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Effect of Maltodextrin on Glass Transition Temperature and Water Activity of Production Banana Flake

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ABSTRACT

Glass transition temperature (T_g) has been identified as a critical factor for predicting the quality of foodstuff during processing or storage. Maltodextrin DE 10 at concentrations of 0.9, 1.8, and 2.7% of banana pulp were added to banana pulp to increase the T_g of banana flake. Differential scanning colorimetry (DSC) was used to determine the T_g of banana flake as a function of water content. The equilibrium moisture content was measured over different saturated solutions using the gravimetric method at 35°C. The T_g values of banana flake decreased with increasing water activity while increased with increasing percentage of maltodextrin. The Gordon and Taylor model was used to predict T_g of banana flake. The Guggenheim-Anderson-deBor (GAB model) was used to predict water content of banana flake. It was shown that maltodextrin content increased monolayer water (M_0) and the T_g of dry solids for banana flake.

Key words: glass transition temperature, sorption isotherm, maltodextrin, banana flake

INTRODUCTION

Most food products that have reduced water content are partially or completely amorphous in nature. This characteristic is formed by various processes such as baking, concentration, drum-drying, freeze-drying, spray-drying and extrusion that minimize water removal time and control the concentration of solids (Slade and Levine, 1991; Roos and Karel, 1991a; Roos, 1995a). Various changes in physical, chemical, and/or biological characteristics of foodstuff occur during processing, storage and distribution. The control and optimization of operating parameters during manipulation and processing of products may, therefore, be considered essential in achieving available and efficient operation, and one might expect that the optimal operating conditions depend on the type of product being processed. One of the product properties linked to structural changes during thermal processing is the temperature at which an amorphous system changes from a glassy to a rubbery state in a second order phase transition known as the glass transition temperature (T_g). T_g is a kinetic and a relaxation process associated with a relaxation of the material (Slade and Levine, 1991).

Foodstuff can be thought of as amorphous

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matrices, composed mainly of water, polysaccharides, proteins, and fats. Various food components are also amorphous, and their physical states at various conditions can be related to the T_g (Roos, 1995a). The amorphous foodstuffs are miscible in water and that the T_g is, therefore, lower at higher water contents (Roos and Karel, 1991a). The effect of water content on the T_g of foods has been reported in the literature. According to these studies, the water has a plastifying effect (Slade and Leviene, 1991; Roos and Karel, 1991b; Roos, 1995b). Understanding the relationship among water content, temperature and chemical reaction rates can be very useful for prediction of food stability. Both water activity and glass transition theory can be used to understand the influence of water on rates of chemical reactions. Water activity essentially considers the state of water in a food. Its relationship to chemical reaction rates is fairly complex and unique to the particular chemical reaction of interest (Nelson and Labuza, 1994).

T_g is mainly a function of water content, molecular weight (MW) and the nature of dry matter compounds in a given substance. The T_g of polymers increases noticeably with increasing MW up to a maximum value, beyond which there is no further change (Roos, 1995a).

The dependence of the glass transition temperature on the average molecular mass of the system has been previously mentioned. The addition of polymers could, therefore, increase the T_g of a product and, hence, increase its stability at a given temperature (T) above T_g. Optimization of storage stability becomes an exercise of determining the appropriate T_g and then, if possible, maintaining the product during storage at a lower temperature and obviously hermetically sealed to avoid water interchange with the atmosphere. Applying the glass transition theory allows for an understanding of textural properties of food systems and helps explaining textural changes which occur during processing and storage. Texture is an important sensory attribute, and the loss of the desired texture leads to a loss in product quality and reduction in shelf-life. Glass transition theory provides a clear approach to understanding the texture change in crisp snacks as water content increases. Water activity and glass transition temperature are important tools for prediction of available water in food and the physical state of solid foods (Roos, 1995a).

This research focused on the production of banana flake using a drum dryer. However, banana flake obtained from drum drying was known to result in poor quality product due to stickiness resulting from rapid absorption of moisture. The purpose of this study was to determine the effect of maltodextrin on glass transition temperature of banana flake and the suitable mathematical model for predicting glass transition temperature.

MATERIALS AND METHOD

Preparation of samples

The freshly harvested mature raw banana Musa (ABB group) was purchased from Amphur Bangkatum, Phitsanulok Province. The bananas after harvest were extremely unripe. Subsequent stages of ripening were selected from fruits stored at 30 ± 2°C. Ripe banana selection was based on the total soluble solids measured by refractometer about 23-25° Brix and reducing sugar of 13-15%. The banana was peeled and separated the pulp (use only outer portion) then blanched at 80-85°C for 10 minutes. The pulp was blended with maltodextrin DE 10 at the concentration of 0.9, 1.8, and 2.7% of solid content. Then the moisture content was adjusted to 75%. The samples were dried using drum dryer under fixed operating conditions at 150°C, drum clearance 1 mm and drum speed 5 rpm.

Proximate analysis

Banana flake samples obtained from 2.1 were analysed for moisture content, ash content, crude fiber content, crude fat content, protein content, and total carbohydrates following the standard procedures of determination AOAC (2000).

Determination of water sorption isotherms and glass transition temperature

The standard saturated salt solutions were prepared following the method described by Labuza (1984) using reagent grade (Merck): $KC_2H_3O_2$, $MgCl_2.6H_2O$, $Mg(NO_3)_2.6H_2O$, $NaNO_2$, and NaCl.

Water adsorption isotherms of the individual components were determined gravimetrically by exposing the samples of banana flake to atmospheres of known relative humidities at 35°C. Samples were weighed daily until the banana flake had reached equilibrium with the atmosphere. Then, three samples out of 6 samples were taken for determined moisture content and the other three samples were used to determine glass transition temperature.

Glass transition temperature was determined by differential scanning calorimetry (DSC7 Perkin Elmer, Norwalk, Conn., U.S.A.) and a system for temperature control using liquid nitrogen (Perkin Elmer Intra Cooler 2 control cooling accessory). The instrument was calibrated for temperature and heat flow with indium (T_g = 156.6°C and ΔH = 28.5 J/g, Perkin Elmer standard). A sample of approximately 8 to 12 mg was transferred into an aluminium pan, and sealed. An empty similar aluminium pans was used as a reference. Aluminium pans were cooled to – 60°C. The scanning was done by heating at 5°C/min from – 60°C to 100°C. The glass transition temperature appeared as an endothermic shift in the specific heat capacity and discontinuity in the baseline. The results were averaged in triplicate.

Mathematical models

Isotherm model

The equilibrium moisture data were fitted using the Guggenheim-Anderson-son-deBor (GAB) model (Eq. 1).

GAB equation: $$M = \frac{\left(M_0 C k a_w\right)}{\left(\left(1 - k a_w\right)\left(1 - k a_w + C k a_w\right)\right)} \quad (1)$$

where a_w is water activity; M is water content of sample on dry basis; M_0 is the monolayer water content; C is the Guggenheim constant; k is the constant correcting properties of multilayer molecules with respect to bulk liquid.

Glass transition model

The models for predicting glass transition temperature (Eq. 2 and Eq. 3) were used to fit experimental data and selected the model which showed good fit to the experimental data.

Linear equation: $T_g = T_{gs}+(T_{gw}-T_{gs})a_w$ (2)

Gordon and Taylor (1952) equation:

$$T_g = \frac{T_{gs} X_s + k T_{gw} X_w}{X_s + k X_w} \quad (3)$$

where T_g, T_{gs}, and T_{gw} are glass transition temperatures of the sample, solid matrix and water, respectively. X_s and X_w are the corresponding percent of solid and water contents and k is an empirical parameter. Glass transition temperature of pure water was taken as T_{gw} = -135°C

The goodness-of-fit for tested equations was determined using the mean relative percent error (%E) as shown in Eq. 4 (Palou *et al*., 1997):

$$\%E = \frac{100}{N} \sum \left| \frac{Y_{exp} - Y_{pre}}{Y_{exp}} \right| \quad (4)$$

where Y_{exp} and Y_{pre} are the experimental and predicted values respectively, and N is the number of observations.

Regression analysis was used to relate T_g with water content or water activity at 35°C of banana flake samples.

RESULTS AND DISCUSSION

Table 1 shows the parameter values and %E for the GAB model that gave the best fit of the isotherms in the a_w ranges from 0.216 to 0.749 at 35°C. The monolayer water content values of banana flake increased with increasing percent of maltodextrin. The monolayer moisture values were 4.03 to 6.01. The monolayer water content values of food vary by composition and process. In general for starchy food, the reported values may vary from 3.2 to 16.0 % (Katz and Labuza, 1981). The monolayer water contents for cookies were higher than those found for corn snacks and generally decreased as temperature increased (Palou *et al.*, 1997). Equilibrium water content increased slowly at low water activity and showed a steep rise at high water activity, which was a typical behavior for substances with high sugar content, including fruit products. About 93% of dry weight of banana flake was carbohydrate (Table 2).

Table 1 Mean moisture contents (g H_2O/100 g dry matter) and GAB parameters of banana flakes at different level of maltodextrin contents at 35°C.

Saturation salts	Water activity (a_w) 35°C	Water content (%) d.b. of banana flake 0 %	0.9 %	1.8 %	2.7 %
$KC_2H_3O_2$	0.216	1.99±0.04	2.44±0.08	2.43±0.07	2.61±0.10
$MgCl_2.6H_2O$	0.321	4.06±0.04	4.66±0.22	4.73±0.25	4.46±0.15
$Mg(NO_3)_2.6H_2O$	0.499	5.38±0.08	7.68±0.70	7.37±0.14	7.35±0.08
$NaNO_2$	0.628	9.88±0.83	10.67±0.11	10.12±0.15	10.58±1.10
NaCl	0.749	15.82±0.45	16.89±0.09	15.39± 0.16	15.50±0.47
GAB parameters at 35°C	M_0 (%)	4.03	5.25	5.27	6.01
	C	2.663	2.904	3.01	2.50
	K	1.030	0.967	0.932	0.901
Corr coef.(r)		0.990	0.996	0.995	0.999

Note: M_0 is the monolayer water content; C is the Guggenheim constant; K is the constant correcting properties of multilayer molecules with respect to bulk liquid.

Table 2 Chemical analysis (g component/100g) of banana flake with different level maltodextrin contents.

Component	Maltodextrin concentration (% w/w) 0%	0.9 %	1.8 %	2.7 %
Moisture content	$1.34±0.78^a$	$0.88±0.16^b$	$0.88±0.55^b$	$0.85±0.14^b$
Ash	$2.37±0.03^a$	$2.26±0.01^b$	$2.11±0.03^c$	$2.12±0.02^c$
Fiber	$1.74±0.64^a$	$1.16±0.17^c$	$1.22±0.13^b$	$1.16±0.03^c$
Fat	$0.15±0.07^a$	$0.14±0.02^{ab}$	$0.13±0.05^{bc}$	$0.12±0.09^c$
Protein	$2.70±0.03^a$	$2.29±0.06^b$	$2.10±0.09^d$	$2.20±0.04^c$
Total carbohydrate[A]	$91.70±0.69^c$	$93.16±0.27^b$	$93.56±0.16^a$	$93.55±0.18^a$
Water activity	$0.183±0.09^a$	$0.171±0.03^b$	$0.165±0.07^c$	$0.128±0.09^d$

[A] Calculated by difference of moisture content, ash, fiber, fat and protien

[a] Means within the same row with different letters are significantly different (p(0.05) by Duncan's New Multiple-Rang Test (DMRT).

The classic thermodynamic theory of glass transition temperature of mixture allows a calculation of the glass transition temperature to be made from the properties of pure components. The theory models the glass transition temperature as a second-order phase transition. The position of the transition is determined by the equality of the entropy in the liquid and glassy states. By assuming that the entropy of mixing is continuous at T_g, an expression for the glass transition temperature of mixture can be derived in terms of T_g values of the pure components and their heat capacity, ΔCp. The glass transition temperatures of the two components are far apart from the glass transition temperature of the mixture predicted by the Gordon and Taylor equation. The application of this model requires the knowledge of the T_g of water as well as the value of T_g of the solid product. The T_g values of water, as reported in the literature, vary between –125°C and –150°C (Roos, 1995 b). In this study, the value of -135 °C was taken as $Tg_{w.}$

Different parameters characteristic of glass transition, such as Tg_{onset}, $Tg_{midpoint}$, Tg_{end} and ΔCp for banana flake at varying water activity are shown in Table 3. The data obtained in the high moisture content domain were found to be fundamentally important, since they followed the Gordon-Taylor model relationship of binary systems. The plasticizing effect of water on glass transition temperature was evident, with great reduction of T_g caused by increasing water content. This observation showed that the T_g was very sensitive to relative humidity of the storage environment.

Table 3 Characteristics parameter of glass transition temperature T_g (onset), T_g (midpoint), and T_g (end) in °C for banana flakes at varying water activity.

Product	Water activity (a_w)	Glass transition temperature		
		T_g (onset)	T_g (midpoint)	T_g (end)
Banana without maltodextrin	0.216	26.53±2.07	32.17±2.14	37.80±2.20
	0.321	7.27±1.11	15.76±0.08	24.25±0.94
	0.499	-2.58±0.48	0.23±0.48	3.04±0.31
	0.628	-18.92±0.25	-14.50±0.61	-10.08±0.97
	0.749	-49.16±1.54	-44.76±1.24	-40.36±0.95
Banana with 0.9% maltodextrin	0.216	31.22±0.38	36.65±0.44	42.08±0.51
	0.321	10.92±1.23	16.41±0.64	21.90±0.05
	0.499	-1.14±0.40	0.68±0.40	3.67±0.49
	0.628	-19.50±1.90	-14.75±1.65	-10.00±1.81
	0.749	-41.20±0.41	-36.16±0.26	-31.13±0.18
Banana with 1.8% maltodextrin	0.216	32.84±0.18	39.23±0.05	45.62±0.28
	0.321	14.53±0.52	20.65±0.96	26.77±1.39
	0.499	1.75±1.36	2.92±1.36	6.91±0.04
	0.628	-14.50±1.30	-8.99±1.20	-3.47±1.09
	0.749	-40.27±0.32	-35.74±0.45	-31.22±0.41
Banana with 2.7% maltodextrin	0.216	35.64±0.07	40.43±0.22	45.22±0.37
	0.321	13.05±0.97	19.79±1.82	24.70±0.85
	0.499	11.61±0.02	18.13±0.01	24.65±0.42
	0.628	-3.62±0.41	0.36±0.21	4.33±0.84
	0.749	-43.65±0.20	-38.58±0.61	-33.52±0.99

The comparison of T_g values of banana flake Eq. 2 and Eq. 3 are presented in Table 4. This range of a_w (0.216-0.749) Eq. 3 could be adequately adjusted to experimental points, with the following parameters calculated by non linear regression: k = 5.35, 4.77, 5.27, and 4.95, respectively. The T_{gs} were 48.70, 54.65, 61.95, and 62.61°C, respectively, and the correlation coefficient were 0.983, 0.993, 0.997, and 0.936, respectively.

The monolayer and T_{gs} of banana flake increased with increasing maltodextrin content added in banana puree. The glass transition temperature depended primarily on moisture content. T_g of banana increased with increasing maltodextrin content. The maltodextrin DE 10 had high molecular weight of 1800 g/g mol and T_g of dry matter was about 160°C. Materials with high monosaccharides, such as fruit juices, exhibited low T_g values and were sticky. Since T_g increased with increasing molecular weight, maltodextrins were used to improve dehydration characteristics, to decrease stickiness, and to improve product stability (Roos and Karel, 1991c).

Figure 1 shows the relationship between water content, T_g and water activity for different banana flakes. Effect of water activity on T_g and water content could be described by mathematical models and represented graphically. Figure 1 suggests use of the GAB equation and the linear equation for the description of water as a plasticizer. The model could be fitted to experimental data and used to show the T_g and water content in single plot. The information in Figure 1 is useful in locating critical values for a_w and water content (Jouppila and Roos, 1994 and Roos, 1995a). Figure 1 shows that water content and corresponding water activity, which decrease T_g to below storage temperature, can be considered as a critical value for stability. According to Roos (1995c) such information showed the combined effects of water activity and temperature on physical state and provided an important tool for the prediction of behavior in processing, handling and storage.

The water content and corresponding water activity decreased T_{gs} to below an ambient temperature and could be considered as a critical value for stability. The shape of isotherms is sigmoid (type II isotherm) and presents a comparison between the isotherm of banana flake. At a_w up to 0.4, the curve of banana flake exhibited a linear relationship. At the moisture sorption a_w > 0.6, the increasing sigmoidal curve might be attributed to adsorption of water by dissolving sucrose and other sugars (Chinachoti and Steinberg, 1986). In the dried fruit, low-molecular-weight sugars occur in the amorphous state (bound

Table 4 Linear and Gordon and Taylor equations, parameter and correlation coefficient (r) of banana flake with different maltodextrin contents.

Parameter	Model	Maltodextrin concentration (% w/w)			
		0 %	0.9 %	1.8 %	2.7 %
T_{gs}	Linear equation	106.25	108.01	115.75	122.78
	Gordon-Taylor equation	48.70	54.65	61.95	62.61
k	Linear equation	-	-	-	-
	Gordon-Taylor equation	5.35	4.77	5.27	4.95
Corr coef. (r)	Linear equation	0.961	0.965	0.975	0.856
	Gordon-Taylor equation	0.983	0.993	0.997	0.936

Note: T_{gs} is glass transition temperatures of solid matrix.
k is estimated using non-linear regression analysis while considering that the glass transition temperature of pure water was taken as T_{gw} = -135°C.

to other macromolecules), that causes much higher hygroscopicity than crystalline form of sucrose (Mazza, 1984). The fact is that some products such as snack foods are more sensitive toward moisture changes and they may be more hygroscopic than the others. The high hygroscopicity of banana flake, may be explained on the basis of large content of carbohydrates about 91-94%.

CONCLUSION

The obtained experimental adsorption data showed that the adsorption isotherm follow the characteristic shape of high sugar foods. It was found that monolayer water (m_0) increased with increasing in maltodextrin. The GAB model gave the best fit for sorption isotherms at 35°C of banana flake with the different concentrations of maltodextrin. The mean percent error of model prediction was less than 9.1%. The monolayer moisture content calculated with the GAB equations were 4.03, 5.25, 5.27, and 6.01% (dry basis), respectively. Glass transition temperature was measured for banana flake as a function of

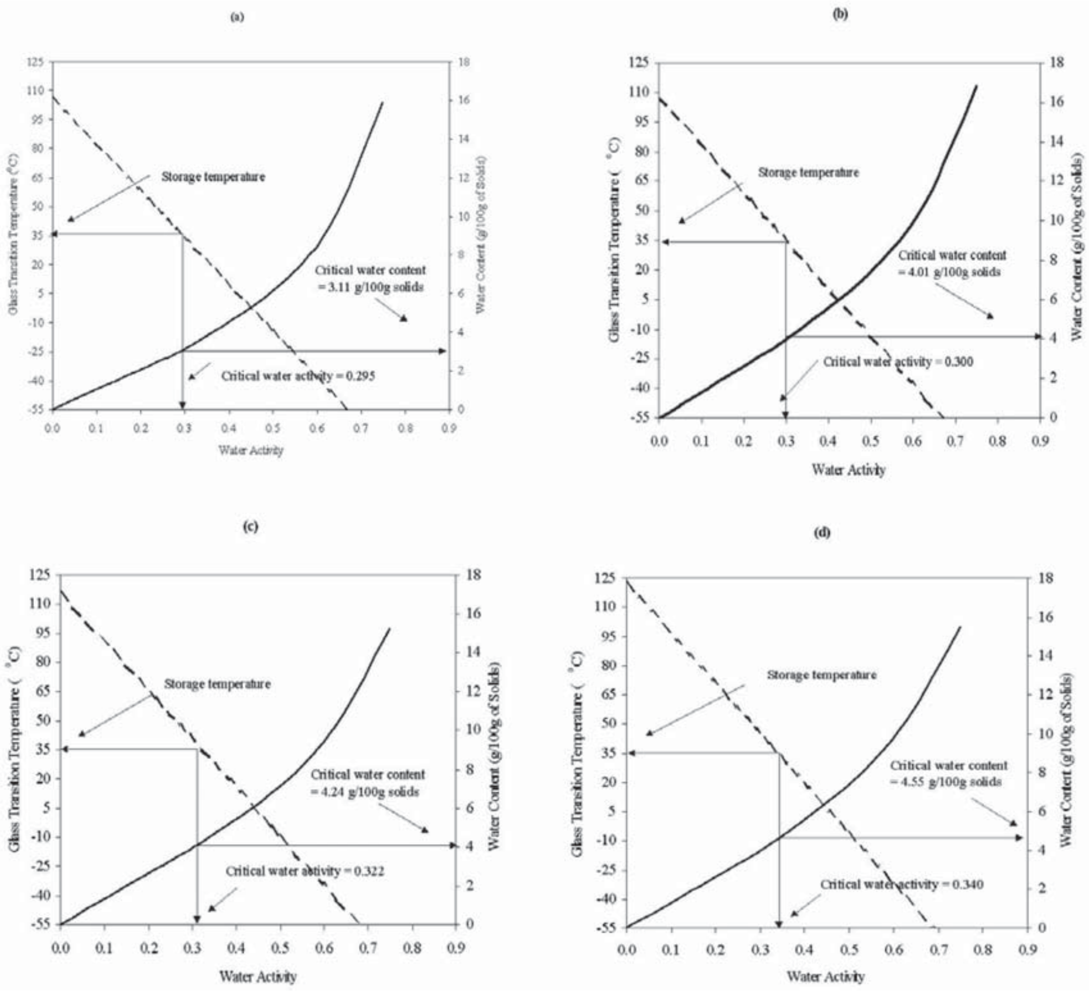

Figure 1 Adsorption isotherms at 35°C (solids line) calculated by GAB equation (Eq.1) and glass transition temperature as function of water activity calculated by the Linear equation (Eq.2) of banana flakes with different maltodextrin content (a) 0 %, (b) 0.9 % (c) 1.8 % and (d) 2.7 % (dashed line).

water activity. The Gordon and Taylor model showed a good fit with experimental data. The T_g values of banana flake decreased with increasing water activity. An increase in the percentage of maltodextrin added resulted in increasing T_g value of banana flake.

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