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Effects of frying temperature, frying time and cycles on physicochemical properties of vacuum fried pineapple chips and shelf life prediction

[1]Wanakamol, W. and [2*]Poonlarp, P.

[1]*Division of Food Science and Technology, Faculty of Agro-Industry, Chiang Mai University, Chiang Mai, 50100, Thailand*

[2]*Division of Food Engineering, Faculty of Agro-Industry, Chiang Mai University, Chiang Mai, 50100, Thailand*

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Abstract

Effects of frying temperature (90, 95°C), frying time (50, 60 minutes) and cycles (8 frying cycles; 4 continuous cycles/day) on physicochemical properties of vacuum fried pineapple (cv. *Phulae*) chips were studied. Frying temperature significantly ($p \leq 0.05$) affected moisture content while frying time affected color of pineapple chips. The optimal vacuum frying condition was at 60 mmHg (abs) and 95°C for 50 minutes. Significant changes in the chip color increased with increasing frying cycles. After the vacuum fried pineapple chips packed in metalized polyethylene pouches with 100% nitrogen flushing were stored in accelerated conditions (ASLT) at 0, 25, 35 and 45°C for 12 weeks, it was found that observed changes in color and rancidity (TBARs) in pineapple chips were time and temperature dependence. The predicted shelf life of pineapple chips stored at 30°C based on the changes in TBARs was 30 weeks.

Introduction

Pineapple (*Ananus comosus* L. Merr.) is a good source of fiber, minerals, vitamins (Yahia, 2011) and antioxidants namely flavonoids (Da Silva *et al.*, 2013), 100 g of fresh pineapple contains 1.4g of fiber, 47.8 mg of vitamin C and 109 mg of potassium (USDA, 2015). Phulae pineapple is a Geographical Indications (GI) of Chiang Rai, Thailand. The outstanding aroma, sweet taste and crispy texture make it is popularly fresh consumed. As pineapple is abundantly produced and harvested throughout the year, oversupply increases postharvest loss while decreases the market value (Techavuthiporn *et al.*, 2017). Converting fresh pineapple to value-added products is necessary to alleviate this problem but less study was done with Phulae. Deep frying is a dehydration process involving heat and mass transfer (Fellows, 2009). Vacuum frying is an alternative frying technology that is often applied to heat sensitive materials as fruits and vegetables. Under a low pressure, preferably lower than 6.65kPa (Moreira, 2014), a boiling point of water decreases below 100°C, hence high heat is not required for frying. Vacuum frying at lower temperatures helps preserve color, flavor and nutritional quality (Da Silva and Moreira, 2008; Fellows, 2009; Dueik *et al.,* 2010). Nunes and Moreira (2009) compared the amount of carotenoid retained in vacuum and atmospheric fried mango chips (6.2g kg^{-1} vs. 3.2g kg^{-1}, respectively). Da Silva and Moreira (2008) reported that the vacuum fried blue potato chips had anthocyanin retention about 60% higher than that fried in atmospheric fryer.

Nowadays, many health-conscious consumers prefer low fat foods. Many studies reported that vacuum fried products had lower oil content than traditional fried products. About 16% and 24% lower oil content was reported for vacuum fried green bean and sweet potato, respectively (Da Silva and Moreira, 2008), whereas vacuum fried carrot, potato and apple chips had lower oil content about 50%, 50% and 25%, respectively (Dueik and Bouchon, 2011). Vacuum frying has been reported to delay deterioration of frying oil quality. For instance, free fatty acid, p-anisidine value and total polar compound in sunflower oil used in vacuum and atmospheric frying were compared (Crosa *et al.*, 2014); they reported much lower values for vacuum fried oil as follows: 0.073, 25.8, 11.2 compared with 0.201, 207.0 and 25.0, respectively. The type of frying oil also has an important role on the rate of oil degradation. Fin *et al.* (2013) evaluated and compared quality of rice bran vs. palm oil used in deep frying of French fries. Free

*Corresponding author.
Email: *pichaya.aey@hotmail.com*

fatty acid of rice bran oil changed from 0.142% to 0.66%, whereas from 0.079% to 0.93% for palm oil. Debnath *et al.* (2012) studied effects of frying cycles on oil quality during deep frying of the traditional Indian food. The level of total polar compound in frying oil was less than 24% after 28 and 21 cycles for rice bran oil and palm oil, respectively. Oryzanol, phytosterols and vitamin E in rice bran oil may have provided antioxidant effects which retarded oil degradation (Watson *et al.,* 2014).

Shelf life is the time period in which a food product still retains its quality and safety and is acceptable to consumers. According to ISO 22000:2005, manufacturers need to communicate the shelf life information to consumers. Shelf life evaluation of food stored under actual condition may take much longer time; hence an accelerated shelf life testing (ASTL) is often used for shelf life prediction (Siripatrawan and Jantawat, 2008). Liu-ping *et al.* (2007) studied shelf life of vacuum fried carrot chips stored at 0, 10 and 25°C. Based on the acid value changes during storage, they predicted shelf life of carrot chips at 55.3, 23.4 and 8.8 months, respectively. Dak *et al.* (2016) predicted that microwave-vacuum dried pomegranate arils packed in aluminum laminated polyethylene could be stored for 6 months at room temperature based on the ASLT data under 38±1°C, 90±1% RH for 3 months.

This study was aimed to investigate the effects of frying temperature and frying time (based on preliminary test, 90°C and 95°C, 50 and 60 minutes were set for frying temperature and frying time, respectively) on physicochemical properties (moisture content, oil absorption and color) of vacuum fried pineapple chips, then the optimal frying condition was chosen. The second objective was to evaluate the changes in pineapple chips qualities (moisture content, oil absorption, color and rancidity) as affected by frying cycles. The last objective was to investigate quality (color and rancidity) deterioration of vacuum fried pineapple chips during ASLT storage at 0, 25, 35 and 45°C for 12 weeks and to predict the shelf life of this product.

Materials and methods

Materials

Pineapples (*Ananus comosus* L. Merr., cv. Phulae) were harvested on June-November 2015 in Chiang Rai, Thailand, transported to Chiang Mai, Thailand, stored in a room with air ventilation (27±3°C and 60±2% RH), and processed within 5 days. Pineapples were vertical cut into 4 equal parts, and then sliced into 5mm thick pieces using a slicer (Handheld Mandoline, Cuisipro, China). By the reason of health benefit and lower degradation rate than palm oil (Debnath *et al*., 2012, Fin *et al*., 2013, Watson *et al*., 2014), rice bran oil was chosen for this study. Rice bran oil (King brand, Thai Edible Oil Co., Ltd., Bangkok, Thailand) was purchased from a local market in Chiang Mai, Thailand.

Vacuum frying

The vacuum fryer used in this study was manufactured by the Owner Foods Machinery Co., Ltd., Bangkok, Thailand. Four different frying conditions at 60mmHg pressure were studied (90°C for 50 minutes, 90°C for 60 minutes, 95°C for 50 minutes, 95°C for 60 minutes). The oil tank was filled with 12 liters of rice bran oil and preheated. Once the oil temperature reached the target value, the frying basket with 1kg of sliced pineapple was placed in the frying vessel and the lid was closed. The vessel was depressurized to 60 mmHg (abs), and the preheated oil was transferred to the vessel until the oil level was above the basket lid. When frying was completed, the oil was transferred back to the oil tank, and the basket was centrifuged at 1000 rpm for 5 minutes to remove the excess oil. The vessel lid was opened after the pressure was back to atmospheric pressure, the vacuum fried pineapple chips were removed from the basket, allowed to cool to room temperature for 15 minutes, then vacuum packed in metalized polyethylene pouches (6 x 9 inch, 0.16 mm thickness) for further analysis. The effects of frying cycles on pineapple chip quality were studied with the chosen frying condition (i.e., 95°C for 50 minutes) up to 8 frying cycles (4 continuous frying cycles in the same day) without oil replenishment.

Accelerated Shelf Life Testing (ASLT)

Approximately 25 g of pineapple chips was filled into 6x9 inch metalized polyethylene pouches with 100% nitrogen flushing (HFE vacuum system, Henkovac, Netherland), which were then stored at 0 (control), 25, 35 and 45°C , ASLT storage condition for dry and intermediate moisture foods recommended by Brody and Lord (2000) for 12 weeks. The samples were taken for color and thiobarbituric acid (TBARs) determination at Day 0 and every 2 weeks of storage.

Determination of moisture and oil content and color

Moisture content of pineapple chips was determined in triplicate according to the AOAC method (AOAC, 2000) using a hot air oven (Memmert, UF 110, Germany). Oil content of pineapple chips was determined in triplicate by petroleum ether extraction using the Soxtec extraction unit (Soxtec

AVANTI 2050, FOSS Analytical AB, Sweden). Color of ground pineapple chips was determined in triplicate using a Chroma meter (Konica Minolta, CR-400, Japan) and expressed as the CIELAB L^*, C^* and $h°$). Browning index (BI) was calculated by using equation (1) (Ding and Ling, 2014):

$$BI = \frac{100(x-0.31)}{0.172} \quad (1)$$

where $$x = \frac{a^*+1.75L^*}{5.645L^*+a^*-3.012b^*}$$

Total color difference *(ΔE)* was calculated by using equation (2) (Tsironi *et al.*, 2009):

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (2)$$

where L_0^*, a_0^* and b_0^* are L^*, a^* and b^* value at day 0.

Determination of thiobarbituric acid (TBARs)

The thiobarbituric acid (TBARs) of pineapple chips was determined in triplicate by a distillation method (Tarladgis *et al.*, 1960). 10 g of ground pineapple chips was blended with 97.5 mL of distilled water and placed into a spherical flask where 2.5 mL of 4 N HCl acid was added to adjust a pH of solution to 1.5. The mixture was distilled and 50 mL of distillate was collected. 5 mL of distillate was pipetted into a test tube, and 5 mL of TBA reagent was added and then immersed in boiling water for 35 minutes. The test tube was cooled down in tap water for 10 minutes. The absorbance was read against the blank (distilled water prepared and treated similarly to the pineapple chip sample) using a spectrophotometer (Thermo Scientific, Genesys 10S UV-Vis, USA) at a wavelength of 538 nm. TBARs were calculated as follows:

$$\text{TBARs (mg malonaldehyde kg}^{-1}) = A_{538} \times 7.8 \quad (3)$$

Kinetic modeling and shelf life prediction

The degradation of foods during storage could be described by changes of quality factor ([A]) at a given time (t) using basic reaction kinetics (Martins *et al.*, 2001) as follows:

$$d[A]/dt = k[A]^n \quad (4)$$

where k is the rate constant and n is the reaction order ($0 \le n \le 2$). Integration of equation (4) for zero-, first-, and second order reactions [equation (5), (6), (7), respectively] were

$$[A] = [A]_0 - kt \quad (5)$$
$$[A] = [A]_0\, e^{-kt} \quad (6)$$
$$1/[A] = 1/[A]_0 + kt \quad (7)$$

To determine the reaction order, adjusted coefficients of determination (R^2_{adj}) and root mean square error (RMSE) (equation (8) of zero-, first-, and second-order reaction were compared (Remini *et al.*, 2015).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}([A]_{pre}-[A]_{obs})^2}{(n-p)}} \quad (8)$$

where $[A]_{pre}$ is the predicted value, $[A]_{obs}$ is the observed value, n and p is the number of data and parameter, respectively. Temperature dependence of the rate constant was explained by the Arrhenius model (Martins *et al.*, 2001) as follows:

$$k = A^*\, e^{-Ea/RT} \quad (9)$$

where k is the rate constant, A^* is a so-called pre-exponential factor, E_a is activation energy, R is the gas constant (8.31 J mol^{-1} K^{-1}) and T is an absolute temperature (K). The Q_{10} was calculated to predict the shelf life (Kilcast and Subramaniam, 2011) as follows:

$$Q_{10}^{(T_2-T_1)/10} = \frac{\theta_{s(T1)}}{\theta_{s(T2)}} \quad (10)$$

where Q_{10} is the change of reaction rate when the temperatures change by 10°C, θ_S is the shelf life, T_1 is the reference temperature (°C) and T_2 is the indicated temperature (°C).

Statistical analysis

Effect of frying temperature and time on moisture content, oil content, and color were studied using factorial design with two levels for frying temperature (90°C and 95°C) and two levels of frying time (50 and 60 minutes). Physicochemical properties of samples were analyzed using SPSS software for Windows v.17.0 by one-way analysis of variance (ANOVA) followed by the Duncan's multiple range test for post hoc multiple comparisons at $p \le 0.05$.

Results and discussion

Effects of frying temperature and time on vacuum fried pineapple chip quality

The moisture content of vacuum fried pineapple chips was 0.62-0.64g kg^{-1} and 0.51-0.53g kg^{-1}, respectively, when fried at 90 and 95°C (Table 1). This indicates that frying temperatures had significant effects on moisture content of vacuum fried pineapple chips. In vacuum frying process, the boiling point of water was reduced due to the pressure reduction, and

Table 1. Physicochemical properties of vacuum fried pineapple chips as affected by frying temperature and time.

Frying temperature (°C)	Frying time (min)	Moisture content (g kg^{-1})	Oil content (g kg^{-1})	L^*	a^*	b^*	C^*	$h°$	Browning index (%)
90	50	0.64 ± 0.01^{b}	1.73 ± 0.03^{NS}	66.29 ± 0.54^{b}	4.14 ± 0.60^{a}	34.47 ± 0.49^{ab}	34.73 ± 0.56^{ab}	83.12 ± 0.95^{b}	74.73 ± 1.92^{a}
	60	0.62 ± 0.01^{b}	1.77 ± 0.05	61.61 ± 1.72^{a}	5.57 ± 0.23^{b}	35.00 ± 0.80^{b}	35.44 ± 0.76^{b}	80.91 ± 0.55^{a}	85.60 ± 1.60^{b}
95	50	0.53 ± 0.01^{a}	1.78 ± 0.08	65.40 ± 1.37^{b}	4.19 ± 0.77^{a}	33.83 ± 0.60^{a}	34.10 ± 0.63^{a}	82.97 ± 1.26^{b}	74.00 ± 3.75^{a}
	60	0.51 ± 0.01^{a}	1.77 ± 0.08	60.64 ± 0.20^{a}	5.61 ± 0.37^{b}	33.73 ± 0.29^{a}	34.20 ± 0.34^{a}	80.56 ± 0.56^{a}	83.58 ± 1.58^{b}

Values are mean ± SD of triplicate determinations.
For each property, the same letter within each column indicates no significant difference ($p>0.05$).
NS indicates no significant difference ($p>0.05$).

the boiling point of water in this study (60 mmHg absolute pressure) was between 40-45°C (Inprasit, 2011). As pineapple slices were immersed in preheated oil, the heat from hot oil transferred inside the sample, and moisture started to evaporate when temperature reached the boiling point (Shyu *et al.*, 2001). Higher frying temperatures could accelerate the moisture loss of fried foods so pineapple chips fried at 95°C had a lower moisture content than the one fried at 90°C, as similarly observed in the studies of Garayo and Moreira (2002), the potato chips vacuum fried at 144°C had higher moisture loss rate when compared to the other one fried at 118°C within the same frying pressure. However, at a given frying temperature, the frying time (50 vs. 60 minutes) did not have a significant effect on moisture content. Shyu and Hwang (2001) also found no significant difference between vacuum fried apple chips fried at 2.67 kPa (abs), 90°C for 15, 20, 25 and 30 minutes as well as Garayo and Moreira (2002) found closed moisture loss trend between potato chips vacuum fried at 132°C and 144°C since 400, 350 and 300 seconds of frying at 16.661, 9.888 and 3.115 kPa, respectively. Garayo and Moreira (2002) and Fellows (2009) explained that mode of heat transfer from medium into the food pieces during initial heat-up stage was convection, subsequently when the temperature inside reached the boiling point, moisture started to evaporate during the constant rate stage. The last stage was falling rate, food surface became dry and crust, moisture was slowly removed by moisture diffusion mechanism. From the result, the evaporation rate of moisture from the 50 and 60 minutes frying time samples might be in the falling rate stage therefore the amount of moisture transfer was not enough to make a significant difference between two frying times.

In this study, the vacuum frying condition [60 mmHg (abs), 90°C and 95°C, 50 and 60 minutes] had no significant effects on the oil absorption of pineapple chips ($p>0.05$). The oil absorption in fried foods occurs during the cooling stage . When fried foods are removed from a vacuum fryer, vapor condensation starts, internal pressure decreases, and the oil on food surface then absorbs into the pores inside the food (Fellows, 2009) as reported by Moreira *et al.* (2009), 86% of total oil content in vacuum fried potato chips was surface oil while 14% was internal oil. Pineapple chips produced in this study had lower oil content (1.73-1.78g kg^{-1}, Table 1) than commercial vacuum fried pineapple chips 2.0 g kg^{-1} (Rodrigues and Fernandes, 2012). The additional centrifugation step used in this study helped reduce oil absorption (Sothornvit, 2011).

Generally frying temperature (90 and 95°C) and time (50 and 60 minutes) had significant effects on color (Table 1). At a given frying temperature, increasing frying time from 50 to 60 minutes significantly ($p \leq 0.05$) decreased the L^* value . However, at a given frying time, increasing frying temperature from 90 to 95°C only slightly (but not significantly) decreased the L^* value. A similar trend was also observed for the $h°$ values (Table 1). The browning index (BI %) significantly increased with increasing frying time (Table 1). Decreasing lightness *(L^*)* and increasing BI indicated development of darker color of pineapple chips. In addition, decreasing hue angle *($h°$)* values as frying time increased indicated that the pineapple chips became redder. In this study, darker color of vacuum fried pineapple chips was a result of the Maillard reaction, a non-enzymatic browning reaction between amino acid and reducing sugar in pineapple (Dueik *et al.*, 2010; Diamante *et al.*, 2012; Setyawan *et al.*, 2013). From Table 1, the frying time inserted more influence on color changes of vacuum fried pineapple chips than frying temperature. Similarly, the study of Garayo and Moreira (2002) reported that oil temperature (118°C, 132°C and 144°C) had no significant effect on vacuum fried potato chip color.

If the vacuum fried pineapple chips are to be produced in Thailand, the process must conform to the Thai Community Product Standard no.1038/2011:

Table 2. Physicochemical properties of pineapple chips vacuum fried at 95°C for 50 minutes as affected by frying cycles.

Frying cycles	Moisture content (g kg^{-1})	Oil content (g kg^{-1})	TBARs (mg malonaldehyde kg^{-1})	*L**	*a**	*b**	*C**	*h°*	Browning index (%)
1	0.53 ± 0.00^{NS}	1.69 ± 0.05^{NS}	0.51 ± 0.01^{NS}	64.21 ± 0.19^{f}	5.26 ± 0.05^{a}	34.51 ± 0.34^{d}	34.92 ± 0.33^{d}	81.36 ± 0.16^{c}	79.19 ± 0.73^{a}
2	0.53 ± 0.01	1.70 ± 0.07	0.53 ± 0.01	60.66 ± 0.68^{e}	6.10 ± 0.38^{b}	34.18 ± 0.40^{cd}	34.72 ± 0.34^{cd}	79.86 ± 0.71^{b}	85.64 ± 0.96^{c}
3	0.53 ± 0.01	1.69 ± 0.07	0.52 ± 0.03	58.62 ± 0.73^{cd}	6.01 ± 0.09^{ab}	31.82 ± 1.00^{ab}	32.39 ± 0.96^{ab}	79.26 ± 0.46^{b}	81.74 ± 1.77^{b}
4	0.53 ± 0.01	1.71 ± 0.02	0.49 ± 0.02	57.81 ± 1.14^{bc}	5.77 ± 0.54^{ab}	31.75 ± 0.49^{ab}	32.28 ± 0.38^{ab}	79.71 ± 1.08^{b}	82.71 ± 1.53^{b}
5	0.53 ± 0.01	1.68 ± 0.01	0.52 ± 0.02	56.45 ± 1.25^{ab}	6.08 ± 0.53^{b}	30.92 ± 0.64^{a}	31.52 ± 0.54^{a}	78.88 ± 1.17^{b}	83.02 ± 1.45^{b}
6	0.53 ± 0.01	1.72 ± 0.03	0.47 ± 0.00	59.75 ± 0.86^{de}	5.98 ± 0.33^{ab}	33.00 ± 0.84^{bc}	33.55 ± 0.86^{bc}	79.78 ± 0.47^{b}	83.60 ± 2.26^{bc}
7	0.53 ± 0.01	1.75 ± 0.06	0.50 ± 0.03	55.21 ± 0.70^{a}	6.51 ± 0.51^{b}	31.94 ± 0.76^{ab}	32.60 ± 0.66^{ab}	78.49 ± 1.08^{ab}	89.88 ± 0.65^{d}
8	0.53 ± 0.01	1.65 ± 0.02	0.51 ± 0.03	55.92 ± 1.15^{a}	7.24 ± 0.44^{c}	31.84 ± 1.16^{ab}	32.66 ± 1.04^{ab}	77.16 ± 1.17^{a}	88.94 ± 1.06^{d}

Values are mean ± SD of triplicate determinations.
For each property, the same letter within each column indicates no significant difference (p>0.05).
NS indicates no significant difference (p>0.05).

Crispy fried fruits and vegetables (Thai Industrial Standard Institute, 2011). The standard mentioned that the moisture content of crispy fried product must not over 0.6g kg^{-1}, so the conforming conditions would be vacuum frying at 95°C for 50 and 60 minutes (Table 1). As also shown in Table 1, a longer frying time caused a darker color. So the optimal condition for vacuum fried pineapple chips production was chosen at 60 mmHg (abs) at 95°C for 50 minutes, which was used in the subsequent study.

Effect of frying cycles on moisture and oil content, TBARs, and Color of pineapple chips

Moisture and oil contents of vacuum fried pineapple chips during 8 frying cycles using the same rice bran oil are shown in Table 2. There was no significant difference (p>0.05) in the moisture content (0.53g kg^{-1}) of pineapple chips among all 8 frying cycles. Debnath *et al*. (2012) also reported that there was no significant (p>0.05) difference in the moisture content of poori (traditional Indian fried food) fried in rice bran oil subjected to increased number of frying cycles (up to 6 cycles). However, they observed an increase in the oil uptake from 2.85 to 3.69g kg^{-1} with an increase in number of frying cycles from 1 to 6. The increased oil viscosity with increasing frying cycles likely resulted in higher oil uptake. In contrast, in our current study, the oil contents of vacuum fried pineapple chips were not significantly different, and ranged from 1.65 to 1.75 g kg^{-1} during 8 frying cycles (Table 2). Crosa et al. (2014) studied the changes in sunflower oil used in vacuum frying of potato chips, no significant difference (p>0.05) in total polar compound found in 1-3 frying cycles of high oleic sunflower oil, 4.2, 5.5 and 6.4, respectively. Safety is another topic to be concerned, the oil qualities as free fatty acid, total polar compound and peroxide value using in 8 vacuum frying cycles of pineapple chips should be studied in the further work for the purpose to ensure if the reused frying oil be safe for consumers' health.

Rancidity is often considered an unpleasant flavor in fried foods and can be indicated by the TBARs value. There was no significant difference in TBARs values (0.47-0.53 mg malonaldehyde kg^{-1}) of all pineapple chips during 8 frying cycles (Table 2). According to Crosa *et al.* (2014), vacuum frying significantly decreased the rate of oil deterioration reactions. This was due to the fact that vacuum frying was operated in a closed system which could retard the oil degradation (Shyu *et al*., 1998; Crosa *et al*., 2014). In addition, rice bran oil contains bioactive compounds such as γ-oryzanol, phytosterols, tocotrienols and tocopherols, which renders resistance to thermal oxidation and deterioration during frying (Debnath *et al*., 2012).

Significant changes in color of vacuum fried pineapple chips were observed as a result of increasing frying cycles (Table 2). Lightness *(L^*)* values decreased from 64.21 to 55.92, the hue angel *(h^o)* values decreased from 81.36 to 77.16, while the BI (%) increased from 79.19 to 88.94 for vacuum fried pineapple chips in the first to the eight cycles. Golden color found in vacuum fried pineapple chips was induced by the Maillard reaction between amino acid and reducing sugar in pineapple. The color of frying oil became darker with increasing frying cycles. Penetration of dark colored oil into pineapple chips during cooling stage could increase darkness of products reported by Fellows (2009).

Shelf life study: color and TBARs changes during storage

There were significant (p≤0.05) changes in pineapple chip color during 12 weeks of storage

Table 3. Experimental data of accelerated test for shelf life prediction of pineapple chips.

Parameters	Storage temperature (°C)	Order reaction	k (mg kg^{-1} week^{-1})	R^2_{adj}	RMSE	E_a (kJ mol^{-1} K^{-1})	R^2_{adj}	Q10
Thiobarbituric acid (TBARs)	25	0	0.1491	0.9560	0.1382	42.063	0.9846	1.74
	35		0.2308	0.8422	0.4317			1.68
	45		0.4348	0.8810	0.6902			1.62

where: k - rate constant
R^2_{adj} - adjusted coefficients of determination
R_{MSE} - root mean square error
E_a - activation energy
Q_{10} - the rate of change of a TBARs as a consequence of increasing the temperature by 10 °C

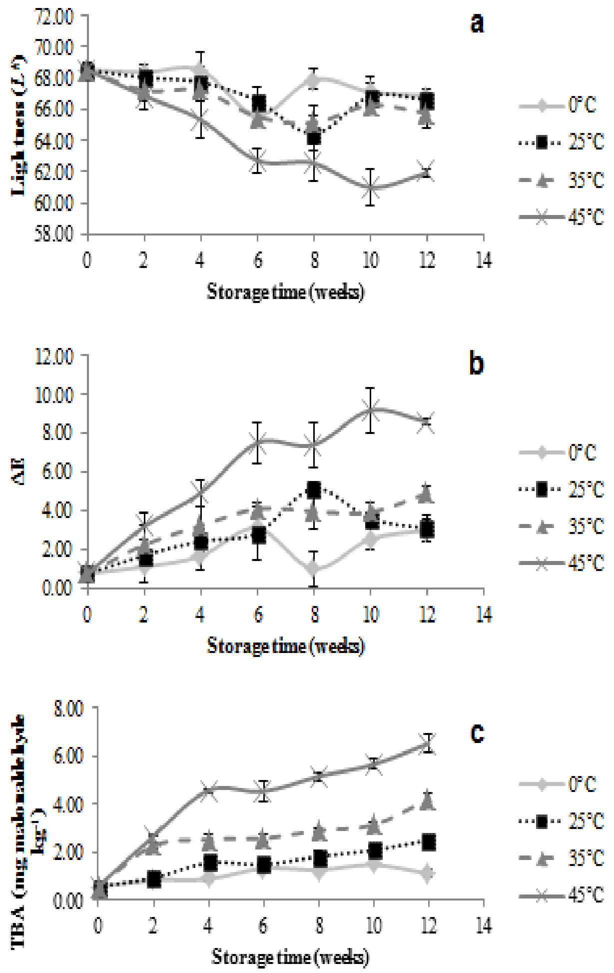

Figure 1. Changes in color lightness (L^*) (a), total color difference (ΔE) (b), and thiobarbituric acid (TBARs) (c) of pineapple chips during storage at 0, 25, 35 and 45°C for 12 weeks.

(Figure 1). Despite some fluctuation, there was an obvious trend showing gradual decreases in lightness *(L^*)* values with increasing storage time. Additionally, the higher the storage temperature, the lower the lightness *(L^*)* value (Figure 1a). A similar trend was observed for the total color difference *(ΔE)* of pineapple chips (Figure 1b). Sharma (2003) reported that the total color difference *(ΔE)* value of 2.3 corresponds to "just noticeable difference" by human eyes. Except for the storage at 0°C, all vacuum fried pineapple chips had the ΔE values of larger than 2.3 after 4 weeks of storage; this means that consumers will likely be able to visually discern these samples from the freshly prepared sample.

There is an obvious trend showing gradual increases in TBARs values with increasing storage time for samples stored at 25 and 35°C, and a sharp increase in TBARs values for samples stored at 45°C (Figure 1c). After 12 weeks of storage, the TBARs values significantly increased from 0.59 (day 0) to 2.51, 4.19 and 6.53 mg malonaldehyde kg^{-1} at 25, 35 and 45°C storage, respectively. Minimal changes in TBARs were observed at 0°C storage. The results indicated that rancidity of vacuum fried pineapple chips depended on both storage time and temperature. Similarly, Abong *et al.* (2011) and Liu-ping *et al.* (2007) reported that storage time and temperature affected rancidity, free fatty acid and peroxide values of deep fried potato chips and acid values of vacuum fried carrot chips, respectively.

Kinetic modeling and shelf life prediction

TBARs values were chosen to predict the shelf life of vacuum fried pineapple chips. In this study, the zero-order reaction was used (Table 3). The reaction order used in this study differed from those reported by Kilcast and Subramaniam (2011) who reported that the first-order reaction was usually found in the lipid oxidation. Higher storage temperature accelerated the oxidation in lipid, the rate constant (k) of TBARs values of 0.1491, 0.2308 and 0.4348 mg kg^{-1}week^{-1} were found at storage temperature of 25, 35 and 45°C, respectively, without changing in volume or density of the sample during storage. Data from the Arrhenius plot (Figure 2) was used for activation energy *(E_a)* calculation (Table 3). The activation energy for lipid oxidation using TBARs

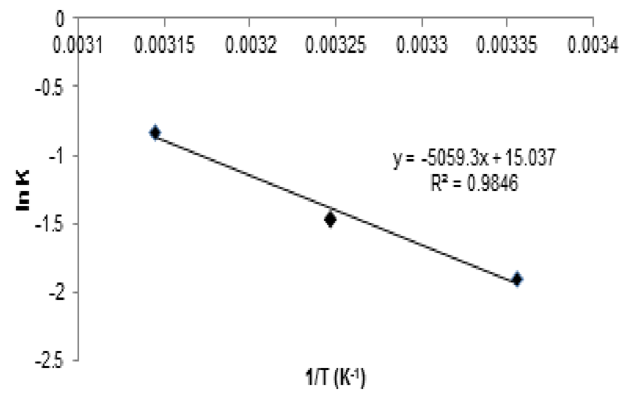

Figure 2. The Arrhenius plot of thiobarituric acid (TBARs) for shelf life prediction.

was 42.063 kJ mol^{-1}K^{-1}, which was within the range of the activation energy in lipid oxidation (40-100kJ mol^{-1}K^{-1}) reported by Labuza (1982). Figure 2 displayed the predicted shelf life of vacuum fried pineapple chips stored, for instance, at 30°C was 30 weeks based on the changes in TBARs.

Conclusion

This study demonstrated that frying temperature (90°C and 95°C), frying time (50 and 60 minutes), frying cycles (1-8 cycles), and storage time (12 weeks) and temperature (0, 25, 35 and 45°C) generally negative affected quality of vacuum fried pineapple chips . Frying temperatures had significant effects on moisture content of vacuum fried pineapple chips. The frying time inserted more influence on color changes of vacuum fried pineapple chips than the frying temperature. Increasing frying cycles did not affect moisture and oil content as well as TBARS, but made the pineapple chips darker and redder. There was an obvious trend showing increases in the total color difference *(ΔE)* and TBARs of pineapple chips during 12 weeks of storage. The predicted shelf life of vacuum fried pineapple chips stored at 30°C was 30 weeks based on changes in TBARs (the zero-order reaction).

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