemical nature and formation of liquid bridges (Emery et al. 2009). In this study, the particles produced with GA showed high shrinkage or wrinkled surface and less inter-particle contact compared to MD. Reducing the inter-particle surface contact decreases interaction and inter-particle bridge and as a result decreases the cohesiveness of the powders (Wang and Langrish 2010). There were no differences between the angle of repose of the powders produced with MD and GA alone ($P < 0.05$).

Also, the use of pectin in combination with maltodextrin did not have any positive impact on the flowability behaviour of apple juice concentrate powders. Increasing the moisture of powders in samples with high concentrations of pectin combined with GA increased the cohesiveness and reduced the flowability of samples. Although Sansone et al. (2011), observed an increase in the flowability of powders containing extracts of medicinal plants using 1% apple pectin in combination with MD. Use of WPC in combination with MD by increasing particle surface shrinkage, decreasing the surface contact and inter-particle surface contact reduced the cohesion and compressibility of samples, but had no effect on the flow behavior of powders prepared in combination with GA ($P < 0.05$). However, in another study tamarind pulp powder produced by WPC showed better flowability and less cohesiveness compared to samples prepared with MD and GA. This was due to the larger size, reduced surface contact, formation of inter particle connections and medium moisture content of the particles (Bhusari et al. 2014).

Hygroscopicity

The moisture absorption in food powders reduces the quality and shelf life and increases rate of the destructive reactions. Figure 1c. shows the effect of different carriers on hygroscopicity of spray dried apple juice concentrate powders. The results showed that the hygroscopicity is influenced by the type and nature of each carrier. Thus, use of pectin and WPC in combination with the carriers increased and decreased hygroscopicity ($P < 0.05$), respectively. The results showed that powders produced by MD and GA, showed low stability due to its high hygroscopicity (storage conditions under relatively high

Table 2 Flowability parameters of spray dried apple juice concentrate powder

Treatments	Hausner ratio	Carr index	Repose angle (°)
50MD	1.230 ± 0.02^{de}	0.187 ± 0.02^{de}	25.50 ± 1.25^{d}
49MD + 1Pec	1.228 ± 0.01^{de}	0.185 ± 0.01^{de}	27.01 ± 1.05^{bc}
48MD + 2Pec	1.240 ± 0.02^{d}	0.193 ± 0.01^{d}	27.33 ± 0.58^{abc}
47MD + 3Pec	1.226 ± 0.01^{def}	0.184 ± 0.01^{de}	26.50 ± 1.5^{c}
45MD + 5Pec	1.223 ± 0.01^{efg}	0.182 ± 0.01^{ef}	27.01 ± 1.5^{bc}
45MD + 5WPC	1.215 ± 0.02^{efgh}	0.177 ± 0.02^{efgh}	25.17 ± 1.1^{def}
40MD + 10WPC	1.206 ± 0.02^{hij}	0.170 ± 0.02^{hi}	24.33 ± 1.04^{fg}
35MD + 15WPC	1.198 ± 0.01^{ijk}	0.162 ± 0.01^{ij}	24.17 ± 0.58^{g}
30MD + 20WPC	1.211 ± 0.01^{fghi}	0.174 ± 0.01^{fgh}	24.01 ± 0.29^{g}
50GA	1.192 ± 0.01^{jk}	0.161 ± 0.01^{ij}	25.33 ± 0.5^{de}
49GA + 1Pec	1.262 ± 0.02^{c}	0.207 ± 0.02^{c}	26.83 ± 0.58^{bc}
48GA + 2Pec	1.290 ± 0.02^{b}	0.224 ± 0.01^{b}	28.17 ± 1.15^{a}
47GA + 3Pec	1.311 ± 0.01^{a}	0.237 ± 0.01^{a}	27.50 ± 1.1^{ab}
45GA + 5Pec	1.296 ± 0.02^{b}	0.228 ± 0.01^{ab}	27.33 ± 0.76^{abc}
45GA + 5WPC	1.268 ± 0.01^{c}	0.211 ± 0.01^{c}	24.84 ± 0.57^{defg}
40GA + 10WPC	1.207 ± 0.01^{ghij}	0.171 ± 0.01^{ghi}	24.83 ± 0.5^{defg}
35GA + 15WPC	1.186 ± 0.01^{k}	0.157 ± 0.01^{i}	24.50 ± 0.76^{efg}
30GA + 20WPC	1.223 ± 0.01^{efg}	0.181 ± 0.01^{efg}	24.33 ± 0.86^{fg}

Data represent mean value of three replicates ± standard deviations

Different letters in the same column indicate statistical significant differences ($P < 0.05$)

moisture). Use of pectin in combination with the carriers also increased hygroscopicity. But use of WPC in combination with any of the carriers resulted in a significant reduction in the hygroscopicity thus maintains the physical state of the powders during storage (Fig. 1c). This finding can be attributed to the ability of proteins to form films with low hygroscopicity around the particle (Sarabandi et al. 2017; Fang and Bhandari 2012).

Moisture absorption on particle surface takes place through hydrogen bonding and this phenomenon is dependent on the temperature and relative humidity (Mauer and Taylor 2010; Lipasek et al. 2012). In case of long term storage of powders in high relative humidity conditions, continuous absorption of moisture in the early stages leads to caking and liquid bridges formation between the particles (Botrel et al. 2014). Because the particles are soluble in water, and bridges liquid contains nuclear substances and this will increase the viscosity of the liquid bridges and cause strong adhesion to each other (Listiohadi et al. 2005). Finally, continuing the process of moisture absorption causes deliquescence phenomenon. During this process, a variety of hygroscopic powders (such as syrup and fruit juices) convert from solid to liquid form (Mauer and Taylor 2010). The hygroscopicity of apple juice concentrate powders was near to hygroscopicity amount of beetroot juice concentrate (Bazaria and Kumar 2016) and Jamun fruit juice (Santhalakshmy et al. 2015) with hygroscopicity of 11.13–15.59 and 17–25.33%, respectively.

Color

Table 3, shows color index values under the influence of the type and combination of various carriers. In all color parameters there was a significant difference between samples produced with MD and GA. For example, samples contained MD showed higher L* value and hue angle than the powders produced with GA. But the color of powders produced with GA as carrier was darker than the former. This can be due to inherent color of the carriers which affects color characteristics of final products. According to pectin concentrations used in combination with MD and GA, there was a change in the color of final product. The b* value of samples contained GA was higher than the samples prepared with a combination of WPC and GA. This difference was due to the red color nature of GA, compared to light cream color of WPC. Also, the hue angle of samples also increased with using of WPC in combination with GA. Among different produced powders, samples containing MD showed the higher hue angle.

In another research the effect of type and concentration of WPC, GA and MD as carrier of tamarind pulp powder on color indexes was studied. The samples produced by WPC showed less lightness than the samples produced with MD. Among different carriers, samples produced by WPC and GA showed higher a* and b* value due to non-enzymatic browning reaction between the reducing sugars and its protein component (Bhusari et al. 2014). The gum arabic is a mixture of glycoproteins and polysaccharide. The protein content ranging from 1 to 3% (hydroxyproline, serine and proline) are three major components for samples from different producing areas. Free amino acids and peptides with a shorter chain length have higher reactivity than complex proteins. Also, the sugar chain moieties affect the amino-carbonyl reaction of glycoproteins with reducing sugars, especially at advanced stages of the reaction (Kato and Matsuda 1996). However, the degree of non-enzymatic browning and the amount of color indices depend on the process time and temperature within the drying chamber. For example, Quek et al. (2007) reported an increase in the color of the powders as a result of the increase in temperature and the non-enzymatic browning process.

Scanning electron microscopy (SEM)

Scanning electron micrographs (Fig. 2), shows a variety of particles with different shapes, surface structure and particle size under the effect of different carrier types. The spray dried apple juice concentrate with MD showed almost smooth surface with medium inter-particle adhesion (Fig. 2a). But the combination of pectin with MD caused formation of relatively globular particles with smooth surfaces and many dents (Fig. 2b). This is probably due to the role of high concentrations of pectin in increasing viscosity and gel formation ability that prevents the formation of particles with uniform wall. Similar results were observed in the spray dried medicinal plant extracts with the combination of pectin and MD as carriers (Sansone et al. 2011). Use of WPC in combination with MD caused a larger and separate particles, less inter-particles adhesion and shrinked surface with many dents on it (Fig. 2c, d). Production of particles with irregular and shrinked surface is a common phenomenon in spray drying of various products, and it is mainly due to rapid formation of crust on the surface of the droplets in the early stages of drying (Wang et al. 2013). These results agree with the findings of Wang and Langrish (2010) that investigated the effect of MD and mixtures of WPI and MD as carrier on the microstructure of spray dried soy sauce powder. They concluded that shrinkage of particles was due to rapid formation of a protein-rich film on droplets in the early stages of drying.

Also in spray dried tamarind pulp powders, particles with whole wall and without any crack were observed. But use of high concentrations of WPC increased the shrinkage of particle surfaces which was due to difficult release of

Table 3 Color characterization of spray dried apple juice concentrates powders

Treatments	L*	a*	b*	Hue angle (°)	Chroma
50MD	53.98 ± 0.04^{c}	-3.96 ± 0.09^{h}	12.37 ± 0.01^{i}	107.74 ± 0.42^{a}	12.98 ± 0.03^{i}
49MD + 1Pec	56.02 ± 0.01^{ab}	-3.98 ± 0.06^{h}	12.31 ± 0.06^{i}	107.92 ± 0.33^{a}	12.94 ± 0.03^{i}
48MD + 2Pec	54.09 ± 0.11^{c}	-3.54 ± 0.02^{g}	13.45 ± 0.06^{h}	104.84 ± 0.02^{c}	13.81 ± 0.07^{h}
47MD + 3Pec	52.31 ± 0.22^{d}	-3.98 ± 0.01^{h}	13.69 ± 0.18^{gh}	106.22 ± 0.25^{b}	14.27 ± 0.17^{gh}
45MD + 5Pec	56.37 ± 0.26^{a}	-3.68 ± 0.06^{gh}	14.19 ± 0.12^{fg}	104.55 ± 0.34^{c}	14.67 ± 0.09^{fg}
45MD + 5WPC	52.40 ± 0.06d	-2.91 ± 0.03^{ef}	10.06 ± 0.18^{j}	106.14 ± 0.45^{b}	10.47 ± 0.17^{j}
40MD + 10WPC	55.18 ± 0.09^{b}	-2.73 ± 0.02^{e}	11.92 ± 0.03^{i}	102.87 ± 0.06^{d}	12.23 ± 0.04^{i}
35MD + 15WPC	56.29 ± 0.04^{a}	-3.16 ± 0.32^{f}	14.84 ± 0.47^{f}	102.46 ± 0.03^{d}	15.17 ± 0.53^{f}
30MD + 20WPC	56.39 ± 0.16^{a}	-3.02 ± 0.27^{ef}	14.62 ± 0.41^{f}	101.19 ± 0.12^{e}	14.93 ± 0.46^{fg}
50GA	48.34 ± 0.37^{g}	2.92 ± 0.14^{a}	29.10 ± 0.15^{a}	84.26 ± 0.23^{i}	29.25 ± 0.16^{a}
49GA + 1Pec	48.40 ± 0.12^{fg}	2.66 ± 0.03^{a}	29.07 ± 0.06^{a}	84.76 ± 0.04^{i}	29.19 ± 0.06^{a}
48GA + 2Pec	46.08 ± 0.19^{i}	2.63 ± 0.01^{a}	26.24 ± 0.02^{b}	84.27 ± 0.03^{i}	26.37 ± 0.02^{b}
47GA + 3Pec	49.03 ± 1.23^{efg}	1.58 ± 0.14^{b}	24.65 ± 1.28^{cd}	86.32 ± 0.17^{gh}	24.69 ± 1.27^{cd}
45GA + 5Pec	47.12 ± 0.73^{h}	1.24 ± 0.61^{b}	25.30 ± 0.94^{c}	87.23 ± 1.30^{f}	25.34 ± 0.97^{c}
45GA + 5WPC	48.33 ± 0.08^{g}	0.38 ± 0.15^{d}	23.98 ± 0.57^{de}	88.42 ± 1.37^{fg}	23.98 ± 0.57^{de}
40GA + 10WPC	49.23 ± 0.09^{efg}	0.79 ± 0.38^{c}	23.38 ± 0.02^{e}	88.09 ± 0.85^{fg}	23.39 ± 0.01^{e}
35GA + 15WPC	49.50 ± 0.12^{ef}	1.48 ± 0.06^{b}	24.21 ± 0.01^{d}	86.44 ± 0.06^{h}	23.95 ± 0.55^{de}
30GA + 20WPC	49.64 ± 1.02^{e}	1.37 ± 0.19^{b}	24.55 ± 0.04^{cd}	86.79 ± 0.49^{h}	24.48 ± 0.21^{d}

Data represent mean value of three replicates ± standard deviations

Different letters in the same column indicate statistical significant differences ($P < 0.05$)

water molecules from protein larger molecules (Bhusari et al. 2014). Figure 2e–h, shows the effect of combination of pectin and GA on the morphology of particles produced with the WPI. The powders obtained by GA, unlike particles produced with MD showed particles shrinkage and uniform size with less adhesion (Fig. 2e). Similar to these research, date powders produced by MD as carrier showed relatively uniform, smooth and globular particles with high agglomerates. However, in the samples obtained with GA higher shrinkage in particles and less agglomeration was observed compared with the samples prepared with MD (Manickavasagan et al. 2015). Use of pectin in combination with GA was reduced particle surface shrinkage (Fig. 2e, f). The same results were observed in the samples prepated by WPC in combination with GA. Also, increasing the concentration of WPC led to production of larger particle (Fig. 2g, h). These findings indicate different effects of carriers and their combination with each other on the surface structure of produced particles. The particles produced with combination of WPC and GA showed lower shrinkage and this effect can be attributed to increase in the wall elasticity of particles. Also, SHEU and Rosenberg (1998) showed that the effect of whey protein on ethyl caprylate particles which improved the structure of particles with a smoother surface and less pores compared with those produced with the MD.

Conclusion

The most important application of carriers is modification of particle structure with purpose of reducing particle adhesion, hygroscopicity, degree of caking, and increasing the stability of powder during storage. The type and concentration of carrier are important in the economical production of products to maintain their suitable physicochemical and functional properties. However, each of the carriers has advantages and disadvantages. The disadvantages and limitations of a carrier can be minimized by applying a combination of two or more carriers in the spray drying process of the produced products. In this study, use of 1% pectin in combination with each of the MD and GA carriers showed little impact on the production yield. Although, the physical and functional properties of spray dried powders was negatively affected in higher pectin concentarion. But, the use of WPC in small quantities in combination with the MD and GA showed better impact and caused substantial increase in process efficiency, production of powders with low adhesion and hygroscopicity, appropriate stability and functional properties. Samples containing MD and GA had the highest and the lowest bulk and tapped density, respectively but using WPC caused significant decrease in the density of the particle. Solubility, wettability, hygroscopicity, colore

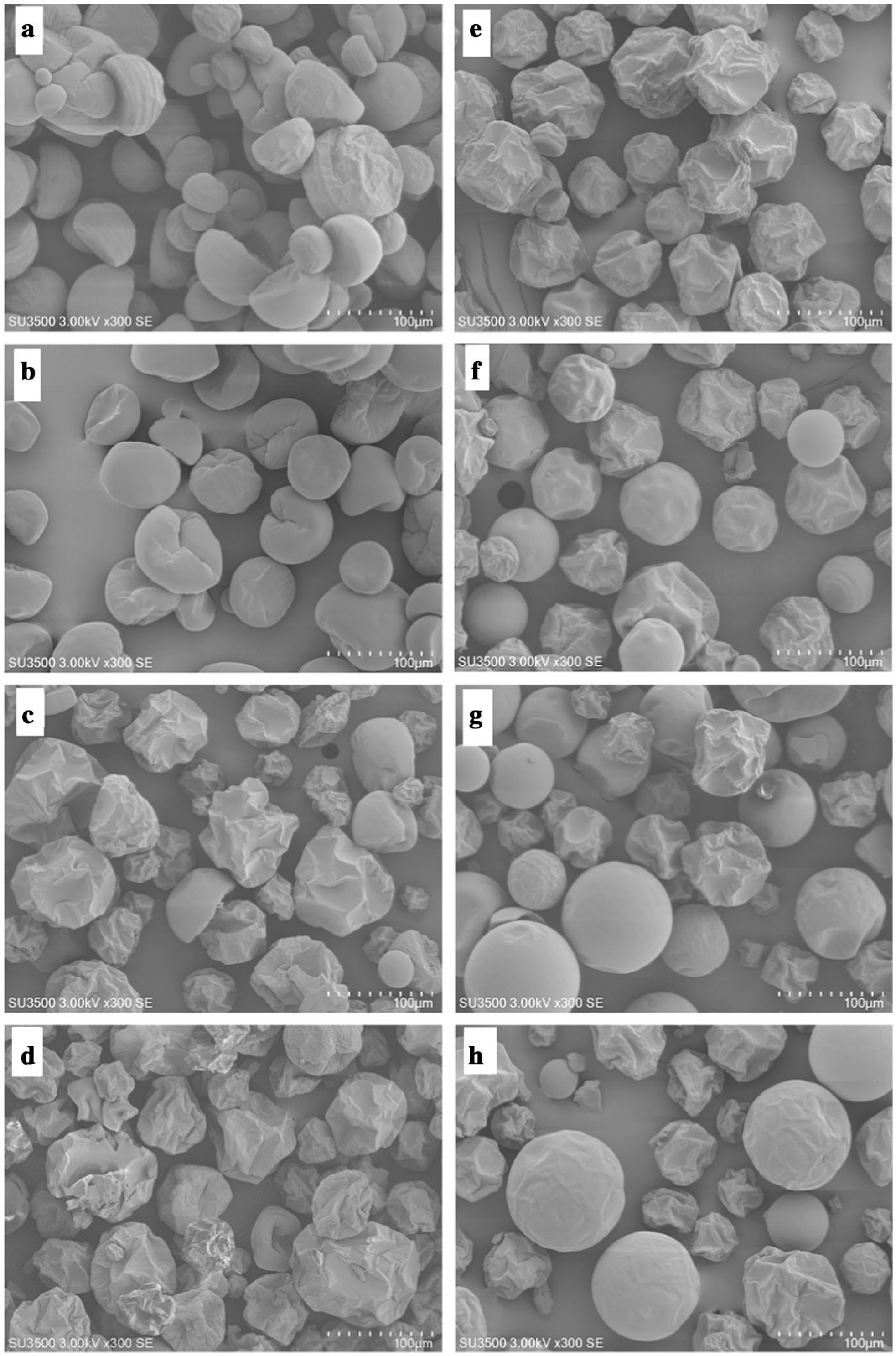


Fig. 2 Scanning electron micrographs of spray dried apple juice concentrate powder prepared by different carrier combination. **a** 50MD, **b** 45MD + 5Pec, **c** 40MD + 10WPC, **d** 30MD + 20WPC, **e** 50GA, **f** 45GA + 5Pec, **g** 40GA + 10WPC, **h** 30GA + 20WPC

characteristics and microstructure of powders were also influenced by the carriers type and their combinations. Taking into account all the parameters, using 10% WPC in combination with MD showed the best result in the production of apple juice concentrate powder with the highest yield (over 60%) and suitable physical characteristics, flowability and functional properties.

References

Abadio FDB, Domingues AM, Borges SV, Oliveira VM (2004) Physical properties of powdered pineapple (*Ananas comosus*) juice—effect of malt dextrin concentration and atomization speed. J Food Eng 64:285–287. https://doi.org/10.1016/j.jfoodeng.2003.10.010

Adhikari B, Howes T, Shrestha AK, Bhandari BR (2007) Development of stickiness of whey protein isolate and lactose droplets during convective drying. Chem Eng Process Process Intensif 46:420–428. https://doi.org/10.1016/j.cep.2006.07.014

Bae EK, Lee SJ (2008) Microencapsulation of avocado oil by spray drying using whey protein and maltodextrin. J Microencapsul 25:549–560. https://doi.org/10.1080/02652040802075682

Bazaria B, Kumar P (2016) Effect of whey protein concentrate as drying aid and drying parameters on physicochemical and functional properties of spray dried beetroot juice concentrate. Food Biosci 14:21–27. https://doi.org/10.1016/j.fbio.2015.11.002

Bhandari BR, Datta N, D'Arcy BR, Rintoul GB (1998) Co-crystallization of honey with sucrose. LWT-Food Sci Technol 31:138–142. https://doi.org/10.1006/fstl.1997.0316

Bhusari SN, Muzaffar K, Kumar P (2014) Effect of carrier agents on physical and microstructural properties of spray dried tamarind pulp powder. Powder Technol 266:354–364. https://doi.org/10.1016/j.powtec.2014.06.038

Botrel DA, de Barros Fernandes RV, Borges SV, Yoshida MI (2014) Influence of wall matrix systems on the properties of spray-dried microparticles containing fish oil. Food Res Int 62:344–352. https://doi.org/10.1016/j.foodres.2014.02.003

Cai YZ, Corke H (2000) Production and properties of spray-dried amaranthus betacyanin pigments. J Food Sci 65:1248–1252. https://doi.org/10.1111/j.1365-2621.2000.tb10273.x

Cano-Chauca M, Stringheta PC, Ramos AM, Cal-Vidal J (2005) Effect of the carriers on the microstructure of mango powder obtained by spray drying and its functional characterization. Innov Food Sci Emerg Technol 6:420–428. https://doi.org/10.1016/j.ifset.2005.05.003

Carneiro HCF, Tonon RV, Grosso CRF, Hubinger MD (2013) Encapsulation efficiency and oxidative stability of flaxseed oil microencapsulated by spray drying using different combinations of wall materials. J Food Eng 115:443–451. https://doi.org/10.1016/j.jfoodeng.2012.03.033

Emery E, Oliver J, Pugsley T, Sharma J, Zhou J (2009) Flowability of moist pharmaceutical powders. Powder Technol 189:409–415. https://doi.org/10.1016/j.powtec.2008.06.017

Fang Z, Bhandari B (2012) Comparing the efficiency of protein and maltodextrin on spray drying of bayberry juice. Food Res Int 48:478–483. https://doi.org/10.1016/j.foodres.2012.05.025

Frascareli EC, Silva VM, Tonon RV, Hubinger MD (2012) Effect of process conditions on the microencapsulation of coffee oil by spray drying. Food Bioprod Process 90:413–424. https://doi.org/10.1016/j.fbp.2011.12.002

Fuchs M, Turchiuli C, Bohin M, Cuvelier ME, Ordonnaud C, Peyrat-Maillard MN, Dumoulin E (2006) Encapsulation of oil in powder using spray drying and fluidised bed agglomeration. J Food Eng 75:27–35. https://doi.org/10.1016/j.jfoodeng.2005.03.047

Goula AM, Adamopoulos KG (2012) A method for pomegranate seed application in food industries: seed oil encapsulation. Food Bioprod Process 90:639–652. https://doi.org/10.1016/j.fbp.2012.06.001

Idham Z, Muhamad II, Setapar M, Hamidah S, Sarmidi MR (2012) Effect of thermal processes on roselle anthocyanins encapsulated in different polymer matrices. J Food Process Preserv 36:176–184. https://doi.org/10.1111/j.1745-4549.2011.00572.x

Jangam SV, Thorat BN (2010) Optimization of spray drying of ginger extract. Dry Technol 28:1426–1434. https://doi.org/10.1080/07373937.2010.482699

Jayasundera M, Adhikari B, Howes T, Aldred P (2011) Surface protein coverage and its implications on spray-drying of model sugar-rich foods: solubility, powder production and characterisation. Food Chem 128:1003–1016. https://doi.org/10.1016/j.foodchem.2011.04.006

Jinapong N, Suphantharika M, Jamnong P (2008) Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration. J Food Eng 84:194–205. https://doi.org/10.1016/j.jfoodeng.2007.04.032

Kato Y, Matsuda T (1996) Effects of the glycoprotein sugar chains on the amino-carbonyl reaction of chicken and Japanese quail ovomucoids with glucose. Biosci Biotech Biochem 60:1490–1491. https://doi.org/10.1271/bbb.60.1490

Lipasek RA, Ortiz JC, Taylor LS, Mauer LJ (2012) Effects of anticaking agents and storage conditions on the moisture sorption, caking, and flowability of deliquescent ingredients. Food Res Int 45:369–380. https://doi.org/10.1016/j.foodres.2011.10.037

Listiohadi YD, Hourigan JA, Sleigh RW, Steele RJ (2005) An exploration of the caking of lactose in whey and skim milk powders. Aust J Dairy Technol 60:207

Lumay G, Boschini F, Traina K, Bontempi S, Remy JC, Cloots R, Vandewalle N (2012) Measuring the flowing properties of powders and grains. Powder Technol 224:19–27. https://doi.org/10.1016/j.powtec.2012.02.015

Mahendran T (2011) Physico-chemical properties and sensory characteristics of dehydrated guava concentrate: effect of drying method and maltodextrin concentration. Trop Agric Res Ext 13:48–54. https://doi.org/10.4038/tare.v13i2.3138

Manickavasagan A, Thangavel K, Dev SRS, Delfiya DA, Nambi E, Orsat V, Raghavan GS (2015) Physicochemical characteristics of date powder produced in a pilot-scale spray dryer. Dry Technol 33:1114–1123. https://doi.org/10.1080/07373937.2015.1014045

Mauer LJ, Taylor LS (2010) Water-solids interactions: deliquescence. Annu Rev Food Sci Technol 1:41–63. https://doi.org/10.1146/annurev.food.080708.100915

Moreira GEG, Costa MGM, de Souza ACR, de Brito ES, de Medeiros MD, de Azeredo HM (2009) Physical properties of spray dried acerola pomace extract as affected by temperature and drying aids. LWT-Food Sci Technol 42:641–645. https://doi.org/10.1016/j.lwt.2008.07.008

Oliveira WP, Bott RF, Souza CRF (2006) Manufacture of standardized dried extracts from medicinal Brazilian plants. Dry Technol 24:523–533. https://doi.org/10.1080/07373930600612073

Quek SY, Chok NK, Swedlund P (2007) The physicochemical properties of spray-dried watermelon powders. Chem Eng Process Process Intensif 46:386–392. https://doi.org/10.1016/j.cep.2006.06.020

Righetto AM, Netto FM (2006) Vitamin C stability in encapsulated green West Indian cherry juice and in encapsulated synthetic ascorbic acid. J Sci Food Agric 86:1202–1208. https://doi.org/10.1002/jsfa.2469

Sansone F, Mencherini T, Picerno P, d'Amore M, Aquino RP, Lauro MR (2011) Maltodextrin/pectin microparticles by spray drying as carrier for nutraceutical extracts. J Food Eng 105:468–476. https://doi.org/10.1016/j.jfoodeng.2011.03.004

Santhalakshmy S, Bosco SJD, Francis S, Sabeena M (2015) Effect of inlet temperature on physicochemical properties of spray-dried jamun fruit juice powder. Powder Technol 274:37–43. https://doi.org/10.1016/j.powtec.2015.01.016

Sarabandi K, Peighambardoust SH, Mahoonak AS, Samaei SP (2017) Effect of carrier types and compositions on the production yield, microstructure and physical characteristics of spray dried sour cherry juice concentrate. J Food Meas Charact 11:1602–1612. https://doi.org/10.1007/s11694-017-9540-3

Sheu T, Rosenberg M (1998) Microstructure of microcapsules consisting of whey proteins and carbohydrates. J Food Sci 63:491–494. https://doi.org/10.1111/j.1365-2621.1998.tb15770.x

Turchiuli C, Munguia MTJ, Sanchez MH, Ferre HC, Dumoulin E (2014) Use of different supports for oil encapsulation in powder by spray drying. Powder Technol 255:103–108. https://doi.org/10.1016/j.powtec.2013.08.026

Wang S, Langrish T (2010) The use of surface active compounds as additives in spray drying. Dry Technol 28:341–348. https://doi.org/10.1080/07373931003641404

Wang W, Zhou W (2015) Characterisation of spray dried soy sauce powders made by adding crystalline carbohydrates to drying carrier. Food Chem 168:417–422. https://doi.org/10.1016/j.foodchem.2014.07.065

Wang W, Jiang Y, Zhou W (2013) Characteristics of soy sauce powders spray-dried using dairy whey proteins and maltodextrins as drying aids. J Food Eng 119:724–730. https://doi.org/10.1016/j.jfoodeng.2013.06.047

Zaidel DNA, Rashid JM, Hamidon NH, Salleh LM, Kassim ASM (2017) Extraction and characterization of pectin from dragon fruit (*Hylocereus polyrhizus*) peels. Chem Eng Trans 56:805–810. https://doi.org/10.3303/cet1756135