TECHNOLOGY AND NUTRITIONAL VALUE OF POWDERED DRINKS

Ömer Utku Çopur, Bige İncedayı, Azime Özkan Karabacak
Department of Food Engineering, Uludag University, Bursa, Turkey

2.1 Introduction

People's concern in salutary, nutritious, and functional foodstuffs has been increasing rapidly in recent years. The reasons why some foods are on the frontline may be attributed to consciousness in consumption, greater emphasis on health, and increased disposable income. At this point, beverages have an importance in human consumption. Beverage term includes a wide variety of compositions including fruit juice, water, tea, coffee, milk, alcohol, energy drinks, soda, or any combination of them. Besides the physicochemical effects on body, some of the beverages as coffee and tea have social impacts between people.

The high content of water leads to microbial spoilage or increased enzyme activity in many beverages. Hence, preservation by the way of drying is one of the preferred method for them. Powdered drink term is available for soft drinks as juice, milk, coffee, salep, or some mixes (Descamps et al., 2013). The beverages in powdered form are currently popular in terms of new flavor options (Varela et al., 2010). The instant structure provides a ready-to-drink character to these commercial and value-added products (Ratnaningrum et al., 2015). Besides wide variety of flavors and good yield of powdered drinks for consumers, drying gains storage, and transportation easiness to the beverages through reduced volume for producers (Varela et al., 2010; Cuq et al., 2011; Sansone et al., 2011).

Today, a great variety of commercially produced powdered drinks with different flavors taken a place in the marketplace (Antúnez et al., 2017). Some of them may be used in different formulations (confectionery, infant formula, soups, sauces, ice cream, or supplements) or together with in powdered beverage mixes. Depending on consumer

Production and Management of Beverages. https://doi.org/10.1016/B978-0-12-815260-7.00002-X

preference, powdered beverages with a fortified content and varied sweetness levels are available (Palmer, 2005).

The drying process optimization is the critical point for quality improvement of powdered drinks. The conditions markedly impact on reconstitution and instant properties of dried beverage powders. Some nutritional losses occur while powdering as much as other preservation techniques. Especially, reductions in vitamins, carotenoids, and anthocyanins were observed in many studies. In this context, types of powdered beverages, production methods, nutritional, sensorial, and reconstitutional properties are detailed.

2.2 The Technology of Powdered Drinks

Powdered drinks are qualified as an instant food. These foods require little effort to reconstitute prior to consumption. The water content of powdered beverage has to be reached to the lowest level after drying to extend the shelf life with highest quality (Shittu and Lawal, 2007; Phisut, 2012). Spray- or freeze-drying techniques should be used for this aim.

Spray driers are widely used for producing powdered milk, soymilk, or juice. The initial feed must be liquid as solution, emulsion, or suspension (Phisut, 2012; Tontul and Topuz, 2017). Through the formation of a thin exterior layer of the droplets by atomizing process of liquid feed, the evaporation of small molecules is enabled (Rocha et al., 2012; Ezhilarasi et al., 2013). This commercial method is preferred due to short heat treatment with higher efficiency (Jinapong et al., 2008; Kha et al., 2010; Phisut, 2012). Brennan et al. (1990) notified that the very short drying times, in the range of 1–20 s, and the relatively low product temperatures are the main features of this process.

Both heat-resistant and heat-sensitive foodstuffs can be spray dried (Phisut, 2012; Tontul and Topuz, 2017). The advantages of spray drying can be summarized as:

- a rapid water removal (compared to lyophilization),
- minimum quality loss of the product,
- control ability of the particle-size distribution, and
- minimum capital and operational costs (Hall, 1996; Obón et al., 2009; Paini et al., 2015).

The spray-dried beverages give a chance to produce stabile powders consumed every period of the year with minimum physical and chemical changes or nutritional losses (Pereira et al., 2014). The difficulties of this method can be ordered as (a) high influence of food characteristics in the drying behavior and (b) the complexity of fluid dynamics in the spray dryer (Masters, 2002).

The process steps in a spray drier are seen in the schema basically in Fig. 2.1.

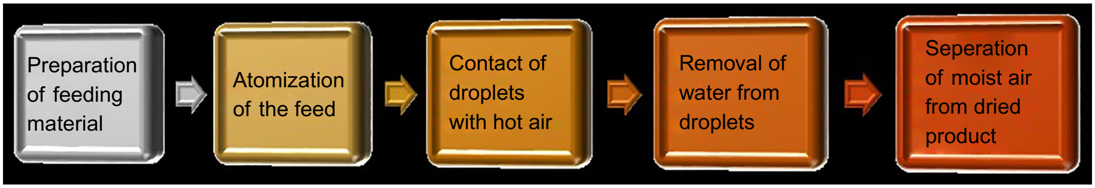

Fig. 2.1 Process steps of spray drying.

Spray drying is standardized based upon inlet and outlet air temperatures, optimum total dry matter concentration, atomization speed and pressure, flow, and feed rate (Perez-Munoz and Flores, 1997; Phisut, 2012; Chauhan and Patil, 2013; Tontul and Topuz, 2017). The thermal and evaporative efficiencies are correlated with all these parameters.

In the first step of drying, concentration of the solution is carried out for the commercial large-scale spray driers. The concentration rate changes according to the content of the food. For example, it is 50%–60% for juices while the small-scale laboratory spray dryer needs to have more diluted concentration in as much as clogging of the nozzle if the feed have high viscosity (Murugesan and Orsat, 2011). Then, the atomization of feed material comes in the second step. The dimensions of atomized droplet are changed according to the atomization pressure, nozzle orifice, characteristics of the solution, flow rate and feeding rate, etc. (Li et al., 2010) and required to be in the interval of 20 and 180 μm. A wide drying area provided by atomization yields maximizes powder amounts. Likewise, the increase in atomization speed or pressure results in higher yield (Fazaeli et al., 2012a; Tontul and Topuz, 2017).

All process optimizations are carried out for achieving an instant structure. The reconstitution of powdered drinks is the main fact for the quality improvement. It is defined as the rate at which dried foods absorb the liquid and revert to the conditions of undried form, when put in contact with a liquid medium. Some applications for the improvement of reconstitutability should be the adjustment of drying conditions, recycling of fines, and rewetting (Brennan et al., 1990).

The particle size of spray-dried powders changes between 10 and 400 μm and they have poor reconstitution properties. In addition, the components such as sugars or organic acids with a low glass transition temperatures (T_g) cause a stickiness on the drier chamber wall during drying (Gong et al., 2008; Zuidam and Shimoni, 2010; Tontul and Topuz, 2017). The glass transition temperatures of the sugars found in many foodstuffs are 62°C, 31°C, and 16°C, for sucrose, glucose, and fructose, respectively (Jayasundera et al., 2009; Fang and Bhandari, 2012; Phisut, 2012). The explanation of glass transition temperature is "the temperature at which the amorphous phase of the polymer is converted between rubbery and glassy states." Besides low glass transition temperatures, the other stickiness factors are (Phisut, 2012):

- high hydroscopicity,
- low melting point, and
- high water solubility of the dry matter.

In more detail, the mechanism of this stickiness is explained as the powders contain thermodynamically unstable amorphous glassy state components and these components become sticky in case of the temperature is increased over the glass transition temperature. It is the result of the particles with reduced surface energy which inclines to interactions with other molecules and adhesion to solid surfaces (Fitzpatrick, 2007a, b). The amorphous glassy state components are also tend to caking with interparticle bridges in due course of storage that lead to undesired reactions and probable losses of the bioactives and quality (Telis and Martínez-Navarrete, 2009). It is essential to retain the amorphous structure in a glassy state to prevent the occurrence of this undesirable phenomenon (Roos and Drusch, 2015). The carriers provide to raise the glass transition temperature during the spray drying and get the feeding material to an economically spray-dryable range (by 25% solids) (Truong et al., 2005; Jayasundera et al., 2011; Phisut, 2012; Karaca et al., 2016, Muzaffar et al., 2016). Besides, the moisture content decreases the glass transition temperature related to behave as a plasticizer (Tontul and Topuz, 2017).

As a result of this thermoplastic behavior and so cohesive structure, a decrement in product yield with an increment in operational and handling problems are seen (Bhandari et al., 1993; Rennie et al., 1999; Teunou et al., 1999; Goula and Adamopoulos, 2003; Fitzpatrick, 2007a, b; Lee et al., 2013; Pereira et al., 2014; Tontul and Topuz, 2017). When the process is particularly dealt with economically, it is concluded as the more product yield (powder recovery), the more benefit. The calculation of the product yield is shown below. The result is required to be minimum 50% for an accomplished drying (Bhandari et al., 1997). Saikia et al. (2014) dried the Khasi mandarin orange, watermelon, carambola, and ananas juices in a spray drier with 20% maltodextrin and procured the highest product yield in Khasi mandarin orange juice (85.27%):

$$\text{Product yield}\,(\%) = \frac{\text{Mass of dry matter in the powder}}{\text{Weight of total solids in the feed}} \times 100$$

Ferrari et al. (2012) reported the protective effect of carriers on sensitive components of powders against environmental factors. Maltodextrin, which is produced by acid hydrolysis of starch (corn, potato, or others), has a good oxidative stability and is commonly used as a carrier (wall material) or encapsulating agent in many spray-dried materials. The main usage aim is preventing the stickiness of feed material to the drying chamber by increasing the glass transition temperature (Gibbs et al., 1999; Adhikari et al., 2004; Fazaeli et al., 2012a; Ferrari et al., 2012; Roustapour et al., 2012; Celli et al., 2015; Barbosa et al., 2016; Mishra et al., 2017). Maltodextrin also plays multiple roles in:

- bulking and film formation,
- binding of flavor and fat, and
- reduction of oxygen permeability of wall matrix (Bae and Lee, 2008; Drusch et al., 2006; Sansone et al., 2011; Silva et al., 2013).

Maltodextrin is a saccharide polymer of *D-glucose* which has a white color, neutral taste, odorless property, and are easily digested and well tolerated. The low viscosity of high concentrated solutions of maltodextrin makes it preferable as a wall material during spray drying process (Pierucci et al., 2007; Tonon et al., 2010; Berg et al., 2012; Tontul and Topuz, 2017).

The classification of maltodextrin is based on its hydrolysis degree and explained as dextrose equivalent (DE) (Obón et al., 2009; Rocha et al., 2009). As Tontul and Topuz (2017) expressed hydrolyzed starch with lower than 20 DE is called maltodextrin, while hydrolyzed starch with higher than 20 DE is called dried glucose syrup. The maltodextrin with lower DE has a high glass transition temperature and so gains better physical stability to dried powders (Bhandari and Hartel, 2005; Gurak et al., 2013) while the maltodextrin with higher DE results in a higher humidity in the powder (Phisut, 2012). The concentration of maltodextrin is also studied by Goula and Adamopoulos (2010) in powdered orange juice. The increase of maltodextrin concentration resulted in increased moisture content in contrast with the results of pineapple juice powder obtained by Jittanit et al. (2010).

The other carriers as gum arabic and proteins such as whey protein isolate, sodium caseinate, and soy protein isolate are widely used in fruit juice powder production to increase the product yield. Some researchers reported an increase up to an 80% in power recovery of sugar-rich feed materials using a minimal dose (<5%) of whey protein isolate (Wang et al., 2011; Fang and Bhandari, 2012).

The flow diagram of encapsulation with carrier agent use is shown in Fig. 2.2.

The instant properties of powdered drinks need to be improved by various methods. One of these processes is “*agglomeration*” which provides proper particle distribution via size and bulk density adjustment during rehydration (Barletta and Barbosa-Cánovas, 1993). The other definition of agglomeration is “size enlargement via joining or binding of fine particles with one another.” Thus, porous and larger structure occurs and the properties as solubility and density of

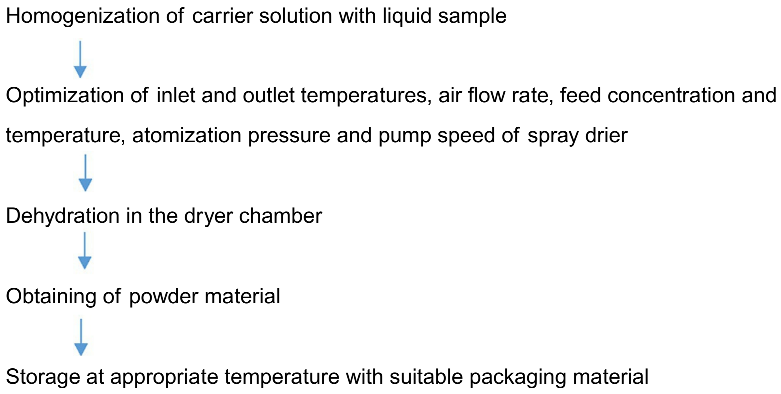

Fig. 2.2 Encapsulation process.

particles are controlled (Barbosa-Cánovas et al., 2005). As is known this porosity and size enlargement directly affects the reconstitution behavior of powdered food. The water penetration into the porous system, mechanical stability, and solubility is better in agglomerated powdered drinks (Schubert, 1980). While the liquid penetration into the gaps between the aggregates (conglomerates) is increased by agglomeration, the water flow inside the fine pores and so wetting is also get easier (Brennan et al., 1990; Hla and Hogekamp, 1999; Knight, 2001). The size of agglomerates varies from 0.1 to 3 mm and has a coarse structure (Dhanalakshmi et al., 2011). The analysis of particle-size distribution gives an opinion about the accomplishment of agglomeration process.

The larger and permanent aggregates are formed by binding the particles with some agents in agglomeration process (Gong et al., 2008). These agents are physically or chemically adhere to the surface of the powder to form the bridges between the collided particles. Powders treated with binder solution collide to each other and then the liquid bridge structure is formed in an agglomerator. The solution evaporates by the following drying process and solid bridges occur this time. The fluidized particles grow through agglomeration whether the wetting, colliding, and drying steps are repeated (Pietsch, 2003; Turchiuli et al., 2005).

The binders are chosen according to the composition and properties of the beverages. It may be lecithin for milk powder (Song et al., 2000), water for chocolate powder (Omobuwajo et al., 2000), and maltodextrin for soymilk powder (Nakarin et al., 2008). This method in which the binder is used is called as wet agglomeration (granulation) (Fig. 2.3). If there is no binder solution in the process, it is expressed as dry agglomeration. Jinapong et al. (2008) used a fluidized-bed agglomeration process for instant soymilk powder production and the

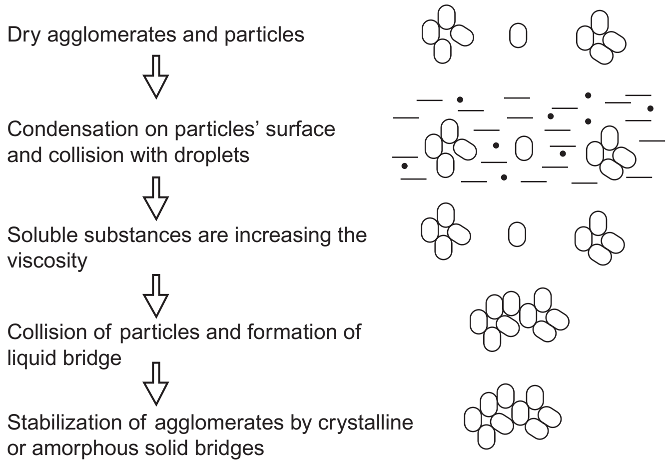

Fig. 2.3 Mechanism of wet agglomeration.

highest particle size (260 μm) and the best handling and reconstitution properties were obtained by using a maltodextrin solution (10%) as a binder.

The bonding mechanism depends on intermolecular forces (Van der Waals force and hydrogen bond), electrostatic power, liquid bonds, solid bridges, and mechanical interlocking. The bonding efficiency of binders differs from each other and the stability of the bond is based on the amount of binder, its structure, and properties (Dhanalakshmi et al., 2011).

There are few methods for agglomeration application; steam agglomeration, fluid-bed agglomeration, thermal agglomeration, and high shear mixers for wet agglomeration (Vissotto et al., 2010). Pietsch (2003) also categorized the agglomeration process in three ways; (a) pressure agglomeration, (b) granulation, and (c) agglomeration through drying. The physicochemical character of the beverage, the initial and final average particle size, thermal sensitivity, etc. specify the selection of agglomeration method. The most used method for powdered beverage production is fluid-bed agglomeration. In this method, fluidization and bulk mixing are enabled by the upwash air, whereas fine droplets of liquid are pulverized by a nozzle located on the fluidized bed (Turchiuli et al., 2005).

Gong et al. (2008) used a fluid-bed granulator and water as a binder for instant bayberry powder production. The agglomeration process was carried out at 50°C for 30 min. Consequently significant effect of inlet and outlet temperatures on powder color was reported. The high temperatures, amount of water or binder used in drying process during agglomeration influence the chemical compounds besides the physical properties of powdered beverage (Larossa et al., 2015). Benković et al. (2015) linked to the effect of the amount of added water on extension process period of agglomerated cocoa powder mixtures.

In Fig. 2.4, the process steps for agglomerated soymilk powder production are shown (Jinapong et al., 2008; Dhanalakshmi et al., 2011).

Agglomerated particles can be also coated (capsulated) by:

- lipids, milk proteins, water soluble biopolymers, corn proteins, and gums (Eichler, 1996; Kha et al., 2010; Fazaeli et al., 2012a) and
- sodium alginate, gelatin, protein concentrates, carboxymethyl cellulose (CMC), kappa-carrageenan, starch hydrolysates (Dewettinck and Huyghebaert, 1999).

The coating agents mentioned above help to prevent the degradation of heat-sensitive compounds during drying, which is most often carried out above 160°C. In addition, the nutritional, textural, and bioactive properties are better protected by coating (Dhanalakshmi et al., 2011; Sun-Waterhouse et al., 2013; Luca et al., 2014; Belščak-Cvitanović et al., 2015). Coronel-Aguilera and Martín-González (2015) suggested to coat the spray-dried encapsulates containing β-carotene with hydroxypropyl cellulose.

The constituents within the particles are preserved in the coated agglomerated granules from degradation by heat, moisture, or light (Dewettinck and Huyghebaert, 1998; Teunou and Poncelet, 2002). Spray coating (fluid coating) is applied by spraying a coating solution on the fluidized particles (Poncelet et al., 2011). The coating material is required to have proper viscosity to pumped and atomized and also resistance to heat. However, the increase in concentration of coating material leads to a difficulty in removal of water and 5%–50% coating can be applied to the power.

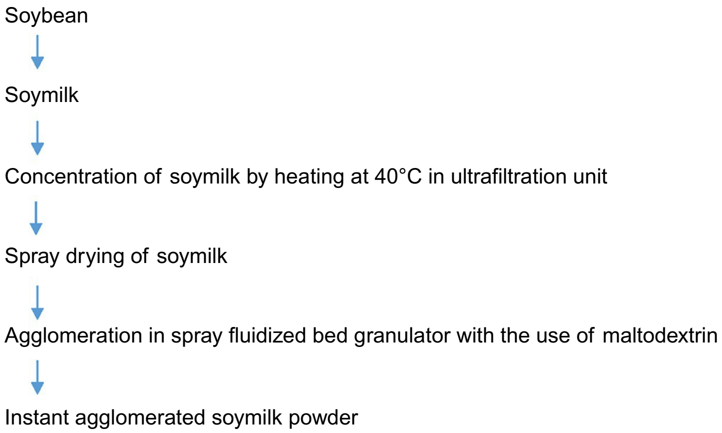

Fig. 2.4 Flow diagram of agglomerated soymilk powder production.

2.3 Powdered Drink Production by Freeze Drying

The freeze drying (lyophilization or sublimation drying) among the drying techniques has an increased interest related to provide a porous structure with favorable quality properties (Krokida and Maroulis, 2000). It is a convenient technique for heat-sensitive foods for long-term storage (Ceballos et al., 2012; Celli et al., 2015; Akbas et al., 2017). The main principle for this method is the sublimation of frozen sample at a low pressure (<300 Pa) and temperature. By this drying technique, the properties of food material (as shape, appearance, color, taste, and texture) are retained as good as original flavor and aroma (Marques et al., 2006, 2009; Nedovic et al., 2011; Ceballos et al., 2012; Oikonomopoulou and Krokida, 2013; Ray et al., 2015). The high quality of freeze-dried powders depends on low processing temperature (−20°C) and the absence of air oxygen during processing (Brennan et al., 1990; Strumillo and Adamiec, 1996; Litvin et al., 1998). The shrinkage ratio changes between 5% and 15% for most of the freeze-dried foodstuffs (Argyropoulos et al., 2011; Horszwald et al., 2013; Russo et al., 2013).

The rate of drying in lyophilization systems is affected by two main factors (Brennan et al., 1990):

- Ratio of water vapor movement from the ice surface through the porous layer of dry material.
- Rate of heat transfer to the ice front.

The various systems for lyophilization are:

- Batch freeze driers
- Multicabinet units
- Tunnel freeze driers

The dry form of the product is usually quite porous, fragile, hygroscopic, and with an excellent rehydration potential (Antal et al., 2011; Argyropoulos et al., 2011; Ceballos et al., 2012; Russo et al., 2013; Oikonomopoulou and Krokida, 2013). The freeze-dried powders have approximately four to six times higher rehydration ratio than air-dried ones (Ratti, 2001). The disadvantages of this method are (Telis and Sobral, 2001; Raharitsifa and Ratti, 2010; Fabra et al., 2009; Ezhilarasi et al., 2013; Celli et al., 2015):

- high-energy requirement,
- long drying time (>20 h),
- amorphous and hygroscopic structures formation after the certain changes (these structures cause to reduce the shelf life and stability of the product), and
- higher costs due to long drying times under vacuum (30–50 times expensive than spray drying).

Spray drying is more economical and faster than this drying technique. The main reason is that of freeze drying requires double processing steps including freezing and drying (Ezhilarasi et al., 2013). Differently, the lyophilization occurs “layer by layer” in disintegrated cell during freezing. This is the cause of long freeze-drying time and required to be improved by controlling the freezing conditions. Also pulverization of a very large surface area per unit volume of material to the drying chamber by atomization results in rapid drying in spray driers (Brennan et al., 1990). Dehnad et al. (2016) determined the highest efficiency of lyophilization method among spray, freeze, vacuum, and convective drying techniques for processing of protein resources. They suggested spray drying method as the second option for this aim due to closer performance.

Hottot et al. (2007) and Ceballos et al. (2012) pointed out that freezing parameters (freezing rate, the lowest temperature during freezing, and the temperature of the frozen layer during drying) affect the subsequent stages in freeze-drying method. As known while fast freezing creates small ice crystals, large ice crystals are generated during slow freezing rate (less than 1°C/min) (Hottot et al., 2007; Rhim et al., 2011). In the course of small freezing, the water diffuses outside from the cell and then crystals are formed in that place (Woo and Mujumdar, 2010). The small ice crystal formation is preferred for homogenous crystallization and high-quality product. This situation is related with pore size and higher mass flow during dehydration and reconstitution (Bindschaedler, 1999; Orrego, 2003). Nowak et al. (2016) investigated the effect of preheat treatment on freezing and then drying. It was concluded that while the hygroscopicity of the material was improved by blanching and mechanical fragmentation, water content of blanched products after rehydration was just about the fresh material’s water content.

Franceschinis et al. (2014) processed the blackberry juice by freeze and spray drying and compared the physical and functional properties of these two products. While the bioactive compounds and antioxidant activity were higher in freeze-dried and maltodextrin containing powders, the physical properties were better in spray-dried blackberry juice with high glass transition temperature and low molecular mobility.

2.4 Instant Properties of Powdered Drinks

The same components in the bulk density after spray drying prevent the separation of components after blending and gain uniformity (Palmer, 2005). All reconstitutional and instant properties specify the quality of powdered products (Brennan et al., 1990; Gong et al., 2008; Mahdavi et al., 2014). Agglomeration improves the instant properties of powdered particles compared to the original primary particles (Dhanalakshmi et al., 2011).

The wettability of the powder is the ability to absorb water on its surface and adjust to float or sink of particles found in different sizes and shapes in food powders (Freudig et al., 1999; Dupas et al., 2015). Sphere characteristics of the powder particles condition the flotation behaviors (Dupas et al., 2015). Large particles with large pores refer to good wettability (Brennan et al., 1990; Dhanalakshmi et al., 2011). The wettability occurs while all particles of the powder get wetted and penetrated to the surface of water because of the capillary forces. It is the initial and rate controlling stage of the reconstitution process (Ceballos et al., 2012; Celli et al., 2015) and characterized by the wetting time. Ferrari et al. (2012) determined that the wetting time of blackberry powders was reduced to 15 s from 120 s by the increased particle size from 74 to about 200 μm after agglomeration.

Dispersibility is the single-particle distribution of powder in the bulk liquid phase. This property is reduced by clump formation and is improved when the sinkability is high (Brennan et al., 1990). Sinkability is explained as the dipping of powder particles under the liquid surface. The size and density characteristics of the particles chiefly impact on sinkability (Brennan et al., 1990). Swelling can powerfully impede sinking (Freudig et al., 1999).

Hygroscopicity term is expressed as the holding ability of the ambient water (Movahhed and Mohebbi, 2016; Tontul and Topuz, 2017). All food powders are sensitive to environmental humidity. The high humidity can cause problems during storage through the adhesion between the particles, clumping, and possible oxidation of the powdered beverage (Teunou and Fitzpatrick, 1999; Torres et al., 2011; Fernandes et al., 2014). In Fig. 2.5, the comparison of the change in physical appearance of functional encapsulants from *Fadogia ancylantha*, *Melissa officinalis*, and *Tussilago farfara* extracts both obtained by using maltodextrin/apple pectin and industrial production are seen (Sansone et al., 2011). However, the ambient conditions were the same, the hygroscopicity property changes based on the carrier used.

The sorption kinetics of dried powders can be used for monitoring the hygroscopicity. The powders containing granules below 100 μm have hygroscopic structure and agglomeration is a solution for this problem (York, 2009). Szulc and Lenart (2012) reported that baby food powders produced by 50% sugar solution or 2% lecithin solution showed a reduction in water adsorption rate compared to the agglomerates produced using water. Nurhadi et al. (2012) expressed the hygroscopic powders as the powders which have more than 20% hygroscopicity. Especially the powder with a low moisture content is more inclined to absorb ambient humidity, as reported in blackberry and acai powders by Tonon et al. (2009) and Ferrari et al. (2012),

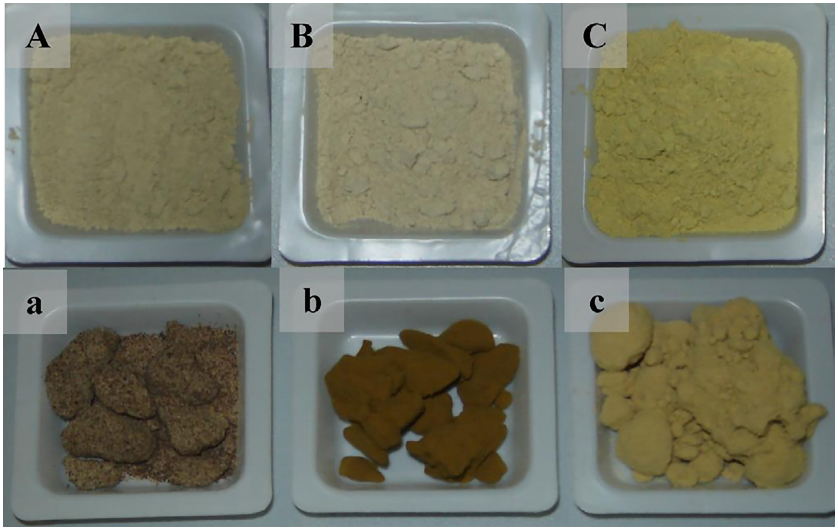

Fig. 2.5 Physical appearance of the powders obtained by using maltodextrin/apple pectin (A, B, C) and industrial products (a, b, c) after six months under accelerated storage conditions.

respectively. The moisture content of spray-dried powder should be generally lower than 5% for a microbial safe and long-term storage. The low moisture content also restricts the ability of the water act as a plasticizer, therefore, affects the caking of the powder during storage (Ertekin, 2015; Santana et al., 2017). In a research, Saikia et al. (2014) determined the hygroscopicity of four different juice powders between 11.63 and 11.99 g/100 g of samples.

Flowability of the powder depends upon the forces including gravity, friction, cohesion, and adhesion. The structure and geometry of particle (size, shape, and surface properties) affects the flowability property.

Solubility is simply dissolving of powder in the water or liquid medium (Dhanalakshmi et al., 2011). This is a criterion that shows the ability of solution or suspension occurrence with aqueous medium. High solubility is desired for spray-dried powders and amorphous structure is more soluble (Du et al., 2014; Bicudo et al., 2015). Some researchers determined that the increased content of maltodextrin, lower feed rate, increased atomization, or higher inlet and outlet temperatures lead to a higher solubility (Avila et al., 2015; Muzaffar et al., 2016; Moghaddam et al., 2017). On the contrary, some researchers reported that higher inlet temperatures cause a harsh surface layer on the powder particle and the solubility is diminished related to decreased diffusion of water through the particle (Gong et al., 2008; Horuz et al., 2012; Avila et al., 2015; Moghaddam et al., 2017). Regarding to these results, Phongpipatpong et al. (2008) optimized the spray drying conditions for longan drink powder and concluded that the most important factor affecting solubility was drying air temperature.

The wettability, dispersibility, and solubility of powdered cocoa beverages varied from 10.7 to 21.7 s, 50.0% to 94.5%, and 44.2% to 76.6%, respectively, by Shittu and Lawal (2007) in Nigeria. Saikia et al. (2014) determined the solubility of spray-dried watermelon, ananas, carambola, and orange juices with 20% maltodextrin between 57.57% and 76.75%. Dissolution time is the restructure velocity of the powder into the liquid medium dependent on the particle size. The smaller particle size leads to faster dissolution.

The *bulk density* gains an easy handling character to powders during storage even as low values can comprise a huge air inclusion that leads to oxidation (Barbosa-Cánovas et al., 2005; Movahhed and Mohebbi, 2016). When the particle size is decreased, the bulk density is increased as desired and this enables to contain more particles in the same volume and so prevents redundant spaces between the particles (Grabowski et al., 2006). The bulk density is expressed in kilogram or gram per cubic meter in international unit because it is measured in cylinders (WHO, 2012). The calculation is given below (Movahhed and Mohebbi, 2016):

$$\text{Bulk Density} = \text{MP} \div \text{VP}$$

MP = Mass of the powder
VP = Volume of the powder

Bicudo et al. (2015) and Kingwatee et al. (2015) investigated the correlations between flowability, solubility, and bulk density. The increment in carrier concentration (Fazaeli et al., 2012b; Miravet et al., 2016), use of maltodextrin with higher DE as a carrier (Goula and Adamopoulos, 2010; Cynthia et al., 2015; Bazaria and Kumar, 2017), and higher drying temperatures (Goula and Adamopoulos, 2010; Horuz et al., 2012) were reported to cause an increment in the bulk density.

The *tapped density* is described as an increased bulk density gained later on mechanically tapping a container comprising the powdered product (WHO, 2012). The calculation of bulk and tap density in brief is as follows (Siaan and Anwair, 2014):

- Bulk density = Mass/initial volume
- Tapped density = Mass/final volume

The proportion between the apparent density and tapped density of a powder, bulk is labeled the "Hausner ratio (HR)." It is used in evaluating the flowability and cohesiveness of powders with "Carr Index (CI)" (Bansal et al., 2015; Jan et al., 2015; Etti et al., 2016):

$$\text{Carr Index} = \frac{\text{Tap density} - \text{Bulk density}}{\text{Tap density}} \times 100$$

The flowability in terms of HR index is classified as:

- HR=1.0–1.1, free flowing powder

- HR˃1.1–1.25, medium flowing powder
- HR˃1.25–1.4, the powder difficult to flow
- HR˃1.4, the powder very difficult to flow (cohesive) (Schmid et al., 2014; Etti et al., 2016)

The *rehydration capacity* of dried beverage powders is a matter to reconstitution. Rehydration is the replenishment of water lost through drying. The rehydration capacity can be calculated as follows (Kim et al., 2012):

$$\text{Rehydration capacity}\,(\%) = \frac{\text{RW} - \text{IW}}{\text{IW}} \times 100$$

RW=The weight of powder after rehydration

IW=The initial weight of powder

Agglomeration process improves the rehydration time of powders (Gaiani et al., 2007). In furtherance, Kim et al. (2012) notified that the rehydration of the powder could be maximized by the adjustment of particle size (obtained by agglomeration) and water activity.

The *water activity* of powdered beverage has an importance in terms of deteriorations during the shelf life of the product. The reduced free water content indicates to reduced water activity and the value of this parameter lower than 0.3 regarded as microbiologically and chemically safe (Vardin and Yasar, 2012; Tontul and Topuz, 2017). The significant impact of the feeding material content to final water activity of the powder was reported by Ruiz-Gutiérrez et al. (2014). The studies on positive or negative effects of different carriers on water activity and the relation between temperature and carrier materials are available (Tontul and Topuz, 2017). Also in some studies, the increment in feed flow rate resulted in high water activity in spray-dried powder (Jangam and Thorat, 2010; Movahhed and Mohebbi, 2016).

In many cases, changes in one or two of these properties can substantially act on the reconstitution behavior of the powder. Brennan et al. (1990) reported that the change of the properties such as density, bulk density, or particle size can affect the appearance or handling characteristics of the powders as well.

In powdered drink production, the aim of all applications and optimizations is to form a stabile product. Also the points effected the stability of the powders (as the water sorption behavior, the glass transition, and the molecular mobility characteristics) should be taken into consideration (Franceschinis et al., 2014).

2.5 Types of Powdered Drinks

Beverage concentrates in liquid or powdered structure may include some ingredients such as sugars, colorants, flavors, or nutrients to form a preferable mix (Piorkowski and McClements, 2014).

Spray-dried dairy products have a large mass of consumption in daily diet. They can be classified as whole milk powder, skimmed milk powder, milk protein isolate, milk protein concentrate, whey protein isolate, whey protein concentrate, casein, and caseinates (Lagrange et al., 2015). These products can be consumed directly or as an input of other products like infant formula, sports dietary supplements, confectionary, snacks, soups, and sauces (Karam et al., 2013; Lagrange et al., 2015). The technology of dairy powders depends on pasteurization, separation, evaporation, and spray drying steps in general. All these thermal steps influence the microbial load (especially spore forming bacteria) of the dairy powders and so comprise the control points as well (McHugh et al., 2017). Checinska et al. (2015) indicated the species of the class *Bacilli* as a main contaminant in dairy powders. The potential species cause a problem by means of quality and hygiene should be manifested by identification and enumeration of all spore formers available in dairy powders (Pennacchia et al., 2014).

Powdered milk formulas are aimed to simulate the breast milk as far as possible by the modification of cow milk (Koletzko et al., 2008; MacLean et al., 2010). The first production step is the standardization of milk fat and protein to the desired amounts. Then, this milk is heated, concentrated, and spray dried (Kelly et al., 2009). These products fulfill nutritional recommendations and are particularly fortified with nutrients like polyunsaturated fatty acids (PUFAs) (Chen et al., 2008). In an attempt to protein-enriched food manufacturing, skimmed milk powders are preferred. The powdered milk formulas have a shelf life for 12–24 months when they are protected in hermetic packages at ambient temperature (Hedegaard and Skibsted, 2013). Plastic bottles, tinplate cans, multi-wall paper sacks, or glass jars are offered as a packaging material for spray-dried milk powders (Brown and Williams, 2003). The overall quality interrupts when the crystallization or recrystallization of lactose, oxidation, and migration of lipid or the Maillard reactions are occurred (Stapelfeldt et al., 1997).

Ratnaningrum et al. (2015) prepared instant ginger-milk drinks fortified with difructose anhydride III (5 g), skim milk (9.375 g), vegetable creamer (6.25 g), calcium lactate (0.385 g), and instant ginger (25 g) in varied amounts and developed the most favorable recipe under favor of given values in parenthetic.

Soymilk is a water extract of soybeans and characterized by high amounts of protein content. It is a popular ingredient due to nutritional value added and cost reducing effects today. When compared with breast milk and cow's milk, the protein, iron, unsaturated fatty acids, and niacin contents are higher while fat, carbohydrates, and calcium values are seemed to be low (Liu, 1997). Drying and powdering of soymilk not only improves the shelf life but also allows utilizing of this nutritional food in different forms by many manufacturers.

Transportation and storage of powdered soymilk becomes easier by drying. Spray drying of soymilk concentrates after ultrafiltration has been experienced in previous years (Ang et al., 1986). Jinapong et al. (2008) researched the characteristics of soymilk products carried out in ultrafiltration, spray drying, and fluidized-bed agglomeration steps. They determined the 10% (w/v) maltodextrin as the optimum binder type and concentration for soymilk production and this agglomerated powder had a low cohesiveness and good flowability. Wijeratne (1993) recommended to agglomerate the spray-dried soymilk powder to improve the wettability property of the product.

Dong et al. (2016) determined a decrement in serum cholesterol total cholesterol (TC), low-density lipoprotein cholesterol (LDLC), and non-high-density lipoprotein cholesterol (HDLC) levels of elderly Chinese adults by 9.3%, 11.4%, and 12.6%, respectively, at the end of 6 months by consuming soymilk powder enriched with phytosterol at a dosage of 2.0 g/d in 30 g soymilk powder.

Mango milk powder is manufactured for the utilization of surplus milk solids. Chauhan and Patil (2013) explained the process steps as follows: (a) mixing of mango pulp, milk, and sugar; (b) homogenization; (c) pasteurization; (d) spray drying of the mixture; and (e) dry blending.

Fruit and vegetable juice powders have further advances over the liquid counterparts such as handling and transportation easiness by reduced weight and volume and prolonged shelf life (Kha et al., 2010). They have a wide range of applications in the food and nutraceutical industries and used as an instant drink, ingredient of bakery products, or pharmaceutical tablets (Raharitsifa and Ratti, 2010). Maltodextrin is generally used as a carrier in fruit juice powder production to increase the glass transition temperature (Gibbs et al., 1999; Adhikari et al., 2004; Fazaeli et al., 2012a; Ferrari et al., 2012; Roustapour et al., 2012; Celli et al., 2015; Barbosa et al., 2016; Mishra et al., 2017).

Lee et al. (2017) produced mandarin beverage powder using 35% corn syrup and 135°C inlet temperature in spray drying. The taste and color of this product was preferred among different carriers (maltodextrin and corn syrup with different concentrations) and inlet temperatures ranged between 120°C and 165°C. Sarabandi et al. (2014) produced a grape syrup powder under the spray drying conditions of 150–170°C inlet air temperature and 4, 2, 1, 0.5 ratios of maltodextrin/grape syrup. According to the results, the highest inlet air temperature and maltodextrin ratios, the increased powder production yield was achieved regarding to the reduced stickiness. Quek et al. (2007) reported the similar effect of maltodextrin concentration on spray-dried watermelon powder production as seen in Figs. 2.6 and 2.7. Sarabandi et al. (2017) spray dried the sour cherry juice concentrate with different carriers and reported as high concentrations of whey protein concentrate in combination with maltodextrin and gum arabic severely reduced

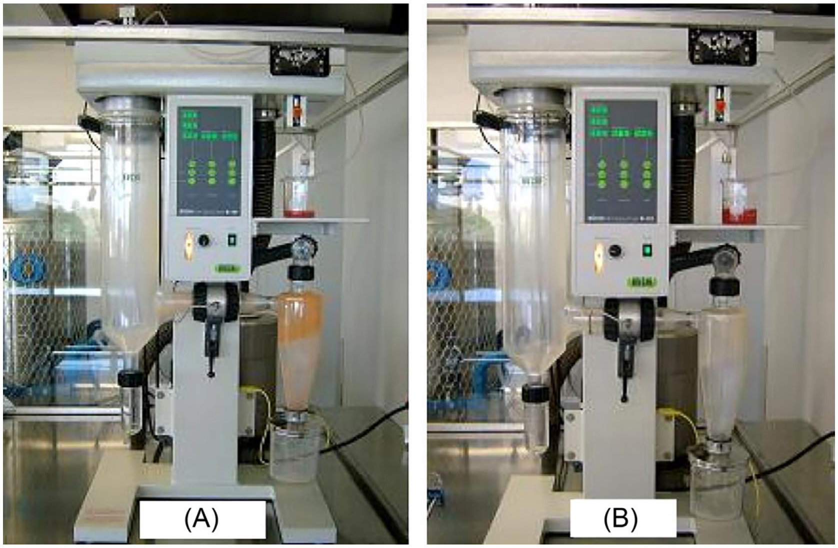

Fig. 2.6 The stickiness of spray dried watermelon powders with 3% (A) and 5% (B) maltodextrin.

Fig. 2.7 The product yield of spray dried watermelon powders with different maltodextrin concentrations.

the solubility and wettability of the powders. Yousefi et al. (2011) determined the lowest solubility in pomegranate juice powder dried by waxy starch carrier in contrast to maltodextrin and gum arabic. Watson et al. (2017) suggested the small amount addition of γ-cyclodextrin to maltodextrin during spray drying of pomegranate juice in terms of increased water holding capacity and better preservation of color. Whey protein isolate is also used in various encapsulated formulations owing to its film forming and stretching abilities (Rajam et al., 2012).

Cuevas-Glory et al. (2017) determined the suitable spray drying conditions for orange juice powder production as 156°C inlet air temperature and 20% maltodextrin concentration. Under these conditions, 81.5% ascorbic acid retention, 5.5% moisture content, and 78% volatiles retention were accomplished. Krishnan (2008) reported the best conditions for spray-dried strawberry juice powder production as 170°C temperature and 25% maltodextrin addition. Pereira et al. (2014) dried the probiotic cashew apple juice containing probiotic bacteria at 120°C inlet and 75°C outlet temperature with maltodextrin alone and gum arabic maltodextrin mix. The highest yield was achieved in production used only maltodextrin.

Bello et al. (2015) aimed for a process simulation of spray-dried pineapple juice powder production. This juice was signaled as the source of bioactive compound, bromelain, which has beneficial effects on health (Steffi et al., 2013). Optimization of powdered pineapple juice production and the final available moisture content is important in as much as its potential commercial value. Maltodextrin DE6 was used as a carrier material for powdered drink production of 25% of total solids. The simulation results were in agreement with experimental data at high inlet air temperatures, but became dissimilar at other air temperatures. In a similar manner, the researchers concluded that the only use of 15% maltodextrin without CMC was given the best results in terms of moisture content, enzyme activity, vitamin C content, and solubility of pineapple juice powder.

Fontes et al. (2014) revealed the optimum operating conditions for spray-dried prebiotic melon, orange, and pineapple juice powder productions as 180°C inlet air temperature, 30 L/min atomizer nozzle flow rate, 0.3 L/h feed flow rate, and 20% maltodextrin (m/m). In the circumstances, the rehydration time varied from 90 to 144 s and the hygroscopicity of the powder was changed between 5.17% and 7.48% in dry basis.

Movahhed and Mohebbi (2016) studied the suitability of carrot and celery juice mix powder with spray drier and optimized the drying conditions. They reported positive correlations between the inlet air temperature, hygroscopicity, powder particle size, and dissolution time. On the contrary, accelerated feed flow rate decreased the same properties. Nishad et al. (2017) investigated the drying parameters of spray-dried sugarcane juice powder. Different type and concentration of carriers such as maltodextrin, gum arabic, carrot fiber and liquid glucose, inlet and outlet temperatures, and feed concentrations were assayed in this research. As a conclusion, 30% maltodextrin is provided the best sensory properties and product yield.

Gurak et al. (2013) produced a grape juice powder by using a freeze drier after reverse osmosis application to 28.5 Brix and showed the positive effect of this sequential method on stability and shelf life of this highly phenolic drink. Akbas et al. (2017) encapsulated the wheat grass juice with freeze drier by using whey protein isolate and maltodextrin as coating materials and investigated the reconstitution properties besides antioxidant activity and phenolic stability of the powder. The gastric digestive resistance properties were found to be good in the samples treated with 1:10 coating ratio and 1:2 whey protein isolate: maltodextrin.

Boonnumma et al. (2014) emphasized the freeze-dried coconut water powder as a healthy nutritional drink material. But the exposure of coconut juice to air and warm processing temperatures destroys the nutrients and cause a loss in flavor. On account of these reasons, processing conditions were needed to be optimized. The production was carried out at the following stages: (a) pre-freeze step at −20°C for 3 h; (b) first drying period for 4 h at −20°C; (c) second drying period for 7 h at −10°C; (d) third period for 6 h at 0°C; and (e) heating up to 30°C. According to the results, vitamins, minerals, and other nutritional properties of freeze-dried coconut water powder were found to be similar to fresh one. The researchers also reported that approximately 64 kg of freeze-dried coconut water powder was obtained from 1 ton of coconut water.

Atiq-Ur-Rahman et al. (2013) prepared *Grewia asiatica* (phalsa) powder to enlarge the consumption period which is used as a popular summer drink indigenous to Pakistan. The results were indicated that powder had a nutritional value four times more than fresh phalsa fruit. The energizing and central nervous system (CNS) stimulant effect of this powdered beverage was seen in laboratory animals.

Powdered cocoa beverages are classified as instant foods which comprise of fine cocoa powder blended with sugar and/or milk powder. It is consumed either cold or warm after stirring (Shittu and Lawal, 2007; Belščak-Cvitanović et al., 2010; Ben Abdelaziz et al., 2014). The technology of cocoa powder production involves in cleaning of cocoa nibs, breaking and sifting, sterilization, alkalization, roasting, drying to desired fineness degrees, and chilling (Redgwell et al., 2003; Meursing, 2009).

The dissolving process of instant powders is broadly ordered as follows (Schubert, 1987):

- In the first step, fluid diffuses into the pore system before the particles sink below the fluid surface.
- In the second step, the particles disperse by low-energy stirring.
- Finally, the particles sink into solution. It means they are soluble in the liquid otherwise they remain suspended (Shittu and Lawal, 2007).

The addition of sugar to the cocoa powder beverage is preferred whenever the dispersibility property of singly cocoa is poor. Also, lecithin addition or alkalization is another improvement. The main instant properties of cocoa powder are based on color and flavor. The other attributes as bulk density, compressibility (compaction), flowability, particle size, and uniformity index are also used for definition of the instant behavior of powdered cocoa (Shittu and Lawal, 2007; Dhanalakshmi et al., 2011). These properties affect product storage, handling, processing, and transportation along with quality and consumer acceptance.

These beverages are usually composed of 80% sugar and 20% cocoa (Minifie, 1989). Ben Abdelaziz et al. (2014) researched the effects of sugar percentage (70–90%), type of sugar (sucrose or lactose), and sugar size (30–480 μm) to the rehydration characteristics of cocoa powders. The use of sugar with a large size and sucrose was achieved the better results on solubility and so rehydration. As similar, Shittu and Lawal (2007) and Belščak-Cvitanović et al. (2010) showed that sugar addition to cocoa powder increased the solubility and dispersibility of the mixes. Because the small particle size and so poor reconstitution, an improvement is required for this powdered beverage (Vu et al., 2003).

Cappuccino powders usually consist of dried soluble coffee, sugar, and spray-dried vegetable fat emulsified in skim milk with stabilizing sodium phosphate. Hoffmann (2000) reported a closer instant property for six commercial cappuccino powders. He notified that the color and foam level above the rehydrated drink was affected from the fat content and the diameter of fat globules.

Instant coffee is preferred by many people and has some beneficial effects when consumed in limits. Technologically, freeze-drying or spray-drying techniques are used for instant coffee production. The process steps and comparison of freeze drying and spray drying for instant coffee production are seen in Table 2.1 (Oliveira et al., 2009).

Chocolate drink powder is preferred by children or adults and may be used in cakes, candies and ice creams as well as flavoring the other beverages (Peixoto et al., 2012). Instant hot chocolate mainly consists of milk, cocoa, sugar, emulsifier, and small amount of flavors. The instant properties such as wettability and solubility of the powder play an important role for the consumer acceptance. Once for all, a good instantized beverage has neither floating particles on the surface nor sediment at the bottom of the cup after minimum stirring. For this reason, agglomeration helps to sort this problem. In accordance with this, Omobuwajo et al. (2000) notified that the main reason of agglomeration is the increment of the solubility capability of the chocolate drink powder. In as much as the high fat content, hydrophobic hydrocarbon groups and capillary structure of

Table 2.1 The Comparison of Freeze-Dried and Spray-Dried Coffee Production

Freeze-Dried Instant Coffee Production	Spray-Dried Instant Coffee Production
(a) Freezing of the concentrated coffee extract **(b)** Sifting of granules to form uniform sizes and sublimation in a vacuum chamber	**(a)** Atomization of concentrated coffee extract in a drying chamber (to 200–300°C air temperature) **(b)** Collection of dried samples
A little change in aroma is seen	A low density and good flowability is seen in the product. Aroma losses and caramel flavor is seen due to the higher process temperatures

cocoa powder, the wettability and so solubility property of this product required to be enhanced by agglomeration process. Aliakbarian et al. (2017) researched the impact of air flow rate and the concentration of maltodextrin on instantizing and physicochemical properties of spray-dried chocolate powder. The product had 74.2 ± 6.8% solubility and 58.7 ± 2.9% dispersibility under the drying conditions of 150°C inlet temperature, 3.5% concentration of maltodextrin, and 27 m^3/h air flow rate.

Salep is the raw material of instant salep beverage. It is obtained from salep tubers in whole or grounded form (Develi Işıklı et al., 2015). The tubers are collected at optimum harvest, dried, and then ground into powder (Tamer et al., 2006). Instant salep drink is preferred by many consumers particularly in winter related to its delicious taste and high glucomannan content (16%–55%) (Kagan et al., 2014). It is prepared by mixing of salep powder and milk with sugar, boiling, and serving with cinnamon sprinkled on top. Some companies produce ready-to-drink salep beverage composed of salep powder, milk powder, sugar, starch, and hydrocolloids. Besides drinking, the powder is also used as an ingredient of ice cream and serves as a both flavoring and thickening agent (Kayacıer and Dogan, 2006; Georgiadis et al., 2012).

Green tea powders are preferred for serving more nutrients to the consumers than the one prepared by extraction. The green tea powder is required to maintain its own characteristic sensory attributes and functional properties. The highest phenolic content and antioxidant capacity make the green tea powders more popular. This powder can also be used for green tea-flavored drinks (Park et al., 2001). Belščak-Cvitanović et al. (2015) indicated that use of gums as a carrier provides the smallest particle size, higher chlorophyll content, and dissolution in powdered green tea extract.

Instant tea powders are very popular in many countries and high stability of these products provides it to consume in a wide season and a mass. Also, it is extensively used in large quantity in various tea premixes (Pandey and Manimehalai, 2014). The original taste, aroma, and flavor can be maintained in conventionally brewed products (Ye et al., 2014). In a research, a novel technology to produce an instant black tea powder with high aroma content was investigated (Ye et al., 2014). Pulsed electrical field-assisted extraction method reduced tea cream and by this way, cold water solubility of instant tea powder was succeeded. In addition, freeze concentration technique was found effective in terms of retention of nutrients and aroma compounds and also prevention of microbial growth in powdered tea. Pandey and Manimehalai (2014) produced instant tea powder by spray drier under the optimum conditions of 200°C inlet air temperature and 20 mL/min feed flow rate. These parameters provided the maximum water removal yield and quality.

Powdered sports drinks are another type of drinking powders which are preferred by sports people. These powders take a place in the daily diet of the individuals and consumed after mixing with water or milk (Ford, 1999; Palmer, 2005). The isotonic property of this beverage depends upon the preciseness on following the instructions for use and electrolyte capacity changes with the structure of the water utilized (Palmer, 2005).

2.6 Nutritional Value of Powdered Drinks

The powdered drinks have long-term stability and the nutrients can be better preserved compared to liquid form. As much as their retarded deterioration rate related with the little amount of water in the powder and prevention of air ingress, the powdered drinks can be ideally fortified with nutrients, especially with vitamins (Palmer, 2005). Accordingly Krishnaiah et al. (2014) reported the positive impact of spray drying on fruit nutrients with the highest stability. Nevertheless, dehydrated products are especially susceptible to oxidative decomposition during drying and storage in air. Among them, the carotenoids are easily oxidized because of the many conjugated double bonds.

Ferrari et al. (2012) concluded that the use of maltodextrin in spray-drying process of blackberry powder gained the highest anthocyanin retention and antioxidant activity with better reconstitution properties. Mishra et al. (2015) determined a good nutritional quality and high total phenolic content for ready-to-serve amla-lemon-based powdered drink. The same researchers (2017) reported the adverse effect of high inlet temperature and maltodextrin level on total phenolic content of spray-dried hog plum juice powder. The lowest loses of total phenolic content and antioxidant activity were seen in powdered samples stored in refrigeration in this research. The color of powdered beverage reflects the color of the incorporated polyphenols (Sun-Waterhouse et al., 2013).

Castillo et al. (2014) determined the highest antioxidant activity in a drink containing the maximum dehydrated asai powder rate (15%) exclusive of 10% and 12% use. Lee et al. (2017) showed that the use of corn syrup as a carrier was more prevented the vitamin C degradation compared to maltodextrin use and higher loss of this nutrient in mandarin beverage powder occurred when inlet temperature and carrier agent concentration were increased.

Nambiar et al. (2017) reported the conditions for better antioxidant capacity and total phenolic content retention of tender coconut water powder produced by spray drying in the conditions of 100°C drying temperature, 10% maltodextrin, and 1.5% *Moringa oleifera* gum concentration (as carriers). Movahhed and Mohebbi (2016) revealed the higher inlet air temperature the less β-carotene content of spray-dried carrot-celery juice powder. Also, the large particle size as a result of higher feed flow rate caused to gain more β-carotene retention in this research. The inverse relationship of inlet temperature on β-carotene and lycopene was also presented in the research of Quek et al. (2007) on watermelon juice powder.

Ersus and Yurdagel (2007) resulted that the higher inlet or outlet air temperatures are the main reason of anthocyanin loss during spray drying. Phisut (2012) emphasized the same effect related with the high sensitivity of these pigments to high temperatures. Mahdavi et al. (2014) notified that spray drying accounts for 80%–90% of encapsulated anthocyanins.

A ready-to-drink powder was obtained using *Antidesma ghaesembilla Gaertn* (mamao) fruits in Thailand by Sithisarn et al. (2015). The extract of mamao ripe fruits was developed as a readily dissolving drink powder by a wet granulation method. The powder manifested a preferable in vitro antioxidant effect and maintained to contain high amounts of total phenolic and total anthocyanin contents.

Ferreira et al. (2015) investigated the tooth enamel dissolution effect of powdered juice consumption in virtue of increased preference of these products. They emphasized that some artificial powdered juices enriched with vitamins or other components attract the people, but low pH values of these beverages show erosive impacts on teeth. Despite this knowledge, no enamel dissolution was detected even so low pH and so high acidity value of artificial powdered orange juice.

2.7 Packaging and Shelf life of Powdered Drinks

Powdered drinks are sensitive to moisture and the slight increase in moisture content of the product during storage makes it sticky. For this reason, dried products have to be stored in a moisture proof packages and they should be kept below the glass transition temperature (Tontul and Topuz, 2017).

In a research, the effect of packaging material between tin can, metalized polyesters, high density polystyrene, and four layer laminates on properties of mango milk powder was investigated and tin container was found to be the optimum material in terms of free flowability under controlled storage conditions. The shelf life of powders stored at 30 ± 1°C and 5 ± 1°C in tin containers was notified as 10 and 11 months, respectively (Chauhan and Patil, 2013). Page et al. (2003) reported the circular cans with lever lids and diaphragm seals as the most available package for powdered beverages such as dried milk or instant coffee. Kelly et al. (2009) proposed to package the dairy powders in oxygen barrier materials as well.

Cesa et al. (2015) monitored the malondialdehyde (MDA-autoxidation product) content of infant milk formulas enriched with PUFAs during the storage period. While the minimum MDA level was found in the samples stored at 20°C in sealed packs, the highest values were detected in samples stored at 28°C for 3 weeks. Mishra et al. (2015) obtained that the storage in room temperature after drying out with highest carrier level and temperature conditions caused the highest quality losses in amla-lemon-based ready-to-serve dry mix. Gurak et al. (2013) reported the phenolic stability of freeze-dried grape juice powder for 120 days at room temperature in dark containers.

The ambient temperature and relative humidity below 43% or the freezer at relative humidity below 60% was indicated to maintain catechin stability in green tea powder by Li et al. (2011). In the study of Zea et al. (2013), the 10% maltodextrin used and freeze-dried pitaya and guava fruit powders were compacted and showed a good microbial stability for a month long storage at room temperature.

Pereira et al. (2014) determined the microbial viability of prebiotic *Lactobacillus casei* NRRL B-442 in spray-dried cashew apple juice powder as 28 days at 25°C, while the vitality of powder stored at 4°C was lasted in 35 days. Barbosa et al. (2016) produced an orange juice powder incorporating probiotic bacteria and investigated the growth of two lactic acid bacteria during the storage period. Especially the addition of lactose to the culture media during spray drying of juice and storage of powder at 4°C was provided at least 12 months shelf life with probiotic property in a package protected from daylight exposure.

2.8 Sensory Evaluation of Powdered Drinks

As well as determining the optimum processing conditions of powdered drinks, to achieve the success on sensory acceptance has also a particular importance. There are some researches on sensory evaluation of powdered beverages. Varela et al. (2010) emphasized the forefront property of brand perception rather than the sensorial quality in overall hedonic perception of powdered drinks.

Movahhed and Mohebbi (2016) indicated that when the carrier agent (maltodextrin) concentration in spray drying is increased, lightness color value is also increased as a result of the preservation of encapsulated pigments. Abadio et al. (2004) and Ferrari et al. (2012) concluded the same results in blackberry powder and pineapple powder, respectively. Nevertheless, higher inlet temperature caused darkening reactions and pigment degradation, thus the lightness was reduced in prebiotic orange juice (Fontes et al., 2014). Lee et al. (2017) reported when the highest maltodextrin and inlet temperature values were used in spray-dried mandarin beverage powder, the less overall acceptability was seen as well. Santhalakshmy et al. (2015) concluded that the higher inlet temperature resulted in the higher moisture content, hygroscopicity, big particles, and shrinkage in powdered jamun fruit juice. The color of the product (brighter and less purple) was mainly affected by increased inlet temperatures in this production. Abadio et al. (2004) reported similar effect of inlet temperature and additives on color of the product.

Tontul and Topuz (2017) summarized the main causes of color alteration as the carrier material, their higher concentration, and caramelization reactions of sugars at high drying temperatures. Saikia et al. (2014) determined the highest color change of spray-dried and reconstituted Khasi mandarin among four types of fruit juices. Total phenolic and total flavonoid contents were substantially decreased associated with color alteration. The nitrogen flushing before cold storage provided color and total phenolic retention of powdered ready-to-serve lemon-amla drink. This mixture had accordingly good scores on sensory assessment (Mishra et al., 2015).

Pourahmad and Khorramzadeh (2015) formulized a drinking powder composed of soymilk powder with different sweeteners (stevia, erythritol, and isomalt) and as a result the ratio of 80% and 90% of stevia were found to be preferable by the panelists. Park et al. (2001) formulated a mixture for improving the dispersibility of green tea powder and optimized the ratio of the final product as 1:1.5 (green tea powder:glucose). The sensory quality and the microstructure of this mixture were chosen to be the best. Zea et al. (2013) manufactured the mix drink powder tablets consist of freeze-dried pitaya and guava powders with addition of 10% maltodextrin. The panelists mostly preferred the mixture containing 10% sugar. The poor dissolution problem of powder tablets was achieved by the addition of an effervescent agent.

Mamede et al. (2015) prepared mix beverages by using powdered cajá-flavored drink with other flavored commercial drink powders including mango, strawberry, jabuticaba, ananas, and cashew flavors.

The strawberry flavored mix drink was the best preferred sample related with its appearance and flavor.

Cardinal et al. (2015) researched the acceptability and perception of 550 consumers on fruit flavored powdered juices (apple, cherry, grape, grapefruit, orange, and pear) by check all that apply (CATA) responses and sensory acceptability. While cherry and grape juices were linked to artificial flavor and color, pear, and orange juices were associated to have natural flavor and good color. Ares et al. (2011) reported the advantages of CATA response such an easiness of application and less evaluation time requirement for consumers.

Secilmis et al. (2015) investigated the sensory properties of a novel powdered herbal coffee (*Pistacia terebinthus* fruit coffee). The roasting methods of fruits (by microwave and pan roasting and each of them together) before powdering were compared among themselves. According to the sensorial evaluation, powdered coffee brews prepared from both roasting processes were preferred to unroasted ones.

2.9 Conclusion

Powdered drinks are the dried form of beverages produced with the aim of shelf life prolongation with the highest quality. The handling, transportation, and preparing easiness are the other advantages of these products. The most common techniques used for powdering are spray and freeze drying, but spray drying is found to be more commercial, profitable, and faster. All operating parameters (air flow, temperature, feed flow rate, atomization pressure, etc.) play a crucial role for providing an instant character to beverages. The type and amount of carriers are the other important key factors for the adjustment of physicochemical properties of powders. Agglomeration process also improves the instant properties of drinking powders by generating larger and permanent aggregates. Besides the instant properties as wettability, bulk density, dispersibility, solubility, and compressibility; the dissolution time, hygroscopicity, compressibility, or flowability characters determine the quality and consumer preference of powdered products.

In this chapter, the technology of powdered drink production, influences of powdering on beverage nutrients, and sensorial properties along with reconstitutional characteristics were reviewed. As general, the results of the studies showed that the processing parameters lead to characterize the product quality, yield, and instant structure. There is a very limited study concerned with nutritional quality of powdered drinks. The changes of vitamins, carotenoids, and anthocyanins contents and so antioxidant effects were only reported in the studies. Thus, more research on nutritional property, bioaccessibility, and consumption limitations of drinking powders are necessary.

References

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

Adhikari, B., Howes, T., Bjandari, B.R., Troung, V., 2004. Effect of addition of maltodextrin on drying kinetics and stickiness of sugar and acid-rich foods during convective drying experiments and modelling. J. Food Eng. 62, 53–68.

Akbas, E., Kilercioglu, M., Onder, O.N., Koker, A., Soyler, B., Oztop, M.H., 2017. Wheatgrass juice to wheat grass powder: encapsulation, physical and chemical characterization. J. Funct. Foods 28, 19–27.

Aliakbarian, B., Casazza, A.A., Nani, A., Perego, P., 2017. Production of chocolate powdered beverage with enhanced instant properties. Chem. Eng. Trans. 57, 6.

Ang, H.G., Kwik, W.L., Lee, C.K., Theng, C.Y., 1986. Ultrafiltration studies of foods: Part 1—the removal of undesirable components in soymilk and the effects on the quality of the spray-dried powder. Food Chem. 20, 183–199.

Antal, T., Figiel, A., Kerekes, B., Sikolya, L., 2011. Effect of drying methods on the quality of the essential oil of spearmint leaves (*Mentha spicata* L.). Dry. Technol. 29 (15), 1836–1844.

Antúnez, L., Vidal, L., de Saldamando, L., Giménez, A., Ares, G., 2017. Comparison of consumer-based methodologies for sensory characterization: case study with four sample sets of powdered drinks. Food Qual. Prefer. 56, 149–163.

Ares, G., Varela, P., Rado, G., Gime'nez, A., 2011. Are consumer profiling techniques equivalent for some product categories? The case of orange-flavoured powdered drinks. Int. J. Food Sci. Technol. 46, 1600–1608.

Argyropoulos, D., Heindl, A., Muller, J., 2011. Assessment of convection, hot-air combined with microwave-vacuum and freeze-drying methods for mushrooms with regard to product quality. Int. J. Food Sci. Technol. 46 (2), 333–342.

Atiq-Ur-Rahman, F.N., Imran, H., Saleem, N., Sohail, T., Rauf, M., Yaqeen, Z., Syed, S., 2013. Nutritional and toxicological evaluation of *Grewia asiatica* (Phalsa) powder used as a summer drink. J. Chem. Soc. Pak. 35 (2), 320–323.

Avila, E.L., Rodríguez, M.C., Velásquez, H.J.C., 2015. Influence of maltodextrin and spray drying process conditions on sugarcane juice powder quality. Rev. Facult. Nac. Agron. Medellín 68 (1), 7509–7520.

Bae, K.E., Lee, S.J., 2008. Microencapsulation of avocado oil by spray drying using whey protein and maltodextrin. J. Microencapsul. 25 (8), 549–560.

Bansal, V., Sharma, H.K., Nanda, V., 2015. Effect of honey addition on flowability and solubility of spray dried low fat milk powder. Int. Proc. Chem. Biol. Environ. Eng. 86, 22–27.

Barbosa, J., Borges, S., Teixeira, P., 2016. Effect of different conditions of growth and storage on the cell counts of two lactic acid bacteria after spray drying in orange juice. Beverages 2, 8. https://doi.org/10.3390/beverages2020008.

Barbosa-Cánovas, G.V., Ortega-Rivas, E., Juliano, P., Yan, H., 2005. Food Powders—Physical Properties, Processing, and Functionality. Kluwer Academic/Plenum Publishers, New York.

Barletta, B.J., Barbosa-Cánovas, G.V., 1993. An attrition index to assess fine formation and particle size reduction in tapped agglomerated food powders. Powder Technol. 77, 89–93.

Bazaria, B., Kumar, P., 2017. Effect of dextrose equivalency of maltodextrin together with Arabic gum on properties of encapsulated beetroot juice. J. Food Meas. Charact. 11, 156–163.

Bello, A.A., Ahmad, A., Ripin, A., 2015. Process simulation of pineapple juice spray drying. Jurnal Teknologi. 75 (6), 27–34.

Belščak-Cvitanović, A., Benković, M., Draženka, K., Bauman, I., Horžić, D., Dujmić, F., Matijašec, M., 2010. Physical properties and bioactive constituents of powdered mixtures and drinks prepared with cocoa and various sweeteners. J. Agric. Food Chem. 58, 7187–7195.

Belščak-Cvitanović, A., Lević, S., Kalušević, A., Špoljarić, I., Đorđević, V., Komes, D., Mršić, G., Nedović, V., 2015. Efficiency assessment of natural biopolymers as encapsulants of green tea (*Camellia sinensis* L.) bioactive compounds by spray drying. Food Bioprocess Technol. 8, 2444–2460.

Ben Abdelaziz, I., Sahli, A., Bornaz, S., Scher, J., Gaiani, C., 2014. Dynamic method to characterize rehydration of powdered cocoa beverage: influence of sugar nature, quantity and size. Powder Technol. 264, 184–189.

Benković, M., Tušek, A.J., Belščak-Cvitanović, A., Lenart, A., Domian, E., Komes, D., Bauman, I., 2015. Artificial neural network modelling of changes in physical and chemical properties of cocoa powder mixtures during agglomeration. LWT-Food Sci. Technol. 64, 140–148.

Berg, S., Bretz, M., Hubbermann, E.M., Schwarz, K., 2012. Influence of different pectins on powder characteristics of microencapsulated anthocyanin and their impact on drug retention of shellac coated granulate. J. Food Eng. 108, 158–165.

Bhandari, B., Hartel, R., 2005. Phase transitions during food powder production and powder stability. In: Onwulata, C., Konstance, R. (Eds.), Encapsulated and Food Powder. Marcel Dekker, New York, pp. 261–292.

Bhandari, B.R., Senoussi, A., Dumoulin, E.D., Lebert, A., 1993. Spray drying of concentrated fruit juices. Dry. Technol. 11 (5), 1081–1092.

Bhandari, B.R., Datta, N., Howes, T., 1997. Problems associated with spray drying of sugar-rich foods. Dry. Technol. 15, 671–684.

Bicudo, M.O.P., Jó, J., Oliveira, G.A., Chaimsohn, F.P., Sierakowski, M.R., Freitas, R.A., Ribani, R.H., 2015. Microencapsulation of juçara (*Euterpe edulis* M.) pulp by spray drying using different carriers and drying temperatures. Dry. Technol. 33, 153–161.

Bindschaedler, C., 1999. Liophilization process validation. In: Rey, L., May, J.C. (Eds.), Freeze Drying/Lyophilization of Pharmaceutical and Biological Products. Marcel Dekker Inc., New York, pp. 373–408.

Boonnumma, S., Chaisawadi, S., Suwanyuen, S., 2014. Freeze-dried coconut water powder processing for natural health drink. Acta Hortic. 1023, 91–94.

Brennan, J.G., Butters, J.R., Cowell, N.D., 1990. Dehydration. In: In: Food Engineering Operations. third ed.. Elsevier Science Publishers Ltd., England, pp. 371–415.

Brown, H., Williams, J., 2003. Packaged product quality and shelf life. In: Coles, R., McDowell, D., Kırwan, M.J. (Eds.), Food Packaging Technology. Blackwell Publishing Ltd., London, pp. 65–95.

Cardinal, P., Zamora, M.C., Chambers, E., Barrachina, A.C., Hough, G., 2015. Convenience sampling for acceptability and CATA measurements may provide inaccurate results: a case study with fruit-flavored powdered beverages tested in Argentina, Spain and U.S.A. J. Sens. Stud. 30, 295–304.

Castillo, Y.M., Lares, M., Hernández, M.S., 2014. Formulation and evaluation of a powdered drink with antioxidant properties made from Asai fruit (*Euterpe precatoria* Mart.) Proc. IIIrd Int. Conf. on Postharvest and Quality Management of Horticultural Products of Interest for Tropical Regions Eds.: Mohammed, M., Francis, J.A. Acta Hort. 1047, 263-268.

Ceballos, A.M., Giraldo, G.I., Orrego, C.E., 2012. Effect of freezing rate on quality parameters of freeze dried soursop fruit pulp. J. Food Eng. 111, 36–365.

Celli, G.B., Ghanem, A., Brooks, M.S.L., 2015. Bioactive encapsulated powders for functional foods-a review of methods and current limitations. Food Bioprocess Technol. 8, 1825–1837.

Cesa, S., Casadei, M.A., Cerreto, F., Paolicelli, P., 2015. Infant milk formulas: effect of storage conditions on the stability of powdered products towards autoxidation. Foods 4, 487–500.

Chauhan, A.K., Patil, V., 2013. Effect of packaging material on storage ability of mango milk powder and the quality of reconstituted mango milk drink. Powder Technol. 239, 86–93.

Checinska, A., Paszczynski, A., Burbank, M., 2015. *Bacillus* and otherspore- forming genera:variations in responses and mechanisms for survival. Annu. Rev. Food Sci. Technol. 6, 351–369.

Chen, P.C., Yeh, Y.N., Lee, T.A., Chow, C.F., 2008. The effect of different iron compounds and vitamins fortification on iron bioavailability in reconstituted milk with different fat levels during in vitro digestion. Taiwanese J. Agr. Chem. Food Sci. 46, 96–102.

Coronel-Aguilera, C.P., Martín-González, M.F.S., 2015. Encapsulation of spray dried β-carotene emulsion by fluidized bed coating technology. LWT-Food Sci. Technol. 62, 187–193.

Cuevas-Glory, L., Bringas-Lantigua, M., Sauri-Duch, E., Sosa-Moguel, O., Pino, J.A., Loría-Sunsa, H., 2017. Spray drying and process optimization of sour orange juice. Acta Aliment. 46 (1), 17–26.

Cuq, B., Rondet, E., Abecassis, J., 2011. Food powders engineering, between knowhow and science: constraints, stakes and opportunities. Powder Technol. 208, 244–251.

Cynthia, S., Bosco, J.D., Bhol, S., 2015. Physical and structural properties of spray dried tamarind (*Tamarindus indica* L.) pulp extract powder with encapsulating hydrocolloids. Int. J. Food Prop. 18, 1793–1800.

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

Descamps, N., Palzer, S., Roos, Y.H., Fitzpatrick, J.J., 2013. Glass transition and flowability/caking behaviour of maltodextrin DE 21. J. Food Eng. 119, 809–813.

Develi Işıklı, N., Dönmez, M.N., Kozan, N., Karababa, E., 2015. Rheological properties of salep powder-milk mixture. J. Food Sci. Technol. 52 (10), 6556–6564.

Dewettinck, K., Huyghebaert, A., 1998. Top-spray fluidized bed coating: Effect of process variables on coating efficiency. Lebensm Wiss. Technol. 31, 568–575.

Dewettinck, K., Huyghebaert, A., 1999. Fluidized bed coating in food technology. Trends Food Sci. Technol. 10, 163–168.

Dhanalakshmi, K., Ghosal, S., Bhattacharya, S., 2011. Agglomeration of food powder and applications. Crit. Rev. Food Sci. 51, 432–441.

Dong, S., Zhang, R., Ji, Y.C., Hao, J.Y., Ma, W.W., Chen, X.D., Xiao, R., Yu, H.L., 2016. Soy milk powder supplemented with phytosterol esters reduced serum cholesterol level in hypercholesterolemia independently of lipoprotein E genotype: a random clinical placebo-controlled trial. Nutr. Res. 36, 879–884.

Drusch, S., Serfert, Y., Heuvel, A.V.D., Schwartz, K., 2006. Physicochemical characterization and oxidative stability of fish oil encapsulated in an amorphous matrix containing trehalose. Food Res. Int. 39, 807–815.

Du, J., Ge, Z.Z., Xu, Z., Zou, B., Zhang, Y., Li, C.M., 2014. Comparison of the efficiency of five different drying carriers on the spray drying of persimmon pulp powders. Dry. Technol. 32, 1157–1166.

Dupas, J., Forny, L., Ramaioli, M., 2015. Powder wettability at a static air–water interface. J. Colloid Interface Sci. 448, 51–56.

Eichler, K., 1996. Lipid coating in the food industries. Food Technol. Europe 3, 122–126.

Ersus, S., Yurdagel, U., 2007. Microencapsulation of anthocyanin pigments of black carrot (*Daucus carota* L.) by spray drier. J. Food Eng. 80, 805–812.

Ertekin, F., 2015. Kurutma, in: Singh, R.P, Heldman, D.R./Baysal, T., İçier, F. (Eds.), Introduction to Food Engineering, 5th ed, Nobel Akademik Yayıncılık Eğitim Danışmanlık Tic. Ltd. Şti., Ankara, pp. 675–710.

Etti, C.J., Yusof, Y.A., Chin, N.L., Mohd Tahir, S., 2016. Effects of formulation on flowability of selected herbal powders using compendial methods and powder flow analyser. Int. Food Res. J. 23, 225–230.

Ezhilarasi, P.N., Karthik, P., Chhanwal, N., Anandharamakrishnan, C., 2013. Nanoencapsulation techniques for food bioactive components: a review. Food Bioprocess Technol. 6, 628–647.

Fabra, M.J., Talens, P., Moraga, G., Martinez-Navarrete, N., 2009. Sorption isotherm and state diagram of grapefruit as a tool to improve product processing and stability. J. Food Eng. 93, 52–58.

Fang, Z., Bhandari, B., 2012. Comparing the efficiency of protein and maltodextrin on spray drying of bayberry juice. Food Res. Int. 48, 478–483.

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

Fazaeli, M., Emam-Djomeh, Z., Kalbasi-Ashtari, A., Omid, M., 2012b. Effect of process conditions and carrier concentration for improving drying yield and other quality attributes of spray dried black mulberry (*Morus nigra*) juice. Int. J. Food Eng. 8, 1–20.

Fernandes, R.V., Marques, G.R., Borges, S.V., Botrel, D.A., 2014. Effect of solids content and oil load on the microencapsulation process of rosemary essential oil. Ind. Crop. Prod. 58, 173–181.

Ferreira, S.S., Cruz, D.P., Youssef, M.N., Aoki, I.V., Hernandez, R.P.B., Sobral, M.A.P., 2015. The effect of powdered juice on human dental enamel dissolution. Clin. Lab. Res. Den. 21 (1), 58–64.

Ferrari, C.C., Germer, S.P.M., De Aguirre, J.M., 2012. Effects of spray-drying conditions on the physicochemical properties of blackberry powder. Dry. Technol. 30, 154–163.

Fitzpatrick, J.J., 2007a. Particle properties and the design of solid food particle processing operations. Food Bioprod. Process. 85, 308–314.

Fitzpatrick, J.J., 2007b. Effect of composition and storage conditions on the flowability of dairy powders. Int. Dairy J. 17, 383–392.

Fontes, C.P.M.L., Silva, J.L.A., Sampaio-Neta, N.A., da Costa, J.M.C., Rodrigues, S., 2014. Dehydration of prebiotic fruit drinks by spray drying: operating conditions and powder characterization. Food Bioprocess Technol. 7, 2942–2950.

Ford, M.A., 1999. The formulation of sports drinks. In: Ashurst, P.R. (Ed.), Production and Packaging of Non-Carbonated Fruit Juices and Fruit Beverages. Springer Science+Business Media, New York, pp. 310–331.

Franceschinis, L., Salvatori, D.M., Sosa, N., Schebor, C., 2014. Physical and functional properties of blackberry freeze- and spray-dried powders. Dry. Technol. 32, 197–207.

Freudig, B., Hogekamp, S., Schubert, H., 1999. Dispersion of powders in liquids in a stirred vessel. In: Górak, A., Stankiewicz, A., Coppens, M.O. (Eds.), Chemical Engineering and Processing: Process Intensification. 38(4–6), pp. 525–532.

Gaiani, C., Schuck, P., Scher, J., Desobry, S., Banon, S., 2007. Dairy powder rehydration: influence of protein state, incorporation mode, and agglomeration. J. Dairy Sci. 90 (2), 570–581.

Georgiadis, N., Ritzoulis, C., Charchari, E., Koukiotis, C., Tsioptsias, C., Vasiliadou, C., 2012. Isolation, characterization and emulsion stabilizing properties of polysaccharides form orchid roots (salep). Food Hydrocoll. 28, 68–74.

Gibbs, B.F., Kermasha, S., Alli, I., Mulligan, C.N., 1999. Encapsulation in the food industry: a review. Int. J. Food Sci. Nutr. 50, 213–224.

Gong, Z., Zhang, M., Mujumdar, A.S., Sun, J., 2008. Spray drying and agglomeration of instant bayberry powder. Dry. Technol. 26, 116–121.

Goula, A.M., Adamopoulos, K.G., 2003. Spray drying performance of a laboratory spray dryer for tomato powder preparation. Dry. Technol. 21, 1273–1289.

Goula, A.M., Adamopoulos, K.G., 2010. A new technique for spray drying orange juice concentrate. 11, 342–351.

Grabowski, J., Truong, V.D., Daubert, C., 2006. Spray-drying of amylase hydrolyzed sweetpotato puree and physicochemical properties of powder. J. Food Sci. 71, 209–217.

Gurak, P.D., Cabral, L.M.C., Rocha-Leão, M.H., 2013. Production of grape juice powder obtained by freezedrying after concentration by reverse osmosis. Braz. Arch. Biol. Technol. 56 (6), 1011–1017.

Hall, C.W., 1996. Expanding opportunities in drying research and development. Dry. Technol. 14, 1419–1427.

Hedegaard, R.V., Skibsted, L.H., 2013. Shelf-life of food powders. In: Bhandari, B., Bansal, N., Zhang, M., Schuck, P. (Eds.), Handbook of Food Powders Processes and Properties. Woodhead Publishing, Oxford, pp. 409–434.

Hla, P.K., Hogekamp, S., 1999. Wetting behaviour of instantized cocoa beverage powders. Int. J. Food Sci. Technol. 34, 335–342.

Hoffmann, W., 2000. Characterization of cappuccino powders. Kiel. Milchwirtsch. Forschungsber. 52 (2), 165–174.

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

Horszwald, A., Julien, H., Andlauer, W., 2013. Characterisation of Aronia powders obtained by different drying processes. Food Chem. 141 (3), 2858–2863.

Hottot, A., Andrieu, J., Vessot, S., 2007. Sublimation kinetics during freeze-drying of pharmaceutical protein formulation. Dry. Technol. 25 (5), 753–758.

Jan, S., Rafiq, S.I., Saxena, D.C., 2015. In: Effect of physical properties on flow ability of commercial rice flour/powder for effective bulk handling. International Journal of Computer Applications (0975-8887). International Conference on Advancements in Engineering and Technology (ICAET 2015), pp. 5.

Jangam, S.V., Thorat, B.N., 2010. Optimization of spray drying of ginger extract. Dry. Technol. 28, 1426–1434.

Jayasundera, M., Adhikari, B., Aldred, P., Ghandi, A., 2009. Surface modification of spray dried food and emulsion powders with surface-active proteins: a review. J. Food Eng. 93, 266–277.

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.

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.

Jittanit, W., Niti-Att, S., Techanuntachikul, O., 2010. Study of spray drying of pineapple juice using maltodextrin as an adjunct. Chiang Mai J. Sci. 37, 498–506.

Kagan, D.A., Boyacioglu, M.H., Boyacioglu, D., 2014. Effects of temperature, shear rate and processing on the rheological properties of salep drink. Ital. J. Food Sci. 26, 268–274.

Karaca, C.A., Guzel, O., Ak, M.M., 2016. Effects of processing conditions and formulation on spray drying of sour cherry juice concentrate. J. Sci. Food Agric. 96, 449–455.

Karam, M.C., Gaiani, C., Hosri, C., Burgain, J., Scher, J., 2013. Effect of dairy powders fortification on yogurt textural and sensorial properties: a review. J. Dairy Res. 80, 400–409.

Kayacıer, A., Dogan, M., 2006. Rheological properties of some gums-salep mixed solutions. J. Food Eng. 72, 261–265.

Kelly, P., Woonton, B.W., Smithers, G.W., 2009. Improving the sensory quality, shelf-life and functionality of milk. In: Paquin, P. (Ed.), Functional and Speciality Beverage Technology. Series in Food Science, Technology and Nutrition, Woodhead Publishing, Cambridge, pp. 170–231.

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

Kim, S.H., Choi, Y.J., Lee, H., Lee, S.H., Ahn, J.B., Noh, B.S., Min, S.C., 2012. Physicochemical properties of jujube powder from air, vacuum, and freeze drying and their correlations. J. Korean Soc. Appl. Biol. Chem. 55, 271–279.

Kingwatee, N., Apichartsrangkoon, A., Chaikham, P., Worametrachanon, S., Techarung, J., Pankasemsuk, T., 2015. Spray drying *Lactobacillus casei* 01 in lychee juice varied carrier materials. LWT-Food Sci. Technol. 62, 847–853.

Knight, P.C., 2001. Structuring agglomerated products for improved performance. Powder Technol. 119, 14–25.

Koletzko, B., Lien, E., Agostoni, C., Boehles, H., Campoy, C., Cetin, I., Decsi, T., Dudenhausen, J.W., Dupont, C., Forsyth, S., 2008. The roles of long-chain polyunsaturated fatty acids in pregnancy, lactation and infancy: Review of current knowledge and consensus recommendations. J. Perinat. Med. 36, 5–14.

Krishnan, J.R., 2008. Development of Spray Dried Strawberry Juice Powder: Degree of Bachelor Engineering in Chemical Engineering. Faculty of Chemical & Natural Resources Engineering Universiti Malaysia Pahang, Malaysia, p. 25. Undergraduates Project Papers.

Krishnaiah, D., Nithyanandam, R., Sarbatly, R., 2014. A critical review on the spray drying of fruit extract: effect of additives on physicochemical properties. Crit. Rev. Food Sci. Nutr. 54, 449–473.

Krokida, M., Maroulis, Z., 2000. Quality changes during drying of food materials. In: Mujumdar, A.S. (Ed.), Drying Technology in Agriculture and Food Sciences. Science Publishers, Inc., Enfield, NH, pp. 61–106.

Lagrange, V., Whitsitt, D., Burris, C., 2015. Global market for dairy proteins. J. Food Sci. 80, 16–22.

Larossa, A.P.Q., Cadaval Jr., K.D.S., Pinto, L.A.A., 2015. Influence of drying methods on the characteristics of a vegetable paste formulated by linear programming maximizing antioxidant activity. LWT-Food Sci. Technol. 60 (1), 178–185.

Lee, K., Wu, T., Siow, L., 2013. Spray drying of red (*Hylocereus polyrhizus*) and white (*Hylocereus undatus*) dragon fruit juices: physicochemical and antioxidant properties of the powder. Int. J. Food Sci. Technol. 48, 2391–2399.

Lee, K.C., Yoon, Y.S., Li, F.Z., Eun, J.B., 2017. Effects of inlet air temperature and concentration of carrier agents on physicochemical properties, sensory evaluation of spray-dried mandarin (*Citrus unshiu*) beverage powder. Appl. Biol. Chem. 60 (1), 33–40.

Li, X., Anton, N., Arpagaus, C., Belleteix, F., Vandamme, T.F., 2010. Nanoparticles by spray drying using innovative new technology: the Büchi nano spray dryer B-90. J. Control. Release 147, 304–310.

Li, N., Taylor, L.S., Mauer, L.J., 2011. Degradation kinetics of Catechins in green tea powder: effects of temperature and relative humidity. J. Agric. Food Chem. 59, 6082–6090.

Litvin, S., Mannheim, C.H., Miltz, J., 1998. Dehydration of carrots by a combination of freeze drying, microwave heating and air or vacuum drying. J. Food Eng. 36 (1), 103–111.

Liu, K.S., 1997. Soybeans: Chemistry, Technology, and Utilization. Chapman & Hall, New York, p. 532.

Luca, A., Cilek, B., Hasirci, V., Sahin, S., Sumnu, G., 2014. Storage and baking stability of encapsulated sour cherry phenolic compounds prepared from micro- and nano-suspensions. Food Bioprocess Technol. 7, 204–211.

MacLean, W.C., Van Dael, P., Clemens, R., Davies, J., Underwood, E., O'Risky, L., Rooney, D., Schrijver, J., 2010. Upper level of nutrients in infant formulas: comparison of analytical data with the revised Codex infant formula standard. J. Food Compos. Anal. 23, 44–53.

Mahdavi, S.A., Jafari, S.M., Ghorbani, M., Assadpoor, E., 2014. Spray drying microencapsulation of anthocyanins by natural biopolymers: a review. Dry. Technol. 32, 509–518.

Mamede, M.E.O., Kalschne, D.L., Santos, A.P.C., Benassi, M.T., 2015. Cajá-flavored drinks: a proposal for mixed flavor beverages and a study of the consumer profile. Food Sci. Technol, Campinas 35 (1), 143–149.

Marques, L.G., Silveira, A.M., Freire, J.T., 2006. Freeze-drying characteristics of tropical fruits. Dry. Technol. 24 (4), 457–463.

Marques, L.G., Prado, M.M., Freire, J.T., 2009. Rehydration characteristics of freeze-dried tropical fruits. LWT-Food Sci. Technol. 42, 1232–1237.

Masters, K., 2002. Spray drying fundamentals, In: Spray Drying in Practice. SprayDryConsult International ApS, Charlottenlund, Denmark, pp. 19–125.

McHugh, A.J., Feehily, C., Hill, C., Cotter, P.D., 2017. Detection and enumeration of spore-forming bacteria in powdered dairy products. Front. Microbiol. 8, 109.

Meursing, E.H., 2009. Dezaan Cocoa and Chocolate Manual, 40th ed. ADM Cocoa International, Koog aan de Zaan.

Minifie, B.W., 1989. Chocolate, Cocoa and Confectionery, third ed. Springer Science & Business Media, New York, p. 904.

Miravet, G., Alacid, M., Obón, J.M., Fernández-López, J.A., 2016. Spray-drying of pomegranate juice with prebiotic dietary fibre. Int. J. Food Sci. Technol. 51, 633–640.

Mishra, P., Rai, G.K., Mahanta, C.L., 2015. Process standardization for development of spray-dried lemon juice powder and optimization of amla-lemon based RTS (ready-to-serve) drink using response surface methodology. J. Food Process. Preserv. 39, 1216–1228.

Mishra, P., Brahma, A., Seth, D., 2017. Physicochemical, functionality and storage stability of hog plum (*Spondia pinnata*) juice powder produced by spray drying. J. Food Sci. Technol. 54 (5), 1052–1061.

Moghaddam, A.D., Pero, M., Askari, G.R., 2017. Optimizing spray drying conditions of sour cherry juice based on physicochemical properties, using response surface methodology (RSM). J. Food Sci. Technol. 54, 174–184.

Movahhed, M.K., Mohebbi, M., 2016. Spray drying and process optimization of carrot—celery juice. J. Food Process. Preserv. 40, 212–225.

Murugesan, R., Orsat, V., 2011. Spray drying for the production of nutraceutical ingredients: a review. Food Bioprocess Technol. 8, 1–12.

Muzaffar, K., Dinkarrao, B.V., Kumar, P., 2016. Optimization of spray drying conditions for production of quality pomegranate juice powder. Cogent. Food Agric. 2, 1127583.

Nakarin, J., Manop, S., Pimon, J., 2008. Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration. J. Food Eng. 84 (2), 194–205.

Nambiar, R.B., Sellamuthu, P.S., Perumal, A.B., 2017. Microencapsulation of tender coconut water by spray drying: effect of Moringa Oleifera gum, maltodextrin concentrations, and inlet temperature on powder qualities. Food Bioprocess Technol. 10, 1668–1684.

Nedovic, V., Kalusevic, A., Manojlovic, V., Levic, S., Bugarski, B., 2011. An overview of encapsulation technologies for food applications. Procedia Food Sci. 1, 1806–1815.

Nishad, J., Selvan, C.J., Mir, S.A., Bosco, S.J.D., 2017. Effect of spray drying on physical properties of sugarcane juice powder (*Saccharum officinarum* L.). J. Food Sci. Technol. 54 (3), 687–697.

Nowak, D., Piechucka, P., Witrowa-Rajchert, D., Wiktor, A., 2016. Impact of material structure on the course of freezing and freeze-drying and on the properties of dried substance, as exemplified by celery. J. Food Eng. 180, 22–28.

Nurhadi, B., Andoyo, R., Indiarto, R., 2012. Study the properties of honey powder produced from spray drying and vacuum drying method. Int. Food Res. J. 19, 907–912.

Obón, J.M., Castellar, M.R., Alacid, M., Fernández-López, J.A., 2009. Production of a red—purple food colorant from Opuntia stricta fruits by spray drying and its application in food model systems. J. Food Eng. 90, 471–479.

Oikonomopoulou, V.P., Krokida, M.K., 2013. Novel aspects of formation of food structure during drying. Dry. Technol. 31 (9), 990–1007.

Oliveira, A.L., Cabral, F.A., Eberlin, M.N., Cordello, H.M.A.B., 2009. Sensory evaluation of black instant coffee beverage with some volatile compounds present in aromatic oil from roasted coffee. Ciênc. Technol. Aliment. Campinas 29 (1), 76–80.

Omobuwajo, T.O., Busari, O.T., Osemwegie, A.A., 2000. Thermal agglomeration of chocolate drink powder. J. Food Eng. 46, 73–81.

Orrego, C.E., 2003. Procesamiento de Alimentos. Universidad Nacional de Colombia, Manizales.

Page, B., Edwards, M., May, N., 2003. Metal cans. In: Coles, R., McDowell, D., Kirwan, M.J. (Eds.), Food Packaging Technology. Blackwell Publishing Ltd, London, pp. 120–152.

Paini, M., Aliakbarian, B., Casazza, A.A., Lagazzo, A., Botter, R., Perego, P., 2015. Microencapsulation of phenolic compounds from olive pomace using spray drying: a study of operative parameters. LWT Food Sci. Technol. 62, 177–186.

Palmer, Q., 2005. Special topics. In: Ashurst, P.R. (Ed.), Chemistry and Technology of Soft Drinks and Fruit Juices, second ed. Blackwell Publishing Ltd., pp. 336–367. London.

Pandey, R.K., Manimehalai, N., 2014. Production of instant tea powder by spray drying. Int. J. Agri. Food Sci. Tech. 5 (3), 197–202.

Park, D.J., Imm, J.Y., Ku, K.H., 2001. Improved dispersibility of green tea powder by microparticulation and formulation. J. Food Sci. 66 (6), 793–798.

Pennacchia, C., Breeuwer, P., Meyer, R., 2014. Development of a multiplex- PCR assay for the rapid identification of *Geobacillus stearothermophilus* and *Anoxybacillus flavithermus*. Food Microbiol. 43, 41–49.

Peixoto, R.R.A., Oliveira, A., Cadore, S., 2012. Multielemental determinations in chocolate drink powder using multivariate optimization and ICP OES. J. Agric. Food Chem. 60, 8117–8122.

Pereira, A.L.F., Almeida, F.D.L., Lima, M.A., Costa, J.M.C., Rodrigues, S., 2014. Spray-drying of probiotic cashew apple juice. Food Bioprocess Technol. 7, 2492–2499.

Perez-Munoz, F., Flores, R.A., 1997. Characterization of a spray drying system for soymilk. Dry. Technol. 15, 1023–1043.

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

Phongpipatpong, M., Patamarajvichian, P., Namkhot, S., Amornviriyakul, S., 2008. Optimization of spray drying condition for longan drink powder using response surface methodology. Acta Hortic. 787, 355–361.

Pierucci, A.P., Andrade, L.R., Farina, M., Pedrosa, C., Rocha- Lehao, M.H.M., 2007. Comparison of a-tocopherol microparticles produced with different wall materials: Pea protein a new interesting alternative. J. Microencapsul. 24 (2), 201–213.

Pietsch, W., 2003. An interdisciplinary approach to size enlargement by agglomeration. Powder Technol. 130, 8–13.

Piorkowski, D.T., McClements, D.J., 2014. Beverage emulsions: recent developments in formulation, production, and applications. In: Phillips, G.O., Williams, G.A. (Eds.), Food Hydrocolloids, vol. 42(1). Elsevier Ltd, London, pp. 5–41.

Poncelet, D., Picot, A., El Mafadi, S., Capsulæ, 2011. Encapsulation: an essential technology for functional food applications. Innov. Food Technol. 2011 (February), 32–34.

Pourahmad, R., Khorramzadeh, D., 2015. Physicochemical and organoleptic properties of drinking powder containing soy milk powder, Stevia, Isomalt and Erythritol. J. Food Process. Pres. 40, 1206–1214.

Quek, Y.S., Chok, N.K., Swedlund, P., 2007. The physicochemical properties of spray-dried watermelon powders. Chem. Eng. Process. 46, 386–392.

Raharitsifa, N., Ratti, C., 2010. Foam-mat freeze-drying of apple juice part 2: stability of dry products during storage. J. Food Process Eng. 33, 341–364.

Rajam, R., Karthik, P., Parthasarathi, S., Joseph, G.S., Anandharamakrishnan, C., 2012. Effect of whey protein—alginate wall systems on survival of microencapsulated Lactobacillus plantarum in simulated gastrointestinal conditions. J. Funct. Foods 4 (4), 891–898.

Ratnaningrum, D., Budiwati, T.A., Kosasih, W., Pudjiraharti, S., 2015. Sensory and physicochemical evaluation of instant ginger drinks fortified with DFA III. Procedia Chem. 16, 177–183.

Ratti, C., 2001. Hot air and freeze-drying of high-value foods: a review. J. Food Eng. 49 (4), 311–319.

Ray, S., Raychaudhuri, U., Chakraborty, R., 2015. An overview of encapsulation of active compounds used in food products by drying technology. Food Biosci. 13, 76–83.

Redgwell, R.J., Trovato, V., Curti, D., 2003. Cocoa bean carbohydrates: roasting-induced changes and polymer interactions. Food Chem. 80, 511–516.

Rennie, P.R., Chen, X.D., Hargreaves, C., Mackereth, A.R., 1999. A study of the cohesion of dairy powders. J. Food Eng. 39, 277–284.

Rhim, J.W., Koh, S., Kim, J.M., 2011. Effect of freezing temperature on rehydration and water vapor adsorption characteristics of freeze-dried rice porridge. J. Food Eng. 104 (4), 484–491.

Rocha, G.A., Trindade, M.A., Netto, F.M., Favaro-Trindade, C.S., 2009. Microcapsules of a casein hydrolysate: production, characterization, and application in protein bars. Food Sci. Technol. Int. 15 (4), 407–413.

Rocha, G.A., Fávaro-Trindade, C.S., Grosso, C.R.F., 2012. Microencapsulation of lycopene by spray drying: characterization, stability and application of microcapsules. Food Bioprod. Process. 90, 37–42.

Roos, Y.H., Drusch, S., 2015. Phase Transitions in Foods, second ed. Academic Press, New York, p. 380.

Roustapour, O.R., Azad, N.M., Sarshar, M., 2012. Determination of pomegranate juice powder properties produced by a pilot plant spray dryer with a two-fluid nozzle. Dry. Technol. 30, 1906–1917.

Ruiz-Gutiérrez, M.G., Amaya-Guerra, C.A., Quintero-Ramos, A., De Jesús Ruiz-Anchondo, T., Gutiérrez-Uribe, J.A., Baez-González, J.G., Lardizabal-Gutiérrez, D., Campos-Venegas, K., 2014. Effect of soluble fiber on the physicochemical properties of cactus pear (*Opuntia ficus indica*) encapsulated using spray drying. Food Sci. Biotechnol. 23, 755–763.

Russo, P., Adiletta, G., Di Matteo, M., 2013. The influence of drying air temperature on the physical properties of dried and rehydrated eggplant. Food Bioprod. Process. 91 (3), 249–256.

Saikia, S., Mahnot, N.K., Mahanta, C.L., 2014. Effect of spray drying of four fruit juices on physicochemical, phytochemical and antioxidant properties. J. Food Process. Preserv. 39, 1656–1664.

Sansone, F., Mencherini, T., Picerno, P., d'Amore, M., Aquino, R.P., Lauro, M.R., 2011. Maltodextrin/pectin microparticles by spray drying as carrier for nutraceutical extracts. J. Food Eng. 105, 468–476.

Santana, A.A., Martin, L.G.P., de Oliveira, R.A., Kurozawa, L.E., Park, K.J., 2017. Spray drying of babassu coconut milk using different carrier agents. Dry. Technol. 35, 76–87.

Santhalakshmy, S., Bosco, S.J.D., Francis, S., Sabeena, M., 2015. Effect of inlet temperature on physicochemical properties of spray-dried jamun fruit juice powder. Powder Technol. 274, 37–43.

Sarabandi, K., Peighambardoust, S.H., Shirmohammadi, M., 2014. Physical properties of spray dried grape syrup as affected by drying temperature and drying aids. Int. J. Agri. Crop Sci. 7 (12), 928–934.

Sarabandi, K., Peighambardoust, S.H., Mahoonak, A.S., Samaei, S.P., 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 (4), 1602–1612.

Schmid, M., Amado, F., Levy, G., Wegener, K., 2014. Flowability of Powders for Selective Laser Sintering (SLS) investigated by Round Robin Test. ETHZürich Research Collection, Conference Paper, p. 5.

Schubert, H., 1980. Processes and properties of instant powdered foods. In: Link, P., Milky, Y., Lockup, J., Laminar, J. (Eds.), Food Processing Engineering. Elsevier Applied Science Publisher Ltd., London, pp. 657–684.

Schubert, H., 1987. Food particle technology. Part I: Properties of particles and particulate food systems. J. Food Eng. 6 (1), 1–32.

Secilmis, S.S., Kocak Yanık, D., Gogus, F., 2015. Processing of a novel powdered herbal coffee (*Pistacia Terebinthus L.* Fruits Coffee) and its sensorial properties. J. Food Sci. Technol. 52 (7), 4625–4630.

Shittu, T.A., Lawal, M.O., 2007. Factors affecting instant properties of powdered cocoa beverages. Food Chem. 100, 91–98.

Siaan, M.M., Anwair, M.A.S., 2014. Effect of preparation method on some physical and mechanical properties of prepared effervescent granules. Int. J. Adv. Pharm. Biol. Chem. 3 (2), 420–422.

Silva, P.I., Stringheta, P.C., Teofilo, R.F., Nolasco de Oliveira, I.R., 2013. Parameter optimization for spray-drying microencapsulation of jaboticaba (*Myrciaria jaboticaba*) peel extracts using simultaneous analysis of responses. J. Food Eng. 117, 538–544.

Sithisarn, P., Gritsanapan, W., Jateleela, S., 2015. Formulation and quality control of readily dissolving drink powder from *Antidesma ghaesembilla* fruits. CMU J. Nat. Sci. 14 (1), 89–101.

Song, Q., Xiong, W.K., Wang, F.B., Shi, Y.P., Zhang, Q.A., 2000. Application of fluidized bed agglomerated lecithin in soybean milk powder. China Dairy Industry. 4, 32–34.

Stapelfeldt, H., Nielsen, B.R., Skibsted, L.H., 1997. Towards use of electron spin resonance spectrometry in quality control of milk powder. Correlation between sensory score of instant whole milk powders and concentration of free radicals and 2-thiobarbituric acid reactive substances. Milchwissenschaft 52, 682–685.

Steffi, Pandjaitan, M., Sutanto, H., 2013. In: Development and optimization of instant drink formulation from pineapple (*Ananas cosmosus*) Juice. Proceedings of 2013 3rd International Conference on Instrumentation, Communications, Information Technology, and Biomedical Engineering (ICICI-BME). International Conference on Instrumentation Communication Information Technology and Biomedical Engineering. pp. 313–316.

Strumillo, C., Adamiec, J., 1996. Energy and quality aspects of food drying. Dry Technol. 14 (2), 423–448.

Sun-Waterhouse, D., Wadhwa, S.S., Waterhouse, G.I.N., 2013. Spray-drying microencapsulation of polyphenol bioactives: a comparative study using different natural fibre polymers as encapsulants. Food Bioprocess Technol. 6, 2376–2388.

Szulc, K., Lenart, A., 2012. Water vapour adsorption properties of agglomerated baby food powders. J. Food Eng. 109, 135–141.

Tamer, C.E., Karaman, B., Copur, Ö.U., 2006. A traditional Turkish beverage: salep. Food Rev. Int. 22 (1), 43–50.

Telis, V.R.N., Sobral, P.J.A., 2001. Glass transitions and state diagram for freezedried pineapple. LWT Food Sci. Technol. 34, 199–205.

Telis, V.R.N., Martínez-Navarrete, N., 2009. Collapse and color changes in grapefruit juice powder as affected by water activity, glass transition, and addition of carbohydrate polymers. Food Biophys. 4, 83–93.

Teunou, E., Fitzpatrick, J.J., 1999. Effect of relative humidity and temperature on food powder flowability. J. Food Eng. 42, 109–116.

Teunou, E., Fitzpatrick, J.J., Synnott, E.C., 1999. Characterization of food powder flowability. J. Food Eng. 39, 31–37.

Teunou, E., Poncelet, D., 2002. Batch and continuous fluid-bed coating: a review and state of the art. J. Food Eng. 53, 325–340.

Tonon, R.V., Baroni, A.F., Brabet, C., Gibert, O., Pallet, D., Hubinger, M.D., 2009. Water sorption and glass transition temperature of spray dried açai (*Euterpe oleracea* Mart) juice. J. Food Eng. 94, 215–221.

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

Tontul, I., Topuz, A., 2017. Spray-drying of fruit and vegetable juices: effect of drying conditions on the product yield and physical properties. Trends Food Sci. Technol. 63, 91–102.

Torres, D.P.M., Bastos, M., Do Pilar, F., Goncalves, M., Teixeira, J., Rodrigues, L.R., 2011. Water sorption and plasticization of an amorphous galactooligosaccharide mixture. Carbohydr. Polym. 83, 831–835.

Truong, V., Bhandari, B.R., Howes, T., 2005. Optimization of concurrent spray drying process for sugar rich foods: Part II—optimization of spray drying process based on glass transition. J. Food Eng. 71, 66–72.

Turchiuli, C., Eloualia, Z., El Mansouri, N., Dumoulin, E., 2005. Fluidised bed agglomeration: agglomerates shape and end-use properties. Powder Technol. 157, 168–175.

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

Varela, P., Ares, G., Giménez, A., Gámbaro, A., 2010. Influence of brand information on consumers' expectations and liking of powdered drinks in central location tests. Food Qual. Prefer. 21, 873–880.

Vissotto, F.Z., Jorge, L.C., Makita, G.T., Rodrigues, M.I., Meneegalli, F.C., 2010. Influence of the process parameters and sugar granulometry on cocoa beverage powder steam agglomeration. J. Food Eng. 97, 283–291.

Vu, T.O., Galet, L., Fages, J., Oulahna, D., 2003. Improving the dispersion kinetics of a cocoa powder by size enlargement. Powder Technol. 130 (1-3), 400–406.

Wang, S., Konkol, E., Langrish, T.A.G., 2011. Spray drying of fruit juice using proteins as additives. Dry. Technol. 29, 1868–1875.

Watson, M.A., Lea, J.M., Bett-Garber, K.L., 2017. Spray drying of pomegranate juice using maltodextrin/cyclodextrin blends as the wall material. Food Sci. Nutr. 5, 820–826.

WHO, 2012. World Health Organization, S.3.6. Bulk density and tapped density of powders. Document QAS/11.450 Final. March 2012. 6 p.

Wijeratne, D.B.T., 1993. Spray drying of soymilk. Ph.D. Thesis, University of Illinois at Urbana-Champaign.

Woo, M.W., Mujumdar, A.S., 2010. Effects of electric and magnetic field on freezing and possible relevance in freeze drying. Dry. Technol. 28 (4), 433–443.

Ye, D., Zhang, L., Sun, S., Chen, J., Fang, T., 2014. Production of high-aroma instant tea powder using various novel technologies. J. Food Process Eng. 37, 273–284.

York, D.W., 2009. Agglomeration from the sharp end. Powder Technol. 189, 38–140.

Yousefi, S., Emam-Djomeh, Z., Mousavi, M.S., 2011. 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, 677–684.

Zea, L.P., Yusof, Y.A., Aziz, M.G., Ling, C.N., Amin, N.A.M., 2013. Compressibility and dissolution characteristics of mixed fruit tablets made from guava and pitaya fruit powders. Powder Technol. 247, 112–119.

Zuidam, N.J., Shimoni, E., 2010. Overview of microencapsulates for use in food products or processes and methods to make them. In: Zuidam, N.J., Nedovic, V.A. (Eds.), Encapsulation Technologies for Active Food Ingredients and Food Processing. Springer, New York, pp. 3–29.