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Quality prediction of nipa palm fruit during osmotic dehydration and drying process

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Abstract

This research aimed to develop osmotic dehydrated (OD) nipa palm fruit, study mass transfer and develop regression models for quality prediction of dried OD nipa palm fruit during the OD and drying processes. The samples in size 1.5x1x0.2 cm^3 were immersed in 65% sucrose solution at 25°C in a water bath with the ratio of sample to solution 1:5 (w/w). During the OD, when the immersion time increased, the moisture content (MC) of OD nipa palm fruit was decreased, while solid gain (SG) and water loss (WL) were increased. OD process of nipa palm fruit reached the equilibrium point in 12 h with 26% SG. Initial MC of samples was 85.98-86.36% (wet basis). After the OD, MC, WL and SG were in the range of 39.64-44.50%, 62.28-62.86% and 25.89-26.47%, respectively. The exponential models were the best models to predict MC, WL and SG. The OD nipa palm fruit was dried in a hot air oven at 50, 60 and 70°C for 240 min. The effects of SG and drying temperature on the qualities of OD nipa palm fruit were studied. The results showed that the drying time was in the range of 180-240 min so that the MC and water activity (a_w) were lower than 18% and 0.75, respectively. Based on the high coefficient of determination and low average mean squared error, the 2nd order polynomial type was suitable to predict MC, a_w and hardness of the dried OD nipa palm fruit during the drying process.

Introduction

Nipa palm *(Nypa fruticans)* is a monoecious palm with special characteristics. Contrast to usual palms like coconut *(Cocos nucifera)* and oil palm *(Elaeis guineensis)*, it thrives in river estuaries and brackish water environment in which salt and fresh water mingle. Nipa palm was found in Southeast Asia (Tamunaidu *et al*, 2011). Their all parts can be used for several purposes. For example, the sap is a source of nipa sugar, around 14-17% sucrose which widely used to produce vinegar, alcohol, and fermented beverage for example they called “tuba” or “soom” in the Philippines, “arak” or “tuak” in Indonesia, and “toddy” in Malaysia, India, and Bangladesh. Young seeds can be eaten or preserved in syrup; in Malaysia they flavor a commercial ice cream (“attap chi”) and enter local ice confections (Hamilton et al, 1988). But nipa palm fruits in syrup or fresh fruits have short shelf-life because they have high moisture content (MC) and water activity (a_w). Too high MC and aw will affect the product by micro organism and bad qualities. Osmotic dehydration (OD) and drying processes are promising food preservative techniques that may lead products to low MC and aw.

OD is a pre - processing step prior to drying and freezing of food products. An OD process of food can remove water from food by soaking it in a hypertonic solution, so that water and little amounts of natural solutes are transferred from the food to the solution and solutes migrate from the solution into food (Lertworasirikul and Saetan, 2010). A hypertonic solution will operate a high osmotic pressure that promotes the diffusion of water from the tissue into the solution and the diffusion of solutes from the osmotic solution into the tissue. OD can reduce MC of products by approximately 50%, also reduces aroma losses and enzymatic browning, increases sensory acceptance. The characteristics of the osmotic agent used, such as its molecular weight and ionic behavior, strongly affect dehydration, both water loss (WL) and solid gain (SG). Moreover, the sensory and nutritive properties of the final product can be affected by the solute used in the osmotic process and it was found that sucrose provides a greater WL and smaller SG when compared to glucose (Silva *et al*, 2014). However, the amount of water remaining in the OD sample is normally still high and a_w is generally higher than 0.9, which do not ensure the stability of products. When shelf stability is an ultimate process objective, other complementary methods of water removal, such as convective drying, freeze drying,

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freezing, etc. are suggested. (Lenart and Cerkowniak, 1996)

Drying is the most widely used technique for food preservation and extends the food shelf-life. The objective in drying process is to reduce MC to a level, which provides safe storage over an extended period. Also, it reduce weight and volume, minimizing packaging, storage and transportation costs (Doymaz, 2007) but the color of the product will change from the original (Barbosa, 2015) and the surface was hardened (Orikasa *et al.*, 2008). Therefore, using OD as a pre-processing step before drying will help improve product characteristics. The most usual drying method is hot air drying (Maskan, 2001). Hot air heats up the samples to empowering the mass diffusion.

Regression model is a mathematical tool (Casla *et al*., 2011) that is commonly used in quantitative analysis (Qiu *et al*., 2015). This model is usually used to determine the relationship between multiple independent variables and dependent variable (Rebechi *et al*., 2016) and used to predict independent variables that desire to study (Khongchoo, 2008). Jain *et al*. (2011) studied the process temperature, syrup concentration, and process time for OD papaya and they found that the regression equation of second order was the best fit for all experiments. Sridevi and Genitha (2012) used Response Surface Methodology (RSM) to investigate WL, SG and weight reduction (WR) and found that quadratic model was the best fit for all experiments. So far there has been no research on the quality prediction using the regression model for nipa palm during OD and drying processes.

Therefore, the aims of this research were to develop OD nipa palm fruit, study mass transfer, and develop regression models to predict qualities of samples during the OD and drying processes.

Materials and Methods

Sample preparation

Nipa palm fruit samples were obtained from Samut Songkhram province. Nipa palm fruit was shelled off before used, and then was rinsed in water and cut into 1.5x1x0.2 cm^3. The average initial MC of the sample was 86.17% in wet basis (wb). Physical characteristics were determined; color using Spectrophotometer (Minolta, CM-3500d, Japan), a_w using Aqualab (Aw CX3TE), hardness determined using Lloyd (TA500) and chemical compositions (AOAC, 2000) were analyzed.

The effect of immersion time on mass transfer of nipa palm fruit during osmotic dehydration

The samples were immersed in sucrose solution with 65°Brix in the ratio of sample to solution 1:5 at a constant temperature (25°C). Samples were taken every 1 h for the study of mass transfer during OD. The following mass transfer parameters during OD were calculated: MC, WL and SG (Rózek *et al.*, 2010; Changchub, 2010). Then, regression models in linear, 2nd order polynomial, exponential forms were used to predict MC, WL and SG.

$$\text{Water loss} = \frac{M_t x_t^W - M_0 x_0^W}{M_0} \times 100 \quad (1)$$

$$\text{Solid gain} = \frac{M_t x_t^{SS} - M_0 x_0^{SS}}{M_0} \times 100 \quad (2)$$

where M is the mass of food and x is the mass fraction. The subscripts 0 and t indicate initial immersion time and immersion time at time t. The superscripts w and ss indicate moisture and solids gain. The mass fraction of each component is expressed as g/g on a wet basis.

The effects of drying parameters on product characteristics

The experimental design was 3x3 factorial in CRD. The drying experiments were performed for 3 initial temperatures; 50, 60 and 70°C and 3 initial %SG; 20, 23 and 26%. The samples were then taken every 1 h for quality measurement. MC and a_w during the drying process of the dried OD nipa palm fruit must less than or equal to 18% and 0.75, respectively, following the standards of Thailand Industrial Standards Institute Ministry of Industry (2007) for product standard of dried fruits (TISI.136/2007). MC and a_w followed the requirements of TISI.136/2007 when drying OD nipa palm fruit for 4 h.

MC, a_w and hardness measurements and data acquisition were performed completely for each initial drying temperature and %SG. During the drying process, the samples were drawn every 20 min starting from 0 until 240 min (4 h) to determine the average moisture content (%, wb) using a vacuum oven (model VD53, Binder, Germany), a_w using a Aqualab (Aw CX3TE) and hardness using Lloyd (TA500).

Development of regression models for quality prediction of nipa palm fruit during osmotic dehydration and drying process

Regression analysis was used for predicting the qualities of OD nipa palm fruit during the OD and the drying processes. To develop and determine the performance of the regression model for the

OD process, experimental input–output data were collected every 1 h from 0 to 15 h. The input was OD time, and the outputs were MC, WL, and SG. Therefore, there were totally 16 input–output pairs. The number of samples for training and validating were 80% and 20%, respectively. For the drying process, experimental input–output data were collected every 20 min from 0 to 240 min interval for 3 levels (50, 60 and 70°C) of the temperature settings and 3 levels of %SG (20, 23 and 26%). The outputs were MC, a_w and hardness. Therefore, there were totally 117 input–output pairs. The number of samples for training and validating were 80% and 20%, respectively.

SPSS version 12 was used to develop and estimate the performance of the regression model by considering mean square error (MSE) and coefficient of determination (r^2). For the OD process, linear, 2nd order polynomial and exponential regression models were used to predict MC, WL and SG of samples. The format of linear, 2nd order polynomial and exponential models were $t=ax+b$, $t=ax^2+bx+c$, and $t=a^x$, respectively, where x was OD time (hours), t was a target output, which was MC, WL, or SG, and a, b, c were parameters of the models.

For the drying process, linear and 2nd order polynomial models were used to fit MC, a_w and hardness of the OD samples. In the drying process, the exponential could not be used to model because there were 3 input and 3 outputs variables. The format of linear and 2nd order polynomial equations for the drying process were $t= ax+by+cz+d$ and $t= ax^2+by^2+cz^2+dx+ey+fz+gxy+hxz+iyz$, respectively, where x was SG, y was drying time (min), z was temperature (°C), and a, b, c, d, e, f, g, h and i were parameters of the models.

Results and Discussion

Determination of characteristics of nipa palm fruit

Physical characteristics and chemical compositions of fresh nipa palm fruit were analyzed as shown in Table 1. The physical characteristics showed that a_w, L^*, a^*, b^* and hardness values were in the range of 0.989-0.993, 44.58-45.32, -1.96-(-1.95), -6.88-(-6.86) and 2.38-3.44 N, respectively.

The chemical compositions showed that MC, fat, fiber, protein, ash and carbohydrate were in the range of 85.98-86.36%, 0.24-0.30, 7.99-8.37, 1-1.24, 0.52-0.76 and 3.57-3.69 g/100g, respectively.

The effect of immersion time on mass transfer of nipa palm fruit during osmotic dehydration

MC, WL and SG of nipa palm fruit during OD were show in Figure 1. MC was decreased but WL and SG were increased because the OD process could remove water and moisture from the samples; therefore, MC was decreased when the immersion time was longer. On the other hand, WL and SG were increased when the immersion time increased because hypertonic solutions provided a high osmotic pressure that promoted the diffusion of water from the product tissue into the solution and the diffusion of solutes from the osmotic solution into the tissue of the samples. The OD process of nipa palm fruit reached the equilibrium point in 12 h with 26%SG. It was also found that %SG from the OD process at 6, 9 and 12 h increased at the same rate from 20, 23 to 26%, respectively.

Table 1. Physical and chemical characteristics of nipa palm fruit

Quality	value
1. Physical	
L*	44.95±0.37
a*	-1.96±0.01
b*	-6.87±0.01
Water activity (a_w)	0.993±0.04
Hardness (N)	2.91±0.53
2. Chemical (g/100g)	
Moisture content (wet basis)	86.17±0.19
Fat	0.27±0.03
Crude fiber	8.17±0.19
Protein	1.12±0.12
Ash	0.64±0.12
Carbohydrate	3.63±0.06

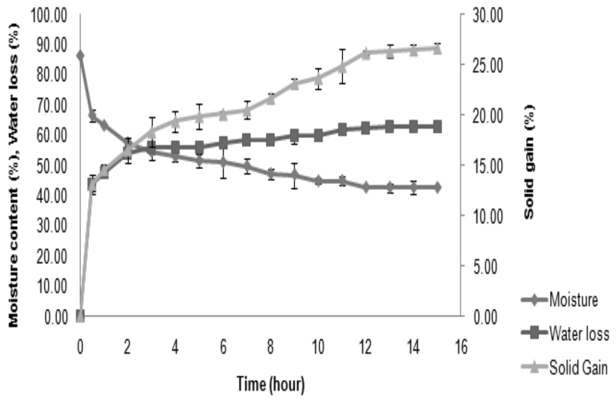

Figure 1. Effect of immersion time on moisture content (%), water loss (%) and solid gain (%) at different osmotic dehydration time of nipa palm fruit

The effects of drying parameters on product characteristics

The samples with 20, 23 and 26% SG were dried at 50, 60 and 70°C, and then sampled every 1 h. MC and a_w followed the standard requirements of TISI.136/2007 after 4 h of drying time. MC, a_w and hardness were determined every 20 min starting from 0 until 240 min. It was found that MC and a_w

Table 2. Coefficient of determination (r^2) and mean squared error (MSE) from regression models for the prediction of moisture content, water loss, and solid gain during osmotic dehydration

Target output	Type	Model	r^2 predicted	MSE predicted	r^2 validated	MSE validated
Moisture content	Linear	$t=-2.0027x + 66.549$	0.6696	5.11	0.6692	6.02
	2nd order Polynomial	$t=0.2314x^2 - 5.3643x + 73.494$	0.8166	3.48	0.8153	4.23
	Exponential	$t=61.505 \exp(-0.029x)$	0.9199	1.58	0.9185	1.72
Water loss	Linear	$t=1.9635x + 40.094$	0.4189	9.76	0.4203	8.11
	2nd order Polynomial	$t=-0.3113x^2 + 6.485x + 30.753$	0.5920	6.73	0.5932	5.94
	Exponential	$t=49.433 \exp 0.0192x$	0.7739	4.07	0.7721	5.03
Solid gain	Linear	$t=1.1627x + 11.847$	0.7390	5.23	0.7382	6.05
	2nd order Polynomial	$t=-0.0949x^2 + 2.5419x + 8.9976$	0.8201	3.17	0.8196	3.96
	Exponential	$t=14.9990 \exp 0.0441x$	0.9177	2.83	0.9164	3.12

were significantly decreased ($p \leq 0.05$) with the drying time. However, hardness was significantly increased ($p \leq 0.05$) since the samples had less MC during the drying process as shown in Figure 2. When the samples had less MC, their texture were hardened corresponding with the results from Aghbashlo *et al.*(2009), in which they reported that the surface moisture evaporated very quickly due to high heat and mass transfer coefficients.

Development of regression models for quality prediction of nipa palm fruit during osmotic dehydration and drying process

For the OD process, linear, 2nd order polynomial, and exponential regression models were used to predict MC, WL and SG of the samples. Table 2 showed MSE and r^2 of nipa palm fruit during the OD process. The results from Table 2 showed that regression analysis could be used to predict MC, WL and SG of OD nipa palm fruit during the OD process since they had high r^2 and low MSE. The exponential models showed better r^2 and MSE values for all predicted characteristics than other models.

For the drying process, linear and 2nd order polynomial models were used to fit MC, a_w and hardness of the OD samples. Table 3 showed MSE and r^2 of dried OD nipa palm fruit during the drying process. The results from Table 3 showed that 2nd order polynomial models were appropriate for predicting MC, water activity and hardness of OD nipa palm fruit during the drying process since they had significantly higher r^2 and lower MSE values than linear regression models for all characteristics.

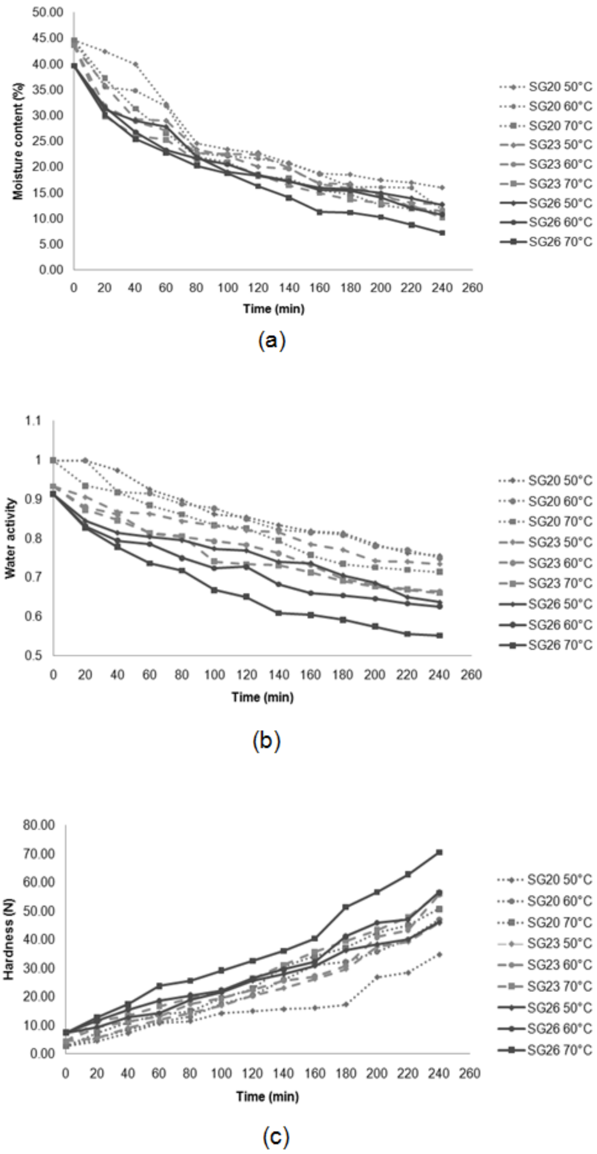

Figure 2. Moisture content (a) water activity (b) and hardness (c) of osmotic dehydrated nipa palm fruit when drying at 50, 60 and 70°C

Conclusions

This study demonstrated that the OD process of nipa palm fruit in 65% sucrose solution reached the equilibrium point at 12 h with 26% of solid gain. The

Table 3. Coefficient of determination (r^2) and mean squared error (MSE) from regression models for the prediction of moisture content, water activity, and hardness

Target output	Type	Model	r^2 predicted	MSE predicted	r^2 validated	MSE validated
Moisture content	Linear	$t=46.707-0.235x\ 0.111y-0.108z$	0.8550	3.5187	0.8610	3.3214
	2nd order Polynomial	$t=-17.153+4.477x-0.323y+0.58z-0.126x^2+0.001y^2-0.006z^2+0.006xy+0.006xz$	0.9570	1.9732	0.9556	2.2347
Water activity	Linear	$t=1.608-0.022x-0.001y-0.003z$	0.9450	0.0246	0.9432	0.0315
	2nd order Polynomial	$t=0.839+0.003x+0.011z+0.000002849x^2+0.000002.35y^2-0.00003205z^2-0.00001.458xy-0.00001457yz$	0.9720	0.0181	0.9731	0.0174
Hardness	Linear	$t=-56.53+1.483x+0.182y+0.43z$	0.9400	3.7279	0.9411	3.5243
	2nd order Polynomial	$t=46.282-3.81x-0.217y-0.257z+0.094x^2+0.001z^2+0.005xy+0.005xz+0.003yz$	0.9750	2.4542	0.9744	3.0026

MC of OD nipa palm fruit was decreased, while WL and SG were increased with the immersion time. During the drying process of OD samples with 20, 23 and 26% SG at 50, 60 and 70°C, the results showed that solid gain, drying temperature and drying time had influences on physical characteristics and MC of OD nipa palm fruit. MC and a_w followed the standard requirements of TISI.136/2007 after 4 h of drying time. The MC and a_w of samples were significantly decreased, while hardness was significantly increased ($p \leq 0.05$) with the drying time. The development of regression models showed that exponential models were the best models for prediction MC, WL and SG during the OD process, while 2nd order polynomial models were the best models for prediction of MC, water activity and hardness during the drying process based on high r^2 and low MSE values.

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