International Food Research Journal 19(4): 1297-1306 (2012)
Journal homepage: http://www.ifrj.upm.edu.my

MiniReview

Spray drying technique of fruit juice powder: some factors influencing the properties of product

Phisut, N.

Faculty of Agricultural Product Innovation and Technology, Srinakharinwirot University, Sukhumvit 23, Bangkok, 10110, Thailand

Article history

Received: 5 January 2012
Received in revised form: 14 February 2012
Accepted: 15 February 2012

Keywords

Fruit juice
spray drying
properties

Abstract

Spray drying is a process widely used to produce fruit juice powders. In powders, it results with the good quality, low water activity, easier transport and storage. The physicochemical properties of powders produced by spray drying depend on the variables of process and/or operating parameters. In the present review, the principle of spray drying was described. In addition, some factors such as inlet temperature, air dry flow rate, atomizer speed, feed flow rate, types of carrier agent and their concentration were reviewed.

Introduction

Fruits are important sources of vitamins and carbohydrates. They are naturally sweet and low in calories. Different fruits contain different type of vitamins, so it is important to have a variety of fruits. Fruits are the important intake of our daily diet life. There is no cause of side effect by fruits because it provides necessary vitamins to our body. The vitamins are important to humans for providing energy to away from various kinds of sickness.

Nowadays, the fast economic development has changed the trend of food consumption from calories assurance to diet nutrient enrichment. The consumers today are well aware of the importance of vitamins. This scenario has increased the global market demand towards the fresh fruits. In order to handle the market demand throughout the year, the fresh fruits are preserved using different techniques. High moisture content in the fruit leads to having high water activity which leads the quality loss in fruits by increasing the enzyme activity and microbial growth. Therefore, the reducing moisture content and water activity in fruits is always desirable to maintain the quality. Drying is an ancient technique, in which used to preserve food by remove moisture content and water activity. There are many drying techniques have invented such as spray drying, freeze drying, tray drying have invented to increase the productivity and achieve the better control of a process to increase the product quality. Among the drying techniques, spray drying is usually applied to produce the fruit juice powder.

Dehydration by spray drying is used in the wide range of products in food industries to produce dry powders and agglomerates. Economic considerations of this method include hygienic conditions during processing, operational costs, and short contact time (Sagar *et al*., 2010; Yousefi *et al*., 2011). The quality of spray dried food depends on the different factors of spray dryer operating systems. Hence, the aim of this review is to describe some factors such as inlet temperature, air dry flow rate, feed flow rate, atomizer speed, types of carrier agent and their concentration affecting the properties of fruit juice powder (Chegni and Ghobadian, 2005; Chegni and Ghobadian, 2007). This review is useful for industry to develop the processing condition and improve the product quality.

Principle of spray drying technique

The first spray dryers were manufactured in the USA in 1933. Spray drying is one of the best drying methods to convert directly the fluid materials into solid or semi-solid particles (Murugesan and Orsat, 2011). Spray drying is a unit operation by which a liquid product is atomized in a hot gas current to instantaneously obtain a powder. The gas generally used is air or more rarely an inert gas, particularly

*Corresponding author.
Email: *phisut@swu.ac.th*

nitrogen gas. The initial liquid feeding can be a solution, an emulsion or a suspension (Gharasallaoui *et al*., 2007). It can be used to both heat-resistant and heat sensitive products.

Spray drying involves in the complex interactions of process, apparatus and feed parameters which all have an influence on the final product quality (Chegini *et al*., 2008). The spray drying process can produce a good quality final product with low water activity and reduce the weight, resulting in easy storage and transportation. The physicochemical properties of the final product mainly depend on inlet temperature, air flow rate, feed flow rate, atomizer speed, types of carrier agent and their concentration. Spray drying is often selected as it can process material very rapidly while providing relative control of the particle size distribution (Obon *et al*., 2009).

Spray dryer

The spray dryer is a device used to produce dried foods. It takes a liquid stream and separates the solute or suspension as a solid and the solvent into a vapor. The solid is usually collected in a drum or cyclone. The liquid input stream is sprayed through a nozzle into a hot vapor stream and vaporized. The solid as forms as moisture contents quickly leave the droplets. A nozzle is usually used to make the droplets as small as possible to maximize the heat transfer and rate of water vaporization. The spray dryers can dry a product very quickly compared to other methods of drying. They also turn a solution or slurry into a dried powder in a single step, which can be the advantage for maximizing the profit and minimize the process (Chegini and Ghobadian, 2007; Murugesan and Orsat, 2011).

Basic steps of spray drying

Concentration of fruit juice

Generally, the feedstock is concentrated before introducing into the spray dryer. The concentrated juice has increased in solid contents thereby reducing the amount of liquids and that must be evaporated in the spray dryer. The feedstock in conventional large scale spray dryer normally concentrates to 50%-60% before introducing to spray dryer. However, the small scale laboratory spray dryer will have more diluted feedstock because it will be clogged easily if the feed have high viscosity (Chegini and Ghobadian, 2007; Murugesan and Orsat, 2011).

Atomization

Atomization refers to the conversion of bulk liquid into a spray or mist, often by passing the liquid through a nozzle. The liquid which sprayed through nozzle will increase the surface area of the liquid which later will be contacted to hot air and dried into a powder. The nozzle size may differ according to the size of spray dryer. Droplet size ranges from 20 µm to 180 µm and it depends on the nozzle. Smaller spray dryer occupies smaller nozzles and reverse in the industrial scale spray dryer. The aim of this stage is to create a maximum heat transferring surface between the dry air and the liquid, in order to optimize heat and mass transfers. The choice upon the atomizer configuration depends on the nature and viscosity of feed and desired characteristics of the dried product (Master, 1986; Patel *et al*., 2009).

Droplet-air contact

The important component of spray dryer is the chamber; here the sprayed droplet is contacted with the hot air and the drying process begins. Air is heated by the heating element which situated before entering the chamber to a predefined temperature depending upon the characteristics of the feed fluid. The hot air is brought in contact with the spray droplets in the following ways through the air distributor.

1. Co-current-Air and particles move in the same direction.
2. Counter-current-air and particles move in the opposite direction.
3. Mixed flow - particles are subjected to co-current and counter-current phase.

The thermal energy of the hot air is used for evaporation and the cooled air pneumatically conveys the dried particles in the system. The contact time of the hot air and the spray droplets is only a few seconds, once the drying is achieved and the air temperature of air drops instantaneously. The nozzle increases the contact area of droplet and hot air influences in the huge heat transfer between droplet and hot air. The hot air evaporates moisture content in the droplet and changes into powder form. In co-current process the liquid is sprayed in the same direction as the flow of hot air through the apparatus, hot air inlet temperature is typically 150-220^{o}C, evaporation occurs instantaneously and then dry powders will be exposed to moderate temperatures (typically 50-80^{o}C) which limits the thermal degradations. In counter-current drying, the liquid is sprayed in the opposite direction of hot air flow for high temperature process. Thermo-sensitive products are usually restricted to in this process. However, the main advantage of this process is considered as more economic in term of consuming energy (Master, 1986; Gharsallaoui *et al*., 2007; Patel *et al*., 2009; Murugesan and Orsat, 2011).

Droplet drying

At the stage of droplets - hot air contacts between the liquid and gas phases and balances the temperature and established the vapor partial pressure. Heat transfer is carried out from the air towards the product and thus induces the difference in temperature. Water transfer is carried out in the opposite direction due to the vapor pressure difference.

Based on the drying theory, three successive steps can be distinguished. Just after the hot air - liquid contact, heat transfer majorly causes the increase of droplets temperature up to a constant value. This value is defined as the air drying humid thermometer temperature; after that, the evaporation of water droplet is carried out at a constant temperature and water vapor partial pressure. The rate of water diffusion from the droplet core to its surface is usually considered as constant and equal to the surface evaporation rate. Finally, when the droplet water content reaches a critical value, a dry crust is formed at the droplet surface and the drying rate rapidly decreases with the drying front progression and becomes dependent on the water diffusion rate through this crust. Drying is finished when the particle temperature becomes equal to that of the air. Each product has a difference of particle-forming characteristics such as expand, contract, fracture or disintegrate. The resulting particles may be relatively uniform hollow spheres, or porous and irregularly shaped (Gharsallaoui *et al*., 2007; Master, 1986; Murugesan and Orsat, 2011; Patel *et al*., 2009).

Separation of dried particles

This separation is often done through a cyclone, placed outside the dryer which reduces product loss in the atmosphere. The dense particles are recovered at the base of the drying chamber while the finest ones pass through the cyclone to separate from the humid air. In addition to cyclones, spray dryers are commonly equipped with the filters, called ‘‘bag houses’’ that are used to remove the finest powder, and the chemical scrubbers remove the remaining powder or any volatile pollutants (e.g. Flavourings). The obtained powder is made up of particles which originate from spherical drops after shrinking. The drop of water and gas content is depending on the composition and these particles can be compact or hollow (Bimbenet *et al*., 2002; Gharsallaoui *et al*., 2007; Master, 1986).

Carrier agent

The problem of powder stickiness is mainly due to the low glass transition temperature (Tg) of the low molecular weight sugars present in such products, essentially sucrose, glucose, and fructose.

The glass transition temperature (Tg), is the temperature at which the amorphous phase of the polymer is converted between rubbery and glassy states. Fruit juice powder obtained by spray drying might have some problems with their property, such as stickiness, hygroscopic and solubility, due to the presence of low molecular weight sugars and acids, which have a low glass transition temperature (Bhandari *et al*., Jittanit *et al*., 2010). Thus, they can stick on the dryer chamber wall during drying, leading to low product yield and operational problems. The low glass transition temperature (Tg), high hydroscopic, low melting point, and high water solubility of the dry solids produce the highly sticky products. Roos and Karel (1991) stated that these solid materials are very hygroscopic in amorphous state and loose free flowing character at high moisture content. These problems can be solved by the addition of some carrier agents, like polymers and gums, to the product before being atomized. Moreover, carrier agent is also used for microencapsulation. It can protect sensitive food components against unfavorable ambient conditions, mask or preserve flavours and aromas, reduce the volatility and reactivity and provide additional attractiveness for the merchandising of food products (Jittanit *et al*., 2010).

The common carrier agents used for fruit juices are maltodextrins and gum Arabic (Cano-Chuca *et al*., 2005; Gabas *et al*., 2007; Righetto & Netto, 2005). Maltodextrins are products of starch hydrolysis, consisting of D-glucose units linked mainly by $\alpha(1\rightarrow4)$ glycosidic bonds. They are described by their dextrose equivalence (DE), which is inversely related to their average molecular weight (Bemiller and Whistler, 1996). Maltodextrins are low cost and very useful for spray drying process on food materials. Gum Arabic is natural plant exudates of Acacia trees, which consists of a complex heteropolysaccharide with highly ramified structure. It is the only gum used in food products that shows high solubility and low viscosity in aqueous solution, making easier the spray drying process (Rodriguez-Hernandez *et al*., 2005).

The use of different carrier agents and different drying conditions produces the different physicochemical properties of powders. Knowledge of food properties is essential to know and thus will help to optimize the processes, functionalities, to reduce costs, mainly in the case of powders produced or used in pharmaceutical and food industries. Properties such as moisture content and water activity are essential for powder stability and storage. Bulk density is important for packaging and shipping considerations. Particle size distribution is having major role in processing, handling and shelf life and the microstructure is related to powders functionality, stability and flowability (O'hagan *et al*., 2005).

Factors influencing the properties of fruit juice powder produced by spray dry technique

Spray drying is a technique widely used in the food industry to produce food powder due to its effectiveness under the optimum condition (Cano-Chuca *et al*., 2005; Jittanit *et al*., 2010). The spray drying parameters such as inlet temperature, air flow rate, feed flow rate, atomizer speed, types of carrier agent and their concentration are influencing as particle size, bulk density, moisture content, yield and hygroscopicity in spray dried foods (Chegini and Ghobadian, 2005; Chegini and Ghobadian, 2007; Yousefi *et al*., 2011). The detail of all these parameters is described below.

Inlet temperature

Powder properties such as moisture content, bulk density, particle size, hygroscopicity and morphology were affected by inlet temperature. Normally, the inlet temperature uses for spray dry technique for food powder is 150-220°C. Chegini and Ghobadian (2005) studied the effect of inlet temperature (110-190°C) on the moisture content of orange juice powder. It was found that at a constant feed flow rate, increasing the inlet air temperature reduced the residual moisture content. The similar observation was obtained in the different fruit juice powders such as watermelon juice (Quek *et al*., 2007), tomato juice (Goula and Adamopoulos, 2008), acai juice (Tonon *et al*., 2008; Tonon *et al*., 2011) and pineapple juice (Jittanit *et al*., 2010). Moisture content is decreased with the increase of drying temperature, due to the faster heat transfer between the product and drying air. At higher inlet air temperatures, there is a greater temperature gradient between the atomized feed and drying air and it results the greatest driving force for water evaporation.

Additionally, the inlet temperature affects the bulk density of powder. Tonon *et al*. (2008) studied the effect of inlet temperature (140, 170, 200°C) on the bulk density of acai juice powder and found that the increased temperature caused the reduction in bulk density. An increase in the inlet air temperature often results in a rapid formation of dried layer on the droplet surface and particle size and it causes the skinning over or casehardening on the droplets at the higher temperatures. This leads to the formation of vapor-impermeable films on the droplet surface, followed by the formation of vapor bubbles and, consequently the droplet expansion (Chegini and Ghobadian, 2005; Finney *et al*., 2002; Tonon *et al*., 2008; Tonon *et al*., 2011). Walton (2000) reported, the increase of drying air temperature generally causes the decrease in bulk, particle density and provides the greater tendency to the particles to hollow.

In addition, the particle size was affected by inlet temperature as reported by Tonon *et al*. (2011). The use of higher inlet air temperature leads to the production of larger particles and causes the higher swelling. The similar finding was also obtained by other authors (Chegini and Ghobadian, 2005; Nijdam and Langrish, 2006; Reineccius, 2001). Reineccius (2001) reported, drying at higher temperatures results in faster drying rates, which was leading to the early formation of a structure and that did not allow the particles to shrink during drying. When the inlet air temperature is low, the particle remains more shrunk and smaller. Nijdam and Langrish (2006) were obtained the similar results in the production of milk powder at 120°C and 200°C. Chegini and Ghobadian (2005) also obtained comparable results in the production of orange juice powder. An increase of inlet air temperature often results in a rapid formation of dried layer at the droplet surface. This hardened the skin to did not allow the moisture to exit from the droplet and its due to the increase of particle size as mentioned previously.

The inlet air temperature has a role on the hygroscopicity of the powder. Tonon *et a*l. (2008) studied the effect of inlet temperature (140, 170, 200°C) on the hygroscopicity of acai juice powder. The powders produced at higher inlet temperatures were more hygroscopic due to the presence of moisture content in the powder. The higher drying temperature is lower the moisture content and increase its hygroscopicity (its capacity to absorb ambient moisture). This is related to the water concentration gradient between the product and the surrounding air, which is great for the less moist powder. It is an agreement with the spray drying of tomato pulp by Goula *et al*. (2004). Moreover, the effect of inlet temperature on process yield of acai juice powder was investigated by Tonon *et al*. (2008). The increase of inlet temperatures has given the higher process yield and it was due to the greater efficiency of heat and mass transfer processes occurring when higher inlet air temperatures were used. This is in accordance with the amaranthus betacyanin pigments by Cai & Corke (2000). On the other hand, the increase of inlet air temperature has reduced the yield and it might be caused by melting of the powder and cohesion wall and therefore the amount of powder production and yield was reduced. (Chegini and Ghobadian, 2007; Dolinsky *et al*., 2000; Dolinsky, 2001).

Furthermore, the inlet temperature also influenced the morphology in acai juice powder as reported by Tonon *et al*. (2008). Figure 1 showed the micrographs of particles at different temperatures and in different magnifications. The particles exhibited the spherical shape and in various sizes, caused by materials produced in spray drying. When the inlet air temperature was low, the particles showed a shriveled surface, while increasing drying temperatures resulted in a larger number of particles with smooth surface. This is associated with the different drying rates, which has the highest rate at higher temperatures, causing the faster water evaporation and then it led to the formation of smooth and hard crust. Alamilla-Beltrán *et al*. (2005) reported, when low inlet air temperatures were used, the crust was more pliable and collapsed, while the use of higher drying temperatures results in a more rigid and porous crust. Nijdam and Langrish (2006) also confirmed the formation of more rigid particles with the use of higher temperatures in the spray drying of milk. The vacuole forms within the particle rapidly after a skin develops on the surface, and it inflates once the particle temperature exceeds the native ambient boiling point and the vapor pressure within the vacuole rises above the local ambient pressure. When the drying temperature is sufficiently high and the moisture is evaporated very quickly and the skin becomes dry and hard. As a result, the hollow particle cannot deflate when vapor condenses within the vacuole as the particle moves into cooler regions of the dryer. However, when the drying temperature is lower, the skin remains moist and supple for longer, so that the hollow particle can deflate and shrivel as it cools.

The inlet air temperature considerably influenced the pigments of fruit juice powder. Quek *et al*. (2007) studied the effect of inlet temperature (145-175°C) on the stability of lycopene and B-carotene in watermelon juice powder. The result showed that, lycopene content was decreased with the inlet temperature. A similar observation was reported in the spray drying of tomato pulp (Goula and Adamopoulos, 2005). The reduction of lycopene content was likely due to the thermal degradation and oxidation. Air dehydration exposes carotenoids to oxygen, which can cause extensive degradation of carotenoids. Dehydrated products that have large surface-to-mass ratios are especially susceptible to oxidative decomposition during drying and storage in air. Carotenoids are easily oxidized because of the large number of conjugated double bonds. Such reactions cause color loss of carotenoids in foods and are the major degradation mechanisms of concern. Because of the highly conjugated, unsaturated structure of carotenoids, the products of their degradation are very complex. During oxidation, epoxides and carbonyl compounds are initially formed. Further oxidation results in formation of short-chain mono- and dioxygenated compounds including epoxy-b-ionone. Generally, epoxides form mainly within the end rings, while oxidative scission can occur at a variety of sites along the chain. For provitamin A carotenoids, epoxide formation in the ring results in loss of the provitamin activity. Extensive autoxidation will result in bleaching of the carotenoid pigments and loss in color. Oxidative destruction of β-carotene is intensified in the presence of sulfite and metal ions (Fenema, 1996).

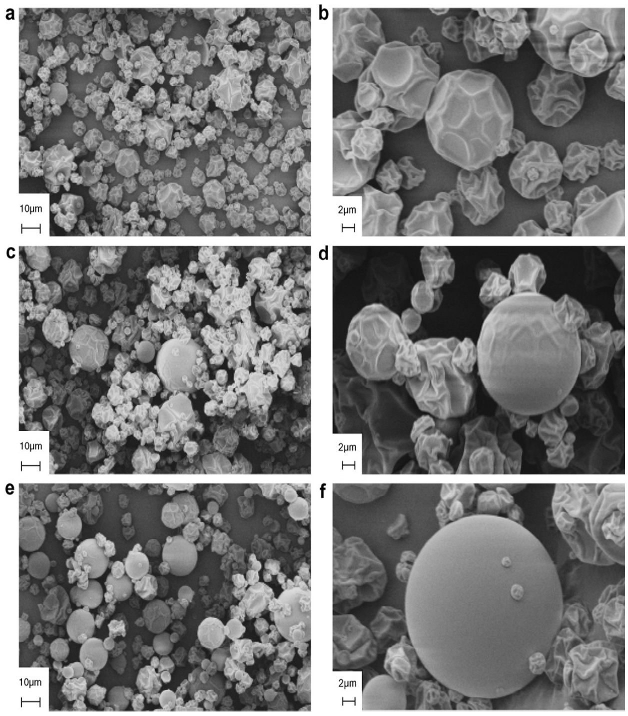

Figure 1. Micrographs of particles of acai juice powder at different temperatures and in different magnifications (a) 138°C, 2000x; (b) 138°C, 7000x; (c) 170°C, 2000x; (d) 170°C, 7000x; (e) 202°C, 2000x; (f) 202°C, 7000x (Tonon *et al*., 2008)

In addition, inlet temperature was affected the stability of anthocyanin in the acai juice powder (Tonon *et al*., 2008). The increase of inlet air temperatures was decreased the anthocyanins, due to the high sensitivity of these pigments to high temperatures.

Air dry flow rate

The moisture content in tomato powder was increased with an increase of drying air flow rate (Goula and Adamopoulos, 2005). Generally, the energy available for evaporation is varied according to the amount of drying air. The rate of air flow must be at a maximum in all cases. The movement of air is decided the rate and degree of droplet evaporation by inducing, the passage of spray through the drying zone and the concentration of product in the region of the dryer walls and finally extent the semi-dried droplets and thus re-enter the hot areas around the air disperser. A lower drying air flow rate causes an increase in the product halting time in drying chamber and enforces the circulatory effects (Goula and Adamopoulos, 2004; Master, 1979; Oakley and Bahu, 2000). The increased residence time led to the greater degree of moisture removal. As a result, an increase of the drying air flow rate, decrease the residence time of the product in the drying chamber and it leads to have higher moisture contents. In addition, the effect of drying air flow rate of powder bulk density depends on its effect on moisture content due to the sticky nature of the product. The higher moisture content in the powder leads to stick together and consequently leaving more interspaces between them and it results the larger bulk volume. Therefore, the raise of air flow rate leads to an increase of moisture content in the powder and decreased in powder bulk density. Masters (1979) reported that, the increasing residual moisture content was increased the bulk density of dry product. In addition, powder solubility was influenced by air dry flow rate. The effect of drying air flow rate on powder solubility depends on its effect on powder moisture content, as low moisture content seemed to be associated with the fast dissolution. The rising of air flow rate was led to the increased of powder moisture content and decrease in powder solubility (Papadakis *et al*., 1998).

Atomizer speed

Chegini and Ghobadian (2005) studied the effect of atomizer speed (10,000-25,000 rpm) on the properties of an orange juice powder. The residual moisture content was decreased when increasing the atomizer speed. At higher atomizer speed, the smaller droplets were produced and more moisture was evaporated resulting from an increased contact surface. This was correlated with the findings of Knipschildt (1986). The higher atomizer speed resulted in a smaller particle size and quicker drying due to the larger surface area and consequently it prevented the ‘‘skinning’’ over the droplets. The increased of atomizer speed was spread the liquid into thin film layer and thus caused the smaller droplet and particle size. Additionally, the higher atomizer speed was higher the bulk density. At the same time, the increased atomizer speed applied on a droplet to spread on a larger surface has reduced the particle size and decreased the bulk density (Greenwald and King, 1981).

Feed flow rate

The feed flow rate was negatively affected the moisture content in the acai juice powder (Tonon *et al*., 2008). Higher flow rates imply in a shorter contact time between the feed and drying air and making the heat transfer less efficient and thus caused the lower water evaporation. The higher feed flow rate showed a negative effect on process yield and that was resulting the decreased heat, mass transfer and the lower process yield. In addition, when higher feed rates were used, a dripping inside the main chamber was observed, when the mixture was passed straight to the chamber and that was not atomized and finally resulting the lower process yield. Toneli et al. (2006) also verified an increase on mass production rate with increasing air temperatures and decreasing pump speeds in the spray drying of innulin. Chegini and Ghobadian (2007) also revealed increasing the feed flow rate increased the wall deposit and reduced yield. At constant atomizer speed, increasing the feed flow rate, more liquid was atomized into chamber, thus time of drying was reduced and finally the drying was incorrect.

Type of carrier agent

The addition of high molecular weight additives to the product before atomizing is widely used as an alternative way to increase Tg of powder (Truong *et al*., 2005). The use of carrier agents such as maltodextrins, gum Arabic, waxy starch, and microcrystalline cellulose, was influenced the properties and stability of the powder. Crystalline and amorphous forms of the same material powder show differences in particle size, particle shape, bulk density, physicochemical properties, chemical stability, water solubility and hygroscopicity (Yousefi *et al*., 2011).

The common carrier agents used for fruit juices are maltodextrins and gum Arabic. Goula and Adamopoulos (2008) studied the effect of maltodextrin addition (maltodextrin 6DE, 12DE, 21DE) on the properties of tomato powder. The result showed that the higher the maltodextrin dextrose equivalent (DE) causes higher the moisture content in the powder. This probably due to the chemical structure of high-DE maltodextrins, which have a high number of ramifications with hydrophilic groups, and thus can easily bind to water molecules from the ambient air during powder handling after the spray drying. Additionally, higher maltodextrin DE caused the increase in bulk density in the powder due to its stickiness. The higher maltodextrin DE was produced the lower glass transition temperature and it lower the elevation of the Tg in fruit pulp-maltodextrin mixture

(Tonon *et al*., 2009).

The different type of carrier agent was having the variance in powder solubility. Starch is generally difficult to soluble in water; however maltodextrin is more soluble in water. Yousefi *et al*. (2011) studied the effect of carrier agents such as maltodextrin, gum Arabic and waxy starch on the solubility of the pomegranate juice powder. The result showed, the lowest solubility was observed in pomegranate juice powder by waxy starch. Furthermore, Tonon *et al*. (2009) reported, the lowest solubility in acai juice powder when added the tapioca starch as compared to maltodextrin 10DE, maltodextrin 20DE and gum Arabic.

Degree of polymerization of maltodextrin also influenced the hygroscopicity of powder. Tonon *et al*. (2011) investigated the effect of carrier agents such as maltodextrin 10DE, maltodextrin 20DE and gum Arabic on the hygroscopicity of acai juice powder. The result was revealed that the particles produced with maltodextrin 10DE showed the lowest moisture adsorption rate, while the samples were produced with maltodextrin 20DE and gum Arabic had more hygroscopic and with faster water adsorption and the lower moisture in the powders. Moreover, the differences in water adsorption can also be explained by the chemical structure of each agent. The phenomenon of water adsorption by a carbohydrate was attributed to the links between the hydrogen present in water molecules and the hydroxyl groups available in the amorphous regions of the substrate and as well as the surface crystalline regions. Maltodextrin 20DE and gum Arabic have a great number of ramifications with the hydrophilic groups. Therefore, it was easily adsorbed the moisture from the ambient air. Maltodextrin 10DE was less hydrolyzed, showing less number of hydrophilic groups and thus adsorbing less water.

Particle size of powder was also affected the degree of polymerization of maltodextrin as reported by Tonon *et al*. (2011). The powder produced with maltodextrin 10DE showed a higher mean diameter as compared with the maltodextrin 20DE. This increased particle size was related to the molecular size of each agent. Higher the maltodextrin DE is obtained from higher degree of hydrolysis and therefore, the chain became shorter. This explained the small size of the particles produced with maltodextrin 20DE, when compared to those produced with the maltodextrin 10DE.

The type of carrier agents considerably influenced the morphology of powder. Figure 2 showed the micrograph of pomegranate juice powder produced with maltodextrin, waxy starch and gum Arabic

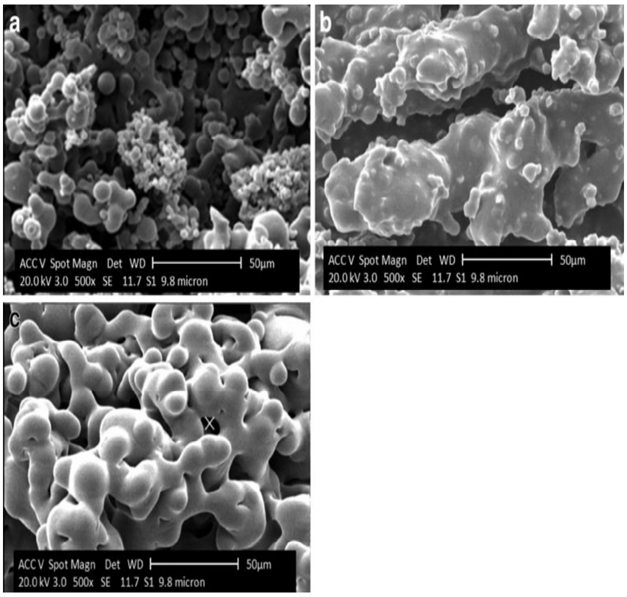

Figure 2. Effect of carrier type on microstructure of powder with gum Arabic (12%) (a), waxy starch (12%) (b) and maltodextrin (12%) (c) (Yousefi *et al*., 2011)

(Yousefi *et al*., 2011). The highest amorphous fraction was found in powder added with the gum Arabic. Gum Arabic has a higher Tg point due to its larger molecular comparing two other carriers therefore the powders produced by Arabic gum showed the less amorphous behavior during spray drying when compared with the waxy starch and maltodextrin.

Concentration of carrier agent

The concentration of the carrier agent also affected the powder properties. Low concentration of carrier agent may obtain the stickiness powder. Quek *et al*. (2007) investigated the effect of maltodextrin concentrations (0, 3 and 5%) on the properties of the watermelon juice powder. The result showed that there were hardy any powders accumulated in the collector if maltodextrin was not added to the feed. The particles produced were very sticky and mainly deposited onto the wall of drying chamber and cyclone and could not be recovered. The addition of 5% maltodextrin to the feed appeared to give better results than addition of 3% maltodextrin. These results showed that the maltodextrin was a useful drying aid in the spray drying process of watermelon juice and as results it was improved the yield of product. The addition of maltodextrin could increase the total solid content in the feed and thus, reduce the moisture content of the product. It was suggested that maltodextrin could alter the surface stickiness of low molecular weight sugars such as glucose, sucrose and fructose and organic acids, therefore, facilitated drying and reduced the stickiness of the spray dried product. However, if the added maltodextrin was more than 10%, the resulted powders lost their attractive red-orange colour (Quek *et al*., 2007).

The concentration of the carrier agent also affected the moisture content of powder. Moisture content of powder had increased with the increase of maltodextrin concentration as reported by Goula and Adamopoulos (2008). The similar observation was attained in the maltodextrin addition on drying kinetics and stickiness of sugar and acid-rich foods during convective drying and it also lowered the drying rate (Adhikari *et al*., 2003). This study was in accordance with the production or orange juice powder (Goula and Adamopoulos, 2010). In contrast, the moisture content of spray dried watermelon juice powders were decreased when the increased addition of maltodextrin. The addition of the drying additives has increased the total solids of the feed and reduced the amount of water evaporation. This was in accordance with the findings of Jittanit *et al*. (2010). Jittanit *et al*. (2010) reported that the increase of maltodextrin concentration was resulted the decreased of moisture content of pineapple juice powder. It was due to the maltodextrin has the capability to hurdle the sugars in the fruit powder that have the highly hygroscopic nature of absorbing the humidity in the surrounding air (Shrestha *et al*., 2007).

An increased in maltodextrin concentration led to a decreased in bulk density in tomato juice powder and orange juice powder as reported by Goula & Adamopoulos (2010). This effect could be the addition of maltodextrin was minimized the thermoplastic particles from sticking and the sticky or less free-flowing nature of a powder was associated with a high bulk density (Kwapinska & Zbicinski, 2005). The effect of maltodextrin on the increase of bulk density was due to its skin forming ability induced the increase the volume of air trapped in the particles as increased with the maltodextrin concentration. According to Kwapinska and Zbicinski (2005), the particles of skin-forming spray dried materials were often contain air bubbles, which can occur as a result of desorption of air that was initially present in the liquid feed or was absorbed during atomization. Generally, an increased volume of trapped air caused a decrease in the apparent density of the particles and this apparent density primarily determined the powder bulk density.

The higher maltodextrin concentrations were also led to produce the larger particles, which may be related to the feed viscosity, which exponentially increased with maltodextrin concentration. According to Masters (1979), the mean liquid droplet size varies directly with the liquid viscosity at constant atomizer speed. The higher the liquid viscosity, the larger the droplets formed during atomization and thus, the larger particles obtained by spray drying. This is in an agreement with the results published by Jinapong *et al*. (2008), on instant soymilk powders produced by ultrafiltration and spray-dried in a rotary atomizer. Keogh *et al*. (2003) observed a linear increase of the particles size with feed viscosity on spray drying of ultra-filtered whole milk concentrated, in a two-fluided nozzle atomizer. In both works, the authors attributed the increase in particle size to the increase on feed viscosity.

Maltodextrin concentration was providing the different powders hygroscopicity. High concentration of maltodextrin reduces the hygroscopicity of powder. This was in an agreement with Tonon *et al*. (2008). The lowest hygroscopicity values were obtained when the highest maltodextrin concentrations were used. This was due to the fact that maltodextrin having low hygroscopicity and confirmed its efficiency as a carrier agent. This was in an agreement with Cai and Corke (2000) and Rodriguez-Hernandez *et al*. (2005).

Additionally, an increased maltodextrin concentration did not cause a reduction in powder solubility. This variation may be attributed to the fact that maltodextrin has a superior water solubility. According to Cano-Chauca *et al*. (2005), maltodextrin was mainly used in the process of spray drying due to its physical properties, such as high solubility in water. Grabowski *et al*. (2006) also reported that the water solubility index of sweet potato powder increased as the amount of maltodextrin increased.

Conclusion

Fruit juice powders have many benefits and economic potentials over their liquid counterparts such as reduced volume or weight, reduced packaging, easier handling and transportation, and much longer shelf life. The quality of spray dried food is quite dependent on the operating parameters. Thus, an understanding of factors affecting the product properties is required for the process optimization, in order to obtain products with better sensory and nutritional characteristics and better process yield.

References

Adhikari, B., Howes, T., Bhandari, B.R. and Troung, V. 2003. Characterization of the surface stickiness of fructose-maltodextrin solutions during drying. Drying Technology 21: 17–34.

Adhikari, B., Howes, T., Bhandari, B.R. and Troung, V. 2009. Effect of addition of maltodextrin on drying kinetics and stickiness of sugar and acid rich foods during convective drying: experiments and modeling.

Journal of Food Engineering 62: 53–68.
Allamilla-Beltran, L., Chanona-Prez, J.J., Jimnez-Aparicio, A.R. and Gutrrez-Lpez, G.F. 2005. Description of morphological changes of particles along spray drying. Journal of Food Engineering 67: 179–184.
Bemiller, J.N. and Whistler, R.L. 1996. Carbohydrates. In: Fenema, O. (Ed). Food Chemistry. Marcel Dekker, New York.
Bhandari, B.R., Snoussi, A., Dumoulin E.D. and Lebert, A. 1993. Spray drying of concentrated fruit juices. Drying Technology 11: 1081-1092.
Bimbenet, J.J., Bonazzi, C. and Dumoulin, E. 2002. Drying of foodstuffs. In : Proceeding of the 13th international drying symposium, 64-80.
Cai, Y.Z. and Corke, H. 2000. Production and properties of spray-dried Amaranthus betacyanin pigments. Journal of Food Science 65: 1248–1252.
Cano-Chauca, M., Stringheta, P.C., Ramos, A.M. and Cal-Vidal, J. 2005. Effect of the carriers on the microstructure of mango powder obtained by spray drying and its functional characterization. Innovative Food Science and Emerging Technologies 6: 420-428.
Chegini, R.G. and Ghobadian, B. 2005. Effect of spray-drying conditions on physical properties of orange juice powder. Drying Technology 23: 657-668.
Chegini, R.G. and Ghobadian, B. 2007. Spray dryer parameters for fruit juice drying. World Journal of Agricultural Science 3: 230-236.
Chegini, R.G., Khazaei, J., Ghobadian, B. and Goudarzi, A.M. 2008. Prediction of process and product parameters in an orange juice spray dryer using artificial neural networks. Journal of Food Engineering 84: 534–543.
Dolinsky, A., Maletskata, Y. and Snezhkin, Y. 2000. Fruit and vegetable powders production technology on the bases of spray and convective drying methods. Drying Technology 18: 747-758.
Dolinsky, A. 2001. High-temperature spray drying methods. Drying Technology 19: 785-806.
Finney, J., Buffo, R. and Reineccius, G.A. 2002. Effects of type of atomization and processing temperatures on the physical properties and stability of spray-dried flavors. Journal of Food Science 67: 1108–1114.
Gabas, A.L., Telis, V.R.N., Sorbal, P.J.N. and Telis-Romero, J. 2007. Effect of maltodextrin and Arabic gum in water vapor sorption thermodynamic properties of vacuum dried pineapple pulp powder. Journal of Food Engineering 82: 246–252.
Goula, A.M. and Adamopoulos, K.G. 2004. Influence of spray drying conditions on residue accumulation—Simulation using CFD. Drying Technology 22: 1107-1128.
Goula, A.M. and Adamopoulos, K.G. 2005. Stability of lycopene during spray drying of tomato pulp. LWT-Food Science and Technology 38: 479–487.
Goula, A.M. and Adamopoulos, K.G. 2005. Spray drying of tomato pulp in dehumidified air: II. The effect on the powder properties. Journal of Food Engineering 66: 35-42.
Goula, M.A. and Adamopoulos, G.K. 2008. Effect of maltodextrin addition during spray drying of tomato pulp in dehumidified air: II. Powder properties. Drying Technology 26: 726-737.
Goula, M.A. and Adamopoulos, G.K. 2010. A new technique for spray drying orange juice concentrate. Innovative Food Science and Emerging Technologies 11: 324-351.
Gharsallaoui, A., Roudaut, G., Voilley, C.O. and Saurel, R. 2007. Applications of spray-drying in microencapsulation of food ingredients: An overview. Food Research International 40: 1107-1121.
Grabowski, J.A., Truong, V.D. and Daubert, D.R. 2006. Spray drying of amylase hydrolyzed sweetpotato puree and physicochemical properties of powder. Journal of Food Science 71: E209–E217.
Greenwald, C.G. and King, C.J. 1981. The effects of design and operating conditions on particle morphology for spray dried foods. Journal of Food Process Engineering 4: 171–187.
Jinapong, N., Suphantharika, M. and Jamnong, P. 2008. Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration. Journal of Food Engineering 84: 194–205.
Jittanit, W., Niti-Att, S. and Techanuntachikul, O. 2010. Study of spray drying of pineapple juice using maltodextrin as an adjunct. Chiang Mai Journal of Science 37: 498-506.
Keogh, M.K., Murray, C.A. and O'Kennedy, B.T. 2003. Effects of ultrafiltration of whole milk on some properties of spray-dried milk powders. International Dairy Journal 13: 995–1002.
Knipschildt, M.E. 1986. Recent Developments in Spray Drying of Milk. APV, Denmark.
Kwapinska, M. and Zbicinski, I. 2005. Prediction of final product properties after co-current spray drying. Drying Technology 23: 1653–1665.
Masters, K. 1979. Spray drying handbook. New York. Halsted Press.
Masters, K. 1979. Spray drying fundamentals: Process stages and layouts. New York: Halsted Press.
Masters, K. 1986. Spray drying: The unit operation today. Indian Journal of Science and Technology 60: 53–63.
Murugesan, R. and Orsat, V. 2011. Spray Drying for the Production of Nutraceutical Ingredients-A Review. Food Bioprocess Technology 8: 1-12.
Nijdam, J.J. and Langrish, T.A.J. 2006. The effect of surface composition on the functional properties of milk powders. Journal of Food Engineering 77: 919–925.
Oakley, D.E. and Bahu, R.E. 2000. Spray/gas mixing behavior within spray dryers. In A. S. Mujumdar and I. Filkova (Eds). Drying. Amsterdam: Elsevier.
Obón, J.M., Castellar, M.R., Alacid, M. and 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. Journal of Food Engineering 90: 471–479.
O'hagan, P., Hasaoidis, K., Coder, A., Helsing, H. and Pokraja, G. 2005. Particle size analysis of food

powders. In Onwulata, C. (Ed). Encapsulated and Powdered Foods. Taylor and Francis, Boca Raton.

Papadakis, S.E., Gardeli, C. and Tzia, C. 1998. Raisin extract powder: Production, physical and sensory properties. In: Proceedings of the 11th international drying symposium IDS ’98, Halkidiki, Greece.

Patel, R.P., Patel, P.M. and Suthar, M.A. 2009. Spray drying technology: an overview. Indian Journal of Science and Technology 10: 44-47.

Quek, Y.S., Chok, N.K. and Swedlund, P. 2007. The physicochemical properties of spray-dried watermelon powders. Chemical Engineering and Processing. 46: 386-392.

Reineccius, G.A. (2001). Multiple-core encapsulation - the spray drying of food ingredients. In P. Vilstrup (Ed). Microencapsulation of Food Ingredients. Leatherhead Publishing, Surrey,U.K.

Righetto, A.M. and Netto, F.M. 2005. Effect of encapsulating materials on water sorption, glass transition and stability of juice from immature acerola. International Journal of Food Properties 8: 337–346.

Rodriguez-Hernandez,G.R.,Gonzalez-Garcia,R.,Grajales-Lagunes, A. and Ruiz-Cabrera, M.A. 2005. Spray-drying of cactus pear juice (*Opuntia streptacantha*): Effect on the physicochemical properties of powder and reconstituted product. Drying Technology 23: 955–973.

Roos, Y. and Karel, M. 1991. Water and molecular weight effects on glass transitions on amorphous carbohydrates and carbohydrate solutions. Journal of Food Science 56: 1676-1681.

Sagar, V.R. and Suresh Kumar, P. 2010. Recent advances in drying and dehydration of fruits and vegetables: a review. Journal of Food Science and Technology 47: 15-26.

Shrestha, A.K., Ua-arak, T., Adhikari, B.R., Howes, T. and Bhandari, B.R. 2007. Glass transition behavior of spray dried orange juice powder measures by differential scanning calorimetry (DSC) and thermal mechanical compression test (TMCT). International Journal of Food Properties 10: 661–673.

Toneli, J., Park, K.J., Murr, F. and Negreiros, A. 2006. Spray drying optimization to obtain inulin powder. In: Proceedings of the 15*th* International Drying Symposium (IDS 2006), Budapest, Hungary.

Tonon, V.R., Brabet, C. and Hubinger, M. 2008. Influence of process conditions on the physicochemical properties of acai powder produced by spray drying. Journal of Food Engineering 88: 411-418.

Tonon, V.R., Brabet, C. and Hubinger, M. 2011. Spray drying of acai juice: Effect of inlet temperature and type of carrier agent. Journal of Food Processing and Preservation 5: 691-700.

Tonon, V.R., Brabet, C., Pallet, D., Brat, P. and Hubinger, D.M. (2009). Physicochemical and morphological characterization of acai powder produced with different carrier agents. International Journal of Food Science and Technology 44: 1950-1958.

Truong, V., Bhandari, B.R. and Howes, T. 2005. Moisture and glass optimization of co-current spray drying process of sugar rich foods: transition temperature profile during drying. Journal of Food Engineering 71: 55–65.

Walton, D.E. 2000. The morphology of spray-dried particles. A qualitative view. Drying Technology 18: 1943–1986.

Yousefi, S., Emam-Djomeh, Z. and Mousavi, M.S. 2011. Effect of carrier type and spray drying on the physicochemical properties of powdered and reconstituted pomegranate juice (*Punica Granatum* L.). Journal of Food Science and Technology 48: 677-684.