

## RESULTS AND DISCUSSION

### 1. Determination of the Moisture Sorption Isotherm of Banana Powder.

#### 1.1 Chemical analysis

Banana powder was prepared by freeze drying and the chemical composition is showed in Table 1. It consisted of 91.39 % carbohydrate, 1.58 % ash, 1.78 % fiber, 0.26 % fat, 2.68 % protein, 2.3 1% moisture content and 17.95 % reducing sugar. It had report percent of moisture and carbohydrate contents closely with banana flake powder from drum dryer which 2.6% and 92% respectively (Anonymous, 1999). Silayoi, (2002) reported that riped banana (Kui Namwa) contained 17-22 % sugar.

Table 1 Chemical composition of banana powder (g component/100g).

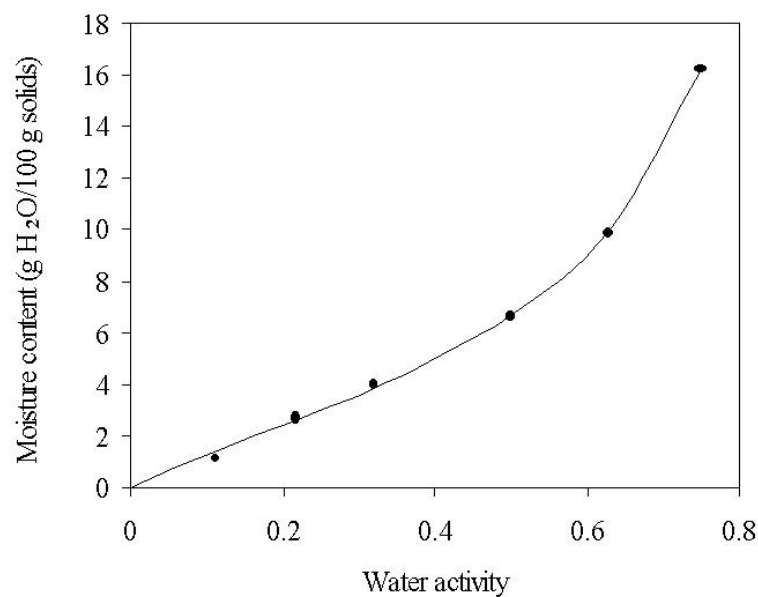
Component	(g component/100g)
Moisture content	2.31±0.11
Ash	1.58±0.03
Fiber	1.78±0.64
Fat	0.26±0.07
Protein	2.68±0.09
Total carbohydrates <sup>a</sup>	91.39±0.15
Reducing sugars	17.95±1.2

<sup>a</sup> Calculated by difference of moisture content, ash, fiber, fat and protein

#### 1.2 Sorption isotherm of banana powder

The sorption data for banana powder determined at 35°C is shown in Table 2. The GAB equation was fitted to experimental data using non-linear regression analysis. The sorption isotherm of banana powder was found to be sigmoid shape (type II isotherm) like dried banana (Chauca *et al.*, 2004) and other fruits such as

strawberry (Moraga *et al.*, 2004; Roos, 1993a), apple (Martinez- Monzo, 1998) and blackberry (Maskan and Gogus, 1998). The adsorption isotherms obtained through experimental adsorption data and calculated using GAB equation was shown in Figure 13. It was found that equilibrium moisture content increased with increasing water activity.



**Figure 13** Adsorption isotherm of banana powder at 35°C. The solid line is fit of GAB equation (Eq. 3).

GAB parameters ( $M_0$ ,  $C$  and  $K$ ) for banana powder were calculated by non-linear regression (Table 2). The correlation coefficients were 0.999. The monolayer moisture content ( $M_0$ ) estimates amount of bound water to specific polar sites in dehydrated food systems (Rahman and Labuza, 1999), and at monolayer moisture a product should be stable against microbial deterioration. The monolayer of banana powder was found to be 4.24% (d.b.) by GAB equation which were range in water activity value about 0.321 –0.499. The monolayer moisture values of foods vary with

the composition and type of process. In general the monolayer moisture for starchy products vary from 3.2 to 16.0% (Katz and Labuza, 1981).

**Table 2** Experimental, calculated moisture contents and GAB parameters of banana powders at 35 °C.

Saturated salts	Water activity ( $a_w$ ) (35°C)	Moisture Content (g H <sub>2</sub> O/g Solids)		
		Experimental	Calculated	
LiCl.H <sub>2</sub> O	0.113	1.12±0.45	1.44	
KC <sub>2</sub> H <sub>3</sub> O <sub>2</sub>	0.216	2.78±0.22	2.62	
MgCl <sub>2</sub> .6H <sub>2</sub> O	0.321	3.99±0.32	3.87	
Mg(NO <sub>3</sub> ) <sub>2</sub> .6H <sub>2</sub> O	0.499	6.65± 0.50	6.64	
NaNO <sub>2</sub>	0.628	9.93± 0.63	9.98	
NaCl	0.749	16.20± 0.75	16.15	
GAB parameter	$M_0$	$C$	$K$	Correlation coefficient ( $r$ )
At 35 °C	4.24	3.31	1.015	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.

The monolayer value of banana powder (4.24%) was found to be reasonable guide with respect to various aspects of interest in dried banana, often considered as the optimal water content for stability.

## **2. Glass Transition Temperature ( $T_g$ ) of Banana Powder**

Different characteristic parameters of glass transition, such as  $T_g$  (onset),  $T_g$  (midpoint), and  $T_g$  (end) for banana powder are given in Table 3. The glass transition temperature of banana powder was found to depend primarily on water activity and water content.

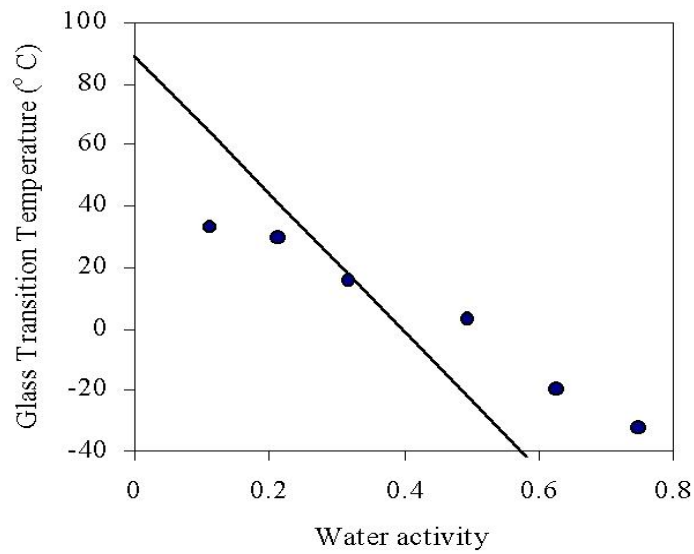
The plasticizing effect of water on glass transition temperature was evident, with great reduction of  $T_g$  caused by increasing water activity and water content. Glass transition temperature  $T_g$  (midpoint) of banana powder was measured as a function of water activity and water content at 35°C using Linear (Eq. 5) and Gordon and Taylor (Eq.6). Results showed that Linear equation and Gordon and Taylor equation adequately fitted the obtained experimental data (Figure 14 and 15). Linear equation was able to predict  $T_g$  of banana powder as function of water activity, whereas Gordon and Taylor equation predicted dependence of  $T_g$  on water content. Both Linear and Gordon and Taylor equation showed a good fit to experimental data with correlation coefficient ( $r$ ) about 0.97 (Table 3).

**Table 3** Glass transition temperature  $T_g$  (onset),  $T_g$  (midpoint), and  $T_g$  (endpoint) of banana powder at varying water activity and Gordon and Taylor Equations parameters.

Saturated salts water activity	Moisture content (g H <sub>2</sub> O/ 100 g solids)	Glass Transition temperature( °C)		
		$T_g$ (onset)	$T_g$ (midpoint)	$T_g$ (end)
0.113	1.12	28.56±0.06	33.28±1.51	37.99±2.38
0.216	2.78	26.78±2.93	29.78±1.13	31.25±1.13
0.321	3.39	7.27±1.56	15.76±0.12	24.25±1.32
0.499	6.65	1.19±0.028	2.92±0.95	4.65±1.61
0.628	9.93	-25.88±0.79	-20.09±0.95	-14.30±1.11
0.749	16.20	-35.31±0.29	-32.21±0.12	-20.27±1.12
Parameter		$T_{gs}$	$k$	Correlation coefficient ( $r$ )
Linear Equation		88.97	-	0.977
Gordon and Taylor Equation.		43.61	4.23	0.970

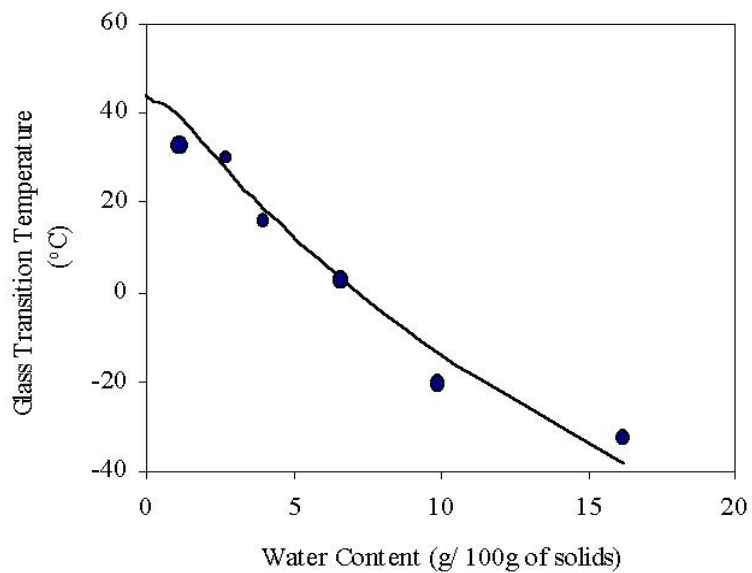
Note:  $T_{gs}$  is glass transition temperatures of solid matrix.

$k$  is estimated using non-linear regression analysis while considering that the glass transition temperature of pure water was taken as  $T_{gw} = -135^\circ\text{C}$ .



**Figure 14** Glass transition of banana powder as function of water activity at 35°C.

(●: experimental data; solid line: Linear equation Eq. 5).



**Figure 15** Glass transition of banana powder as function of water content at 35°C.

(●: experimental data; solid line: Gordon and Taylor equation Eq. 6).

In the range of  $a_w$  (0.113-0.749) Gordon and Taylor equation could be adequately predicted  $T_{gs}$  value of banana powder using the following parameters calculated by non-linear regression:  $k= 4.23$ ,  $T_{gs} = 43.61$  °C and  $r = 0.970$ . The  $k$  value obtained from banana powder was similar to those reported for other fruits such as strawberry, blueberry, blackberry (Khalloufi *et al.*, 2000; Moraga *et al.*, 2004) and kiwifruit (Moraga *et al.*, 2006).

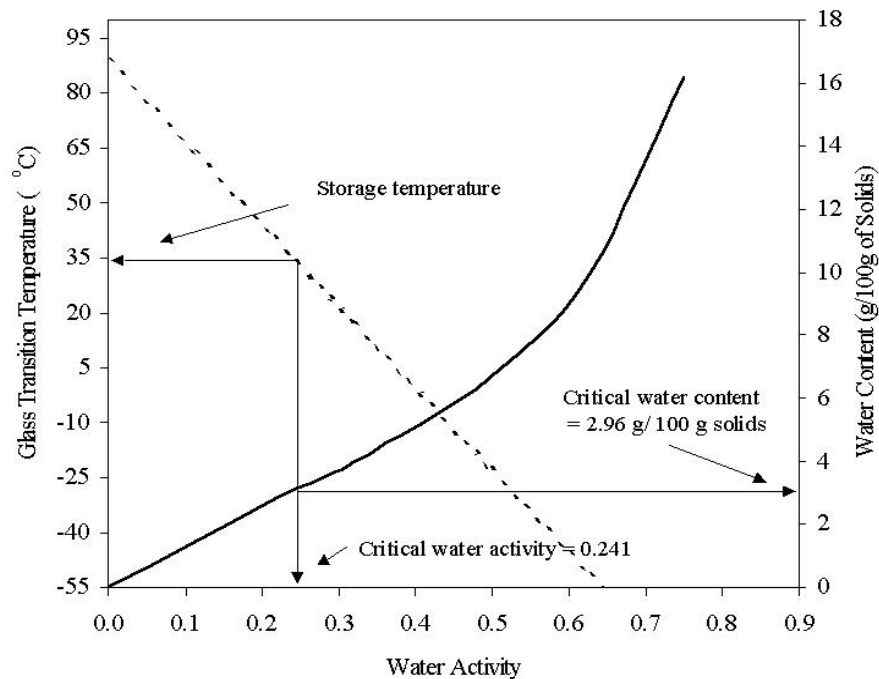
### **3. Correlation of Glass Transition Temperature and Water Activity/ Water content of Banana Powder, Applying the Appropriate Mathematical Models.**

The combination of sorption model and Linear model for description of water plasticization. The models fitted experimental data and showed the  $T_g$  and water sorption in a single plot (Figure 16). This plot is useful in locating critical values for  $a_w$  and water content, defined as those decreasing  $T_g$  to ambient temperature. The relationship between  $T_g$  and  $a_w$  at constant temperature provides a simple method for prediction of the effects of relative humidity (RH) during storage on the  $T_g$ . Such prediction is useful in evaluating the stability of various low moisture foods, such as food powders, low moisture cereals and snack foods.

An attempt has been made to combine data of sorption isotherms and glass transition of banana powder that indicates a gap in the way the well-established criteria for product stability is used. Both water activity and glass transition have been used extensively in the literature to evaluate the stability of a food product. The former argues that a product is the most stable at its monolayer moisture content, i.e. a water activity value of about 0.1-0.3 (Rockland and Nishi, 1980). At this monolayer moisture content (4.24%) the water activity of banana powder in the range of 0.321 – 0.499 and the calculated  $T_g$  was 13.94°C.

The  $T_g$  of banana powder (13.94°C) is lower than the ambient temperature (30°C). Therefore the banana powder will be unstable if it is storage at this temperature. Deterioration such as stickiness, and non-enzymatic browning occurred due to glass transition and water activity. Roos (1993a) pointed out that the stickiness, crispness, collapse, amorphous to crystalline transformations and the rates of non-

enzymatic browning which are not related to a monolayer value. The overriding mechanism of these deteriorative processes is the molecular mobility that relates directly to  $T_g$ . So far, the link between  $a_w$  and  $T_g$  as a function of temperature has been documented, in addition to earlier work on molecular weight. The latter suggests that formulations product were at or below the corresponding glass transition temperature. In doing so, we should also derive a relationship between product characteristics (e.g. chemical composition) and critical value of water activity at the corresponding glass transition temperature. The calculated critical water activity of banana powder at storage temperature of 35 °C was 0.241 by Linear equation using  $T_{gw}$  (-135°C) and  $T_{gs}$  (88.97°C) in Table 3. The critical water content obtained by GAB equation using parameters ( $M_0$ ,  $C$  and  $K$  in Table 2) for banana powder calculated at water activity of 0.241 was 2.96 g/ 100g solids.



**Figure 16** Water content isotherms and glass transition temperature of banana powder as a function of water activity. The water content (solid line) was calculated with GAB equation (Eq.3). The  $T_g$  values (dashed line) were calculated using the Linear equation (Eq.5).

The outcome of sorption isotherm, glass transition, critical water activity and critical water content of banana powder were used to formulate banana flake which has  $T_g$  higher than the storage temperature by adding high molecular weight ingredients (such as maltodextrin) to banana paste before drying.

#### **4. Development of Banana Flake Product Using Maltodextrin.**

Banana flake were developed varying 4 concentrations of maltodextrin 0, 0.9, 1.8 and 2.7% respectively. The obtained results are given below:

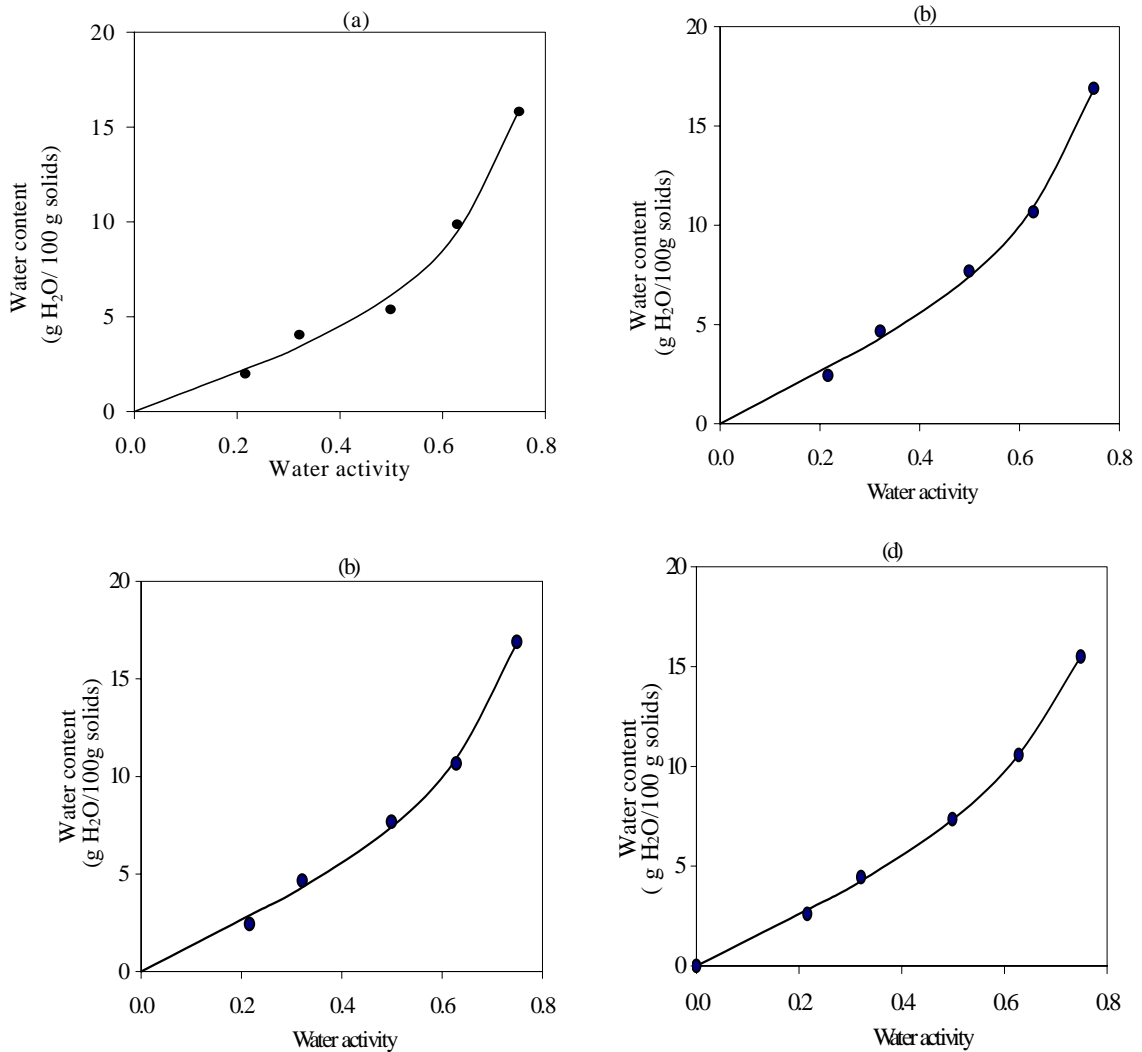
##### 4.1 Sorption isotherm of banana flake

The experimental data of water sorption isotherm of banana flake could successfully fit with GAB isotherm equation are shown in Table 4. The GAB model gave the best fit of the isotherms in the  $a_w$  range of 0.216 to 0.749 at 35°C. Banana flakes with 0, 0.9, 1.8 and 2.7 % maltodextrin had the typical sigmoid curves(Figure 17). The monolayer water content values of banana flake were increased with increasing maltodextrin content. The range of water activity in equilibrium with the monolayer values were 0.321-0.499 (Table 4) which were similar to banana powder. The monolayer water content values of foods vary with the composition and processing of banana flakes as discussed above. The monolayer water content values of banana flake with 2.7% maltodextrin was higher than those with 0.9 and 1.8 %maltodextrin since the banana flakes with increasing maltodextrin increased the water holding capacity. The water holding capacity is a term frequently employed to describe the ability of matrix of molecules, usually macromolecules present at low concentrations, to physically entrap large amounts of water in a manner that inhibits exudation (Fennema, 1996).

**Table 4** Mean moisture contents (g H<sub>2</sub>O/100 g dry matter) and GAB parameters of banana flakes at different level of maltodextrin contents at 35°C.

Saturation salts	Water activity (a <sub>w</sub> ) 35°C	Water content (%) d.b. of banana flake			
		0 %	0.9 %	1.8 %	2.7 %
KC <sub>2</sub> H <sub>3</sub> O <sub>2</sub>	0.216	1.99±0.04	2.44±0.08	2.43±0.07	2.61± 0.10
MgCl <sub>2</sub> .6H <sub>2</sub> O	0.321	4.06±0.04	4.66±0.22	4.73±0.25	4.46± 0.15
Mg(NO <sub>3</sub> ) <sub>2</sub> .6H <sub>2</sub> O	0.499	5.38±0.08	7.68±0.70	7.37±0.14	7.35± 0.08
NaNO <sub>2</sub>	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	<i>M</i> <sub>0</sub> (%)	4.03	5.25	5.27	6.01
	<i>C</i>	2.663	2.904	3.01	2.50
	<i>K</i>	1.030	0.967	0.932	0.901
	Corr coef.( <i>r</i> )	0.990	0.996	0.995	0.999

Note: *M*<sub>0</sub> is the monolayer water content; *C* is the Guggenheim constant; *K* is the constant correcting properties of multilayer molecules with respect to bulk liquid.



**Figure 17** Adsorption isotherm of banana flake with different maltodextrin content (a) 0 %, (b) 0.9 % (c) 1.8 % and (d) 2.7 % at 35°C.

Normally the type of sorption isotherm depends on chemical composition and processing. Chemical analysis of banana flakes are shown in Table 5. Total carbohydrates of banana flake were increased with increasing maltodextrin. Maltodextrin are used as source of carbohydrate. Water activity and moisture content were decreased with increasing maltodextrin. Because bound water of banana flake were increased with increasing maltodextrin which free water of banana flake with maltodextrin was binding. The reducing sugar ash, fiber, fat and protein contents of banana flakes were also significantly decreased with increasing maltodextrin content.

**Table 5** Chemical analysis (g component/100g) of banana flake with different level maltodextrin contents.

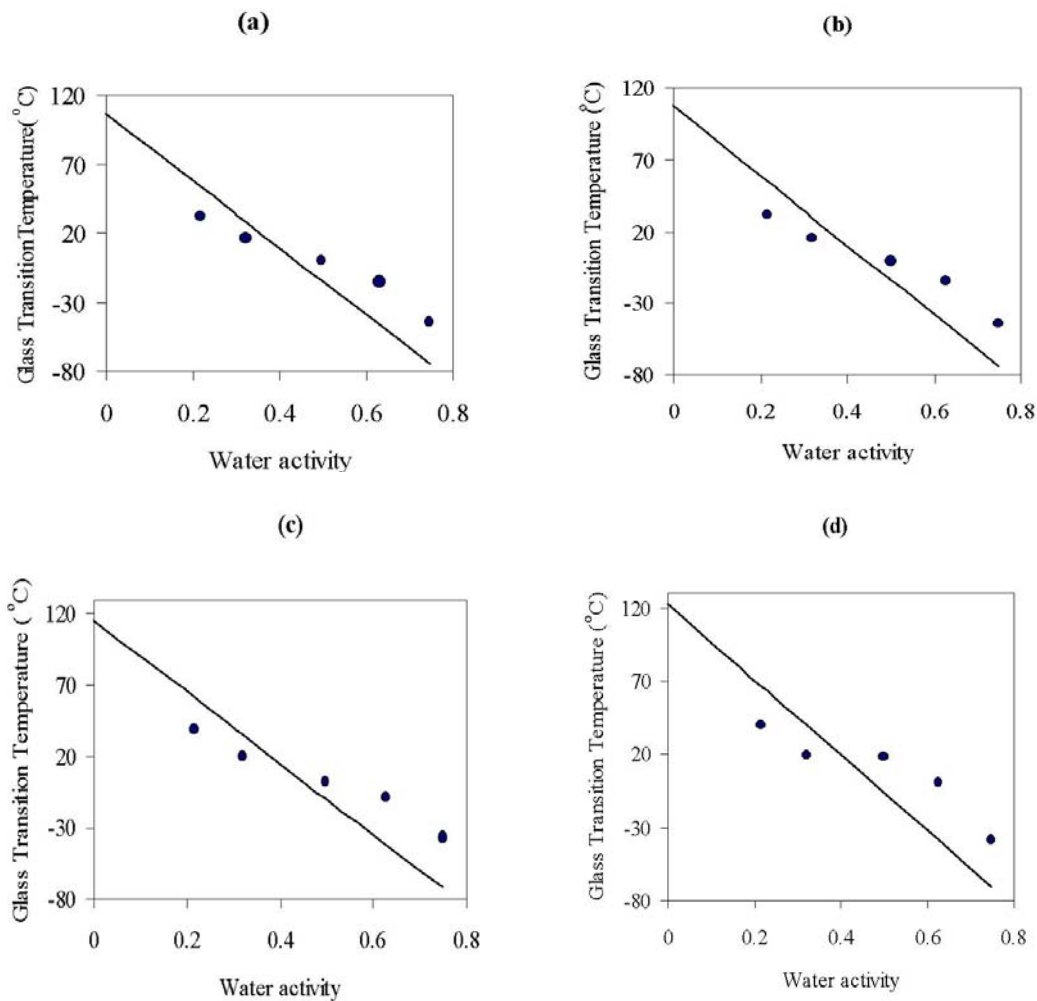
Component	Maltodextrin concentration ( % w/w)			
	0%	0.9 %	1.8 %	2.7 %
Moisture content	1.34±0.78 <sup>a</sup>	0.88±0.16 <sup>b</sup>	0.88±0.55 <sup>b</sup>	0.85±0.14 <sup>b</sup>
Ash	2.37±0.03 <sup>a</sup>	2.26±0.01 <sup>b</sup>	2.11±0.03 <sup>c</sup>	2.12±0.02 <sup>c</sup>
Fiber	1.74±0.64 <sup>a</sup>	1.16±0.17 <sup>c</sup>	1.22±0.13 <sup>b</sup>	1.16±0.03 <sup>c</sup>
Fat	0.15±0.07 <sup>a</sup>	0.14±0.02 <sup>ab</sup>	0.13±0.05 <sup>bc</sup>	0.12±0.09 <sup>c</sup>
Protein	2.70±0.03 <sup>a</sup>	2.29±0.06 <sup>b</sup>	2.10±0.09 <sup>d</sup>	2.20±0.04 <sup>c</sup>
Total carbohydrate <sup>A</sup>	91.70±0.69 <sup>c</sup>	93.16±0.27 <sup>b</sup>	93.56±0.16 <sup>a</sup>	93.55±0.18 <sup>a</sup>
Reducing sugar	17.95±0.12 <sup>a</sup>	16.59±0.75 <sup>b</sup>	16.44±0.59 <sup>c</sup>	15.81±0.92 <sup>d</sup>
Water activity	0.183±0.09 <sup>a</sup>	0.171±0.03 <sup>b</sup>	0.165±0.07 <sup>c</sup>	0.128±0.09 <sup>d</sup>

<sup>A</sup> Calculated by difference of moisture content, ash, fiber, fat and protien

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

#### 4.2 Glass transition of banana flake

The relationship between glass transition temperature (T<sub>g</sub> midpoint) and water activity of banana flakes are shown in Figure 18. Both water activity and glass transition temperature are importance tools for prediction of available water in foods and physical state of solid foods. Glass transition temperature of banana flakes decreased linearly with increasing water activity. Similarity, the effect was found in date pastes, horseradish and strawberries as reported by Ahmed et al., (2005); Paakkonen and Roos, (1990); and Roos, (1987), respectively. Water plasticization effect of T<sub>g</sub>, obtained for the different samples as a function of water activity, was observed.

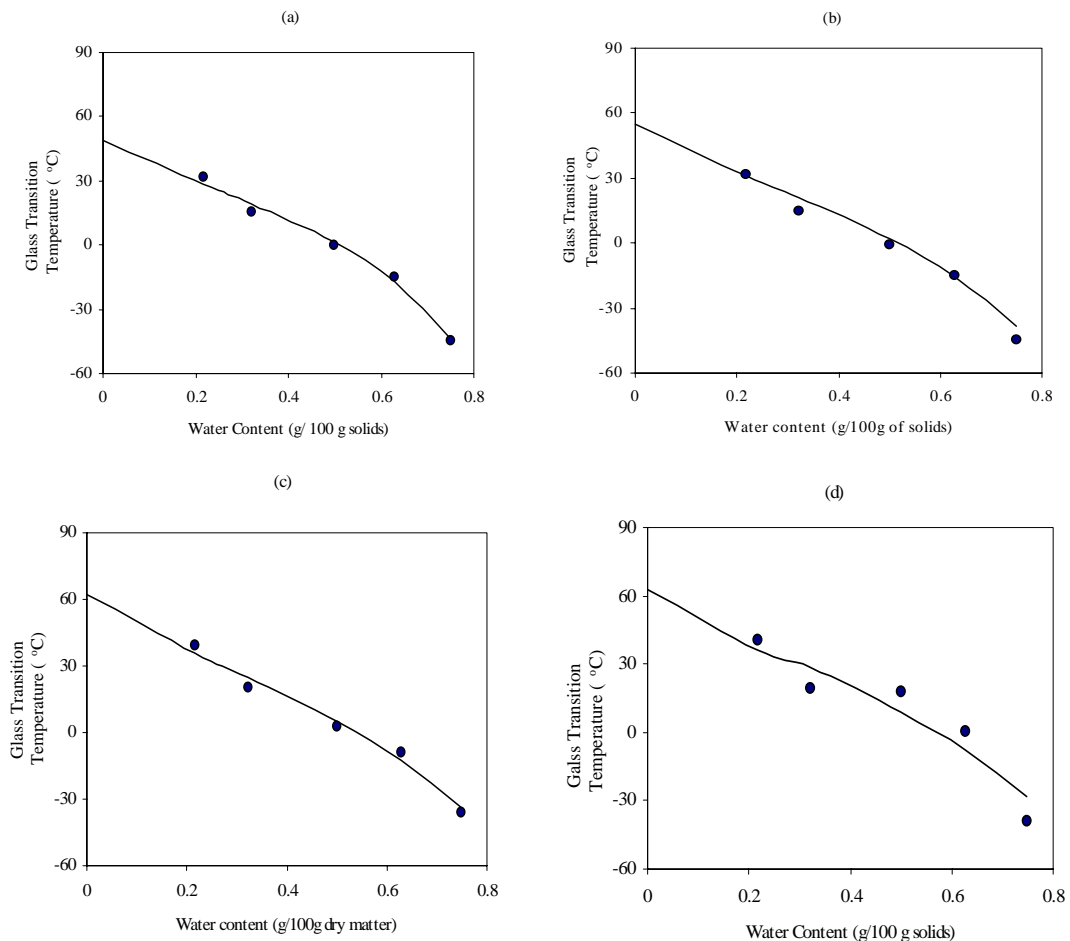


**Figure 18** Glass transition temperature of banana flake with different maltodextrin contents (a) 0 %, (b) 0.9 % (c) 1.8 % and (d) 2.7 % as function of water activity at 35°C (●: experimental data; solid line: Linear equation).

Figure 19 shows the relationship between water content and glass transition temperature of banana flakes with different maltodextrin contents. The  $T_g$  of banana flake with different maltodextrin contents were decreased with increasing water content. The Gordon and Taylor equation fitted the experimental data very well (Table 6). Similarly, food materials can be considered as binary mixtures of solids and water, which allows us to predict water plasticization using the Gordon and Taylor equation, i.e. apple slice (Bai *et al.*, 2001); strawberry (Telis and Sobral.,

2001); tuna (Rahman *et al.*, 2000); tomato (Moraga *et al.*, 2004); freeze-dried camu-camu (Silva *et al.*, 2005). The effect of water content on the  $T_g$  of foods has been reported in the literature. According to the studies, the water has a plastiizer effect (Roos, 1995a; Roos and Karel, 1991b; Slade and Leviene, 1991).

The plasticizing effect of water on glass transition temperature was evident, with great reduction of  $T_g$  caused by increasing water content. The amorphous foodstuffs are miscible in water and the  $T_g$  is therefore lower at higher water contents (Roos and Karel, 1991b).



**Figure 19** Glass transition temperature of banana flake with different maltodextrin contents as function of water content (a) 0 %, (b) 0.9 % (c) 1.8 % and (d) 2.7 % at 35°C (●: experimental data; solid line: Gordon and Taylor equation).

Banana flake with different maltodextrin were amorphous polymer. Plasticizers in amorphous polymers decrease their glass transition temperatures. At the glass transition temperature free volume and mobility of molecules is increased which leads to decreased viscosity, and therefore a changed physical structure of amorphous substances. In amorphous food materials when plasticized by water the changes of the physical structure for example collapse structure, stickiness and probably to increased rates of deteriorative reaction in the plasticized rubbery state (Roos and Karel, 1991).

The comparison  $T_{gs}$ ,  $k$  and correlation coefficient ( $r$ ) for fitting  $T_g$  (midpoint) values of banana flake using Linear and Gordon and Taylor equations were presented in Table 6. In the range of  $a_w$  (0.216-0.749) Linear equation could be adequately predicted  $T_{gs}$  value of banana flake. The  $T_{gs}$  of banana flake with maltodextrin 0, 0.9, 1.8 and 2.7 % are 106.25, 108.01, 115.75 and 122.78 °C respectively, and the correlation coefficient are 0.961, 0.965, 0.975, and 0.856, respectively. On the other hand, the calculated  $k$  values and  $T_{gs}$  from the Gordon and Taylor equation were:  $k = 5.35, 4.77, 5.27, 4.95$ , and  $T_{gs} = 48.70, 54.65, 61.95$ , and  $62.61^\circ\text{C}$ , respectively. The correlation coefficient are 0.983, 0.993, 0.997, and 0.936, respectively. The Gordon and Taylor equation can be fitted to experimental data better than Linear equation because of the direct relating of the molecular mobility of water content to  $T_g$  (Sablani *et al.*, 2004).

The monolayer and  $T_g$  of banana flake were increased with increasing maltodextrin content. This was due to high molecular weight of maltodextrins (Roos and Karel, 1991). The glass transition temperature depended primarily on molecular weight therefore maltodextrins was used to improve dehydration characteristics, to decrease stickiness, and to improve product stability (Levine and Slade, 1986; Roos and Karel, 1991c, d). It had been reported reported that  $T_g$  of polymers increased noticeably with increasing in molecular weight (Roos, 1995b, Ferry, 1980, Roos and Karel, 1991b, Silva *et al.*, 2005).

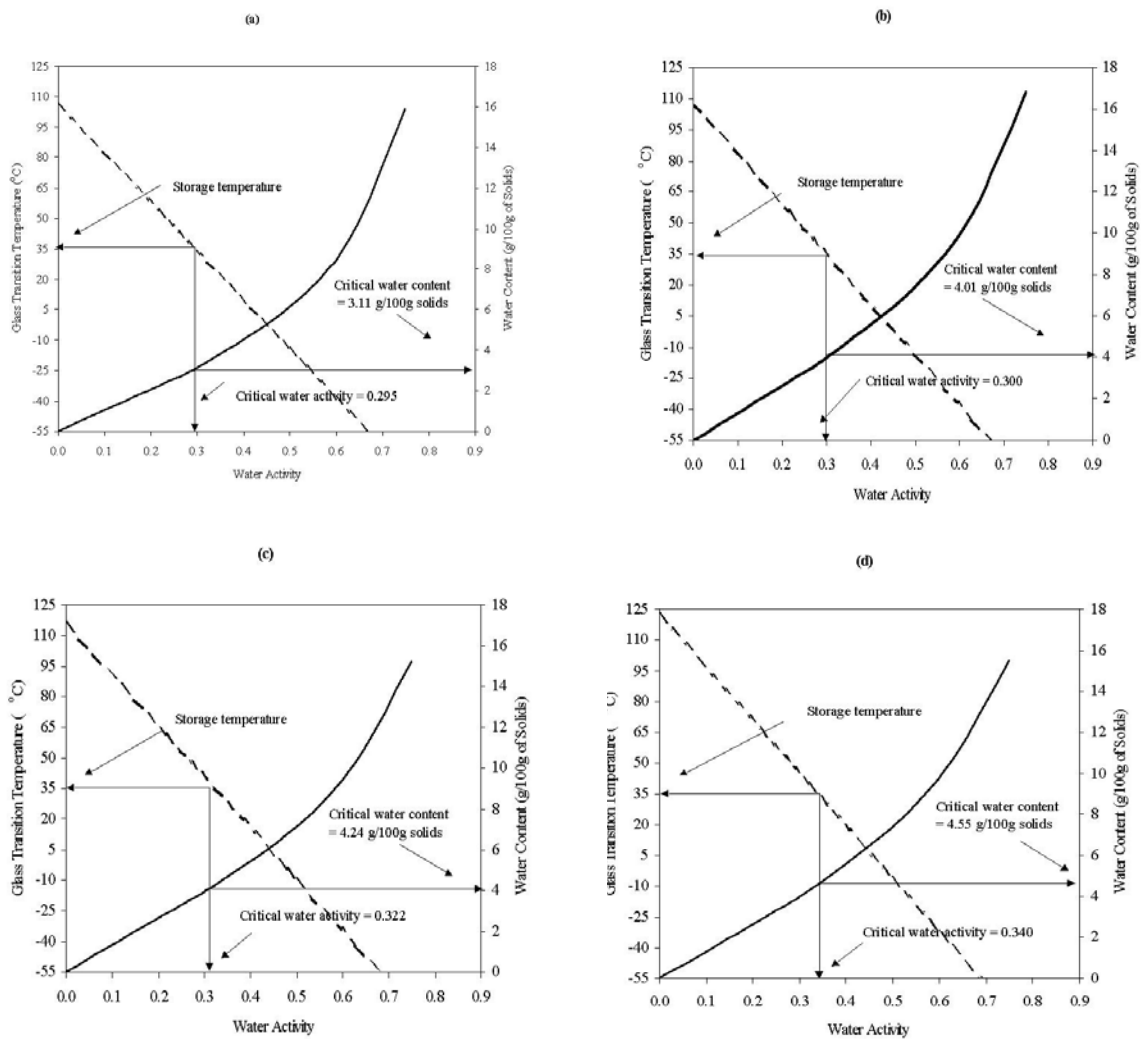
**Table 6** Linear and Gordon and Taylor equations, parameter and correlation coefficient (r) of banana flake with different maltodextrin contents.

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  $T_{gw} = -135^{\circ}\text{C}$ .

Effect of water activity on glass transition temperature and water content can be described by mathematical models and represented graphically. The water content and corresponding water activity caused a decrease in  $T_g$  to below the ambient temperature and can be considered as a critical value for stability. Figure 20 suggested the use of GAB equation and the Linear equation for the description of water as a plasticizer. The information in Figure 20 is useful in locating critical values for  $a_w$  and water content of the product at which the glass transition occurred at a given storage temperature. As shown in Figure 20 the critical water content and corresponding water activity, was obtained when  $T_g$  decreases  $T_g$  to an ambient temperature. According to Roos, (1995a) such information shows the combined effects of water activity and temperature on physical state and provides an important tool for the prediction of behavior in processing, handling and storage.



**Figure 20** Adsorption isotherms at 35°C (solids line) calculated by GAB equation (Eq.3) and glass transition temperature as function of water activity calculated by the Linear equation (Eq.5) of banana flakes with different maltodextrin content (a) 0 %, (b) 0.9 % (c) 1.8 % and (d) 2.7 % (dashed line).

The critical water activity and water content of banana flakes with different maltodextrin content at 35°C are shown in Table 7. The critical water activity were calculated by Linear equation, using  $T_{gw}$  (-135°C) and  $T_{gs}$  (106.25, 108.01, 115.75 and 122.78°C) shown in Table 6. The critical water content of banana flake were calculated by GAB equation, using parameters ( $M_0$ ,  $C$  and  $K$  in Table 4) for banana flake and water activity values from calculating by Linear equation

showed in Table 7. The initial water activity of banana flakes with 0, 0.9, 1.8 and 2.7% maltodextrins were 0.183, 0.171, 0.165 and 0.128 respectively. The results showed that the water activity of banana flake decreased with increased maltodextrin. However all sample of banana flakes had lower water activity than the critical water activity ( $a_w = 0.295, 0.300, 0.322, \text{ and } 0.340$  respectively).

**Table 7** Critical water activity and water content of banana flake having different level of maltodextrin contents at 35°C.

Maltodextrin concentration (% w/w)	Critical water activity	Critical water content g/ 100 g solids
0 %	0.295 <sup>d</sup>	3.11 <sup>d</sup>
0.9 %	0.300 <sup>c</sup>	4.01 <sup>c</sup>
1.8 %	0.322 <sup>b</sup>	4.24 <sup>b</sup>
2.7 %	0.340 <sup>a</sup>	4.55 <sup>a</sup>

<sup>a</sup> Means within the same column with different letters are significantly different ( $p \leq 0.05$ ) by Duncan's New Multiple-Rang Test (DMRT).

The critical water activity and critical water content of banana flake were increased with increasing maltodextrin content. Likewise, Roos (1993b) reported that evaluation the stability of maltodextrin samples which created a homologous family of various molecular weight. The result indicated that molecular weight of material required a rise in critical water activity from 0.09 to 0.70 in order to depress the  $T_g$  to ambient temperature. Schaller-Povolny *et al.*, 2000 compared water activity and glass transition data of four different molecular weights of inulin. Similarly, their study indicated that increasing molecular weight increased the critical water activity from 0.44 to 0.60 required at a given  $T_g$ .

The critical water activity and critical water content of banana flake increased with increasing maltodextrin content. The critical water activity and water content of banana flake with 1.8 and 2.7% maltodextrin were not different.

### 4.3 Physical measurement

Color of banana flake was significantly affected by the addition of maltodextrin (Table 8). Color parameters,  $L^*$  (lightness),  $a^*$  (redness) and  $b^*$  (yellowness) values of banana flake increased with increasing maltodextrin content. The browning occurred during drum drying reaction in banana flakes without maltodextrin more than with maltodextrin. Because maltodextrin is non sweet, nutritive saccharide polymer so banana flake without maltodextrin had more sugar content than those banana with maltodextrin. Similar, it has been reported that browning reaction affects color during thermal processing of cookie. During the heat treatment, sucrose and starch may hydrolyse respectively into glucose and fructose, or maltodextrin, maltose and glucose. The newly formed maltose and monosaccharides are reducing sugars which can further participate in the caramelisation and the maillard reaction when amino-acids are present. Both reactions produce brown polymers, which contribute to the surface coloration of cookie. Browning is the final step of both the maillard reaction and caramelisation (Many, 1998; Wade, 1988).

Hardness of banana flake also affected by maltodextrin as shown in Table 8. Hardness values of banana flake increased with increasing maltodextrin due to the decrease of (Table 5). The hardness of banana flakes were increased with decreasing water content. Similarly, Nowakowski and Hartel, (2002) reported that hardness of amorphous sugar products increased as water content decreased. On the other hand, maltodextrin (DE below 20) have compositions that reflect the nature of the starch used depending on the amylose/amylopectin ratio in starch. The formation of a maltodextrin network depends on dissolution and quench temperature, time and polymer concentration (Fennema, 1996). The decreased DE of maltodextrin will increase the viscosity so that the hardness of banana flake were increased with increasing maltodextrin after the drying process.

**Table 8** The physical values of banana flake with different maltodextrin contents.

Banana flake with different maltodextrin	$L^*$	$a^*$	$b^*$	Hardness (N)
0 %	44.57±1.32 <sup>c</sup>	13.51±0.22 <sup>b</sup>	20.58±0.22 <sup>d</sup>	30.53±2.11 <sup>d</sup>
0.9 %	44.82±0.51 <sup>b</sup>	13.31±0.27 <sup>b</sup>	21.43±0.31 <sup>c</sup>	32.28±2.77 <sup>c</sup>
1.8 %	45.49±0.79 <sup>ab</sup>	14.27 ±0.11 <sup>a</sup>	21.67 ±0.21 <sup>b</sup>	34.55±2.41 <sup>b</sup>
2.7 %	45.82±0.16 <sup>a</sup>	14.16±0.13 <sup>a</sup>	22.25±0.09 <sup>a</sup>	39.34±2.56 <sup>a</sup>

<sup>a</sup> Means within the same row with different letters are significantly different ( $p \leq 0.05$ ) by Duncan's New Multiple-Rang Test (DMRT).

#### 4.4 Sensory Analysis

Mean liking scores for sensory attributes of banana flake with different maltodextrin contents were given in Table 9. The result found that maltodextrin affected the appearance, flavor and crispness of banana flake. Means liking scores for appearance and crispness attribute of banana flake were increased with increasing maltodextrin content. Because maltodextrin contains polysaccharide or large molecule so it increased crispness and appearance of banana flake with increasing maltodextrin. Flavor scores for banana flake were decreased with increasing maltodextrin. Because maltodextrin is a flavorless substance so the flavor of banana flake were decreased with increasing maltodextrin content into banana. Color and taste attributes were not significantly different ( $p \geq 0.05$ ) between banana with and without maltodextrin (0.9, 1.8 and 2.7%). Overall acceptance of banana flake with maltodextrin 1.8% was the highest but was not significantly different ( $p \geq 0.05$ ) from banana without maltodextrin and banana with maltodextrin 0.9% and 2.7%.

**Table 9** Means of hedonic rating for sensory attributes of banana flakes with different maltodextrin contents.

Banana flake with Different Maltodextrin	Sensory Attributes					Overall liking
	Appearance	Color	Flavor	Crispness	Taste	
0 %	6.52±1.05 <sup>b</sup>	7.00±0.96 <sup>a</sup>	7.52±0.67 <sup>a</sup>	7.30±0.76 <sup>b</sup>	7.48±0.85 <sup>a</sup>	7.26±1.01 <sup>a</sup>
0.9%	6.64±1.04 <sup>ab</sup>	6.76±1.16 <sup>a</sup>	7.26±0.86 <sup>ab</sup>	7.57±0.54 <sup>a</sup>	7.43±0.99 <sup>a</sup>	7.22±0.80 <sup>a</sup>
1.8%	6.64±1.08 <sup>ab</sup>	6.84±0.90 <sup>a</sup>	7.00±1.00 <sup>b</sup>	7.74±0.45 <sup>a</sup>	7.30±0.76 <sup>a</sup>	7.35±0.88 <sup>a</sup>
2.7%	6.8±1.12 <sup>a</sup>	6.80±0.91 <sup>a</sup>	6.96±0.93 <sup>b</sup>	7.78±0.42 <sup>a</sup>	7.30±0.88 <sup>a</sup>	7.30±0.70 <sup>a</sup>

<sup>a</sup> Means within the same row with different letters are significantly different ( $p \leq 0.05$ ) by Duncan's New Multiple-Rang Test (DMRT). Scale of 1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely

Glass transition temperature the banana flake containing 1.8 % maltodextrin was higher than banana flake containing 0.9% and was selected to future study. The  $T_g$ . value of 2.7% maltodextrin was not different from banana flake containing 1.8 % maltodextrin. Therefore banana flake with 1.8 % optimize about the cost production and extent shelf life. So that the banana flake with 1.8% maltodextrin was selected for study on storage stability at storage temperature -18°C, 23°C, 35°C and 45°C and also sensory consumer tests.

### 5. Effect of Storage Temperature on Quality of Banana Flake.

Banana flake was developed by adding 1.8 % maltodextrin and stored at  $-18^{\circ}\text{C}$  (control),  $23^{\circ}\text{C}$ ,  $35^{\circ}\text{C}$  and  $45^{\circ}\text{C}$ . The changes in physico-chemical properties and sensory quality of banana flake during storage were showed in Figure 21-25 and Table 10.

Water activity of banana flake stored at  $-18^{\circ}\text{C}$  and  $23^{\circ}\text{C}$  were quite steady while banana flake stored at  $35^{\circ}\text{C}$  and  $45^{\circ}\text{C}$ , the water activity decreased with storage time (Figure 21). Due to low relative humidity of the surrounding air at  $35^{\circ}\text{C}$  and  $45^{\circ}\text{C}$  which causes a moisture migration from package.

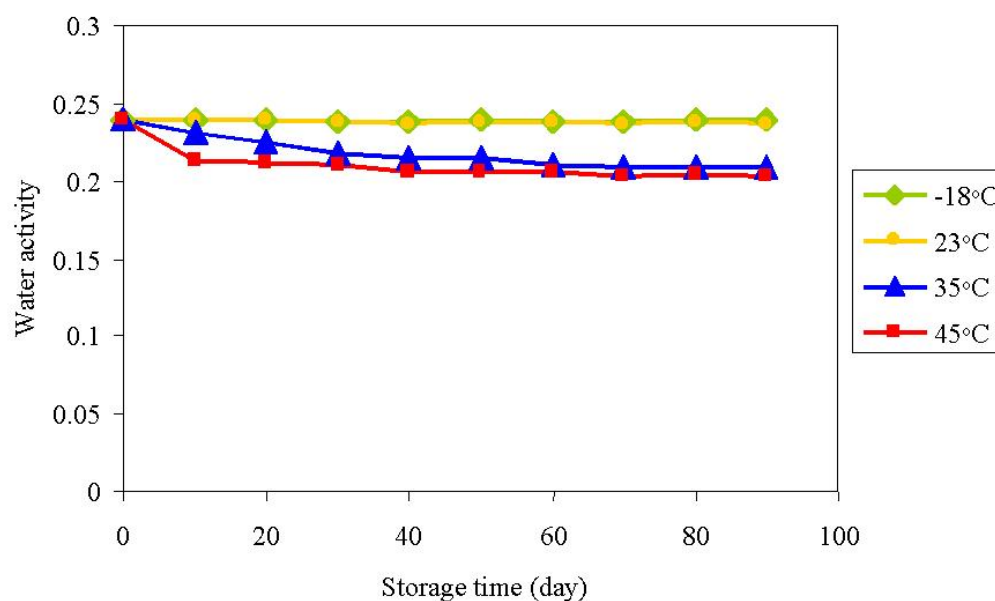


Figure 21 Effect of storage temperature on water activity of banana flake.

The  $a^*$ (redness) and  $b^*$  (yellowness) values were not significant different ( $p \geq 0.05$ ) throughout the storage period. But the  $L^*$  (Lightness) of banana flake stored at 45 °C decreased with storage time (Figure 22). Similarly, the result from sensory evaluation by quantitative descriptive analysis (QDA), the color intensity of banana flake stored at 45°C slightly increased with increasing storage time (Figure 26). The color intensity of banana flake related to lightness ( $L^*$  value). The decrease in the lightness value could be attributed to nonenzymatic browning reaction (Maillard reaction) during storage.

Banana flake was amorphous food. Most deteriorative reactions in amorphous foods, such as nonenzymatic browning, are suggested to be related to molecular mobility controlled by glass transition (Slade and Levine, 1991; Kramas *et al.*, 1992; Kramas and Karel, 1994; Roos, 1993a). Kramas and Karel (1994) have suggested that brown pigment formation is influenced by water activity, glass transition, and crystallization of the matrix. Browning reaction in banana flake similar results were reported by Kramas *et al.* (1992) derived  $T_g$  values for cabbage, carrots, onions, and potatoes and analyzed their browning rates as a function of  $T-T_g$ . The results showed that nonenzymatic browning occurred above a critical  $T-T_g$ . Banana flakes were stored at 45 °C which higher than  $T_g$  of banana flake with 1.8% maltodextrin (35°C). In addition was observed that the amount of reducing sugar of banana flakes stored at 45 °C were decreased with increasing storage times (Figure 25).

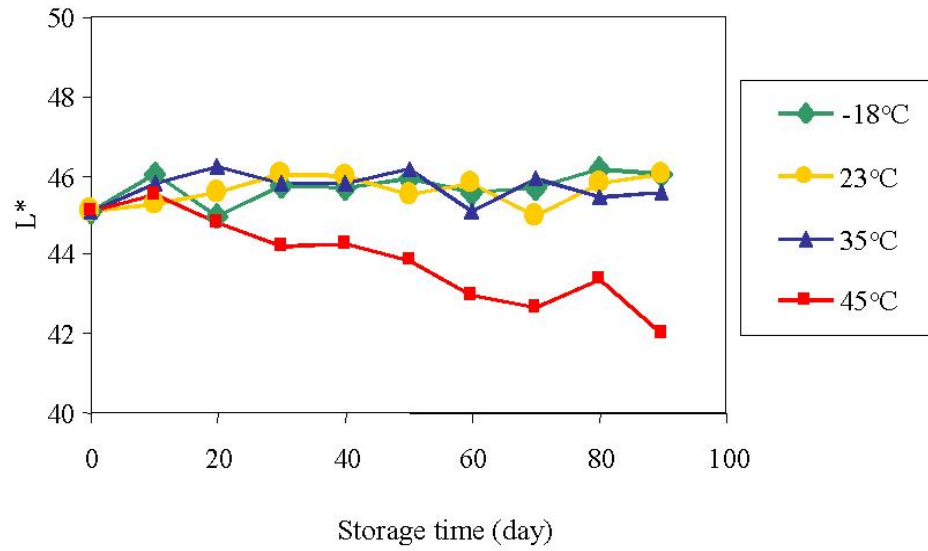


Figure 22 Effect of storage temperature on  $L^*$  values (lightness) of banana flake.

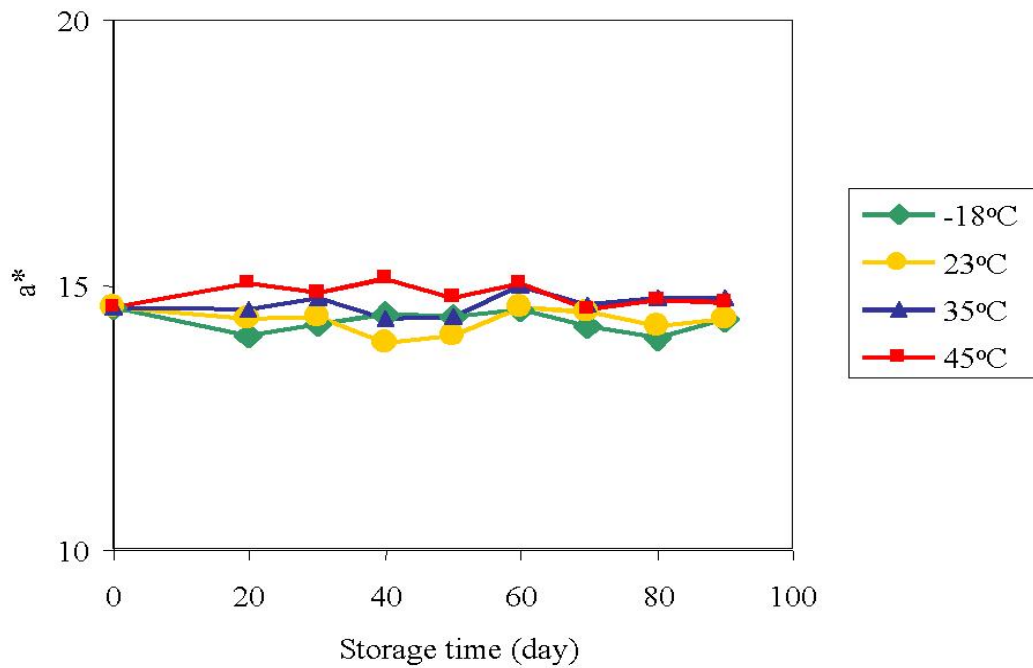
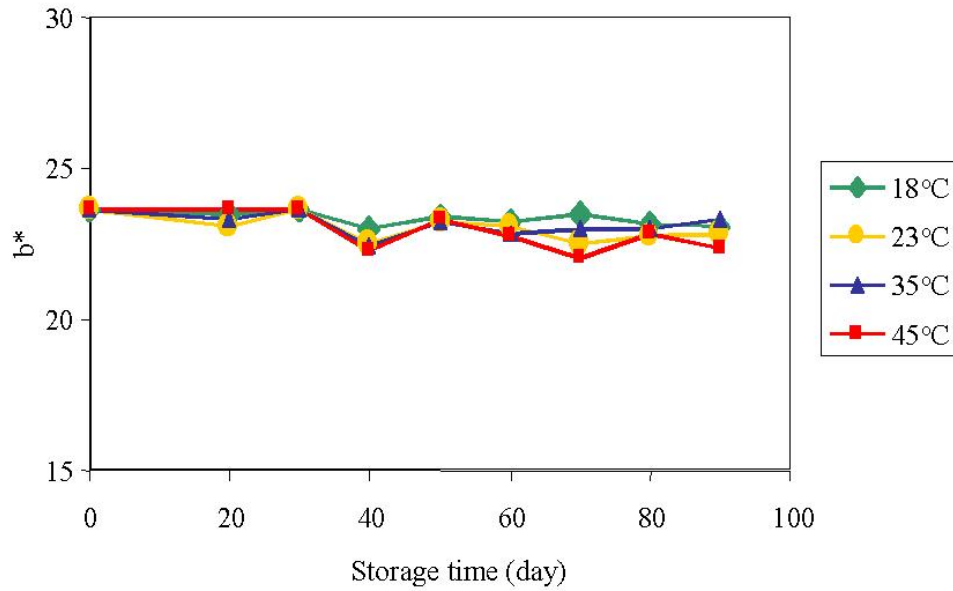
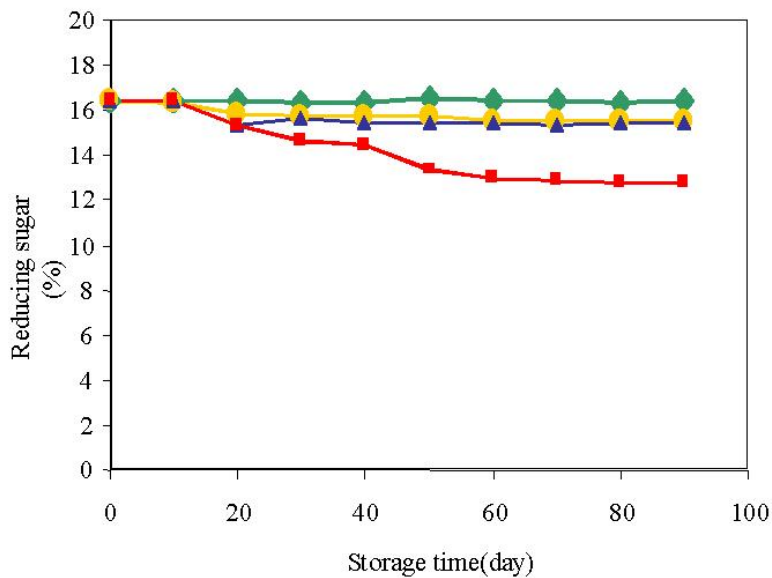


Figure 23 Effect of storage temperature on  $a^*$  values of banana flake.



**Figure 24** Effect of storage temperature on b\* values of banana flake.



**Figure 25** Effect of storage temperature on reducing sugar content of banana flake.

The hardness value of banana flake decreased as storage temperature and storage time increased (Table 10). However, the crispness and adhesiveness intensities of banana flakes at different storage temperatures were not different (Figure 27 and 28). The banana flake at 45°C can stored 50 days.

**Table 10** Effect of storage temperature on hardness of banana flake.

Time (day)	Hardness (N) at different storage temperatures			
	-18°C	23°C	35°C	45°C
0	35.43±0.43 <sup>a</sup>	35.43±0.43 <sup>a</sup>	35.43±0.43 <sup>a</sup>	35.43±0.43 <sup>a</sup>
10	34.19±1.99 <sup>a</sup>	27.77±2.21 <sup>b</sup>	25.57±2.57 <sup>b</sup>	24.98±2.41 <sup>c</sup>
20	34.55±2.77 <sup>a</sup>	27.89±2.71 <sup>b</sup>	25.75±3.21 <sup>c</sup>	25.87±2.11 <sup>c</sup>
30	34.39±1.29 <sup>a</sup>	26.53±1.83 <sup>b</sup>	25.77±1.57 <sup>b</sup>	25.99±2.44 <sup>b</sup>
40	34.68±1.36 <sup>a</sup>	25.56±2.96 <sup>b</sup>	25.61±2.50 <sup>b</sup>	25.06±2.56 <sup>b</sup>
50	35.92±4.14 <sup>a</sup>	26.25±5.41 <sup>b</sup>	25.02±4.10 <sup>b</sup>	25.27±4.26 <sup>b</sup>
60	34.73±5.46 <sup>a</sup>	23.18±0.50 <sup>b</sup>	21.60±3.02 <sup>b</sup>	20.45±2.14 <sup>b</sup>
70	34.82±5.68 <sup>a</sup>	22.82±2.04 <sup>b</sup>	20.52±2.89 <sup>b</sup>	18.05±1.21 <sup>b</sup>
80	34.35±4.97 <sup>a</sup>	23.23±4.17 <sup>b</sup>	19.54±3.07 <sup>b</sup>	19.55±2.67 <sup>b</sup>
90	34.60±4.51 <sup>a</sup>	21.77±3.93 <sup>b</sup>	19.83±3.41 <sup>b</sup>	19.82±2.59 <sup>b</sup>

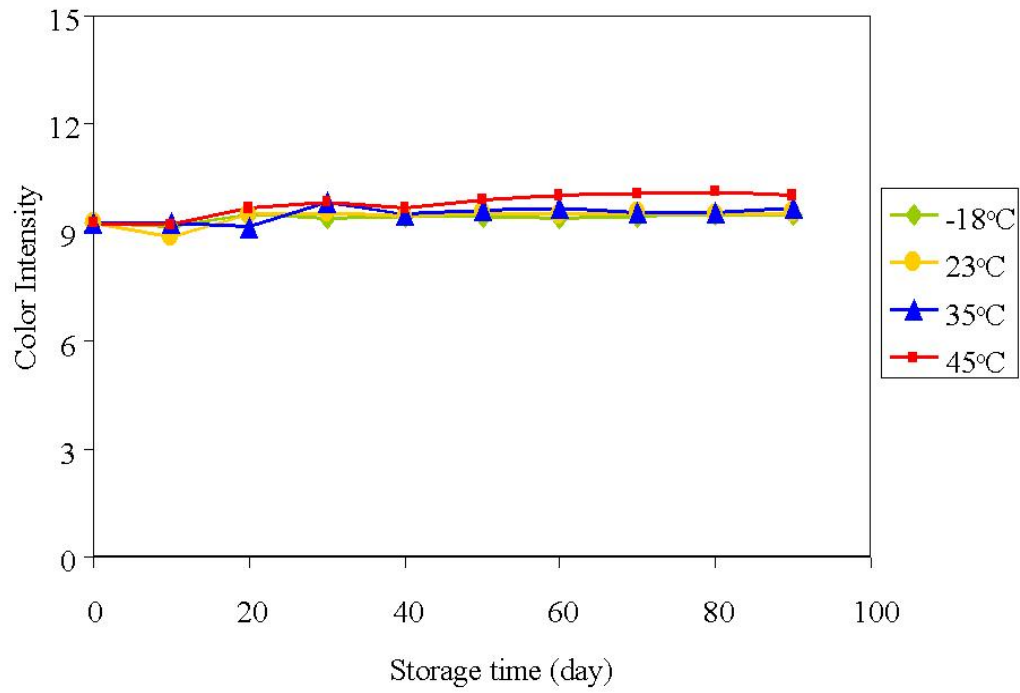
<sup>a</sup> Means within the same row with different letters are significantly different ( $p \leq 0.05$ ) by Duncan's New Multiple-Rang Test (DMRT).

The evaluation sensory quantitative descriptive analysis (QDA) was made by 12 trained panels, who were used to establish the profiles of the banana flake during storage. The consensus vocabulary developed 6 attributes of banana flake included brown color, crispness, adhesiveness, tastes roast banana, sweetness and flavor roast banana (Table 11). The intensity ratings of attribute were scored on a line of 15 cm. Effect of storage temperature on sensory properties of banana flake was analysed by QDA and given in Figure 26 -31.

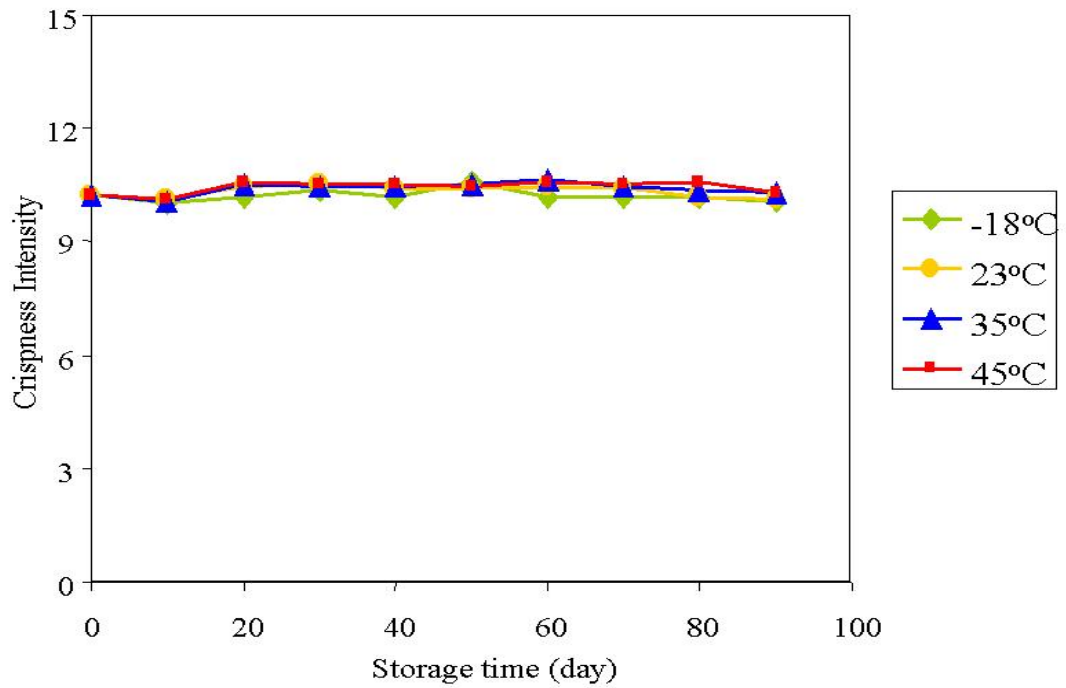
Table 11 Terms used in descriptive analysis of banana flake.

<b>Sensory attribute</b>	<b>Description</b>
<b>Appearance</b>	
Brown color of Banana flake	The intensity of strength of the color from light brown to dark brown
<b>Texture</b>	
Crispness	Force crispness to break sample
Adhesiveness	Force required to remove sample from a given surface
<b>Odor</b>	
Roast Banana	The aromatic associated with cooked banana by oven
<b>Tastes</b>	
Sweet	The taste on the tongue associated with sugars
<b>Flavor</b>	
Roasted Banana	Flavor associated with banana in mouth after swallow 1min

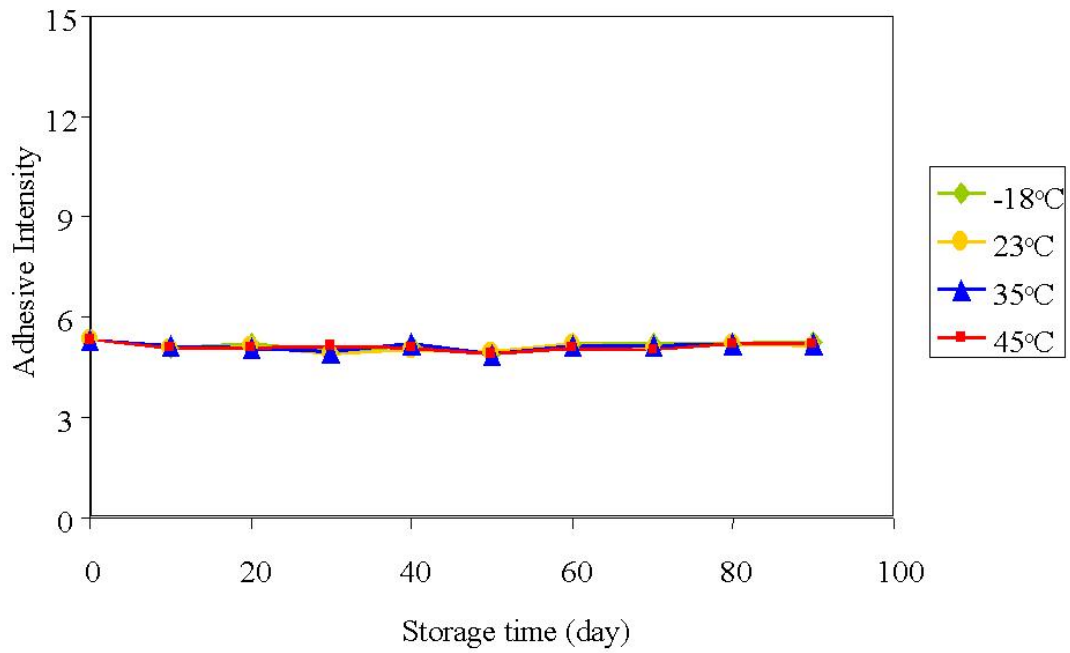
The 6 attributes of banana flake stored during 0- 90 day included brown color, crispness, adhesiveness, tastes roast banana, sweetness and flavor roast banana. The intensity rating of brown color of banana flake at storage temperature 45° C were increased with increasing storage time whereas banana flake at storage temperatures - 18 °C, 23°C and 35°C showed non-significant differences (p(0.05). The intensity of brown color of banana flake related to lightness (nonenzymatic browning reaction). The lightness value of banana flake were decreased with increasing intensity of brown color. The intensity crispness of banana flake in all storage temperatures showed non-significant different (p(0.05). The intensity of adhesiveness, taste roast banana, and sweet intensities of banana flake were non significant differences (p(0.05) with increasing storage temperature for every storage time. The flavor roast banana intensities were decreased with increasing storage time after 80 and 90 days in every storage temperature.



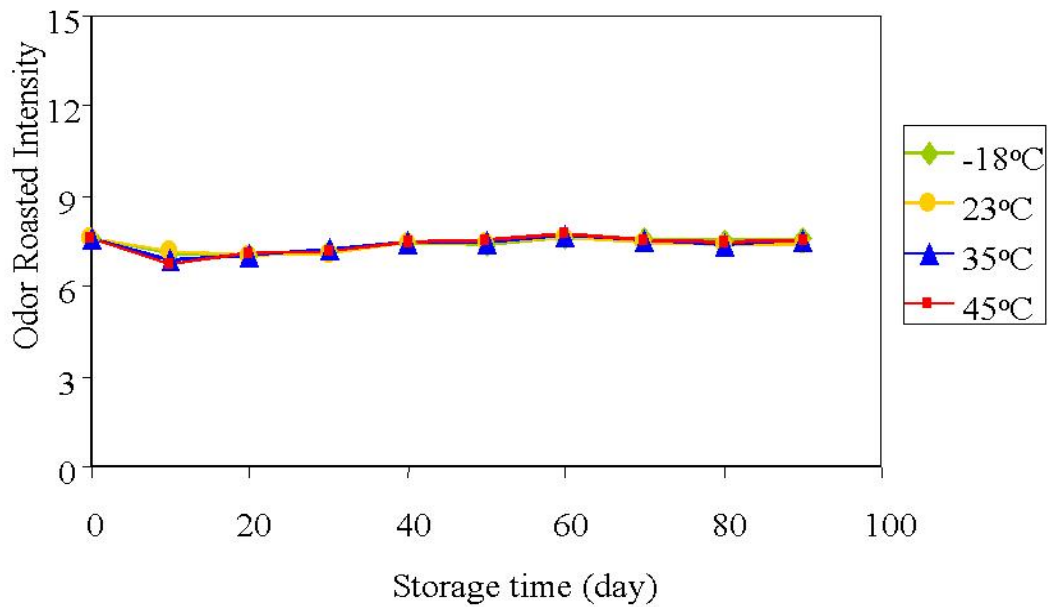
**Figure 26** The effect of storage temperature on brown color attribute of banana flake.



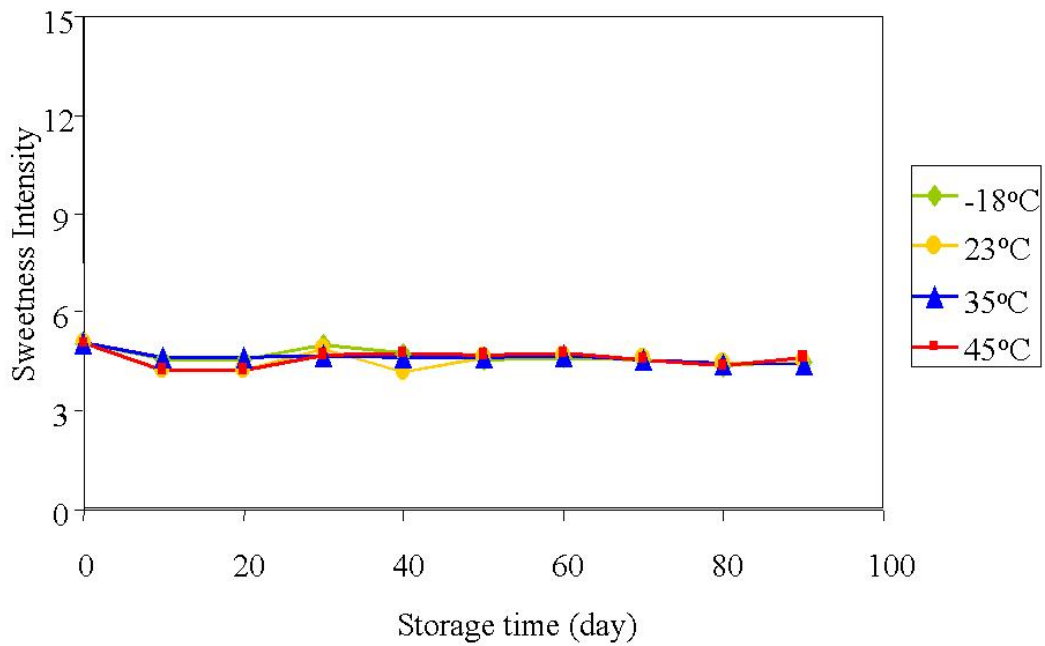
**Figure 27** The effect of storage temperature on crispness attribute of banana flake.



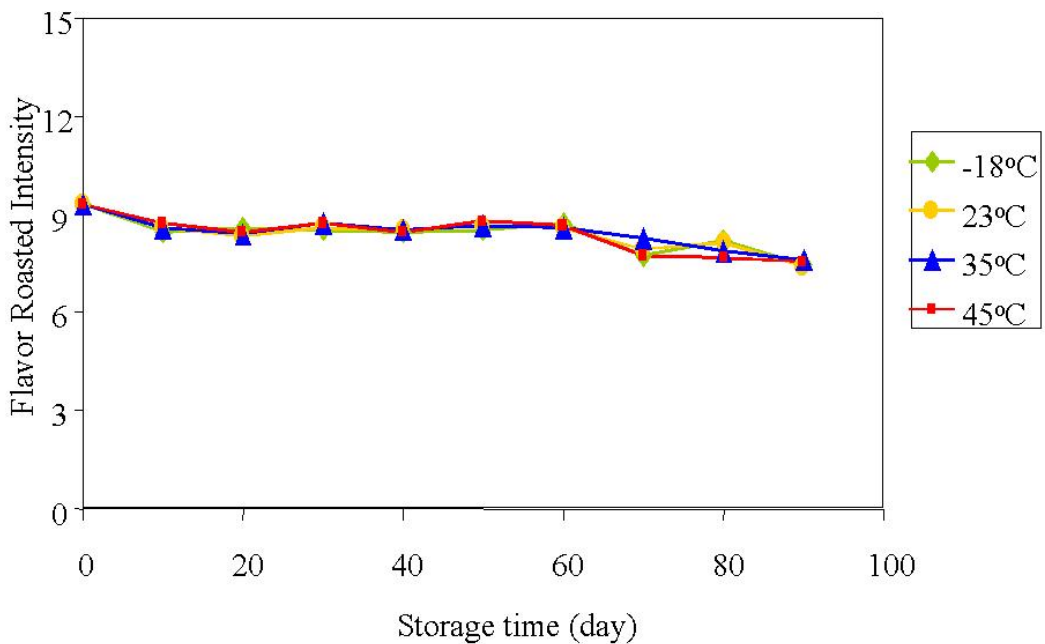
**Figure 28** The effect of storage temperature on adhesive attributes of banana flake.



**Figure 29** The effect of storage temperature on odor roasted banana attribute of banana flake.



**Figure 30** The effect of storage temperature on sweetness attribute of banana flake.



**Figure 31** The effect of storage temperature on flavor roast banana attribute of banana flake.

## **6. Consumer Tests**

Selected demographic and food consumption characteristics of 300 consumers in the consumer acceptance test of banana flake are shown in Table 12. The group was composed of 45% male and 55% female. The majority (69.0%) was well distributed in the range of 12-14 years of age, representing the target consumer group for banana flake.

Table 13 shows mean of hedonic rating and standard deviations of sensory acceptance of banana flake product by consumers test. Scores of appearance and color were 6.99 and 6.80 respectively. Flavor, crispness and taste were 7.34, 8.23 and 7.93. Score of overall liking was 7.77. The suggestion of consumers improved about appearance and color with increasing size and decreasing brown color of banana flake.

Consumers interested and accepted in banana flake were 97 % and 98 % (Table 14 and 15). Consumers would consider purchasing was 75 % (Table 16).

Table 12 Selected demographic characteristics of participants in the consumer acceptance test for banana flake

Demographic characteristics	%
Age( years old)	
9-11	31.0
12-14	69.0
Gender	
Male	45.0
Female	55.0
Education	
Primary school	36.0
Junior high school	64.0

Table 13 Means of hedonic rating for sensory attributes and overall acceptance of banana flake.

Sensory Attributes	Hedonic rating score
Appearance	6.99±1.41
Color	6.80±1.29
Flavor	7.34±1.33
Crispness	8.23±0.95
Taste	7.93±1.23
Overall liking	7.77±1.13

<sup>a</sup> Means within the same row with different letters are significantly different ( $p \leq 0.05$ ) by Duncan's New Multiple-Rang Test (DMRT). Scale of 1 = dislike extremely, 5= neither like nor dislike, 9= like extremely

Table 14 Factor of interesting of banana flake production from *Musa* (ABB group).

Factor	Frequency	Percent
Interested	291	97.0
not interested	9	3.0
Total	300	100.0

Table 15 Factor of acceptance for developed banana flake.

Factor	Frequency	Percent
Accept	293	98.0
Non accept	7	2.0
Total	300	100.0

Table 16 Factor of decision making trend for buying banana flake.

Factor	Frequency	Percent
Buy	225	75.0
Non buy	6	2.0
Not sure	69	23.0
Total	300	100.0

## CONCLUSION

Kluai Numwa (*Musa* ( ABB group ), was used for producing banana powder and flake in this study. The sorption isotherm of banana powder as major ingredients for producing of banana flake had a sigmoid shape. The GAB model was well fitted isotherm of banana powder at 35°C and provided the moisture content and water activity at monolayer about 4.24% db. and 0.335, respectively. Glass transition temperature ( $T_g$ ) of banana powder was determined using Differential Scanning Calorimetry (DSC) with the Gordon and Taylor and linear equation fitting the data. It was found that  $T_g$  of dried powder are 43.61°C . The critical water activity and critical water content of banana powder at 35 °C calculated by linear equation and GAB equation were 0.241 and 2.96 g/ 100g solids respectively.

For banana flake production, maltodextrin DE 10-12 (0 %, 0.9 %, 1.8 % and 2.7 %) were added. Results showed that the moisture content of banana flake at monolayer 35°C was increased from 4.03 – 6.01 % when maltodextrin content was increased for 0 % to 2.7 %. In contrast,  $T_g$  values of banana flake were increased. For storage stability study, banana flakes contain maltodextrin 1.8 % was selected and two hundred grams of them were packed into aluminium foil bags (OPP 30µ/Alu 7µ /LLDPE 5µ). They are kept for 3 months at four storage temperatures -18°C, 23°C, 35°C and 45°C, respectively. Results showed that within 3 months there was insignificantly physical and chemical changes of banana flake stored at -18°C, 23°C, 35°C while banana flake kept at 45°C was significantly physical and sensory change after 50 days.

Consumer test was done by 300 people being 9-14 years old. Results showed that 98 % of them accepted this product.