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Development of cantaloupe (*Cucumis melo*) pulp powder using foam-mat drying method: Effects of drying conditions on microstructural of mat and physicochemical properties of powder

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ABSTRACT

In this study, the effects of drying conditions on moisture content, water activity (a_w), dissolution time, solubility, hygroscopicity, β-carotene, color, glass transition temperature (T_g), and sticky point temperature (T_s) of foam-mat-dried cantaloupe pulp powders and microstructure of dried cantaloupe pulp foams were investigated. Drying was performed in three temperatures (40, 55, and 70°C) on 3- and 5-mm thicknesses. The analysis of scanning electron microscopy micrographs with grey-level co-occurrence matrix showed that there is wide porous structure of dried foams at higher speeds drying. The temperature increase reduced moisture content and a_w, and increased hygroscopicity, and thickness rise increased moisture content and a_w and consequently decreased powders' hygroscopicity under the same thickness and drying temperature, respectively. Increase in drying temperature would increase the reconstitution speed of powders into water and therefore the dissolution time decreased. In addition, results showed that the powder produced at 40°C have higher β-carotene content than those of produced at 55 and 70°C. With increasing drying temperature from 40 to 70°C, Lightness parameter (L) was increased while redness parameter (a) was decreased. The T_g and T_s were compared by plotting them in a graph against moisture content. For all drying processes the T_s was higher than the T_g. The drying conditions at 70°C (higher drying temperature) and 3 mm (lower thickness) led to a shorter drying time and consequent lower energy demand to produce a powdered cantaloupe pulp with high stability (low moisture content, a_w, and high T_g and T_s) and reconstitution speed of powder into water.

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β-Carotene; color; GLCM; hygroscopicity; SEM; T_g and T_s

Introduction

Cantaloupe (*Cucumis melo*) is a seasonal fruit grown in tropical regions and is regarded as one of the most important fruits of world. The nutritional importance of cantaloupe is mainly due to its high amounts of β-carotene,[1] a carotenoid which provides various health benefits, including pro-vitamin A and antioxidant activity as well as vitamin C that act as a reducing agent to reverse oxidation in aqueous solutions.[2] Antioxidants have an important role in defending body against free radical damage and are able to prevent or repair the damage to body cells by inhibiting the oxidation of biomolecules that is caused by oxygen. However, cantaloupe is a perishable fruit with short storage shelf life which is limited to approximately 15 days.[3] Development of shelf stable product from fresh fruit is an important consideration to reduce postharvest losses. The use of suitable technologies in food industry might reduce the processing time and improve the industrial operating conditions, resulting in high quality products that preserve the natural characteristics of the foods.[4] Between the agricultural processing technologies, drying method has a great importance as a postharvest technology; but drying of cantaloupe pulp has two main problems: (1) Cantaloupe is sensitive to high temperature treatments, because thermal processing of cantaloupe pulp results in off-flavor formation, color, vitamins, and aromatic compound degradation[5]; and (2) Cantaloupe pulp contains high sugar content and is sticky and viscous so that the removal of water is difficult and subsequently drying time is increased.[6] From different available drying methods, foam-mat drying can be performed at lower temperatures and used for heat-sensitive and high-sugar-content products, due to increase in surface area and porous structure of materials by the incorporation of air/gas, mass transfer is enhanced leading to shorter drying times and consequently acquiring higher quality in the dried product.[7] Therefore, foam-mat drying is highly suitable to be applied to cantaloupe. Foam-mat-drying technique has

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been successfully applied to many foodstuffs such as: starfruit,[8] apple juice,[9] mango,[10,11] banana,[12] mandarin,[13] seabuckthorn,[14] blackcurrant pulp,[15] egg white,[16] button mushroom,[17] shrimp,[18] and yacon juice.[19]

A major property of food powders manufactured for consumer use is the ease of reconstituting in water in terms of solubility and dissolution time. Fruit powders, such as cantaloupe pulp powder, can be reconstituted into juice and used as instant beverages as well as ingredients for the preparation of other products, such as bakery or extruded cereal products, baby foods, and pharmaceutical tablets.

Hygroscopicity is the tendency of food powder to absorb moisture from high relative humidity environment and receive to equilibrium with water in the atmosphere.[20] Hygroscopicity is an important parameter for selecting packaging materials. Fruits containing high levels of sugars that was dried to low moisture content have high hygroscopicity that can influence others quality properties of powder. In the fruit powders, sugars such as glucose and fructose are responsible for strong interaction with the water molecule due to the polar terminals present in these molecules.[21,22]

Understanding the glass transition of solid food systems allows us to design better processes, innovative products, and better packages to increase shelf life. Glass transition temperature (T_g) is defined as the temperature at which an amorphous system changes from a glassy to a rubbery state.[23] The T_g is a function of moisture content as well as the concentration of solutes such as sugars. Fruit powders have a low T_g, due to their high content of sucrose (62°C), fructose (5°C), and glucose (32°C). They have high molecular mobility at relatively low temperatures which confers a sticky nature to the powders. Stickiness has been one of the key topics of food powder technology in recent years, because it can influence the process, handling abilities, and powder quality such as flowability.[24] Sticky point temperature (T_s) is defined as the value at which a food powder will start caking. Since the stickiness of dried fruit powders normally develops once the transition from glassy to rubbery took place, the T_s is always higher than the T_g, it occurs generally at 10–20°C above the T_g.[25] Various techniques and instrumentations have been developed for characterization of the stickiness behavior of the powder particles.[26] A rotational viscometer technique is a simple method based on the measurement of the torque during stirring of a powder sample, and it is suitable for the determination of stickiness behavior of powders that effects flow properties.[27]

Although several reports are available in the literature on the preservation of cantaloupe, but no report exists on the application of foam-mat drying for the production of cantaloupe powder. In our previous study,[28] foaming conditions of cantaloupe were optimized using response surface methodologies and the effect of drying conditions was investigated on the foam-mat drying. This paper reports the effects of drying conditions on the microstructure of dried cantaloupe pulp foam mats and physicochemical properties of cantaloupe pulp powder including moisture content, water activity (a_w), solubility, dissolution time, hygroscopicity, color, carotenoid content, glass transition, and sticky point temperatures.

Materials and methods

Materials

Fresh cantaloupe (*C. melo* L. var. *til*) was obtained from local market (Mashhad, Iran). Xanthan gum as the stabilizer of foam and egg white powder as the foaming agent were purchased from Sigma Chemical Company, USA and Gol Powder Company, Iran, respectively.

Preparation of optimized cantaloupe pulp foam for drying

Fresh cantaloupes were cut, peeled, and diced into smaller pieces. Cantaloupe pulp was extracted using a blender (Bosch, type CNSM03EV). Cantaloupe pulp was analyzed for total soluble solids (TSS), ash,[29] moisture content, water activity, β-carotene content,[30] and color.

XG solution was prepared by dissolving a suitable amount of the selected gum powder in distilled water and stirring with a magnetic stirrer to obtain a uniform solution. The resulted solution was refrigerated at 4°C for 18–24 h to complete hydration.

According to optimized conditions obtained in our previous study,[28] to prepare the foam samples, appropriate amount of cantaloupe pulp (77 g), egg white powder (3 g), and xanthan gum (20 g with a concentration of 0.85%) were poured into a glass beaker and mixture then was whipped with a mixer (Gosonic, model No. GHM-818) with maximum speed at ambient temperature for about 8.80 min.

Foam drying

For the foam-mat drying, the optimized foam of cantaloupe pulp was spread uniformly on aluminum plates

with 10-cm diameter at thicknesses of 3 and 5 mm (load of 12 ± 0.01 and 20 ± 0.01 g of foam with initial moisture content about 90.91% wet basis, respectively), then put into the drying chamber. Drying was performed in a batch cabinet dryer (Soroush Medical Company, Iran) equipped with a centrifugal fan, at three drying temperatures of 40, 55, and 70°C and at constant parallel superficial air velocity of $1.5\ m\ s^{-1}$. Drying was continued to reach constant moisture content. The time required to dehydrate foamed cantaloupe pulp with thicknesses of 3 and 5 mm with drying air temperatures of 40, 55, and 70°C were found to be 140, 90, 65 and 270, 150, and 110 min, respectively, in triplicate. Finally, the foam-mat-dried products were scraped, milled, and sieved (mesh size of sieve was 80) to obtain powders. The resulting powders were stored at refrigerator temperature in air tight plastic bottles until needed for analysis.

Microstructure of dried foam mat

A scanning electron microscope (SEM; XL-30, Philips, Amsterdam, Netherlands) was used to study the microstructure. The dried cantaloupe pulp foam mats were placed on two-side adhesive tape attached to metal stubs and was coated with gold. The sample SEM micrographs were taken at an accelerating voltage of 20 kV and systematically observed with magnification of ×100.

To better understand the effects of drying conditions on mats, grey-level co-occurrence matrix (GLCM) is used for obtaining SEM images. The GLCM is one of the mostly used statistical texture analysis methods, in which texture feature is extracted from the co-occurrence matrix by some statistical approaches.[31] The GLCM creates a square matrix of dimensions equal to the maximum intensity and composed by the frequency of the different intensities of grey within the stack. This processing is strongly influenced by the pixel pitch and the direction. The matrix is constructed by counting the number of pixel pairs ($x_1\ y_1$) ($x_2\ y_2$) with the grey value i and j at direction θ (mostly, $\theta = 0$) and distance d (mostly, $d = 1$). The GLCM calculates up to 14 different features, or descriptors, however those considered in this work are[32]:

1. ***Contrast***, showing the amount of local variations present in an image:

$$\textbf{Contrast} = \sum_{n=0}^{G-1} n^2 \left\{ \sum_{i=1}^{G} \sum_{j=1}^{G} P(i,j) \right\}, |i-j| = n \tag{1}$$

2. ***Entropy***, indicating the amount of the order in an image:

$$\textbf{Entropy} = -\sum_{i=0}^{G-1} \sum_{j=0}^{G-1} P(i,j) \times \log(P(i,j)) \tag{2}$$

3. ***Energy***, also called Angular Second Moment and Uniformity in, is a measure of textural uniformity of an image:

$$\textbf{Energy} = \sum_{i=0}^{G-1} \sum_{j=0}^{G-1} P(i,j)^2 \tag{3}$$

4. ***Homogeneity***, it returns a value that measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal:

$$\textbf{Homogeneity} = \sum_{i=0}^{G-1} \sum_{j=0}^{G-1} \frac{P(i,j)}{1+|i-j|} \tag{4}$$

where G is the total numbers of rows or columns of the GLCM (rows = columns).

Analysis of the foam-mat-dried powder

Moisture content

The moisture content of cantaloupe pulp powders was determined by drying at the temperature of 105°C in the oven until a constant weight was obtained.[33]

Water activity

A water activity meter (Rotronic Hygrolab, Switzerland) was used to measure a_w of the foam-mat-dried powders at ambient temperature.[18]

Solubility

Solubility was determined according to the method used by Cano-Chauca et al.[34] A quantity of 100 ml of distilled water was transferred into a blender jar. A quantity of 1 g of each sample was carefully added to the blender which operates at 15,000 rpm for 5 min. The solution was transferred in a tube and centrifuged (Centrifuge model: Sigma, 2-16KC, Germany) at $3{,}000 \times g$ for 5 min. An aliquot of the supernatant (about 25 ml) was then transferred to preweighed petri dishes and dried in oven at 105°C for 5 h. The solubility (%) was calculated as the weight difference.

Dissolution time

The dissolution time was performed as described by Solval et al.[1] A quantity of 50 mg of the powder was dissolved in 1 ml of distilled water and vortexed at

1,500 rpm. The time taken for the powder to fully reconstitute in water was determined using a stop clock.

Hygroscopicity

Hygroscopicity was determined according to the method proposed by Tonon et al.[35] Samples of each powder (1 g) were placed at 25°C in a container with NaCl saturated solution. After about 1 week, samples were weighed and hygroscopicity was expressed as g of adsorbed moisture per 100 g dry solids (g/100 g).

Determination of total carotenoids

Total carotenoids were determined using the modified method described by Koca et al.[30] According to this method, 0.5 g cantaloupe powders was extracted in a 25-ml 7:3 hexane:acetone mixture using a shaker. The extract was vacuum filtered through a Buchner funnel with Whatman No.1 filter paper. The residue was re-extracted until became colorless. The filtrates were combined in a separating funnel and washed with 50 ml distilled water. The water phase was discarded. Then, about 10 g Na_2SO_4 was added as desiccant. The hexane phase was transferred to a 100-ml volumetric flask and brought to volume with hexane. The concentration of carotene in the solution was determined by its absorbance at 450 nm with a UV–Vis instrument (Model 160A Shimadzu, Kyoto, Japan). The total carotenoid content determined as β-carotene from the standard curve of prepared β-carotene standard.

Color measurement

The color of powders was determined using a Chroma meter (Minolta CR-410 series, Japan) calibrated with a white standard tile. Sample was placed in a plate and the surface was smoothened. The sensor of the color meter was then placed on the surface of the sample and the color parameters were read in ambient temperature. This was performed on three randomly selected points of each sample surface and the average value was determined. *L*, *a*, and *b* define a three-dimensional color space, the results were expressed as Hunter color values of *L*, *a*, and *b*: *L* represents brightness, ranging from white (100) to black (0), *a* represents the tones between green (−*a*) and red (+*a*), and *b*, between blue (−*b*) and yellow (+*b*).[19]

Glass transition temperature

Differential scanning calorimeter (DSC, model OIT-500 SANAF Electronics Co., Iran) was used to measure the glass transition temperature of cantaloupe pulp powders. After the calibration instrument with indium, about 10–12 mg of the powder was taken in the sample aluminum pan. An empty pan was used as a reference. Liquid nitrogen was used for sample cooling at the rate of 10°C/60 s to bring down the sample temperature to 10°C from ambient temperature. All the scans were conducted at the same heating rate of 10°C min^{-1} from 10 to 100°C. The mid-point of the glass transition was considered as the characteristic temperature of the tran sition.[36] The duplicate determinations were conducted.

Sticky point temperature

In this study, a Brookfield viscometer (model LV) coupled with a spindle (model SC4) was used to determine the sticky point temperature of cantaloupe pulp powders using a modified method of Ozkan et al.[37] The schematic of the setup viscometer technique is shown in Fig. 1. For stickiness measurement, the sample powder (approximately 6 g), was transferred into a cup with a temperature-controlled jacket that was connected to a water bath. Then, stirrer was centrally inserted into the sample. The rotational speed of the spindle was maintained at 45 rpm during the experiment. To obtain a uniform temperature, the powder was kept in the cup to equilibrate to a certain temperature (30°C) for about 20 min. The water bath temperature was then raised about 1°C every 3 min and heating was done slowly so that the powder temperature remained in equilibrium with the bath temperature. The torque generated due to the rotation of the spindle was continuously monitored using a data logging system connected to the viscometer. With increasing powder temperature, the particle surface becomes less viscous allowing stickiness at the contacting surfaces. As a result, the powder sample becomes more viscous as compared to that in its free-flowing state. At a certain temperature, which depends upon the moisture content of the powder, the force required to stir the powder increased dramatically. The point temperature

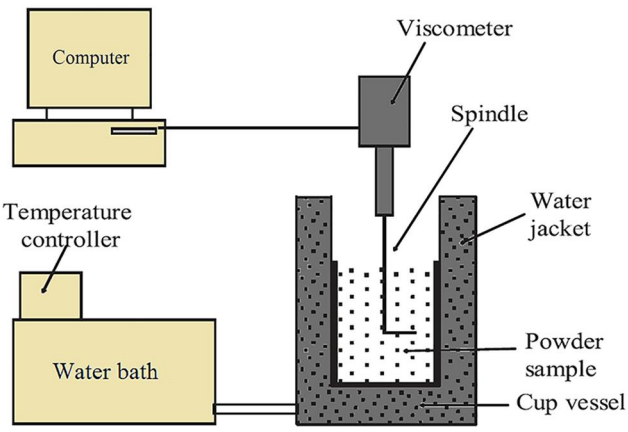

Figure 1. Experimental setup to determine sticky-point temperature with a Brookfield viscometer.

at which this occurred was usually characteristic, and it was referred to as the sticky point temperature. Determinations were conducted in duplicate.

Statistical analysis

The data were analyzed using the analysis of variance with Minitab software (Minitab 16; Minitab Inc., Minneapolis, USA). Bonfroni test was used to establish the comparisons of mean values that were considered at 95% significance level ($p < 0.05$).

Results and discussion

Physicochemical properties of the cantaloupe pulp

Moisture content and water activity of the cantaloupe pulp were 92.54 (g/100 g) and 0.96, respectively. This indicated that the shelf life of cantaloupe pulp could be short because almost all microorganisms can grow in a_w above 0.9.[1] Also, cantaloupe pulp contained 187.59 ± 8.16 μg of β-carotene/g of dry solids, 0.45 ± 0.01% of ash, and 7.83 ± 0.04 (°Brix) of TSS that most of TSS are sugars such as glucose, fructose, and sucrose that can contribute to powder stickiness during processing and storage.[26] The values of *L*, *a*, and *b* for cantaloupe pulp were 38.97 ± 0.78, 18.60 ± 0.61, and 25.86 ± 0.95, respectively. In addition, Chroma and hue angle values were 31.87 ± 0.43 and 54.26 ± 1.87, respectively.

Scanning electron microscopy analysis of the dried foam mats

Microstructure investigation can help to understand product changes during processing and may also improve the understanding of mechanisms and changes in quality factors. Mechanical and thermal stability of foam is necessary for foam-mat drying. Stable foams retain their porous structure, which aids improvement in the reconstitution properties of the foam-mat-dried product, whereas, unstable foamed products are difficult to dry and have poor color, texture, flavor, and nutritive value.[7] SEM micrographs of cantaloupe pulp foam mats at all drying processes have been demonstrated in Fig. 2. As can be seen in this figure, the drying

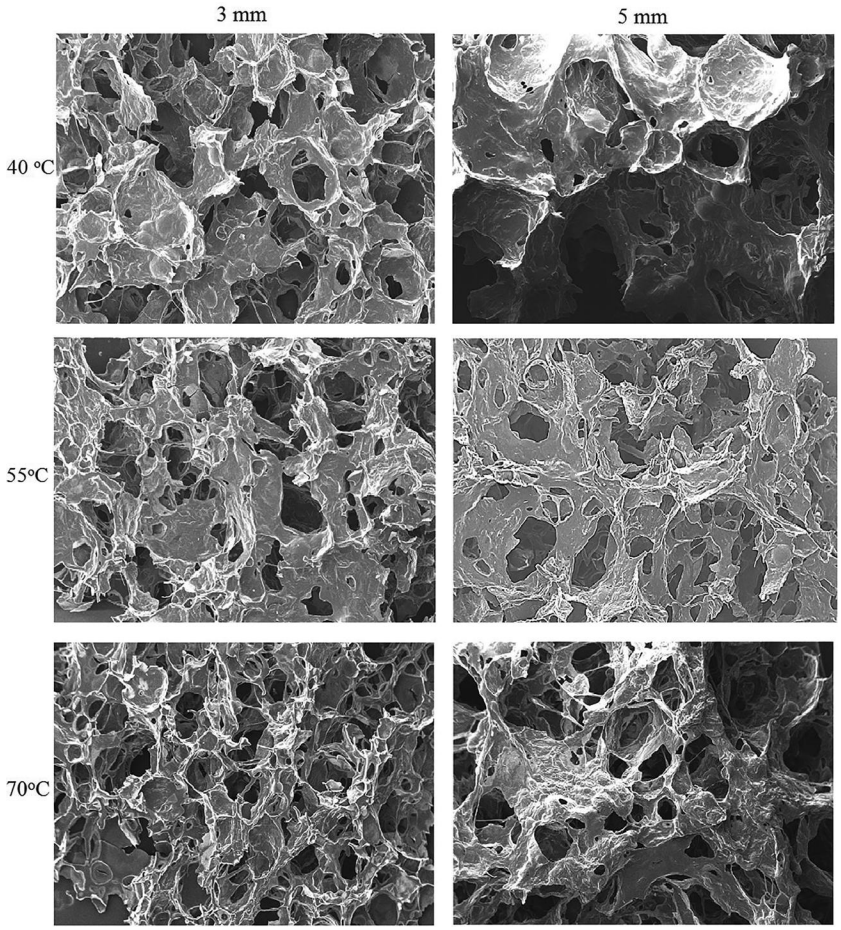

Figure 2. Scanning electron micrographs of dried cantaloupe pulp foam mats at different drying conditions.

Table 1. Effects of drying conditions on GLCM features of SEM images.

Drying conditions	Contrast	Energy	Entropy	Homogeneity
3 mm-40°C	296.81 ± 8.981^{bc}	0.00031 ± 0.00004^{b}	9.059 ± 0.051^{c}	0.218 ± 0.007^{c}
3 mm-55°C	325.40 ± 8.511^{b}	0.000298 ± 0.00005^{b}	9.137 ± 0.072^{b}	0.210 ± 0.003^{c}
3 mm-70°C	389.67 ± 6.282^{a}	0.000237 ± 0.00002^{b}	9.181 ± 0.040^{a}	0.205 ± 0.006^{c}
5 mm-40°C	136.67 ± 7.561^{d}	0.00201 ± 0.00011^{a}	8.101 ± 0.083^{e}	0.350 ± 0.005^{a}
5 mm-55°C	176.32 ± 4.374^{d}	0.000597 ± 0.00003^{b}	8.136 ± 0.074^{e}	0.293 ± 0.009^{b}
5 mm-70°C	275.01 ± 9.052^{c}	0.00044 ± 0.00006^{b}	8.980 ± 0.055^{d}	0.240 ± 0.008^{c}

Values are means ± SD of duplicate determination.
Means with same letter in each column are not significant different ($p > 0.05$).
GLCM, grey-level co-occurrence matrix; SEM, scanning electron microscope.

conditions strongly affected the structure of dried foam mats so that the porous structure was different among the samples dried at higher and lower temperatures and foam thicknesses. Images showed that the there is wide porous structure of foams at higher drying speeds that is directly related to higher heat and mass transfer. With increasing drying temperature (due to reduced drying times), combination of adjacent bubbles and therefore, collapse of foam structure occur less. Also, the images showed that with increasing foam thickness, dried foams were more uniform and had less porous due to the extent of collapse and coalescence of adjacent bubbles increased which causing less porosity and less uniformity of pore-size distribution. Our previous study shows that with an increase in drying temperature or a decrease in foam thickness, the drying time of the samples decreased and the drying rate increased accordingly.[28] Similar observations reported for foam-mat drying of shrimp.[18]

The results concerning the effect of the drying conditions on the GLCM texture features of the SEM images are presented in Table 1. In both thickness, as the drying temperature increased from 40 to 70°C, contrast values increased significantly ($p < 0.05$), indicating that there is high amount of porous structure in mats at higher drying speeds. Similar results also were obtained for entropy. With increasing foam thickness, entropy decreased, indicating that dried foams had less porosity and were more uniform. With respect to the energy, it decreased with increasing temperature from 40 to 70°C especially in 5-mm thickness, indicating nonhomogeneous changes in the energy value on the image. Also, increasing foam thickness caused to increase in energy. Homogeneity value which measures local changes in image texture, decreased significantly ($p < 0.05$) as the drying temperature increased from 40 to 70°C in 5-mm thickness, but in 3-mm thickness there were no significant changes ($p < 0.05$). On other hand, increasing foam thickness from 3 to 5 mm caused to increase homogeneity.

Physicochemical properties of cantaloupe pulp powders

Moisture content and water activity

The moisture content of the cantaloupe pulp powders ranged from 4.59 g 100 g^{-1} (3 mm-70°C) to 8.86 g 100 g^{-1} (5 mm-40°C) (Table 2). The results showed that under the same thickness, moisture content of powders decreased with increase in air drying temperature. This is due to the fact that at higher temperatures, the rate of heat transfer to the sample would increase,[38] therefore, it provides greater driving force for moisture evaporation which results in the dried foams with reduced moisture content. Similar results were reported by Kolawole and Okocha,[39] Kadam and Balasubramanian,[40] and Azizpour et al.[18] for foam-mat drying of plantain and cooked banana, tomato juice, and shrimp, respectively. At the same temperature, as the foam thickness increased, the final moisture content of powders increased. Based on our previous study,[28] with increasing foam thickness, drying rate decreased. Moreover, due to increased drying times and probably collapsed structure of foams and therefore weak pore structure, drying was performed difficultly which causes to retain more water in dried foams. Similar results were reported by Franco et al.[19] for foam-mat drying of yacon juice. The effects of drying conditions on a_w are in agreement with their effects on moisture content

Table 2. Physicochemical characteristics of cantaloupe pulp powders obtained by foam-mat drying under different conditions.

Drying conditions	Moisture content (g/100 g, wb)	Water activity (a_w)	Solubility (%)	Dissolution time (s)	Hygroscopicity (g/ 100 g)
3 mm-40°C	8.02 ± 0.09^{b}	0.262 ± 0.012^{ab}	82.88 ± 0.81^{a}	7.46 ± 0.94^{b}	17.70 ± 0.19^{c}
3 mm-55°C	6.82 ± 0.11^{d}	0.218 ± 0.008^{c}	82.96 ± 0.57^{a}	6.35 ± 0.77^{bc}	18.73 ± 0.20^{b}
3 mm-70°C	4.59 ± 0.07^{f}	$0/147 \pm 0/011^{d}$	81.76 ± 0.77^{a}	4.91 ± 0.81^{c}	20.76 ± 0.25^{a}
5 mm-40°C	8.86 ± 0.11^{a}	0.288 ± 0.010^{a}	82.31 ± 0.64^{a}	9.20 ± 0.73^{a}	16.73 ± 0.12^{d}
5 mm-55°C	7.34 ± 0.08^{c}	0.232 ± 0.013^{bc}	82.33 ± 0.52^{a}	6.54 ± 0.97^{bc}	18.49 ± 0.21^{b}
5 mm-70°C	5.18 ± 0.06^{e}	0.159 ± 0.009^{d}	81.53 ± 0.85^{a}	5.23 ± 0.75^{c}	20.38 ± 0.17^{a}

Values are means ± SD of triplicate determination.
Means with same letter in each column are not significant different ($p > 0.05$).

(Table 2). In general, higher drying air temperatures and lower foam thickness showed lower a_w. A decrease of a_w prevents from development of microorganisms, reduces the rate of enzymatic reactions, and retards nonenzymatic browning.[41] Basically, food with a_w less than 0.6 is microbiologically stable.[1] In this study, a_w of all dried samples ranged from 0.147 to 0.288, thus can be considered them microbiologically stable during storage. Moreover, low a_w values (between 0.1 and 0.4) contribute to pigment and/or color stability, since auto-oxidation reactions are minimal due to inactivation of the lipoxygenases.[11] The a_w determined for the cantaloupe powders is in line with the results of other studies. For instance, yacon juice powder dried using foam-mat method at 50, 60, and 70°C resulted in a_w from 0.1 to 0.22,[19] and shrimp foams dried at 45 to 90°C resulted in a_w from 0.126 to 0.251.[18]

Solubility

Solubility is the extent of dissolving of components of the powder particles in the water. This parameter is the most reliable criterion to evaluate the behavior of powder in aqueous solution. Solubility is attained after the powder undergoes dissolution steps of sinkability, dispersability, and wettability.[42] Result showed that no significant difference ($p > 0.05$) was found between the powder solubility for all drying process (Table 2). Similar observations were also reported by Franco et al.[19] and Chaux-Gutiérrez et al.[11] for foam-mat-drying yacon juice powder and mango, respectively, and also Sousa et al.[43] and Kha et al.[44] for spray-dried tomato and Gac fruit powders, respectively. It may be due to the fact that the solubility of powder mainly is influenced by its chemical composition and physical state rather than the proposed processing condition.[45,46] Solubility of cantaloupe pulp powder, which showed values between 81.53 and 82.96 g. $100\ g^{-1}$, was more soluble than mango juice powder (51.83 and 66.65 g. $100\ g^{-1}$),[47] and shrimp powder (18.06 and 19.58 g. $100\ g^{-1}$)[18] obtained by foam-mat-drying method. Also, similar solubility was reported for yacon juice powder (80.49 and 84.16 g. $100\ g^{-1}$).[19] The good solubility of the obtained powder in this study may be attributed to the significant amount of carbohydrates and proteins and low level of lipids in its composition,[48] and also, low moisture content of the powders, since the lower the moisture content, less sticky is the powder, which has in addition a higher surface area available for contact with hydration water.[38]

Dissolution time

Instant properties of powders such as dissolution time are directly related to microstructure. The dissolution time measured the reconstitution speed of powders into water and was expressed as time taken by the powder to complete reconstitute in water by vortex mixer. Based on obtained results, the dissolution time was affected by the drying conditions and ranged from 4.91 s (3 mm-70°C) to 9.20 s (5 mm-40°C) (Table 2). With increased drying temperature, the reconstitution speed of powders into water increased and therefore dissolution time decreased. Also, increasing foam thickness from 3 to 5 mm had the adverse effect on the dissolution time and led to increase this parameter especially in 40°C. At higher temperature, as evaporation rates are faster, products dry to a more porous or fragmented structure and implying a more porosity of dried foams as shown in SEM micrographs. Based on the results obtained from SEM of dried foams, decrease of drying time induced by increasing temperature or decreasing the thickness, the structure of the foam will be retained and dried foams are more porous. With increasing porosity, due to greater specific surface area the dissolution time can be decreased. Reconstitution properties of the foam-mat-dried products are influenced by stability of foams during drying.[7] The reconstitution speed of cantaloupe pulp powder obtained by foam-mat-drying method in this study was more than the cantaloupe juice powder obtained by spray-drying method (20.33–23.0 s).[1]

Hygroscopicity

As shown in Table 2, it was found that the hygroscopicity of cantaloupe pulp powders was affected by drying conditions. The cantaloupe pulp powders showed hygroscopicity values from 16.73 (thickness 5 mm and drying temperature 40°C) to 20.76 g $100\ g^{-1}$ (thickness 3 mm and drying temperature 70°C). In fact, higher hygroscopicity values were obtained with increasing drying temperature and decreasing foam thickness, which were the variables that affected powder moisture content, in an opposite way. Also, drying temperature exerted greater influence on hygroscopicity with respect to foam thickness. Due to the presence of low moisture content in the powders produced in the higher drying temperature and lower thickness, water concentration gradient between the powders and the surrounding air is higher and powders have a greater capacity to absorb ambient moisture.[35,49,50] Similar hygroscopicity (15.24 and 22.31 g. $100\ g^{-1}$) was reported by Franco et al.[19] for yacon juice powder in different drying temperatures (50, 60, and 70°C) and thicknesses of the foam layer (0.5, 1.0, and 1.5 cm). They stated that the low hygroscopicity at low temperatures and higher thicknesses can be explained by the fact that powders obtained under these conditions have higher moisture content

and, as a consequence, lower moisture gradient between product and ambient. Our results are far higher than those outlined by Jaya and Das[20] as ideal for instant products, between 5.13 g. 100 g^{-1} (instant coffee) and 9.38 g. 100 g^{-1} (tomato soup instant powder). The high values obtained are attributed to the chemical nature of the powder. For instance, in powdered fruit juices, sugars (sucrose, glucose, and fructose) are mainly responsible for water absorption due to the ability of hydroxyl groups to form hydrogen bonds with water molecules.[20]

β-Carotene analysis

The β-carotene content of the pulp powders ranged from 84.01 μg g^{-1} (5 mm-70°C) to 108.96 μg g^{-1} (3 mm-40°C) as dry basis (Table 3). The results showed that the β-carotene content of cantaloupe pulp powders was affected by the drying conditions, and there was a significant reduction in ($p < 0.05$) β-carotene content in the cantaloupe pulp powder dried at higher temperature of 70°C when compared to drying at lower temperature of 40°C. A similar β-carotene loss (164.54 to 121.42 μg g^{-1}, dry solid) was reported for spray-dried cantaloupe juice powders when drying temperature increased from 170 to 190°C.[1] Moreover, β-carotene loss was higher for 5-mm thickness than for 3-mm thickness foam due to a longer drying time at higher thickness. Carotenoids are very susceptible to heat destruction and oxidation because of their highly unsaturated chemical structure.[51] Moreover, they may undergo isomerization during thermal processing.[52] Similar behavior for β-carotene loss (6,598 to 7,950 μg/100 g) was reported for foam mat drying of alphonso mango pulp using various foaming agents in different drying temperatures (60–75°C) and thicknesses of the foam layer (1–3 mm).[10]

Color measurement

Table 3 shows the results of color measurements of cantaloupe pulp powders. The cantaloupe pulp powders showed L from 70.89 to 74.38, and the results were influenced ($p < 0.05$) by the drying conditions. Based on the obtained results, in both thicknesses, with increasing drying temperature from 40 to 70°C, L increased. All powders produced at 5-mm thickness were a little less brighter than the 3-mm ones, which can be attributed to the longer drying time needed to dry the 5-mm foams. Franco et al.[19] found the same behavior during drying of yacon juice foam: L decreased as drying time increased. Redness parameter of all dried samples ranged from 7.97 to 9.73 (Table 3). With increasing drying temperature, a in both thicknesses was decreased, and increasing foam thickness causes to increase a. Furthermore, the drying conditions (air temperature and foam thickness) significantly influenced on the b, and this parameter ranged from 7.97 to 9.73 (Table 3). Drying temperature and time of drying are important parameters for color change of foods.[53] Possible explanation for these changes is that with increasing drying temperature, due to the high speed of drying, the time of browning reactions decreased and formation of brown pigment during the drying process decreased. Also, in higher drying temperatures oxidation of the pigments (carotenoids) can be increased.[43] Cantaloupe fruit contains high amounts of sugars that can participated in Maillard reaction. In hot air drying process, due to much more oxygen and moisture available, the Maillard reaction can be facilitated. As browning increases, L values decrease and a values increase. Solval et al.[1] reported lab parameters for spray-dried cantaloupe juice powders as function of drying temperatures from 170 to 190°C (L: 89.06–94.53; a: 3.35–6.16, and b: 22.71–24.29). Also in Table 3, amounts of hue angle and chroma in different drying conditions are reported. Hue angle measures the property of the color, and chroma indicates the color intensity or saturation. Hawlader et al.[54] stated that a decrease in hue angle's values is an indication of more browning color.

Glass transition and sticky point temperatures

Glass transition is a critical parameter in powder products, because some problems such as collapse, stickiness, caking, and agglomeration have been related

Table 3. β-Carotene content and color parameters of the cantaloupe pulp powders obtained by foam-mat drying under different conditions.

		Color parameters				
Drying conditions	β-Carotene (μg g^{-1} dry basis)	L	a	b	Hue	Chroma
3 mm-40°C	108.96 ± 6.06^{a}	71.64 ± 0.38^{c}	9.16 ± 0.19^{ab}	32.30 ± 0.52^{ab}	74.17 ± 0.23^{a}	33.57 ± 0.54^{ab}
3 mm-55°C	101.43 ± 4.45^{a}	72.18 ± 0.46^{bc}	8.58 ± 0.28^{bcd}	31.21 ± 0.61^{bc}	74.63 ± 0.73^{a}	32.37 ± 0.50^{bcd}
3 mm-70°C	94.83 ± 4.35^{ab}	74.38 ± 0.39^{a}	7.97 ± 0.20^{d}	30.08 ± 0.50^{c}	75.15 ± 0.59^{a}	31.12 ± 0.43^{d}
5 mm-40°C	103.65 ± 5.49^{a}	70.89 ± 0.52^{c}	9.73 ± 0.24^{a}	33.19 ± 0.53^{a}	73.66 ± 0.61^{a}	34.59 ± 0.45^{a}
5 mm-55°C	95.23 ± 5.30^{ab}	71.58 ± 0.27^{c}	8.97 ± 0.26^{bc}	31.79 ± 0.47^{ab}	74.24 ± 0.45^{a}	33.03 ± 0.42^{bc}
5 mm-70°C	84.01 ± 3.80^{b}	73.26 ± 0.58^{ab}	8.42 ± 0.27^{cd}	30.86 ± 0.28^{bc}	74.74 ± 0.27^{a}	31.98 ± 0.58^{cd}

Values are means ± SD of triplicate determination.
Means with same letter in each column are not significant different ($p > 0.05$).

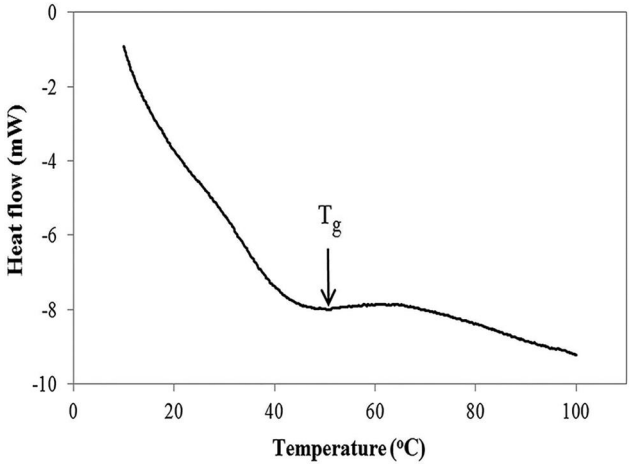

Figure 3. DSC profile for foam-mat-dried cantaloupe pulp powder produced in 70°C and 3 mm thickness conditions. *Note*: DSC, differential scanning calorimeter.

to the rubbery state of the amorphous matrix of the product.[55,56] Moreover, the importance of sticky behavior of amorphous food powders has been recognized over many decades in the food industry. In Fig. 3, a sample of DSC profile for foam-mat-dried cantaloupe pulp powder (produced at 70°C and 3 mm thickness) is shown. Also, in Fig. 4 a sample of the values of the torque required to rotate the spindle inserted in the cantaloupe pulp powder (produced at 70°C and 3 mm thickness) as a function of temperature is shown.

The results for the T_g and T_s measurements are shown in Table 4. As expected, in this study for all cantaloupe pulp powders produced in different drying conditions the T_s was higher than the T_g. Agreement of the findings is observed among several studies.[28,36,57] Powders' T_s produced in 40, 55, and 70°C and thickness of 3 and 5 mm were 11.3, 12.9, 17.6 and 11.2, 11.8, and 16.9°C higher than T_g, respectively. Jaya and Das[36] reported the T_g and T_s as function of moisture content for different powders produced by mixing with maltodextrin and tri calcium phosphate. At moisture content 0 and 5%, the difference in the T_g and T_s for mango, pineapple, and tomato powders were 15.5, 3.5, 5.25 and 11.5, 2.5, and 19°C, respectively.

Table 4. T_g and T_s parameters of the cantaloupe pulp powders obtained by foam-mat drying under different conditions.

Drying conditions	T_g (°C)	T_s (°C)
3 mm-40°C	38.9 ± 0.6^{de}	50.2 ± 1.4^{c}
3 mm-55°C	44.6 ± 0.8^{bc}	57.5 ± 1.9^{abc}
3 mm-70°C	50.3 ± 0.5^{a}	67.9 ± 0.8^{a}
5 mm-40°C	35.1 ± 0.4^{e}	46.3 ± 1.5^{c}
5 mm-55°C	42.7 ± 1.1^{cd}	54.5 ± 2.1^{bc}
5 mm-70°C	48.2 ± 0.9^{ab}	65.1 ± 2.3^{ab}

Values are means ± SD of duplicate determination.
Means with same letter in each column are not significant different ($p > 0.05$).

In general, the T_g and T_s are measured as a function of moisture content of the sample. From Fig. 5, we clearly note that the T_g and T_s of cantaloupe pulp powders decreased as moisture content increased. Also, with increases in moisture content of the powders, the difference between T_g and T_s decreased. Water acts as a plasticizer and decreases the T_g of the powder with the increase in moisture content and a_w.[36] Under the influences of water and/or thermal plasticization, a glassy material transforms into a rubbery state. In this condition, the material surface is readily sticky. So, sticky behavior of sugar-rich foods tends to first occur at temperatures several degrees above the T_g. In different stages of drying processes, powder handling and storage, the knowledge of glass transition, water plasticization, and solid composition are required to control and reduce powder stickiness. Silalai and

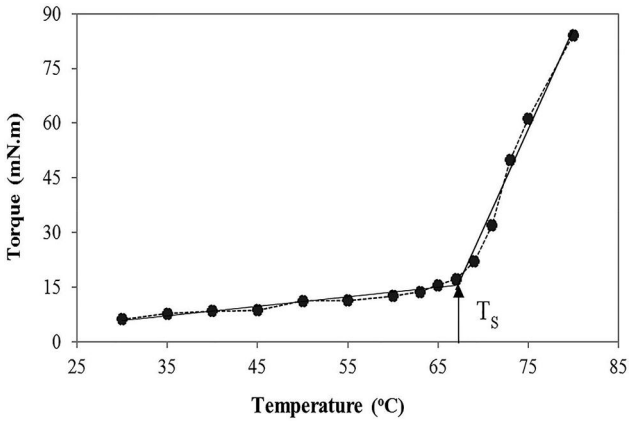

Figure 4. The values of torque as a function temperature for the cantaloupe pulp powder produced in 70°C and 3-mm thickness.

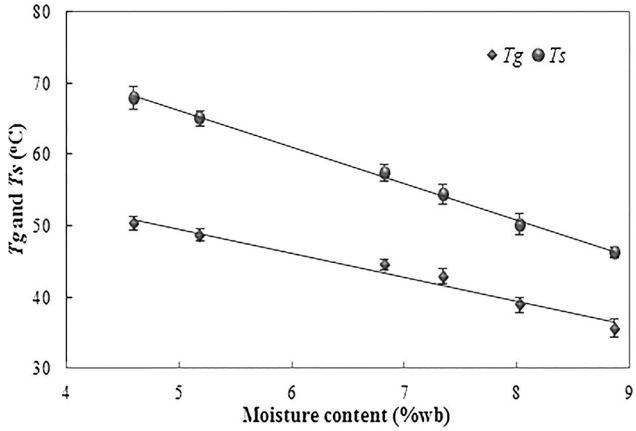

Figure 5. Relationship between moisture content, glass transition, and sticky-point temperatures for cantaloupe pulp powder.

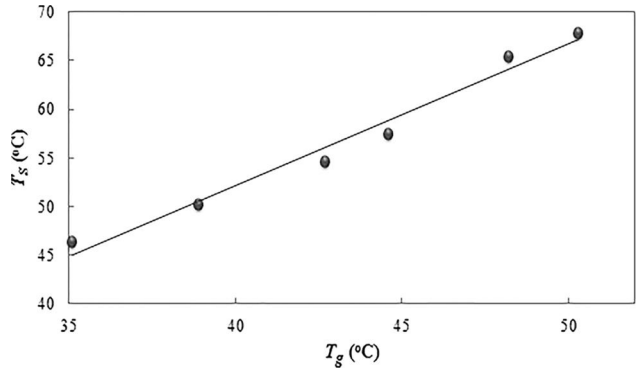

Figure 6. Correlation between T_g and T_s of cantaloupe pulp powder.

Roos[28] evaluated the water sorption, lactose crystallization, and stickiness properties of milk powders to establish relationships between protein and sugar composition, water sorption, glass transition, and powder stickiness. The results showed that at low protein contents, precrystallization of lactose decreased the T_s, but increasing protein content in milk powders decreased stickiness at all water activities. Furthermore, glass transition can be used to describe time-dependent stickiness and crystallization phenomena, and it can be used as a parameter to control and reduce stickiness of dairy solids with various compositions. Boonyai et al.[26] stated that the sticky-point diagram (T_s as functions of moisture content and/or a_w) can be used for selecting suitable conditions of drying process, handling, packaging, and storage for food powders to prevent losses due to stickiness; so that the region above the sticky-point curve represents sticky conditions for the powder, whereas at conditions below that curve the powder has free flowing.

Also, in this research, attempts have been to make the overall correlation between T_g and T_s parameters. As shown in Eq. (5), a linear equation with R^2 of 0.976 can be used to predict T_s if T_g of the cantaloupe pulp powder is known (Fig. 6).

$$T_s = 1/462\ T_g - 6/316\ (R^2 = 0.976) \qquad (5)$$

Conclusion

Cantaloupe has many potential health benefits, but it is a seasonal fruit and its shelf life is limited. Foam-mat drying proved to be an efficient alternative for the processing of cantaloupe pulp, since it allowed the development of a powder with appropriate features for pure consumption or addition as a food ingredient. Cantaloupe pulp powder can be used in beverages as a juice concentrate and/or as a coloring and flavoring agent in bakery or extruded cereal products, as well as ice cream, yoghurt, jellies, and candies.

In this research, cantaloupe pulp was subjected to foam-mat drying using different temperatures (40, 55, and 70°C) and thicknesses of the foam layer (3 and 5 mm). The resulting pulp powders were assessed for microstructure of mats and physicochemical properties of powders. The images obtained by SEM indicated that by increasing drying temperature, the mat structure porosity increased. Based obtained results, with increased drying temperature from 40 to 70°C, moisture content, a_w, dissolution time, a and β-carotene content were reduced and, L, hygroscopicity, T_g and T_s were increased. But, solubility showed nonsignificant difference between samples. The combination between the higher drying temperature (70°C) and the lower thickness (3 mm) led to a shorter drying time and consequent lower energy demand to produce a powdered cantaloupe pulp with high stability (low moisture content and water activity, and consequently, high T_g and T_s) and reconstitution speed of powder into water.

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