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Sorption isotherm study of preserved wild mangosteen (kra-thon yhee) with replacing humectants

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Abstract

This research aimed to study moisture sorption isotherms of preserved wild mangosteen influenced by three kinds of humectants e.g. glycerol, maltitol and maltodextrin at different replacing levels of the sucrose substitutes (2.5%, 5.0% and 7.5%) in the product. Preserved wild mangosteen products were cut into a size of 1 cm^3. To study sorption isotherms, a gravimetric method was used and the experimental water adsorption isotherm. The data was analyzed using the Brunauer-Emmett-Teller (BET) and Guggenheim-Anderson-de Boer (GAB) models. Results showed that the GAB was found to be the best fit in order to explain the measured moisture sorption isotherm of 5.0% Glycerol (R^2 = 0.99), 5.0% Maltodextrin (R^2 = 0.99) and 7.5% of maltitol (R^2 = 0.99) of sucrose replacement in the product. Changes in texture, color, a_w, moisture, total soluble solid (TSS), pH and titratable acidity (TA) were investigated during the storage. Results obtained from this research were important in the selection of humectants in order to minimize water content in high sugar containing products resulting in the extension of shelf life of the products.

Introduction

Wild mangosteen, a tropical fruit tree in Meliaceae family, is a fruit native to Southeast Asia. Its scientific name is *Sandoricum Koetjape* (Burm. f.) Merr., and its common names are sentul, santol, red sentol, yellow sentol, wild mangosteen and Kra-thon (a common Thai name). In Thailand, Kra-thon or wild mangosteen is wildly growth in several provinces, for example, Lampang, Srisaket, Ubonratchathani, Surin, Lopburi, Singburi, Nakhonnayok, Prachinburi, Suratthani and Nakhonratchasima. It has green color when its fruit is young. The skin color of the fruit turns into yellow as it ripens. In general, it has round shape, and its size is about 5-15 cm in diameter. Usually, it contains 3-5 seeds inside one fruit (Suviriyo, 2011). In addition to frequent consumption as fresh commodities, Kra-thon is also popularly consumed as preserved fruit products such as Kra-thon laokhaw (a sweet preserved made of sour fruit steeped in syrup), frozen Kra-thon, Kra-thon cheuam, Kra-thon chae-im, and Kra-thon yhee. These products have been locally produced in the program of Thai government "One Tambon One Product (OTOP)" in many provinces. During the fruiting season, large amount of Kra-thon fruits more than 28,000 kg have been harvested (Prachinburi Provincial Agriculture Office, 2012). Some parts of the harvest are pre-cut, preserved, and/or frozen for further processing during the year. However, during the storage, several problems on quality losses of these preserved products have been observed due to the high concentration of sugar content. For example, liquidation and agglomeration of sugar granules affect product consistency, quality and consumer acceptability.

To preserve fruits, ripened fruits added with sugar are heated and constantly mixed. This process allows some parts of water to evaporate out. The concentrated product has increased in sweetness. Commonly, salt and acidify agent have been added during the process. The "Yhee" process is one of the common perverse processes in Thailand. In general, Yhee process uses whole and/or trimmed fruits, and then the fruits are preserved with, in addition to sugar, salt and citric acid until saturation of sugar into the fruits. The products are further subjected to drying process and mixing with the seasoning powder (Thai industrial standards institute. 2004). This preserve method can inhibit microbial growth due to low water activity (a_w). Thus, the shelf life

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of the preserved product can be greatly extended. Moreover, the humectants food additives are also used for the purpose of controlling moisture and reduce water activity, sugar alcohol (glycerol and maltitol) and maltodextrin (3-17 glucose units connected with α1-4 glycosidic bonds) are used widely in the food industry as sweeteners and binder agent. In commercial foodstuffs, sugar alcohols are commonly used in place of sucrose, often in combination with high intensity artificial sweeteners to counter the low sweetness. The hydroxyl group (-OH) in the structure attached to each carbon and form hydrogen bonds with water molecules. When they adsorb the water, monolayer water in foodstuff are decrease and the storage stability increase.

In theory, moisture and temperature are the two important parameters affecting the reaction rate in foods. Until the 1980s, the influence of moisture on chemical reactions, in particular the reactions to food stability had been described in terms of water activity (Labuza, 1984; Labuza *et al*., 1998). Water activity has been considered as the factor which is more important than the total amount of water, concerning to quality and stability of food stuff. Water sorption isotherms are important thermodynamic tools for predicting the interactions between water and food components. In 1984, Labuza describe the relationship between water activity and the equilibrium moisture content of a food product and provided useful information for food processing operations such as drying, packaging and storage. Sorption isotherms are generally described by mathematical models based on empirical and/or theoretical criteria. The most commonly used equations in food are Brunauer-Emmett-Teller (BET) and Guggenheim-Anderson-de Boer (GAB) as equation (1) and (2), respectively. With some theoretical background and parameters, these equations provide a physical meaning related to the sorption process. (Maroulis *et al*., 1988; Hossain *et al*., 2001; Al-Muhtaseb *et al*., 2002; Yan *et al*., 2008).

$$X_e = \frac{(X_m C_{BET} a_w)}{[(1-a_w)(1-a_w+C_{BET}a_w)]} \quad (1)$$

$$X_e = \frac{(X_m G_{GAB} K_{GAB} a_w)}{[(1-K_{GAB}a_w)(1-K_{GAB}a_w+G_{GAB}K_{GAB}a_w)]} \quad (2)$$

where X_e = equilibrium moisture content (g water/g dry matter), X_m = monolayer moisture content (g water/g dry matter), a_w = water activity, C_{BET} = constant of equation (1), K_{GAB} = constant of equation (2) and G_{GAB} = constant of equation (2).

This research aimed to study water sorption isotherm of the Kra-thon yhee products, which their sucrose contents have been partly substitutes with different humectants. The lower (monolayer) and C K constant related to heat and energies of their isotherm using BET and GAB model were compared. In addition, changes in several physical and chemical quality aspects during storage were monitored as the effects of the selected humectants.

Materials and Methods

Reagents

Maltodextrin (DE10) was purchased from Buri-Juker (Samut-Bangkok,Thailand). Maltitol was donated by Ueno Fine Chemicals Industry. Ltd (Bangkok, Thailand) and glycerol were purchased from Vicchi Enterprise Co., LTD (Bangkok, Thailand). All chemical reagents: LiCl, CH_3COOK, $MgCl_2.6H_2O$, NaBr, KI, $NaNO_3$, NaCl and KNO_3 were purchased from Sigma Chemical Company (St. Louis, Mo., USA).

Raw material preparation

Wild mangosteen or Kra-thon fruits were locally purchased from the agricultural cooperative at Bandongbang (Prachinburi, Thailand). The fruits were peeled, removed all the seeds, and then slide into 0.5x1.0 inch. The pre-cut fruits were washed with clean water and soaked in saline solution (12% w/v) for 12 h. The excessive amounts of water were squeezed out of the fruit. The pre-treated fruits were packed in plastic bags made form linear low density polyethylene (LLDPE) kept in containers, and stored under -17°C±2°C until the experiments were carried out.

Sample preparation

The prepared wild mangosteen fruits from the above explanation were ground using a mincer under die pore size 0.3 mm. (Trespade; Food EQ co.,LTD, Thailand). The excess water was removed, and then stirred in a brass pan under the heat using an automatic stirring brass pan with a 6-inch propeller (18-inch pan with single phase 110/220 volts, gas heating. King machine, Thailand). The composition of preserved wild mangosteen was minced wild mangosteen 68.3% sucrose 20% glucose syrup 10% citric acid 1.5% and salt 0.2%, respectively. Different three kinds of humectants (glycerol, maltitol and maltodextrin) were replaced sucrose at three levels (2.5 5.0 and 7.5% wt/wt). The stirring and mixing of the minced fruits could be divided into 3 steps. In the first step, ground sugar and salt was added and stirred at 70°C for 50 min until the product was thick, viscous, and gluey. In the second step, glucose syrup and citric acid were added, and constantly stirred for 30 min. In

the final step, the stirring speed was controlled under 75°C for 70 min. The preserved fruit mince was then prepared into cubes (1 cm^3), which was dried in a heating oven at 85°C for 40 min. The finish products were cooled down at room temperature, and stored in LLDPE bags for further studies.

Moisture sorption Isotherm characteristics

To determine the isotherm of sample, 2 g were equilibrated against the saturated salt solutions (11% LiCl, 23% CH_3COOK, 33% $MgCl_2.6H_2O$, 57% NaBr, 69% KI, 74% $NaNO_3$, 84% NaCl and 93% KNO_3) as a modified PEC described by Lang *et al*. (1981). The sample holder was a plastic weighing dish with 45 mm diameter and 55 mm deep. A clean dry sample holder was weighed and placed in the proximity equilibration cell (PEC) containing saturated salt solution for 24 h at 25±2°C. The sample holder was weighed again after 24 h and 2 g sample was placed in the holder. The sample holder was then inserted in the PEC for equilibration. The required time for equilibration was 1–2 weeks, based on the change in sample weight, which did not exceed 0.1%. All treatments were performed in triplicate.

Sorption isotherms are generally described by mathematical models based on empirical or theoretical criteria, which can be easily found in the literature. Thus, in this work, sorption isotherms data were modeled according to GAB and BET models, using the Solver algorithm of Microsoft Excel. The goodness of fit was evaluated by the determination coefficient (R^2) and the mean relative deviation modulus (E), where V_E is experimental value and V_P is predicted value.

$$E = \frac{100}{N}\sum_{i=1}^{N}\frac{V_E - V_P}{V_E} \qquad (3)$$

Physical and chemical properties during the storage

Selected preserved products under the consideration of the best fit according to lowest X_m, highest R^2 and %E from the previous experiment were studied on changes in physical and chemical properties during the storage. 25 g of samples were packed in a LLDPE bag (8 x 12 cm size), and stored at 27±2°C for 2 months. The samples were taken every 7 days for further analysis according to the following details.

Texture and color measurement

Texture properties of sample were evaluated using texture analyzer (TA.XT.2i, Stable Macro System, England). The experiments conducted with texture profile analysis (TPA) mode using 36 mm P/36R probe and test speed at 1 mm/s. Hardness, adhesiveness, cohesiveness, gumminess and chewiness of the products were reported. Color characteristics were measured using a colorimeter (Color Flex 4510, Aekchai, USA). All samples were ground into small particles before transferred into a quartz container. The color was evaluated by means of CIE Lab color components (L^*; lightness, a^*; redness and b^*; yellowness).

Moister content and water activity

All samples were ground into small particles. Moisture content of sample was done using the standard methods described in AOAC (2000). 5 g of sample was dried in vacuum dryer set at 70°C with 100 mmHg. pressure for 15 h. The loss of mass of the sample was weighted and calculated respectively. Water activity: Approximately, 2.5 g of samples were used for the analysis using a water activity meter (Aqua Lab, Model. CX3TE, England). All determinations were performed in triplicates.

Total soluble solid (%) total titratable acidity (TA) and pH

Samples (20 g) were soaked in water (80 g) (w/w). Mixed and blended (Sharp, EM-44A, Thailand) for 1 min. The residues were removed using paper filtration (whatman No.4). Total soluble solids (TSS) were measured using a refractometer (Atago, N-1E, Japan). Total titratable acidity of sample was determined as described by Woo (1996). Citric acid was used as a standard compound. The solution was measure using pH meter (model pH 720, Inolab, Germany).

Statistical analysis

All experiments were performed in triplicate. The data were reported as mean± standard deviation. An analysis of variance (ANOVA) was performed. Duncan's multiple range tests were applied on the individual variables to compare the mean and to assess their significant difference (at significant level $p<0.05$). All calculations were performed by SPSS18 (http://www.spss.com; SPSS Inc.,Chicago, IL).

Results and Discussion

Moisture sorption isotherm characteristics of preserved wild mangosteen

To study moisture sorption isotherm characteristics, moisture content equilibrium values (X_e) were evaluated from the samples with different levels of humectants to replace sucrose under different levels of relative humidity (11-92%) as shown in

Table 1. Estimated BET and GAB parameters for wild mangosteen (Kra-thon Yhee) with different humectants

Sample	Parameter								
	BET				GAB				
	X_m	C_{BET}	R^2	E(%)	X_m	C_{GAB}	K_{GAB}	R^2	E(%)
Control	262.7940	0.1409	0.9768	95.417	5.9644	4.9275	0.7679	0.9947	98.940
Glycerol 2.5%	243.5892	0.1485	0.9426	88.849	5.4313	2.6287	0.8035	0.9738	94.833
Glycerol 5.0%	137.8277	0.2026	0.9841	96.847	0.5692	7.6925	0.8256	0.9976	99.524
Glycerol 7.5%	194.4129	0.1681	0.9869	97.394	3.3893	3.1378	0.8229	0.9988	99.768
Maltitol 2.5%	171.3828	0.1746	0.9835	96.733	3.0750	3.1177	0.8312	0.9962	99.231
Maltitol 5.0%	184.6701	0.1794	0.9871	97.443	3.5792	2.1352	0.9206	0.9985	99.700
Maltitol 7.5%	64.2331	0.3101	0.9935	98.697	1.4975	5.0801	0.8135	0.9996	99.923
Maltodextrin 2.5%	115.2013	0.2150	0.9815	96.341	1.5440	4.0324	0.8558	0.9934	98.681
Maltodextrin 5.0%	92.7182	0.2509	0.9832	96.671	0.2223	11.0772	0.8569	0.9952	99.036
Maltodextrin 7.5%	208.6521	0.1651	0.9871	97.438	4.0721	2.9015	0.8241	0.9987	99.749

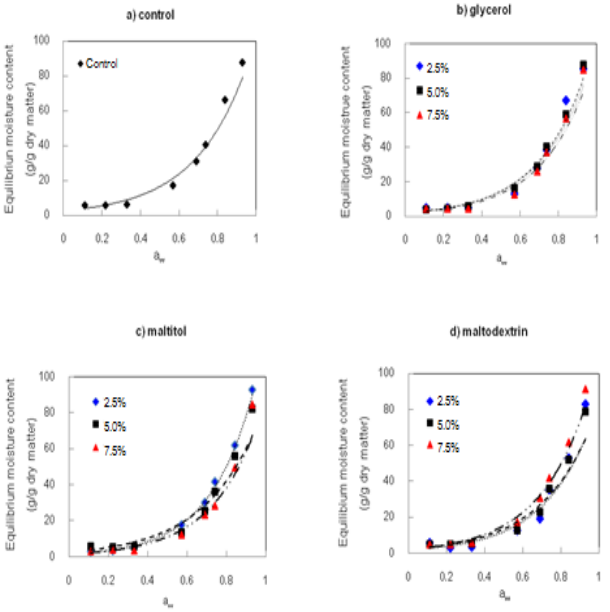

Figure 1. Equilibrium moisture content (X_e (g/100g dry matter) of preserved wild mangosteen (Kra-thon Yhee) with different humectants: a) control, b) glycerol, c) maltitol and d) maltodextrin

Figure 1. These values were used to fit in the GAB and BET models in the equation 1-2 to obtain several parameters as illustrated in Table 1.

Results suggested that the GAB model showed better fit with the experimental data according to the lowest X_m values (monolayer moisture content), the highest correlation coefficient values close to 1, and the %E values close to 100 than the BET model. The influence of concentrations on X_m was described by the number of hydroxyl group (-OH) in maltodextrin > maltitol > glycerol, respectively. Its affinity to form hydrogen bonds with molecules of water as water absorption. Therefore, when the concentrations increased the X_m was decreased. It should be noted that optimal sucrose replacement levels using humectantsin the preserved wild mangosteen products were 5.0% for glycerol and maltodextrin, and 7.5% for maltitol. Considering X_m values, the higher the X_m value, the shorter the shelf life of the product during the storage is suggested (Saravacos *et al*., 1986; Hossain *et al*., 2001). Sorption isotherm characteristics (moisture content vs a_w plots) of the products treated the selected humectants fitted by the GAB model were illustrated in Figure 2 (a-d). Moreover, in comparison between the sample (with humectants) and control, all samples (with humectants) not only showed the X_m value lower than control but also showed the lower X_m in GAB models, such as at 2.5% glycerol were 262.7940 and 5.9644 in the BET and GAB models, respectively.

In principle in order to effectively predict the moisture content in the monolayer of foods (X_m), adsorbed moisture is in the "ideal" inert gas, and the adsorption surfaces (sites) should have no interaction with each other. In food matrices, they are composed of carbohydrates, proteins, and lipids, at which are inconsistently organized and different size distribution. Especially, hydrophilic components could interact with water via hydrogen bonding (Wisitudonkan, 1997; Al-Muhtaseb *et al*., 2002). The five general types (I-V) of adsorption isotherm are classified (Heldman and Lund, 1992) and moisture sorption isotherms of most foods are nonlinear, generally sigmoidal in shape and have been classified as Type II and III. Food rich in soluble components, such as sugars, however, have been found to show Type III behavior, this due to the solubility of sugar in water. BET and GAB model exist to describe water sorption isotherms and no sorption isotherm model could fit data over the entire range of relative humidity because water is associated with the food matrix (Labuza, 1972; Labuza *et al*., 1984). The GAB model good description of sorption behavior from a water activity of 0 to 0.9 of almost all foods, while

Table 2. Texture profile analysis of wild mangosteen (Kra-thon Yhee) with different humectants

Sample	Hardness (kg)	Adhesiveness (kg*sec)	Cohesiveness (%)	Chewiness	Gumminess
Control	10.43±0.12^{d}	1.47±0.27^{a}	2.57±0.22^{h}	13.55±0.33^{d}	32.24±0.35^{e}
Glycerol 2.5%	8.93±0.25^{e}	1.95±0.38^{f}	4.00±0.32^{b}	13.10±0.21^{e}	17.90±0.22^{g}
Glycerol 5.0%	6.95±0.35^{f}	2.49±0.33^{e}	2.93±0.43^{f}	10.44±0.47^{g}	15.66±0.09^{g}
Glycerol 7.5%	6.26±0.32^{g}	4.34±0.65^{b}	1.37±0.42^{j}	12.64±0.12^{f}	12.14±0.02^{h}
Maltitol 2.5%	23.14±0.46^{a}	3.19±0.23^{d}	5.24±0.73^{a}	27.66±0.23^{a}	70.21±0.45^{a}
Maltitol 5.0%	18.09±0.32^{b}	4.16±0.21^{c}	3.76±0.13^{c}	26.82±0.52^{b}	67.67±0.37^{b}
Maltitol 7.5%	13.07±0.56^{c}	4.88±0.45^{a}	3.61±0.24^{e}	25.98±0.34^{c}	64.04±0.33^{c}
Maltodextrin 2.5%	6.89±0.33^{f}	0.12±0.27^{i}	3.62±0.18^{d}	11.48±0.22^{h}	22.22±0.26^{f}
Maltodextrin 5.0%	6.61±0.46^{gf}	0.45±0.16^{h}	2.64±0.37^{g}	9.16±0.32^{i}	29.99±0.63^{f}
Maltodextrin 7.5%	4.63±0.39^{h}	0.50±0.56^{h}	1.83±0.21^{i}	8.30±0.17^{i}	38.79±0.25^{d}

Mean (±SD) with different superscript letters in the same column indicate significant different ($p<0.05$).

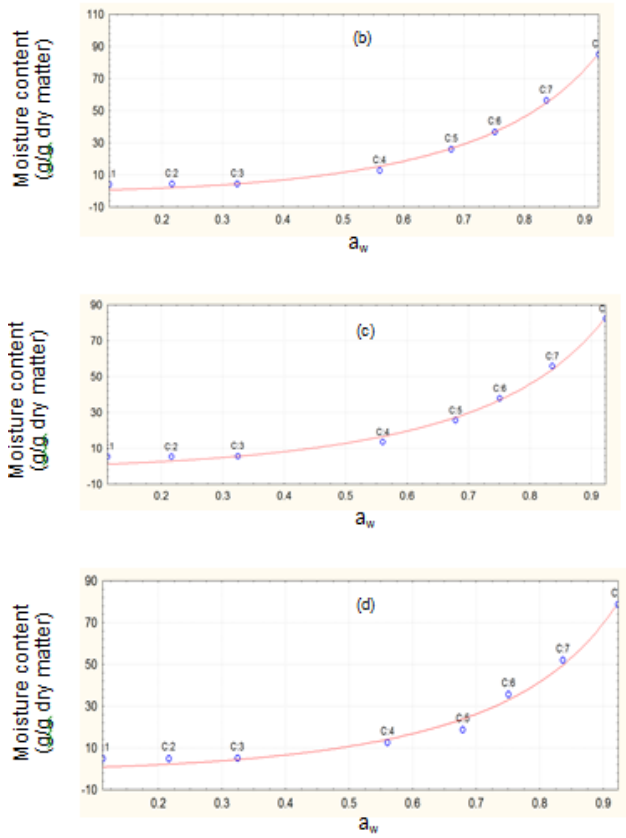

Figure 2. Sorption isotherm of preserved wild mangosteen (Kra-thon Yhee) with and without replacing different humectantsl; a) control, b) 5.0% glycerol, c) 7.5% maltitol and d) 5.0% maltodextrin; $^{o}C_{1}$-C_{8} data from experiment; - GAB model.

the BET model used to fit experiment data in range 0.05 to 0.35 (Al-Muhtaseb *et al*., 2002). This could be a reason that the BET model could not fit well with food samples, while the GAB model performed better. In addition, it was noted that the GAB model was able to explain sorption behavior of almost all foods from a water activity 0-0.9 (Hossain *et al*., 2001; Al-Muhtaseb *et al.*, 2002) and good description of a wide range of tested temperatures (25-80^{o}C) (Wongsakpairote, 2002).

Physicochemical properties of preserved wild mangosteen products

Table 2 shows effects of adding the humectants at the 3 different levels of the substitution in comparison with the control (without humectants). Results showed that adding glycerol and maltodextrin into the products decreased hardness, adhesiveness, chewiness and gumminess compared with the control. In the contrary, the products with maltitol exhibited higher hardness, adhesiveness cohesiveness, chewiness, and gumminess than the control. Even though maltitol was used only at 2.5% replacement, chewiness and gumminess values of the product were 27.66 and 70.21 kg, which were increased twice from the control. This suggested that lots of energy to chew the product are required before swallowed. It was found that observed product appearance was very thick and hard for preparation and consumption. In addition, since maltitol give 90-95% of sucrose, the product with maltitol was sweeter than other humectants.

Table 3 shows the water activity and pH values, there were no significant differences ($p<0.05$) observed among tested samples. Moisture contents of all samples were around 6.05-7.26%. For the color measurement, results showed that the products with humectants exhibited lower L^{*} (lightness) value than

Table 3. Physicochemical properties of wild mangosteen (Kra-thon Yhee) with different humectants

Sample	a_w	pH	Moisture Content (%)	Color		
				*L**	*a**	*b**
Control	0.42±0.03	2.60±0.2	7.27±0.50^a	36.88±0.00^a	4.243±0.04^e	3.27±0.32^g
Glycerol 2.5%	0.43±0.03	2.64±0.3	6.50±0.70^c	34.21±0.01^d	4.453±0.02^d	4.32±0.12^d
Glycerol 5.0%	0.43±0.05	2.70±0.2	6.05±0.50^i	33.64±0.02^e	4.229±0.05^e	3.85±0.21^e
Glycerol 7.5 %	0.44±0.01	2.82±0.4	6.25±0.8^i	32.11±0.03^h	3.984±0.03^f	3.54±0.03^f
Maltitol 2.5%	0.41±0.02	2.59±0.3	6.36±1.0^f	36.12±001^b	7.213±0.05^a	6.99±0.04^a
Maltitol 5.0%	0.43±0.04	2.68±0.1	6.89±1.1^b	36.07±0.02^b	7.317±0.04^a	6.58±0.10^b
Maltitol 7.5%	0.44±0.02	2.81±0.1	6.41±0.8^e	35.34±0.02^c	6.897±0.01^b	6.21±0.09^c
Maltodextrin 2.5%	0.42±0.03	2.62±0.4	6.32±0.5^h	33.32±0.01^f	5.012±0.06^c	3.61±0.04^f
Maltodextrin 5.0%	0.43±0.01	2.66±0.2	6.36±0.7^g	32.57±0.02^g	4.333±0.05^{de}	3.34±0.02^g
Maltodextrin 7.5%	0.44±0.01	2.79±0.2	6.50±0.4^d	32.13±0.01^h	3.987±0.05^f	3.01±0.03^h

Mean (±SD) with different superscript letters in the same column indicate significant different ($p<0.05$)

the control, while a^* (redness) and b^* (yellowness) of the product with maltitol was higher than other treated products and the control. However, the products with glycerol and maltodextrin had a^* and b^* values similar to the control.

The sugar alcohol (glycerol) have two fewer hydrogen atoms and the hydroxyl groups. The hydroxyl group (-OH) in the structure form hydrogen bonds with water molecules and retains the moist in the air nearby with the absorption, drawing the water vapor into food surface. Therefore, wild mangosteen with partly substituted with humectants decreased the hardness and gumminess. While maltodextrin consists of D-glucose units and classified by DE (dextrose equivalent). The higher DE value, the shorter the glucose chains, hydroxyl group in the glucose units can be bound with the water molecules. On the other hand, maltital known as 4-O-α-glucopyranosyl-D-sorbitol, a disaccharide produced by hydrogenation of maltose from starch. It exhibits a negligible cooling effect and form crystal surface. The crystal nucleation occur more readily around surface by two step: disassociation of hydration water molecules and diffusion-aggregation to form nuclei. (Bensouissi *et al.*, 2010). From that reasons cause the hardness and gumminess of the products showed highest value. However, the variation in sorption properties of food is caused by biological variation in food, pretreatment of food and difference in experimental techniques adopted (Saravacos *et al.*, 1986). According to sorption isotherm, texture, and color characteristics, using maltodextrin at 5% of the substitution was selected for the further study in changes in physicochemical properties of the product during the storage at room temperature.

Changes in physicochemical properties of the product during the storage

As shown in Table 4 Resulting of physicochemical properties of preserved wild mangosteen (control and with 5% maltodextrin), results showed that hardness, adhesiveness, cohesiveness, gumminess of the preserved wild mangosteen product without maltodextrin were 11.77-23.72 kg, 2.01-13.45 kg*sec, 2.71-8.33%, 17.87-22.56 and 28.14-35.66, respectively, while the values for the product with maltodextrin were 8.38-16.40 kg, 1.24-8.98 kg*sec, 2.81-9.26%, 8.36-19.14, and 18.89-25.27, respectively. Interestingly, these values were increased during the storage (data not shown).

For the water activity and pH value, there were no significant differences ($p<0.05$). The a_w values were around 0.41-0.48%, which is considered as safe from microbial spoilage since the water activity of the product is still lower than 0.6 (Labuza *et al.*, 1972). There was slightly increased of pH (data not showed). Moreover, moisture contents were also increased during the storage.

TSS of control were decreased during storage (44.84 to 41.35%) while TA were increased (10.31 to 13.68 g citric /100 g sample). These results were similar in sample with 5% maltodextrin. In the control sample, the L^* and b^* values were around 36.93-29.89 and 14.57-14.06, respectively. These values were decreased, while the a^* value (around 16.41-19.34), was increased during the storage. For the treated sample with 5% maltodextrin, the a^* and b^* values were 12.12-21.01 and 11.21-14.53, respectively.

However, these values were increased, and the L^* value (around 38.25-30.72) was increased during the storage. Decreasing in L^* b^* and increasing in a^* may probably affected by Maillard reaction. Maillard reaction is non-enzymetic browning reaction, which is reacted between carbonyl group from reducing sugar and amine group in protein. This gives brown food. (Martins *et al*., 2000; Belitz *et al*., 2009).

Conclusion

Types and concentrations of humectants influenced on moisture content in monolayer indicated by the X_m value. At the 5% of sucrose substituting level, glycerol and maltodextrin exhibited the lowest X_m values, while the lowest X_m value of the product treated with maltitol was at 7.5%. The GAB model was the best fit to explain the relationship between equilibrium moisture content and aw value, and to obtain X_m from the equation. Thus, the suitable humectant for the product was maltodextrin at 5%, resulting good texture properties (hardness, chewiness and gumminess). In addition, changes in moisture contents, aw values, and color parameters were similar to the control sample. To improve the shelf life of the product, the effect of temperature on X_m and T_g should be further investigated.

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