Stability and microstructure of freeze-dried guava pulp (*Psidium guajava* L.) with added sucrose and pectin

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Abstract Freeze-dried guava pulp powders, formulated with the addition of sucrose (0–20 g/100 g pulp) and pectin (0–1.0 g/100 g pulp), were obtained, and their stability was evaluated with respect to the water adsorption isotherms, thermal analysis and microstructure. The GAB (Guggenheim-Anderson-de Boer), Peleg and BET (Brunauer-Emmett-Teller) models were used to evaluate the water adsorption. The microstructure was examined using optical microscopy with polarized light and scanning electron microscopy (SEM). The GAB and BET parameters showed that the moisture content of the monolayer (X_m) increases with increasing pectin concentration in the adsorption isotherms. Optical microscopy micrographs showed that the pulp consisting of sucrose showed crystalline structures present in a higher amount and size, and this behavior is enhanced with increasing relative moisture. SEM showed that the increase in sucrose and pectin concentrations produced powders with lower porosity, providing greater stability to the product. The glass transition temperature increased slightly with increasing pectin concentration and decreased with increasing moisture content in the guava pulp powder. The kinetic curves, ratio of the increase of the water content against the storage time, of the guava pulp treated with 20 g sucrose per 100 g pulp and higher pectin concentration (0.5 or 1.0 g pectin per 100 g pulp) showed reduced adsorption and yielded freeze-dried pulps that were more stable.

Keywords Microscopy · Fruit pulp · Food powders · Stability

Introduction

In Brazil, the guava is among those fruits with the highest production and highest loss rates. Among the preservation methods, dehydration can offer many advantages, notably an increase in product stability and weight reduction, which causes significant reductions in packaging, storage and transportation costs.

Guavas are often considered as superfruits being rich in vitamin A and C in the pericarp, omega-3 and 6 polyunsaturated fatty acids in the seeds and have high levels of dietary fiber (Verma et al. 2015). Freeze-drying is the dehydration process that yields a product with better functional and sensory characteristics than products dehydrated using other methods (Sagar and Suresh 2010; Garcia-Noguera et al. 2014). Freeze-dried tropical fruits are characterized by their high hygroscopicity and consequent potential for caking. In freeze-dried products, the phase transitions cause important changes in the physical state of the material during processing, storage and consumption. (Sá and Sereno 1994; Khalloufi et al. 2000; Telis and Sobral 2001).

Food powders containing amorphous sugars present collapses during freeze-drying and/or caking problems when exposed to temperatures above glass transition temperature (T_g), which is a function of moisture content/water activity of the powder (Jouppila and Ross 1994; Foster et al. 2005; Silva et al. 2006; Goula et al. 2008). Collapses result in structure loss, reduction in pore size and shrinkage at higher temperature (Sagar and Suresh 2010). For this reason, knowledge of the water absorption properties of these products is of great importance, and such

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properties are commonly studied by determining isotherms. The isotherms are curves that are used to evaluate the hygroscopic behavior and, consequently, the potential for physicochemical stability of the freeze-dried products.

The production of powders with controlled and desired properties has been a challenge. Amorphous products are described as being more cohesive, hygroscopic and more difficult to flow and disperse compared with the crystalline products. Crystalline products have the disadvantage of low porosity but are easier to manipulate (Chiou et al. 2008; Alves et al. 2010). The behavior of powders with glassy and rubbery states and powder crystallization has been explored. Some studies report that, in the hygroscopic domain, the results are consistent with the hypothesis that the adsorption behavior and thermal properties such as T_g of freeze-dried fruits are influenced by the water content and the presence of pectin (Maia and Cal-Vidal 1994; Telis and Sobral 2001; Sablani et al. 2008). Other authors state that the T_g and the water activity (a_w) are affected by the constituent structural elements of the fruit tissue acting as the dispersing medium for water and species of low molecular weight such as sugars, salts and organic acids. Within these media, hydrocolloids, primarily soluble pectin, strongly affect the viscosity but have no effect on the water activity and the T_g (Venir et al. 2007; Bezerra et al. 2015). Guava pulp with added pectin and sucrose has been targeted as the raw material in the manufacture of jams and sweets. The use of guava pulp powders, with these ingredients pre-added, could be an alternative for use in processing these delicacies, with ease of transport, storage and dosing during preparation.

In view of these considerations, the present study aimed to obtain edible freeze-dried guava pulp powder with added sucrose and pectin and, to evaluate the effect of sucrose and pectin on the adsorption of water and the microstructural properties of the powders resulting from the freezing drying process of the guava fruit pulp. The final aim was to determine which combination of added sucrose and pectin resulted in the greatest stability of the dehydrated product.

Materials and methods

Sample preparation

The guavas (Pedro Sato variety) were selected as whole and intact fruits with uniform maturity. These fruits were collected by hand in the early morning and placed in previously sterilized polyethylene boxes before transporting to the laboratory. Fully mature fruits were selected with matte-green peel coloration, firm pulp, and absence of mechanical and physiological injuries. The fruits were washed under running water, weighted, and disinfected by

Table 1 Mixtures of guava pulp with added sucrose and pectin

Treatments	Sucrose (g/100 g of pulp)	Pectin (g/100 g of pulp)
1	–	–
2	–	0.5
3	–	1.0
4	10	–
5	10	0.5
6	10	1.0
7	20	–
8	20	0.5
9	20	1.0

submerging them in a sodium hypochlorite solution (0.01 g/L) at room temperature for 5 min. The guavas were processed whole and unpeeled using a fruit pulper (Tomas-Model DPT-50, Brazil). The pulps underwent a pre-treatment (Table 1), when sucrose (Isotar-Brazil) (0.0–20.0 g/100 g of pulp) and citrus pectin (GENU[®] Pectin type 105 Rapid Set; degree of esterification, 69.4 %; pH of 1 % solution, 3.4; CP Kelco-Brazil) were added (0.0–1.0 g/100 g of pulp) and homogenized with the aid of a Turratrec TE-102 mixer (Tecnal, Campinas, Brazil).

Freeze-drying

Freezing phase

The guava pulp was placed in 100 ml glass containers, using only 50 % of the useful volume of the flask. Subsequently, the samples were subjected to freezing in static air in a freezer (Deep Freezer-Revco, Asheville, USA) at a temperature of -85°C until processing time.

Freeze drying of samples

The frozen pulp was taken to a freeze dryer (Liobras-Model L108, São Carlos-Brazil). The average time to freeze-dry the samples was 72 h at -50°C with a pressure of 0.98 mbar. The freeze-dried products were then broken, milled and homogenized using a Turratrec grinder (Tecnal, model-TE-102, Brazil) and stored in desiccators containing phosphorus pentoxide (Vetec-Brazil) for twenty days to remove the residual humidity and transferred to desiccators containing silica gel until analysis time.

Determination of hygroscopic behavior

Determination of sorption characteristics

The appropriate environments for the determination of the water sorption behavior of the freeze-dried products were

created in containers that were closed hermetically using saline solutions of varying saturation levels with the following water activities (*aw*) at 25 °C: LiCl, 0.11; CH₃COOK, 0.22; MgCl₂·6H₂O, 0.32; Mg(NO₃)₂·6H₂O, 0.53; NaCl, 0.75; KCl, 0.8; and BaCl₂, 0.90.

After freeze-drying, 5.0 g samples were weighed and evenly distributed in triplicate into plastic containers and taken to desiccators containing saturated salt solutions. The data for the analysis of the water adsorption dynamics of the freeze-dried products were obtained at 25 °C for each environment with controlled relative humidity. The sorption isotherms were built using the water activity measurements that were made using a dew point hygrometer (Aqualab, Decagon; model 3TE, Pullman, Washington, USA) with a time interval of 12 h on the first day and of 24 h up to the fourth day. The measurements were made over the subsequent days at a time interval of 48 h until equilibrium was established. The water sorption behavior was plotted on a graph relating the product water activity as a function of the equilibrium relative humidity of the environments and the storage time.

Determination of the water sorption isotherms

The isotherms of the freeze-dried material were obtained from graphs that relate the equilibrium moisture content values of the samples as a function of the water activity of the humidity environments to which they were exposed (Varghese et al. 2014). The experimental data were subjected to BET, GAB and Peleg mathematical models. Mathematical adjustments for adsorption isotherms were performed using the software Statistica version 8.0, Quasi-Newton model, with convergence criterion of 0.0001. The criteria used to select the best fit of the models to the experimental data were determined according to the parameter estimates as well as the values of the residual standard error (*P*) and coefficient of determination (*R*²). Table 2 shows the mathematical models used for adjustment.

Table 2 Mathematical models used for adjustment of the experimental data

Model	Equation
BET	$X = \frac{X_m C_{aw}}{(1-aw)[1+(C-1)aw]}$
GAB	$X = \frac{X_m C_{GAB} K_{GAB} aw}{(1-K_{GAB} aw)(1-K_{GAB} aw + C_{GAB} K_{GAB} aw)}$
Peleg	$X = K_1 aw^{n_1} + K_2 aw^{n_2}$

X_m is the monolayer moisture content (g of water/g of dry solid); *C* is the BET constant related to the excess sorption enthalpy; *C_{GAB}* and *K_{GAB}* are the GAB sorption constants related to energy interactions between molecules of the monolayer at a given sorption site; and *K₁*, *K₂*, *n₁* and *n₂* are the Peleg model parameters

Differential scanning calorimetry

Thermal properties were measured as a function of the concentration and water activity in the systems. The *T_g* and the other parameters were determined by differential scanning calorimetry (DSC-60A, Shimadzu-Japan). A liquid nitrogen system was used for temperature control.

The instrument was calibrated for temperature and heat flow with indium (*T* = 156.6 ± 6 °C and Δ*H* = 30.25 J/g) and zinc (*T* = 28.5 ± 1.5 °C and Δ*H* = 104.71 J/g). A sample of approximately 5 mg of each formulation was transferred to a pan, which was sealed and weighed immediately. A similar empty pan was used as a reference. The samples were cooled to −100°C, and scanning was performed by heating at 5 °C/min from −100 to 100 °C. The glass transition appeared as an endothermic decline.

Microstructural analyses

Light microscopy

The study of the microstructure of the sugar crystals in the freeze-dried pulp before and after preparation of the adsorption isotherm was performed by light microscopy under a microscope (Meiji, ML 5000, Japan) with a polarized light filter and coupled to a video capture system.

Scanning electron microscopy

The freeze-dried products were fixed onto an aluminum support (stubs) with double-sided carbon tape. The aluminum support was sputter-coated under vacuum with a thin film of metallic gold using a Bal-Tec model SCD 050 evaporator (Balzers, Liechtenstein). A Nanotechnology Systems (Carl Zeiss, Oberkochen, Germany) model Evo[®] 40 VP scanning electron microscope was used with an accelerating voltage of 20 kV and a working distance of 9 mm to obtain digital images using the Leo User Interface software at varying magnifications. The images were processed using Corel Draw 14 Photo-Paint Software.

Statistical analysis

All treatments were performed in two replicates, and each replicate was evaluated three times. The experimental results were subjected to single-factor analysis of variance and a comparison of means using Tukey's test at the 5 % level using the statistical package R (R Development Core Team, Vienna, Austria).

◀**Fig. 1** Effect of sucrose on the water sorption isotherm of freeze-dried guava pulp with 0.5 g pectin/100 g pulp and **a** 0 g sucrose, **b** 10 g sucrose, and **C** 20 g sucrose as a function of storage time in controlled humidity environments

Fig. 2 Effect of sucrose and 0.5 g pectin/100 g pulp on the adsorption isotherm of freeze-dried guava pulp adjusted by the models **a** GAB, **b** Peleg and **c** BET. Filled square sucrose 0 g, filled circle sucrose 10 g, filled triangle sucrose 20 g

Table 3 Parameter estimates, standard error (P) and coefficient of determination (R^2) of the models of GAB, Peleg and BET to evaluate the sorption isotherms of freeze-dried guava powders

Formulations	Control		Sucrose	Pectin	Sucrose	Pectin	Sucrose	Pectin	Sucrose	Pectin
Estimates	0 %	0 %	10 %	0 %	10 %	0.5 %	10 %	1 %	20 %	0.5 %
Model of GAB										
X _m	0.047		0.039		0.054		0.064		0.064	
C _{GAB}	0.027		0.057		0.280		0.033		0.033	
K _{GAB}	0.166		0.082		0.026		0.113		0.113	
P	0.021		0.024		0.020		0.022		0.022	
R ²	0.945		0.928		0.944		0.944		0.944	
Model of Peleg										
K ₁	0.147		0.150		0.146		0.151		0.115	
n ₁	1.227		1.111		1.034		1.162		1.007	
K ₂	0.147		0.150		0.146		0.151		0.115	
n ₂	1.227		1.111		1.034		1.162		1.007	
P	0.022		0.024		0.020		0.021		0.020	
R ²	0.946		0.929		0.944		0.946		0.915	
Model of BET										
X _m	0.057		0.059		0.060		0.061		0.044	
C	9.260		16.698		22.692		9.431		221.867	
P	0.012		0.023		0.021		0.021		0.016	
R ²	0.970		0.892		0.907		0.920		0.895	

Results and discussion

Water sorption isotherms of freeze-dried guava pulp

Changes in the water activities (aw) as a function of the equilibrium relative humidity of the environments (RH) and the storage time are shown in Fig. 1 for the systems with 0.5 g of pectin/100 g of pulp and sucrose. Figure 2 shows the adsorption isotherms for the freeze-dried guava powder obtained from pretreatment with sucrose and pectin adjusted by the GAB model (Fig. 2a), the Peleg model (Fig. 2b), and the BET model (Fig. 2c).

Figure 1 shows that increasing the sucrose concentration reduced the absorption of water in tested systems with additives and also when compared with control system (data not shown). The lowest rate was observed at a concentration of 20 g/100 g pulp (Fig. 1c). When the sucrose concentration was maintained constant at 10 g/100 g of pulp and the pectin concentrations were changed, the results show that the pectin concentration apparently did not influence the water adsorption kinetics compare to the control system (data not shown).

For the systems with higher equilibrium relative humidity environments and greater storage time, pretreatment with sucrose at concentrations of 10 g/100 g of pulp (Fig. 1b) or 20 g/100 g of pulp (Fig. 1c) resulted in lower water activities on the final day of storage. In the environments with a low relative humidity, the water activities of the systems quickly increased on the first day. At the low

water activities, water can be adsorbed only to the surface hydroxyl groups of the crystalline sugar. Therefore, the moisture content is low in the region with the low water activity. The dissolution of the sugar occurred at the high water activities when the crystalline sugar was converted into an amorphous sugar. The amount of adsorbed water increased greatly after this transition due to the increase in the number of adsorption sites upon breakage of the crystalline structure (Marques et al. 2007; Varghese et al. 2014).

Figure 2 shows that the isotherm shape is typical of products with high sugar content, which adsorb relatively small amounts of water at low water activity and present a sharp increase in the amount of adsorbed water at higher water activities (Telis and Sobral 2001). Several studies showed similar results for tropical fruits (Hubinger et al. 1992). The increase in sorption with increasing water activity is due mainly to the dissolution of sugars (Hubinger et al. 1992; Tsami et al. 1998; Fabra et al. 2009). The sorption region called the monolayer is characterized by low and intermediate water activity. The moisture content then increases linearly with the water activity, while at high water activity levels, the region called capillary condensation is characterized (Goula et al. 2008).

Despite the isotherms displaying the same behavior regardless of treatment, there is a difference in terms of the equilibrium moisture content for the powders obtained from the freeze-dried guava pulp. In treatments consisting of 0.5 g of pectin/100 g pulp and different concentrations

Fig. 3 Thermogram of freeze-dried guava pulp and 10 g sucrose/100 g pulp with **a** 0 g pectin and **b** 0.5 g pectin exposed to different water activities

of sucrose, at the second inflection point of the curve, we observe higher values in the formulation consisting of 0.5 g of pectin/100 g pulp and 10 g sucrose/100 g pulp, compared with the other treatments. At water activities above 0.3, the equilibrium moisture content in all formulations of freeze-dried guava pulp shows elevation with high water activity, which is a typical behavior for substances with high sugar content (Khalloufi et al. 2000; Venir et al. 2007). Regarding sucrose, the equilibrium of the systems

consisting of 0.5 g pectin/100 g pulp and 10 g sucrose/100 g pulp is higher, also observed in the adsorption behavior of freeze-dried guava pulp during storage, as mentioned in the previous item.

The GAB and Peleg models (Table 3) describe the adsorption isotherms for water activity from 0.11 to 0.90, with correlation coefficient values ranging from 91.45 to 94.58 %. The parameters of the BET model for predicting the hygroscopic behavior of the freeze-dried guava pulp powders, represented in the sorption isotherms, are also shown in Table 3, where the values of the correlation coefficient ranged from 89.21 to 97.01 %.

When the treatment is compared with the control, Table 3 shows that for systems consisting of 10 g sucrose/100 g pulp and different concentrations of pectin, the moisture content of the monolayer (X_m) increases with increasing pectin concentration in the adsorption isotherm described by the GAB and BET models. The moisture content of the monolayer (X_m) indicates the amount of water that is strongly adsorbed at specific locations on the food surface, and X_m is considered an important value to ensure food stability (Tonon et al. 2009). The X_m values found for freeze-dried guava pulp with added sucrose and pectin varied from 4.44 to 6.11 % according to the BET model and 3.89–6.37 % according to the GAB model. These values are consistent with values for other types of fruit pulp such as 3.1–5.8 % (BET model) and 3.2–6.3 % (GAB model) obtained by Tonon et al. (2009) for freeze-dried açai juice; 5.7–6.1 % (BET model) and 4.6–5.0 % (GAB model) by Moraga et al. (2006) for freeze-dried kiwi; and 4.5 % (BET) and 7.4 % (GAB) by Syamaladevi et al. (2009) for freeze-dried raspberry powders. Gabas et al. (2007) determined adsorption isotherms of powders of vacuum-dried natural pineapple pulp and with additives and obtained values of the monolayer for natural pulp of approximately 14.6–16.6 %, 7.2–7.3 % (on average) for pulp with 18 % added gum arabic and 6 to 6.3 % (on average) for pulp with 18 % added maltodextrin, at temperatures of 20 and 30 °C. According to Labuza (1968) and Roos (1995), the BET isotherm shows satisfactory

Table 4 Glass transition temperature (T_g) and enthalpy (ΔH) of freeze dried guava powders combined with 10 g of sucrose/100 g of pulp (A) without and (B) with 0.5 g of pectin/100 g of pulp after

ERH	T_{gA} (°C)	T_{gB} (°C)	ΔH_A (J/g °C)	ΔH_B (J/g °C)
aw = 0.843	-58.28 ± 2.37^{aB}	-54.76 ± 2.78^{aA}	1.09 ± 0.18^{bA}	1.26 ± 0.19^{cB}
aw = 0.530	-29.70 ± 2.46^{bB}	-22.51 ± 3.03^{bA}	0.96 ± 0.20^{aA}	1.05 ± 0.17^{bA}
aw = 0.226	-4.56 ± 0.86^{cA}	-3.55 ± 0.40^{cA}	1.09 ± 0.24^{bA}	0.93 ± 0.21^{aA}

The values with different superscript lowercase letters within a column differ significantly from one another ($p < 0.05$) and the values with different superscript capital letters within a row differ significantly from one another ($p < 0.05$). Values are mean $\pm$ standard deviation

exposure to environments with different water activities (only significant results are shown)

Fig. 4 Photomicrographs of guava pulp with **a** 0 g pectin + 0 g sucrose, **b** 0.5 g pectin + 0 g sucrose and **c** 1.0 g pectin + 10 g sucrose per 100 g pulp

adjustment only for sorption data with an a_w value between 0.1 and 0.5 for most foods. In the case of grapefruit, the threshold used for the BET model was a water activity of

0.68, indicating the limit of the most important solute–solvent interactions in this fruit (Roos 1993; Fabra et al. 2009).

Differential scanning calorimetry

Figure 3a and b show the differential scanning calorimetry thermograms around the glass transition zones of freeze-dried guava powder with 10 g of added sucrose/100 g of pulp and without pectin (Fig. 3a); 10 g of sucrose/100 g of pulp and 0.5 g pectin/100 g of pulp (Fig. 3b), respectively, after exposure to different environments at 25° C. The characteristic parameters of the mean values of T_g and enthalpy changes (ΔH values) of the freeze-dried materials are shown in Table 4.

Figure 3 and Table 4 show that the glass transition found depends primarily on the moisture content of the samples. The higher the moisture content of the sample, the lower the temperature at which the glass transition occurs. Additives can have two opposite effects on the T_g of a given material. If an additive lowers the T_g of a substance, it is called a plasticizer; if the additive raises the T_g of that substance, then it is referred to as an antiplasticizer. The antiplasticizer phenomenon has been observed in food materials, but it has been associated with a moisture toughening effect. What is observed in Fig. 3 and Table 4 is that the presence of additives influences the T_g of the systems, which also depends on the moisture content of the samples. Marques et al. (2007) found T_g values for guava pulp of -17.9 °C immediately after freeze-drying. The results of this study show that the addition of sucrose and pectin, as pre-freezing treatments, increased the T_g when considering the storage environment with the lowest water activity (a_w 0.226).

Microstructural analysis

Optical microscopy

Figure 4 shows the photomicrographs obtained by light microscopy with polarized light of the powders obtained immediately after freeze-drying of systems made up of guava pulp with or without added pectin and sucrose after storage with phosphorus pentoxide and silica gel. The crystalline structures are identified by lighter, brighter regions in the photomicrographs due to the scattering of the polarized light, and the amorphous material can be identified by the darker regions.

In systems consisting of 0.5 g of pectin/100 g of pulp, the crystal structures are observed in greater number and size in these systems with 10 g of added sucrose/100 g of pulp (Fig. 4b) and 20 g of added sucrose/100 g of pulp (figure not shown). The frequency distribution of these

Fig. 5 Photomicrographs, by optical microscopy and polarized light, of freeze-dried guava pulp with **a** 0 g sucrose + 0.5 g pectin, **b** 10 g sucrose + 0 g pectin, **c** 10 g sucrose + 0.5 g pectin per 100 g pulp, exposed to environments of a_w of (1) 0.226; (2) 0.530 and (3) 0.843

structures is observed to be proportional to the concentration of the sucrose in this system. This relationship is contrary to systems consisting of 10 g of sucrose/100 g of pulp and different pectin concentrations (Fig. 4c). Treatment with higher pectin concentrations resulted in powders with amorphous structures and the regions characteristic of crystalline systems were reduced with the increase in pectin concentration.

The photomicrographs in Fig. 5 show the powders obtained from the freeze-dried guava pulp with (A) 0.5 g of added pectin/100 g of pulp without sucrose; (B) 10 g of added sucrose/100 g of pulp without pectin; (C) 10 g of added sucrose/100 g of pulp + 0.5 g of pectin/100 g of pulp, after reaching equilibrium in environments with controlled relative humidity with $a_w = 0.226$; $a_w = 0.530$ and $a_w = 0.843$ at 25 °C. The crystal structures are present in frequency and size only in those systems composed of

sucrose (Systems B and C) and are observed with more intensity as the equilibrium water activity of the environments to which they are exposed is increased (Fig. 5a3, b2, b3, c2, c3).

When comparing the systems containing 10 g of added sucrose/100 g of pulp + 0.5 g of added pectin/100 g of pulp (Fig. 5c) with systems containing 10 g of added sucrose/100 g of pulp and absence of pectin (Fig. 5b) under different environmental conditions, the presence of pectin is found to influence the formation of crystalline structures.

Amorphous products are metastable and tend to become sticky. The hygroscopic potential of dehydrated foods containing sugars is closely linked to their physical state. Sugars are mainly responsible for high hygroscopicity, and reducing sugars, especially fructose, are more hygroscopic than sucrose. The higher porosity of the freeze-dried

Fig. 6 Electron micrographs of freeze-dried guava pulp and 0.5 g pectin/100 g pulp with **a** 0 g sucrose, **b** 10 g sucrose and **c** 20 g sucrose

product favors water diffusivity, and absorption favors the formation of liquid and solid bridges, partial melting and crystallization of dissolved substances that give rise to highly rigid aggregates (Scoville and Peleg 1981).

Scanning electron microscopy

The examination of the surface of the guava powders obtained by freeze-drying was performed three-dimensionally by scanning electron microscopy analysis. This

procedure allows correlation of the particle microstructure with the photomicrographs obtained via optical microscope with polarized light.

Figure 6 shows scanning electron micrographs of the freeze-dried guava pulp powders after treatment with of 0.5 g of added pectin/100 g of pulp and different concentrations of sucrose.

In formulations of freeze-dried guava pulp with higher concentrations of sucrose, there was lower porosity, thereby decreasing the hygroscopicity of freeze-dried pulp during storage. This behavior was also observed for the isotherms, in which the formulation that showed higher sucrose content showed lower water adsorption, i.e., lower hygroscopicity and hence lower porosity. The powders produced with added pectin presented coated surfaces with a microencapsulation aspect.

Freeze-drying provides dry products with a porous structure. The solid state of the water during freeze-drying protects the primary structure and minimizes alterations in the product shape, with minimal shrinkage (Marques et al. 2007). The differences in moisture sorption capacity can be explained by differences in the volume of the porosity and the pore size of the dry materials (Singh et al. 2015). Freeze-drying results in a highly porous product with small pores that absorb more water than the other dry materials (Tsami et al. 1998).

Conclusion

The addition of pectin slightly increased the T_g value. The moisture content in freeze-dried guava pulp influenced the T_g values that decreased with the increase in moisture content in the freeze-dried guava pulp. The crystal structures were present in greater number and size in the freeze-dried guava pulp formulations consisting of sucrose. This behavior was enhanced according to the concentration of sucrose in the systems and the water activity of the environment. The presence of pectin was found to influence the formation of crystalline structures and the effect was more intense with high water activities. Formulations of freeze-dried guava pulp with high sucrose levels had less structural porosity when analyzed by scanning electron microscopy. Freeze-dried guava fruit pulp that was pretreated with no sugar had amorphous structures and was highly porous; these absorbed more water than those pretreated with the sucrose. Sucrose is amorphous and metastable, but yielded protected structures with less signs of collapse. Thus, the higher the sucrose concentration is, the lower the hygroscopicity of the freeze-dried guava pulp and the greater the stability during storage.

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