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Original Article

Effect of microwave-assisted vacuum frying on the quality of banana chips

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Abstract

This article examines the capability of microwave-assisted vacuum frying (MWVF) on saving frying time and quality improvement of fried banana chips. The MWVF machine was designed to combine vacuum frying (VF) and microwave heating (MW) in which electromagnetic distribution was simulated by COMSOL Multiphysics application software. Fresh banana chips were fried at 95 °C and 2 kPa, at various vacuum frying times (25–75 min), and at microwave heating times of 5 and 10 min. The quality of the banana chips was considered in terms of moisture, oil content, texture, color, and sensory attributes. The results showed that MWVF could provide a significantly shorter frying time than VF, from 75 min to 50 min (VF40MW10). The MWVF techniques were able to preserve the quality of banana chips similar to the VF method. The banana chips made by MWVF had a better sensory evaluation than the ones fried only by vacuum.

Keywords: combined microwave frying, banana chips, vacuum frying, microwave time

1. Introduction

Banana cv. Hom Thong (*Musa sapientum* L.) is one of the most popular fruits among millions of people in many countries worldwide. It is grown commercially all over the world in tropical and subtropical areas. For the human diet, banana plays an important role because it is one of the most nutritious fruits providing high sugar, fiber, and nutrients such as vitamins and minerals. However, banana is a rapidly perishable commodity and its post-harvest losses are around 25–30% (Kachhwaha, Chille, Khare., & Metha, 1991). The current post-harvest problems are the deterioration caused by microorganisms and losses during storage. Therefore, effective post-harvest methods should be promoted to prolong the shelf life of bananas.

A number of techniques have been developed to preserve bananas. Several drying technologies have been used: sun-drying; hot air-drying; freeze-drying; and the deep-frying process. One of the most preferred commercial dried banana products is the banana chip which is normally produced by a deep-frying process (Fasano & Mancini, 2007; Yamsaengsung & Moreira, 2002a, 2002b). Although deep-frying is a favorable method widely used in the food industry, it requires a long frying time due to the low energy efficiency. There is a chance that the quality of the product will deteriorate in terms of physical and chemical changes (Yamsaengsung & Moreira, 2002a, 2002b). Moreover, deep-fried products contain a high level of fat which may not be

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preferred by health-conscious consumers. Furthermore, the products may become rancid after long storage because of lipid oxidation during the preservation process (Gamble, Rice, & Selman, 1987; Taylor, Berg, Shoptaugh, & Traisman, 1983). To avoid oily products and preserve the product quality, banana chips can be prepared by the vacuum frying (VF) method (Garayo & Moreira, 2002; Shyu, Hau, & Hwang, 1998; Yamsaengsung, Ariyapuchai, & Prasertsit, 2011).

Although VF can preserve the natural quality of bananas and reduce the adverse effects of frying with oil, it has a poor mass transferring rate and consumes a long frying time. Typically, in the last stage of frying, the moisture content of a material is close to the destination moisture content which provides a low driving force of mass transfer (Quan, Zhang, Zhang, & Adhikari, 2014; Song, Zhang, & Mujumdar, 2007). For industrial applications, microwave (MW) and radio-frequency (RF) dielectric heating have traditionally been considered as tools to improve the food preserving process and as a means to reduce cost and improve the efficiency. MW- and RF- assisted heating offers a better way to improve the quality of fried products than other frying techniques. Theoretically, RF- and MW-assisted heating offers convective drying with high-frequency electromagnetic energy that can be applied at different drying stages to supplement the thermal energy supplied with dried air. By adjusting the balance between the component of conventional drying technologies and MW-, RF- assisted heating techniques, it is possible to optimize the hybrid systems in terms of food processing efficiency and cost effectiveness. Among the various hybrid systems based on MW irradiation, MW-assisted vacuum drying and MW-assisted freeze-drying have found the widest applications in dehydrating fruits, foods, and others materials (Roussy & Pearce, 1995; Thuery, 1992). Theoretically, the mechanism of microwave heating is based on ionic polarization and dipole rotation of charged groups. The result is generation of internal heat (Rattanadecho & Makul, 2016). Microwave is considered an attractive and energy saving heating source over conventional methods because it has a rapid heating rate and short processing time.

In many cases, microwave heating is more effective than conventional heating because it enables heat to penetrate materials without directly getting in contact with them. Moreover, it has selective energy absorption, instantaneous electronic control, unique and fine internal structure development, and it is non-polluting (Basak, Samanta, & Jindamwar, 2008; Ratanadecho, 2002; Rattanadecho & Makul, 2016).

Therefore, a combination of microwave techniques and conventional drying methods is possibly a better alternative way to dehydrate food products. Several food products were successfully dried using microwave energy. Barutcu *et al.* investigated the effects of MW-assisted frying of various flour types on the microstructure of batter coatings (Barutcu, Sahin, & Sumnu, 2009). The results showed that MW fried samples had lower bulk density and higher porosity values and also a smoother inner surface than conventionally fried samples. Several reports also suggested that the combination of microwave heating pretreatment with conventional drying and frying greatly improved the quality of fried food products (Bai-Ngew, Therdthai, & Dhamvithee, 2011; Rattanadecho & Makul, 2016; Therdthai & Zhou, 2009; Varith, Dijkanarukkul, Achariyaviriya, & Achariyaviriya, 2007; Zhang, Zhang, Shan, & Fang, 2007). Therefore, MWVF is a promising alternative technique which speeds up the drying process, increases mass transfer, and improves the quality of fried materials.

The objective of this study was to determine the feasibility of using a combined rectangular waveguide microwave with a VF system to evaluate the quality parameters of fried banana chips undergoing MWVF compared to the VF method. The quality attributes of the fried banana chips, including the physical and sensory properties, were analyzed.

2. Materials and Methods

2.1 Materials

The samples in this study were fresh bananas cv. Hom Thong (*Musa sapientum* L.) bought at a local market. A commercial color scale (Chiquita®, Brand, Inc.) was employed to assess the ripeness of the bananas and to ensure homogeneous samples. Ripe bananas with the 6-color index (completely yellow peel and tip) were chosen. An initial moisture content of 40–45% (w.b) was determined by the Approved Method 44-40, AOAC, 1995. The total soluble solid content was approximately 22–25 °Brix measured by a refractometer. The fresh bananas were peeled and sliced to produce uniform slices of 3.5–4.5 mm in thickness. The cross-sectional diameter of the slices ranged from 25 to 30 mm. The sliced bananas weighing 1000 g were used in each experimental condition.

2.2 Experimental apparatus

2.2.1 Vacuum fryer machine

The prototype vacuum fryer used in this study was assembled according to the procedure developed by the Department of Food Engineering, Kasetsart University, Nakhon Pathom, Thailand. The vacuum fryer (Figure 1) consisted of a vacuum frying tank, an oil tank, a liquid petroleum gas burner, a liquid ring vacuum pump, a cooling tower, and a control panel box. The vacuum fryer was constructed of 304 stainless steel with a diameter of 520 mm, height of 600 mm, and wall thickness of 5 mm. The stainless-steel lid of the fryer had a thickness of 8 mm.

2.2.2 Combined microwave-vacuum fryer

The combined MWVF system (Figure 1) was established by connecting the 1000-watt magnetron (LG, Model 2M226: 03GWH, 2.45 GHz Korea) to the frying tank via a specific rectangular waveguide which was designed with TE_{10} mode (Rattanadecho & Makul, 2016). The position to install the specific rectangular waveguide to the frying tank was simulated by COMSOL Multiphysics version 5.1 software to ensure good electromagnetic distribution inside the waveguide through the frying tank. The software was used to construct domain meshes while finite element methods were used to solve the problems (Jani, Yapa, & Rattanadecho, 2010). Figure 2 shows the results of the simulation which represents good electromagnetic distribution both in the waveguide and frying tank or cavity.

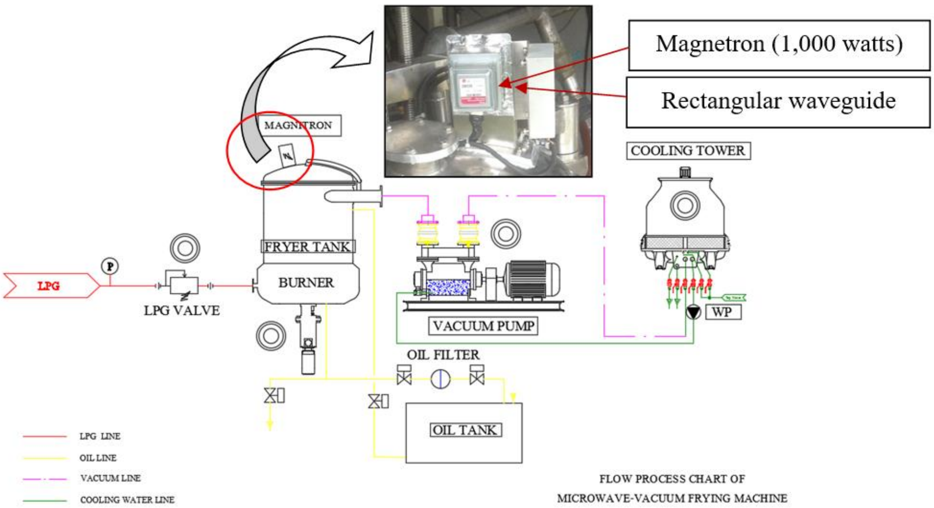


Figure 1. Conceptual design for the microwave vacuum frying machine.

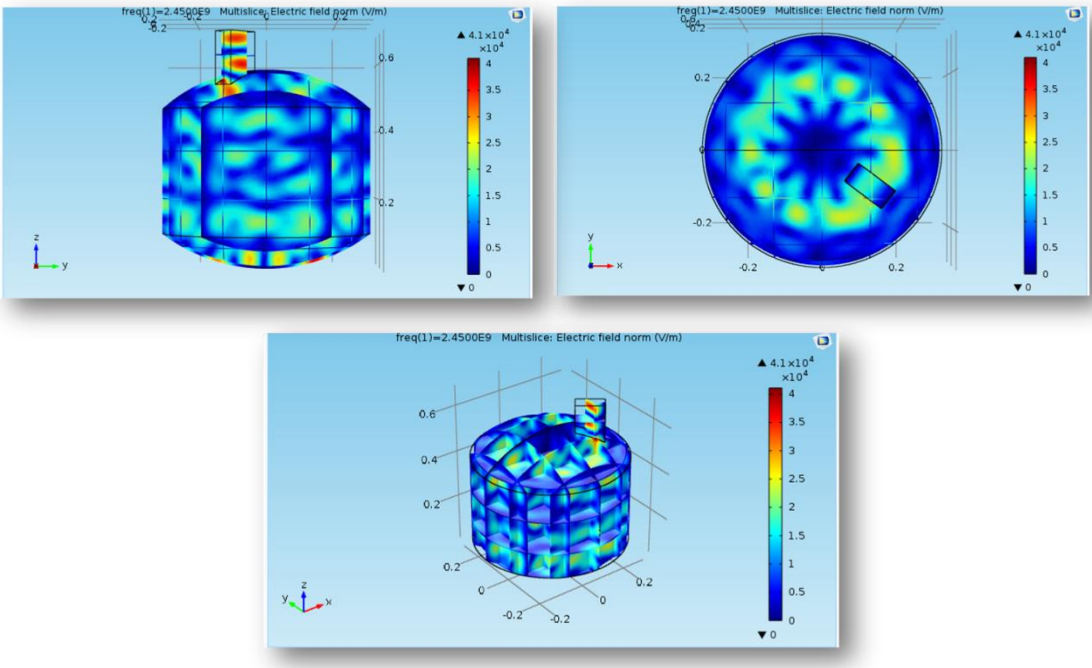


Figure 2. Optimized electromagnetic field simulation result of waveguide and cavity installation design from COMSOL Multiphysic Software Version 5.1.

The frying basket lid was modified for compatibility with the microwave condition using polypropylene as described by Alin & Hakkarainen, (2010) (Figure 3a). The lid was drilled as a screen to provide open areas for the release of steam. Finally, the microwave leakage detector (Research Center of Microwave Utilization in Engineering, the Department of Mechanical Engineering, the Faculty of Engineering, Thammasat University) was used to determine microwave leaking (Figure 3b).

2.3 Experimental procedure

2.3.1 Vacuum fryer operation procedures (reference condition)

The vacuum frying process consisted of heating the oil to the target temperature and vacuum frying of the samples. The procedures of heating the palm oil and vacuum frying of the sample were as follows. First, the vacuum system

(a)

(b)

Figure 3. Modifications and safety of microwave vacuum frying machine: (a) Modification of frying basket slid using polypropylene and (b) Test of microwave leakage by RCME Microwave Leakage Detector. (RCME: Research Center of Microwave Utilization in Engineering, the Department of Mechanical Engineering, the Faculty of Engineering, Thammasat University)

started and was applied only to the frying tank to draw in the palm olein oil (45 liters) into the tank with different pressures between the frying tank and the oil tank. The oil was heated to 95–100 °C and then drained to the oil tank by applying the same vacuum pressure to both tanks. Then, the amount of 1000 g of freshly sliced bananas was put into the frying basket with the samples arranged at the bottom of the basket plate to ensure heat distribution during frying. After that the frying basket with the samples was placed into the frying tank with a hole at the center of basket well fitted with the rotational shaft. The lid of the frying tank was closed and the parameter of frying was set based on required conditions. The reference vacuum frying conditions were controlled at 95 °C and 2 kPa for 75 min. The sensory evaluation showed the comparable qualities of the banana chips from a reference condition and commercial banana chips (Table 1). After the vacuum system was turned on and oil was drawn from the oil tank to the frying tank by the same heating procedure, the frying time and temperature were monitored by the controller until the end of the process. During the frying step, the frying basket was rotated at a slow speed at 15 revolutions per minute (rpm) to provide a uniform heat transfer around the frying basket. After the time reached a set point, the oil valve was opened to drain the frying oil into the oil tank using gravitational transfer. The samples were then centrifuged for 5 min at 450 rpm to remove the excess of oil from the surface to minimize oil absorption (Yamsaengsung *et al.,* 2011). After the frying process, the banana chips were removed from the vacuum fryer and allowed to cool at room temperature (25–30 ºC) for 30 min. The banana chips were kept in sealed aluminium bags to prevent moisture loss and rancidity and stored at room temperature for further analysis. The banana chip samples collected from the three replications were analyzed. The average value of ten samples from each replication was reported.

2.3.2 Combined microwave-vacuum fryer operation procedures

The microwave process was combined with VF by testing at 5 min and 10 min after vacuum frying (Table 2). Using the combined microwave-vacuum fryer, the oil was drained from the frying tank to the oil tank before the microwave treatment while the vacuum system was still running. Then, the fried banana chips were subjected to the protocol which was similar to the VF method until the end of the process.

2.4 Measurement of banana chips quality

2.4.1 Moisture measurement

The residual moisture content of the banana chip samples was determined using a hot air oven by determining the difference in the weights of the samples before and after drying. Approximately 3 g of samples in each condition were oven dried at 105 ºC until the mass was stabilized (AOAC, 1995).

Table 1. Sensory evaluation of the vacuum fried banana chips.

Method[1]		Parameters				
Vacuum frying time (min)	Microwave time (min)	Color yellow	Rancid odor	Taste	Crispiness	Overall preference
75	0	6.8±0.4b	3.7±0.1c	6.5±0.1b	7.5±0.2b	6.5±0.1b
65	5	6.2±0.1c	3.5±0.2c	7.5±0.7a	8.5±0.1a	7.8±0.3a
55	10	7.0±0.2b	3.8±0.3b	7.8±0.5a	7.8±0.3ab	6.9±0.4ab
40	10	6.0±0.1c	3.6±0.1c	7.2±0.7a	8.1±0.2a	7.1±0.1a
25	5	8.0±0.1a	8.5±0.4a	1.1±0.9d	1.0±0.4d	1.5±0.2d
Commercial vacuum fried banana chips		7.5±0.3b	4.1±0.1b	6.0±0.2c	6.7±0.1c	6.0±0.2c

[1]Assays were performed in six replicates. Mean ± standard deviation values in the same column followed by different letters are significantly different at P≤0.05.

Table 2. Parameters at different operating conditions.

Method				Parameters[1]				
No	Vacuum frying time (min)	Microwave time (min)	Reduced total frying time (%)	Crispiness (g)	Moisture % (w.b.)	Oil content (%)	Color values	
							*L**	*b**
1	75	0	Reference	4,082±354^{a}	4.17±0.40^{c}	16.28±0.63^{b}	60.82±1.31^{b}	24.88±0.87^{a}
2	65	5	7%	3,982±466^{a}	4.66±0.81^{c}	16.06±0.75^{b}	64.69±2.08^{a}	24.36±0.69^{a}
3	65	10	0%		(Total time equaled the reference condition)			
4	55	5	20%		(Mixed between crispy and not crispy chips)			
5	55	10	13%	3,196±340^{b}	4.55±0.20^{c}	15.66±0.69^{b}	59.2±2.28^{b}	24.18±1.28^{ab}
6	40	5	40%	n.d.				
7	40	10	33%	3,595±520^{ab}	5.53±0.40^{b}	16.40 ±0.18^{b}	63.48±0.90^{a}	24.55±0.74^{a}
8	25	5	60%	n.d.	8.63±0.67^{a}	30.67± 0.65^{a}	55.80±2.13^{c}	23.19±1.33^{b}
9	25	10	53%	n.d.				
10	Commercial		-	4,073±709^{a}	4.37±0.67^{c}	17.21±0.82^{b}	63.68±2.42^{b}	24.63±0.92^{a}

[1]Assays were performed in six replicates. Mean±standard deviation values in the same column followed by different letters are significantly different (P≤0.05).
[2]n.d .represents not detected values

2.4.2 Oil measurement

The oil content of the dried banana chip samples was determined using AOAC Official Method.960.39 fat (crude) or ether extract (AOAC, 1984).

2.4.3 Texture measurement

The textural properties of the banana samples were analyzed using a Texture Analyzer (Model TAXTplus, Stable Micro Systems™ Co., England). A fresh banana sample was placed over the hollow planar base (Bourne, Kenny, & Barnard, 1978) and was compressed using a 2 mm spherical probe at a test speed of 2 mm/s through a distance of 10 mm. The texture properties of the fried samples were evaluated using a 1/4 inch (~6 mm) diameter probe at a compression speed of 1 mm/s through a distance of 4 mm or until the sample cracked. The maximum compression force from the force-deformation curve of each sample was considered as an indicator of hardness. Ten samples were used for each test run. Data were evaluated using the Texture Expert Software (SMS Ltd., Version 1.19, Stable Micro Systems™ Co., England).

2.4.4 Image analysis

The banana chip samples were laid on a white counter for contrast. Digital images of the banana chip samples were obtained using a digital handheld camera (Nikon D7000, Tokyo, Japan) stabilized with a camera stand. The camera was positioned at 30 cm for top view photos and 40 cm for side view photos. Lighting of the samples used a controlled LED light source of 5 watts at a distance of 1.5 m for each sample. The size and resolution of the images were 2,634×1,985 pixels (22.3×16.81 cm) and 300 dots per inch, respectively.

2.4.5 Sensory evaluation

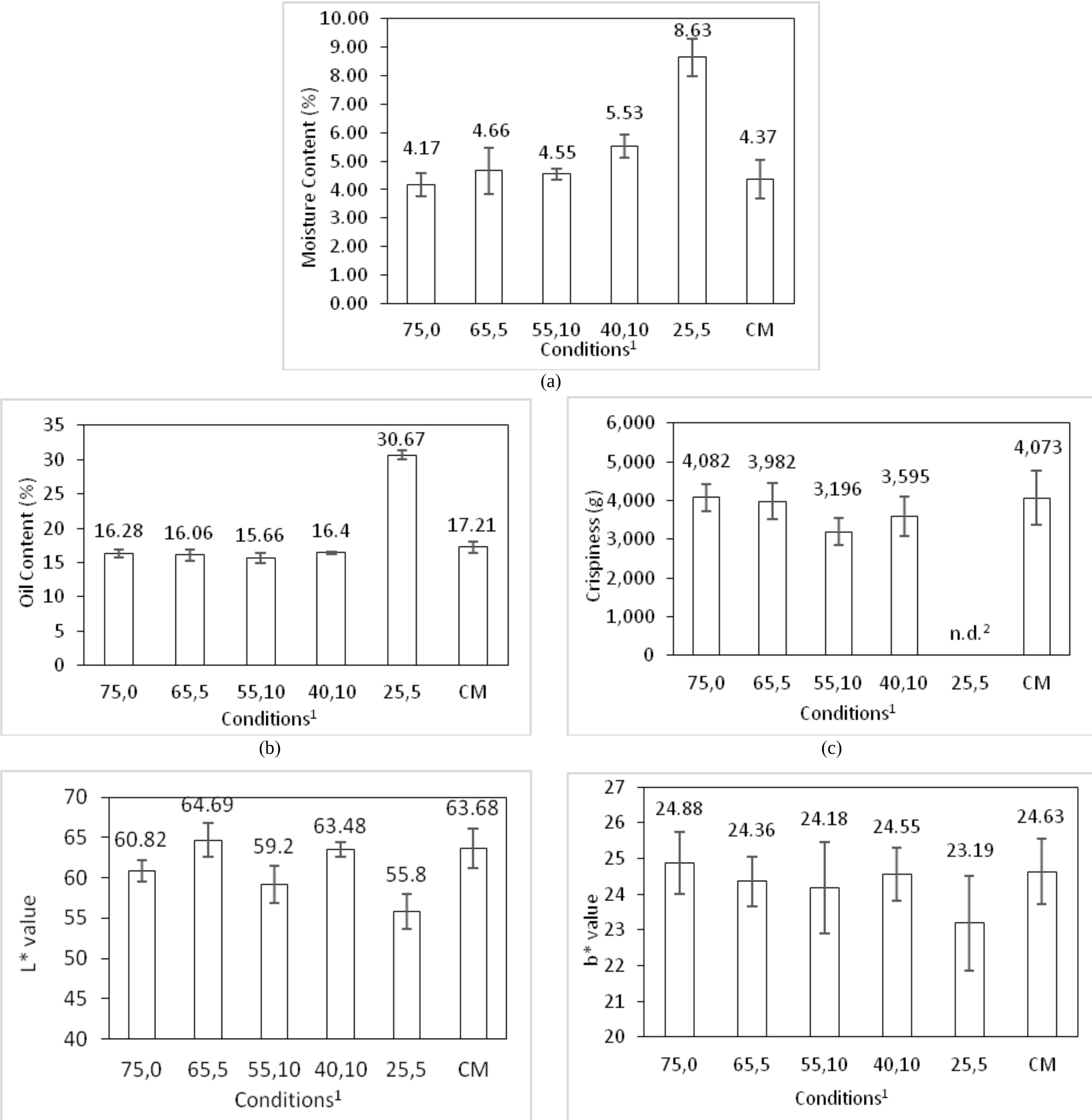
Sensory evaluation of the banana chips was performed by 50 consumer panelists at the Department of Sustainable Energy and Environment Technology and Management Rattanakosin College for Sustainable Energy and Environment, Rajamangala University of Technology Rattanakosin. Dried banana chips from each combined microwave experiment with high values of crispiness were selected for sensory evaluation using a nine-point hedonic scale in the range of 1 to 9 compared with those samples from VF and commercial fried banana chips produced at atmospheric pressure. The quality attributes in this work were considered in terms of color (yellow), flavor (rancid smell), taste, texture (crispiness), and overall preference.

2.5 Statistical analysis

Raw and fried banana chips properties as well as differences among treatments are expressed as mean±standard deviation values. Data were analyzed using one-way analysis of variance (ANOVA). The analysis showed significant differences (P≤0.05). The means were compared using Duncan's multiple range test. The statistical analysis was performed using PASW Statistics 18 software (SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

The quality parameters of each condition are displayed in Table 2. Only crispy banana chips provided from each condition were taken into the study in terms of moisture content, oil content, and color. However, the non-crispy banana chips provided from the VF25MW5 condition at the same time were taken into account to represent a non-crispy case condition. The VF65MW10 condition was not tested in this study because the total time was equal to the reference condition. The results from the VF55MW5 condition provided both crispy and non-crispy banana chips. Therefore, this condition was not taken into consideration. Figure 4 shows the condition of crispy banana chips, which had the quality parameters measured.



(d) (e)

[1]First number represents vacuum frying time, second number represents microwave time and CM represents commercial fried banana chips. Assays were performed in ten replicates.
[2]n.d .represents not detected values

Figure 4. Parameters of the different operation studies.

3.1 Effect of vacuum frying time and microwave time on moisture of fried banana chips

The effects of the combined microwave-vacuum fryer operation at 5 min and 10 min of MW time for each VF time on the moisture content of banana chips are shown in Figure 4a. The moisture content value was established by measuring the remaining water in the sample after the combination of frying in the microwave process. The VF65MW5 and VF55MW10 banana chip samples had no significant differences in moisture content compared to the reference sample VF75MW0 and commercial banana chips 4.37% (w.b.) (Figure 4a). The banana chip samples taken from the VF40MW10 condition showed a significant difference in moisture content 5.53% (w.b.) compared to the reference samples and commercial banana chips. To understand this, both crispiness and moisture content would be taken into consideration. At the higher MW time in the frying process, the moisture content in banana chips increased from 4.17 to 5.53% (w.b.) as the VF time was reduced. The results indicated that the application of microwave-assisted VF provided a shorter frying time. A previous study reported the same phenomenon where the application of MWVF was found to greatly reduce the frying time and increase the moisture evaporation (Quan *et al.,* 2014). The accelerated moisture removal rate in the MWVF process is attributed to the distinction between the heating mode of the microwave and the moisture content in the banana chips. During the microwave time, the water in the banana chips absorbed the microwave energy and the extent of its vibration increased. Vibration of the water molecules results in internal friction and conversion to heat energy (Rattanadecho & Makul, 2016). According to this phenomenon, the high amount of water remaining in the banana chips made the water molecule vibrations increase which was converted into thermal energy which ultimately helped the water evaporate faster. This can be explained in terms of mass transfer. The rate of mass transfer by MWVF was considered higher than by VF due to the vibration of the water molecules. For the VF mass transfer, the evaporation of water occurred at the boundary near the crust. This means that the MWVF process consumes a shorter frying time and at the same time provides similar moisture content.

3.2 Effect of vacuum frying time and microwave time on oil content of fried banana chips

Oil content is one of the most important quality attributes of fried products. High oil content in fried products is usually not preferred by health-conscious consumers and may be considered as unhealthy products. Moreover, high oil content in fried products typically becomes rancid after a long period of storage because of lipid oxidation during the preservation process. Therefore, it is necessary to determine the oil content in MWVF fried products to reduce residue oil content in order to preserve the quality of the products.

Figure 4b represents the effects of the combined microwave-vacuum fryer operation at 5 min and 10 min of MW time at different VF times on the oil content of banana chips. The percentages of oil in the MWVF banana chip samples were in the range of 15.66–16.40% which were not significantly different than the control VF75MW0 (16.28%) and the commercial vacuum frying banana chips (17.21%). However, when the VF time was reduced to 25 min, the oil content extracted from the VF25MW5 sample went up to 30.67% which was similar to the oil content of fried potato chips (range 35.3–44.5%). According to Quan *et al.* (2014), these high values might affect crispiness. The cause of the high oil content in the VF25MW5 samples was possibly due to being less hydrophilic at the crust surface during the frying process. In the early stage of frying (<25 min), the water remaining in the bananas was still held in the material while the rate of moisture evaporation at the crust surface was high. Thus, the crust at the surface of the banana chips became dryer and less hydrophilic, ultimately resisting the outward diffusion of interior moisture. Figure 5 and 6 represents the process of pore formation and oil absorption in fried products. In addition, during the frying process, the formation of larger pores on the surface caused by moisture evaporation at the crust surface generated a driving force for the oil at the surface to penetrate the pores. The oil content increased over the frying time until it filled the pores left vacant by the evaporated water. This allows greater contact between oil and pore and even the non-porous areas of the chips (Gamble *et al.,* 1987).

3.3 Effect of vacuum frying time and microwave time on texture of fried banana chips

Most of the water evaporated from the bananas during frying which made the texture of the samples crispy. This parameter is the key parameter that represents a decision point to evaluate the quality of banana chips. The textural firmness in chips was measured in terms of breaking force. The breaking force can be used as an indicator of the crispiness of vacuum-fried chips (Fan, Zhang, & Mujumdar, 2005). The crispiness of banana chips was achieved when the crust at the surface of the banana chip formed (Farkas, Singh, & Rumsey, 1996) (Figure 5). The results showed that 3 conditions could not detect crispiness: VF40MW5, VF25MW5, and VF25MW10. The VF55MW5 condition was considered not crispy because both crispy and non-crispy banana chips were found. The crispiness of banana chips increased from 3196 g to 3595 g by reducing the VF time and increasing the MW time (Figure 4c). The crispiness results of the VF65MW5 and VF40MW10 conditions were not significantly different from the control (VF75MW0, 4082 g) and commercial banana chips (4073 g). This observation was related to the diffusion of water from the internal part to the crust surface at the vacuum frying stage and at the later stage.

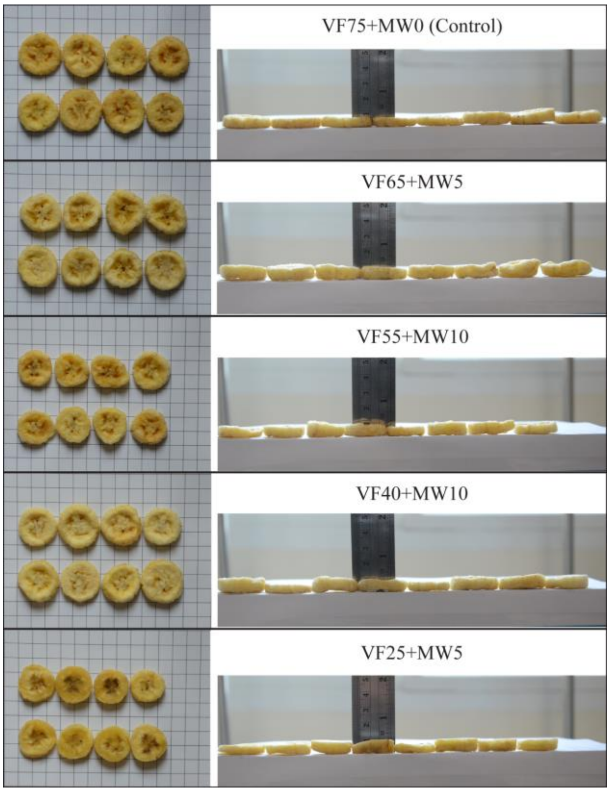


Figure 5. Characteristics of the banana chips after vacuum frying and microwave vacuum frying in different conditions.

The application of microwave radiation enhanced the outward diffusion of moisture from the chip surface to the atmosphere. The fast water evaporation rates at the surface may create a higher pore density of larger pores in the chips since a porous texture was expected to increase the crispiness in chips (Figure 6). Surprisingly, when the VF time was reduced to 25 min at a MW time of 5 min (VF25MW5), the crispiness could not be detected by the texture analyzer. The banana chips after this treatment showed highly sticky properties which was related to the high moisture and oil contents of 2.98% and 30.67%, respectively. This result may be due to the restriction of internal moisture diffusion outward through the surface during the frying process (Schiffmann, 1995).

3.4 Effect of vacuum frying time and microwave time on the color of fried banana chips

Changes in the color of the fried banana chips samples were observed by analyzing the L^* (lightness) and b^* (yellow-blue chromaticity) parameters. The effects of MWVF on the color of banana chips after frying at different VF and MW times are shown in Figures 4d and 4e. Typically, $L^*$is a critical parameter in food frying. It is used to determine the lightness of the samples. Higher L^* values indicate a lighter color which is possibly more desirable for consumers. On the other hand, if the lightness is very high, it means the product was not cooked well enough. The fried banana chips using MWVF were visually lighter compared to the fried samples using VF (Figure 5). The lightness (L^* values) of the banana chips increased from 54.80 to 64.69 as the VF time reduced and as the MW time increased (Figure 4d). The lightness of the VF65MW5 and VF40MW10 samples were not significantly different than the lightness of the control banana chips (VF75MW0, L^*=60.82) and commercial banana chips (L^*=63.68). However, when the VF time was reduced to 25 min at a MW time of 5 min (VF25MW5), the lightness of the chips was at the lowest degree (L^*=55.80), which was related to the highest level of oil content that could be explained by reduced light scattering. The formation of darker colors (low L^* values) during frying is associated with non-enzymatic browning reactions, including the Maillard reaction, caramelization, and chemical oxidation (Baixauli, Salvador, Fiszman, & Calvo, 2002).

The yellow-green chromaticity of the fried banana chip samples is shown in Figure 4e. There were no significant differences in the yellowness (b^* value) of the MWVF samples (b^*, 24.18–24.55) obtained using different VF and MW times compared to the control VF75MW0 (b^*=24.88) and commercial banana chips (b^*=24.63). However, the lowest yellowness of banana chips could be observed in samples when the VF was 25 min and the MW time was 5 min (VF25MW5), which was related to the lowest lightness and the highest residual oil content. This observation agreed with an earlier report that stated as the microwave power level increased, the rate of non-enzymatic browning reactions increased (Quan *et al.*, 2014).

3.5 Overall quality results and % reduced total frying time

Based on the quality parameters, the overall quality results of the VF40MW10 and VF55MW10 conditions were 33% and 13%, respectively (Table 2). There was no sign of reduced total frying time for the VF65MW5 condition.

3.6 Sensory evaluation of fried banana chips

The sensory evaluation results of the fried banana chips and commercial fried banana chips are shown in Table 1. The MWVF banana chips had a significantly higher score in terms of taste, texture, and overall preference than the experimental vacuum fried samples.

Meanwhile, the preference scores of flavor (rancid) in all samples were not significantly different, except the VF25MW5 condition. However, the texture (crispiness) and overall preference of the fried banana chips derived from the VF65MW5 and VF40MW10 conditions had higher scores than those of the VF75MW0 condition and the commercially fried banana chips. This indicated that the banana chips fried using MWVF were more preferable than those fried using only the VF condition.

4. Conclusions

This study investigated the drying technique of sliced bananas in order to compare banana chips using only VF and combined MWVF treatments. The results showed that the dried banana chips from the optimized MWVF techniques provided similar values of color, crispiness, moisture, and oil content to those from the VF and commercial vacuum fried banana chips. From the sensory evaluation, the chips from the optimized MWVF techniques were more preferred in terms of texture and overall preference compared to the commercial vacuum fried banana chips and VF.

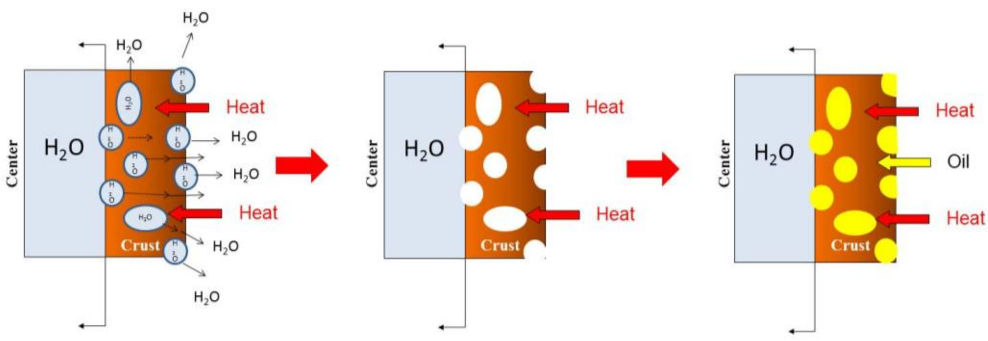


Figure 6. Phenomena of moisture and lipid exchange on banana crust.

In addition, the frying rates of the combined MWVF technique were higher than the VF method. The MWVF conditions consumed shorter frying times and were more efficient in frying temperature. The best condition for MWVF was the VF40MW10 or 50 min of total frying time which had a 33% decreased total frying time compared to the reference VF process. The combined MWVF technique is capable of producing acceptable fried products that are crispy with similar oil content, color, and sensorial quality.

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