ASEAN Journal of Chemical Engineering 2022, Vol. 22, No. 2, 228 – 247

Effect of Carrier Agents and Operational Parameters on the Physical Quality of Spray-Dried Tomato Powder: A Review

S M Anisuzzaman[*,1]
Collin G. Joseph[*,2]
Janice L. H. Nga[3]
Fatin Nadiah Ismail[1]
[1]*Chemical Engineering Programme, Faculty of Engineering,*
Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia.
[2]*Industrial Chemistry Programme, Faculty of Science and Natural Resources, Universiti Malaysia. Sabah, 88400 Kota Kinabalu, Sabah, Malaysia*
[3]*Planning and Development Economics Programme, Faculty of Business, Economics and Accountancy, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia.*
*****e-mail: anis_zaman@ums.edu.my ; collin@ums.edu.my

Submitted 23 December 2021 *Revised* 14 October 2022 *Accepted* 27 October 2022

Abstract. Tomatoes are one of the most frequently consumed crops in the world, and they can be cultivated all year using present production methods. Tomatoes are produced for either manufacturing tomato paste, tomato pulp, tomato sauce, and ketchup or consumed as fresh fruit. However, excessive moisture levels in tomatoes generally result in increased water activity that promotes quality degradation and increases enzymatic activity, which leads to microbial growth. Therefore, the spray drying method is used to produce dried food powder, which may reduce postharvest losses while adding value to the raw product. The purpose of the paper is to review scientific research on the influence of carrier agents and operational parameters of spray-drying fruit extracts on physicochemical qualities such as moisture content, hygroscopicity, solubility, bulk density, water activity, and color difference. The current paper reviews the various formulation and process factors that impact the physicochemical characteristics of tomato powder microparticles produced by spray drying in order to find the optimum parameters to produce tomato powders with a high and effective product yield with improved powder qualities.

Keywords: Carrier agents, Gum Arabic, Lycopene, Maltodextrin, Pectinase, Spray Drying

INTRODUCTION

Tomato fruit is well known for its high nutritional content and health-promoting effects. However, it has a short shelf life of fewer than 2 weeks as it is easily spoiled and perishes due to the natural physiological process, incidence and severity of external injury during the harvesting process, handling, and storing, together with the growth of microbiological and parasitic microorganisms (Gharib et al., 2020, Swetha and Lalunaik, 2018, Kader, 2013). Therefore, drying tomatoes is widely applied in the food industry to increase the shelf-life of foods as dehydration can lead to a low water content, eventually slowing its chemical, physical and biological degradation. Improving the downstream benefits of tomato products brings economic

DOI: 10.22146/ajche.71487

considerations for the social uplifting of the farmers and the surrounding communities. This, in turn, reduces the possibility of overproduction of similar crops and stabilizes the price of this product in the market while generating a stable income for the farmers and other sectors involved in producing, transporting, and exporting tomato powder.

Foods must be preserved to maintain their quality for a longer time since nutritional values, color, texture, and edibility of foods are prone to deteriorate. Food preservation refers to the techniques or methods used to maintain internal and external variables that might cause food spoilage. The primary importance of food preservation is to extend its shelf life while maintaining nutritional content, color, texture, and taste (Amit et al., 2017). Several procedures have been recommended to improve the shelf-life of food products, such as drying, storing in vinegar under acidic conditions, canning, freezing, fermenting, dry salting, curing, smoking, and sealing (Niakousari et al., 2017). There are several techniques for food preservation, including conventional methods and modern preservation technologies. The drying process is one of the traditional processes that have been improved over time to benefit the significant food industry (Sharif et al., 2017). There are various drying processes, such as natural dryings such as sun drying or simulated drying under controlled temperatures, using specially developed chambers called dehydrators or dryers (Sharangi and Datta, 2015).

However, food drying operations help in water removal and cause changes in taste, flavor, appearance, texture, and nutritional value. Thus, it may decrease the final product quality and sometimes cause dissatisfaction due to its quality. Zhu et al. (2014) stated that a lack of fresh tomato flavor is the main reason for consumer dissatisfaction with tomato products. The final product quality is determined by spray dryings process parameters such as feed concentration, inlet, and outlet air temperature, feed flow rate, compressor air flow rate, drying flow rate, atomizer type, and atomizer speed (Fazaeli et al., 2012). Recovery of powder in spray drying fruit and vegetables is challenging owing to low molecular weight sugars such as glucose and fructose. Eventually, the high hygroscopicity, thermoplasticity, and low glass transition temperature (T_g) of these low molecular weight substances become part of the cause of the stickiness problem. The resulting spray-dried powders could frequently lose their original color due to the high carrier agent concentration and high drying temperature. According to Gharsallaoui et al. (2007), among the various methods for microencapsulating food components, spray drying is the most often implemented technology in the food industry due to the low cost and the availability of equipment.

Relying on the physical and chemical characteristics of the solution feed and the operating circumstances, the spray dryer helps to produce dried products in powder form, grain, or lumps (Raghavan and Orsat, 2007). Spray drying is also regarded as the most cost-effective drying process, as it requires low operating costs and is one of the most effective drying processes for converting raw fluid material into solid or semi-solid particles (Murugesan and Orsat, 2011). The spray-drying method is more economically efficient than the freeze-drying method, which consumes a longer time and energy (De Jesus and Maciel Filho, 2014, Barbosa et al., 2015). Spray drying entails elaborate interactions of process, equipment, and feed elements, affecting the quality of the end product (Chegini and Ghobadian, 2007). The spray drying method has the potential to create a high-quality final product with minimal water activity while also reducing weight, making it much easier for storage and transportation. The physicochemical characteristics of the final product are primarily determined by the input temperature, air flow rate, feed flow rate, atomizer speed, carrier agent type, and concentration of the carrier agent. The spray drying method is preferable because it is quick and offers relative control over particle size distribution (Obon et al. 2009). The typical water activity and moisture content ranges for spray-dried powder are 0.2% to 0.6% (Shishir and Chen, 2017, Patil et al., 2014). According to Tan et al. (2011), powdered products highly resist microbiological activities and have low oxidative losses. With low particle size powder, spray-dried products have higher bulk density simultaneously (Barbosa-Cánovas and Juliano, 2005).

The main factors that influence the consistency of spray-dried microcapsules are the spray drier's processing index and the feed solution's properties or constitution (Hu et al. 2016). However, sensitive compounds such as lycopene, β-carotene, anthocyanins, vitamin C, colors, and flavors may be influenced by the high temperature of drying, regardless of the multiple benefits shown by this process. In addition, this technique often leads to a low yield of product due to the losses of dry particles in the drying vessel wall (Zhu et al., 2014). Furthermore, a wide range of size distribution is induced by the absence of droplet size and shape regulation (Ozkan et al., 2019).

Furthermore, several studies have shown that the key downside of spray drying fruit and vegetables is difficulty drying (Shishir and Chen, 2017, Bhandari et al., 1997). They can remain as syrup during the drying process, stick on the dryer wall, or form undesired accumulations in the dryer chamber and transport system during the drying process, leading to lower product yields and operating problems (Krishnaiah et al., 2015, Krishnaiah et al., 2014). According to Karaca et al. (2016), poor product recovery is due to the stickiness issue of the food materials. The stickiness issue is correlated with the existence of compounds rich in sugars and organic acids, i.e., fructose, glucose, sucrose, malic acid, citric acid, and tartaric acid. These compounds have low molecular weight with low T_g change. According to Fazaeli et al. (2012), stickiness occurs when the molecular mobility of the responsible compounds is improved, and this results in a weak-flowing product and limited product recovery when the drying temperature is greater than 20°C above T_g. A yield percentage value of more than 50% is considered a good drying value for sticky products (Karaca et al., 2016). For example, spray drying sugar-dried materials is impossible without adding any carrier agents to raise the T_g of the (Tontul and Topuz, 2017). Material-based, process-based, and combined methods can solve the stickiness issue throughout the spray-drying process of sugar-rich materials (Sobulska and Zbicinski, 2020). Adding a carrier with a high T_g in the material-based method helps to increase the Tg of fruit juice and honey.

Meanwhile, process-based approaches are being developed to change the parameters of the spray drying process to counteract the powder's stickiness problem. The approaches include using drying chamber surface scraping, cooling the spray dryer walls, and lowering the outlet air temperature towards the end of the drying process to retain the product temperature below the sticky point (Sobulska and Zbicinski, 2020). In the meantime, spray drying has a low thermal efficiency since hot air flows in a wide volume of the drying chamber without interacting with the spray droplets (Shishir and Chen, 2017). In addition, Dalmoro et al. (2012) reported that there is limited control over the size of droplets in spray drying, which might result in large particle distribution and often irregular microstructure. Due to the low T_g of the present low molecular weight sugars, spray drying tomato slurry is extremely challenging. It may adhere to the dryer wall or create undesirable accumulations in the dryer chamber, resulting in decreased powder yields and operational issues. Hence, maltodextrin and an anti-caking agent need to be added to the feed to overcome the problem. Therefore, several steps have been taken to solve this issue, including introducing high molecular weight of carrier agents to improve the temperature of the feed mixture's T_g, using low humidness and temperature drying conditions, and changing the properties surfaces of atomized droplets by adding proteins such as whey, casein and soy protein (Muzaffar et al., 2015).

Several studies have been conducted on the effects of different carrier agents on process parameters and the qualities of spray-dried goods. However, there is a scarcity of review articles that provide in-depth insight into the effects of different carrier agents on the varied physical characteristics of powders. This study focuses on practical knowledge about carrier agents in spray-drying performance and the effects of various factors influencing the properties of spray-dried powder products.

ASPECTS RELATED TO SPRAY-DRIED POWDER QUALITIES

Moisture Content

Moisture content is the water composition in food, whereas water activity is the amount of free water accessible for biochemical processes in food, which affects its shelf life (Pui et al., 2020). According to Karaca et al. (2016), moisture content and water activity **(**A_w**)** are crucial parameters for spray-dried powders since they reflect overall drying performance. The reduced moisture content of spray-dried powders restricts the potential of water to serve as a plasticizer, which impacts powder caking during storage (Santana et al., 2017, Tonon et al., 2011). Pui et al. (2020) mentioned that powders with moisture content lower than 10% are considered to be microbiologically safe.

Water Activity (A_w)

A_w is an essential parameter for spray-dried powders since it influences the product's shelf life. Increasing water activity implies increasing the quantity of free water accessible for deteriorative interactions, reducing shelf life (Vardin and Yasar, 2012). Even though there may be a relationship between overall moisture content and food-water activity, this relationship does not have to be present at all times (Bicudo et al., 2015). Powders having an A_w lower than 0.3 are considered to be microbiologically and chemically safe (Tonon et al., 2011).

Glass Transition Temperature (T_g)

According to Ferrari et al.(2013), the T_g is a helpful indication of storage stability. For a spray-dried product to be stable, the T_g ought to be at least 20ºC higher than the ambient storage temperature. As predicted by the model stated by Karaca et al. (2016), the significant parameters influencing the Tg are the feed flow rate, sour cherry content, and carrier type. According to Tontul and Topuz (2017), the glass transformation of the powder is primarily affected by the constitution of the raw material (due to the low T_g of acids and sugars) and the water content of the final product. The powder is converted into a sticky shape by slightly increasing moisture content. Therefore, spray-dried materials must be stored in a water-tight container and kept below the (Tontul and Topuz 2017). In the study by Goula and Adamopoulos (2008) for the spray drying tomato pulp in dehumidified air, the T_g of tomato powder is found to be increasing with the decreasing dextrose equivalent (DE) of maltodextrin.

Hygroscopicity

Hygroscopicity is measured as the capability of the food powder to absorb moisture from its surrounding (Rodrguez-Hernandez et al., 2005). The capacity of a food powder to absorb moisture from its surroundings is assessed as hygroscopicity (Rodrguez-Hernandez et al., 2005). It is preferable to produce food powder with a low hygroscopicity, as high hygroscopicity has a larger propensity to take up water and induce powder stickiness during storage (Tontul and Topuz 2017). Fazaeli et al. (2012) stated that the spray-dried powders become more hygroscopic when the drying temperature is 20°C higher than the T_g because the molecular mobility of the associated compounds is increased. However, the powder is not considered very hygroscopic if the powder has less than 20% hygroscopicity (Nurhadi et al. (2012). It is better to produce food powder with a low hygroscopicity as larger hygroscopicity implies a higher inclination to absorb water and develop stickiness (Tonon et al. 2008). The powder's hygroscopicity is usually linked to its composition, the concentration and type of the carriers, and the powder particle size (Du et al. 2014).

Water Solubility

The most reliable approach for assessing powder behavior in an aqueous solution is solubility, or the capacity of powders to dissolve in a solution or suspend in water. This characteristic indicates the spray-dried powder's capacity to create a solution or suspension in water. Higher solubility is preferable, specifically if the powder is employed as an ingredient in the manufacturing of various goods. A powder’s solubility is controlled by raw material qualities, carrier material properties, and powder parameters like moisture content, particle size, and particle physical state in which it is more soluble in an amorphous state (Tontul and Topuz, 2017). The solubility of powdered products is another essential quality attribute that can directly impact the reconstitute behavior of spray-dried food products.

Color Characteristics

Food color is one of the most significant sensory characteristics influenced by several variables throughout the spray drying process, for instance, drying temperature and carrier agents (Abadio et al., 2004). Lycopene, which is accountable for the tomato's red color, can be diminished by heat processing. This characteristic can be influenced during spray drying by air conditions such as the flow rate and inlet or outlet temperature, the feed conditions such as the addition of carrier agents and feed flow rate, and the speed of atomization, among other aspects (Cai and Corke, 2000). Aside from that, the carrier material's greater concentration, natural hue, and non-enzymatic browning reactions of sugars at high drying temperatures affect the product's color. The color characteristic will be analyzed with a laboratory spectrophotometer, where the total color difference of the powder will be calculated. A color difference of 0 to 1.5 is regarded as minimal, and based on the visual observation, it does nearly identical. However, the color difference may be recognized if the color difference is between the ranges of 1.5 to 5. The total color difference above 5 indicates that the color difference is highly obvious (Obon et al., 2009).

Particle Size

Another significant physical property of powders is particle size, which impacts their handling, transportation, and storage features. Furthermore, particle size influences the stability of functional elements susceptible to environmental conditions (Shi et al., 2013). This is also supported by Ferrari et al. (2013), in which the exposed surface area of the particle to the environmental factors gets larger when the particle size is smaller; thereby, the degradation of sensitive compounds increases. Another literature by Gong et al. (2007) stated that small particle size (<50 µm) of spray-dried powders regards poor handling and reconstitution properties. In addition, the particle size relies on the temperature of inlet drying (Shishir and Chen, 2017). Spray-dried powders with tiny particle sizes lower than 50 mm imply poor handling and reconstitution characteristics (Gong et al., 2007).

Bulk Density

Bulk density is higher in powders with a fine and consistent surface (Tontul and Topuz, 2017). Powders having a lower bulk density require more packing capacity to hold the same quantity of material (Bicudo et al., 2015). In general, bulk density increases as particle size decreases because more particles fill a given volume, allowing fewer empty areas between particles (Grabowski et al., 2006). It is preferable to have a high bulk density in order to save money on transportation and packaging (Movahhed and Mohebbi, 2016). Furthermore, bulk density has an impact on other powder characteristics such as flow ability and solubility (Bicudo et al., 2015).

FACTORS INFLUENCING THE PROPERTIES OF SPRAY-DRIED POWDER PRODUCTS

Parameters of spray drying, such as inlet air drying temperatures, air flow rate, feed flow rate, atomizer speed, carrier agent type, and concentration, all have an impact on the physical quality of spray-dried foods (Chegini and Ghobadian, 2005, Chegini and Ghobadian, 2007, Yousefi et al., 2011).

Effect of The Inlet Air Drying Temperatures

The temperature of the inlet air impacts powder characteristics, including moisture content, particle size, bulk density, hygroscopicity, and morphology. The spray-dry method for food powder generally has an inlet temperature of 150-220°C (Chegini and Ghobadian, 2005). When the drying temperature is increased, the moisture content will be lower, and the drying rate will become higher. Identical outcomes were found with several powdered fruit juice, including acai juice, gac fruit aril powder, pineapple juice, tomato juice, and watermelon juice (Tonon et al., 2011, Goula and Adamopoulos, 2008; Kha et al., 2010, Jittanit et al., 2010, Quek et al., 2007). The larger the difference in the temperature between the drying air and the atomized feed at greater inlet air temperatures, the better the water evaporation driving force.

Moreover, the temperature of the inlet air influences the powder's bulk density (Tonon et al., 2008). Drying at an increasing inlet temperature usually results in faster-dried layer development on the particle size and surface of the droplet and casehardening on the droplets. This causes the droplet surface to develop vapor-impermeable films, causing the production of vapor bubbles and, as a result, droplet enlargement (Finney et al., 2002). In terms of bulk density produced by spray drying, as the drying temperature is increased, a decrease in the bulk density can be observed (Kha et al., 2010, Walton, 2000, Sun et al., 2016). Meanwhile, the bulk density is inconsistent when the temperature increases (Chang et al., 2020). Other than that, the final product's particle size is also influenced by the spray drying's input temperature (Tonon et al., 2011, Chegini and Ghobadian, 2005, Tran and Nguyen, 2018, Nazir et al., 2018, Nijdam and Langrish, 2006). According to Nazir et al. (2018), drying at a greater temperature contributes to faster drying rates, leading to the primary development of a structure during the drying process, preventing the particles from shrinking. An elevation in the incoming air's temperature tends to lead to the fast development of a dried layer on the droplet surface which hardens the skin, thus, preventing moisture from escaping the droplet (Chegini and Ghobadian, 2005, Nijdam and Langrish, 2006). The particle size distribution has a significant role in shelf life, handling, and processing, and the microstructure of the powder is connected to powder stability, flowability, and functionality (Singh et al., 2006).

The temperature of the inlet air affects the hygroscopicity of the powder, where the hygroscopicity is the ability to absorb surrounding moisture (Tonon et al. (2008), Goula et al., 2004). The greater the temperature for drying, the lesser the moisture level and the greater the hygroscopicity. Alternatively, an increment in the input air temperature reduces the quantity of powder produced, thus reducing the yield (Chegini and Ghobadian, 2007, Dolinsky et al., 2000). Furthermore, Tonon et al. (2011) also testified that the inlet temperature impacted the morphology of acai juice powder. According to Alamilla-Beltrán et al. (2005), lower input air temperatures will likely result in a much more flexible and collapsed crust. Nijdam and Langrish (2006) also verified the production of many rigid particles while spray-drying milk at higher temperatures.

The temperature of the inlet air substantially affects the colors of dried powder. The influence of inlet temperature on Β-carotene and lycopene stability in watermelon juice powder was investigated by Quek et al. (2007) using a temperature inlet of 145 to 175°C. The results revealed that the lycopene concentration dropped as the inlet temperature increased. A comparable outcome was made on spray-drying tomato pulp by Goula and Adamopoulos (2008). The results show a decrease in lycopene concentration which was most likely caused by heat degradation and oxidation. The high drying temperature may influence sensitive compounds such as lycopene, β-carotene, anthocyanins, vitamin C, colors, and flavors, regardless of the multiple benefits shown by this process. Zhu et al. (2014) mention that this technique often leads to a low product yield due to the dry particle losses in the drying vessel wall.

Effect of The Air Dry Flow Rate

The moisture content of tomato powder increases as the drying air flow rate also increases (Goula and Adamopoulos, 2005). Due to the sticky nature of the product, the influence of drying air flow rate toward powder bulk density is dependent on its effect on moisture content. Increasing the air flow rate results in a rise in the powder moisture content and a decrease in the powder bulk density (Santos et al., 2017). Furthermore, the dry flow rate of air affected powder solubility. The influence of the drying air flow rate on powder solubility depends on the effect of the drying air flow rate on powder moisture content, as low moisture content appears to be linked with rapid dissolution. The increase in air flow rate resulted in a rise in powder moisture content and a reduction in powder solubility (Papadakis et al., 1998). According to Chegini and Ghobadian (2007), a higher feed flow rate leads to a poorer process yield.

As the input flow rate rises, the moisture content of spray-dried powder increases. According to Banat et al. (2002), increasing the input flow rate increases particle size and bulk density. The drying air flow rate into the drying chamber is another essential component in spray drying since the energy required for evaporation changes based on the drying air supply in the drying chamber. A decreased drying airflow rate prolongs the drying time of the droplets and improves the circulatory systems (Goula et al., 2004, Goula and Adamopoulos, 2004). Goula and Adamopoulos (2005) discovered that increasing the spray drying air flow rate ranging from 17.5 to 22.75 m^3/h increased the moisture content in tomato pulp powder. Furthermore, lycopene loss in tomato pulp powder increases when the drying air flow rate increases.

Feed Flow Rate

The increased feed flow rate had a detrimental influence on process yield, leading to reduced heat transfer, mass transfer, and poorer process yield (Tonon et al., 2008). Furthermore, when greater feed rates were employed, leaking could be observed into the main chamber when the mixture was delivered directly into the chamber without being atomized, leading to a decreased process yield. A report by Toneli et al. (2010) demonstrated a rise in mass production rate with rising air temperatures and reduced pump speeds. Chegini and Ghobadian (2007) discovered that raising the feed flow rate enhanced wall deposit while decreasing yield. More liquid was atomized into the chamber with a constant atomizer speed and an increasing feed flow rate, resulting in a shorter drying period and leading to improper drying.

Atomizer Speed

Chegini and Ghobadian (2005) investigated the influence of atomizer speed (10,000-25,000 rpm) on the characteristics of orange juice powder. When the atomizer speed was increased, the residual moisture content dropped. Smaller droplets were formed at faster atomizer speeds, and more moisture was evaporated due to the increased contact surface. The higher atomizer speed dispersed the liquid into a thin film layer, reducing droplet and particle sizes—furthermore, the greater the atomizer speed, the larger the bulk density. Simultaneously, the higher atomizer speed given to a droplet to distribute it across a wider surface has a smaller particle size and bulk density.

Types of Carrier Agents

Stickiness due to the sugar-rich material, deposition of the wall, and low yield are among the most common problems faced with the spray drying process. Due to the existence of acids and low molecular weight sugars that have a T_g, spray-dried fruit juice powder may show certain properties like solubility, hygroscopicity, and stickiness (Bhandari et al., 1997, Jittanit et al., 2010). As a result, the powder might adhere to the dryer chamber wall during the drying process, resulting in operational issues and reduced product yield. The very sticky products are formed by the dry solids' high-water solubility, high hygroscopic, low melting point, and low T_g. Roos and Karel (1991) reported that these amorphous solid constituents are extremely hygroscopic and have a loose, free-flowing nature and high moisture content. These issues may be addressed by incorporating certain encapsulating materials, like gums or polymers, into the product before atomization. One of the most usual mitigation taken is applying a carrier agent into the drying process. This is another crucial factor in spray drying fruit or vegetable because the sugar-rich materials in the fruit or vegetable juices can cause difficulties in spray drying if it is directly dried without carrier agents. Carrier agents are common in spray drying because they may enhance T_g and yield % while reducing the powdered product's stickiness and hygroscopicity. Furthermore, a carrier agent is employed for microencapsulation. The carrier agent can preserve delicate food components from harsh environmental conditions, conceal or retain the aromas and flavors, minimize reactivity and volatility, and give an extra appeal for food product retailing (Jittanit et al., 2010).

Several types of carrier agents are commonly used in spray dryings, such as gum Arabic, maltodextrin, gelatin, starches, pectin, methylcellulose, alginates, tricalcium phosphate, glycerol monostearate, and a few combinations of them ((Fazaeli et al., 2012, Shishir and Chen, 2016, Chang et al., 2020, Bazaria and Kumar, 2018, Liu et al., 2017). Normally, the selection of the carrier agent to be used in the spray drying process will depend on the objectives of the process as well as the physicochemical behavior of the material itself. It is important to ensure that the carrier agent used is certified with "generally recognized as safe" (GRAS) material for food application or in a short form; it must be food graded. The carrier agent used in the spray drying must have a high molecular weight and a high T_g to enhance the finished product's anti-adherence. According to Desai and Park (2005), the selected carrier agent must be able to maintain the sensitive compound in the material, especially from heat. Adding carrier agents of high molecular weight to the desired product before it is atomized is a popular alternative for increasing the Tg of powder (Truong et al., 2005, Yousefi et al., 2011).

Maltodextrins and gum Arabic are the typical carrier agents mostly used for fruit juices (Cano-Chuca et al., 2005, Gabas et al., 2007, Righetto and Netto, 2005). Maltodextrin is characterized by the dextrose equivalence (DE), which is conversely linked to the average molecular weight of the maltodextrins, as stated by Bemiller and

Whistler (1996). They are inexpensive and highly convenient for the spray drying of food products. Gum Arabic is a naturally occurring plant exudate derived from Acacia trees that are made up of complex heteropolysaccharides with a highly ramified structure. Gum Arabic is the only gum used in food processing as it has a low viscosity and is highly soluble in an aqueous solution, making spray drying much easier (Rodriguez-Hernandez et al., 2005). Goula and Adamopoulos (2008) investigated the influence of maltodextrin incorporating maltodextrin 6DE, 12DE, and 21DE on tomato powder characteristics. It was found that the greater the maltodextrin DE, the greater the moisture content in the powder.

Furthermore, increasing maltodextrin DE resulted in intensification in powder bulk density due to its stickiness. The greater the maltodextrin DE, the lower the T_g, and therefore the lesser the increase of the T_g in the fruit pulp-maltodextrin combination (Tonon et al., 2009). Powder solubility varied depending on the type of carrier agent employed. Starch is generally hard to dissolve in water, whereas maltodextrin is much more water-soluble.

Furthermore, Tonon et al. (2009) found that tapioca starch had the lowest solubility in powdered acai juice compared to the other carrier agents. The maltodextrin degree of polymerization also impacts the powder's hygroscopicity. According to Tonon et al. (2009), the degree of polymerization of maltodextrin is also impacted by powder particle size. The type of carrier agent has a substantial outcome on the morphology of the powder (Yousefi et al., 2011). The powder containing gum Arabic was discovered to contain the most amorphous fraction. Due to gum Arabic having a greater T_g point than the other two carriers and having a bigger molecular size, the powders formed by gum Arabic exhibited a lesser amorphous behavior after spray drying in opposition to maltodextrin and waxy starch.

The Concentration of Carrier Agents

The carrier agent concentration influenced the powder characteristics as well. A low concentration of carrier agent may result in forming of a sticky. Quek et al. (2007) studied the influence of maltodextrin concentrations of 0,3% and 5% on the characteristics of powdered watermelon juice. The feed with the addition of 5% maltodextrin seems to provide greater outcomes compared to the one with the addition of 3% maltodextrin. Maltodextrin is proposed to modify the stickiness of the surface of low molecular weight sugars such as sucrose, glucose, and fructose, along with organic acids, which eases drying and lowers the spray-dried product stickiness (Adhikari et al., 2003). The powder moisture content is likewise impacted by the carrier agent concentration. According to Goula and Adamopoulos (2008), the powder moisture content increased as maltodextrin concentration increased. According to Jittanit et al. (2010), increasing the maltodextrin content caused the moisture content in pineapple juice powder to decrease. This is because maltodextrin has the capacity to modify the sugar present in the fruit powder, which is extremely hygroscopic in nature and absorbs humidity from the adjacent air (Shrestha et al., 2007). Higher maltodextrin concentrations resulted in higher particles that might be attributed to an increasing feed viscosity that rose exponentially with the concentration of maltodextrin.

At constant atomizer speed, the liquid droplet means size changes along with the viscosity of the liquid. The greater the viscosity of the liquid, the bigger the formation of droplets during atomization, and consequently, these large particles are obtained by spray drying (Santos et al., 2017). The maltodextrin concentration was used to evaluate the hygroscopicity of the varied powders. The hygroscopicity of powder is reduced by a high concentration of maltodextrin. As the highest concentrations of maltodextrin were utilized, the lowest hygroscopicity values were achieved (Tonon et al., 2008, Cai and Corke, 2000, Rodriguez-Hernandez et al., 2005).

Furthermore, powder solubility does not decrease with the increased maltodextrin content. This difference might be attributable to maltodextrin's greater water solubility. As Cano-Chauca et al. (2005) stated, maltodextrin is commonly employed in the spray drying process mostly owing to its physical characteristics, such as high water solubility. Grabowski et al. (2006) also found that increased maltodextrin in powdered sweet potato enhanced its water solubility index. Table 1 summarizes the study of spray-dried tomato powder using different spray-drying conditions and carrier agents.

Table 1. List of reviewed studies of spray-dried tomato powder

No.	Fruit extract	Spray drying conditions	Carrier agent	Properties of powder	Effect of the spray drying variables towards product yield and powder properties	References
1	Tomato pulp	Inlet temperatures: 130, 140, 150°C Feed ratio (pulp/maltodextrin): 4.00, 1.00, 0.25 Atomizer pressure: 5.0 bar Feed rate: 1.75 g/min Feed solids concentration: 14% Feed temperature: 32.0°C Drying air flow rate: 22.75 m^3/h Compressed air flow rate: 800 l/h	21DE maltodextrin, 12DE maltodextrin, 6DE maltodextrin	Powder stickiness	The drying rate also increased when the inlet temperature increased. Higher DE decreases the drying rate. Wall deposits decreased with the increase in inlet temperature. The lower the DE, the lower the powder stickiness as Tg increases. The lower the ratio, the sooner the drop becomes complete. non-sticky A combination of lower DE maltodextrin and dehumidified air can overcome the powder stickiness efficiently.	Goula and Adamopoulos (2008)
2	Tomato pulp	Inlet temperatures: 130, 140, 150ºC Feed ratio (pulp/ maltodextrin): 4.00, 1.00, 0.25 Atomizer pressure: 5.0 bar Feed rate: 1.75 g/min Feed solids concentration: 14% Feed temperature: 32.0ºC Drying air flow rate: 22.75 m^3/h Compressed air flow rate: 800 L/h	21DE maltodextrin, 12DE maltodextrin, 6DE maltodextrin		The moisture content decreases as the inlet air temperature increases. The moisture content increases as maltodextrin concentration increases. Higher DE of maltodextrin results in higher moisture content Increased inlet temperature causes a reduction in bulk density (large particle size) Increased maltodextrin concentration reduced bulk density High DE of maltodextrin increased bulk density. An increase in inlet temperature increases the solubility.	Goula and Adamopoulos (2008)

				Higher DE of maltodextrin reduced the solubility. High maltodextrin concentration reduced solubility. Powder hygroscopicity decreases with an increase in inlet temperature and maltodextrin concentration. High DE maltodextrin increases powder hygroscopicity. The quality of the powder is better when the moisture content and the hygroscopicity are low, with high bulk density and solubility.	
3	Tomato juice	Inlet temperature: 200, 210, 220°C Feed flow rate: 127, 201, 276 g/min Atomization: 25000, 30000, 35000 rpm Outlet air temperature: 90°C Blower velocity: 30000 rpm	10DE maltodextrin (10%)	The controlled variable did not significantly affect the moisture content, solubility, and wettability compared to color. A decrease in inlet temperature and atomization speed leads to better color retention of tomato powder. While flow rate affected less significantly on the color properties. An atomization speed of 25000 rpm and inlet temperature of 200°C is optimum for the preservation of powder color and good reconstitution properties.	Sousa et al., 2008
4	Tomato pomace	Inlet temperature: 110-200°C Carrier agent concentration: 5-35%	Inulin; Gum Arabic	An increase in carrier agent concentration caused an increase in particle size Inulin produced powders with the smoother outer surface, whereas the gum Arabic particles showed the formation of teeth or concavities Encapsulation efficiency is better with inulin compared to gum Arabic. Better lycopene retention by inulin compared to gum Arabic. Drying yield is better with inulin as a carrier agent and a higher drying temperature. A high concentration of carrier agents caused the drying yield to decrease. Inulin addition as a carrier agent showed better quality of tomato powder than gum Arabic, but both carrier agents have successfully encapsulated the tomato pomace.	Corrêa-Filho et al., 2019

5	Tomato concentrate	Compressed air pressure: 350 kPa Drying air flowrate: 700 l/h Feed flow rate: 34 mL/min Inlet temperatures: 160ºC Outlet temperature: 80ºC Feed concentration ratio: 1:3 The concentration of carrier agent: 33, 50, 100%	Maltodextrin Whey protein isolate Modified starch	Moisture content: Modified starch > Maltodextrin >Whey protein isolate; Solubility & hygroscopicity: Maltodextrin > Modified starch > Whey protein isolate Lycopene content: Maltodextrin > Modified starch > Whey protein isolate Maltodextrin and modified starch, as well as the combination of both, were the encapsulating agents that offered the best lycopene preservation throughout drying and storage.	Souza et al., 2018
6	Tomato pulp	Inlet temperature: 210, 200, 220ºC Feed flow rate: 127, 201, 276 g/min Atomization speed: 25000, 30000, 35000 rpm	10 DE maltodextrin	High temperature and low feed flow rate reduced the moisture content. Atomization speed shows no significance on the moisture content. High inlet temperature, low feed flow rate, and high atomization speed reduced apparent density. High atomization speed and low feed flow rate reduced particle size.	Souza et al., 2009
7	Tomato pulp	Inlet temperature: 110, 120, 130, 140ºC Drying air flow rates: 17.50, 19.25, 21.00, 22.75 m^3/h Atomizing agent: 500, 600, 700, 800 l/h. Atomizer pressure: 5 bar Feed rate: 1.75 g/min Feed temperature: 32ºC	None	High inlet temperature, high compressed flow rate, and high drying rate increased the degradation of lycopene.	Goula and Adamopoulos (2005)

FUTURE TREND OF SPRAY DRYING ON THE PRODUCTION OF TOMATO POWDER

Spray drying is widely utilized in the food sector due to its performance in producing products with good physical characteristics, a much rapid drying time, and the economic possibilities for scaling up. On the other hand, spray drying is typically done at high temperatures (150-250oC), which results in the loss of heat-sensitive nutrients such as anthocyanins, carotenoids, flavonols, and vitamin C, and so on (Goula and Adamopoulos., 2008). Tomatoes are nutrient-dense vegetables as it contains high-powered antioxidants such as beta-carotene, vitamin C, and lycopene which are sensitive to heat. Recent studies have addressed this constraint by integrating various techniques with spray drying, one of which is dehumidified air spray drying, established by Goula and Adamopoulos (2005). Dehumidified air spray drying systems exhibit improved performance compared to conventional spray drying in terms of reducing stickiness and enhancing powder recovery. This drying technique gives a powdered product lower moisture content and a higher bulk density than usual spray drying (Goula et al., 2004).

In the research of dehumidified air spray drying of tomato pulp, the drying approach has higher powder recovery compared to traditional spray drying, as well as lowered outlet temperature and drying air humidity, resulting in the smooth formation of microsphere crust and minimal wall deposition. Lower output temperature and humidity in this drying method may aid in reducing thermal or oxidative losses of sensitive chemicals. Tomato pulp powder had significantly reduced moisture content and a much greater bulk density in comparison to conventional spray drying (Goula and Adamopoulos, 2005). Moisture content in powdered products can influence powder flow ability, stickiness, and shelf life, and this is due to the plasticizing and crystallization properties. The powdered product's high bulk density with low moisture content is preferred for packing and storage. Hence, dehumidified air spray drying is more favorable compared to conventional spray drying for producing better powder product qualities.

Furthermore, low output temperature and humidity can preserve sensitive functional components from thermal or oxidative losses in dehumidified air spray drying. In conclusion, novel spray-drying trends will likely increase the performance of spray-drying fruit and vegetable juices. Despite the fact that available research on this approach has been limited, the findings are promising. Traditional spray drying may be enhanced by integrating it with modern techniques, such as ultrasonic atomization and dehumidifying air supply systems. The drying performance and product quality can be enhanced by incorporating the advantages of ultrasonic atomization and a dehumidifying air supply system into conventional spray drying.

CONCLUSIONS

Spray drying is an appropriate approach compared to the other drying methods in producing fruit and vegetable powdered products. This is due to its ability to generate a high yield of powder in various sizes while consuming little energy and time. The resulting products are of excellent quality, possessing great powder characteristics such as low hygroscopicity, low moisture, and high bulk density. Different elements of the spray dryer were reviewed, and each portion of the spray dryer is critical to ensuring the high efficiency of the drying process. According to the literature reviews, as mentioned above, the moisture content should be less than 10% to ensure that it is microbiologically and chemically safe, and the water activity should be less than 0.30 to ensure that there is not enough free water inside the powders for any biochemical reactions to occur.

Moreover, the powder's T_g should be 10-20°C higher than the ambient temperature during storage to prevent the powder from acquiring ambient moisture and maintain a minimal hygroscopicity. In contrast to hygroscopicity, solubility and product yield should be greater to exhibit acceptable behavior in an aqueous solution, and the free-flowing characteristics of powders developed. These qualities are crucial in determining whether it is acceptable for consumption. Following that, the color difference between tomato powders and tomato fruit should not be too significant since a larger difference indicates a high degradation of sensitive chemicals, which is undesirable due to the high nutritional value of tomatoes. Aside from that, the bulk density of the powders formed should be high to facilitate storage and transportation. Thus, the particle size should be reduced in order to improve the bulk density, as smaller particle sizes reduce the empty spaces between the powder particles.

Additionally, in order to get the desired production of tomato powder, the temperature should not be too high or too low. Following that, numerous investigations have shown that the concentration of carrier agents should not be too high or too low in order to minimize moisture retention, which might cause the powder to become sticky. Incorporating innovative technologies into spray drying can enhance the quality of fruit and vegetable powder, such as dehumidified air supply, which has been shown to improve powder recovery, moisture content, and bulk density. More study on this approach is anticipated to increase the effectiveness of spray drying, which remains the primary technology for powdering fruit and vegetable juices.

ACKNOWLEDGMENT

To undertake this project, the authors would like to acknowledge the financial support given by the Universiti Malaysia Sabah, under the SDN Grant Scheme, with code DN21100- Phase 1/2021.

REFERENCES

Abadio, F. D. B., Domingues, A. M., Borges, S. V. and Oliveira V. M. 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., Bhandari, B. R. and Troung, V. 2003. "Characterization of the surface stickiness of fructose-maltodextrin solutions during drying," *Drying Technol. 21,* 17-34.

Amit, S. K., Uddin, M. M., Rahman, R., Islam, S .M. R. and Khan, M. S. 2017. "A review on mechanisms and commercial aspects of food preservation and processing," *Agric. Food Secur. 6,* 1-22.

Allamilla-Beltran, L., Chanona-Prez, J. .J., Jimnez-Aparicio, A. R. and Gutrrez-Lopez G.F. 2005. "Description of morphological changes of particles along spray drying," *J. Food Eng. 67,* 179-184.

A-Sun, K., Thumthanaruk, B., Lekhavat, S. and Jumnongpon, R. 2016. "Effect of spray drying conditions on physical characteristics of coconut sugar powder," *Int. Food Res. J. 23,* 1315-1319.

Barbosa, J., Borges, S., Amorim, M., Pereira, M. J., Oliveira, A., Pintado, M. E. and Teixeira, P. 2015. "Comparison of spray drying, freeze drying and convective hot air drying for the production of a probiotic orange powder," *J. Funct. Foods 17,* 340-351.

Barbosa-Canovas, G. and Juliano, P. 2005. "Compression and compaction characteristics of selected food powders," Adv. Food Nutr. Res. 49, 233-307.

Banat, B. F., Jumah, R., Al-Asheh, S. and Hammad, S. 2002. "Effect of operating parameters on spray drying of tomato paste," *Eng. Life Sci. 2,* 403-407.

Bemiller, J. N. and Whistler, R. L. 1996. Carbohydrates. In: O. R. Fennema, Ed., Food Chemistry, Marcel Dekker, New York, 157-225.

Bicudo, M. O. P., Jó, J., Oliveira, G. A. D., Chaimsohn, F. P., Sierakowski, M. R., Freitas, R. A. D. and Ribani, R. H. 2015.

"Microencapsulation of jucara (Euterpe edulis M.) pulp by spray drying using different carriers and drying temperatures," *Drying Technol. 33,* 153-16.

Bhandari, B. R., Datta, N. and Howes, T. 1997. "Problems associated with spray drying of sugar-rich foods," *Drying Technol. 15,* 37-41.

Bazaria, B. and Kumar, P. 2018. "Optimization of spray drying parameters for beetroot juice powder using response surface methodology (RSM)," *J. Saudi Soc. Agric. Sci. 17,* 408-415.

Cai, Y. Z. and Corke, H. 2000. "Production and properties of spray-dried amaranthus betacyanon pigments," *J. Food Sci. 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," *Innov. Food Sci. Emerg. Technol. 6,* 420-428.

Chang, L. S., Tan, Y. L. and Pui, L. P. 2020. "Production of spray-dried enzyme-liquefied papaya (*Carica papaya* L.) powder," *Braz. J. Food Technol. 23,* 1-16.

Chegini, R. G. and Ghobadian, B. 2007. "Spray dryer parameters for fruit juice drying," *World J. Agric. Res. 3,* 230-236.

Chegini, R. G. and Ghobadian, B. 2005. "Effect of spray drying conditions on physical properties of orange juice powder," *Drying Technol. 23,* 657-668.

Corrêa-Filho, L. C., Lourenço, S. C., Duarte, D. F., Moldão-Martins, M. and Alves, V. D. 2019. "Microencapsulation of tomato (*Solanum lycopersicum* L.) pomace ethanolic extract by spray drying: Optimization of process conditions, " *Appl. Sci. 9,* 1-15.

Dalmoro, A. Barba, A., Lamberti, G. and d'Amore, M. 2012. "Intensifying the microencapsulation process: Ultrasonic atomization as an innovative approach," *Eur. J. Pharm. Biopharm. 80,* 471-477.

De Jesus, S. S. and Filho, M. R. 2014. "Drying of α-amylase by spray drying and freeze-drying-A comparative study," *Braz. J. Chem. Eng. 31,* 625-631.

Desai, K. G. H. and Park, H. G. 2005. "Recent developments in microencapsulation of food ingredients," *Drying Technol. 23,* 1361-1394.

Dolinsky, A., Maletskata, Y. and Snezhkin, Y. 2000. "Fruit and vegetable powders production technology on the bases of spray and convective drying methods," *Drying Technol. 18,* 747-758.

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

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

Ferrari, C. C., Germer, M. S. P., Alvim, I. D. and de Aguirre, J. M. 2013. "Storage stability of spray-dried blackberry powder produced with maltodextrin or gum Arabic," *Drying Technol. 31,* 470-478.

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," *J. Food Sci. 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," *J. Food Eng. 82,* 246-252.

Gharib, H. M., Abajy, M. Y. and Omaren, A. 2020. "Investigating the effect of some fluoroquinolones on C-reactive protein levels and ACh-Induced blood pressure reduction deviations after aging of diabetes in STZ-Induced diabetic wistar rats," *Res. J. Pharm. Technol. 13,* 5993-5998.

Gharsallaoui, A., Roudaut, G., Voilley, C. O. and Saurel, R. 2007. "Applications of spray-drying in microencapsulation of food ingredients: An overview," *Food Res. Int. 40,* 1107-1121.

Gong, Z., Zhang, M., Mujumdar, A. S. and Sun, J. 2007. "Spray drying and agglomeration of instant bayberry powder," *Drying Technol. 26,* 116-121.

Goula, A. M. and Adamopoulos, K. G. 2008. "Effect of maltodextrin addition during spray drying of tomato pulp in dehumidified air: I. Drying kinetics and product recovery," *Drying Technol. 26,* 714-725.

Goula, A .M. and Adamopoulos, K. G. 2005. "Stability of lycopene during spray drying of tomato pulp," *LWT - Food* Sci Technol. 8, 479-487.

Goula, A. M., Adamopoulos, K. G. and Kazakis, N. A. 2004. "Influence of spray drying conditions on tomato powder properties," *Drying Technol. 22,* 1129-1151.

Grabowski, J. A., Truong, V. D. and Daubert, D. R., 2006. "Spray drying of amylase hydrolyzed sweetpotato puree and physicochemical properties of powder," *J. Food Sci. 71,* E209–E217.

Hu, L., Zhang, J., Hu, Q., Gao, N., Wang, S., Sun, W., Sun, Y. and Yang, X. 2016. "Microencapsulation of brucea javanica oil: Characterization, stability and optimization of spray drying conditions," *J. Drug Deliv. Sci. Technol. 36,* 46-54.

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

Kader, A. A. 2005. "Increasing food availability by reducing postharvest losses of fresh produce.," *Acta Hortic. 682,* 2169-2176.

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

Kha, T., Nguyen, M. and Roach, P. (2010). "Efefcts of spray drying conditions on the physicochemica and antioxidant properties of the Gac (*Momordica cochinchinensis*) fruit aril powder," *J. Food Eng. 98,* 385-392.

Krishnaiah, D., Bono, A., Sarbatly, R., Nithyanandam, R. and Anisuzzaman, S. M., 2015. "Optimisation of spray drying operating conditions of Morinda citrifolia L. fruit extract using response surface methodology," *J. King Saud Univ. Eng. Sci. 27,* 26-36.

Krishnaiah, D., Nithyanandam, R. and 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.

Liu, Y., Chen, F. and Guo, H. 2017. "Optimization of bayberry juice spray drying process using response surface methodology," *Food Sci. Biotechnol. 26,* 1235-1244.

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

Murugesan, R. and Orsat, V. 2011. "Spray Drying for the production of nutraceutical ingredients-A review," *Food Bioproc. Tech. 8,* 1-12.

Muzaffar, K., Nayik, G. A. and Kumar, P. 2015. "Stickiness problem associated with spray drying of sugar and acid rich foods: A mini review," *J. Nutr. Food Sci. S12:003,* 1-3.

Nazir, F., Bashir, M., Salim, R. and Nissar, N. 2018. "Microencapsulation techniques for food ingredients," *Int. J. Adv. Res. Sci Eng. 8,* 2163-2167

Niakousari, M., Gahruie, H. H., Razmjooei, M., Roohinejad, S. and Greiner, R. 2017. "Chapter 5-Effects of innovative processing technologies on microbial targets based on food categories: Comparing traditional and emerging technologies for food preservation," *Innov. Technol. Food Preserv.* 133-185.

Nijdam, J. J. and Langrish, T. A. J. 2006. "The effect of surface composition on the functional properties of milk powders," *J. Food Eng. 77,* 919-925.

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

Obon, J. M., Castellar, M. R., Alacid, M. and Fernandez-Lopez, 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.

Ozkan, G., Franco, P., De Marco, I., Xiao, J. and Capanoglu, E. 2019. "A review of microencapsulation methods for food antioxidants: Principles, advantages, drawbacks and applications," *Food Chem. 272,* 494-506.

Papadakis, S. E., Gardeli, C. and Tzia, C. 2006. "Spray drying of raisin juice concentrate," *Drying Technol. 24,* 173-180.

Patil, V., Chauhan, A. K. and Singh, R. P. 2014. "Optimization of the spray-drying process for developing guava powder using response surface methodology," *Powder Technol. 253,* 230-236.

Pui, L. P., Karim, R., Yusof, Y. A, Wong, C. W. and Ghazali, H. M. 2020. "Optimization of spray-drying parameters for the production of 'Cempedak' (*Artocarpus integer*) fruit powder," *J. Food Meas. Charact. 14,* 3238-3249.

Quek, S. Y., Chok, N. K. and Swedlund, P. 2007. "The physicochemical properties of spray-dried watermelon powders," *Chem. Eng. Process. 6,* 386-392.

Raghavan, G. S. V. and Orsat, V. 2007. "Recent advances in drying of biomaterials for superior quality bioproducts," *Asia-Pac. J. Chem. Eng. 2,* 20-29.

Righetto, A. M. and Netto, F. M. 2005. "Effect of encapsulating materials on water sorption, glass transition and stability of juice from immature acerola," *Int. J. Food Prop. 8,* 337-346.

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

Roos, Y. and Karel, M. 1991. "Water and molecular weight effects on glass transitions on amorphous carbohydrates and carbohydrate solutions," *J. Food Sci. 56,* 1676-1681.

Santana, A. A., Martin, L. G. P., de Oliveira, R. A., Kurozawa, L. E. and Park, K. J. 2017. "Spray drying of babassu coconut milk using different carrier agents," *Drying*

Technol. 35, 76-87.

Santos, D., Maurício, A. C., Sencadas, V., Santos, J. D., Fernandes, M. H., Pedro, S. and Gomes, P. S. 2017. Spray Drying: An Overview, Biomaterials - Physics and Chemistry - New Edition, Rosario Pignatello and Teresa Musumeci, Intech Open.

Sharif, Z. M., Mustapha, F., Jai, J., Yusof, M. N. and Zaki, N. 2017. "Review on methods for preservation and natural preservatives for extending the food longevity," *Chem. Eng. Res. Bull. 19,* 145-153

Sharangi, A. B. and Datta, S. 2015. Value addition of horticultural crops: Recent trends and future directions. Springer, 1-339.

Shi, Q., Fang, Z. and Bhandari, B. 2013. "Effect of addition of whey protein isolate on spray-drying behaviour of honey with maltodextrin as a carrier material," *Drying Technol. 31,* 1681-1692.

Singh, R., Mangaraj, S. and Kulkarni, S. D. 2006. "Particle size analysis of tomato powder," *J. Food Process. Preserv. 30,* 87-98.

Shishir, M. R. I. and Chen, W. 2017. "Trends of spray drying: A critical review on drying of fruit and vegetable juices," *Trends Food Sci. Technol. 65,* 49-67.

Shrestha, A., Ua-arak, T., Howes, T., Adhikari, B. and Bhandari, B. 2007. "Glass transition behavior of spray dried orange juice powder measured by differential scanning calorimetry (DSC) and thermal mechanical compression test (TMCT)," *Int. J. Food Prop. 10,* 661-673.

Sobulska, M. and Zbicinski, I. 2021. "Advances in spray drying of sugar-rich products," *Drying Technol. 39,* 1-26.

Sousa, A. S., Borges, S. V., Magalhães, N. F., Ricardo, H. V. and Azededo, A. D. 2008. "Spray-dried tomato powder: reconstitution properties and colour," *Braz. Arch. Biol. Technol. 51,* 807-814.

Souza, A. L. R., Hidalgo-Chávez, D. W., Pontes, S. M., Gomes, F. S., Cabral, L. M. C. and Tonon, R. V. 2018. "Microencapsulation by spray drying of a lycopene-rich tomato concentrate: Characterization and stability," *LWT 91,* 286-292.

Souza, A. S., Borges, S. V., Magalhães, N. F., Ricardo, H. V, Cereda, M. P. and Daiuto, E.R. 2009. "Influence of spray drying conditions on the physical properties of dried pulp tomato," *Food Sci. Technol. Int. 29,* 291-294.

Swetha, K. and Lalunaik, B. 2018. "Alternative technologies for tomato postharvest quality preservation," *J. Pharmacogn. Phytochem. 7,* 1678-1682.

Tan, L. W., Ibrahim, M. N., Kamil, R. and Taip, F. S. 2011. "Empirical modeling for spray drying process of sticky and non-sticky products" *Procedia Food Sci. 1,* 690–697.

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

Toneli, J., Park, K. J., Negreiros, A. and Murr, F. 2010. "Spray drying optimization to obtain inulin powder," *Drying Technol. 28,* 369-379.

Tonon, R. V., Freitas, S. S. and Hubinger, M. D. 2011. "Spray drying of açai (*Euterpe Oleraceae Mart.*) juice: Effect of inlet air temperature and type of carrier agent," *J. Food Process. Preserv. 35,* 691-700.

Tran, T. and Nguyen, H. 2018. "Effects of spray-drying temperatures and carriers on physical and antioxidant properties of lemongrass leaf extract powder," *Beverages* 4, 84-98.

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," *J. Food Eng. 71,* 55-65.

Walton, D. E. 2000. "The morphology of spray-dried particles. A qualitative view," *Drying Technol. 18,* 1943-1986.

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

Yousefi, S., Emam-Djomeh, Z. and Mousavi, S. M. 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.

Zhu, M., Chen, G., Zhou, S., Tu, Y., Wang, Y., Dong, T. and Hu, Z. 2014. A new tomato NAC (N AM/A TAF1/2/C UC2) transcription factor, SlNAC4, functions as a positive regulator of fruit ripening and carotenoid accumulation," *Plant Cell Physiol. 55,* 119-135.