Effect of Storage Conditions on Qualities and Water Sorption Isotherm of Khanom La

Woralak Panyathitipong[1], Sansanee Tempiam[1], Walaiporn Suttha[2], Nantawan Chomshome[2] and Supuksorn Masavang[1,*]

[1]Department of Food Science and Technology, Faculty of Home Economics Technology, Rajamangala University of Technology Phra Nakhon, Dusit, Bangkok 10300, Thailand
[2]Department of Food and Nutrition, Faculty of Home Economics Technology, Rajamangala University of Technology Phra Nakhon, Dusit, Bangkok 10300, Thailand

(*Corresponding author's e-mail: supuksorn.m@rmutp.ac.th)

Abstract

This research aimed to investigate the effects of atmospheric storage condition (at 0.33 and 0.75 water activity, a_w) and storage time on the qualities of Khnom La. The sorption isotherm also was studied. The moisture content of Khanom La was adjusted using the saturated salt solution at different relative humidity levels. The sorption isotherm, hardness, color and peroxide values of Khanom La were then evaluated. The sorption isotherm data of Khanom La was fitted to BET and GAB models. The experimental result showed that monolayer values of the sample were in the range of 3.15 to 3.39 g water/ 100 g dry solids when its water activity was in the range of 0.11 to 0.84. Khanom La samples were stored in closed containers at an ambient temperature either at 0.33 and 0.75 a_w for 35 days. Lightness and hardness of Khanom La decreased, while the redness yellowness and peroxide value of those desserts increased with storage time. The effects were more pronounced when samples were stored at 0.75 a_w. The results indicated that crispy Khanom La might retain the desirable attributions during days of storage in a sealed container at low water activity.

Keywords: Hardness, Khanom La, Peroxide value, Sorption isotherm, Water activity

Introduction

Crispy Khanom La is a traditional dessert of the Southern region of Thailand and is a famous product of Nakhon Si Thammarat province. It is made by mixing rice flour and sugar and then pour the flour using containers with many holes into the pan that is thinly covered by egg yolk to create a golden web and then fold the web into a roll. Khanom La is one of desserts used during the Festival of the 10th Lunar Month. Khanom La can be classified into as La Chet and La Korb. Khanom La Chet is thick and has less oil with a soft texture, whereas Khanom La Korb is a crispy one which contains more sugar and is deep-fired in the vegetable oils [1]. Nowadays, people are selling Khanom La all year round, not only in October that has an event anymore. Crispy Khanom La is deep-fat fried food. During cooking of deep-fried food products, frying oils are subjected to various alterations such as hydrolysis and thermal oxidation [2]. Heating transfer from oil to fried foods leading to mass transfer of water evaporation and oil uptake. Apart from heat, starches gelatinize, proteins denature, moisture and some nutrients are lost specifically vitamins, flavors develop, color change, crispness is produced, crust is formed and pores occur accompanied by structural changes. These changes lead to the development of the golden-brown color, fried aroma, crispy texture and improve the overall palatability of fried products [3,4]. The major problem associated with frying is the deterioration of oil over time. During frying, the fat is exposed to light, elevated temperatures, and atmospheric oxygen, hence, a number of changes take place in oil, involving a complex pattern of thermolytic and oxidation reactions. Oxidation of oil results in the formation of hydroperoxides, the primary oxidation product. These peroxides decompose free radicals to form a variety of chemical products [5,6]. A major consequence of lipid oxidation is the production of volatiles that impart odors and flavors to the rancid [5]. Moreover, several factors affecting fat uptake and qualities of fried products have been discussed such as the kind and quality of frying medium and frying

parameters (time, temperature and vacuum condition) for French fried [6], deep-fired batter and bread coating for deep-fried prawns [7], fried pineapple, carrot, potato and apple chips [8,9].

Recently, Khanom La is packed in a plastic bag. According to this traditional packing process produces a short-shelf life of fried food. During storage, the texture of Khanom La always changed, especially crispness. The instability of crispness causes unacceptability of customers. Therefore, the parameters affecting the crispness of fried durian slices should be studied. Crispness is sensed through a combination of tactile, kinesthetic, visual and auditory. It represents the texture of food products. Normally, the crispness of the food products has been related to their water activity during storage [10]. Crispy Khamon-La contains low moisture content and fat content, making it susceptible to physicochemical and microbiological degradation under high relative humidity condition. Therefore, this research aimed to study at a water activity of crispy Khanom La. The sorption isotherm of Khanom La was presented. Moreover, hardness values of crispy Khanom La at storage at different water contents for 35 days were evaluated. The obtained results can be used to find the approaches to improve the packing process of Khanom La.

Materials and methods

Materials

Khanom La was purchased from local Khanom La processor at Nakhon Si Thammarat province, Thailand. The water content of the Khanom La was immediately evaluated. It contains 50 % rice flour, 25 % granulated sugar, 12 % palm sugar, 12 % water and 1 % egg yolk. Granulated and palm sugar was added into water and then put over the low heat until the sugar was completely dissolved. Then the syrup was mixed with flour slowly. For frying process, the mixture is poured into a can with holes in it. This is then swung above the preheated palm oil in circle motions until a kind of spider's web is weaved. In this work, Khanom La was set hard with golden brown color and a kind of poker is then used to make the cylinder shape. It was be cooled at room temperature and stored in a sealed plastic bags for sale. Khanom La samples were then cut into shorter cylinder with 1 inch in length for sorption isotherm and hardness determination and ground samples were prepared for color and peroxide measurements.

Sorption isotherm and modeling of crispy Khanom La

The adsorption isotherms were determined by the standard static, gravimetric method using a saturated salt solution prepare as recommended in [11]. Khanom La was placed in the desiccator containing P_2O_5 to reduce the water content of the Khanom La. Then Khanom La was kept in the container until its weight was constant. After that the Khanom La samples were placed at ambient temperature in the air-tight container containing saturated salt solutions including lithium chloride $(LiCl_2)$, magnesium chloride $(MgCl_2)$, potassium carbonate (K_2CO_3), magnesium nitrate $(Mg(NO_3)_2)$, sodium chloride $(NaCl)$ and potassium chloride (KCl) to receive water activity (a_w) at 0.11, 0.32, 0.44, 0.54, 0.75 and 0.84, respectively. The sample weights (m) were controlled until a constant value $(\Delta m < \pm 0.0005 \text{ g})$ was reached. The final water contents of the samples were then determined using Eq. (1).

$$M = \frac{M_{eq} - M_{dry}}{M_{dry}} \times 100 \tag{1}$$

where; M is water content (g water/100 g dry solids), M_{eq} is the weight of Khanom La after achieving equilibrium at given water activity, and M_{dry} is the weight of the sample after attaining equilibrium moisture content in a desiccator containing P_2O_5 [12].

The Brunauer-Emmett-Teller model (BET) and Guggenheim-Anderson-DeBoer (GAB) model as following equations were used to predict the water activity of the samples [13,14].
BET model:

$$M = \frac{m_0 C_{BET} a_w}{(1-a_w)(1-(C_{BET}-1)a_w)} \tag{2}$$

where; M is water content (g water/100 g dry solids), a_w is water activity, m_i is monolayer water content (g water/100 g dry solids), and C is sorption energy constant.
GAB model:

$$M = \frac{m_0 C_{BET} k a_w}{(1 - k a_w)(1 - (C_{BET} - 1) k a_w)} \tag{3}$$

where; M is water content (g water/g dry solids), a_w is water activity, m_0 is monolayer water content (g water/g solids), C is constant related to monolayer sorption heat, and k is constant related to multilayer sorption heat.

The constants of the equations were estimated by regression analysis using the Solver option of Microsoft Excel software (2019). To evaluate the goodness of fit of each model, the percentage deviation modulus (E) using Eq. (4), and the standard error of estimate is used [15].

$$E = \frac{100}{N} \sum_{i=1}^{N} \frac{|m_1 - m_{pi}|}{m_i} \tag{4}$$

where m_i is the experimental value, m_{pi} is the predicted value, and N is the number of experimental data.

Hardness measurement
A compression test was performed to analyze the hardness of Khanom La samples. A cylinder-shape sample was cut to make 1-inch long. The test was performed using a texture analyzer (Stable Micro Systems, TA.XT. Plus, UK). These specimens were subjected to deformation with single compression. A 50-mm cylinder probe was used with a constant speed of 5 mm/s until the sample was cracked. Hardness was expressed as the maximum force exerted during the 1st compression cycle.

Color measurement
The color for each Khanom la sample was measured using spectrophotometer (Konica Minolta, model CM-3500d, Japan), after calibration with black and white standard tiles (L* = 96.33; a* = +0.09; b* = +1.98). The color indexes are described by the lightness (L*, where L* = 0 for dark and L* = 100 for bright), the redness/greenness (a*, where +a* for red and –a* for green) and the yellowness/blueness (b*, where +b* for yellow and –b* for blue). Three measurements were taken for each sample.

Determination of peroxide value (PV)
A given weight (5.0 ± 0.05 g) of the samples into 250 mL glass stoppered Erlenmeyer flasks and the weights recorded. By graduated cylinders, 30 mL of the acetic acid-chloroform solution was added. The flasks were swirled until the samples were completely dissolved. Using 1 mL Mohr pipettes, 0.5 mL of saturated potassium iodide solution was added. The flasks were stoppered and the contents of the flasks were shaken for exactly 1 min then the flasks were placed in a dark place for 1 min. By graduated cylinders, 30 mL of distilled water were added, the flasks stoppered and shaken vigorously to liberate the iodine from the chloroform layer. Burettes were filled with 0.1 N sodium thiosulphate. One mL of the starch indicator was added to every flask and titration with the thiosulphate was done until the blue-grey color disappeared in every flask. A starch indicator was prepared by pouring 100 mL of hot distilled water to 2 g of starch. Also, titration was performed for blank. The peroxide values were computed utilizing the rule below:

$$\text{Peroxide value} = \frac{(S - B) \times N \times 1000}{weight\ of\ sample} \tag{5}$$

where; S is the volume of thiosulphate used in the titration of the sample (mL), B is the volume of thiosulphate used in the titration of the blank (mL), and N is the normality of sodium thiosulphate (N). To ensure the stability of the results, 3 replicates of every sample were analyzed.

Statistical analysis
All experiments were performed in triplicate. Data analysis was performed using the SPSS statistical software package (version 17; SPSS Inc.; Chicago, IL, USA). The 1-way analysis of variance (ANOVA) was determined. Duncan's multiple range test was used to establish the multiple comparisons of the mean values at a 95 % confidence level.

Results and discussion

Adsorption isotherm and mathematic model fitting of Khanom La
Khanom La was obtained from Baan Mea Prim, Nakhon Si Thammarat province. This snack was then packed in a vacuum-sealed plastic bag at room temperature. Moisture and fat content are important quality parameters of Khanom La sample. Before the storage experiment, the physicochemical characteristics of samples were determined and the results are presented in **Table 1**.

Table 1 Physiochemical characteristics of Khanom La before storage.

Physiochemical characteristics	Value
Water content (g/100 g dry solids)	2.31 ± 0.05
Water activity (p/p$_0$)	0.3102 ± 0.0004
Color	
Lightness (L*)	60.58 ± 0.13
Redness (a*)	10.91 ± 0.04
Yellowness (b*)	36.58 ± 0.05
Total crude fat (%)	12.79 ± 0.07
Hardness (N)	5.40 ± 0.54

Note: Mean (n = 3) $\pm$ standard error of estimation.

      The water sorption isotherm of Khanom La at ambient temperature was shown in **Figure 1**. The shape of the curve was typically sigmoid for starch-based materials. Interestingly, the moisture content almost constant for equilibrating water activity below 0.6 a$_w$, while moisture content shows a sharp increase for equilibrating water activity greater than 0.6 a$_w$. This observation may be attributed to the preferentially cross-linking of biopolymer matrix by sugars when the availability of water is low [16]. For a$_w$ higher than 0.6, the accessibility of the hydroxyl groups to water molecules increases due to the swelling of the biopolymer, so there is a rise inaccessibility of the polar groups to the water molecules. Furthermore, the observed behavior was typical of products with high sugar content, which absorb relatively small amounts of water at low water activities but exhibits a sharp increase in sobbed water at higher water activity.
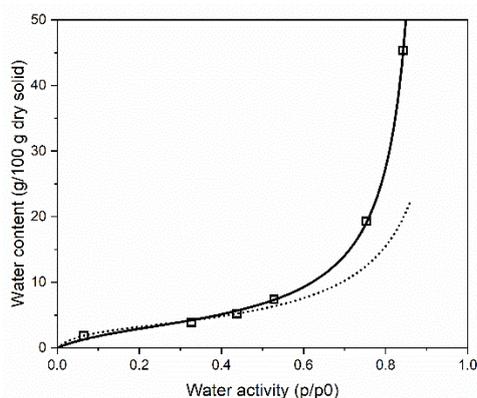

Figure 1 Sorption isotherm of Khanom La; □ represented experimented data; solid line represented GAB model for whole data range; • represented experimental data; and dot line represented BET model up to 0.52 a$_w$ data fitting.

      This could be due to the effect of solute-solvent interactions associated with sucrose instead of the previous prevailing effect of sucrose-biopolymer interactions hindering interactions with water molecules [17,18]. Similar observations were reported for dry biscuits [19], sponge cakes [20], and cereal bars [21]. **Table 2** showed the values of fitted BET and GAB models and the associated E value. In the case of BET, the data was modeled both whole ranges and up to 0.52 a$_w$, as suggested in the literature [22-24]. The E values obtained on applying the 2 models were < 5 %, showing accurate fits. The monolayer water content (m_0) given by BET and GAB model were 3.15 g water/100 g dry solids and 3.39 g water/100 g dry solids, respectively. The value revealed the amount of water that was adsorbed to specific sites on the food surface and had related to food stability [23]. Most foods are known to be the most stable to quality changes during storage at a monolayer value [25]. Accordingly, Khanom La in the range of 0.11 - 0.44 a$_w$ may stay at its best during storage. Monolayer moisture content of GAB was higher than BET which agreed with [25] for corn chips; [26] for yam flour and [27] for extruded waxy maize starch-glycerol systems.

Table 2 BET and GAB values for Khanom La and their associated error function (E).

Model	Model parameters			
	m_o	C	K	E
GAB (whole range)	3.39	7.21	0.96	8.25
BET (modelled up to 0.52 a_w)	3.15	7.91	-	1.17

From the fitting parameters in **Table 2**, the C_{BET}, C_{GAB} and k_{GAB} are the thermodynamic parameters. According to Brunauer *et al.* [13], C_{BET} is related to the difference in heat of sorption between the monolayer and the multilayer of food matrix as well as k_{GAB} contributes similarly to C_{GAB} to the fitting. In the case of k_{GAB} towards a value of 1 would indicate a reduction in sorption energy in Khanom La at the multilayer, suggesting a de-structuring behavior from a multilayer to a bulk liquid like domain [28]. The difference in this parameter from GAB and BET would come mainly fitting procedure; in the case of GAB it includes the extra parameter k_{GAB}, which contributes similarly to C_{GAB} to the model fitting. Theoretically, the GAB equation separates the sorption energies in the monolayer and multilayer domain, therefore it would be expected to obtain smaller values for C_{GAB} compared to C_{BET} [23]. This trend also was reported for this work (**Table 2**).

Effect of storage condition and storage time on the hardness of Khanom La
The hardness values of Khanom La samples stored at 0.33 and 0.75 a_w for 35 days were shown in **Figure 2**. For samples stored at 0.33 a_w in the range of 64.31 to 68.45 N, the hardness was almost constant. These were still crispy. However, the hardness of samples stored at 0.75 a_w showed that the water activity and storage times significantly affected the hardness and the results were in the range of 17.40 to 65.29 N. Hardness of Khanom La decreased until 21 days-storage, then it was independent of storage time.
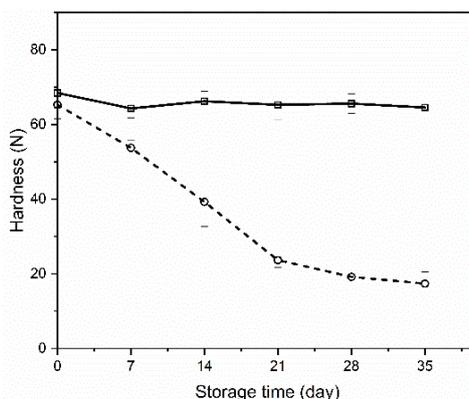

Figure 2 Hardness of Khanom La stored at 0.33 a_w (•, solid line) and 0.75 a_w (○, dash line) for 35 days. Each point represents the mean of 3 independent experiments and error bars indicates ± SE.

These resulted in a softening of texture, which might be due to the plasticizing effect of water that affected on the glass transition temperature of the sample. Hydration of cereal based-products is known to lead to plasticization and softening of the starch-protein matrix and thus to alter the strength of the product during storage at a high relative humidity environment [29]. As in **Figure 2**, these results indicated that the Khanom La was not crispy when the water content more than 3.39 g water/100 g dry solids as its monolayer water content by GAB fitting (**Table 2**). However, the result should be compared with the sensory results.

Effect of storage condition and storage time on PV of Khanom La
Storage conditions and times as well as their interactions significantly affected the peroxide values (PV) of lipids extracted from the Khanom La samples (**Figure 3**). Samples are generally oxidized during storage that is dependent upon the storage time and condition.
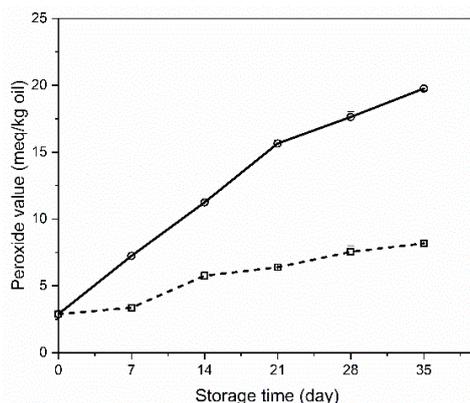
Figure 3 Peroxide values of oil extracted from Khanom La stored at 0.33 a_w (☐, dash line) and 0.75 a_w (O, solid line) for 35 days. Each point represents the mean of 3 independent experiments and error bars indicates ± SE.

The PV of lipid extracted from the snacks was progressively increased ($p < 0.05$) during storing, which is indicative of the occurrence of oxidation of the samples. The PV of Khanom La stored at 0.75 a_w were higher ($p < 0.05$) than those stored at 0.33 a_w; moreover, the samples stored at lower a_w were oxidized at a much slower rate than those stored under higher a_w condition. The greater increase in PV indicates that the Khanom La stored at high a_w experienced auto-oxidation. The increase in lipid oxidation with a_w observed in this study was possibly due to more available free water, which dissolved and mobilized chemical species such as prooxidant metal ions as well as increased hydration and swelling of laver lipids, thereby exposing new reactive sites [30]. After 7, 14, 21, 28 and 35 day storages at low a_w, the PV of samples increased ($p < 0.05$) from 7.36 and 21.17 meq/kg oil, respectively, while those of snacks kept at high a_w for 7, 14, 21, 28 and 35 days increased ($p < 0.05$) to 13.24 and 30.52 meq/kg oil, respectively. These findings in the present study agreed with the reported by [31,32] who found similar trends in potato chips fried in high linoleic sunflower or cottonseed oil and then stored in either dark or light.

According to product formulation, Khanom La is made from rice flour, sugar and egg yolk, therefore the lipid oxidation products (lipid oxidation radical, hydroperoxides, aldehydes and epoxides) may also react with protein, starches, and other food components, indicating as co-oxidations [33]. These interactions might decrease the actually values of the lipid oxidation analysis due to the lipid oxidation products are removed from the reaction steam. Furthermore, the progress of co-oxidation degradation in low moisture foods has been slow resulting in the studies on the co-oxidation in food product is complicated [34]. Thus, the measurement of co-oxidation must be measured along with lipid oxidation products to provide accurately the full extent of oxidation. There are limited data on the co-oxidation lipids with other food components in fried foods.

Color parameter (lightness, redness and yellowness)
The changes observed in the color attributes of Khanom La storing at 0.33 and 0.75 a_w atmospheric conditions are as presented in **Figure 4** as typical images. The visual observation of these images revealed that the color of Khanom La stored at 0.33 a_w and 0.75 a_w for 35 days was slightly darker than the sample at 0-day storage. Due to the subjective perception of color and its variety from observer, coloring measuring devices are used a reliable color determination. According to the consideration of the storage time, significant differences were found in the L*, a* and b* values of sample stores at both low and high a_w. Additionally, the photo of Khanon La were compared the visual color before and after 35 days of storage (**Figure 5**).
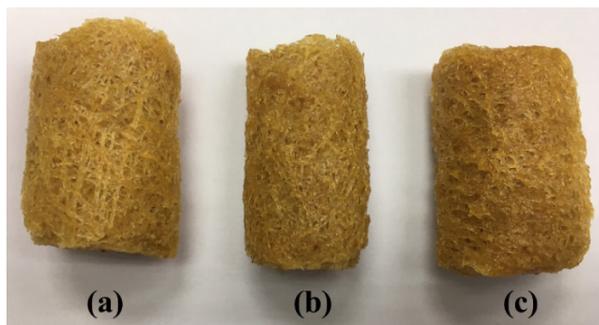
Figure 4 Photographs of Khanom La at 0-day storage (a), 35-day storage at 0.33 a_w (b) and 35-day storage at 0.75 a_w (c).

Lightness, a critical color parameter of fried foods, is usually used as a quality control determinant when determining product acceptance [35]. For all the storage conditions in this study, L* values decreased as storage time progressed. It was more pronounced for samples stored at 0.75 a_w.

Low L* values indicate a dark color and are mainly associated with non-enzymatic browning reactions which accelerates at high temperature [36,37]. This trend is similar to what was observed by Odenigbo *et al*. [38]. As with the case of the redness parameter, a* is also affected by the a_w of atmospheric storage conditions and storage time (**Figure 5**).
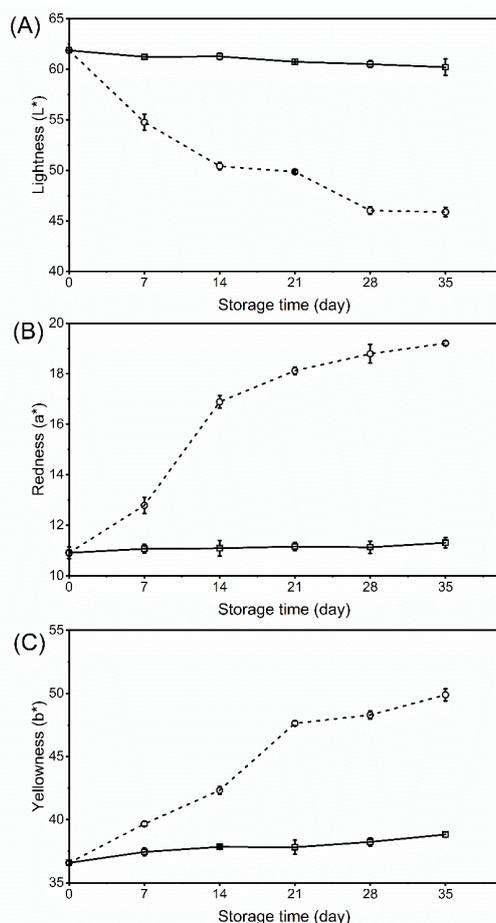

Figure 4 Changes of L* (A), a* (B) and b* (C) values in Khanom La stored at 0.33 a_w (•, solid line) and 0.75 a_w (○, dash line) for 35 days. Each point represents the mean of 3 independent experiments and print bars indicates ± SE.

As shown in this figure the redness of Khanom La increased during storage and this effect was more pronounced for sample keeping at high aw. For samples stored at 0.33 a_w, a* was independent of storage times. A similar trend was shown for yellowness (b*) in **Figure 5**.

Lightness in current work was stored at an ambient temperature the brightness increased while a* and b* decreased with the passing of storage days. The results agreed with values provided by Lee and Pangloli [32] with a decrease in brightness of potato chips stored in closed containers at an ambient temperature either in dark or under fluorescent light for 6 weeks. The lightness of sample decrease, while redness and yellowness increased with storage time.

Changes in color values (L*, a* and b*) of Khamon La in this study might be due to the lipid oxidation that generally occurred in this fried dessert during storage. In the presence of basic groups in proteins, aldol-condensation of carbonyls produced from lipid oxidation may catalyze and results in the formation of brown pigments [32]. Furthermore, the increase in redness (a*) and yellowness (b*) for all samples keeping at both low and high a_w may imply that all samples experienced an increase in browning with increased storage time. This could be due to the Maillard reaction resulting from the utilization of available reducing sugars and amino groups in proteins [38]. These observations are in line with the experimental results of [39].

Furthermore, a decrease in L* during storage is probably due to the lipid oxidation can also promote an increase in browning of foods. According to Bordin *et al*. [2], color development in fried food is proportional to the amount of reducing sugars and amino acid in the food, since both browning and Maillard reactions are stimulated by the level of oxidation of the food. Additionally, the carbonyl compounds produced in the lipid oxidation pathway will compete with carbohydrate-derived carbonyls for amino compounds to produce carbonyl-amine reaction products for browning reaction [40].

Conclusions

The sorption isotherm of Khanom La was classified as the sorption isotherm type II that is usually found in high starch and protein. BET and GAB models can be used to predict sorption isotherm of the fried durian slice. Depending on storage condition and storage time, the relation between water activity and hardness of Khanom La was found. The hardness of Khanom La reduced which increases its water content, resulting in the sample was not crispy when the water content more than 3.39 g water/100 g dry solids as the monolayer of GAB fitting. According to the peroxide and chromatic values, Khanom La was degraded progressively during storage in the sealed container within 35 days. Furthermore, this work indicated that the effects are pronounced when samples store under high relative humidity conditions. Additional research is needed to investigate ways to retard the lipid oxidation as well as water migration of Khanom La during storage.

Acknowledgements

References

[1] A Thanonkeaw and P Ruankla. Effect of frying oil on quality changes of Khanom La during storage at room temperature. *RMUTSV Res. J*. 2017; **8**, 203-18.

[2] K Bordin, MT Kunitake, KK Aracava and CSF Trindade. Changes in food caused by deep fat frying: A review. *Arch. Latinoam. Nutr*. 2013; **63**, 5-13.

[3] E Tabee, M Jagerstad and PC Dutta. Frying quality characteristics of French fries prepared in refined olive oil and palm olein. *J. Am. Oil Chem. Soc*. 2009; **86**, 885-93.

[4] JC Lumanlan, WMADB Fernanado and V Jayasena. Machanisms of oil uptake during deep frying and applications of predrying and hydrocolloids in reducing fat content of chips. *J. Food Sci. Technol*. 2020; **55**, 1661-70.

[5] D Goburdhun, SB Jhaumeer-Laulloo and R Musruck. Evaluation of soybean oil quality during conventional frying by FTIR and some chemical indexes. *Int. J. Food Sci. Nutr*. 2001; **52**, 31-42.

[6] SL Melton, S Jafar, D Sykes and MK Trigiano. Review of stability measurements for frying oils and fried food flavor. *J. Am. Oil Chem. Soc*. 1994; **71**, 1301-8.

[7]   A Kita, G Lisinska and M Powolny. The influence of frying medium degradation on fat uptake and texture of French fries. *J. Sci. Food Agric.* 2005; **85**, 1113-8.

[8]   KY Voong, AB Norton, TB Mills and IT Norton. Characterisation of deep-fried batter and breaded coatings. *Food Struct.* 2018; **16**, 43-9.

[9]   V Dueik and P Bouchon. Vacuum frying as a route to produce novel snacks with desired quality attributes according to new health trends. *J. Food Sci.* 2011; **76**, E188-E195.

[10]   A Hirte, RJ Hamer, MBJ Meinders, KVD Hoek and C Primo-Martin. Control of crust permeability and crispness retention in crispy breads. *Food Res. Int.* 2012; **46**, 92-8.

[11]   Z Yan, MJ Sousa-Gallagher and FAR Oliveira. Effect of temperature and initial moisture content on sorption isotherms of banana dried by tunnel drier. *Int. J. Food Sci. Technol.* 2008; **43**, 1430-6.

[12]   KJ Hellevang. *Grain moisture content effects and management*. North Dakota State University Extension Service, North Dakota, 1995, p. 1-8.

[13]   S Brunauer, PH Emmett and E Teller. Adsorption of gases in multimolecular layers. *J. Am. Chem. Soc.* 1938; **60**, 309-19.

[14]   CVD Berg and S Bruin. *Water activity and its estimation in food systems: Theoretical aspects. In*: LB Rockland and GF Stewart (Eds.). Water activity: Influences on food quality. Academic Press, New York, 1981, p. 2-61.

[15]   S Basu, US Shivhare and AS Mujumdar. Models for sorption isotherms for foods: A review. *Dry. Technol.* 2006; **24**, 917-30.

[16]   P Hazaveh, AM Nafchi and H Abbaspour. The effects of sugars on moisture sorption isotherm and functional properties of cold water fish gelatin films. *Int. J. Biol. Macromol.* 2015; **79**, 370-6.

[17]   JH Daly, D Hayward, J Liggat and AR Mackintosh. Ageing and rejuvenation of Biopol (TM), [poly(3-hydroxybutyrate-co-3-hydroxyvalerate)] copolymers: A dielectric study. *J. Mater. Sci.* 2004; **39**, 925-31.

[18]   E Tsami, D Marinos-Kouris and ZB Maroulis. Water sorption isotherms of raisins, currants, figs, prunes and apricots. *J. Food Sci.* 1990; **55**, 1594-7.

[19]   C Bourlieu, V Guillard, H Powell, B Valles-Pamies, S Guilbert and N Gontard. Modelling and control of moisture transfers in high, intermediate and low a_w composite food. *Food Chem.* 2008; **106**, 1350-8.

[20]   V Guillard, B Broyart, C Bonazzi, S Guilbert and N Gontard. Moisture diffusivity in sponge cake as related to porous structure evaluation and moisture content. *J. Food Sci.* 2003; **68**, 555-62.

[21]   BV Pallavi, R Chetana, R Ravi and SY Reddy. Moisture sorption curves of fruit and nut cereal bar prepared with sugar and sugar substitutes. *J. Food Sci. Technol.* 2013; **52**, 1663-9.

[22]   AH Al-Muhtaseb, WAM McMinn and TRA Magee. Moisture sorption isotherm characteristics of food products: A review. *Food Bioprod. Process.* 2002; **80**, 118-28.

[23]   JI Enrione, SE Hill and JR Mitchell. Sorption and diffusional studies of extruded waxy maize starch-glycerol systems. *Starch* 2007; **59**, 1-9.

[24]   CVD Berg. *Development of B.E.T.-like models for sorption of water on foods, theory and relevance. In*: D Simatos and JL Multon (Eds.). Properties of water in foods. Springer, Dordrecht, Netherlands, 1985, p. 119-31.

[25]   BK Adeoye, CJ Oladejo, AD Adeniran and HT Opawuyi. Sorption isotherm of corn chips made from blends of corn flour and bambara groundnut nut flour. *Am. J. Chem. Eng.* 2020; **8**, 70-5.

[26]   TP Labuza. Sorption phenomena in foods. *Food Technol.* 1968; **22**, 15-24.

[27]   OJ Oyelade, T Tunde-Akintunde and JC Igbeka. Predictive equilibrium moisture content equations for yam (Dioscorea rotundata, Poir) flour and hysteresis phenomena under practical storage conditions. *J. Food Eng.* 2008; **87**, 229-35.

[28]   EJ Quirijns, AJBV Boxtel, WKPV Loon and GV Straten. Sorption isotherms, GAB parameters and isosteric heat of sorption. *J. Sci. Food Agric.* 2005; **85**, 1805-14.

[29]   N Martinez-Navarrete, G Moraga, P Talens and A Chiralt. Water sorption and the plasticization effect in wafers. *Int. J. Food Sci. Technol.* 2004; **39**, 555-62.

[30]   M Mathlouthi. Water content, water activity, water structure and the stability of foodstuffs. *Food Control* 2001; **12**, 409-17.

[31]   P Pangloli, SL Melton, JL Collins, MP Penfield and AM Saxton. Flavour and storage stability of potato chips fried in cottonseed and sunflower oils and palm olein/sunflower oil blends. *J. Food Sci.* 2002; **67**, 97-103.

[32]   JH Lee and P Pangloli. Volatile compounds and storage stability of potato chips fried in mid-oleic sunflower oil. *Int. J. Food Prop.* 2013; **16**, 563-73.

[33] M Mariscal and P Bouchon. Comparison between atmospheric and vacuum frying of apple slices. *Food Chem*. 2008; **107**, 1561-9.

[34] KM Schaich. Lipid co-oxidation of proteins: One size does not fit all. *Int. News Fats Oils Relat. Mater*. 2014; **25**, 134-9.

[35] H Wazir, SY Chay, M Zarei, FS Hussin, NA Mustapha, WZW Ibadullah and N Saari. Effects of storage time and temperature on lipid oxidation and protein co-oxidation of low-moisture shredded meat products. *Antioxidants* 2019; **8**, 486.

[36] V Dueik, P Robert and P Bouchon. Vacuum frying reduces oil uptake and improves the quality parameters of carrot crisps. *Food Chem.* 2010; **119**, 1143-9.

[37] F Salehi. Color changes kinetics during deep fat frying of kohlrabi (*Brassica oleracea var. gongylodes*) slice. *Int. J. Food Prop.* 2019; **22**, 511-9.

[38] A Odenigbo, J Rahimi, M Ngadi, D Wees, A Mustafa and P Seguin. Quality changes in different cultivars of sweet potato during deep-fat frying. *J. Food Process. Technol.* 2012; **3**, 156.

[39] AB Oyedeji, OP Sobukola, F Henshaw, MO Adegunwa, OA Ijabadeniyi, LO Sanni and KI Tomlins. Effect of frying treatments on texture and colour parameters of deep fat fried yellow fleshed cassava chips. *J. Food Qual.* 2017; **2017**, 8373801.

[40] R Zamora and FJ Hidalgo. The Maillard reaction and lipid oxidation. *Lipid Technol.* 2011; **23**, 59-62.