Vol.63: e20190538, 2020
http://dx.doi.org/10.1590/1678-4324-2020190538
ISSN 1678-4324 Online Edition

Article - Food/Feed Science and Technology

Effect of Maltodextrin Concentration and Inlet Air Temperature on Properties of Spray Dried Powder from Reverse Osmosis Concentrated Sweet Orange Juice

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Received: 2019.09.23; Accepted: 2020.06.01.

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HIGHLIGHTS

- Powder properties obtained from spray drying of concentrated and control sweet orange juices were compared.
- Spray dried powder from concentrated juice offered better powder properties in comparison to the powder from control juice
- Better retention of vitamin C in powder obtained from concentrated juice observed.
- In terms of flowability and cohesiveness, spray dried sweet orange powder was classified as “possible and fair”.

Abstract: Sweet orange juice is an important part of diet since it is nutritious beverage offering good taste and play significant part in a healthy diet. High hygroscopicity, thermo-plasticity and presence of low molecular weight components in sweet orange juice offer low glass transition temperature (T_g), likely to form soft particle with sticky surface leading to sticky powder during drying. Maltodextrins are amorphous drying aids that tend to inhibit sugar crystallization and form a high T_g product after drying. In this study, the effect of the different spray drying parameters on the quality of powder derived from control and concentrated juice at three inlet air temperatures 120, 130 and 140 ˚C and at three levels of juice total soluble solids (TSS): maltodextrin levels at 1:0.5; 1:1 and 1:1.5 were studied. The impact of inlet air temperature and maltodextrin concentration has significantly affected various properties of sweet orange powder. For control juice, process yields increased with increase in inlet air temperature and maltodextrin concentration. However, for reverse osmosis (RO) concentrate, process yield increased with increase in maltodextrin concentration and decreased with increase in inlet air temperature. For control juice, process yields obtained were in the range of 12.59-41.16% and in case of concentrated juice, the process yield obtained was in the range of 21.35-56.95% at different combinations of inlet air temperature and maltodextrin concentrations. Spray-dried powder was considered as “possible” and “fair” in terms of flowability and cohesiveness. Vitamin C retention was high at lower inlet air temperature with lower concentration of maltodextrin.

Keywords: sweet orange; spray drying; process yield; moisture content; vitamin C content; Hausner's ratio; Carr index; solubility time; water solubility index; water absorption index (3-10).

INTRODUCTION

Citrus fruits are primarily enriched with vitamin C and also the vital source of nutrients such as amino acids, inorganic salts and carbohydrates in the edible portion of fruit that provide supplementary nutritional value. Among citrus fruits, sweet orange (*Citrus sinensis)* is extensively grown throughout the world. Fresh sweet orange juice is a tasty nutritious beverage and becomes a part of a healthy diet. The proportions of various components of sweet orange fruit were reported [1] as peel (23.66%), juice (37.95%), pomace (32.09%) and seed (6.3%). Proximate composition of sweet orange juice contain carbohydrates (10.5%), proteins (0.6%), fat (0.05%), fibre (0.12%), ash (0.3%), moisture content (88.4%), total soluble solids (TSS) (10.0%), pH (3.7), ascorbic acid (43.0 mg/100mL) [1]. Sweetness of juice is due to occurrence of fructose and glucose. Reducing and non-reducing sugars are distributed in equal ratio in the juice [2]. Sweet orange powder is an important value addition of sweet orange juice. During drying, presence of low molecular weight simple sugars and acids in sweet orange juice decreases glass transition temperature (T_g), become highly hygroscopic and likely to form soft particle and converted to glassy state with the reduction of surface viscosity for adhesion, thus, producing sticky powder [3,4]. Studies have shown that adhesion and cohesion of particle surface of amorphous powder occurs at critical viscosity in between 10^7 and 10^{12}Pas [5]. Further, viscosity of amorphous powder depends on moisture content and becomes critical at temperatures 10-20 °C higher than glass transition temperature [6]. Thus, T_g may be regarded as the pivotal parameter to characterize fruit powders in terms of the stickiness and caking attributes. Powders with low moisture content stored at temperature below glass transition may be regarded as stable [5,7-8].

Numerous workers have used spray drying techniques for generation of fruit powders as spray dried powders have low water activity [9-12], good reconstitution characteristics and is also appropriate for heat sensitive components [13]. The major difficulties in fruit juice spray drying are sticking of the powder in the drying and collecting zones and scorching of the product. The recovery of product from a spray drier is limited by its stickiness [12,8]. In order to control powder stickiness during spray drying, either process based approaches like introduction of dehumidified air, cooling the drier chamber or material science approaches like addition of drying adjunct may be used during spray drying [14]. There are many materials used as carriers. Maltodextrin, tricalcium phosphate, soybean proteins, pectins and hemicelluloses have been used as structural element in powders [12].

Maltodextrin (molecular weights ranging 550-3600 Da), commonly used drying agent, is an amorphous, highly hygroscopic, with varying range of glass transition temperatures from 100 to 188 °C based on their dextrose equivalent (DE 36-5) property, respectively [15]. Addition of maltodextrin improves drying rate, reduces hygroscopicity and thus prevents stickiness encountered during spray drying by hindering crystallization of sugar and finally, enhances powder flowability [16,11]. Literature review on spray drying of RO concentrated sweet orange juice is limited and fragmentary. Hence, in this present study, influence of maltodextrin and inlet air temperature on properties of spray dried powder from RO concentrated sweet orange juice were investigated and presented.

MATERIAL AND METHODS

For this study, freshly harvested matured healthy sweet orange fruits (Variety: Sathgudi) were procured from local market of Vijayawada, Andhra Pradesh, India during June 2017. Initially, dirt adhering fruits were removed by rinsing with water and then shade dried. Sweet oranges were cut and juice was extracted using hand operated juicer. Extracted juice was pre-filtered with muslin cloth and a preservative, Sodium benzoate was added at the rate of 0.1% [17]. Clarification of Sweet orange juice was done by microfiltration (MF) using cellulose acetate membrane of average pore diameter 0.2 µm. The experiments were carried out using stirred batch cell (Make: M/s. Technoquips Separation Equipments Pvt. Ltd., Kharagpur, India) at a transmembrane pressure of 206.84 kPa [18]. Spray drying of clarified juice (8-9 °Brix) as well as juice concentrated (18 °Brix) by reverse osmosis (RO) at 55 bar using composite polyamide RO membrane was done in a pilot scale spray dryer (Make: S.M. Scientech, Kolkata, India, Capacity: 3 L of water evaporation/h) equipped with 0.7 mm orifice diameter two fluid nozzle was situated in a laboratory with stable environmental conditions. Experiments were conducted at the ambient temperature of 28-32 ˚C and relative humidity of about 58-65%. Two fluid nozzle with orifice diameter of 0.7 mm and a compressed air of 2 bar pressure were used to disperse feed into fine mist. In all experiments feed rate was maintained at 10 mL/min and also at constant air volume with a blower speed of 2000 rpm. The experimental design included of randomized full factorial design with three independent factors. The factors were: (A) maltodextrin content (Make: Loba Chemie, DE-20) in the proportions of 1:0.5, 1:1 and 1:1.5, (total soluble solids in juice:maltodextrin solids, w/w); (B) inlet air temperature (120-140 °C); (C) condition of juice (control or RO concentrated). Various response variables evaluated were process yield, moisture content, water activity, bulk density, tapped density, Carr Index, Hausner ratio, Water solubility index, water absorption index, solubility and vitamin C content. Each response variable was evaluated using a multiple regression method and significance of the equation parameters for each response variable was analyzed statistically using the Design Expert 10.0 software (Stat-Ease Inc., Minneapolis, MN, USA).

Determination of Properties of Powder

Yield

The yield was calculated as the percent of the mass of solids collected after spray drying to the amount of solids in feed solution [19,20]. While computing yield, total weight of powder obtained from drying chamber and cyclone were added.

Moisture Content

Moisture analysis has been performed on dry samples using an infrared (IR) Moisture balance (Make: Shimadzu, Model: Mu 63). Moisture content of all spray-dried and freeze dried samples were determined by subjecting samples to Infrared heating to a temperature of 105 ˚C. All samples were stored in sealed vials and physical characterizations have been performed within 24 hours.

Sticky Point Temperature

The sticky point temperature was measured by using a Hot plate. A sample weighing 1 g was kept on a soft plate and heater was turned on with intermittent stirring with glass rod. The temperature at which the particles begin to cohesion was noted as sticky point temperature [21].

Bulk Density

The bulk density of powder was determined by the procedure as followed previous researchers [22,23]. 2 g of powder was transferred to a 50 mL graduated measuring cylinder. The bulk density was calculated by dividing the mass of the powder by the volume occupied in a graduated cylinder.

Tapped Density

The tapped density is an increased bulk density attained after mechanically tapping a container containing the powder sample. The tapped density was obtained by 25 times mechanically tappingof the graduated cylinder on a rubber mat from a height of 15 cm. The tapped density was calculated by dividing the mass of the powder by the volume occupied in a graduated cylinder.

Hausner Ratio

The flowability of powder is correlated with the parameter Hausner ratio. The Hausner ratio was calculated by the formula [24].

$$H = \rho_T/\rho_B \quad (1)$$

Where ρ_B was the freely settled bulk density of the powder, and ρ_T was the tapped bulk density of the powder. A Hausner ratio greater than 1.25 indicate poor flowability.

Carr Index (CI)

The compressibility of a powder is correlated with the Carr Index. The Carr index was calculated by the formula [25],

$$C.I. = (1- V_T/V_B) \times 100 \quad (2)$$

Where V_B was the volume that a given mass of powder would occupy if let settled freely and V_T was the volume of the same mass of powder would occupy after "tapping down". It can also be expressed as , CI = 100(1- ρ_B/ρ_T) where ρ_B was the freely settledbulk density of the powder, and ρ_T was the tapped bulk density of the powder. Detailed specifications for Carr's Index and Hausner's Ratio was presented in Table 1 [26,27].

Table 1. Specifications for Carr's index and Hausner ratio

Flowabillity	Carr's Index	Hausner's ratio
Excellent	0-10	1.00-1.11
Good	11-15	1.12-1.18
Fair	16-20	1.19-1.25
Possible	21-25	1.26-1.34
Poor	26-30	1.35-1.45
Very poor	32-37	1.46-1.59
Very very poor	>38	>1.60

Water Absorption Index (WAI)

A suspension of 2.5 g juice powder in 25 mL distilled water was agitated for 1 hour and centrifuged at 3000 rpm for 10 min. The free water was removed from the wet residue, which was drained for 10 min. The wet residue was then weighed [28].

$$\text{WAI (\%)} = \frac{\text{Weight of residue}}{\text{Weight of sample}} \times 100 \tag{3}$$

Water Solubility Index (WSI)

Spray dried juice powder (2.5 g) and distilled water (30 mL) were vigorously mixed in 100 mL centrifuge tube incubated at a 37 ˚C water bath for 30 min and then centrifuged for 20 min at 10000 rpm (11410 g) in a centrifuge. The supernatant was carefully collected in a pre-weighed beaker and oven dried at temperature 103±2 ˚C. The WSI (in %) was calculated as the percentage of dried supernatant with respect to the amount of original 2.5 g fruit juice powder [28].

Solubility time

The solubility time of powder was determined by adding 2 g of the powder to 50 mL distilled water at 26 ˚C. The mixture was agitated in 100 mL using a low form glass beaker with a Heidolph magnetic stirrer at 892 rpm using a stirrer bar of size 22×7 mm. The time required to dissolve powder completely was recorded [29].

Water Activity (a_w)

Water activity of the powder samples was determined using a pre-calibrated water activity meter (Rotronic, Germany).

Estimation of vitamin C as ascorbic acid content

Vitamin C as ascorbic acid content was determined as per procedure suggested [30]. Principle of the estimation of ascorbic acid involved titration of sample extract in oxalic acid against standard sodium 2, 6 dichloro phenol indophenol dye 0.04% to a faint pink colour which persists for 5-10 seconds.

i) Sodium 2, 6 dichlorophenol indophenol dye 0.04%: 40 mg of 2, 6-dichlorophenolindophenol was weighed and added to 150 mL hot distilled water. 42 mL sodium bicarbonate was added and the solution was cooled and made to 200 mL with water and kept in refrigerator

ii) 4% oxalic acid was prepared by dissolving 40 g Oxalic acid in water and made to 1000 mL.

iii) Standard Ascorbic acid solution: 100 mg ascorbic acid was dissolved in 100 mL of oxalic acid and 10 mL was diluted to 100 mL with oxalic acid and standard ascorbic acid was prepared.

iv) Sample preparation: 10 g of sample was taken and 4% Oxalic acid was added to make volume 100 mL. The solution was thoroughly mixed and filtered/centrifuged.

10 g of sample filtrate was taken and titrated against Indophenol dye. Titer was noted. Three replications of each sample analyzed and Ascorbic acid content was estimated from Equation 4.

$$\text{Ascorbic acid (mg/100 g)} = \frac{Titre \times Dyefactor \times Volumemadeup \times 100}{Aliquotofextracttakenforestimation \times Volumeofsampletakenforestimation} \quad (4)$$

RESULTS

The physico-chemical characterization of the raw materials used in spray drying was shown (Table 2). As observation trials, sweet orange juice was spray dried without using drying aid at three temperature ranges (120-150 ˚C). Results indicated that in all the tests, no powder was produced and the material was cohered to the wall chamber and cyclone and powder could not be obtained after scrapping on wall surfaces.

Table 2. Physico-chemical characterization of the raw materials used in spray drying

Parameter	Control /Fresh	Concentrated juice	Maltodextrin
Pre treatments	Muslin cloth filtration and Microfiltration	Muslin cloth filtration and Microfiltration and RO	Dextrose Equivalent 20
Total soluble solids (TSS), °Brix	9±1.7	17±1	
pH	3.8-4.2	3.8-4.2	4-7 (20% in water)
Viscosity (mPas)	1.2-1.3	2.00-2.30	
Vitamin C (mg/100g)	30-45	60-80	
Water Solubility Index (%)	-	-	96.05
Glass transition temperature (˚C)			122

J: MD- Juice

Effect of inlet air temperature and maltodextrin concentration on process yield

For control juice samples, process yields obtained were in the range of 12.59- 41.16% at various inlet air temperatures and maltodextrin concentrations (Figure 1 a). A maximum process yield of 41.16% was obtained at an inlet air temperature of 140 ˚C and with juice TSS: maltodextrin concentration of 1:1.5. At a constant inlet air temperature, increase in concentration of maltodextrin increased process yield and vice versa. At lower maltodextrin concentration, feed has lower total solids causing lower viscosity and this might lead to shearing action between high velocity compressed air and low velocity feed producing high velocity atomized spray droplets colliding with internal walls of the drying chamber at greater speed and intensity, generating increased wall deposits and thus, decrease the process yield. Similar reduction of yield by rotary nozzles of spray dryer at lower maltodextrin concentration was reported [31]. Several authors reported an increase in recovery of feed solids in the product due to an increase in maltodextrin content [12,32-34].

Similarly, at a particular maltodextrin concentration, as the inlet air temperature increased, the process yield was increased. This might be due to the inclusion of maltodextrin might have enhanced the glass transition temperature of feed and then increase of inlet air temperature had given the greater efficiency of heat and mass transfer process. Similar findings were reported for Acai powder whose process yields were increased from 28 to 45% as inlet air temperatures increased from 138-202 °C for a feed rate of 25 g/min [35] and similarly powder productivity increased from 83 g/h to 107 g/h, as inlet air temperature increased from 150-210 °C for amaranthus betacyanin pigments [36]. However, at inlet air temperature of 140 ˚C and at lower 1:0.5 maltodextrin concentration, process yield was recorded as lowest as 12.59%. The reason for such trend might be due to greater evaporation capacity at high temperature causing melting and adhesion of powder to the internal walls of drying chamber which were irrecoverable [21,37,38].

However, in case of concentrated sweet orange juice, the process yield obtained was in the range of 21.35-56.95% (Figure 1 b). Spray drying of RO concentrate juice had intricate behavior that depended on the combination of parameters under study and has given different trends for each combination of parameters. At a constant inlet air temperature, increase in maltodextrin concentration increased process yield. At the same time, increase in inlet air temperature decreased process yield at a constant maltodextrin concentration level. Reason for this trend could be explained under the following cases: 1) At higher inlet air temperature 2) decreasing maltodextrin content at high inlet air temperature at 140 ˚C 3) increasing maltodextrin concentration at low temperatures i.e., at 120 ˚C (condition of higher solid contents and lower water content in the feed).

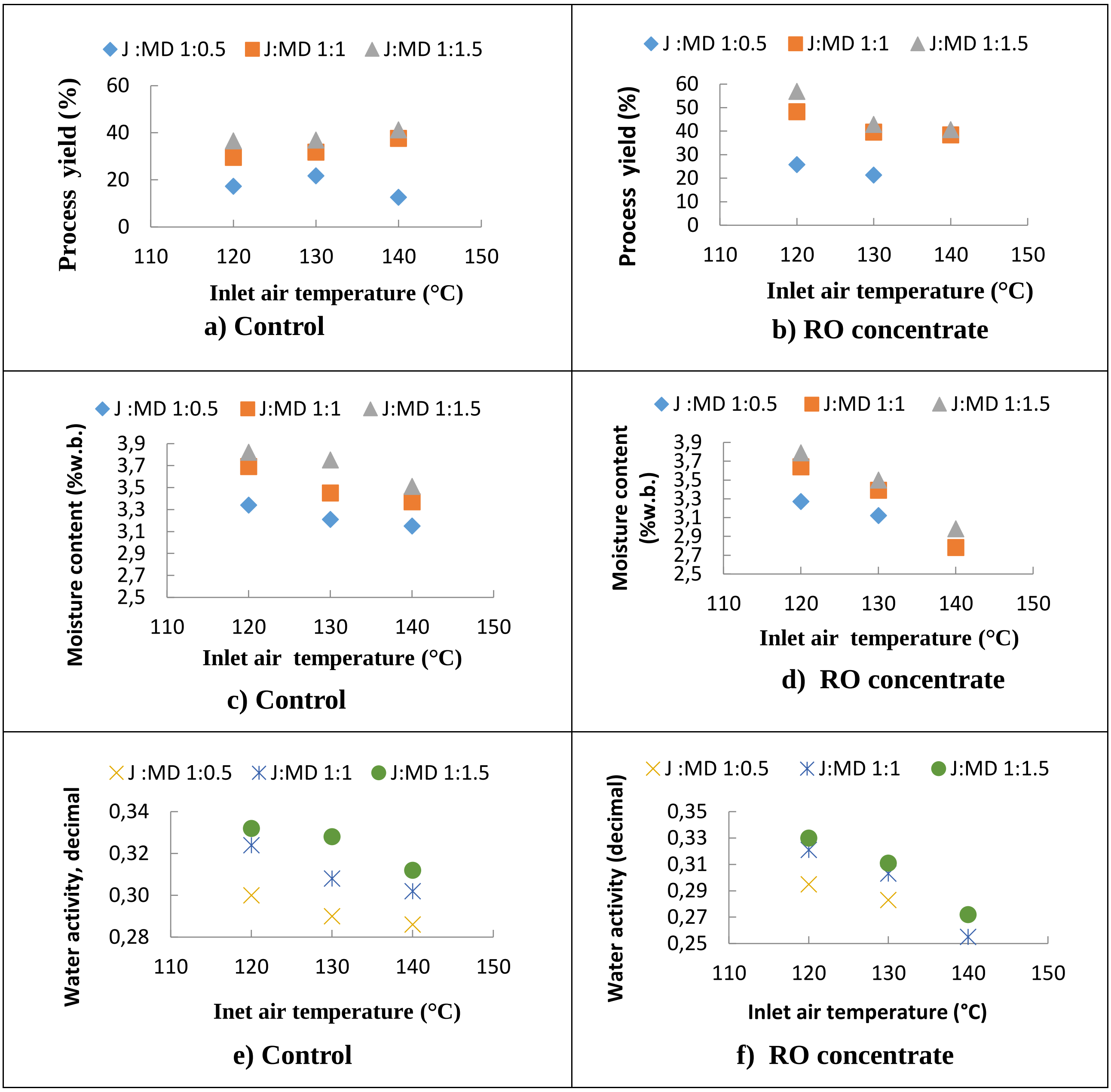
Case 1) At higher inlet air temperature decreased the process yield due to the melting of the powder and sticking on to wall surface. The results obtained on process yield of concentrated juice were in accordance with Chegini and Ghobadian [21].

Case 2) Lower maltodextrin content (1:0.5) at high inlet air temperature (140 ˚C). In this condition, experimental trials were unsuccessful and powder could not be recovered. This might be due to the reason that concentrated sweet orange juice was a very thermo-sensitive and sugar-acid rich food and at 140 ˚C, the dry solid might have attained a first order transition upon fusion [4]. Another possible reason might be due to the fact that added maltodextrin had a dextrose equivalent of 20, with glass transition temperature of 122 ˚C. Lower concentration of maltodextrin, might not improve the glass transition temperature of low molecular weight of components of the sweet orange juice, that might have caused surface stickiness and reduction in the process yield.

Case 3) Increasing maltodextrin concentration at low temperatures i.e*.,* at 120 ˚C (condition of higher solid and lower water content in the feed) initiated enhancement in glass transition temperature of dry product. Low drying temperatures, generated less deposits inside the drying chamber and more in cyclone. Similar results were reported for sugarcane juice [34]; for orange juice [39]; acai juice [36] and grape juice [32]. In the present study, highest process yield (56.95%) was derived in case of RO concentrate at a temperature of 120 ˚C and maltodextrin concentration of 1:1.5.

Moisture and Water activity of the sweet orange powder

The moisture content of the control spray dried powder varied from 3.15 to 3.69% (w.b.), where as for powder from RO concentrate, moisture content differed from 2.78 to 3.64% (w.b.) (Figure 1 c-d). At constant maltodextrin concentration, as the air temperature increased from 120 to 140 ˚C, the moisture content of the powder reduced for control as well as for RO concentrated samples. Greater the temperature difference between inlet air temperature and atomized feed droplets, the greater would be the driving force and thus higher is the rate of heat and mass transfer, causing faster rate of moisture removal. Further, at any particular inlet air temperature, the moisture content of the powder was also increased with increase in maltodextrin content of the feed. This could be explained depending on the fact that addition of maltodextrin improved the total solids in the feed liquid and it would be difficult for water molecules to diffuse past the large sized maltodextrin molecules holding more water within the matrix [40]. The results of trend on moisture content of the powder obtained were in agreement with reports by various researchers [11,21,29,34,41]. Water activity of the spray dried sweet orange powder followed same trend as that of moisture content. For powders obtained from control samples, a_w varied from 0.290 to 0.328 at different inlet air temperatures and maltodextrin concentrations and for powders obtained from concentrated samples, a_w recorded lower values than control samples in the range of 0.255-0.321.



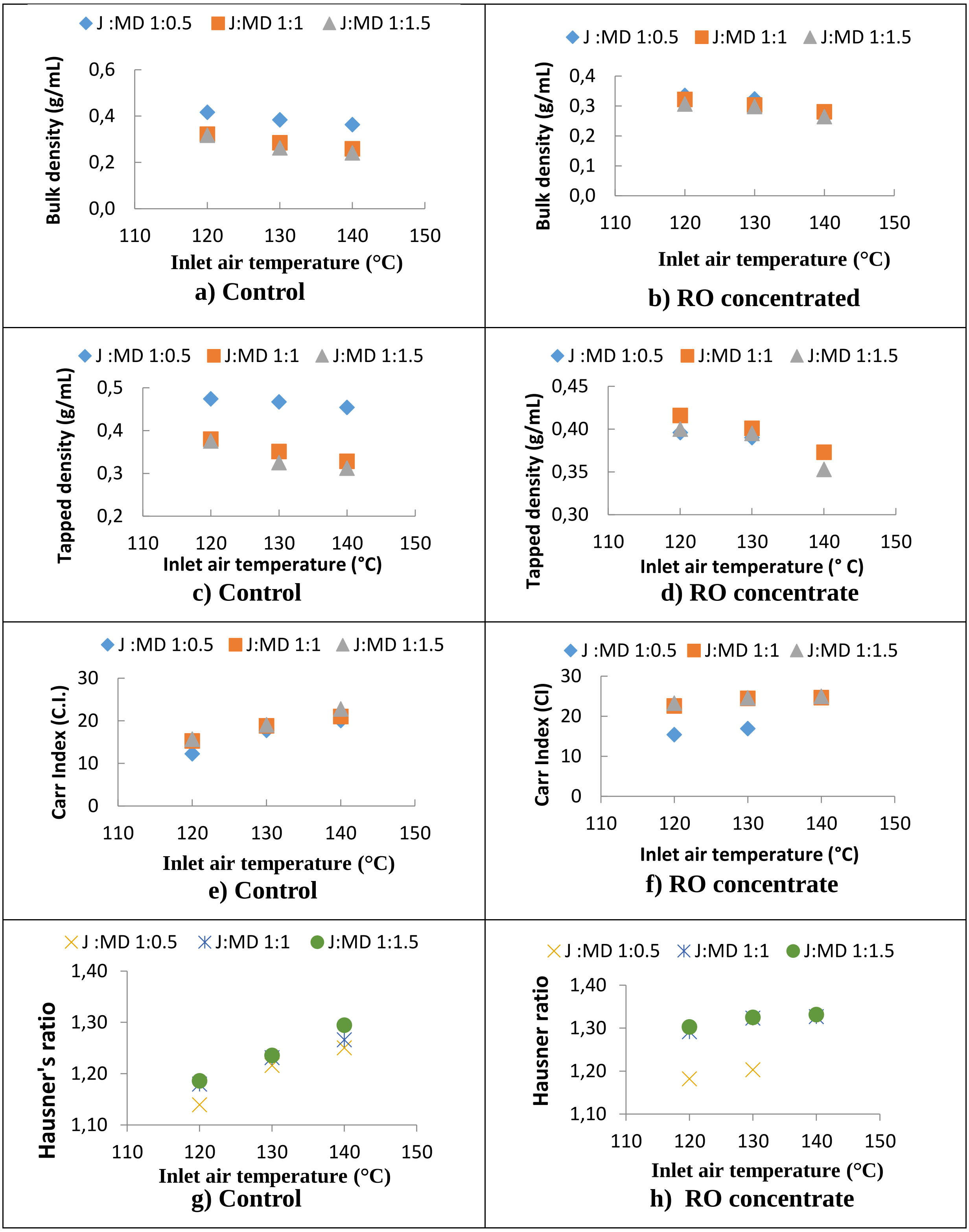
*J:MD – Juice. TSS:Maltodextrin solids

Figure 1. Effect of air inlet temperature and concentration of maltodextrin on i) Process yield, ii) moisture content and iii) water activity.

Bulk density, Tapped density Hausner ratio (HR) and Carr index (CI) of powder

Bulk density of the sweet orange powder obtained from control juice varied from 0.241 to 0.416 g/mL and for concentrated juice, bulk density varied from 0.265 to 0.335 g/mL (Figure 2 a-b). It was observed that, as increase in inlet air temperature aided in faster evaporation rates, caused feed mass to dry faster and products becomes porous and fragmented thereby reducing it's bulk density. Further, increasing the drying air temperature causes particle inflation-ballooning thus, making particle to become hollow thereby decreasing bulk and particle density [42]. Further, the effect of inlet air temperature on bulk density in terms of the product moisture content was reported [43]. As inlet air temperature increased, which reduced powder moisture as well as make it less denser and finally decreasing its bulk density. Further, bulk density of powder decreased with an increase in maltodextrin concentration (a skin forming material) that might have minimized thermoplastic particles from sticking which might improve the volume of particle due to entrapped air. It was reported that spray dried powder particles contained air bubbles that could be due to desorption of air in the feed mass or might be re-absorption during atomization [44]. Generally, air entrapped particles caused a decrease in the apparent density of the particles and finally determined the powder bulk density. An increase in maltodextrin concentration led to a decrease in bulk density was also reported for honey [45]; lime juice powder [41]; tomato juice powder and orange juice powder [22]; concentrated orange juice powder [21]. Further,bulk density of powder from control juice was higher than that for powder from RO concentrate (Figure 2 a-b). This might be due to availability of less moisture for evaporation in case of concentrated juice and products dry to a more porous or fragmented structure yielding low bulk density. Similar analogy could be applied in case of tapped density also (Figure 2 c-d). Tapped density of the sweet orange powder obtained from control juice varied from 0.312-0.474 g/mL and for concentrated juice, bulk density varied from 0.353-0.416 g/mL.

CI and HR of sweet orange powder spray dried from control juice were observed to be in the range of 12.2 to 22.8 and 1.14 to 1.29 and for powder obtained from concentrated juice were in the range of 15.4-24.9 and 1.18 to 1.33, respectively (Figure 2 c-f). In this study, HR was considered as “possible” and “fair” powders as per classification given in Table 1. In a free-flowing powder, the value of CI would be smaller as the bulk density and tapped density of the powder would be closer in value. Whereas, in a poor-flowing powder the difference between the bulk and tapped density observed would be greater, as there are greater inter particle interactions causing larger Carr index values. Further, moisture content of the powder significantly affects flowability, sticking and caking properties. Higher the moisture content, greater is the cohesive forces resulting in poor flowability [46-48]. The methodology followed in evaluating CI and HR was in agreement with other researchers [49]. HR values of the spray dried honey powders ranged from 1.05 to 1.29 [45]. Further, greater the moisture content of the powder, the higher was the Hausner ratio. Similarly, higher bulk density of powder, lower the Hausner ratio.



*J:MD – Juice. TSS:Maltodextrin solids

Figure 2. Variation of i) bulk density ii) tapped density iii) Carr's index iv) Hausner's ratio of sweet orange powder with change in air inlet temperature and maltodextrin concentration.

Sticky point temperature

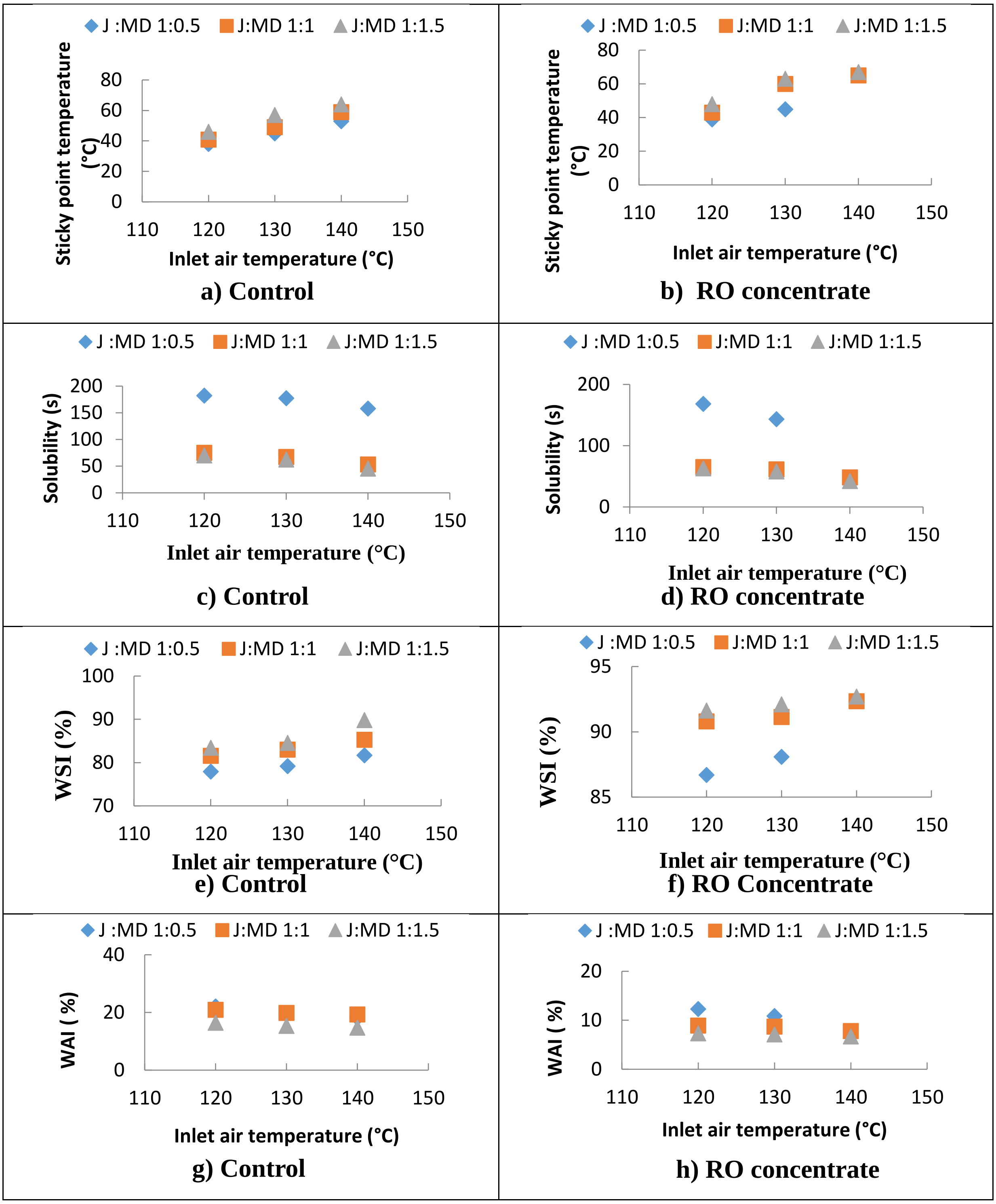
Sticky point temperature for sweet orange powder was found varying from 38-64 ˚C in case of spray dried control juice and 39-67 ˚C in case of spray dried concentrated sweet orange juice (Figure 3-b). Occurrence of moisture content and its interaction with solids was the main cause of stickiness and caking in low moisture fruit powders and has tendency to stick to surface of equipment of packaging materials [50]. Increase in moisture causes water plasticization in foods that reduces viscosity and enhances molecular mobility of the system that allowed liquid and solid bridges formation and caking [51].Thus, sticky point temperature improved with increase in inlet air temperature and decrease in maltodextrin concentration as they influence moisture content of product. Similar observation was reported [52].

Solubility time, Water solubility index (WSI) and Water absorption index (WAI) of powder

The most desirable property of a powder is it's ability to dissolve in water in quick time as they are intended for rehydration. Hence, an ideal food powder would wet quickly, thoroughly, disperse and dissolve without lumps, sink rather than float. Solubility time for spray dried sweet orange powder from control juice as well as from concentrated juice varied from 45-182 s and 42-168 *s,* respectively. Increase in inlet air temperature from 120-140 ˚C might have resulted in increase in particle size, that might sink, thus, reducing solubility time for complete dissolution [53]. Usually, concentration of maltodextrin would not directly influence the solubility of the powder. Nevertheless, low concentration of maltodextrin resulted in lower moisture content (Figure 3 c-d), thus, powder would be less sticky and thus, higher would be surface area contact with the rehydration water, hence would take more time to completely dissolve. However, increase in maltodextrin concentration, increased the powder's moisture content and reduced its solubility time as maltodextrin had superior water solubility and was mainly used in the process of spray drying due to its high solubility in water. The relationship between dissolution and moisture content was in accordance with the conclusions of researchers [29,54,55]. Many researchers had reported similar trends solubility time for fruit powders of ginger [56]; pineapple [57] and grapes [19].

Similarly, water solubility index (WSI) followed the same analogy as that of solubility time. Both terminologies described the dissolution of the powder in water. If solubility time described the time of dissolution, WSI described how well dissolution had taken place without leaving undissolved powder sediments during reconstitution. Water solubility index (WSI) was recorded in the range of 77.9 to 89.8% for a spray dried sweet orange powder from control juice and 86.7 to 92.7% for a spray dried sweet orange powder from concentrated juice (Figure 3 e-f). Results showed that as the solubility time was less, more water soluble index was recorded indicating minimum undissolved sediments during reconstitution.

Water absorption index (WAI) indicated left over powder residue after dissolution during rehydration. The behaviour of the spray dried sweet orange powder was observed to follow converse to the solubility and WSI. Water absorption index (WAI) was recorded in the range of 14.70 to 22.08% for a spray dried sweet orange powder from control juice and 6.7 to 12.3% for a spray dried sweet orange powder from concentrated juice (Figure 3 g-h).



*J:MD – Juice TSS:Maltodextrin solids

Figure 3. Variation in solubility, water solubility index and water absorption index of spray dried sweet orange powder at various inlet air temperature and concentration of maltodextrin

Effect of inlet air temperature and concentration of maltodextrin on vitamin C

The data presented in the Table 3 suggested that in control samples, vitamin-C retention was in the range of 10 to 21 mg/100 g and in concentrated samples, retention was around 39 to 58 mg/100 mg. Vitamin-C being thermally sensitive, degradation of vitamin C was observed during spray drying of control as well as concentrated juice. Vitamin C retention was more in lower inlet air temperature with lower concentration of maltodextrin. Similar trend was reported for spray dried sweet orange juice at maltodextrin concentration of 6, 9 and 12% at inlet air temperatures of 130 to 150 ˚C [58].

Table 3. Influence of inlet air temperature and concentration of maltodextrin on vitamin C.

Inlet air temperature (˚C)	J: MD	Vitamin C (mg/100 g)	
		Control	**Concentrated**
120	1:0.5	21.18	58.80
	1:1	18.72	54.25
	1:1.5	16.48	49.13
130	1:0.5	18.34	53.78
	1:1	17.52	49.34
	1:1.5	14.32	47.25
140	1:0.5	15.45	Unsuccessful
	1:1	13.21	45.36
	1:1.5	10.15	39.14

*J:MD – Juice TSS:Maltodextrin solids

Coded second order regression coefficients of response variables of sweet orange juice powder were presented (Table 4). All the response variables were significant and were affected by independent variables and their interactions. Significant model terms for process yield were analyzed as inlet air temperature, maltodextrin concentration, condition of the feed either control or concentrated, interaction between process variables. Similarly for other response variables, significant model terms were presented.

CONCLUSION

Spray drying of control as well as RO concentrate sweet orange juice without addition of drying aid has not produced powder and changing inlet air temperature hasn't improved powder production. The effect of inlet air temperature and maltodextrin concentration has significantly affected various properties of sweet orange powder. For control juice, process yields improved with increase in inlet air temperature and maltodextrin concentration. However, for RO concentrate, process yield enhanced with increase in maltodextrin concentration and reduced with increase in inlet air temperature. In terms of handling properties, the spray-dried powder was considered as "possible" and "fair" powders in terms of flowability and cohesiveness. Sticky point temperature for spray dried powder was in the range of 38 to 64˚C for control and in 39 to 67 ˚C for RO concentrate. Solubility improved at higher inlet temperature and higher maltodextrin concentration for both powder made from control and RO concentrate. Vitamin C retention was in the range of 10-21 mg/100 g for control juice and 39-58 mg/100 mg in RO concentrate juice depending upon air inlet temperature and maltodextrin concentration. Vitamin C retention was high at lower inlet air temperature with lower concentration of maltodextrin. Thus, spray dried powder from concentrated juice offered better powder properties in terms of solubility, water solubility index, flowability with better retention of vitamin C in comparison to the spray dried powder from control juice.

Funding: "This research received no external funding".
Conflicts of Interest: "The authors declare no conflict of interest."

REFERENCES

1. Syed HM, Ghatge PU, Machewad G, Pawar S. Studies on Preparation of Squash from Sweet Orange.2012;1:311. Available from: doi:10.4172/ scientificreports.311
2. Kale S, Adsule PG. Citrus. In: Handbook of Fruit Science and Technology (Production, Composition, Storage andProcessing). Salunkhe DK, Kadam SS, editors. 1995;Marcel Dekker Inc. 47 p.
3. Muzaffar K, Nayik GA, Kumar P. Stickiness Problem Associated with Spray Drying of Sugar and Acid Rich Foods: A Mini Review. J Nutr Food Sci. 2015; 12:003. Available from: doi:10.4172/2155-9600.1000S12-003.
4. Roos YH. Phase Transitions in Foods. Academic Press, New York, USA. 1995.
5. Downton GE, Flores-Luna JL, King GJ. Mechanism of stickiness in hygroscopic, amorphous powders. Industrial Engineering and Chemistry Fundamentals. 1982;21(4):447-51.
6. Roos YH, Karel M. Water and molecular weight effects on glass transitions in amorphous carbohydrates and carbohydrate solutions. J Food Sci. 1991a;56(1):1676-81.
7. Allen G. A history of the glassy state. In: The glassy state of foods. Blanshard JMV and Lillford PJ, editors. Nottingham University Press. UK. 1993.
8. Boonyai P, Bhandari B, Howes T. Stickiness Measurement Techniques for Food Powders: A Review. Powder Technol. 2004;145:34-46.

9. Mishra P, Mishra S, Mahanta C. Effect of maltodextrin concentration and inlet temperature during spray drying on physicochemical and antioxidant properties of amla (*Emblica officinalis*) juice powder. Food Bioprod Process. 2013. Available from: http://dx.doi.org/10.1016/j.fbp.2013.08.003.
10. Mahendran T. Physico-chemical properties and sensory characteristics of dehydrated guava concentrate: effect of drying method and maltodextrin concentration. Trop Agric Res Ext.2010; 13(2): 48-54.
11. Adhikari B, Howes T, Bhandari BR, Troung V. Characterization of the surface stickiness of fructose-maltodextrin solutions during drying. Int J Food Prop. 2003;21:17-34.
12. Bhandari BR, Datta N, Howes T. Problems associated with spray drying of sugar rich foods. Drying Technol. 1997;15:671-84.
13. Dib-Taxi CM, Menezes HC, Santos AB, Grosso CR. Study of the microencapsulation of camu-camu (*Myrciaraidubia*) juice. J. Microencapsul. 2003; 20(4): 443-8.
14. Gupta AS. Spray drying of citrus juice. American Institute of Chemical Engineers, 7th Annual meeting, paper no.55f. 1978.
15. Roos YH, Karel M. Plasticizing Effect of Water on Thermal Behaviour and Crytallization of Amorphous Food Models. J Food Sci. 1991b; 56: 38-43.
16. Wang YJ, Wang L. Structures and properties of commercial maltodextrins from corn, Potato and rice starches. Starke. 2000; 52: 296-304.
17. Shahnawaz M, Sheikh SA, Minhas S. Role of sodium benzoate as a chemical preservative in extending the shelf life of orange juice. Global Advanced Research Journal of Food Science and Technology. 2013;2(1):7-18.
18. Vishnuvardhan S. Membrane concentration of sweet orange juice for production of powder. An unpublished Ph.D. thesis submitted to Acharya N.G. Ranga Agricultural University, Lam, Guntur, India. 2018.
19. Sarabandi K, Peighambardoust SH, Shirmohammadi M. Physical properties of spray dried grape syrup as affected by drying temperature and drying aids. Int J Agric Crop Sci.2014; 7(12): 928-34.
20. Chegini GR, Gobadian B. Effect of spray drying conditions on quality of orange powder. Drying Technol. 2005;23:657-68.
21. Chegini GR, Ghobadian B. Spray drying parameters for fruit juice drying. World J Agric Sci. 2007;3(2):230-6.
22. Goula AM, Adamopoulos KG. A new technique for spray drying orange juice concentrate. Innovative Food Sci Emerg Technol. 2010;11:342-51.
23. Goula AM, Karapantsios TD, Achilias DS, Adamopoulos KG. Water sorption isotherms and glass transition temperature of spray dried tomato pulp. J Food Eng. 2008;85:73-83.
24. Beddow JK. Particle and particle systems characterization. 1995; 12:213.Available:doi:10.1002/ppsc.19950120411
25. Bowker R, Michael I, Stahl PH. Preparation of water-soluble compounds through salt formation. The Practice of Medical Chemistry. Camille Georges Wermuth, Ed., Burlington, MA: Elsevier. 2008;747-66.
26. Lebrun P, Krier F, Mantanus J, Grohganz H, Yang M.,Rozet E. Design space approach in the optimization of the spray-drying process. European J. Pharm. Biopharm.2012; 80(1): 226-34.
27. Kanig JL, Leon L, Herbert A. The theory and practice of industrial pharmacy (3rded.). 1986; Available from: Philadelphi./../..uuyoouytl ii 67i767e w88e u6u a: Lea and Febiger.ISBN0-8121-0977-5.
28. Sabhadinde VN. The physicochemical and storage properties of spray dried orange juice powder. Indian Journal of Fundamental and Applied Life Sciences. 2014; 4(4): 153-9.
29. Goula AM,Adamopoulos KG. Effect of maltodextrin addition during spray drying of tomato pulp in dehumidified air: ii. Powder properties. Drying technol. 2008;26:726-37.
30. Ranganna S. Proximate constituents (chap 1), Vitamins (chap 5) In: Handbook of analysis and quality control for fruit and vegetable products. Mc Graw Hill education private limited. 2019; 9-16, 105-6.
31. Masters K. Spray Drying. 4th edition. Longman Sci. and Techn., John Wiley and Sons, New York. 1991;725.
32. Papadakis S, Gardeli C, Tzia C. Spray drying of raisin juice concentrate. Drying Technol. 2006;24:173-80.
33. Roustapour OR, Hosseinalipour M, Ghobadian B. An Experimental Investigation of Lime Juice Drying in a Pilot Plant Spray Dryer. Drying Technol. 2006;24:181-8.
34. Avila EL, Rodríguez MC, Velásquez HJC. Influence of maltodextrin and spray drying process conditions on sugarcane juice powder quality. Rev. Fac. Nal. Agr. Medellín. 2015;68(1):7509-20.
35. Cai YZ, Corke H. Production and properties of spray-dried amaranthus betacyanin pigments. J Food Sci. 2000;65:1248-52.
36. Tonon VR, Brabet C, Hubinger M. Influence of process conditions on the physicochemical properties of acai powder produced by spray drying. J Food Eng. 2008;88:411-8.
37. Dolinsky A, Maletskata Y, Snezhkin Y. Fruit and vegetable powders production technology on the bases of spray and convective drying methods. Drying Technol. 2000;18:747-58.
38. Dolinsky A. High-temperature spray drying methods. Drying Technol. 2001;19:785-806.
39. Shrestha AK, Uarak T, Adhikari BR, Howes T, Bhandari BR. Glass transition behavior of spray dried orange juice powder measured by differential scanning calorimetry (DSC) and thermal mechanical compression test (TMCT). Int J Food Prop. 2007;10(3):661-73.
40. Adhikari B, Howes T, Bhandari BR, Troung V. Effect of addition of maltodextrin on drying kinetics and stickiness of sugar and acid-rich foods during convective drying: experiments and modelling. J Food Eng.2004; 62:53-68.

41. Zareifard MR, Niakousari M, Shokrollahi Z, Javadian S. A feasibility study on the drying of lime juice: the relationship between the key operating parameters of a small laboratory spray dryer and product quality. Food Bioprocess Technol. 2012;5:1896-1906.
42. Walton DE. The morphology of spray-dried particles. A Qualitative view. Drying Technology. 2000;18:1943-86.
43. Chegini GR, Gobadian B. Effect of spray drying conditions on quality of orange powder. Drying Technol. 2005;23:657-68.
44. Kwapinska M, Zbicinski I. Prediction of final product properties after co-current spray drying. Drying Technol. 2005; 23: 1653-65
45. Samborska K, Gajek P, Dwórznicka AK. Spray drying of honey: the effect of drying agents on powder properties. Polish J Food Nutr Sci. 2015; 65(2): 109-18.
46. Teunou E, Fitzpatrick JJ, Synnott EC. Characterization of food powder flowability. J Food Eng.1999; 39(1):31-7
47. Fitzpatrick JJ, Iqbal T, Delaney C, Twomey T, Keogh MK. Effect of powder properties and storage conditions on the flowability of milk powders with different fat contents. Journal of Food Engineering. 2004; 64(4): 435-44.
48. Kim HJ, Lee JH. Physicochemical properties of Salicornia herbacea powder as influenced by drying methods. Food Eng. Prog. 2009;13:105-9.
49. Patil V, Chauhan KA, Singh PR. Optimization of the spray-drying process for developing guava powder using response surface methodology. Powder Technol. 2014;253:230-6.
50. Barbosa-Canovas G, Ortega-Rivas E, Juliano P, Yan H. Food powders: Physical Properties, Processing and Functionality. Springer, New York. 2005.
51. Peleg M. Mapping the stiffness-temperature-moisture relationship of solid biomaterials at and around their glass transition. Rheol Acta. 1993;32:575-80.
52. Jaya S, Das H. Effect of maltodextrin, glycerol monostearate and tricalcium phosphate on vacuum dried mango powder properties. J Food Eng. 2004;63:125-34.
53. Walton DE. The morphology of spray-dried particles. A Qualitative view. Drying Technology. 2000;18:1943-86.
54. Quek YS, Chok NK, Swedlund P. The physico chemical properties of spray-dried watermelon Powders. Chem Eng Process. 2007;46:386-92.
55. Grabowski JA, Truong VD, Daubert CR. Spray drying of amylase hydrolyzed sweet potato puree and physicochemical properties of powder. J Food Sci. 2006; 71:E209−17.
56. Singhanat P, Anong S. Spray-drying of ginger juice and physicochemical properties of ginger powders. Sci Asia. 2010;36:40-5.
57. Jittanit W, Niti-Att S, Techanuntachaikul O. Study of spray drying of pineapple juice using maltodextrin as an adjunct. Chiang Mai J Sci.2010; 37(3): 498-506.
58. Sathyashree HS, Ramachandra CT. Effect of spray drying conditions and feed composition on sweet orange juice powder. Int J Agric Eng. 2017; 10(1): 191-8.