Water vapour sorption thermodynamic properties and stability of spray dried avocado milkshake powder

VK Shiby¹, KS Babu², P Thorakkattu² and MC Pandey¹

Received: 25 August 2021 / Accepted: 17 February 2021 / Published online: 27 July 2021
© Indian Dairy Association (India) 2021

Abstract: Correlation of sorption and glass transition properties were determined for avocado milkshake pulp powder obtained by spray-drying with varying levels (2,6,12%) of maltodextrin (MD). The isotherms were Type III, and GAB model was found to be adequate to predict the sorption data. At 25 °C, the critical water content that ensures the glassy state of the shake powder during storage increased from 0.05 to 0.08 g water/g product while the critical water activity increased from 0.14 to nearly 0.6, yield increased, and stickiness decreased with increasing levels of MD. (2 to 12%). The correlation between glass transition temperature (T_g) and the water fraction present in the sample was fitted using the Gordon–Taylor model showing satisfactory values of R^2 (0.89). From the combined plot of T_g and equilibrium moisture content versus water activity, the critical water activity at 20° C is 0.1, which increased to 0.6 at -5°C.

Keywords: Avocado, Spray drying, Sorption, Glass transition temperature, Stability

Introduction

Among all the fruits, the avocado (*Persea americana*) is a fat-rich fruit mainly consumed fresh. It is known for its pleasing taste and predominance of monounsaturated fatty acids (Duester, 2000). It is also recognized as a functional food containing health-promoting phytochemicals such as glutathione and beta-sitosterol (Rainey et al. 1994). Additionally, avocado is a good

source of vitamins (A, B, C, E), minerals (potassium, phosphorus, magnesium, calcium, sodium, etc.), and fibre, offering significant health benefits. The preservation of avocado is a challenge to the food technologists due to browning and heat-induced sensory changes in the product. In order to increase commercialization on a large scale and give avocado an added value, it is essential to develop food products derived from this fruit with a shelf life long enough for their transportation and distribution to consumers (Dorantes et al. 2004).

Due to the growing market of dairy companies, there has been a merging of dairy products and fruit beverage markets, introducing hybrid dairy products that offer health, flavour, and convenience. Instant dairy mixes like milk powders, dry ice cream mix, and lassi powder do not contain phytonutrients. Very limited studies have reported the value addition and utilization of avocado in dairy products. There is a great scope for developing spray-dried dairy mixes fortified with phytonutrients derived from avocado pulp with suitable additives to reduce stickiness and heat-induced bitterness.

Drying produces a stable, easy-handling form that reconstitutes rapidly to a good quality product resembling the original one as close as possible. Nevertheless, drying of fruit juices and other high sugar content products with introduces practical complexities due to its thermoplasticity and hygroscopicity at high humidities and temperatures (Adhikari et al. 2004; Gabas et al. 2007). Consequently, the addition of maltodextrin (MD) and gums alongside other additives such as calcium silicate, carboxymethyl cellulose, and pectin has been used in the production of powder juices (Bhandari et al. 2005). These characteristics are attributed to lower molecular weight sugars such as fructose, glucose, sucrose, and organic solids such as citric, malic, and tartaric which are major solids in fruit juices. The low glass transition temperature (T_g), high hygroscopicity, high water solubility and low melting point of these solids lead to a highly sticky product when spray-dried. The drying carriers or aides are compounds with high molecular weight that have high T_g ; accordingly, they can raise the T_g value of feedstuff and the resultant powder (Shrestha et al. 2007). The hygroscopicity problems and thermo plasticity happening in drying of dairy-

¹Defence Food Research Laboratory, Siddharthanagar Mysore-570011, India

²Department of Animal Sciences and Industry/ Food Science Institute, Kansas State University, Manhattan, KS 66506, USA

VK Shiby (✉)

Freeze drying and Animal Products Technology Division, Defence Food Research Laboratory, Siddharthanagar Mysore-570011, India

E-mail: shibykg@gmail.com

based or fruit juice with high sugar content can be overcome by adding some carriers such as MD and Arabic gum (Cano Chauca et al. 2005), waxy starch, etc. MDs have high water solubility and are mainly used in materials that are difficult to dry (Reineccius, 1991) and to reduce stickiness and agglomeration problems during storage, thereby improving product stability (Silva et al. 2006). Sugar and tricalcium phosphate were found to enhance the flowability of powders with high-fat content (Shivakumar et al. 2012). The fat in the cream powder was encapsulated by lactose or maltodextrin, and casein resulted in cream powder with good emulsion properties and solubility as those of the cow milk powder (Xiong et al. 2004). Moisture sorption isotherms illustrate the relationship between water activity and equilibrium moisture content of a food product. Familiarity of water sorption isotherms and isosteric heat of sorption is of essential importance to numerous food processes such as storage, drying, and packaging since they are used to calculate drying time, to predict ingredients behaviour upon mixing, packaging selection, modelling moisture changes that occur during storage, and estimating shelf-life stability, which is very important mainly for food powders. These properties give information about the interactions between food components and the water sorption mechanism. They also help to establish the final moisture content and permit the estimation of energy requirements of the drying process.

Numerous mathematical models for the description of foods moisture sorption behaviour are available. Some of these models are based on theories on the sorption mechanism; others are purely empirical or semi-empirical. The principles used to select the most appropriate sorption model are the degree of fitting of experimental data and the physical meaning of the model. Recently, the concepts related to water activity have been coupled with those of the glass transition temperature, T_g , providing an integrated approach to the role of water in foods. The glass transition is defined as the temperature at which an amorphous system changes from the glassy state to the rubbery state. Molecular mobility in the glassy state is extremely slow due to the high viscosity of the matrix (about 10^{12} Pa s). Therefore, the T_g can be taken as a reference parameter to characterize the properties, quality, stability and safety of food systems. Structural alterations, such as stickiness, agglomeration, caking and crystallization, occur in amorphous food powders when stored at temperatures above the T_g . Foods with low-moisture contents and T_g value above the storage temperature can be considered stable. However, a slight increase in moisture significantly reduces the T_g . Therefore, the moisture sorption and T_g supply critical values for the water activity and moisture content at room temperature (Khalloufi et al. 2000; Roos 1995; Roos and Karel, 1991).

The aim of the present work was to evaluate the influence of varying levels of maltodextrin on the physical properties, water sorption, T_g , and stability of spray-dried avocado milkshake powder. Modeling of the sorption isotherms and T_g using

selected models from the literature was studied, and attempts were made to couple sorption data with T_g for better prediction of the stability of the product.

Materials and Methods

Materials

Avocados were purchased from a local market (Mysore, India). The avocados were stored in a cold chamber at 4°C and thawed according to the quantity required to produce the spray-dried milkshake powder. Milk was procured from Nandini Dairy (Mysore, India). The carrier agent used was Maltodextrin (DE 10), procured from Pristine Organics, Bangalore.

Preparation of avocado milkshake

Avocados (*Persea americana* Mill.) were washed, disinfected with Potassium permanganate. Then the pulp was separated from the peel using a sterilized knife. The extracted pulp was ground in a mixer-grinder. The fine ground pulp was homogenized with milk along with powdered sugar, and carrier material maltodextrin (DE 10) was added at the rate of 2, 6, and 12% of the blend containing milk and avocado pulp. Sugar was added at the rate of 10%.

Spray drying

Milkshake was prepared by mixing milk and pulp in the ratio 3:1 with the addition of 10% sugar. Maltodextrin (DE 10) was added at 2, 6 and 12% of the milk shake blend without sugar. The spray drying process was performed using a laboratory spray dryer (S.M Scientific, Kolkata). The dryer was equipped with a spray nozzle with an orifice of 0.7 mm in diameter. The avocado milkshake was fed into the drying chamber using a peristaltic pump. The inlet air temperature was 175°C, and the outlet air temperature varied from 90 to 100°C for each sample. The feed pump rpm was 20, feed rate was 500 ml per hour and the blower speed was 2350 rpm during the spray drying process. The compressed air pressure was maintained between 2-3 kg/cm² corresponding to air flow rate of 0.66 – 1.33 CFM.

Proximate analysis

The samples with varying levels of MD were taken and analyzed for moisture, protein, and fat according to the AOAC, 2005 methods. Moisture and protein determinations were performed in triplicates, and single fat analysis was conducted for each sample. The powder sample (5-10g) was incinerated in a muffle furnace at 550°C for 3-4 hours to determine the ash content.

Modelling of sorption isotherms

Sorption isotherms were determined by means of the gravimetric method. The initial moisture content in powder samples were

determined by drying in a vacuum oven (Ranganna, 2004). Two to three grams samples of powder filled in sterilized glass bottle weighing dishes were placed in six separate desiccators containing saturated salt solutions for maintaining relative humidity (RH) levels from 11 to 85 %. The six jars were placed in an oven adjusted to a stable temperature for 24 h in order to bring the salt solutions to a constant temperature. Triplicate samples were used (2–3 g each) equilibrated over saturated salt solutions (1, providing relative humidity values of 11.15%, 32.73%, 43.80%, 52.86%, 75.32% and 84.32%, respectively in desiccators at 25°C until equilibrium. The air inside the desiccators was removed with the help of a vacuum pump. A glass dish containing 5 ml toluene was placed in desiccators with relative humidity higher than 75 % to check mold growth. The samples were weighed periodically till they attained equilibrium, after which they were analyzed for moisture content. To establish moisture sorption isotherms, the equilibrium moisture contents, determined by static gravimetric method, were plotted against water activity. The hygroscopic equilibrium of samples was reached in 7-10 days. The equilibration moisture content in samples were determined by subtraction method and expressed as g water/100 g solids. To establish moisture sorption isotherms, the equilibrium moisture contents were plotted against water activity. The physical appearance of the samples was also observed to check whether the powder had suffered any transformation such as agglomeration, caking or collapse.

Several models (empirical, semi-empirical, and theoretical) with two or more parameters have been used in the literature to describe the sorption isotherms. Equations based on sorption theories, such as BET and GAB models, are usually preferred by most researchers, since some physical meaning may be attached to their parameters, aiding in the understanding of the water sorption phenomena. Derived by simple extension and generalization of Langmuir's theory of unimolecular adsorption, the classic BET Eq. (1) (Brunauer et al. 1938) is a two-parameter model assuming the condensation of an infinite number n of layers from the vapor phase onto the adsorbent surface.

$$\text{Eq. (1)} X_e = \frac{X_m C a_w}{[(1 - a_w)(1 - a_w + C a_w)]}$$

X_e : equilibrium moisture content (g water/g dry matter), X_m : monolayer moisture content (g water/g dry matter), a_w : water activity, C : constant of BET.

GAB model shown in Eq 2 was also used to fit experimental data.

$$\text{Eq. (2)} X_e = \frac{X_m C K a_w}{[(1 - K a_w)(1 - K a_w + C K a_w)]}$$

X_e : equilibrium moisture content (g water/g dry matter), X_m : monolayer moisture content (g water/g dry matter), a_w : water activity, K and C : constant of GAB and BET, respectively.

In order to obtain the model parameters, a non-linear regression analysis was carried out using the Graphpad Prism (USA) software package. The degree of fitness of each model was evaluated by the determination coefficient and mean relative deviation modulus E

$$E = \frac{100}{N} \sum_{i=1}^N \frac{|V_e - V_p|}{V_e} \text{Eq. (3)}$$

N : population of experimental data, V_e and V_p : experimental and predicted value, respectively.

Glass transition temperature

About 10 mg of avocado milkshake powder were placed into differential scanning calorimetry (DSC) aluminum pans, which was equilibrated over saturated salt solutions in desiccators at 25°C until equilibrium was reached. The samples were then hermetically sealed with lids for analysis and weighed. The mass of each sample pan was matched in advance with the mass of an empty reference pan to within ± 0.1 mg. The DSC analyses were carried out in a TA-MDSC-2920 (TA Instruments, New Castle, De, USA). For temperatures below 70°C, liquid nitrogen was used. After cooling the sample to -30°C, the glass transition temperature was determined on thermo-analytical curves obtained by heating the sample at 10°C/min up to 110°C (or other values for the initial and final temperatures, according to the sample). The second scanning of each sample was performed to reduce the enthalpy relation of the amorphous powder, which appears in the first scan. All analyses were done in triplicate and the data were treated by the software Universal Analysis 2.6 (TA Instruments, New Castle, De, USA).

To describe the plasticizing effect of water on avocado milkshake powder, the glass transition temperature data were fitted to the Gordon-Taylor model (Gordon and Taylor, 1952)

$$T_g = \frac{W_s T_{gs} + k W_w T_{gw}}{W_s + k W_w} \text{Eq. (4)}$$

W : weight fractions (g/g total), s : solids, w : water, T_g : glass transition temperature (°C), k : constant.

The T_{gw} value was taken at 135°C (Johari et al. 1987). A non-linear regression analysis was carried out using the Graph Pad

Prism (Ohio, USA) software package to obtain the model parameters k and T_g .

Results and Discussion

Proximate composition and quality characteristics of spray-dried avocado milkshake

Fresh avocado showed moisture content in the range of 65-75%, total acidity of $1.02 \pm 0.39\%$ (as citric acid content), and pH 6.38 ± 0.02 , respectively. The fresh pulp had a total solid content of 8 - 9 °Brix. The milk used in formulation of butter fruit milkshake (BFMS) samples contained 3% fat and 8.5% SNF. The proximate composition of BFMS before drying are shown in Table 1.

Spray dried avocado milkshake powder

Spray dried avocado milk shake (BFMS-SD) powder containing varying level of MDs were evaluated for colour, water activity, sorption behaviour and glass transition temperature. BET and GAB models were used to fit the experimental sorption data, and the monolayer moisture content in spray-dried samples were estimated as parameters of these models. DSC was used as a tool to evaluate the T_g and endothermic and exothermic phase transitions in the products over a range of -30 to 110 °C.

Colour values and water activity

L^* , a^* , b^* values and water activity of fresh and spray dried avocado milkshake containing varying levels of maltodextrin (MD) were estimated using Hunter lab colourimeter, and the results are shown in Table 2. Color values of BFMS-SD powders differed significantly from the colour values of fresh avocado pulp (data not shown). With increasing level of MD there was slight variation in values, but there was no specific trend observed. The BFMS-SD containing 12 % MD showed the highest L value indicating maximum deviation from the greenish colour of pulp due to addition of various additives and treatment given. The addition of varying levels of MD did not affect a_w values of BFMS samples. The powder samples obtained after drying differed significantly ($P < 0.05$) in a_w values based on the content of MD present. The a_w of BFMS-SD varied between 0.205 to 0.311 depending on the content of MD. BFMS powder is stable with respect to lipid oxidation, non-enzymatic browning, enzyme activity, and of course, the various microbial parameters with water activity in the range mentioned. As a_w increases, the

Table 1 Proximate Composition and Quality characteristics of butter fruit milk shake (BFMS)

Quality Parameter	BFMS*
Moisture content (%)	79.6 $\pm$ 0.5
Ash (%)	3 $\pm$ 0.04
Protein (%)	2.4 $\pm$ 0.02
Fat	6 $\pm$ 0.1
Carbohydrate (%)	9 $\pm$ 0.2
Acidity (% citric acid)	1.03 $\pm$ 0.03
pH	6.3 $\pm$ 0.1
TSS(Brix)	17 $\pm$ 1

*Values shown are mean $\pm$ standard deviation of 6 samples

probability of the food product deterioration increases (Rahman, 2007). The stability of food with respect to oxidative changes is maximum at 0.4 and is in the a_w range 0.2 to 0.6 Water activity less than 0.2 or higher than 0.6 has an adverse effect on the oxidative stability of the product (Rahman, 2010). As avocado pulp contains high-fat content compared to other fruit pulps, the oxidative stability of the product is of great significance. Water activity is a crucial aspect that determines shelf life. The maltodextrin added powder was found to have good stability than plain BFMS powder. It was observed that when the level of maltodextrin was increased, the water activity reduced; hence the product become more shelf-stable.

Sorption isotherms

The correlation between water activity (a_w) and water content is complex. An increase in a_w is usually be associated with by arise in water content, however in a non-linear pattern. This correlation between a_w and moisture content at a given temperature is called the moisture sorption isotherm. These curves are determined experimentally and constitute the fingerprint of a food system. Isotherms can be employed to help predict product stability over time in different storage conditions. The knowledge and understanding of sorption isotherms are extremely crucial in food processing for the design and optimization of drying equipment, design of packages, predictions of quality, stability, shelf-life, and for calculating moisture changes that may occur during storage. Equilibrium moisture content for avocado milkshake powders added with varying levels of maltodextrin were plotted against at the six water activities. The sorption isotherms showed an increase in equilibrium moisture content with increasing water

Table2 Color and water activity values of spray dried avocado milkshake (BFMS) powder containing varying levels of maltodextrin (MD)

Avocado milk shake Powder	L^*	a^*	b^*	Water activity
BFMS-SD 2% MD	85.46 $\pm$ 0.2	-4.51 $\pm$ 0.01	21.41 $\pm$ 0.1	0.311 $\pm$ 0.05
BFMS-SD 6% MD	85.5 $\pm$ 0.1	-2.59 $\pm$ 0.02	17.55 $\pm$ 0.1	0.27 $\pm$ 0.01
BFMS-SD 12% MD	87.24 $\pm$ 0.2	-2.81 $\pm$ 0.01	15.84 $\pm$ 0.05	0.205 $\pm$ 0.02

*Values shown are mean $\pm$ standard deviation of 3 samples

Fig 1. Water sorption isotherms (GAB Model) of spray dried avocado milkshake powder (BFMS-SD), formulated with 2, 6 and 12% maltodextrin (MD)

Fig 2. Water sorption isotherms (BET Model) of spray dried avocado milkshake powder (BFMS-SD), formulated with 2, 6 and 12% maltodextrin (MD)

Table 3 Estimated parameters of GAB and BET models fitted to sorption data of spray dried avocado milkshake (BFMS) powder produced with different levels of maltodextrin (MD)

Avocado milk shake Powder	GAB				BET		
	X _m	C	k	R ²	X _m	C	R ²
BFMS-SD 2% MD	0.0970	0.4992	1.0870	0.9957	0.1165	-9.452	0.7944
BFMS-SD 6% MD	0.1311	0.7219	1.0420	0.9992	0.1177	-2.473	0.8653
BFMS-SD 12% MD	0.0726	4.3410	1.0550	0.9995	0.1114	1.293	0.9949

activity, at constant temperature. These isotherms can be classified as type III, according to Brunauer's classification, characteristic of non-porous or macroporous solids due to weak gas-solid interactions. The weakness causes uptake at lower water activity to be small. But once a water molecule has become adsorbed, the adsorbate-adsorbate forces will promote the adsorption of further water molecules and the resulting isotherms will become convex to pressure axis. The sorption isotherms fitted to GAB and BET models are presented in Figure 1 and 2. These curves are used to estimate the coefficients of two sorption models.

At a given water activity, EMC of the samples decreased with increasing levels of MD. Similar results were reported by other workers (Gabas et al. 2007; Mara and Maria, 2005). The presence of additives in the avocado milkshake powder probably modified the balance of hydrophilic/hydrophobic sites, promoting a decreased amount of sorbed water as reported by Perez-Alonso et al. (2006) for pure and blended carbohydrate polymers.

Similar isotherms were observed for protein hydrolysates from fish, pineapple, tomato pulp, West Indian cherry and lactose hydrolysed skim milk powders (Gabas et al. 2007; Shrestha et al. 2007). This type of curve was also observed by, Gabas et al. (2007) for vacuum dried pineapple containing maltodextrin and

gum Arabic, and Kurozawa et al. (2009) for spray-dried chicken meat hydrolysate protein produced with these same carrier agents.

Experimental data of the sorption isotherms for spray-dried avocado milkshake powder produced with different levels of carrier agent maltodextrin was fitted to GAB and BET models. Each model was tested for adequacy and goodness of fit by determining the coefficient R². The estimated parameters with the coefficient of determination (R²) are presented in Table 3.

Both BET and GAB models showed a good fit to experimental data, with high R². The results showed that for all the different MD concentrations studied, the GAB model presented a better fit than the BET model, with coefficient of determination close to unity. Hence GAB model gives a better prediction of the adsorption behavior of both SD avocado milk shake powder. As the R² values calculated by the BET model were lower, this model lacked prediction accuracy than GAB model for the sorption data of powdered avocado milkshake. This can be explained due to the limiting values for the constants C_{BET} as suggested by Lewicki (1997), established on the mathematical analysis of the model. For sigmoidal type curves, constants values are in the range $0.24 \ll K_{GAB} \ll 1$ and $5.6 \ll C_{GAB}$, to guarantee a relatively good description of the isotherms and to fulfill the requirements of the GAB model, as well as assuring that the calculated monolayer

Fig 3. Thermograms of spray dried avocado milkshake powder (BFMS-SD), formulated with 2, 6 and 12% maltodextrin (MD)

Fig. 4 Thermograms of spray dried avocado milkshake powder (BFMS-SD) equilibrated at different water activities and formulated with 12% maltodextrin

moisture content values differed by no more than 15.5% from the true monolayer capacity.

For samples containing 12% MD, both the models showed good degree of fit to predict the sorption behavior. Both BET and GAB models are based on the monolayer moisture concept and give the value of monolayer moisture content of the material (X_m), considered as the safe moisture for dried foods during preservation, while most other models lack this parameter. The monolayer moisture content (X_m) indicates the amount of water that is strongly adsorbed to specific sites at the food surface and

is considered an important value to assure food stability. X_m values were obtained from the linear plot of a_w versus $1/(EMC*(a_w-1))$ and calculated using the equation $X_m = 1/(s+i)$ where s is the slope and i is the y-intercept. The X_m values obtained by fitting BET & GAB models to sorption data of BFMS-SD containing varying levels of MD varied from 0.07 to 0.13 g/g db.

DSC thermograms of BFMS powder

BFMS-SD samples containing varying levels of MD were analysed in the temperature range -30°C to 110°C at the rate of 10

Fig. 5 Residual plots obtained for spray dried avocado milkshake powder (BFMS-SD) and Gordon –Taylor fitting for moisture vsTg values containing 12 % maltodextrin (MD)

°C/min and the results obtained are summarized in this section. The thermograms of spray-dried BFMS powders containing 2, 6 and 12% MD had Tg values 26.1, 27.52, and 33.9 respectively showing increase with increasing levels of MD in the blend. MD upto 12% was required for spray dried samples to avoid stickiness during drying and also to increase the product yield. A satisfactory product cannot be obtained with 2% MD with spray drying technique.

DSC thermograms of BFMS samples equilibrated at different RH conditions

DSC thermograms of selected BFMS samples (SD sample containing 12% MD) were analyzed to study the plasticizing effect of water. In general, the thermograms showed the typical second-order transition that produces a step change in the heat flow due to changes in heat capacity at the temperature of phase transition. The glass transition temperature was taken as the midpoint of the glass transition. Glass transition temperature of powders obtained with different drying methods equilibrated at different RH conditions varied from -8 to 20.81°C. The changes in exothermic and endothermic phase transitions due to changing moisture content in BFMS-SD samples were analysed.

Tg values for samples equilibrated at different water activities were correlated with sorption data (Figure 4). Tg decreased with increasing water activity. Plasticisation by an increasing water content results in the decrease of the glass transition. At the critical water activity, the Tg is decreased to storage temperature and further increases in a_w result in a decrease in viscosity of particles, stickiness, caking, and rapid increases in rates of lactose crystallisation and diffusion-controlled reactions. Two endotherms and one exotherm were observed in most of the

thermograms analysed for plasticizing effect of water. At higher water activities the onset of crystallization differed significantly whereas the changes in melting curves were not significant due to the plasticizing effect of water. The crystallization peaks and melting peaks shifted to lower temperatures with increasing moisture content indicating the lower stability of samples containing high moisture. These differences were highly significant in samples equilibrated at a_w of 0.75 and above.

The correlation between Tg and the water fraction present in the sample was fitted using the Gordon–Taylor model (Figure 5) showing satisfactory values of R^2 (> 0.85). The sticky-point temperature is normally about 10-23°C higher than the glass transition temperature and, in spray drying, particles which are above this temperature stick to the dryer wall and degrade, and/or clump together, adversely affecting the free-flowing property. In the case of avocado milkshake powder, considering its low sugars and acids level, the sticky-temperature is much higher than 85°C (the outlet air temperature) and that would result in a high degree of stickiness and thus help in a significant powder yield. There spray drying could be efficiently employed for the production of avocado milkshake powder. In a study on skim milk powder, it is reported that the glass transition temperature was found to be virtually the same as the sticky-point temperature measured using a thermo-mechanical test. It has been shown in previous reports that Ts and Tg (glass transition temperature) are very closely correlated, and both can be used to assess stickiness of powder materials (Ozmen and Langrish, 2002; 2006). As Tg is dependent on sugar and acid composition, sticky point (Ts) also varies based on these.

Product stability based on water activity and glass transition

Fig. 6 Variation of glass transition temperature and equilibrium moisture content with water activity for spray dried avocado milkshake powder (BFMS-SD) produced with 12% maltodextrin (MD)

From the combined plot of Tg and EMC vs water activity (Figure 6) the critical water activity corresponding to different storage temperatures above its Tg value can be determined. This data is useful in determining the ideal storage conditions for the product. For example, if the powder has to be stored at 5°C its critical water activity from the plot is 0.6. From the plot for spray dried milk shake powder the critical water activity at 20°C is 0.1. For powders which have Tg above room temperatures the critical water activity is determined by extrapolating to the Tg curve at 25°C.

Both water activity and glass transition temperature have been widely used to evaluate storage stability. Roos (1995) reported that the plasticization of biosolids is a result of combined effects of water and temperature. According to the author, the prediction of food stability based only on sorption isotherms data is not enough, since certain physicochemical and structural processes such as stickiness, crispness, collapse, amorphous-to-crystalline transformations and the rates of non-enzymatic browning are not related to a monolayer value and they are better correlated to the glass transition temperature through plasticization by water or temperature. Thus, the use of state diagrams that indicate the material's physical state, combined with the sorption isotherms, helps in the prediction of food stability, regarding to its physical characteristics.

Several authors have coupled the data of sorption isotherms with those of glass transition temperature, in order to obtain the critical conditions for food storage (Moraga et al. 2004, 2006). The critical water content/ water activity is the value at which the glass transition temperature of the product is equal to the room temperature. Above this temperature, the amorphous powders are susceptible to deteriorative changes like collapse, stickiness and caking, resulting in quality loss.

Conclusions

Among all the samples prepared by spray drying with varying levels of MD, avocado milkshake powder with 12% MD was found to be the best without any stickiness and bitter taste. The colour was also acceptable for this sample. GAB model was found to be adequate ($R^2=0.99$) to describe the experimental sorption data obtained for the spray-dried avocado milkshake powder. The glass transition temperature was determined for different water activities, in which an increase in moisture content caused a significant decrease in the glass transition temperature. The data for Tg fitted well with the Gordon-Taylor model. ($R^2=0.89$). The addition of maltodextrin increased the Tg and consequently contributed to the stability of the powder. These data could be used to assist the proper spray drying operational conditions with respect to stickiness and storage behaviour of the milk shake of a fat rich fruit like avocado. Likewise, powder with 12% maltodextrin was more stable at a higher relative humidity (critical water activity 0.6), which contributes to the prevention of caking and diffusion controlled deteriorative processes. This combined plot of Tg and sorption is a better tool for determining the ideal storage conditions for the product.

References

- Adhikari B, Howes T, Bhandari BR, Troung V (2004) 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* 62: 53-68
- AOAC (2005). Official methods of analysis of the association of official analytical chemists international. USA: Maryland
- Bhandari BR, Hartel RW (2005) Phase transitions during food powder production and powder stability
- Brunauer S, Emmett PH, Teller E (1938) Adsorption of gases in multimolecular layers. *J Am Chem Soc* 60: 309-319

- Cano-Chauca, M, Stringheta, PC, Ramos AM, Cal-Vidal J (2005) Effect of the carriers on the microstructure of mango powder obtained by spray drying and its functional characterization. *Innov Food Sci Emerg Technol* 6: 420-428
- DorantesL, Parada L, Ortiz A (2004) Avocado: post-harvest operation. AGST/FAO.
- Duester KC (2000) Avocados a look beyond basic nutrition for one of nature's whole foods. *Nutr Today* 35: 151-157
- Gabas AL, Telis VRN, Sobral PJA, Telis-Romero J (2007) Effect of maltodextrin and arabic gum in water vapor sorption thermodynamic properties of vacuum dried pineapple pulp powder. *J Food Eng* 82: 246-252
- Gordon M,TaylorJS(1952)Ideal copolymers and the second order transitions of synthetic rubbers. I. Non crystalline copolymers. *J Appl Chem* 2: 493-500
- Johari GP, Hallbrucker A, Mayer E (1987) The glass-liquid transition of hyper quenched water. *Nat* 330: 552-553
- KhalloufiS, El MaslouhiY, Ratti C (2000) Mathematical model for prediction of glass transition temperature of fruit powders. *J Food Sci* 65: 842-848
- KurozawaLE, Park KJ, Hubinger MD (2009) Effect of maltodextrin and gum arabic on water sorption and glass transition temperature of spray dried chicken meat hydrolysate protein. *J Food Eng* 91: 287-296
- LewickiPP(1997) The applicability of the GAB model to food water sorption isotherms. *Int J Food Sci Technol* 32: 553-557
- Mara RighettoA, Maria Netto F (2005) Effect of encapsulating materials on water sorption, glass transition and stability of juice from immature acerola. *Int J Food Prop* 8: 337-346.
- Moraga G, Mart3nez-Navarrete N, Chiralt A (2004) Water sorption isotherms and glass transition in strawberries: influence of pretreatment. *J Food Eng* 62: 315-321
- Moraga G, Mart3nez-Navarrete N, Chiralt A (2006) Water sorption isotherms and phase transitions in kiwifruit. *J Food Eng* 72: 147-156
- Ozmen L, Langrish TAG (2002) Comparison of Glass Transition Temperature and Sticky Point Temperature for Skim Milk Powder. *Drying Technol*20: 1177-1192
- P3rez-Alonso C, Beristain CI, Lobato-Calleros C, Rodr3guez-Huezo ME, Vernon-Carter EJ (2006) Thermodynamic analysis of the sorption isotherms of pure and blended carbohydrate polymers. *J Food Eng* 77: 753-760
- Rahman MS (2010) Food stability determination by macro-micro region concept in the state diagram and by defining a critical temperature. *J Food Eng* 99: 402-416
- Rahman MS (2007) Handbook of Food preservation. CRC press.
- Rainey C, Affleck M, Bretschger K, Alfin-Slater RB (1994) The California avocado: a new look. *Nutr Today* 29: 23-27
- Ranganna S (2004) Handbook of analysis and quality control for fruit and vegetable products. Tata McGraw-Hill Education.
- Reineccius GA (1991) Carbohydrates for flavor encapsulation. *Food Technol* 45: 144-146
- Roos YH (1995) Food components and polymers. Phase transitions in foods, 109-156
- Roos Y, Karel M (1991) Amorphous state and delayed ice formation in sucrose solutions. *Int J Food Sci Technol* 26: 553-566
- Shivakumar KM, Chetana R, Reddy SY (2012) Preparation and properties of encapsulated fat powders containing speciality fat and ω /PUFA-rich oils. *Int J Food Prop* 15: 412-425
- Shrestha AK, HowesT, Adhikari BP, Bhandari BR (2007) Water sorption and glass transition properties of spray dried lactose hydrolysed skim milk powder. *Lwt-Food Sci Technol* 40: 1593-1600
- Silva MA, Sobral PJA, Kieckbusch TG (2006) State diagrams of freeze-dried camu-camu (*Myrciariadubia* (HBK) Mc Vaugh) pulp with and without maltodextrin addition. *J Food Eng* 77: 426-432.
- Xiong H, Tang HM, Xiong XQ, Zheng WW (2004) Nutritional and functional properties of cream powder of imitation mother's dairy [J]. *China Dairy Industry*, 8 www.cnki.com.cn