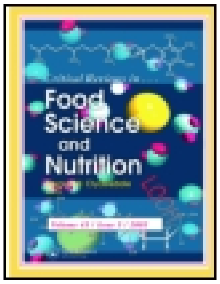

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Spray Drying of Fruit and Vegetable Juices- A Review

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Spray Drying of Fruit and Vegetable Juices- A Review

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ABSTRACT

The main cause of spray drying is to increase the shelf life and easy handling of juices. In the present paper the studies carried out so far on spray drying of various fruits and vegetables are reported. The major fruit juices dried are mango, banana, orange, guava, bayberry, watermelon, pineapple etc. However, study on vegetable juices is limited. In spray drying the major optimized parameters are inlet air temperature, relative humidity of air, outlet air temperature, atomizer speed which are given for a particular study. The juices in spray drying require addition of drying agents which include matlodextrin, liquid glucose etc. The drying agents are added to increase the glass transition temperature. Different approaches for spray dryer design have also been discussed in present work.

1. INTRODUCTION

Wide variety of fruits and vegetables in tropical, subtropical, temperate and arid regions are produced in world. Now a day the interest of the food industry in natural flavor- and color-enriched additives has been increased significantly due to the demand of consumers for reducing the use of synthetic food additives with potential short- and long-term health risks. Although there is no direct evidence, people usually associate artificial food additive consumption with the occurrence of cancer and reproductive problems in adults, as well as, behavioral problems in children (DiTommaso et al. 2003). Additionally, most of the tropical fruits posses intense colors and flavors which make them excellent candidates as a source of new and diverse natural additives. Therefore an interesting alternative is to transfer those molecules responsible for sensory and or bio-functional properties to a solid phase which will be able to enhance their stability and control their release in food matrices.

Drying is the major food processing operation to increase the shelf life (Mani et al. 2002). Freeze drying and spray drying are commonly used drying techniques that have been engineered up to date in the food industry whereby diverse dehydration principles are employed in each technique specifically. Food dehydration by freeze-drying technique basically utilizes the mechanism of ice sublimation under low pressure. Conversely, in spray drying moisture is removed from the food specimens by rapid evaporation on spray droplet under high temperature exposure (Karel and Lund, 2003). In freeze drying much of water is removed which makes product light weight. It prevents the survival of yeast and bacteria and retains its taste, shape and appearance when water is re-introduced. But the freeze drying equipments are expensive and the process is very time taking and requires great deal of work.

Spray drying is method of producing a dry powder from a liquid or slurry by rapidly drying with a hot gas in a single processing step. For thermally sensitive materials such as foods and pharmaceuticals spray drying is preferred method. All spray dryers use some type of atomizer or spray nozzle to disperse the liquid or slurry into a controlled drop size spray. Contact between spray and drying medium results in moisture evaporation. The hot drying gas can be passed as a co-current or counter-current flow to the atomizer direction. Such operating conditions include in the design of spray drying process which increase the product recovery and produce end product of precise quality specification. Product recovery is mainly determined by powder collection efficiency (Goula and Adamopoulos, 2005). At present, this technology is well established, rather inexpensive and straightforward.

The heat and mass transfer during drying occurs in the air and vapor films surrounding the droplet. This protective envelope of vapor keeps the particle at the saturation temperature. As long as the particle does not become "bone-dry", evaporation is still taking place and the temperature of the solids will not approach the dryer outlet temperature (Marshall and Seltzer, 1950; Patsvas, 1963). This is why many heat sensitive products can be spray dried easily at relatively high inlet temperatures. Spray drier has high performance due to low residence time (of a few seconds). It is a continuous process with easy installation. Spray drier turns a solution or slurry into a dried powder in a single step, which can be advantageous for profit maximization and process simplification.

2. BASIC CONSIDERATIOS

2.1 Spray Drying Steps

Spray drying process mainly involves following five steps (Patel et al. 2009) :

1. Feedstock is normally concentrated before processing.
2. In second step atomization takes place which creates the optimum conditions for evaporation to a dried product having the desired characteristics.
3. In third stage atomized liquid is brought into contact with hot gas.
4. Moisture evaporation takes place here in two stages. In first stage evaporation takes place at constant rate at the surface of droplet (Keey and Pham, 1976). In second stage there is no longer enough moisture to maintain the saturated conditions at the droplet surface. So evaporation depends on diffusion of moisture through the shell, which is increasing in thickness.
5. Finally the separation step takes place for which cyclones, bag filters, wet scrubbers and electrostatic precipitators may be used.

2.2 Modeling of spray drying

In a spray-drying operation, there are three main phenomena:

1. Atomization of the liquid feed
2. Drying of the droplets once they are formed
3. Motion of the droplet in the spray-drying unit (Shabde, 2006).

Masters, 1991 provided a procedure for the design of spray-drying chambers based mainly on experiential knowledge of the process. Oakley, 2004 and Kieviet, 1997 had tried to design spray dryers using fundamental principles. According to Shabde, 2006 the final product properties are desirable in the design of spray-drying chamber. The size of the final particle and the amount of solvent in the final product are the most important factors. The choice of the atomizer affects the particle size distribution and the rate of solvent evaporation is influenced by the amount of drying gas. In the design of the spray dryer, the important design parameters are the chamber dimensions, the heating gas flow rate and the residence time of the particles in the spray dryer. The following approach is obtained for the design parameters of the spray dryer:

Step 1. The design criterion selected is that the largest particle contains ≤ 10% water.

Step 2. Choose the atomizer type and spray-drying chamber geometry. An atomizer and a chamber geometry of a cylindrical top and conical bottom are selected to provide a comparison to the results obtained from a similar laboratory scale unit. The droplet size distribution is fixed by choice of atomizer.

Step 3. Spray-dryer design and droplet equations are solved simultaneously to track the largest droplet as it passes through the chamber. The axial distance of the particle from the atomizer at this point gives the length while the radial distance gives the radius of the spray drying chamber.

Step 4. The residence time of the particles is obtained from the velocity equations.

The numerical solver must be able to obtain accurate estimates of the heating requirements, chamber size and the gas flow rate. It is an iterative process.

The design equations for the spray-drying chamber are given by the following equations:

According to Masters, 1991 tangential, radial, and axial components of the droplet velocity are considered. The momentum balances for a representative droplet are given by (Katta and Gauvin, 1976),

$$\frac{dV_t}{dt} = -\frac{V_t V_r}{r} - \frac{3C_D \rho_g V_f (V_t - V_{gt})}{4d_i \rho}$$

$$\frac{dV_r}{dt} = -\frac{V_t^2}{r} - \frac{3C_D\rho_g V_f (V_r - V_{gr})}{4d_i\rho} + \frac{F_L}{m}$$

$$\frac{dV_V}{dt} = g - \frac{3C_D\rho_g V_f (V_V - V_{gv})}{4d_i\rho}$$

Where

$$V_f = \sqrt{(V_V - V_{gv})^2 + (V_t - V_{gt})^2 + (V_r - V_{gr})^2}$$

is magnitude of the relative velocity between the particle and the gas phase; V_t, V_r, and V_v are the tangential, radial, and axial velocities of the droplet, respectively; and V_g represents the drying gas velocity.

The variable F_L represents the shear lift force on the droplets and is a function of the gas density and the radius of the droplet,

$$F_L = 20.25\rho_g d_i^{\,2}(\frac{V_{gv}}{K})^{0.5} KV_f$$

$$K = 1.4V_{gv}(r/(x\tan(\theta)))^2 = 1.4V_{gv}(\frac{r}{r_5})^2$$

In the above equation x is the axial distance from the entrance of the liquid feed, θ is the half angle of the cone formed by the liquid spray with the drying chamber's centerline, and r5 is the width of the spray a distance x from the entrance of the liquid feed. The shear lift force is transverse to the direction of flow and thus acts in the radial direction (Legendre and Magnaudet, 1998).

The radial variation in the tangential velocity of the gas stream is given by,

$$V_{gt} = C_1(\frac{r}{R_X})^{0.5} \qquad 0 \le r \le R_X$$

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where the radius of the chamber (R_x) is a function of the axial distance, x, as measured from the entry point of the liquid feed.

The radial variation in the axial velocity of the gas stream is given by,

$$V_{gv} = C_2 (\frac{r}{R_X})^{2.5} \qquad 0 \leq r \leq R_x$$

The coefficients, C_1 and C_2 are found experimentally (Katta and Gauvin, 1976).

The heat (q) supplied to the droplets and the amount of solvent lost by the droplets due only to the mass-transfer between the droplets and the gas are given by,

$$\frac{dq}{dt} = k_g N_u \pi d_i n_i (T_g - T_s)$$

$$\frac{dm}{dt} = D_V \rho_g S_h d_i n_i (c_s - c)u$$

where n_i is the number of droplets, kg is the thermal conductivity of the gas, Dv is the solvent-gas binary diffusion coefficient, c_S is the solvent concentration at the surface of the droplet, and c is solvent concentration in the gas surrounding the droplet.

The amount of gas, Wg, required to dry the droplet is found by taking an overall energy balance over the spray dryer,

$$W_g C_s (T_{gi} - T_{go}) = W_w \lambda + W_w C_f (T_{go} - T_w) + W_f C_f (T_w - T_f) + W_p C_{ps} (T_p - T_w) + q_l$$

where q` is the heat loss, which is assumed to be 20% of the total heat supplied.

The evaporation rate is given by,

$$E_X = \frac{dq}{\lambda dt} + \frac{dm}{dt}$$

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In the entrainment zone, the gas temperature at any distance x from where the liquid feed entered the chamber can be determined analogously to the nozzle zone (Shabde, 2006),

$$T_X = T_{gi} - \frac{(E_X \lambda + (E_X - W_p) C_f (T_{go} - T_w) + W_p C_{ps} (T_p - T_w) + q_{lx}}{W_g C_s}$$

Wang and Langrish, 2008 reported two fundamental approaches of modeling drying processes, namely lumped-parameter approaches and distributed- parameter approaches. They reported that in Lumped-parameter approaches it is assumed that the physical properties and components of the drying materials remain uniform throughout the thickness or depth in the material. Characteristic drying curve (CDC) and the reaction engineering approach (REA) are the examples of such models. While, distributed-parameter approaches allow for different regions within a drying material to contain different concentrations of the components with different physical properties. According to Adhikari et al. 2007; Kim et al. 2003; Nijdam and Langrish, 2006 distributed-parameter approach is consistent with the observed component migration phenomenon. Drop drying models for carbohydrate solutions has been reported in papers of Adhikari et al. 2006; Adhikari et al. 2003; Adhikari et al. 2004 to investigate surface stickiness. They investigated sucrose, glucose, fructose, citric acid and maltodextrin. The distributed parameter models used for these works were all based on moisture diffusion through solids and the model divides each droplet into layers, and evaporation only occurs on the surface. It is assumed that the droplet is non-hollow solid sphere (made of the solutes) and moisture diffuses from the centre to the surface before evaporating. The flux equation at the surface is given here for water (Adhikari et al., 2003). They found that this distributed-parameter model predicted the moisture content of the particles well, with an average error of 4.5–6%.

$$N_{1,i} = k_{g,i}^{*} \frac{M_w P_{atm}}{RT_{av,film}} \ln \frac{(1 - \frac{P_{v,db}}{P_T})}{(1 - \frac{P_{vs,Td}}{P_T})}$$

Here $k^*_{g;i}$ stands for corrected mass-transfer coefficient (m s^{-1}), A_p is the surface area of droplet (m^2), R is the gas constant (J mol-1 K^{-1}), $T_{av,film}$ is the film temperature, the average temperature of the fluid film in the boundary layer outside each particle (K), P_{atm}, $P_{v,db}$ and $P_{vs,Td}$ are atmospheric, vapour and saturated vapour pressures, respectively (Pa).

Adhikari et al. 2003 used the model investigated the glass-transition temperature Tg, which was used as an indicator of stickiness and reported that maltodextrin alters the surface stickiness of the products and thus is an effective drying aid. According to Shabde, 2006 there are basically four approaches to model the spray drying process i.e.

1) Material and energy balances between the two phases – the droplet phase and the bulk gas phase.

2) Material and energy balances between these two phases and a description of the equilibrium between the dispersed and continuous phases.

3) Rate-based descriptions, which do not assume the existence of an equilibrium.

4) Particle-source-in-cell models, which are not limited by spray chamber geometry.

He wrote that mass and energy balances are used during a preliminary design because their solutions give the feed rates and temperatures to achieve the desired quality of drying. According to Fletcher and Langrish, 2003;Crowe, 1980 the mechanistic rate-based models to model the heating gas flow patterns are rigorous but usually require sophisticated computational fluid dynamics (CFD) techniques to solve these models. Katta and Gauvin, 1976 presented that rate-based models that contain empirical correlations to model the flow of the gas phase can represent the particle phase accurately. Crowe, 1980 introduced a particle source- in-cell (PSI-Cell) model and Fletcher and Langrish, 2003 solved this model by using computational fluid dynamic (CFD) techniques. Palencia et al. 2002 present a mechanistic approach to spray-dryer modeling by representing the spray dryer to be a cascade of mixing tanks.

2.3 Operating conditions

The physicochemical properties of powders produced by spray drying depend on some process variables, such as the characteristics of the liquid feed (viscosity, particles 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, in order to obtain products with better sensory and nutritional characteristics and better process yield (Tonon et al. 2008).

2.4 Powder properties

The shape of most spray dried particles is spherical, which provides for fluid-like flow properties. This makes many downstream operations, such as packaging, pressing, filtering, and handling easier and less costly (Katta and Gauvin, 1976; Sommerfeld and Blei, 2001; Shrestha et al. 2007). Spray drying produces the most homogeneous product from multi-component solutions and slurries. Each particle will be of the same chemical composition as the mixed feed.

Lower moisture content, lower hygroscopicity, lower degree of caking and increasing rehydration abilities are the main properties of spray dried powder (Goula and Adamopoulos 2010; Tonon et al. 2008).

3. STICKINESS DURING SPRAY DRYING

About 90% of dry substances in fruit juices consist of different carbohydrates such as monosaccharides (glucose, fructose), disaccharides (sucrose) and polysaccharides (Dolinsky and Gurov, 1986). During their drying process stickiness on the drier wall, wet and plastic appearance and agglomeration and clumping in packing container occur which results in operational problems and increase losses. The glass transition related changes of food powders containing amorphous sugars is well recognised. It causes stickiness and caking problems in a number of food powders including fruit powders (Bhandari et al. 1997; Bhandari et al. 1993; Brennan et al. 1971; Lazar et al. 1956). High hygroscopicity, high solubility, low melting point temperature and low glass transition temperature (Tg) of sugar rich feedstock are the major factors of stickiness (Masters, 1991). In general, stickiness occurs when liquid bridges of amorphous sugar, fatty or dissolved material composition form between adjacent powder particles (cohesion) or between the particle and another surface such as a spray dryer wall (adhesion) (Aguilera et al. 1995; Papadakis and Bahu, 1992; Peleg, 1983; Roos, 1995).

Sticky point is defined as the temperature at which caking is instantaneous with slow stirring. In spray drying, stickiness occurs when particles are insufficiently dry collide with one another or with the dryer walls and become stuck (Mani et al. 2002). The sticky-point test was developed by Lazar et al. in 1956 and has been used since by several workers in the field (Downton et al. 1982; Wallack and King, 1988; Buhler and Liedy, 1989; Jaya, 2002). Drying parameters and drier design influence the stickiness property of droplet. For preventing stickiness and production of powder two ways were introduced: (i) Use of drying agent material, improvement in spray drier design and specific equipment to facilitate the handling of powder (Chegini and Ghobadian, 2005; 2007, Lazar et al. 1956, Masters, 1985, Papadakis and Babu, 1992). (ii) Maintaining chamber wall temperature lower than the Tg of the powder could reduce deposition of such powders.

In the 1990s, the notion of glass transition was introduced to provide a better fundamental understanding and predictability of the sticky point temperature. It is generally accepted that the sticky point temperature lies 10–20˚C above the glass transition temperature, especially for low molecular weight sugars and carbohydrates (Hennigs et al. 2001; Roos and Karel, 1991) .

The fruits and vegetables which have been spray dried are banana, orange, bayberry, mango, apricot, blackcurrant, raspberry, ginger, guava, lime, pineapple, tomato, watermelon etc.

4. METHODS OF SPRAY DRYING SUGAR-RICH FOODS

For sugar rich food products such as fruit juices, that are characterized by stickiness and are usually spray dried, common approaches involve modifying the sticky characteristics of the material most frequently through the addition of drying aid agents, trying to control the surrounding product or air temperatures, such as using appropriate outlet drying air temperature (Bhandari et al. 1997) or introducing of cold air into the bottom part of the dryer (Lazar et al. 1956) or cooling of the wall temperature (Brennan et al. 1971). The improvement of the spray drying performance while applying these methods to reduce stickiness has been reviewed elsewhere (Bhandari et al. 1997).

4.1 Addition of Drying aids

Drying aids, which have high molecular weight, aiming at avoiding spray drying operational problems such as stickiness on the dryer chamber wall, as well as structural transformations such as collapse and crystallization, during food processing and storage, which is especially important in the case of sugar rich products such as fruit juices (Tonon et al. 2010). The drying aids could form an outer layer on the drops and alter the surface stickiness of particles due to the transformation into a glassy state (Adhikari et al. 2003; 2004). The changes in surface stickiness reduce the particle-particle cohesion resulting in less agglomeration, and therefore, lower water-holding capacity of the powders (Grabowski et al. 2006). The additives must reduce the hygroscopic and thermoplastic properties of the fruit juice while not alter the quality and solubility of the produced powder. The use of maltodextrins as drying aids has been in practice since the 1970s (Brennan et al. 1971; Gupta, 1978). Bhandari et al. 1993; Chegini and Ghobadian, 2005; Kabanov, 1985; Jaya and Das, 2004; Shrestha et al. 2007; Rao and Gupta, 2002; Tsourouflis et al. 1976; Roustapour, 2006 used additives in the research included: maltodextrin, liquid glucose, and methylcellulose. Such agents reduce powder hygroscopicity and increase the glass transition temperature and normally used for microencapsulation, which can protect sensitive food components against unfavorable ambient conditions, mask or preserve flavors and aromas, reduce the volatility and reactivity and provide additional attractiveness for the merchandising of food products (Ré, 1998). The lowest hygroscopicity values were obtained when the highest maltodextrin concentrations were used (Bhandari and Hartel, 2005; Bhandari et al. 1993, 1997; Peleg and Hollenbech, 1984; Silva et al. 2006). As maltodextrin concentration increases, the moisture content of samples significantly reduces (Papadakis et al. 2006; Kha et al. 2010). Higher drying aid concentrations favour flowability (Quek et al. 2007).

4.2 Scrapping of dryer surfaces

Karatas, 1989 developed an experimental spray dryer with a chamber wall scraper for tomato juice. This method is useful for relatively less thermoplastic sugars such as lactose and sucrose. Karatas and Esin, 1994, investigated the fundamental aspects involved in the drying of tomato concentrate droplets fully exposed to air of constant humidity and velocity.

4.3 Cooling of dryer chamber walls

As far as the cooling of the drying chamber walls is concerned, the cool wall will be favorable to minimize the thermoplastic particles from sticking, as the wall will be cold enough to cool and solidify the outer surface of the thermoplastic particles coming in contact. This method, however, was found to improve the process but not to resolve the problem. The reason is that the cold chamber wall will also cool the surrounding environment and cause an increase in the relative humidity of the air close to the wall surface (Goula and Adamopoulos, 2010; Chegini and Ghobadian, 2005; Chegini et al. 2008; Gransmith, 1971; Jayaraman and Das Gupta, 1995; Spicer, 1974). Lower temperatures of wall and lower humidities of the drying air resulted in the formation of a solid particle surface, which decreased residue accumulation or dryer fouling, and minimized the number of thermoplastic particles sticking to the dryer wall. Masters, 1994 modeled a pilot plant spray dryer with a cooling air jacket that reduced the particle stickiness on the wall. Masters, 1985 introduced chambers with air brooms, which rotate slowly close to the wall, can also cool the wall surface to prevent stickiness of powders. The air broom arm contains a row of nozzles that direct compressed air on to the wall surface. An intermediate sweeping of chamber wall with dehumidified cold air can remove loosely adhered particles on the chamber wall. Mani et al. 2002 used air broom system for spray drying of banana and mango juice. The design aspects of the rotating air broom system can be found in literature (Masters, 1985; Sudhagar, 2000).

4.4 Admission of atmospheric air

Introduction of cool air at the lower part of the dryer chamber resulting in the formation of a solid particle surface can also reduce the stickiness of the powder particles (Ponting et al. 1973). However, a limited amount of air can only be introduced because the cooling process will also raise the relative humidity of the air that can once again aggravate the situation by increasing the surface moisture level (Bhandari et al., 1997b).

5.ADDITION OF DRYING AIDS-MALTODEXTRIN DURING SPRAY DRYING

The effect of addition of a drying aid (maltodextrin) on the drying kinetics of low molecular weight sugars and organic acids and on the surface stickiness of these materials was studied by Adhikari et al. 2004. Adhikari et al. 2003 conducted single drop drying experiments and developed predictive tools for prediction of stickiness of drops of binary solutions. Adhikari et al. 2004 presented the drying kinetics of sugar-rich solutions and acid rich foods including their predicted stickiness history. They conducted experiments on sugars/maltodextrin mixtures and (sugars+citric acid)/ maltodextrin mixtures at different concentrations of maltodextrin and analyzed the morphological changes, moisture content changes and temperature changes of drop. The effect of addition of maltodextrin on the moisture and temperature histories of low molecular weight sugars and organic acids was predicted by them by numerically solving following eqs.

$$\frac{\partial u}{\partial z} = \frac{\partial}{\partial z}(D_W(u,T)C_S^2 r^4 \frac{\partial u}{\partial z})$$

$$\frac{dT_d}{dt} = \frac{4\pi R^2[h_g^*(T_a - T_d) - \Delta H_v F] + 0.5\pi D_f \sqrt{h_g^* D_f k_f}(T_a - T_d)}{m_s(uC_{p,w} + C_{p,s})}$$

The first equation is diffusion equation introduced by Van der Lijn et al.1972 and the second equation represents temperature history developed by Incropera and DeWitt, 2002. Here

D_w (u, T), u, C_s and r in are the moisture diffusivity (m^2/s), moisture (kg water/kg solid), concentration of solid in solution (kg/m^3) and radial distance (m), respectively. z is the spatial variable in a solute-fixed coordinate system . R, F , m_s, $C_{p,s}$, $C_{p,w}$, and ΔH_v are the drop radius (m), flux of water [kg/(m^2 s)] leaving the drop surface, mass of dry solid in the drop (kg), specific heat capacity of solid [J/(kg ˚C)], specific heat capacity of water [J/(kg ˚C)] and latent heat of vaporization of water (J/kg), respectively. Similarly, h^*_g ,D_f , k_f , T_f and T_d are the heat transfer coefficient [W/(m^2 ˚C] corrected for high flux, diameter (m) and thermal conductivity [W/ (m ˚C)] of the glass filament, temperature of the bulk air (˚C) and temperature of the drop (˚C), respectively.

Addition of maltodextrin lowers the drying rate. As the amount of maltodextrin in the drop increases, the surface area increases and diffusion path decreases which enhance the flux of water leaving the drop. Pure sucrose and fructose drops remain spherical at drying. When the amount of maltodextrin in sucrose or fructose drops is increased to 50%, the drops deviate from sphericity and become pear-shaped (elongated) after 5 min of drying. This shape retains throughout the course of their drying. This shape allows more water to leave the drop and acts to offset the resistance to moisture diffusion caused by the formation of a skin on the surface. The glass transition temperature of the surface layer gave quite a reasonable prediction of the surface stickiness of the mixture drops. The drop surface becomes completely non-sticky when surface layer temperature (T_g) exceeds the drop temperature (T_d) by 10 ˚C. The presence of acid prolongs the surface stickiness of sugar-rich foods (Adhikari et al. 2004).

The spray drying studies reported for fruit and vegetable juices is discussed below individually.

6. APPLICATION OF SPRAY DRYING TO FRUIT JUICES

6.1 Acai Juices

Tonon et al. 2008 spray dried acai pulp and studied the influence of inlet air temperature, feed flow rate and maltodextrin concentration on process yield, powder moisture content, powder hygroscopicity and anthocyanin retention, during the microencapsulation. They used laboratory scale spray dryer Lab Plant SD-05 (Huddersfield, England) with drying air flow rate 73 m^3/h and compressor air pressure was 0.06 MPa. Inlet air temperature varied from 138 ºC to 202 ºC and feed flow rate varied from 5 to 25 g/min. Maltodextrin with $9.0 \leq DE \leq 12.0$, was used as carrier agent. They resulted that increasing temperature led to higher process yield, powder hygroscopicity, and to lower moisture content and anthocyanin retention. They also concluded that feed flow rate had negative effect on process yield and hygroscopicity, and positive influence on moisture content. According to them increase on maltodextrin concentration also led to the production of larger particles, which is related to the increase on feed viscosity.

Tonon et al. 2009 spray dried açai juice with different carrier agents and modeled sorption isotherms according to BET and GAB models and T_g was modeled according to the Gordon–Taylor model. They performed experiments on laboratory scale spray dryer Lab Plant SD-05 (Huddersfield, England) with drying air flow rate $73 m^3/h$ and compressor air pressure 0.06 MPa, feed flow rate used was 15 g/min, inlet and outlet air temperatures were 140 ± 2 ºC and 78 ± 2 ºC. Maltodextrin 10 DE with 20DE, gum Arabic and tapioca starch was used by them as drying agent. They concluded that critical water activities varied from 0.535 to 0.574 and critical moisture contents varied from 0.061 to 0.100 g/g dry matter, respectively and above these values, açai powder can become collapsed and sticky.

Tonon et al. 2010 studied the effect of temperature, water activity and type of carrier agent on the anthocyanin stability and antioxidant activity of spray-dried açai juice. The spray drying process was performed in a laboratory scale spray dryer Lab Plant SD-05 (Huddersfield, England) with drying air flow rate of 73 m^3/h and compressor air pressure of 0.06 MPa, feed flow rate used 15 g/min, and the inlet and outlet air temperatures were 140 ± 2 ºC and 78 ± 2 ºC. They used maltodextrin 10 DE with 20DE, gum Arabic and tapioca starch as drying agent. After experiments they concluded that temperature had negative influence on anthocyanin stability, due to the high sensitivity of these pigments to heat. They resulted that increase of water activity also resulted in higher degradation. According to them maltodextrin 10DE produced particles with the highest half-lives, followed by gum Arabic.

6.2 Acerola

Moreira et al. 2009 spray dried acerola known as Barbados cherry or West-Indian cherry. Bhandari and Hartel, 2005; Bhandari et al. 1993, 1997; Peleg and Hollenbech, 1984; Silva et al. 2006 reported that APE has moisture content, 95.4 g/100 g, total and reducing sugars, 4.0 g/100 g and 3.6 g/100 g, respectively (expressed as glucose), titratable acidity, 0.55 g/100 g (expressed as malic acid) and ascorbic acid content was 0.16 g/100 g and after addition of drying aids, the extracts had total solids contents in the range of 7.8–15.6 g/100 g. Moreira et al. 2009 identified that on increasing the drying aid/acerola ratio the powder hygroscopicity reduced. They studied effect of inlet temperature of the spray drier, degree of replacement of maltodextrin by CTG, drying aid/acerola ratio on moisture content, flowability, hygroscopicity and water solubility of spray dried acerola pomace extract. They used Mini Spray Dryer Bu¨ chi B-290 (Bu¨ chi Labortechnik AG, Flawil, Switzerland) under the following operational conditions: feed rate, 0.49 kg/h; peristaltic pump rate, 1.23 kg/h; aspirator flow rate, 5.51 $\times 10^4$ kg/h. The powders obtained by the spray drying process were packaged in sealed metallized bioriented polypropylene bags at 24± 2 ºC and experiments were run at inlet temperature (170–200 ºC), drying aid/ acerola solid ratio (2:1–5:1), and percent replacement of MD by CTG (0–100%). Moreira et al. 2009 resulted that high proportions of the drying aid agent tended to slightly decrease the solubility of the powders. Same result was described by Abadio et al. 2004 and Cano-Chauca et al. 2005. Moreira et al. 2009 concluded the best processing conditions to obtain a free-flowing and least hygroscopic acerola pomace extract powder by spray drying: inlet temperature above 194 ºC; drying aid/acerola ratio of 4.0, the drying aid being constituted by at least 80% cashew tree gum.

6.3 Banana

Izidoro et al. 2011 aimed to investigate the physical and chemical properties of green banana starch. They used green banana of variety 'Nanica' (Musa cavendish) and dried it by using a conventional oven method and by spray-dryer combined with cyclic sound pressure (ultrasound) treatment. They reported the physicochemical parameters of green banana. The moisture (%) was 73.13 ± 0.15, pH was 5.52 ± 0.01, soluble solids (ºBrix) was 5.55 ± 0.44, titratable acidity (g/100 g) was 0.165 ± 0.01 (expressed in molarity of malic acid) and firmness (N) was 31.35 ± 1.61. These results were similar to those previously obtained by Izidoro, 2008. A MSD 1.0 model mini spray dryer (LM Labmaq, Brazil) with an inlet temperature of 130 ºC ± 5 and outlet temperature of 47 ºC ± 5 was used with a 15% starch solution. The flow speed was set at 0.75 L h^{-1}, the air drying flow rate was 0.6 m^3 min^{-1} and the compressed air flow was 30 L min^{-1} then a conventional oven at 50 ºC was used to dry the starch for a period of 4 h. The dried starch collected was weighed, labeled and stored. Finally they concluded that the spray drying technique increases GBS solubility, swelling power and water absorption capacity, due to high temperature and the atomization character of this technique, which were further increased with ultrasound treatment.

Mani et al. 2002 spray dried banana powder using modified spray dryer with rotating air broom system. The processing of banana into banana juice involves as dipping in warm water, peeling, slicing, blanching, pulping, dilution and filtering. The filtered banana juice was spray dried to get the banana powder. The spray dryer feed flow rate (kg/hr) was 33.5, initial feed solid content (fraction) was 0.09, final feed solid content (fraction) was 0.93, airflow rate (kg dry air/hr) was 1658, feed temperature was 60 ºC, air inlet temperature was 168.5 ºC, air outlet temperature was 101.8 ºC. They observed that powder deposition was about 2 kg with the rotating air broom system. Finally they resulted that one kg of whole banana could produce about 100 g of banana fruit powder having the moisture content of 7% (wb). The powder retained its color and flavor.

6.4 Bayberry

Bayberry fruits are rich in polyphenols, including anthocyanins, flavonols, and phenolic acids (Bao et al. 2005; Fang et al. 2007; Fang et al., 2009). Fang et al. 2011 spray dried the bayberry fruits (cultivar Biqi). The bayberry juice had a total solids content of 11.0 ± 0.5 ºBrix, with 1.53 ± 0.15% total acids and 8.24 ± 0.21% total sugars. After mixing the maltodextrin (10 DE) the final solution 11 ºBrix was obtained. A Büchi B-290 mini spray dryer was used. They resulted that bayberry powder was successfully obtained when the juice was spray dried with maltodextrin (DE 10) as the carrier, with inlet and outlet temperatures of 150 ºC and 80 ºC, respectively. The retentions of total TPC (total phenolic content) and ACN (total anthocaynins) during drying process were about 96% and 94%. They also observed that at the end of 6 months storage, at an aw (water activity) of 0.11–0.44 and storage temperature of 5 ºC the TPC and ACN in bayberry powders decreased by about 6–8% and 7–27%, respectively. Thus they suggested that spray dried bayberry powder should be stored at less than 25 ºC and aw of 0.33, on account of the polyphenol stability.

6.5 Blackcurrant, Apricot and Rasberry

Bhandari et al. 1993 used two spray dryers tested to obtain powders from concentrated juices of blackcurrant, apricot, raspberry, with different maltodextrins as drying-aid agents. Composition of fruit juices and dextrose equivalent for maltodextrin are considered. Best results were obtained for a ratio juice to maltodextrin DE6 of 65/35 for blackcurrant, of 60/40 for apricot and 55/45 for raspberry, and low air temperatures (160–90°C).

6.6 Cashew Apple juice

De Oliveira et al. 2009 aimed to study the replacement of MD10 with CTG in spray drying of cashew apple juice. They used Mini Spray Dryer Bu¨ chi B-290 (Bu¨ chi Labortechnik AG, Flawil, Switzerland) under the following operational conditions: inlet temperature, 185 ˚C; outlet temperature, 90 ˚C. The CTG was presented as a good drying aid agent, reducing the hygroscopicity of the spray dried cashew apple juice powder when compared with that produced by using MD10 as drying aid. When using a drying aid/cashew apple juice dry weight ratio of 5:1, CTG replacing maltodextrin in 50%, more than 90% of the ascorbic acid was retained during spray drying, and a powder with good flowing properties and water solubility was obtained.

6.7 Durian pulp

Chin et al. 2008 studied the impact of spray and freeze-drying process on the qualitative changes of aroma profiles from the fresh and dried durian pulp using headspace SPME (Solid Phase Microextraction) coupled to fast GC (Gas Chromatography)-TOFMS (Time-of-Flight Mass Spectrometry). They used co-current spray dryer (Niro model 2000A, Denmark) for spray drying operation with inlet air temperature 160 ± 2 ºC and outlet temperature maintained at 85 ± 3 ºC under atomization at 3 bar pressure. They collected the dried powder in aluminum laminated polyethylene packaging material and stored at 4 ºC until analyzed within a week. They concluded that during spray drying, selective diffusion occurs only when a layer of selective permeable membrane is generated to prohibit the diffusion of volatiles except moisture vapor molecules at the onset of falling rate period.

6.8 Gac Fruit

Kha et al. 2010 investigated the effects of varying maltodextrin concentrations and spray drying temperatures on the physicochemical and antioxidant properties of Gac fruit powder made from its aril. They used maltodextrin 12 DE as drying agent in the three ratios to the juice,10%, 20% and 30% weight/volume (w/v). They performed experiments on Lab Plant SD-05 spray dryer (Lab Plant Ltd., England at inlet temperatures/measured outlet temperatures 120 ºC/83 ºC, 140 ºC/94 ºC, 160 ºC/103 ºC, 180 ºC/112 ºC and 200 ºC/125 ºC. They studied the different properties of powder obtained and resulted that moisture content, bulk density, color characteristics, TCC, EE and TAA were significantly influenced by maltodextrin concentration and by the inlet air temperatures. Whereas pH, aw and WSI were not significantly affected by the different spray drying conditions. They finally concluded that Gac powder spray-dried at inlet

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temperature of 120 ºC and maltodextrin concentration of 10% was adequately effective in preserving color, TCC and TAA.

6.9 Guava

Osorio et al. 2011 encapsulated aqueous extract of pink-fleshed guava fruit of Roja variety by using spray dryer and evaluated their physical and chemical properties under different humidity conditions. They used a laboratory scale spray-drier LabPlant SD-06 (Huddersfield, England). 38 °Brix feed-mixture was used by them. Air flow rate of 100 m^3/h and a compressor air pressure of 4 bar was kept by them. The feed flow rate was 485 mL/h, and the inlet and outlet air temperatures were 200±2 °C and 100±4 °C, respectively. MD (corn maltodextrin DE 19-20), AG (arabic gum), AGMD-1 (arabic gum/maltodextrin 1:5 w/w), and AGMD-2 (arabic gum/maltodextrin 1:10 w/w) were used as drying agents. They concluded that spherical microencapsulates were formed by spray drying. They also identified that the increase of relative humidity causes a significant loss of structure and posterior volatile release, thus, the shelf-life of these products highly depends on humidity during storage. The results showed that microencapsulates AGMD-1 and AGMD-2 were the most accepted by adults and MD and AGMD-1 by children. The sensory characteristic of different microencapsulates influenced the consumer perceptions of freshness and sweetness. Taken collectively these results, MD and AGMD-1 microencapsulates were selected as promising materials for food industry.

Chopda and Barrett, 2001 used clarified guava juice to make powders by freeze-drying, spray-drying and tunnel-drying. They found that freeze-dried product exhibited superior sensory quality but the spray-dried product was more stable and economically favourable.

6.10 Mango

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Khalil and Sial, 1974 studied the parameters for production of instant mango juice powder. Mangoes were selected and washed, and juice was extracted, pasteurized, homogenized and then spray-dried under different drying conditions. Juices of 23°Brix were dried with or without addition of 0.25 or 0.5% sodium alginate or glyceryl monostearate, with drying outlet temp. of 70-80° or 80-90°C, and voltages of 200 or 250. Fresh juice and powdered samples were assessed for microbiological quality, moisture content, total titratable acidity, pH, ascorbic acid, reducing and non-reducing sugars, total carotenoids, and sensory quality. They resulted that colour, flavour and taste were good only in the samples without additives.

Cano-Chauca et al. 2005 spray dried the mango juice with 12 ºBrix. Maltodextrin, gum arabic and starch waxy in the concentration of 12% were used as drying aids. Powder was obtained by means of Mini Spray dryer (BUCHI, B-191, Laboratory-Techniques LTD, Flawil–Switzerland). The inlet air temperature was 160 ºC and outlet air temperature was 70–75 ºC. The liquid feed to the dryer was about 10 mL min^{-1}.The flow of the drying air was about 0.7 m^3 min^{-1}. The experiments were performed at constant process conditions. The material obtained was placed into commercial bags (approximately 100 g), stored in a desiccators containing silica gel until posterior utilization. For powder observation, a Scanning Electronic Microscopic JEOL JSM-T200 (Jeol, Tokyo, Japan) working with a voltage of 10 kV was used. It was observed that in the systems with 0% and 3% of cellulose, particles were larger, amorphous, all piled up and with a strong attraction from each other and the particles tended to become more spherical and more scattered when concentration of cellulose increased. The crystallinity of powder was determined by powder X-ray diffraction method. Solubility was identified according to the Eastman and Moore method, 1984, with some modifications. Stickiness was determined according to the Chen and Hosney, 1995 method with some modification. It was reported that for maltodextrin, stickiness decreases with cellulose concentration until reaching values of 0.15 kg-f when 9% cellulose is added and for arabic gum (carrier), the stickiness value was 0.22 kg-f using 9% of cellulose and for the waxy starch treatment with addition of 9% of cellulose, the value stickiness was 0.11 kg-f. Thus addition of cellulose addition had low effect on the stickiness. They concluded that on using cellulose with drying aids solubility of mango powder decreases. Malto-dextrin treatment solubility decreased from 90% to 72% on using 9% whereas for arabic gum treatment solubility decreased to 71% when 9% of cellulose was added. In the waxy starch treatment solubility decreased 31% for a level of 9% of addition cellulose. Yu, 2001 reported that amorphous solids possess high solubility and high velocity of dissolution as compared to the crystalline state. Thus Cano-Chauca et al. 2005 concluded that the cellulose had an effect on the powder microstructure therefore it influences the functional proprieties.

Mani et al. 2002 spray dried the mango variety of Dasheri. The mango pulp was diluted with water by 1:2 ratio on weight basis. Maltodextrin was added as drying aid to the pulp with different ratios on total soluble solid basis. The experimental trials were conducted with commercial maltodextrin in different ratios of fruit pulp solid: maltodextrin such as 50:50, 45:55 and 40:60 under fixed operating conditions. The pilot plant spray dryer was a co-current type, bottom suction dryer. It consisted of the drying chamber with conical bottom, hot air duct, indirect air heater/radiator, supply fan with inlet air filter, nozzle assembly, main cyclone, exhaust air duct, rotary valve, exhaust fan, balance tank, high pressure triplex reciprocating pump. The other accessories such as electromagnetic hammer, pressure gauge, frequency controller, temperature sensors and U tube manometer were also provided in the plant. At the bottom of the dryer, a rotating air broom system was provided up to the conical portion to cool the wall surface further. Stickiness of mango powder was measured using sticky point apparatus and the procedure was reported by Downton et al. 1982; Wallack and King, 1988; Buhler and Liedy, 1989; Jaya et al. 2002. Mani et al. 2002 kept the feed flow rate of spray dryer 22 kg/hr, initial feed solid content (fraction) 0.19, final feed solid content (fraction) 0.95, airflow rate (kg dry air/hr) 950, feed temperature (ºC) 60, air inlet temperature (ºC) 167.3, air outlet temperature (ºC) 89. They produced 0.261 kg of powder having 5% (wb) moisture content from one kg of mango. The powder had good reconstitution property, color and flavor retention. Caking of mango powder took place when it was stored at ambient air and room temperature. According to Mani et al. 2002 ratio of fruit juice soluble solid and maltodextrin of 55:45 was considered as the optimum for production of mango powder. This optimum ratio was comparable with work of Bhandari et al. 1993.

6.11 Orange

Brennan et al. 1971 used sodium carboxymethyl cellulose, Gum Acacia, and liquid glucose as additives for spray drying of mango. Liquid glucose was found to be the most satisfactory additive, producing a powder with good flavour, free-flowing characteristics and a minimum of wall deposition. They resulted that variations in air inlet temperature, feed temperature and rate and atomizer speed, within a limited range, had no significant changes in the bulk density and particle size of the product. The higher temperatures did result in some change in colour and an increase in insoluble solids.

Gupta, 1978 introduced a method for producing a free-flowing orange juice powder having improved flavor using cocurrent spray dryer. They provided an aqueous slurry having up to about 65% solids, about 50-85% of which is orange juice with water-dispersible or water-soluble drying aid and obtained powder having an average moisture content of less than about 4% under carefully controlled drying conditions.

Chegini and Ghobadian, 2007 carried out spray drying of Iranian concentrated orange juice in three steps. In first step they did not use any additive and in next two steps they used additives maltodextrin and liquid glucose. The orange juice had total solids 63%, total sugar 42-45 g/100 ml and citric acid was 8-12 g/100 ml. They used Buchi model laboratory spray dryer. In this dryer, feed with rate was 7.5-42 ml min^{-1} by peristaltic pump transport on rotary atomizer with 25000-rpm speed. They kept the feed flow rate 15 ml/min and inlet air temperature 130ºC without using additives. With liquid glucose they kept the feed flow rate 20 ml/min and inlet air temperature 140ºC. With maltodextrin they kept the feed flow rate 25 ml/min and inlet air temperature 150ºC. They concluded that without using any additive there was no powder formation. They found that on using maltodextrin the yield was increased to 18-35% and on using liquid glucose the yield was increased and the wall deposition was decreased. They also concluded that inlet air temperature and feed flow rate has significant effect on yield and deposit of powder.

Shrestha et al. 2007 produced orange juice powder by spray drying a mixture of juice and maltodextrin with DE of 6 at 160 °C. The major components of orange juice such as fructose, glucose, and citric acid have very low Tg of 5, 31 and 16 °C, respectively, in a pure, dry state, which decrease drastically when moisture is absorbed. Due to this characteristic, the spray drying of orange juice is complex. They reported the Tg value of (anhydrous orange juice: maltodextrin 6 DE) (50:50) powder equal to 66.4 °C, whereas an increase in maltodextrin level from 50 to 60 parts resulted in a Tg value of 86.4 °C.

Goula and Adamopoulos, 2010 proposed a new technique for spray drying of orange juice concentrate using dehumidified air as drying medium and maltodextrin as drying agent. They modified original design of spray drier by connecting the dryer inlet air intake to an absorption air dryer. They used a pilot-scale spray dryer (Buchi, B-191, Buchi Laboratoriums-Technik, Flawil, Switzerland) with co-current regime and a two-fluid nozzle atomizer. 21 DE, 12 DE and 6 DE maltodextrins were used as drying agents. Concentrated orange juice (62.0±0.3%) was spray dried at inlet air temperatures of 110, 120, 130, and 140 °C and (concentrated orange juice solids)/(maltodextrin solids)(o:m) ratios of 4, 2, 1, and 0.25. Powders were analyzed for moisture content, bulk density, rehydration, hygroscopicity, and degree of caking.They concluded that the residue yield decreases with increasing maltodextrin concentration because the lower the o:m value, the higher the elevation of the Tg of the orange juice concentrate–maltodextrin mixture . They also found that 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, rehydration ability increases and hygroscopicity and degree of caking decreases with an increase in inlet air temperature and maltodextrin concentration and a decrease in dextrose equivalent.

6.12 Pineapple

Abadio et al. 2004 spray dried the pineapple juice (brand MAGUARY, Brazil). The objective of this research was to verify the effects of maltodextrin concentration and atomization speed on physical properties of powdered pineapple juice. They used 10 DE (dextrose equivalent) maltodextrin and spray dried in a pilot scale spray dryer (home made/DTA, UFRRJ, Brazil). The feed was pulverized in a rotary atomizer with a co-current airflow produced by a blower. The inlet and outlet air temperature were 190 and 90 ºC, respectively, blower velocity was 25,000 rpm and feed rate was 0.18 kg/min. The statistical analyses were carried out according to Barros et al. 1995. The powdered samples were filled into low-density polyethylene pouches and stored at 10 ºC until analyzed. They used vacuum oven at 70 ºC (constant weight—IAL 1977) to measure the moisture content of pineapple juice and powder and color was determined by MINOLTA spectrophotometer. The apparent bulk density (DA) of the powders was determined by measuring the volume of a determined weight of powder in a glass cylinder. The true bulk density (TD) of the powdered juice was determined in a picnometer according to the methodology of Lewis, 1993. The solubility was determined by homogenization, centrifugation and determination of the insoluble residue from the dissolution of 1g of powdered juice in 10 ml distilled water, according to the methodology of IAL, 1977.

They finally concluded that on increasing the maltodextrin concentration moisture content of powder decreased because the solids in the feed increased and amount of free water for evaporation decreased. They also resulted that on increasing maltodextrin concentration, true density decreased because of the lower moisture content of the products. They found that reduction in maltodextrin concentration improved the solubility. They produced light yellow powder with very low densities. Abadio et al. 2004 recommended the use of lower atomization speeds and 10% maltodextrin to obtain free-flowing products with good solubility.

6.13 Pomegranate

Vardin and Yasar, 2012 spray dried pomegranate juice with 18 and 7 dextrose equivalent (DE) maltodextrins (MD) as drying-aid agents. They used lab-scale spray-dryer and resulted that inlet temperature has great influence on the physical properties and anthocyanin degradation of the spray-dried powders. The maximum achieved ratio of PJC ⁄ MD was 1 ⁄ 1, and it was obtained with the use of DE7 MD. However, graphical optimisation studies resulted in 125–145 ˚C and 0.6–0.8 PJC ⁄ MD ratio as optimum variables to produce acceptable dried powder. It was observed that increasing inlet air temperature increases solubility time and loss of anthocyanins and decreases bulk density and moisture content of the powder.

6.14 Watermelon

Quek et al. 2006 produced spray dried watermelon powder using two different maltodextrin concentrations (3% and 5%). They carried out experiments using Buchi mini spray dryer B-191 with flow rate of 600 L/h, pressure 4.5 bar and inlet air temperatures 145, 155, 165, 175ºC. The spray dried powder was analysed for moisture content, water activity, dissolution test, color, sugar, lycopene and ß-carotene analysis. They resulted that if maltodextrin was not added in the feed, the particles produced were very sticky and deposited on the wall of drying chamber. They used the maltodextrin of low dextrose equivalent with DE of 8-12. They finally concluded that on adding 5% maltodextrin to the feed, yield of the product was improved and better results were obtained, while on using 10% maltodextrin, the powder lost their attractive red color. They also reported that at higher inlet air temperature the lightness, lycopene and ß-carotene of spray dried powder was reduced. At 155ºC they got the best colorimetric results, low moisture content, low water activity and good lycopene and ß-carotene contents in powder.

7. APPLICATION OF SPRAY DRYING TO VEGETABLE JUICES

7.1 Carrot

Ersus and Yurdagel, 2006 spray dried anthocyanin extracts from black carrot (var. Daucus carota L.) to determine the effects of different spray drying temperatures on the anthocyanin content of the powders. They used maltodextrin MDX 29 (28–31 DE) as carrier agent. Spray drying was performed by them in Lab Plant SD4 spray drier (Lab Plant Ltd., England) with TSS of 11.90 ± 0.14º Brix. They kept the feed mixture temperature at 25ºC and feed flowrate 5 ml/min. They carried out experiments at three different inlet temperatures 160,180 and 200ºC and outlet temperatures 107 ± 2, 118 ± 2 and 131 ± 2, respectively. They found the dry matter as 13.15 ± 0.08 g/100 g fresh weight while in research of Ersus et al. 2004 the similar purple carrot's dry matter content was found 18.85 g/100 g fresh weight because of different climate conditions and harvest time. Ersus and Yurdagel, 2006 finally concluded that anthocyanin losses occur at higher temperatures (≥160-180ºC) and 20–21 DE maltodextrin which is Glucodry 210 gives the better yield of powder. They also concluded that better half life of powder was obtained on storing it at 4ºC.

Wagner and Warthesen, 1995 spray dried carrot with various dextrose equivalent (DE) hydrolyzed starches. Hydrolyzed starch of 36.5DE was superior to 4, 15, and 25DE in improving retention of the carotenes.

7.2 Ginger

Phoungchandang et al. 2010 spray dried the ginger juice. Ginger rhizomes contain about 82.6% moisture and phytochemical substances such as (n)-gingerol, zingerone, and (n)- shogaol1 which function as an antioxidant and anticancer agent (Yogeshwer et al. 2007). The spray drying experiments were performed using a pilot plant spray dryer (PML- 20, Pamalyne). They used the ginger maturity with the age of 10–12 months in the drying process. The feed rate of the spray dryer was 14–18 ml/min by a peristaltic pump. An electric heater heated the inlet air to a temperature of 120–150 °C. The outlet air temperature was 75–85 °C. Maltodextrin and liquid glucose were used as drying aids at the concentration of 0, 5 and 10%. The pilot plant spray dryer was situated in a food processing pilot plant with a stable environment. The ambient air temperature was 30.5 °C and the relative humidity was 71.5±1.9%. In all experiments, atomizer speed and air pressure were constant at 35000g and 3.0 kPa, respectively. Moisture content was determined by the AOAC method. The color of ginger powder was measured using Hunter Lab (ULTRASCAN XE U3115, Color Global Co.). Phoungchandang et al. 2010 concluded that the moisture content, water activity, bulk density, water adsorption index, 6-gingerol content, and color values of ginger powders decreased with increasing inlet air temperatures. Particle size, solubility, and water solubility index increased with increasing inlet air temperatures. Moisture content, water activity, water adsorption index, and particle size decreased with increasing the drying aids. Solubility, water solubility index, and yield increased with increasing the drying aids. The moisture content and density of ginger rhizomes decreased with the increasing fiber and 6-gingerol content. The inlet air temperatures and drying aids affected the quality of dried ginger powders. Liquid glucose as a drying aid increased the drying yield to 15.7%. The best quality ginger products were achieved at 120 °C inlet temperature and 5% liquid glucose.

7.3 Purple Sweet Potato

Ahmed et al. 2009 investigated the effects of drying temperature (55, 60, and 65°C) and addition levels of maltodextrin (MD) (10, 20, and 30%) on the physicochemical properties and nutritional quality of purple sweet potato flour. They resulted that MD-added flours had higher L* values, water soluble index, total phenolic, and anthocyanin contents than untreated flour. It was observed that untreated flour had a higher ascorbic acid content compared to the MD-treated flour. With increasing drying temperatures Ascorbic acid contents decreased, whereas anthocyanin content was not significantly different. According to them MD was positively correlated with phenolic content, anthocyanin, hue angle, and water soluble index. The best quality product was obtained when samples were pretreated with MD before drying, regardless of drying temperature.

Ahmed et al. 2011 produced encapsulated flour from purple fleshed sweet potato of variety Ipomoea batatas L. Lam by using mini spray dryer EYELA, SD-1000. They aimed to study the effects of combinations of various levels of maltodextrin and ascorbic acid on the bioactive components, physicochemical properties, morphological changes and glass transition temperature of spray-dried encapsulated and non-encapsulated purple sweet potato flours. They kept the solid content 11±0.5 g/ 100 g, inlet air temperature 150 ºC, outlet air temperature 85± 4 ºC, rotary atomizer14 ×10 kPa and blower rate 0.60± 0.2 m^3/min. They found the glass transition temperatures of non-encapsulated and encapsulated flours were approximately 10.15-29.37ºC which was similar with the results of Ahmed et al. 2010. They concluded that the encapsulated flours had higher total phenolic content and antioxidant capacity as compared to the non-encapsulated flour. Their results showed that encapsulated with 10 g kg^{-1} ascorbic acid and 30 g kg^{-1} maltodextrin flour could be used to make the higher quality product that would be more attractive to product developers and consumers.

7.4 Tomato

According to Gransmith, 1971; Jayaraman and Das Gupta, 1995; Masters, 1979; Spicer, 1974, a spray drying plant capable of producing a free-flowing product that on reconstitution compares favorably with tomato paste has been designed featuring a co-current drying chamber that has a jacketed wall for air-cooling. Cooling air intake is controlled to enable close maintenance of wall temperature in the range of 38–50 ˚C. The paste is sprayed into the drying air entering the chamber at a temperature of 138–150 ˚C. An alternative approach to the above process has been the Birs Tower process. The drying takes place in a very tall tower into which the tomato juice is introduced as a spray at a predetermined height. The whole drying process relies on the time-delayed fall of the product droplets and the very low temperature (not exceeding 30 ˚C) of the upward airflow. In this way, explosion-type evaporation is avoided and the particles are not exposed to high temperatures likely to damage their organoleptic properties (Goose and Binsted, 1964; Gransmith, 1971).

Goula and Adamopoulos, 2005 studied the performance of a modified spray dryer for tomato powder preparation under various operating conditions and the effects of preliminary air dehumidification on product recovery while in their next study they investigated the effect of modification in system on powder property. They used tomato pulp of constant solid mass concentration of 14 ± 0.05%. Buchi mini spray dryer (Model 191, Buchi Laboratoriums-Technik, Flawil, Switzerland) was used for the spray drying process. They made the modification on the original design consisted in connection of the spray dryer inlet air intake with an absorption air dryer and thus the products yields ranged from 36.62% to 65.86%, whereas residue accumulation varied from 20.17% to 45.83%.when they employed experiments on standard laboratory spray drying system, product recovery was 19.90–48.23% lower and residue accumulation was 21.49–49.50% higher. They concluded that much lower outlet temperatures and humidity of drying air in the modified system resulted in the formation of a solid particle surface and so, decreased the residue accumulation minimizing the thermoplastic particles from sticking. Regarding the powder properties they concluded that powder moisture content decreases with an increase in air inlet temperature and compressed air flow rate, and with a decrease in drying air flow rate, bulk density increases with a decrease in drying air flow rate and air inlet temperature, and with an increase in compressed air flow rate, solubility increases with a decrease in drying and compressed air flow rate, and with an increase in air inlet temperature.

Goula et al. 2008 modeled the sorption isotherms using selected equations by spray drying tomato pulp and defined the glass transition temperature, water activity and water content relationships. They used Buchi mini spray dryer (Model 191) with modification in original design. They kept the atomizer pressure, the feed temperature, and the feed rate 5 ± 0.1 bar, 32.0 ± 0.5 ºC, and 1.75 ± 0.05 g/min, respectively and constant total solids mass concentration of 14 ± 0.05%. Experiments were performed at air inlet temperature of 130 ºC (±1 ºC), drying air flow rate of 22.75 m^3/h (±0.18 m^3/h), and atomizing agent flow rate of 600 l/h (±20 l/h). They determined the glass transition temperature by DSC, with a Perkin–Elmer Pyris 1 differential scanning calorimeter supplied with proper software. They finally concluded that water acts as a plasticizer in spray dried tomato pulp decreasing its glass transition temperature and the Gordon and Taylor model could adequately represent the sugar matrix glass transition curve.

8. CONCLUSIONS

Inlet air temperature showed significant effect on all the responses studied. In most juices increasing temperature led to higher process yield and powder hygroscopicity, and to lower moisture content. Feed flow rate negatively influenced process yield and hygroscopicity, and positively influenced moisture content. Maltodextrin concentration had negative effect on powder hygroscopicity, confirming its efficiency as a carrier agent. The increase on this variable also caused a reduction on process yield, probably due to the increase on feed viscosity. In respect to powder morphology, increasing temperatures resulted in a greater number of particles with smooth surface and with larger sizes, due to the higher drying rates. The increase on maltodextrin concentration also led to the production of larger particles, which is related to the increase on feed viscosity. The design of spray dryers usually is based on knowledge obtained through pilot plant tests or prior experience .The choice of spray dryer configuration – cocurrent, counter-current or mixed-flow, is decided based on the desired qualities of the final product .The residence time and the amount of evaporation required are the two most important factors to be considered in the spray dryer design. These two factors are used to determine equipment size and the heat duty. The operating conditions can be determined by knowing the throughput required, the residence time, and the heat duty. In this work, a rate-based model approach will be used in conjunction with empirical relationships for the heating gas flow pattern to determine the design parameters for the spray dryer when the final product is the manufacture of hollow particles .

NOMENCLATURE

ABBREVIATIONS	**SYMBOLS**
ACN- Total Anthocaynins	**aw**- Water Activity
AG- Arabic Gum	**ß**- Beta
AOAC-Association of Official Analytical Chemists	**g**- gram
APE- Acerola Pomace Extract	**kg-f**- Kilogram Force
BET- Brunauer-Emmett-Teller	**kV**- Kilo Volt
GAB- Guggen-Heim-Anderson-de Boer	**MPa**- Mega Pascal
CTG- Cashew Tree Gum	**Tg**- Glass Transition Temperature
DE- Dextrose equivalent	**wb**- By Weight
EE- Encapsulation Efficiency	**w/v**- Weight by Volume
GBS- Green Banana Starch	
GC- Gas Chromatography	
IAL- Instituto De Adolfo Lutz	
MD- Maltodextrin	
rpm- Round Per Minute	
SPME- Solid Phase Microextraction	
TPC- Total Phenolic Content	
TSS- Total Soluble Solids	

TCC- Total Carotenoid Content	
TAA- Total Antioxidant Activity	
TOFMS- Time-of-Flight Mass Spectrometry	
Var.- Variety	
WSI- Water Solubility Index	

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Table 1: Spray Drying of various fruits and vegetables.

		SPRAY DRYING CONDITIONS						
S.N.	FRUIT/ VEGETABLE	INLET AIR TEMP. (ºC)	OUTLET AIR TEMP. (ºC)	TSS (ºbrix)	AID USED	TYPE OF SPRAY DRYER	OBSERVATION	REFERENCE
1.	Acai juice	138-202	-	-	Maltodextrin 9.0 6 ≤ DE ≤ 6 12.0	LabPlant SD-05	Increasing temperature led to higher process yield and powder hygroscopicity, and to lower moisture content and anthocyanin retention.	Tonon et al. 2008
2.	Acai juice	140 ± 2	78 ± 2	-	Maltodextrin 10 DE with 20DE, gum Arabic and tapioca starch	LabPlant SD-05	Critical water activities varied from 0.535 to 0.574 and critical moisture contents varied from 0.061 to 0.100 g/g dry matter increase of water activity also resulted in higher degradation.	Tonon et al. 2009, Tonon et al. 2010
3.	Acerola pomace extract	>194	-	7.8–15.6 g/100 g	Maltodextrin :acerola extract (4) with 80%Cashew tree gum	Mini Spray Dryer Bu¨ chi B-290 (Bu¨ chi Labortechnik AG, Flawil, Switzerland)	Higher inlet temperatures favored the desired physical properties of the powders, decreasing their moisture contents and hygroscopicity, and increasing flowability.	Moreira et. al. 2009
4.	Banana (var. Nanica' Musa cavendish)	130 ± 5	47 ± 5	5.55 ± 0.44	Starch solution (15%)	Mini spray dryer (LM Labmaq, Brazil)	Ultrasound treatment improved the solubility, swelling power, water absorption capacity, rheological properties and gelatinization of starches even those with high resistant starch	Izidoro et al. 2011

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							content.	
5.	Banana	168.5	101.8	-	-	Modified spray dryer with rotating air broom system	One kg of whole banana could produce about 100 g of banana fruit powder having the moisture content of 7% (wb). The powder retained its color and flavor.	Mani et al. 2002
6.	Bayberry	150	80	11.0 ± 0.5	Maltodextrin (DE = 10)	Büchi B-290 mini spray dryer	Bayberry powder was successfully obtained when the juice was spray dried with maltodextrin (DE 10) as the carrier, with inlet and outlet temperatures of 150 ºC and 80 ºC, respectively.Spray dried bayberry powder should be stored at less than 25 ºC and aw of 0.33, on account of the polyphenol stability.	Fang and Bhandari, 2011
7.	Black Carrot (var. Daucus carota L.)	160,180,200	107.118,131	11.90	Maltodextrin (20-21 DE)	Lab Plant SD4	20–21 DE maltodextrin which is Glucodry 210 gives the better yield of powde and half life of powder was obtained on storing it at 4ºC.	Ersus and Yurdagel, 2006
8.	Blackcurrant, Apricot and Rasberry	160	90	-	Maltodextrin (DE6)	-	Best results were obtained for a ratio juice to maltodextrin DE6 of 65/35 for blackcurrant, of 60/40 for apricot and 55/45 for raspberry, and low air temperatures (160–90°C).	Bhandari et al. 1993
9.	Carrot	-	-	-	Hydrolyzed starch (36.5DE)	-	-	Wagner and Warthesen, 1995
10.	Cashew apple	185	90		CTG	Mini Spray	The CTG was presented as a good	De Oliveira et al.

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	juice					Dryer Bu¨ chi B-290	drying aid agent, reducing the hygroscopicity of the spray dried cashew apple juice powder when compared with that produced by using MD10 as drying aid.	2009
11.	Durain pulp	160 ±2	85 ±3	-	-	Co-current spray dryer (Niro model 2000A, Denmark)	98% and 99% amount of volatiles were loss during spray-drying process.	Chin et al. 2008
12.	Gac fruit	120	83	-	Maltodextrin 12DE	Lab Plant SD-05 spray dryer	The Gac powder spray-dried at inlet temperature of 120 ºC and maltodextrin concentration of 10% was adequately effective in preserving colour, TCC and TAA.	Kha et al. 2010
13.	Ginger rhizomes	120	75– 85	-	Maltodextrin, Liquid glucose	pilot plant spray dryer (PML-20, Pamalyne)	Yield was increased to 15.7% with liquid glucose concentration of 10% at 120 °C. Moisture content, bulk density, water adsorption index, 6-gingerol and colour value of ginger powders decreased with increasing inlet air temperature.	Phoungchandang and Sertwasana, 2010
14.	Guava (var. Roja)	200±2	100±4	38	Maltodxtrin(DE 19-20) Arabic gum	spray-drier LabPlant SD-06 (Huddersfield, England)	Microencapsulation is a useful alternative to preserve the sensory and biofunctional properties of guava in processed products.	Osorio et al. 2011
15.	Guava	-	-	-	-	-	They found that freeze-dried product exhibited superior sensory quality but the spray-dried product was more stable	Chopda and Barrett, 2001

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							and economically favourable.	
16.	Lime juice	-	-	-	Silicon dioxide , maltodextrin	-	-	Nijdam et al. 2000 and Roustapour et al. 2006
17.	Mango	-	80-90	23	sodium alginate	-	They resulted that colour, flavour and taste were good only in the samples without additives.	Khalil and Sial, 1974
18.	Mango	160	70-75	12	Maltodextrin, Gum Arabic, Starch waxy cellulose	Mini Spray dryer (BUCHI, B-191)	Addition of cellulose to the juice led to higher stickiness stability; however, the functional property of solubility was also affected.	Cano-Chauca et al. 2005
19.	Mango(var. dhasheri)	167.3	89	-	Maltodextrin	Pilot plant spray dryer	One kg of mango could produce about 0.261 kg of powder having 5% (wb) moisture content. The powder had good reconstitution property, color and favor retention. Caking of mango powder was observed when it was packed and stored in ambient air at room temperature.	Mani et al. 2002
20.	Orange	-	-	-	Liquid glucose	-	They resulted that variations in air inlet temperature, feed temperature and rate and atomizer speed, within a limited range, had no significant changes in the bulk density and particle size of the product.	Brennan et al. 1971
21.	Orange	-	-	65%	-	-	produced a free-flowing orange juice powder having improved flavor using cocurrent spray dryer.	Gupta, 1978
22.	Orange juice	110-140	-	62.0±0.3	Maltodextrin	(Buchi, B-	Combination of maltodextrin	Goula and

	concentrate			%	(DE6 ,DE12, DE21)	191, Buchi Laboratoriums-Technik, Flawil, Switzerland	addition and use of dehumidified air as drying medium seems to be an effective way of producing a free-flowing orange powder.	Adamopoulos, 2010
23.	Orange juice	130	85	63%	Liquid glucose	Buchi model laboratory spray dryer	Liquid glucose was suitable agent material for drying of orange juice so the yield increased and the wall deposit considerably was reduced.	Chegini and Ghobadian, 2007
24.	Orange	160	-	-	Maltodextrin (DE6)	-	They reported the Tg value of (anhydrous orange juice: maltodextrin 6 DE) (50:50) powder equal to 66.4 °C, whereas an increase in maltodextrin level from 50 to 60 parts resulted in a Tg value of 86.4 °C.	Shrestha et al. 2007
25.	Pineapple(var. MAGUARY, Brazil)	190	90	-	Maltodextrin 10 DE	Pilot scale spray dryer (home made/DTA, UFRRJ, Brazil)	Lower atomization speeds and 10% malt dextrin is sufficient to obtain free-flowing products with good solubility.	Abadio et al. 2004
26.	Pomegranate	125–145	-	-	Maltodextrin (DE7)	lab-scale spray-dryer	It was observed that increasing inlet air temperature increases solubility time and loss of anthocyanins and decreases bulk density and moisture content of the powder.	Vardin and Yasar, 2012
27.	Purple sweet potato	65	-	30%	Maltodextrin	-	The best quality product was obtained when samples were pretreated with MD before	Ahmed et al. 2009

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							drying, regardless of drying temperature.	
28.	Purple Sweet Potato	150	85± 4	11±0.5 g/ 100 g	Maltodextrin, ascorbic acid	Mini spray dryer EYELA, SD-1000	Results showed that encapsulated with 10 g kg^{-1} ascorbic acid and 30 g kg^{-1} maltodextrin flour could be used to make the higher quality product.	Ahmed et al. 2011
29.	Tomato pulp	110-130	19–24	14 ± 0.05%	-	Buchi mini spray dryer (Model 191)	product recovery was 19.90–48.23% lower and residue accumulation was 21.49–49.50% higher.	Goula and Adamopoulos, 2005
30.	Tomato pulp	130	-	14 ± 0.05%	-	Buchi mini spray dryer (Model 191)	Water acts as a plasticizer in spray dried tomato pulp decreasing its glass transition temperature.	Goula et al. 2008
31.	Tomato	138–150	-	-	-	Co-current spray dryer	Explosion-type evaporation is avoided and the particles are not exposed to high temperatures likely to damage their organoleptic properties	Gransmith, 1971; Jayaraman and Das Gupta, 1995; Masters, 1979; Spicer, 1974
32.	Water melon	155	-	-	Maltodextrin	Buchi mini spray dryer (Model B-191)	Drying the watermelon juice above 165ºC has overall lead to inferior products due to nutrient loss and changes in colour.	Quek et al. 2007

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