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Effects of osmotic pretreatment and frying conditions on quality and storage stability of vacuum-fried pumpkin chips

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Summary The effects of osmotic (OP), ultrasound-assisted osmotic pretreatment (UAOP) and frying conditions on quality and storage stability of vacuum fried pumpkin chips were investigated. The pumpkin samples were pretreated in maltodextrin solution and subsequently fried at different temperatures (90–110 °C) and time periods (10–30 min). The results demonstrated that the moisture content, water activity, lightness, yellowness and carotenoid content of the fried chips decreased, while oil content, hardness and *a** (dark brown colour) value increased with increasing frying temperature and time. UAOP reduced about 16.0% of oil absorption and enhanced approximately 70% of carotenoid retention in the fried chips. UAOP samples were also more stable during storage than the untreated ones, indicated by lower degradation kinetics constants of key quality parameters. The proposed pretreatment could be an effective method for food industries to develop vacuum fried pumpkin chips with improved quality and stability.

Keywords Oil content, osmotic dehydration, pumpkin, ultrasound-assisted, vacuum frying.

Introduction

Snacks are the most commonly used foods between meals and preferred by consumers due to particular sensory attributes (Peksa *et al*., 2016). Due to rapid increase in global demand of snacks, nontraditional raw ingredients such as pumpkin, pineapple, mango, sweet potato and beetroot chips have attracted increasing attention. Pumpkins (*Cucurbita moschata*) are widely cultivated in the world as a preferred vegetable and consumers' demand for pumpkin ingredient has risen due to its high content of carotenoids, vitamins, flavonoids and other bioactive compounds (Carvalho *et al*., 2014). In general, various types of snacks can be produced by frying technology. Fried foods are preferred because of their taste, smell and texture (Oladejo *et al*., 2018). However, fried products usually contain high content of oil which may reach up to 50% of the weight in some products (Mellema, 2003). With growing consumer interest in healthy foods, processors are urged to develop fried snacks with lower fat content. The oil absorption in fried products (García-Segovia *et al*., 2016) can be efficiently reduced by using vacuum frying technology. As the process is carried out below atmospheric pressure (6.65 kPa), frying temperature can be lower than 90 °C (Dueik & Bouchon, 2011). The low frying temperature also helps reduce undesirable chemical reactions such as lipid oxidation and food browning (Mariotti-Celis *et al*., 2017). It has been reported that various pretreatments could be used to enhance the efficiency of frying process and quality of fried products (Oladejo *et al*., 2018). Osmotic dehydration is usually applied to reduce initial moisture content of the ingredients before frying. During frying, moisture in the product is believed to be replaced with oil. Therefore, the final oil content of fried products can be lowered if initial moisture content of the ingredient is partially removed (Karizaki *et al*., 2013). Diamante *et al*. (2011a) obtained vacuum fried kiwifruits with lower oil content by pretreating the samples in maltodextrin solution. Osmotic dehydration was also found to improve sensory, nutritional quality and extend the shelf life of fried foods (Lagnika *et al*., 2018). Nunes & Moreira (2009) demonstrated that osmotic dehydration with maltodextrin increased crispness of vacuum fried mango chips. Osmotic dehydration could be further improved by ultrasound treatment. High intensity

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ultrasound waves disintegrate cell structures and produce acoustic cavitation, which facilitates the removal of water from food products (Fan *et al.*, 2017). Karizaki *et al.* (2013) showed that ultrasound-assisted osmotic dehydration shortened pretreatment time, improved colour and reduced the oil content of fried potatoes. Even though various osmotic pretreatments have been investigated for vacuum frying, there is scanty information regarding the effects of ultrasound-assisted osmotic pretreatment and frying conditions on the quality and storage stability of fried pumpkin chips.

The aim of this study was to evaluate the impacts of ultrasound-assisted osmotic pretreatment (UAOP) and frying conditions on oil absorption, carotenoid retention and other quality attributes of vacuum fried pumpkin. The implication of UAOP in storage stability of the products was also investigated.

Materials and methods

Materials and sample preparation

Palm oil was supplied by Suksomboon Palm Oil Industry (Chon Buri, Thailand). Maltodextrin and β-carotene were acquired from Sigma-Aldrich (St Louis, MO, USA). All other chemicals were of analytical grade. Fresh pumpkins (*Cucurbita moschata* Decne) were purchased from the local market in Chiang Mai province (Thailand). The fruits ($n = 50$) were selected during September and October with an average weight of 6.0 ± 0.5 kg to ensure their uniformity. After washing under tap water, the peel and seeds of pumpkins were removed. Then, the flesh was cut into slices of 2 mm thickness by a slicer machine (CW09; Wasino, Samut Prakan, Thailand). The samples were stored at 5 °C until further experiments. All experiments were conducted in triplicates. However, five replications were applied for colour and water activity measurement and twenty replications were used for texture analysis.

Osmotic pretreatment of samples with maltodextrin solution

Pumpkin samples were subjected to OP and UAOP in maltodextrin solution (1:4, w/w). Preliminary experiments were conducted at different maltodextrin concentrations (20–40%, w/v), temperatures (35–55 °C) and immersion time (OP: 30–90 min, UAOP: 10–30 min) to evaluate the water loss and solid gain of the samples. Temperature of the samples was controlled by a water bath (WNE 7; Memmert, Schwabach, Germany). The ultrasound-assisted pretreatment was performed at 40 kHz using an ultrasonication instrument (VGT-1730QTD; GT SONIC, Guangdong, China). Under given experimental conditions, immersing samples in maltodextrin solutions without ultrasound did not result in significant water loss. The pumpkin slices slightly gained water at low maltodextrin concentrations (20–30%) and experienced no net change in water content at 40% maltodextrin concentration. Subsequently, maltodextrin solution of 40% was selected for the study. To ensure adequate maltodextrin absorption (~2% solid gain) prior to frying, the immersion time was fixed at 90 min at 35 °C. On the other hand, the application of ultrasound during osmotic pretreatment was conducive to considerable water loss. Maximum water loss of approximately 7.0% was achieved at 30 min and 55 °C. These pretreatment conditions were consequently selected for the frying experiments.

Vacuum frying

Before frying, the samples were frozen at −18 °C for 24 h to improve the quality of vacuum fried products. All samples were vacuum fried in palm oil (1:25, w/v) following the method of Da Silva & Moreira (2008) with slight modifications. Frying temperatures and time were varied from 90 to 110 °C and 10 to 30 min, respectively. After frying, the chips were centrifuged at 100 r.p.m. for 30 min for de-oiling and placed on paper towels to remove the excess oil. The fried pumpkin chips were cooled to room temperature and stored in sealed aluminum foil laminated bags with nitrogen flushing until further analysis.

Analyses of physicochemical properties

Fried pumpkin chips were analysed for their moisture content, water activity, oil content, carotenoid content, colour, texture and microstructure. Moisture content was determined by the AOAC standard method (AOAC, 2005). Water activity was measured by a water activity meter (AW-CENTER 200; Novasina, Lachen, Switzerland). The hardness, the maximum force required to break the sample, was determined by a texture analyser (TAXT plus, Stable Micro Systems, Ltd., Surrey, UK). Oil content was determined by extraction with petroleum ether (AOAC, 2000). Total carotenoid content was analysed by the method of Yang *et al.* (2012). Calibration curve was developed using β-carotene and the absorbance was read at 450 nm with the help of a UV spectrophotometer (Model 6405; Jenway, Dunmow, Essex, UK). Colour parameters (L^*, a^* and b^*) were measured by a Hunter spectrocolorimeter (ColorFlex, Hunter Color Lab, Reston, VA, USA). Microstructure of the samples was characterised by a scanning electron microscope (SEM) (SU 8020; Hitachi, Tokyo, Japan). Briefly, the samples were attached to SEM stubs by carbon tape and dried in a desiccator for 3 days. The samples were then coated with a thin gold layer (IB-2 Ion coater, Eiko

Engineering CO., LTD, Tokyo, Japan) and the pictures were taken at an accelerating voltage of 1 kV.

Storage stability of fried pumpkin chips

The effects of pretreatment and frying conditions on storage stability of fried samples were investigated. It was reported that the desirable crispness and the shelf life of fried chips were obtained at moisture content approximately lower than 2% (w.b) (Tarmizi & Niranjan, 2013). Reduced oil absorption was also the focus of this study. Therefore, only samples with moisture content <2% and the lowest oil content were selected for the storage stability test (Table S1). The fried pumpkin chips, packed in sealed aluminum foil laminated bags with nitrogen flushing, were subjected to accelerated shelf life testing at 35, 45 and 55 °C for 35 days. The samples were analysed for the moisture content, peroxide value, colour parameters and texture at 7-day intervals. The peroxide value was determined by the official method of American Oil Chemist Society (AOCS, 1972). The kinetics of quality degradation was described by the first order equation (Ratanapoompinyo *et al.*, 2017):

$$\frac{C_t}{C_0} = e^{-\mathrm{k}t}, \tag{1}$$

where t was the storage time. C_0 and C_t were the quality attributes of the sample at the beginning and at time t, respectively. k was the kinetics constant (day^{-1}).

Statistical analysis

All experiments were conducted in triplicates. One-way analysis of variance (ANOVA) was analysed by the Minitab® 16 Statistical Software (Minitab Inc., State College, PA, USA). Duncan's multiple range test (DMRT) was used to compare mean values and statistical significance was expressed at 95% confident interval.

Results and discussion

Effect of pretreatment and frying conditions on quality of fried pumpkin chips

Moisture content and water activity

The moisture content and water activity of fried pumpkin chips significantly ($P < 0.05$) decreased with increasing frying temperature and time (Table 1). The phenomenon could be attributed to the higher rate of water evaporation from the sample at higher frying temperature (Diamante *et al.*, 2011a). The longer time of sample in contact with the heating medium also helped remove more water and produced products with lower moisture content and water activity (Kawas & Moreira, 2001). Similar findings were reported for fried pineapple (Perez-Tinoco *et al.*, 2008), apple (Shyu & Hwang, 2001) and carrot chips (Fan *et al.*, 2005a).

Moisture content and water activity of the samples subjected to osmotic pretreatment were not significantly ($P < 0.05$) different from the control. However, UAOP reduced the moisture content and water activity of the fried chips significantly ($P < 0.05$). The ultrasound pretreatment might have modified the microstructure and physical properties of the samples, which consequently enhanced the rate of water diffusion during frying (Liu *et al.*, 2014). The water activity of all the samples was less than 0.2, which was lower than those reported for vacuum fried banana chips (Sothornvit, 2011), carrot chips (Dueik *et al.*, 2010) and vacuum fried peas (Zhu *et al.*, 2015).

The samples were frozen prior to vacuum frying to further improve the quality attributes of the fried products. Shyu & Hwang (2001) reported that freezing the apple slices prior to vacuum frying resulted in porous sponge-like appearance. This might be due to rapid heat transfer from frozen cells and water was evaporated at faster rate from frozen samples under vacuum frying. Shyu *et al.* (2005) reported that vacuum fried carrot chips without freezing pre-treatment exhibited high moisture content, uneven porosity and surface shrinkage due to rapid evaporation of surface water. However, the vacuum fried carrot chips pretreated with osmotic dehydration and freezing showed lower moisture and oil contents. Fan *et al.* (2005b) demonstrated that osmotic dehydration and freezing treatments prior to vacuum frying improved the porosity of carrot chips and reduced the surface shrinkage.

Oil absorption

The amount of oil absorbed is one of the most important attributes of fried foods. For some products, the oil content can account up to 50% of their weight (Bouchon, 2009). In this study, the oil content of control sample ranged from 22.70% to 36.16%. The pretreatment resulted in significant reduction in the oil uptake. OP and UAOP produced fried chips with oil content from 16.79% to 26.66%, and from 15.46% to 23.76%, respectively. The frying temperature and time were also vital factors affecting the oil absorption (Table 1). The oil uptake was more significant with increasing frying temperature and time. Elevated temperatures induced more expansion of tissue and pores in the food matrix. As a result, oil adhesion on the pore was higher (Sobukola *et al.*, 2013). Similar trends were reported for potato chips (Garayo & Moreira, 2002) and vacuum fried gilthead sea bream (*Sparus aurata*) fillets (Andrés-Bello *et al.*, 2010). Lower oil content in osmotically pretreated samples might be

Table 1 Effect of vacuum frying and pretreatment conditions on quality parameters of fried pumpkin chips

Quality parameters	Frying temperature (°C)	Frying time (min)	Control (without pretreatment)	Osmotic pretreatment	Ultrasound-assisted osmotic pretreatment
Moisture content (% w.b.)	90	10	3.42 ± 0.03^{aA1}	3.40 ± 0.03^{aA1}	2.81 ± 0.04^{aA2}
		20	3.24 ± 0.03^{aB1}	3.22 ± 0.02^{aB1}	2.65 ± 0.05^{aB2}
		30	2.43 ± 0.03^{aC1}	2.38 ± 0.04^{aC1}	2.10 ± 0.05^{aC2}
	100	10	3.13 ± 0.04^{bA1}	3.09 ± 0.05^{bA1}	2.45 ± 0.04^{bA2}
		20	2.59 ± 0.04^{bB1}	2.56 ± 0.06^{bB1}	1.96 ± 0.05^{bB2}
		30	1.95 ± 0.03^{bC1}	1.91 ± 0.05^{bC1}	1.74 ± 0.05^{bC2}
	110	10	2.68 ± 0.04^{cA1}	2.66 ± 0.04^{cA1}	2.31 ± 0.04^{cA2}
		20	2.07 ± 0.03^{cB1}	2.05 ± 0.03^{cB1}	1.80 ± 0.02^{cB2}
		30	1.80 ± 0.04^{cC1}	1.76 ± 0.04^{cC1}	1.52 ± 0.04^{cC2}
Water activity	90	10	0.166 ± 0.003^{aA1}	0.163 ± 0.002^{aA1}	0.116 ± 0.003^{aA2}
		20	0.159 ± 0.003^{aB1}	0.157 ± 0.001^{aB1}	0.110 ± 0.002^{aB2}
		30	0.136 ± 0.005^{aC1}	0.132 ± 0.003^{aC1}	0.100 ± 0.006^{aC2}
	100	10	0.124 ± 0.001^{bA1}	0.121 ± 0.002^{bA1}	0.108 ± 0.002^{bB2}
		20	0.118 ± 0.002^{bB1}	0.115 ± 0.003^{bB1}	0.100 ± 0.004^{bB2}
		30	0.101 ± 0.007^{bC1}	0.098 ± 0.005^{bC1}	0.090 ± 0.002^{bC2}
	110	10	0.099 ± 0.003^{cA1}	0.097 ± 0.002^{cA1}	0.087 ± 0.002^{cA2}
		20	0.092 ± 0.001^{cB1}	0.090 ± 0.002^{cB1}	0.080 ± 0.003^{cB2}
		30	0.086 ± 0.004^{cC1}	0.082 ± 0.002^{cC1}	0.074 ± 0.002^{cC2}
Oil content (%)	90	10	22.70 ± 0.36^{aA1}	16.79 ± 0.17^{aA2}	15.46 ± 0.22^{aA3}
		20	25.97 ± 0.14^{aB1}	18.68 ± 0.42^{aB2}	16.97 ± 0.10^{aB3}
		30	32.34 ± 0.39^{aC1}	22.03 ± 0.43^{aC2}	20.12 ± 0.25^{aC3}
	100	10	25.28 ± 0.36^{bA1}	18.93 ± 0.04^{bA2}	17.29 ± 0.20^{bA3}
		20	28.46 ± 0.42^{bB1}	21.30 ± 0.19^{bB2}	18.62 ± 0.28^{bB3}
		30	34.79 ± 0.20^{bC1}	23.42 ± 0.43^{bC2}	21.15 ± 0.34^{bC3}
	110	10	29.37 ± 0.46^{cA1}	20.18 ± 0.46^{cA2}	18.28 ± 0.49^{cA3}
		20	33.98 ± 0.44^{cB1}	23.19 ± 0.26^{cB2}	20.48 ± 0.41^{cB3}
		30	36.16 ± 0.14^{cC1}	26.66 ± 0.39^{cC2}	23.76 ± 0.09^{cC3}
Hardness (N)	90	10	2.22 ± 0.10^{aA1}	3.07 ± 0.14^{aA2}	2.65 ± 0.19^{aA3}
		20	2.56 ± 0.13^{aB1}	3.37 ± 0.13^{aB2}	2.97 ± 0.12^{aB3}
		30	2.85 ± 0.13^{aC1}	3.66 ± 0.14^{aC2}	3.24 ± 0.12^{aC3}
	100	10	2.52 ± 0.11^{bA1}	3.47 ± 0.15^{bA2}	3.05 ± 0.14^{bA3}
		20	2.80 ± 0.15^{bB1}	3.76 ± 0.10^{bB2}	3.31 ± 0.11^{bB3}
		30	3.12 ± 0.10^{bC1}	4.01 ± 0.10^{bC2}	3.69 ± 0.12^{bC3}
	110	10	2.82 ± 0.12^{cA1}	3.85 ± 0.15^{cA2}	3.31 ± 0.12^{cA3}
		20	3.18 ± 0.15^{cB1}	4.09 ± 0.17^{cB2}	3.61 ± 0.13^{cB3}
		30	3.50 ± 0.12^{cC1}	4.77 ± 0.14^{cC2}	3.96 ± 0.99^{cC3}
Carotenoids content (μg g^{-1} fresh pumpkin)	90	10	224.20 ± 0.28^{aA1}	225.49 ± 0.32^{aA2}	242.01 ± 0.16^{aA3}
		20	189.33 ± 0.42^{aB1}	194.56 ± 0.42^{aB2}	217.41 ± 0.42^{aB3}
		30	165.37 ± 0.16^{aC1}	177.95 ± 0.27^{aC2}	198.69 ± 0.16^{aC3}
	100	10	141.78 ± 0.42^{bA1}	170.69 ± 0.42^{bA2}	193.82 ± 0.32^{bA3}
		20	115.17 ± 0.48^{bB1}	139.77 ± 0.16^{bA2}	165.09 ± 0.42^{bB3}
		30	96.62 ± 0.69^{bC1}	105.81 ± 1.20^{bC2}	118.29 ± 0.42^{bC3}
	110	10	121.32 ± 0.42^{cA1}	158.03 ± 0.16^{cA2}	158.95 ± 0.27^{cA3}
		20	98.47 ± 0.16^{cB1}	131.69 ± 0.27^{cB2}	153.53 ± 0.42^{cB3}
		30	79.01 ± 0.42^{cC1}	84.88 ± 0.27^{cC2}	94.98 ± 0.160^{cC3}
Colour parameters					
*L**	90	10	82.82 ± 0.41^{aA1}	85.25 ± 0.60^{aA2}	88.20 ± 0.65^{aA3}
		20	78.20 ± 0.68^{aB1}	80.60 ± 0.56^{aB2}	84.42 ± 0.49^{aB3}
		30	68.26 ± 0.75^{aC1}	70.89 ± 0.73^{aC2}	75.80 ± 0.63^{aC3}
	100	10	69.97 ± 0.67^{bA1}	73.10 ± 0.22^{bA2}	80.78 ± 0.69^{bA3}
		20	65.34 ± 0.45^{bB1}	65.98 ± 0.71^{bB1}	75.33 ± 0.73^{bB2}
		30	58.25 ± 0.48^{bC1}	62.30 ± 0.47^{bC2}	68.22 ± 0.82^{bC3}
	110	10	61.53 ± 0.44^{cA1}	67.25 ± 0.48^{cA2}	73.24 ± 0.96^{cA3}
		20	54.02 ± 0.71^{cB1}	60.91 ± 0.83^{cB2}	64.92 ± 0.80^{cB3}
		30	48.13 ± 0.52^{cC1}	54.55 ± 0.58^{cC2}	59.06 ± 0.89^{cC3}
*b**	90	10	71.24 ± 0.63^{aA1}	80.08 ± 0.96^{aA2}	87.86 ± 0.74^{aA3}

Table -0001 (*Continued*)

Quality parameters	Frying temperature (°C)	Frying time (min)	Control (without pretreatment)	Osmotic pretreatment	Ultrasound-assisted osmotic pretreatment
		20	65.63 ± 0.83^{aB1}	72.64 ± 0.71^{aB2}	81.08 ± 0.48^{aB3}
		30	61.57 ± 0.84^{aC1}	66.43 ± 0.82^{aC2}	74.87 ± 0.86^{aC3}
	100	10	65.84 ± 0.96^{bA1}	71.34 ± 0.68^{bA2}	75.73 ± 0.81^{bA3}
		20	62.81 ± 0.81^{bB1}	65.20 ± 0.49^{bB2}	71.23 ± 0.69^{bB3}
		30	54.88 ± 0.86^{bC1}	59.26 ± 0.32^{bC2}	66.11 ± 0.23^{bC3}
	110	10	56.73 ± 0.56^{cA1}	63.84 ± 0.84^{cA2}	72.67 ± 0.51^{cA3}
		20	48.99 ± 0.63^{cB1}	57.71 ± 0.59^{cB2}	64.44 ± 0.55^{cB3}
		30	38.28 ± 0.81^{cC1}	42.52 ± 0.63^{cC2}	54.65 ± 0.49^{cC3}
*a**	90	10	-16.01 ± 0.61^{aA1}	-7.41 ± 0.43^{aA2}	-12.29 ± 0.35^{aA3}
		20	-11.48 ± 0.34^{aB1}	-2.32 ± 0.42^{aB2}	-5.06 ± 0.51^{aB3}
		30	-2.40 ± 0.37^{aC1}	2.46 ± 0.41^{aC2}	1.30 ± 0.36^{aC3}
	100	10	-12.25 ± 0.30^{bA1}	-4.14 ± 0.41^{bA2}	-7.00 ± 0.59^{bA3}
		20	-4.41 ± 0.39^{bB1}	4.12 ± 0.55^{bA2}	2.38 ± 0.40^{bB3}
		30	6.17 ± 0.49^{bC1}	12.51 ± 0.60^{bC2}	9.31 ± 0.62^{bC3}
	110	10	-5.22 ± 0.28^{cA1}	3.22 ± 0.38^{cA2}	1.50 ± 0.47^{cA3}
		20	8.16 ± 0.51^{cB1}	16.37 ± 0.74^{cB2}	12.52 ± 0.55^{cB3}
		30	15.08 ± 0.81^{cC1}	21.52 ± 0.90^{cC2}	19.50 ± 0.71^{cC3}

Data were reported as mean ± standard error followed by different superscript letters indicating significant differences ($P < 0.05$) among mean observations. The superscript letters (A–C) within a column represent significant differences among mean observations with change in frying time and superscript letters (a–c) within a column indicate significant differences among mean observations with change in frying temperatures at a given time. The superscript digits (1–3) within a row indicate the significant differences among mean observations with change in pretreatment condition.

due to the soluble solids from osmotic solution penetrating to the food matrix (García *et al.*, 2002). The osmotic solution on food surfaces formed a crust with less structural damage or pores. Ultimately, the oil intake during pressurisation and cooling process was reduced (Sobukola *et al.*, 2013).

The removal of oil adhered to the products is a major concern after frying processes. In case of vacuum frying, a de-oiling process is essential to remove the oil on the surface and the oil absorbed in the pores during frying. The centrifugation after vacuum frying is quite useful to reduce the oil absorption in the fried products; hence, vacuum fryers are often coupled with centrifugation process (Moreira *et al.*, 2009). Shyu *et al.* (2005) reported that centrifugation after vacuum frying reduced the oil content (12.3% w.b) in fried carrot chips.

Hardness

The hardness of fried pumpkin chips significantly increased with increasing frying temperature and time (Table 1). The higher temperature of the oil caused faster moisture loss and accelerated crust formation at the outer zone of the sample, leading to the increased hardness of the final product (Esan *et al.*, 2015). On the other hand, the control samples had the lowest hardness, followed by ultrasound-assisted osmotic samples. The augmented hardness of OP sample was possibly due to maltodextrin solution that filled the pores in the microstructure of sample and coated at the surface. These observations were in accordance with Diamante *et al.* (2011a) who reported an increased hardness of fried kiwifruit, pretreated with 33.0% of maltodextrin before frying.

Carotenoid content

The carotenoid content of raw pumpkin was 360.58 ± 1.14 μg g^{-1} of fresh sample. After frying, carotenoid content of the control samples was from 79.01 to 224.20 μg g^{-1}. The OP and UAOP samples were found to have carotenoid contents in the range 84.88–225.49, and 94.98–242.006 μg g^{-1}, respectively (Table 1). Carotenoids are highly unsaturated and easily destroyed by high temperature (Aman *et al.*, 2005). Therefore, the carotenoid content of all fried pumpkin chips was significantly ($P < 0.05$) decreased with increasing frying temperature and time. Gomes *et al.* (2013) reported that the higher was the frying temperature, the greater was the loss of β-carotene from cassava roots. Pretreated samples had higher retention of carotenoids as compared to the control. This could be attributed to the coated dextrin on the surface of the sample, which acted as a protective barrier against high temperature (Diamante *et al.*, 2011b). Azoubel *et al.* (2015) reported that ultrasound-assisted osmotic treatment retained 64.9% carotenoids of papayas as compared to untreated sample that retained only 24.0% carotenoids after frying. In addition, the carotenoid content is mainly decreased by oxidation and the UAOP can retain higher carotenoid content by inactivating the oxidative enzymes (Koca *et al*., 2007).

Colour attributes

Frying temperature and time significantly influenced ($P < 0.05$) L^*, a^* and b^* values of the fried samples. In fried pumpkin chips, a decrease in L^* value and an increase in a^* value was associated with the development of the undesirable dark brown colour. b^* value relates to yellow colour of the fried chips which is preferred by consumers. The results showed that L^* and b^* values were decreased, while the a^* value was increased with increasing frying temperature and time. Decrease in L^* and increase in a^* values were previously reported for fried tofu (Baik & Mittal, 2003), and fried chicken nugget (Ngadi *et al*., 2007). It was found that b^* value correlated with β-carotene content of pumpkins (Rachel & Eileen, 2009). Therefore, a decrease in b^* value during frying process could reflect degradation of carotenoids (Chen *et al*., 1995). The pretreated samples had higher L^* and b^* values. In addition, their appearance was brighter as compared to fried chips without pretreatment (Figure S1). This might be explained by the protective effects of maltodextrin coated on the sample surface during pretreatment, which acted as a barrier against hot oil (Diamante *et al*., 2011b).

Microstructure

Figure 1 presents the SEM micrographs of vacuum fried pumpkin chips at selected conditions. The microstructure of control (Fig. 1a) and OP (Fig. 1b) samples were similar. Open pores and distorted cell structures were observed, probably created due to the evaporation of water through the food matrix during frying (Xiaojian *et al*., 2016). The formation of microscopic channels by cavitation effects were clearly seen in the UAOP samples (Fig. 1c). Karizaki *et al*. (2013) noted similar effects for the fried potato chips, where ultrasound pretreatment resulted in increased poration inside the samples as compared to untreated ones. This disruption of cell structure would be associated with higher water diffusivity (Cárcel *et al*., 2012).

Effects of pretreatment and storage conditions on stability of fried chips

Moisture content

The moisture content of fried pumpkin chips with or without pretreatment were not significantly different ($P < 0.05$) (Table 2). However, the kinetics constant for moisture absorption of pretreated samples was slightly lower than that of the control (Table 3). Moisture content augmented faster at higher storage temperatures. Increase in storage temperature would accelerate the rate of moisture diffusion into the package. Similar results were previously reported for potato chips and banana chips which indicated that there was increase in the moisture content of chips with increasing storage temperature compared with the chips stored at lower temperature (Ammawath *et al*., 2002; Abong *et al*., 2011).

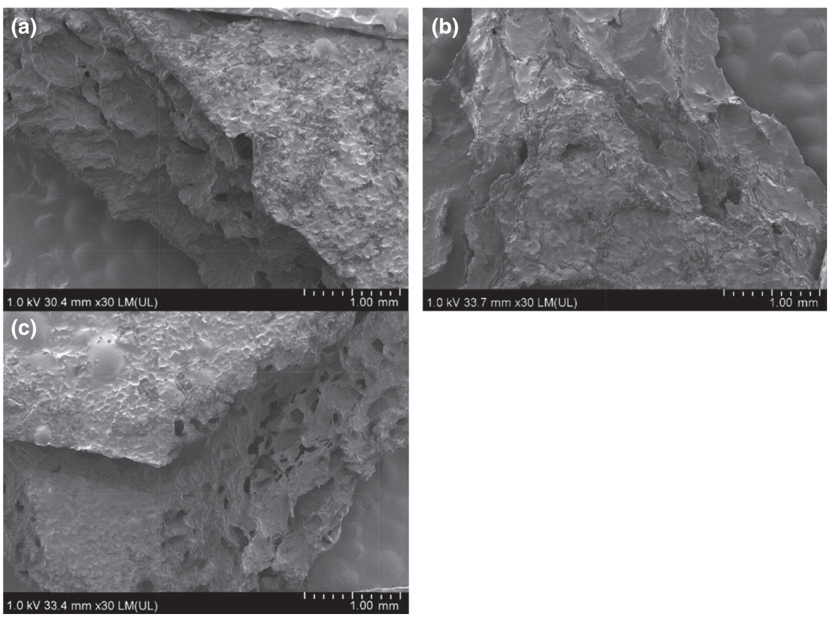

Figure 1 Scanning electron micrographs of vacuum fried pumpkin chips: (a) control, (b) osmotic pre-treatment and (c) ultrasound-assisted osmotic pretreatment.

Table 2 Effects of storage temperature and time on quality attributes of vacuum fired pumpkin chips

Quality parameters	Sample	Storage temperature (°C)	Storage periods (days) 0	7	14	21	28	35
Moisture content (% w.b.)	Control	35	1.96 ± 0.05^{a1}	2.15 ± 0.13^{a2}	2.40 ± 0.11^{a3}	2.58 ± 0.13^{a3}	2.80 ± 0.09^{a4}	3.11 ± 0.08^{a5}
		45		2.26 ± 0.06^{a2}	2.55 ± 0.02^{a3}	2.81 ± 0.08^{b4}	3.20 ± 0.09^{b5}	3.59 ± 0.06^{b6}
		55		2.46 ± 0.03^{b2}	2.80 ± 0.13^{b3}	3.19 ± 0.06^{c4}	3.52 ± 0.07^{c5}	4.10 ± 0.04^{c6}
	Ultrasound-assisted	35	1.95 ± 0.03^{a1}	2.12 ± 0.12^{ab2}	2.24 ± 0.07^{a2}	2.46 ± 0.06^{a3}	2.63 ± 0.08^{a4}	2.86 ± 0.09^{a5}
	osmotic	45		2.23 ± 0.08^{ab2}	2.45 ± 0.07^{b3}	2.75 ± 0.12^{b4}	3.10 ± 0.04^{b5}	3.41 ± 0.09^{b6}
	pretreatment	55		2.37 ± 0.02^{c2}	2.65 ± 0.09^{c3}	3.01 ± 0.08^{c4}	3.46 ± 0.08^{c5}	3.84 ± 0.05^{c6}
Peroxide value (meq kg^{-1} of sample)	Control	35	0.10 ± 0.09^{a1}	0.63 ± 0.10^{a2}	1.13 ± 0.15^{a3}	1.53 ± 0.06^{a4}	2.17 ± 0.12^{a5}	3.40 ± 0.10^{a6}
		45		1.03 ± 0.35^{a2}	1.73 ± 0.25^{b3}	2.87 ± 0.06^{b4}	4.53 ± 0.25^{b5}	6.47 ± 0.23^{b6}
		55		1.60 ± 0.25^{b2}	2.80 ± 0.20^{c3}	4.50 ± 0.10^{c4}	7.20 ± 0.17^{c5}	12.43 ± 0.55^{c6}
	Ultrasound-assisted	35	0.10 ± 0.11^{a1}	0.50 ± 0.11^{a2}	0.90 ± 0.10^{a3}	0.97 ± 0.058^{a3}	1.56 ± 0.058^{a4}	2.10 ± 0.10^{a4}
	osmotic	45		0.77 ± 0.11^{b2}	1.17 ± 0.20^{a3}	1.93 ± 0.058^{b4}	2.77 ± 0.058^{b5}	4.23 ± 0.058^{a6}
	pretreatment	55		1.40 ± 0.15^{c2}	2.47 ± 0.15^{b3}	3.97 ± 0.058^{c4}	5.90 ± 0.10^{c5}	9.13 ± 0.16^{a6}
Hardness (N)	Control	35	3.12 ± 0.10^{a1}	3.25 ± 0.11^{a2}	3.71 ± 0.10^{a3}	4.21 ± 0.18^{a4}	4.80 ± 0.13^{a5}	5.35 ± 0.25^{a6}
		45		3.49 ± 0.11^{b2}	4.00 ± 0.19^{a3}	4.68 ± 0.10^{b4}	5.49 ± 0.28^{b5}	6.28 ± 0.28^{b6}
		55		3.70 ± 0.09^{c2}	4.22 ± 0.27^{b3}	5.12 ± 0.20^{c4}	5.91 ± 0.13^{c5}	6.78 ± 0.10^{c6}
	Ultrasound-assisted	35	3.31 ± 0.11^{a1}	3.42 ± 0.15^{a2}	3.75 ± 0.09^{a3}	4.14 ± 0.13^{a4}	4.48 ± 0.16^{a5}	4.96 ± 0.07^{a6}
	osmotic	45		3.72 ± 0.09^{b2}	4.08 ± 0.13^{b3}	4.51 ± 0.12^{b4}	5.02 ± 0.11^{b5}	5.42 ± 0.14^{b6}
	pretreatment	55		4.07 ± 0.13^{c2}	4.50 ± 0.16^{c3}	4.94 ± 0.14^{c4}	5.47 ± 0.11^{c5}	6.08 ± 0.15^{c6}
Colour parameters								
*L**	Control	35	58.25 ± 0.48^{a1}	56.36 ± 0.55^{a2}	54.25 ± 0.35^{a3}	52.48 ± 0.39^{a4}	50.18 ± 0.81^{a5}	48.51 ± 0.50^{a6}
		45		54.36 ± 0.45^{b2}	50.33 ± 0.52^{b3}	47.28 ± 0.73^{b4}	45.27 ± 0.70^{b5}	41.33 ± 0.56^{b6}
		55		51.49 ± 0.42^{c2}	47.23 ± 0.51^{c3}	42.29 ± 0.77^{c4}	39.18 ± 0.97^{c5}	35.91 ± 0.75^{c6}
	Ultrasound-assisted	35	75.33 ± 0.73^{a1}	74.18 ± 0.84^{a2}	71.29 ± 0.48^{a3}	67.87 ± 0.78^{a4}	64.77 ± 0.91^{a5}	61.97 ± 0.74^{a6}
	osmotic	45		71.16 ± 0.47^{b2}	67.05 ± 0.44^{b3}	64.47 ± 0.45^{b4}	60.57 ± 0.44^{b5}	57.54 ± 0.62^{b6}
	pretreatment	55		69.11 ± 0.30^{c2}	65.45 ± 0.63^{c3}	61.81 ± 0.80^{c4}	58.42 ± 0.49^{c5}	55.14 ± 0.76^{c6}
*a**	Control	35	6.17 ± 0.49^{a1}	7.05 ± 0.31^{a2}	9.08 ± 0.15^{a3}	12.61 ± 1.01^{a4}	17.07 ± 0.47^{a5}	21.27 ± 0.28^{a6}
		45		7.67 ± 0.26^{b2}	11.32 ± 0.48^{b3}	15.19 ± 0.73^{b4}	20.66 ± 0.79^{b5}	26.23 ± 1.03^{b6}
		55		9.13 ± 0.14^{c2}	13.26 ± 0.51^{c3}	17.44 ± 0.64^{c4}	22.97 ± 0.79^{c5}	32.82 ± 0.35^{c6}
	Ultrasound-assisted	35	2.38 ± 0.40^{a1}	2.56 ± 0.18^{a2}	4.49 ± 0.38^{a3}	6.25 ± 0.67^{a4}	9.36 ± 0.40^{a5}	12.34 ± 0.87^{a6}
	osmotic	45		4.17 ± 0.10^{b2}	6.97 ± 0.22^{b3}	10.60 ± 0.51^{b4}	15.35 ± 0.76^{b5}	20.99 ± 0.73^{b6}
	pretreatment	55		4.60 ± 0.24^{c2}	7.41 ± 0.33^{c3}	13.42 ± 0.50^{c4}	18.23 ± 0.54^{c5}	25.93 ± 0.74^{c6}
*b**	Control	35	54.88 ± 0.86^{a1}	53.58 ± 0.53^{a2}	49.74 ± 0.86^{a3}	46.10 ± 0.67^{a4}	43.24 ± 0.40^{a5}	39.53 ± 0.37^{a6}
		45		52.43 ± 0.72^{b2}	48.05 ± 0.58^{b3}	44.65 ± 0.52^{b4}	40.16 ± 0.67^{b5}	37.06 ± 0.52^{b6}
		55		50.29 ± 0.58^{c2}	44.24 ± 0.44^{c3}	40.06 ± 0.73^{c4}	35.63 ± 0.50^{c5}	32.13 ± 0.60^{c6}
	Ultrasound-assisted	35	71.23 ± 0.69^{a1}	68.64 ± 0.24^{a2}	64.20 ± 0.45^{a3}	58.96 ± 0.88^{a4}	53.93 ± 0.72^{a5}	50.82 ± 1.30^{a6}
	osmotic	45		65.15 ± 0.75^{b2}	59.94 ± 0.84^{b3}	54.30 ± 0.50^{b4}	49.11 ± 0.59^{b5}	44.49 ± 0.92^{b6}
	pretreatment	55		63.92 ± 0.39^{c2}	56.94 ± 0.64^{c3}	50.14 ± 0.69^{c4}	43.81 ± 0.55^{c5}	38.16 ± 0.51^{c6}

Data were reported as mean ± standard error followed by different superscript letters indicating significant differences ($P < 0.05$) among mean observations. The superscript letters (a–c), within a column represent significant differences among mean observations with change in storage temperature. The superscript digits (1–6) within a column, represent significant differences among means observations during the storage period.

Oxidative stability

The vacuum fried pumpkin chips stored at 55 °C had higher peroxide value as compared to samples stored at 35 and 45 °C throughout storage time. The peroxide value of fried pumpkin chips was found to increase slowly at the beginning stage, followed by rapid increase until the end of storage period. Moreover, the kinetics constant of peroxide value increased with increasing storage temperature in all samples (Table 3).

High storage temperature, moisture gain and high water activity can accelerate lipid oxidation and formation of peroxide. The peroxide value of control and pretreated vacuum fried chips was not significantly ($P < 0.05$) different during 0–28 days of storage. After 35 days, peroxide value of pretreated samples was significantly lower than that of control samples at 45 and 55 °C. The difference might be due to the oil content in control (34.79%) and pretreated (18.62%) samples. Higher oil content may result in higher rate of lipid oxidation in the stored products. Similar results were reported by Abong *et al*. (2011), who reported that there was an increase in peroxide value of fried chips with increase in storage temperature. This was due to the fact that rate of oxidation is generally accelerated with increase in storage temperature.

Texture degradation

The reaction rate constant determined from hardness degradation of UAOP chips was lower as compared to the control sample. The rate of hardness degradation was also significantly affected by storage temperature and time. As the storage time and temperature increased, both pretreated and control samples gradually lost their crispness characteristics, indicated by increased hardness. Since the fried chips gradually absorbed moisture during storage, more force was required to break the samples. Similarly, Miranda *et al*. (2011) showed that the hardness of dried apricots increased more at higher storage temperature.

Colour stability

The storage temperature and time significantly affected the colour parameters of fried pumpkin chips. Increase in temperature had negative impacts on lightness (L^*) and yellowness (b^*) values, indicated by higher reaction rate constants at higher temperatures (Table 3). Decrease in yellowness (b^*) was closely associated with degradation of carotenoids which could be due to their isomerisation and oxidation (Provesi *et al*., 2011). On the other hand, b^* value of UAOP samples was not as stable as that of the control sample during storage. This could be due to difference in the content of carotenoids in the UAOP (165.097 μg g^{-1}) and untreated fried pumpkin (88.923 μg g^{-1}). For redness (a^*) value, significant increase was observed in all the samples when storage temperature was increased. The trend might be due to the browning reaction or lipid oxidation (Sra *et al*., 2014). Kortei *et al*. (2015) observed similar change in redness of dried mushrooms during storage.

Conclusions

The osmotic, ultrasound-assisted osmotic pretreatments and frying conditions had significant impacts on quality attributes of the fried pumpkin chips. The pretreatment improved colour, texture, retention of carotenoid content and reduced the oil absorbed by the products. Extended frying time and elevated temperature would result in increased in oil adsorption and adversely affect carotenoid retention and appearance of the chips. Oxidative stability and crispness of the UAOP fried pumpkin was significantly improved during storage. The application of UAOP could be adopted by industries to improve quality and stability of vacuum-fried pumpkin. In addition to storage stability and quality, future studies should consider the effects of pretreatments and frying conditions on sensory analysis and consumer perceptions.

Table 3 Quality degradation kinetics of fried pumpkin during storage

Sample	Storage temperature (°C)	Moisture content (% w.b.)		Peroxide value (meq kg^{-1} sample)		L^*		a^*		b^*		Hardness	
		k	R^2	k	R^2	k	R^2	k	R^2	k	R^2	k	R^2
Control	35	0.0128	0.991	0.0573	0.962	0.0054	0.998	0.0406	0.996	0.0107	0.998	0.0180	0.999
	45	0.0164	0.998	0.0661	0.998	0.0093	0.989	0.0437	0.993	0.0125	0.997	0.0212	0.999
	55	0.0179	0.996	0.0721	0.995	0.0130	0.997	0.0444	0.997	0.0159	0.999	0.0221	0.996
Ultrasound-assisted osmotic pretreatment	35	0.0109	0.995	0.0489	0.988	0.0065	0.999	0.0555	0.985	0.0111	0.996	0.0131	0.999
	45	0.0157	0.999	0.0612	0.995	0.0075	0.997	0.0574	0.991	0.0137	0.999	0.0137	0.998
	55	0.0177	0.995	0.0660	0.999	0.0081	1.000	0.0623	0.985	0.0185	0.999	0.0142	1.000

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Conflict of interest

None.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Optimised vacuum frying conditions.

Figure S1. Vacuum fried pumpkin chips subjected to different pre-treatment methods: (a) control, (b) osmotic pre-treatment and (c) ultrasound-assisted osmotic pretreatment.

