Effect of Spray Dryer Parameters on different Properties of Fruit Juice Powder

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Abstract— *Spray drying is one of the most complex method for fruit juice drying. Fruit juice is very sensitive and affected by the different drying parameters. 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. Besides, their physical state provides a stable, natural and easily dosable ingredient, which generally finds usage in many foods and pharmaceutical products such as flavoring and coloring agents. Spray drying process is unique because it involves both particle formation and drying. These parameters should be tested and determined before the design of the dryers. The investigated parameters include: drying agent material, feed flow rate, inlet and out let air temperature and sticky point temperature.*

Keywords— Spray drying, drying parameters, Carrier agents, physiochemical properties, fruit juice powder, storage stability.

I. INTRODUCTION

Spray drying is a method of producing a dry powder from a liquid or slurry by rapidly drying with a hot gas. This is the preferred method of drying of many thermally sensitive materials such as foods and pharmaceuticals. A consistent particle size distribution is a reason for spray drying of some industrial products such as catalysts. Air is the heated drying medium, however, if the liquid is a flammable solvent such as ethanol or the product is oxygen sensitive then nitrogen is used[1].Spray drying is a well-established and widely used technique to turn liquid foods or suspensions into powder form in a onestepprocess and is also suitable for the preparation of coatedcrystals as intermediates for tablet manufacture. There are threemain steps in the spray-drying operation: (1) atomization of the liquid feed, (2) drying of the droplets once they are formed and(3) motion of the droplet [2].

A spray dryer 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. Solids form as moisture quickly leaves the droplets. A nozzle is usually used to make the droplets as small as possible, maximizing heat transfer and the rate of water vaporization. Droplet sizes can range from 20 to 180 μm depending on the nozzle. There are two main types of nozzles: high pressure single fluid nozzle (50 to 300bars) and two fluid nozzles: one fluid is the liquid to dry and the second is compressed gas (generally air at 1 to 7 bars).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 advantageous for profit maximization and process simplification.

The products to be spray dried can be categorized into two major groups: non-sticky and sticky products. Sticky products are generally difficult to use in the spray-drying process. During the drying process, they may remain as syrup, stick on thedryerwall or form unwanted agglomerates in the dryer chamberand conveying system, which causes lower product yields and operating problems. Some examples of such sticky products arefruit and vegetable juice powders, honey powders and amorphouslactose powder. Non-sticky products can be dried using asimpler dryer design and the obtained powder is relatively lesshygroscopic andfree flowing [3]. Natural hygroscopic and thermoplastic properties are the basicproblems in the transport and handling of fruit juice powderproduced by spray drying. Sugar-rich materials are difficult tospray dry because they produce highly hygroscopic powdersthat are prone to stickiness and flow problems. Possible consequences include impaired product stability, decreased yields because of stickiness on the drier chamber walls and even operational problems with the spray drier. The sticky behavior Is attributed to a high concentration of low molecular weight sugars and organic acids, which have low glass transition temperatures(T_g) and are rubbery and thermoplastic at the temperatures in thechamber. The fast moisture removal during spray-drying resultsin an amorphous and highly hygroscopic product. Stickinessdoes not occur when higher molecular weight carbohydrate such as maltodextrins (MDs) are spray dried. Instead, MDs facilitate drying of sugar-rich foods because their $T_g$increasingeffect reduces the hygroscopicity of powders. Thus, they arefrequently used as drying aids (Moreira et al., 2008).Another issue is the complex chemical composition of juices.About 90% of dry substances in juices consist of hydrocarbonssuch as monosaccharides (glucose, fructose), disaccharides (sucrose) and polysaccharides.Bhandariet al.[4] used a varietyof methods to obtain powder from concentrated juices. Accordingto their experiments, the results were obtained for a juice toMD ratio of 65/35 for blackcurrant, 60/40 for apricot, and 55/45for raspberry at inlet air temperatures between 90 and 160^{o}C[5].

Spray drying is also a useful technique for producing powders suitable for inhalation [6]. The physicochemical properties of powders produced by spray drying depend onprocess variables such as the characteristics of the liquid feed(viscosity, particle size, flow rate) and of the drying air (temperature, pressure) as well as the type of atomizer. Therefore, it is important to optimize the drying process to obtain products with better sensory and nutritional characteristics and to optimizeprocess yield. Evaluation of the surface properties of these particles can improve our understanding of the production processand assist in the optimization of the powder composition.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 [7, 8]. 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 [9, 10]. This review is useful for industry to develop the processing condition for different fruit juices and improve the product quality.

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 [10,11].

Lemon fruit juice

Lemon (*Citrus limon L.*) is one of the citrus fruits that has been increasing throughout the world and is cultivated in countries with temperate and dry climates such as the United States, Argentina, Spain, Italy, Egypt, India and Japan. The production of lemon and limes reached nearly 27,000 metric tons. A lot of alkaline elements are found in the lemon. Vitamin C is found in abundant amounts in the fresh juice of lemons. If left exposed to the air for long periods of time, most of the valuable vitamin C in the juice is lost, for this reason, fresh juice should be preferred. Important nutrients such as the element potassium and the vitamin B1 are also found in high amounts in the lemon. Citric acid also makes up about five to six per cent of the juice and tissues of lemons and limes this percentage is very high compared to oranges at about one to one and a half percent or the grapefruit, at about one to two percent citric acid. In common with other citrus fruits, the lemon is classified as an acidic fruit - it shares this denomination with fruits like the cranberries and the loganberries, loquats, strawberries, pineapples and pomegranates, as well as tamarinds and a few other sour fruits. In general, fresh fruits have high moisture content and therefore, are very perishable, having a limited shelf life. In order to prolong shelf life, processing and preservation methods, such as drying of fruit pieces or fruit juice, may be used. Drying of fruit juice produces a stable, easy handling form of the juice that reconstitutes rapidly to a good quality product resembling the original juice as close as possible. Dried juice products are used mainly as convenience foods and have a long storage life at ordinary temperatures.

Properties of Spray dried powder

Lallan Ram and Dinesh Kumar [12] developedthe value-added products from underutilized citron (*Citrus medica L.*) fruit. The free flow powder recovery in citron juice was of

10 per cent along with the particle size ranged from 0.44 micron (fine) to 0.77 micron (coarse), respectively in cyclone-I and II. The moisture of the juice powder was observed to be recorded as 2.5per cent initially at the time of product development, while it was recorded as 3.0per cent during the ambient storage. The juice powder being highly hygroscopic it was protected from coming in to contact of moisture.

Table.1: Changes in chemical composition of citrus juice powder under ambient storage conditions.

Parameter	Fresh juice	Juice powder in ambient storage (30 ± 2°C)		
		Initial*	6 month**	12 month
TSS (%)	9.0	9.0	9.0	9.0
Acidity (%)	6.14	1.08	1.76	1.34
Vit 'C' (mg/ 100ml)	32	10	8	9
Limonin (ppm)	5.57	3.41	3.61	4.02
Carotenoid (mg/ml)	-	0.05	0.05	0.04
Colour L*	1.27	1.0	0.79	3.47
a*	-0.10	-0.12	0.11	0.17
b*	0.35	0.04	-0.50	-0.72
a/b*	-0.28	-3.00	-0.22	-0.23
Flavour	7.5	7.0	7.0	7.0
Aroma	8.1	7.4	7.5	7.5
Texture	8.0	7.2	7.1	7.0

*L = lightness/darkness, a = greenness, b = yellowness, a/b = orange

The Table 1 revealed that TSS, ascorbic acid, carotenoids, limonin and colour of spray dried juice powder remain unchanged up to 12 months under ambient storage condition which ranges as 9.0 per cent (TSS), 1.08-1.76 per cent (acidity), 8-10 mg/ 100 ml (vitamin-C), 3.41-4.02 ppm (limonin), 0.05-0.04 mg/ ml juice (carotenoids) from the day developed (initial) to 12 months during storage, respectively, indicating the stability in quality of biochemical aspects of the juice powder with unchanged limonin, which ranged between acceptable limits, possibly due to non- thermal process involved in spray drying techniques [10].However, the aroma, flavor and texture of juice powder had scored the value between 7-8 during the ambient storage upto 12 months showing the high acceptability of sensorial attributes by the panelist, which further strengthened stability of the product. Similar findings on Nagpur mandarin fruit juice powder was also reported by Ram and Singh[13].

Orange Juice

A new technique for spray drying of concentrated orange juice using dehumidified air as drying medium andmaltodextrin as drying agent was developed [14]. A pilot-scale spray dryer was employed for the spray dryingprocess. The modification made to the original design consisted in connecting the dryer inlet air intake to anabsorption air dryer. 21 DE, 12 DE, and 6 DE maltodextrins were used as drying agents. Concentrated orangejuice was spray dried at inlet air temperatures of 110, 120, 130 and 140°C and (concentrated orange juicesolids)/(maltodextrin solids) ratios of 4, 2, 1, and 0.25. Data for the residue remaining on the walls weregathered and the powders were analyzed for moisture content, bulk density, rehydration, hygroscopicityand degree of caking. The combination of maltodextrin addition and use of dehumidified air was proved to be an effective way of reducing residue formation.

Properties of Spray dried powder

Residue formation decreases with an increase in maltodextrin concentration and a decrease in inlet air temperature and dextrose equivalent[14]. The residue yielddecreases with increasing maltodextrin concentration, because the lower the (concentratedorange juice solids)/(maltodextrin solids) value, the higher the elevation of the T_g of the orangejuice concentrate–maltodextrin mixture. Werner et al. (2007) used a probe tacktest to map the level of stickiness of droplets containing 20 and 40% ofmaltodextrins 5 DE, 10 DEand 18 DE, reported that low-DEmaltodextrins develop stickiness faster and reach a state of nonadhesionfaster than high-DE maltodextrins.

Moisture content decreases with an increase in inlet air temperature and a decrease in maltodextrin concentration and dextrose equivalent. Bulk density increases with an increase in dextrose equivalent and a decrease in inlet air temperature and maltodextrin concentration. This effect may be attributed to the fact that maltodextrin addition minimizes thermoplastic particles from sticking. In addition, an increase in maltodextrin concentration may cause an increase in the volume of air trapped in the particles, as maltodextrin is a skin-forming material[14].

Glass transition temperature

Values of T_g obtained for the orange juice powders produced byspray drying of orange juice concentrate at 140 °C without maltodextrinand conditioned to maintain the water activity at ten levels between 0.04 and 0.95. T_g decreased by increasing moisture content due to the plasticizing effect of water. This plasticizing activity may be based on the weakening of hydrogen bonds and dipole–dipole intra and inter macromolecular interactions due to the shielding of these mainly attractive forces by water molecules[14].The glass transition temperatures of 21 DE, 12DE and 6 DE maltodextrins conditioned at various water activities were determined by differential scanning calorimetry[15]. A strong plasticizing effect of water wasfound with a large reduction of $T_g$when the moisture content increased. In addition, low-dextrose equivalent maltodextrins werefound to give higher glass transition temperatures than high-DEmaltodextrins at the same moisture contents.

Rehydration ability

Rehydration ability increases with an increase in inlet air temperature and maltodextrin concentration and a decrease in dextrose equivalent. Increasing the drying air temperature generally produces an increase in particle size [16] and so a decrease in time required for the powder to be rehydrated. Large particles may sink, whereas small ones are dustier and generally float on water, making for uneven wetting and reconstitution.This can beattributed to the fact thatlow-moisture content seems to be associatedwith fast rehydration [17].Since the lowerthe moisture content the less sticky the powder is and, thus, the higherwill be the surface area in contact with the rehydration water.

Hygroscopicity

Hygroscopicity and degree of caking decrease with an increase in inlet air temperature and maltodextrin concentration and a decrease in maltodextrin dextrose equivalent[14].According to Downtonet al. [18], water absorbs on particle surfaces forming a saturated solution and thereby making the particles stickyand capable of forming liquid bridges. Thus, increase in inlet airtemperature and maltodextrin concentration and decrease inmaltodextrin dextrose equivalent lead to lower hygroscopicity andas a result, to lower caking degree. A similar trend was reportedduring spray drying of tomato pulp–maltodextrin mixture [17].According to Roos[19], physical changes in low-moisture, highsugardehydrated powdered foods, including hygroscopicity areattributable to the glass transition temperature and the higher thepowder T_g, the lower its hygroscopicity. Thus, the effect of the processvariables on powder hygroscopicity depends on their effect on T_g.Increase in inlet air temperature and maltodextrin concentration anddecrease in maltodextrin dextrose equivalent lead to higher powder$T_g$and as a result to lower hygroscopicity. This observationis similar to that reported by other researchers [20, 21].

Temperature did not significantly affect the hygroscopicity of Pomegranate juice powder ($P>0.05$), but maltodextrindid[22]. However, studies conducted by Moreira et al.[23] and Goula and Adamopoulas, [15] on spray drying of acerolapomace and tomato puree, respectively, revealed that an increase in temperature caused a decrease in hygroscopicity.Increasing the amount of maltodextrin in the feedmixture caused a decrease in the water-holding capacityof powders. Rodriguez-Hernandez et al.[24] reportedthat lower hygroscopicity was obtained when theamount of in cactus pear juice maltodextrin increased duringspray drying. Similar results were determined by other researchers[23, 25, 26]. It was known that low-molecular-weightcomponents (e.g., simple sugars and organic acids presentin fruit juices) have more hydrophilic groups hence, theirhygroscopicity is higher. Maltodextrin has a high molecular weight compared to sugars and acids and has relatively lower hygroscopicity. Therefore, maltodextrin increases thebulk molecular weight of pomegranate powder mixtureand decreases the water absorption capacity of powders[27].

Mango Juice

Cano-Chaucaet al.[28]conducted experiment on spray drying of mango juice. The spray nozzle with an orifice of 1 mm in diameter. The inlet air temperature was 160°C for all of the solutions investigated and the outlet air temperature was 70–75°C. The liquid feed to the dryer was about 10 ml/min. Flow of the drying air was about 0.7 m /min. The experiments were performed under constant process conditions. Spray drying of sugar-rich foods such as fruit juice has great economic potential. However, fruit juice powders obtained by spray drying have some drawbacks in their functional properties such as stickiness, solubility and hygroscopicity that make their packaging and utilization difficult. The possibility of creating a highly organized structure during spray drying could reduce the stickiness, considering that crystalline sugar has a lower water sorption potential. According to Bhandariet al.[26] the sticky behavior of sugar and acid-rich materials is attributed to low molecular weight sugars such as fructose, glucose sucrose and organic acids such as citric, malic and tartaric acid, which constitute more than 90 per cent of the solids in fruit juices and purees. These materials have low glass transition temperatures (sucrose: 62°C; fructose: −5°C; glucose: 32°C). These compounds are very hygroscopic in their amorphous state and have a loose free flowing nature at high moisture contents [29]. According to Sebhatuet al. [30], fruit juice powder obtained by spray drying favors the yield of high sugar content solids, most of them present in the amorphous state. These sugars are very hygroscopic, which affects the functional characteristics of the dehydrated material, mainly its tendency to become sticky (stickiness) and form high agglomerates. This tendency to agglomerate may become accentuated as the amorphous state sugar transforms into crystalline sugar through the adsorption of small amounts of water.

Electronic Microscopy

The three-dimensional characteristics of the surfaces of powder particles obtained from mango juice by spray drying were analyzed using electronic microscopy. When MD was used as a carrier with 0 and 3 per cent of cellulose, the particles were larger, amorphous, aggregated and strongly attracted to each other. The microstructure of the powders obtained using an AG carrier with added cellulose revealed a more uniform shape and a better distribution of particles with smooth and intact surfaces, varying sizes. The microstructures obtained using waxy starch carriers with or without added cellulose contained some hexagonal particles among the spherical particles [28].

X-Ray Powder Diffraction

The crystalline state is of great importance for the stability of powdered juice and its presence can be determined through X-ray diffraction (XRD). Amorphous materials display diffuse and large XRD peaks because molecules in the amorphous state yield wide bands whereas, crystalline materials yield sharp and defined peaks because they are presented in a highly ordered state. The XRD profiles of the standard sucrose, cellulose, glucose, and crystalline fructose were studied to comparethe crystalline structures.XRD profiles of the particles using MD as a treatment andcellulose at 0, 3, 6, and 9 per cent verify that the system without addedcellulose presents a totally amorphous surface, which is confirmed by the presence of large, non defined peaks with abundant noise [28]. The XRD profile of powdered particles prepared using AG as a carrier and added cellulose was also examined. These particles were amorphous and partially crystalline materials, that is, peaks with considerable noiseand semidefined peaks were observed, which means that theaddition of cellulose influenced the formation of partially crystalline structures. Amorphous material may present because the material did not reach the conditions necessary for crystallization during drying. According to Reineccius and Risch[31]the high molecular weight and high viscosity of AG increase the glass transition temperature, which favors conditions for theamorphous state. The change from the amorphous state to thecrystalline state occurs above the glass transition temperature.

Stickiness

Spray drying is a dynamic process and physical changes may occur during drying. Stickiness is considered the biggest problem in fruit juice spray drying and this phenomenon is related to a low glass transition temperature (T_g).The stickiness of MD was observed by Cano-Chaucaet al.[28] to decrease with cellulose concentration until reaching0.15 kg-f at 9per cent cellulose. Higher stickiness valuesmay be related to the characteristics of the microstructure of the powder when compared with other additives. Using AGas the carrier with 9per cent cellulose yielded a stickiness value of0.22kg-f. Similar behavior was observed in samples treated with MD i.e. decreasing stickiness as a function of the concentration of cellulose. However, these carriers presentedthe greatest values of cohesive force, higher than that obtainedwith MD. For the waxy starch treatment with 9 per cent cellulose,the stickiness was 0.11kg-f. The value of stickiness decreasesslightly as a function of the concentration of cellulose. Thus,adding cellulose had little effect on stickiness. Stickiness occursbecause the particles are better dispersed, which decreases thecohesive force among them.

Solubility

The solubility of powdered mango juice was studied as afunction of cellulose concentration. In all treatments, the solubility of powdered mango decreases as a function of celluloseconcentration. MD treatment yields a highly soluble powderwith solubility greater than 90per cent without added cellulose,whereas adding 9per cent cellulose decreases the solubility to around72per cent. MD is the most frequently used carrier in spraydrying due to its physical properties such as its high solubility in water. For the AG treatment, the solubility greater than90 per cent without added cellulose and decreased to 71 per cent when 9 per centcellulose was added [28].

Several researchers recommend the use of AG as the carrier in fruit juicespray drying because of its emulsification ability and its highwater solubility. AG treatment with different levels of celluloseresults in a highly soluble powder. The waxy starch treatmentresulted in solubility values of around 31per cent for 9per cent added cellulose. The solubility of powdered mango juice decreases as a function of the concentration of cellulose and this decrease ismore pronounced in the starch treatments for two reasons: first, the starches have low solubility in cold water (around 35–40%) and second, the presence of crystalline surfaces in the materialmay result in greater particle organization.Cellulose was not suitable for inducing the crystallization ofsugar, but it did affect the powder microstructure and thereforeinfluenced the functional properties. Adding celluloseto the juice led to higher stickiness stability, however, the functional property of solubility was also affected.

The short time is a measure of the high solubility of the powder. The solubility of powders decreased with increasing temperature and maltodextrin content of the feed mixture. The solubility of Pomegranate juice powders was the lowest (high solubility time) at highest percentage MD (60%) and drying temperature(140°C)[22]. Maltodextrin has lower solubility in coldwater compared to PJ powder due to its high molecularweight. Adding more maltodextrin may increase the bulk solubility of the powder. In addition, a high drying temperature may damage the water absorption sites of powder. This may be another reason why the solubility decreased asthe temperature increased. Queket al.[32] and Goulaet al.[33] obtained similar results for spray drying of watermelonjuice and tomato juice.

Watermelon

Spray drying can be used to turnthe watermelon juice into a powder that has longer shelf life and is readily available. Ideally, the spray-dried watermelon powder should have instant properties or serve as a lycopene-richfunctional food ingredient for incorporation into food products. Since the main dietary lycopene source is currently tomato, the development of lycopene-rich watermelon powder will provide consumers with an alternative choice, according to Queket al.[32].Spray drying was carried out at an aspirator rate of 60per cent, flow rate of 600 L/hour, pressure of 4.5 bar and feed temperature of20°C. These conditions were chosen after conducting initial trial runs. Four inlet air temperatures were investigated: 145, 155, 165 and 175°C. MD (3 and 5%) was added according to the weight of the watermelon juice.

Effect of Carrier agent (Maltodextrin)

From the observations of Queket al. [32], very little powder accumulated in the collector if, MD was not added to the feed.The particles produced were very sticky, were mainly depositedonto the wall of the drying chamber and cyclone which could notbe recovered. Therefore, MD of 3 and 5per cent (of the total feed solution) was added to the juice prior to spray drying to investigate its effects on the resulting product. The MD (DE 9) used was a low-DE MD with DE of 8–12. Other researchers have reported that low-DE MDs have better nutrient binding properties[34, 35, 24]. MD has also proven to be a very good encapsulate for low molecular weight sugars such as fructose and organic acids [36, 27]. It was observed that the condition improved by results and powder quantity with the addition of MD. The addition of 5per cent MD to the feed appeared to give betterresults than the addition of 3per cent MD. These results showed thatMD was a useful drying aid in the spray drying of watermelon juice, as it improved the yield of product.

It was suggested by Queket al. [32] that MD could alter the surface stickiness of low molecular weight sugars such as glucose, sucrose, fructose and organic acids, therefore facilitate drying and reduce the stickiness of the spray-dried product [36, 37]. However, if more than10per cent MD was added, the resulting powders lost their attractivered-orange color.

Moisture Content

The results showed that at constant feed flow rate, the moisture content of the spray-dried powders decreased with the increased inlet and outlet air temperature (Table 2). This is because at higher inlet temperatures, the rate of heat transfer tothe particle is greater, providing greater driving force for moisture evaporation. Consequently, powders with reduced moisturecontent are formed. The results were consistent with other findings [33].

The moisture content of the spray-dried powder decreased when moreMD was added[32]. In a spray-drying system, the water content ofthe feed has an effect on the final moisture content of the powderproduced [38]. Addition of MD to the feed priorto spray drying increased the total solid content and reduced theamount of water for evaporation, resulting in decreased moisture content of the powder. This meant that powders with lower moisture content could be obtained by increasing the percentage of added MD. However, if the proportion of MD was veryhigh, the powder produced would be of lower quality becausethe nutrients from the watermelon juice would be diluted. Increases in air inlettemperature and maltodextrin led to lower moisture contents[22].At low percentageMD, the increase in temperature resulted in a slight increase in moisture content, whereas, at high percentage MD the increase in temperature led toa decrease in moisture content. Other researchers [39, 25]showed that increasing the inlet air temperature increased the drying rate and hence, the moisture content of the powder was reduced.

Table.2: Physical properties of spray dried powder adapted from Quek et al. [32]

Inlet temperature (°C)	Outlet temperature (°C)	Maltodextrin (%)	Moisture content (%)
145	94.7	3	2.78±0.21
155	101	3	2.29±0.18
165	105	3	1.62±0.20
175	108.6	3	1.49±0.32
145	95.4	5	1.62±0.11
155	101.5	5	1.55±0.10
165	107.6	5	1.57±0.08
175	112.7	5	1.49±0.21

Color Measurement

Measurements for watermelon powders with 5per cent MD are shown in Table 3. L-value measures the lightness of the sample, +a measures the red color and +b measures the yellow color. Hue angle measures the property of thecolor and it is the ratio of a*and b*.Chroma indicates the color intensity or saturation (chroma=$(a^{*2}+b^{*2})^{1/2}$).According to Queket al. [32], when inlet temperature increased, the +b values increased, while the +a values first increased then decreased at 175°C. This contributed to the changesin hue angle and chroma(Table 3)**.** One of the explanations for this phenomenon is that watermelon contains sugars that could contribute to browning of the powders at higher inlet temperatures. As the inlet temperature increased, the hue angles also increased from 47.39 to 53.49. These figures correspond to the regions of red to yellow color where 0 is pure red and 90 is yellow. This meant that there was a decrease in the red color when the inlet temperature was increased. The changes in hue angle might be caused by the destruction of lycopene and β-carotene at higher temperature.

Table.3: Colorimetric results of the spray-dried powders [32]

Inlet temperature (°C)	L*	a*	b*	Hue angle (°)	Chroma
145	74.63	+14.91	+16.21	47.39	22.02
155	70.68	+18.60	+20.60	47.92	27.79
165	67.76	+20.00	+23.66	49.79	30.98
175	66.91	+18.94	+24.66	53.96	31.09

As the temperature and percentage MD in the mixture increased, the change in total color difference also increased [22]. At low and high temperatures, the increase in percentage MD resulted in a large increase in the DE value. However, at low and high percentage MD, the increase in temperature caused a slight increase in the DE value. It can be arguedthat maltodextrin affects the total color difference more than the temperature does. The maximum color difference was observed at the highest temperature and the highest percentage MD. This may be due to the sensitivity of colorpigments to the heating process and the diluting effect ofmaltodextrin (colorless) in color. Ferrari et al.[40] andMurugesan and Orsat(2011) found similar results for spraydrying of blackberry and elderberry juices, respectively [41].

Lycopene and β -Carotene Content

The results of Quek et al. [32] showed that the watermelon studied had an average lycopene content of36.45 ± 2.05 μg/g of fresh fruit, which was consistent with the [42] study. The lycopene content of the watermelon varies across cultivars and is also affected by factorssuch as seasons and growing environment [42, 43]. The β-carotene content of watermelon wasfound to be 2.80 ± 0.22 μg/g of fresh fruit, which was muchlower than the lycopene content. Thelycopene content decreased with increased inlet temperature (Table 4). A similar observation was made for the spray drying of tomato pulp [33]. The reduction in lycopene content was likely due to thermal degradation and oxidation. Goulaet al. [33] reported that the spray-dried powders produced atlower inlet temperature had a tendency to undergo agglomeration because of their higher moisture content. This is especiallytrue for powders with a sticky nature, which contain a highconcentration of sugars. Agglomeration would lower the exposure of powders to oxygen and therefore protect the lycopenefrom destruction. For β -carotene, a similar trend was observed.

Queket al. [32] found that the percentage loss of β–carotene was slightly higher than lycopene when the inlet temperature increased. For example, the loss of lycopene was 24.06per cent compared with 27.08per cent for β -carotene when the inlet temperature increased from 145 to 175°C.Carotenoids are reported to be very susceptible to heat destruction and oxidation because of their highly unsaturated chemical structure [44]. However, β –carotene could be more heat sensitive than lycopene [45].

Table.4:Lycopene and β-carotene contents of the raw fruits, juices and spray-dried powders [32]

Inlet temperature (°C)	Lycopene content	B-carotene content
Fruits (µg/g)	36.45±2.05	2.80±0.22
Spray-dried powders (µg/g)		
145	954.02±3.11	31.46±0.34
155	907.66±2.15	29.47±0.61
165	820.35±1.82	26.71±0.42
175	724.48±1.15	23.05±0.32

The lycopene and β-carotene content could both affect the color of the spray-dried powders produced. However, the effect from lycopene would predominate, as its content was muchhigher in watermelon. The lycopene and β -carotene contents(Table 4) could correlate with the L* a* b* color analysis(Table 3). Both the lycopene and β -carotene content were found to be inversely proportional to the hue angle. Thus, when the inlet temperature was increased, the lycopene and β -carotene content were reduced, reflecting in the reduction in thered-orange color of the powder.

Pomegranate

Spray drying can be applied to turn pomegranate juice into powder that has a longer shelf life and is readily available throughout the year. Horuzet al.[22]produce pomegranate juice in powder form by spray drying of pomegranatejuice concentrate from unclarified juice, to determinethe optimum drying conditions for the productionprocess and the final product quality and to investigatephysical, chemical and sensory properties of the powders produced. The spray dryer inlet air temperature was between 100 and150°C and the feed mixture concentration (pomegranate juice + maltodextrin DE6) was between 19.61 and 44.11°Brix. The proportion of maltodextrin with respect to total solids in the feed mixture was 39.08 to 64.12per cent. This concentration was selected in a preliminary study as the lowest concentration without excessive powder stickiness on the chamber wall. Below this concentration, the high powder stickiness resulted in an insignificant process yield. The drying air flow rate of 0.353m^3/min. and feed flow rate used was 7mL/min.

Anthocyanin Content

Anthocyanins provide the characteristic color of fruits and vegetables. Unstable anthocyanins are negatively affected by heating and finally denaturated or polymerized with other phenoliccompounds causing color loss [46]at low percentage MD, the increase in temperature resulted in a sharp decrease in anthocyanincontent[22]. Investigations conducted by Tononet al.[47] on the spraydrying of a tropical fruit acai, Queket al.(2007) on spraydrying of watermelon,Cai and Corke[48] on spray dryingof Amaranthusbetacyanin pigmentandErsusandYurdagel[49] on the drying behavior of black carrotrevealed that increasing temperature negatively affectedthe anthocyanin content of the material studied. On theother hand, at high maltodextrin concentration, theincrease in temperature resulted in a slight increase inanthocyanin content. This may be due to the high encapsulationrate of excess maltodextrin present in the feed mixture,preventing anthocyanins from degradation, asreported by Khaet al.[39].

Bulk Density

Bulk density was expressed as weight of powders (g) perunit volume (mL). Experimental bulk density values of powders varied between 0.3450 to 0.4720 g/mL[22]. At low percentage MD,temperature had no effect on bulk density. However, at high percentage MD, temperature significantly affected the bulk density ($P<0.05$); that is, as the temperature increased, the bulk density increased. This behavior was related to moisture content of powder. Pomegranate juice powder has high moisture content at low drying temperature. The higher the powder moisture content, the more particles tend to stick together, leaving more interspaces between them, which results in increased bulk volume of particle and therefore decreased bulk density of particle[22]. In contrast to these results [39, 48, 33] reported that increasing residual moisture content increased the bulk density of a dry product.

Total Phenolics Content

Horuzet al.[22] investigated that the temperature and maltodextrin affected the totalphenolics content proportionally. At low and high percentageMD, the increase in temperature resulted in an increase in total phenolics content. Similarly, at low and high temperatures,the increase in percentage MD resulted in an increase in the total phenolics content of Pomegranate powders.However, maltodextrin had a statistically greater effect($P<0.05$) on the total phenolics content than temperature.This may be due to the encapsulation effect of maltodextrinprotecting phenolic compounds against external actions. Khaet al.[39] found that, inactivation of polyphenol enzymes by the heating process during spray drying may be another reason for the increased amount of phenolics.Capanogluet al.[50] and Turkmen et al.[51] investigated the total phenolics and antioxidant activities of some vegetables during heating process. They observed that the total phenolics content of squash, peas and leek decreased but the total phenolics content of green pepper, green beans, broccoli and spinach increased.

Antioxidant Capacity

Pomegranate contains a significant amount of phenoliccompounds, which have antioxidant properties. Thesecompounds play an important role in human health byinactivating free radicals (Gil et al., 2000). Drying temperature significantly increasedthe antioxidant capacity pomegranate juice powder (PJ) ($P<0.05$)[22]. Antioxidant capacity increased with increasing drying air temperature. Similar results were presented in the literature.Tezcanet al.[52]indicated that commercially sold PJshave a higher antioxidant capacity than fresh PJ. CommercialPJs undergo heat treatment and chemical reactionscan take place during heat treatment. The Maillardreactionis one of these reactions. It has been reported that the product from Maillard reaction has very high antioxidant capacity. Morales et al.[53] and Capanogluet al.[50] reported that the antioxidant capacity of tomato increased by heat treatments. Turkmen et al.[51] investigated the effect of heat treatment on the antioxidant capacity of green vegetables and observed that the antioxidant activity of green pepper, green beans, broccoli and spinach increased with increasingtemperature and the antioxidant capacity of squash,peas and leek were the same as fresh. Maltodextrin had no statistically significant effect ($P>0.05$) on the antioxidant capacity of PJ powder because maltodextrin does not have any antioxidative properties. Similar results were reported by other authors [52, 50,51,54].

Yield

According to Horuzet al.[22] product yield increased significantly($P<0.05$) with increasing percentage MD in the mixture.Maltodextrin encapsulates organic acid and simple sugarspresent in pomegranate juice, which helps the PJ particlesflow freely through the drying chamber; that is, stickinessto the chamber wall is prevented. Temperature had no significanteffect ($P>0.05$) on yield. Only a slight decrease inyield was observed as the temperature increased. The yieldof pomegranate juice powders varied between 86.0 and 19.67per cent. The highest and lowest yield values were obtained from the samples with the highest and lowest maltodextrincontents, respectively.Papadakiset al.[55] studied thespray drying of raisin juice and found that the yieldincreased with increasing percentage MD in the feed mixture.

According to Cai and Corke[35] a higher inlet temperature, which contributes to better efficiency of heat and mass transfer may lead to a greater yield. In fact, utilization of the optimum additive is also important [26]. An inappropriate maltodextrin concentration can adversely affect powder recovery by increasing the viscosity of the mixture. This causes more paste to stick on the spray dryer chamber resulting in lower powder output [35]. Inlet temperature of 160°C and a ratio of fruit juice solid:maltodextrin of 40:60, the recovery of fruit powder was highest [56]. This observation was comparable with [26] who reported that the optimum ratio of fruit solid to maltodextrin for blackberry, apricot and raspberry was 35:65, 40:60 and 45:55 respectively.

II. CONCLUSION

Spray drying is widely used in both food and pharmaceutical manufacturing processes. This technique offers short contact times (5–100 s), allowing some properties of foods such as flavor, color and nutrients to be retained in high percentages[57, 58]. However, the main problem during spray drying of sugar-rich foods such as fruit juices has their thermoplastic behavior. The chemical composition of fruit juice represented by components of low glass transition temperature (T_g; i.e., sucrose, glucose, fructose and citric acid) and during drying they may either remain as syrup or stick on the dryer chamber wall [59]. This might lead to low product yields and operating problems. Some additives such as starch, Gum Arabic and maltodextrins are commonly used as carrier agents to prevent stickiness of product by increasing the T_g of the product during spray drying [59, 48]. This paper reviewed the spray drying of fruit extracts and the effects of different parameters on the physicochemical properties of the products. Microcapsules obtained under optimal spray drying conditions showed a higher recovery of bioactive compounds and thus, can be used as additives in the food processing or pharmaceutical industries. This review also demonstrates that the additive concentration and inlet temperature of spray drying influence physicochemical properties such as residue formation, moisture content, bulk density, rehydration, hygroscopicity, yield and degree of caking. Besides, the problems of stickiness, residue accumulation or dryer fouling can be solved by modification of spray-drying system.

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