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Shrimp Cassava Cracker Puffed by Microwave Technique: Effect of Moisture and Oil Content on Some Physical Characteristics

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ABSTRACT

Low-fat products have been proposed as a substitute for deep fried foods due to their improved shelf life and as a response to consumers' health concerns with fried foods. Microwave puffing was used to puff shrimp cassava cracker (SCC) as a substitute for deep fried SCC in this study. The dried semi-product with various levels of initial moisture content (IMC) from 16 to 31.5% on a wet basis and added oil percentage (AOP) from 0 to 21% by weight were puffed by microwave heating for 1 min. Deep oil fried SCC was also used in comparison tests of hardness, volume expansion and sensory evaluation. It was clear that after microwave puffing, the hardness and volume expansion were significantly different at various levels of IMC and AOP. At the suitable IMC, the hardness of SCC without oil was noticeably higher than that of the sample with oil whereas its volume was significantly higher. The AOP had a negative correlation with hardness and volume expansion (%) at a highly significant level ($P < 0.01$). Hardness and volume expansion had a positive correlation at $P < 0.05$. The optimum level of IMC for volume expansion of SCC was 21.5% on a wet basis and an AOP at 15% and these could reduce the hardness comparable to the fried SCC. Although the volume expansion of microwave SCC was less than that of fried SCC, the sensory evaluation indicated that microwave heating at the optimum conditions was acceptable by the panelists as a new technique for puffed SCC product, especially in terms of avoiding high oil content.

Keywords: shrimp cracker, microwave, puffing, frying, moisture content, hardness, volume expansion.

INTRODUCTION

Shrimp cassava cracker is one of the popular snacks in South East Asia that is normally produced by frying in deep fat. In deep immersion oil frying, the sample receives heat contact from all directions resulting in quick volume expansion and a uniform and larger size (Farkas, 1994; Farkas *et al*., 1996). In addition, a porous structure is formed and the final fried cracker provides high-quality softness, crispiness and improved volume expansion. However, since the water is replaced by hot oil (Fellows, 2000) after the frying process, the oil content in the final fried products is relatively high—up to approximately 35% (Shachat and Raphael, 1990). Apart from concerns resulting from increasing health awareness by consumers, the high oil content also affects the rancid odor and flavor and shortens the shelf life of the product during storage. Moreover, during the frying process, aromatic compounds are lost due to high temperature; the final product might be

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dominated by an oil odor and/or the by-products of oil heated to a high temperature and other ingredients. Therefore, the flavor of the added ingredient, for instance the shrimp flavor, would be reduced. Another problem is that the conventional deep fat frying method might not be comparably economic due to the usage of oil since the oil is the most costly material in fried shrimp cracker production (Wu *et al*., 2010).

Microwave heating methods have been recognized by the industry and scientists due to their heating advantages over conventional heating methods (Venkatesh and Raghavan, 2005; Castro-Giráldez *et al*., 2012). Microwave heating is of interest in the puffing process due to the low-fat, healthy food obtained in comparison to deep-fat fried products (Rakesh and Datta, 2011a, b). The absorption of microwaves by dielectric materials results in the microwaves giving up their energy to the material with a consequential rapid rise in temperature and volumetric mass transfer (Ni *et al*., 1999; Sumnu and Sahin, 2005; Singh and Heldman, 2008). This was hypothesized to be the physical force for the puffing process (Boehmer *et al*., 1992; Schwab *et al*., 1994; Brown *et al*., 1996; Rakesh and Datta, 2011a, b).

Volume expansion is one of the most important characteristics of a cracker required by consumers and this also affects the texture of the cracker. Microwave puffing might relate to the physical and the chemical status of material. For puffing, evaporation and pressure generation play a major role (Baek *et al*., 2005). Pre-drying processes to form a thin coating layer before puffing certainly influence the volume expansion of the cracker. A coating layer before puffing results in better puffing volume (Prasert and Suwannaporn, 2009) since it provides good conditions for building up the pressure. The chemical properties of flour and exogenous components are also important factors in volume expansion (Linko *et al*., 1981; Beleia *et al*., 2006; Taewee, 2011). Apart from the ratio of amylose to amylopectin in starch, their interaction with other ingredients in the dough is strongly related to cracker volume (Matz, 1984; Wang, 1997). Lipids and proteins have either positive or negative effects on the puffing volume. Their contents in starch were found to delay volume expansion (Taewee, 2011). However, their role and impact in the starch interaction and the expansion properties are not completely understood. Decreased expansion of the fried cracker was found when the dough contained a high amount of protein and lipid with the explanation being the inhibition of full gelatinization (Kyaw *et al*., 2001). For a relevant puffing product such as popcorn, it has been found that the total fat affected the expansion volume of the popcorn (Sweley *et al*., 2012a, b). Palm oil (Elaesis guineensis) is a common exogenous lipid used in cracker production due to its popularity with regard to nutritional and health benefits. However, it is mainly composed of palmitic acids and oleic fatty acids, which are nonpolar lipids. The nonpolar lipid might hurt the volume expansion (Pareyt *et al*., 2011) although it might tenderize the texture (Smith and Johansson, 2004). For microwave shrimp cassava cracker puffing, this information is still limited.

Microwave puffing leads to better product quality in comparison with puffing by deep-oil frying due to the reduced oil content (Rakesh and Datta, 2011a, b); however, for the microwave puffing process, a relatively high temperature is required to generate the pressure for puffing. The high temperature can facilitate sensitive chemical reactions in the long treatment period leading to undesirable effects on the appearance of the finished product. Therefore, for microwave puffing, a short treatment period at a high microwave power level should be applied to avoid the burnt appearance and a high oil content in the final product.

The parameters of greatest concern for microwave heating are the ionic polarization and dipole rotation involved in food composition

(Singh and Heldman, 2008). A multiphase, porous media reacts differently with microwaves depending on whether there is a high or low initial moisture content in the product (Ni *et al*., 1999; Castro-Giráldez *et al*., 2012). The oil has a much lower dielectric loss factor and specific heat than water and thus exhibits a much lower rate of heating than water (Singh and Heldman, 2008). Together with water, oil is the most marked nonpolar molecule influencing heating rates; their relationship with the microwave power has not been predicted especially for porous media. Therefore, for microwave puffing of a cassava product, it is necessary to determine the suitable percentage of oil to be added and the water content for the puffing process to obtain a good compromise between puffing volume, texture and the flavor of the final product.

As mentioned, although the use of microwave heating in the puffing process has increased, research related to microwave puffing of shrimp cassava cracker is still limited. Therefore, the current study aimed to determine the suitable initial moisture content and added oil content for puffing shrimp cracker using a microwave-puffing technique. The output of this study can provide comparable substituted properties of shrimp cassava cracker to compare with conventional deep fat frying including such properties as volume expansion, sensory evaluation and texture attributes.

MATERIALS AND METHODS

Materials

The cassava flour used in shrimp cracker formula—namely, “Pla Mang Korn”—was bought from the Tong Jan Company, Bangkok, Thailand. Fresh shrimps were purchased in a local market. After de-heading, de-shelling, and de-gutting, the shrimps were ground by a blender (Model AY 46, Moulinex, Bangkok, Thailand). The palm oil used in making the dough and in the frying process was bought from the Morakot Industry Company, Bangkok, Thailand. Salt, pepper and garlic powder were purchased from the Prungthip Company, Bangkok, Thailand the Raitanya Company, Bangkok, Thailand and the Decho Grocery Company, Bangkok, Thailand, respectively.

Shrimp cracker formula and initial moisture content preparation for semi-product

Shrimp cracker formulas were prepared that included cassava flour, shrimp (15%, weight by weight, w/w), salt (2%, w/w), garlic powder and ground pepper. The ratio between the cassava flour and shrimp was 5.5:1 (w/w)and was kept constant for all crackers tested in the experiments. The oil content (by weight) was varied at 0%, 3%, 6%, 9%, 12%, 15%, 18% and 21%, respectively, which was based on the total weight of all ingredients (Kyaw *et al*., 2001). The ground shrimp was thoroughly mixed with the other ingredients of salt, pepper, garlic, color and oil. Then, the mixture was carefully mixed with cassava flour, hot water at 100 °C and well-kneaded to prepare the dough. The loaf was shaped into a rectangular shape 10 cm × 5 cm × 1.5 cm (Figure 1). After incubation for 30 min, the loaf was steamed for 1 h to enhance the starch gelatinization. Then, it was cooled down at room temperature for 30 min and stored in a freezer overnight at -2 °C. After that, the loaves were cut into slices of 1.5–2 mm thickness and molded into a flower shape (Figure 1). To obtain the different initial moisture contents before puffing in a microwave oven, samples were dried at 70 °C by a dehydration machine (Dorr-Automat; ABC Electro; Haldenwang, Germany) for various times (10, 20, 30, 40, 50 and 60 min, respectively).

Microwave puffing operation

In the puffing process, semi-products were placed on the turntable of a microwave able (Model KOG-3725; Daewoo; Bangkok, Thailand) and heated for 1 min at an output power level of

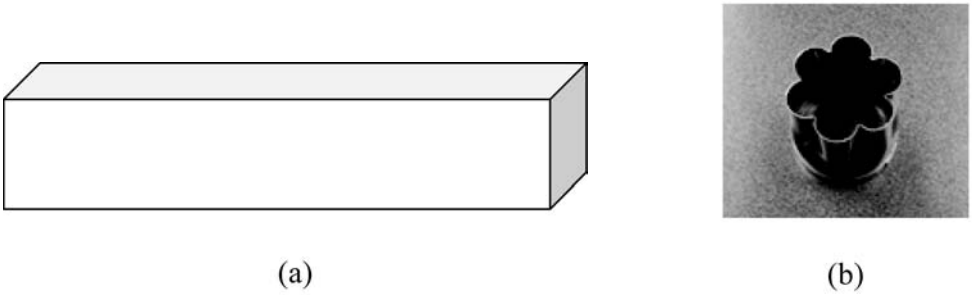

Figure 1 The loaf: (a) formed in a rectangular shape of 10 cm × 5 cm × 1.5 cm: (b) mold use to form the flower shape.

1,200 W. After 5 min of use, the microwave oven was stopped for 5 min to cool down. The data were obtained from triplicate tests. After puffing and the cooling down, the crackers were stored in plastic bags for further analysis.

Frying process

Using various initial moisture contents, the samples were fried in deep oil at 190 °C for 20 s using an electric fryer (Fryer Pro; Princess; the Netherlands). This frying period was determined in a preliminary experiment used to obtain the fully puffed volume and an acceptable appearance. After frying, the crackers were taken out and excess oil was allowed to absorb into a layer of paper tissue to reduce the oil content. Then, they were stored in plastic bags until later inspection.

Moisture content and moisture loss

The moisture content of the dried crackers was determined by the hot air oven method (Association of Official Analytical Chemists, 1990). The samples were dried in an oven at 135 °C and weighed after 2 h until constant weight. Two grams of cracker was cut into small pieces and spread out in an aluminum can. The weight of the cracker was determined using triplicate measurements. The moisture content was calculated using Equation 1:

$$X = \frac{M_1 - M_2}{M} \times 100 \tag{1}$$

where X is the moisture content of the cracker (%), M is the weight of the sample (in grams), M_1 is the weight of the sample before drying (in grams) and M_2 is the weight of the sample after drying (in grams).

Moisture loss is defined as the percentage of water evaporated during the puffing process. It was calculated based on Equation 2:

$$\Delta m = \frac{m_2 - m_1}{m_1} \tag{2}$$

where m_1 is the weight of the cracker before puffing (in grams), m_2 is the weight of cracker after puffing (in grams) and Δm is the moisture loss of the cracker (%).

Volume expansion

The volume expansion of the crackers was determined by the seed displacement method (modified from Sahin and Sumnu, 2006). The cracker was put in a known volume container containing dried black sesame seeds. This container was tapped and smoothed by a ruler and then weighed. The volume expansion of the fried and puffed crackers was measured by calculating the change in the volume of the seed displacement. The density of the seed was based on the research of Tunde-Akintunde and Akintunde (2004).The volume expansion was determined before and after puffing in a microwave and deep-frying, respectively, according to Equations 3–6:

$$W_{seed} = W_{total} - W_{sample} - W_{container} \quad (3)$$

$$V_{seeds} = \frac{W_{seeds}}{\rho_{seeds}} \quad (4)$$

$$V_{sample} = V_{container} - V_{seeds} \quad (5)$$

$$\Delta V = \frac{V_2 - V_1}{V_1} \times 100 \quad (6)$$

where W is the weight (in grams), V is the volume (in cubic centimeters), ρ is the density of sesame seeds (in grams per cubic centimeter), V_1 is the volume of the cracker before frying or puffing (in grams), V_2 is the volume of the cracker after frying or puffing (in grams), ΔV is the volume expansion of the cracker (%).

Texture analysis

A TA-XT.Plus Texture Analyzer (Stable Micro Systems; Godalming, UK) was used with the Texture Exponent 32 software to measure the hardness of the fried and puffed shrimp crackers. The testing conditions were modified from Salvador *et al*. (2009). The texture analyzer was set up with a spherical probe (P/0.25S) of 0.635 cm diameter and force/displacement measurement of a 25 kg load cell. The samples were put on the platform corresponding with HDP/BS. Crackers were tested at the conditions of speed 1 mm.s^{-1}, trigger force 5 g and travel distance of the probe 5 mm. The peak (maximum force) was recorded and represented the hardness.

Sensory analysis

Forty panelists, consisting of fourth year Bachelor degree students, teachers and staff in the Department of Food Science and Technology, Faculty of Agro-Industry, Kasetsart University, Bangkok, Thailand, participated in the sensory evaluation. The panelists received 3-digit encoded samples (962 and 587) with questionnaires and instructions for the evaluation of samples. Evaluation of the hardness and crispness of samples was done with a 9-point hedonic scale. A paired preference test was also conducted with a similar scale after obtaining the average score from the sensory evaluation.

Statistical analysis

The data were analyzed using the Statgraphic Centurion version XV software (StatPoint Technologies, Inc., Warrenton, VA, USA). The differences in mean values were compared by analysis of variance and the least significant difference multiple range test at the 95% confident level. Pearson correlations between each pair of variables were used in the multiple-variable analysis at $P < 0.001$, $P < 0.01$, and $P < 0.05$ respectively. The moisture content, hardness, volume expansion and sensory score were expressed as mean ± standard deviation.

RESULTS AND DISCUSSION

Effect of moisture content on puffing ability

The moisture content, moisture loss, volume expansion and puffed appearance of the samples are shown in Table 1. Significantly different levels of moisture content were obtained with 10–60 min of pre-heating corresponding to moisture of 31.5–16% on a wet basis (w.b.). Higher IMC samples resulted in samples with high moisture losses when heated in the 1,200 W microwave oven. For different IMC samples, after 1 min of being puffed by microwaves, the moisture losses also varied for different IMC samples. However, there seemed to be no significant differences in the puffed samples when the IMC of the dried semi-products was 18.6 and 16% w.b. in terms of volume expansion, moisture loss and appearance, although small differences could be seen in the volume expansion and moisture loss. Both samples seemed to be fully puffed but the volume expansion and appearance were less compared to those of the higher IMC sample (21–24% w.b.); the appearance of the puffed crackers showed evidence of having been burnt in this IMC range. This could be explained by the fact that at those levels of moisture (less than 18.6% w.b.), the dominant moisture in the sample is in the form of bound water, which is not removed much in a short heating period. In other words, with 1 min of heating, the moisture could not be removed to cause a significant difference from the previous sample. In addition, at the lower moisture level of 18.6% w.b., with 1 min heating by microwave, the crackers had a burnt appearance (image not shown) although they did appear to be fully puffed (Table 1). When the semi-products were dried to a lower moisture content, the percentage of other ingredients increased, especially salt. With the presence of more salt, heat was generated faster (Murugesan and Bhattacharya, 1986; Singh and Heldman, 2008; Maisont and Narkrugsa, 2010). In addition, there was less water transfer due to low moisture, so the surface of the product cooled down more slowly; the increased temperature on the surface lead to the burnt appearance.

The volume expansion and appearance of the microwave puffed shrimp crackers noticeably depended on the IMC before puffing by microwave. A combination of the volume expansion and appearance of the cracker resulted in the semi-product not being appropriate for microwave puffing if the IMC was approximately higher than 28% w.b. or lower than 18% w.b. On the other hand, although a slight increase in the volume was evident when the initial moisture content decreased from 31 to 28%, the final product was not fully puffed (dense) compared to its counterparts. The samples were fully puffed for the semi-products with an IMC range from 16 to 24.6% w.b. The lowest volume expansion was obtained for the sample with an initial moisture of 31% w.b. The best puffing ability of crackers occurred when the semi-product was dried for 40 min corresponding to an IMC of 21.6 ± 0.23%. At this moisture content, the cracker was puffed fully and had an appropriate appearance. The explanations are referred to the microwave heating mechanism described by Singh and Heldman (2008); the

Table 1 Various levels of initial moisture content, moisture loss, volume expansion and puffed appearance.

Drying Time (min)	Moisture Content after initial drying (% wet basis)	Volume Expansion (%)	Moisture loss after heating 1 min by microwave (%)	Appearance
10 min	$31.5^{f} \pm 0.03$	$105.68^{d} \pm 4.30$	$37.99^{e} \pm 0.96$	Not fully puffed, dense
20 min	$28.5^{e} \pm 0.43$	$117.63^{c} \pm 5.06$	$30.54^{d} \pm 0.71$	Not fully puffed, dense
30 min	$24.7^{d} \pm 0.30$	$129.66^{b} \pm 4.41$	$22.77^{c} \pm 0.44$	Fully puffed, good appearance
40 min	$21.6^{c} \pm 0.23$	$141.74^{a} \pm 6.76$	$19.89^{b} \pm 0.53$	Fully puffed, good appearance
50 min	$18.6^{b} \pm 0.38$	$128.52^{b} \pm 2.28$	$13.10^{a} \pm 0.88$	Fully puffed, burnt appearance
60 min	$16.0^{a} \pm 0.40$	$126.31^{b} \pm 4.55$	$13.04^{a} \pm 1.10$	Fully puffed, burnt appearance

Values shown are the mean ± standard deviation (moisture content: n = 3, volume expansion: n = 8, moisture loss: n= 6).
Means with different superscript letters within the same column differ significantly ($P < 0.05$).

heat is generated due to the collision of dielectric molecules including the ionic polarization and dipole rotation in food especially of water and salt. The samples containing suitably high moisture content generated more heat faster, which helped water to be converted quickly to vapor pressure since higher free water leads to liquid diffusion in the form of outward flux plus vapor diffusion, which are generated under high pressure or higher mass transfer during heating. Similarly, this phenomenon was found in the research of Rakesh and Datta, (2011a). Moreover, this process will be facilitated with the presence of salt. In the current study, this explained the higher level of moisture loss (as shown in Table 1) and the better volume expansion obtained.

Nevertheless, the dried semi-products can be well-puffed at a suitable moisture content; if the semi-product contained too high a level of free moisture content (greater than 24.7 to 31.5% w.b.), such samples could not be puffed well. This was due to the fact that at a high IMC, a longer heating time is required (more than 1 min) to get sufficient energy for outward flux evaporation. On the other hand, for low moisture content (less than 18% w.b.), the dominantly bound water is normally at a lower vibration in the electromagnetic wave; thus, there was less moisture evaporation than in a free water sample. In other words, the level of water transfer was not sufficient to cause the physical force to expand the volume as there was not the appropriate moisture level. Subsequently, the product surface was not adequately cool enough to prevent the increased surface temperature and thus resulted in the burnt appearance. Moreover, the process might be enhanced with the presence of a higher salt concentration when the moisture was lost. From the results, the optimal volume expansion and appropriate appearance of microwaved puffed shrimp cracker obtained was at an IMC of 21.6 ± 0.23%.

Effect of oil content on the texture of microwave puffed crackers

The influence of the oil content on the hardness and volume expansion of microwave puffed shrimp cracker is shown in Table 2. Hardness and volume expansion both decreased when the oil content increased except in the sample containing 3% oil. Volumes changed noticeably with the different oil contents. When 3% oil was added to the dough, the hardness instantly reduced from 24.04 ± 0.96 N (no oil) to 17.45 ± 0.10 N and then continually decreased as the oil content increased up to 21%. The hardness of the cracker was found to be inversely proportional to oil addition, which means that a cracker containing more oil is softer than one with a low oil content. With an added oil content from 6 to 21%, as more oil was added, the lower the volume expansion that was obtained; a highly significant correlation ($P < 0.001$) was also found for the oil content and volume expansion (Table 2). There was a significant difference in the comparisons of the volume expansion of crackers containing no oil, 3%, 6%, 12% and 19% oil content ($P < 0.05$). Moreover, adding 3%, 6% or 9% oil content resulted in the corresponding hardness obtained decreasing significantly ($P < 00.5$). However, from 9 to 18% oil content, there was no significant difference in the hardness between the following pairs: 9 and 12%, 12 and 15%, 15 and 18%; however, a significant reduction in hardness was found between 21 and 18% oil content. These results indicated that the effect of lipids on hardness varied greatly for different added contents, which corresponded to the study of Pareyt *et al*. (2011). The changes in the volume and hardness of a cracker can be explained by the following theory. Due to the interaction of amylose and the fatty acid chain of monoglyceride, the retrogradation of starch is reduced (Larsson 1980; Eliasson *et al*., 1981a, b; O'Brien, 2009) which results in lower hardness of the cracker. The amylose leaching can be blocked by the formation of an amylose-lipid complex on the granule surface

Table 2 Effect of oil content on the texture of microwave puffed cracker.

Oil Content (%)	Hardness (N)	Volume expansion (%)	Sensory evaluation
0%	$24.04^{g} \pm 0.96$	$141.74^{b} \pm 6.76$	No oil on surface, no oil smell
3%	$17.45^{f} \pm 0.10$	$148.61^{a} \pm 4.83$	No oil on surface, no oil smell
6%	$14.29^{e} \pm 1.19$	$137.00^{c} \pm 1.41$	No oil on surface, no oil smell
9%	$12.99^{d} \pm 1.37$	$135.43^{c} \pm 1.88$	No oil on surface, no oil smell
12%	$12.08^{cd} \pm 0.96$	$115.20^{d} \pm 2.27$	No oil on surface, no oil smell
15%	$10.96^{bc} \pm 0.21$	$112.30^{d} \pm 4.47$	No oil on surface, no oil smell
18%	$10.44^{b} \pm 0.75$	$106.90^{e} \pm 3.76$	Oil appearing on surface, a slight smell of oil
21%	$8.18^{a} \pm 1.03$	$96.52^{f} \pm 2.23$	Oil appearing on surface, a slight smell of oil

Values shown are the mean ± standard deviation; (hardness: n = 5, volume expansion: n = 8).
Means with different superscript letters within the same column differ significantly ($P < 0.05$).

or on lipid-coated starch granules which results in the inhibition of the gelatinization process and water absorption during dough making. The reduction in the volume expansion was found to be related to the inhibition of the gelatinization process as explained by Kugimiya *et al.* (1980) and Chin *et al.* (2007). On the other hand, the amylopectin-lipid complex also was proposed as a factor reducing the firming rate or hardness of crackers (Smith and Johansson, 2004), while the lipid content has been considered to play a role as a barrier for moisture migration resulting in softness (Pareyt *et al.*, 2011).

In addition, liquid oil also causes weak, thin cell walls in the dough (Watanabe *et al.*, 2003), so that there might not be sufficient strength in the cell walls to control the pressure or puffing ability of the cracker. An explanation based on the polarity was described by Pareyt *et al.* (2011), where the polar lipid-air interface strengthened the air cell and was beneficial to product puffing. Conversely, a non-polar lipid (such as palm oil) cannot stabilize the air cell. Their results are proposed to explain the reduction of volume when there was a large amount of oil added. MacRitchie and Gras (1973) also reported that the presence of endogenous, non-polar lipid affected the loaf volume.

Nevertheless, crackers containing too much oil (18 and 21%) did not fare well in the sensory evaluation. It was found that a layer of oil covering the cracker is an undesirable characteristic. This could cause a greasy smell that was considered unsatisfactory by the panelists due to their concerns about the healthiness of such a product. In addition, although the oil helped in tenderizing the cracker, it had an unexpected effect of reducing volume expansion as shown in Table 2 (except for 3% oil).When lipid was added, no improvement in the volume was observed which was similar to the results of Leissner (1988).

According to Table 3, highly significantly negative correlations were found between the oil content and hardness and volume expansion ($P < 0.001$). an increased oil content resulted in a sample with lower hardness and a smaller volume expansion, the reasons for which have been explained earlier.

An interesting result in this study was that when 3% oil was added to the dough, the volume of the cracker expanded the most with every moisture content level although in most cases, there was no significant difference (Figure 2). Pareyt *et al.* (2011) mentioned that volume expansion requires a suitable ratio of oil with other ingredients in the dough mixture. It is due to the fact that with a suitable lipid content there may be a good interaction with protein or starch to resist the gas cell structure. Many researchers in the last decade have reported that the volume expansion of crackers was affected by the protein content (Faubion *et al*., 1982; Peri *et al*., 1983) and was related to the lipid content (Linko *et al*., 1981).

Texture and volume comparison for fried and microwave puffed crackers

The highest volume expansion sample of microwave puffing was chosen to compare with fried cracker at the sample IMC as shown in Table 4. These attributes of fried and microwave puffed crackers were found to be significantly different. Puffed cracker produced by microwave was harder than fried cracker whereas the volume expansion was much smaller that of the cracker produced by deep oil frying. This could be explained by the fact that the crust formation of the fried cracker was uniform and thicker than that of the microwave puffed sample which was considered as a good condition for building pressure resulting in high volume expansion. During the deep oil frying process, the heat transfer mechanism involved conventional heating which meant that the heat transfer from the oil to the surface of the product was by convection and then from the surface to the center of the product by conduction. This caused an increase in the temperature which reached boiling temperature and the water started evaporating (Yagua and

Table 3 Correlation between oil content, hardness and volume expansion.

	Oil (%)	Volume expansion (%)
Hardness (N)	-0.9208**	0.8069*
Oil (%)		-0.9597***

Pearson product moment correlations between each pair of variables using multivariable analysis
(n=8: the number of pairs of data values used to compute each coefficient)
***,** and * = Statistically significant correlations at P <0.001, P < 0.01 and P < 0.05, respectively.

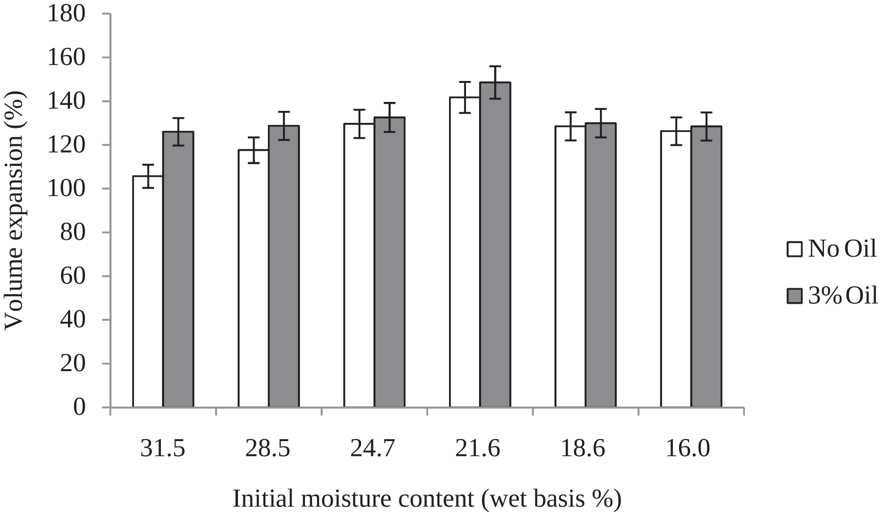

Figure 2 Volume expansion of cracker without and with 3% oil at various initial moisture contents. (The vertical bars represent ± SD)

Moreira, 2011). In this test, crackers were fried at 190 oC which is a relatively high temperature compared to the normal boiling point of water. The water evaporated at a faster rate under atmospheric pressure (Kilcast, 2004) which resulted in a high rise in the interior temperature. With longer frying, the different temperature between the surface and the inner layer became sufficient to form the crust or coating layer. This layer facilitated enhanced pressure resulting in the improved expanded volume. The volume expansion corresponded to air bubble formation inside the cracker and therefore a higher porous structure of the cracker and subsequently lower hardness (Farkas, 1994; Farkas *et al*., 1996).

The added oil content of 3% led to the reduced hardness and increased volume. However, when compared with fried crackers, the hardness was still higher than that of the common eating level. The reduced hardness of microwave puffed crackers was obtained by adding oil. From the results of this research, no significant difference in hardness was found for the crackers with 15 and 18% oil content (Table 2). Fried and 15% oil content microwave puffed crackers had similar hardness (Table 4). If considered from an economic aspect and from consumer demand, the higher oil content may be not recommended. Therefore, it can be stated that 15% oil content can be applied in the industrial production and provides a soft texture comparable with fried crackers.

Sensory evaluation

The 15% oil microwave sample was chosen to compare with fried crackers in terms of hardness and crispness, which were expressed by sensory evaluation as shown in Table 5.

There was no significant ($P < 0.05$) difference between the hardness and crispness of fried and 15% content oil microwave puffed crackers, although the crispness of samples obtained by deep oil frying was ranked higher than that from microwave puffing. The crispness and hardness seemed to be correlated; higher crispness resulted in samples with lower hardness and similarly, samples with lower crispness had higher hardness. This was due to the fact that higher crispness correlated with a higher air porous structure inside resulting in a structure that was not

Table 4 Texture comparison of fried and microwave puffed crackers containing no oil and 15% oil.

Sample	Fried Cracker	Microwave Puffed cracker	
		No oil	15% oil
Hardness (N)	$11.38^{a} \pm 0.56$	$24.04^{b} \pm 0.96$	$10.96^{a} \pm 0.21$
Volume Expansion (%)	$300.49^{a} \pm 4.31$	$141.74^{b} \pm 6.76$	$112.30^{c} \pm 4.47$

Values shown are the mean ± standard deviation; (hardness: n = 5, volume expansion: n = 8).
Means with different superscript letters within the same row differ significantly ($P < 0.05$).

Table 5 Sensory evaluation of fried and 15% oil content-microwave crackers.

Sample	Hardness	Crispness	Probability of preference	Sensory evaluation
Fried	$3.7250^{a} \pm 1.2606$	$6.9000^{a} \pm 0.7425$	0.45	Good appearance, oil smell
Microwave	$4.2250^{a} \pm 1.2087$	$6.7500^{a} \pm 0.7442$	0.55	Good appearance, no oil smell

Values shown are the mean ± standard deviation; (n = 40).
Means with different superscript letters within the same column differ significantly ($P < 0.05$).
Hardness: 1 = Extremely hard, 9 = Extremely soft; Crispness: 1 = Not extremely crisp, 9 = Extremely crisp.

dense, which led to lower hardness as measured by the texture analyzer. In addition, the probability of preference for a fried sample was 0.45 and that of a microwave sample was 0.55. This indicates that puffed crackers were preferred more than fried crackers. These results infer that consumers are concerned regarding the oil content of the puffing cracker rather than the volume expansion or the specific hardness and crispness. The 15% oil content added in the sample was found to be sufficient to provide good flavor, which was not expressed as a dominant oil flavor by the sensory panelists. This may be a critical point in cracker production.

CONCLUSION

The puffing ability of crackers varied with their initial moisture content and the added oil percentage. The highest volume was found at a moisture content of 21.5% wet basis for dough without oil added. At this level of moisture content, the 15% added oil was found to provide a good compromise between volume expansion and hardness, which were comparable to fried shrimp cassava crackers. There were notably significant differences in the hardness of deep oil frying and microwave puffed samples. The hardness of microwave puffed crackers without added oil was substantially higher than that of fried samples; however, this could be reduced by using a suitable oil content. The hardness reduction was positively corrected to the increased oil content while the volume expansion was negatively correlated to added oil (except for 3% added oil). For microwave puffing, to obtain a compromise between the puffing properties of flavor and texture, the optimal initial moisture content and added oil percentage for a specific microwave power level and a certain exposure time should be formulated for cracker products. The interaction of shrimp cassava components with microwaves and the other ingredients should be the subject of further research.

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LITERATURE CITED

Association of Official Analytical Chemists. 1990. **Official Method of Analysis of the Association of Official Analytical Chemists.** 15th ed. Association of Official Analytical Chemists. Arlington, Virginia. 1298 pp .

Baek, S., P.B. Wells, K.R. Rajagopal and J.D. Humphrey. 2005. Heat-induced changes in the finite strain viscoelastic behavior of a collagenous tissue. **J. Biomech Eng.** 127(4): 580–586.

Beleia, A., S.S. Butarelo and R.S.F. Silva. 2006. Modeling of starch gelatinization during cooking of cassava (Manihot esculenta Crantz). **LWT – J. Food Sci. Tech.** 39(4): 400-405.

Boehmer, E.W., W.L. Bennet, T.J. Guanella and L. Levine. 1992. Microwave expandable half product and process for its manufacture. **U.S. Patent** 5165950.

Brown, G.E., E.C. Schwab and T.R. Harrington. 1996. Multilayered puffed RTE cereal and high intensity microwave method of preparation. **U.S. Patent** 5558890.

Castro-Giráldez, M., P.J. Fito, J.M. Prieto, A. Andrés and P. Fito. 2012. Study of the puffing process of amaranth seeds by dielectric spectroscopy. **J. Food Eng.** 110(2): 298–304.

Chin, N.L., S.K. Goh, R.A. Rahman and D.M. Hashim. 2007. Functional effect of fully hydrogenated palm oil-based emulsifiers on baking performance of white bread. **Int. J. Food Eng.** 3: 1–17.

Eliasson, A.C., K. Larsoson and Y. Miezis. 1981a. On the possibility of modifying the gelatinization properties of starch by lipid surface coating. **Starch/Stärke** 33(7): 231–235.

Eliasson, A.C., T.L.G. Carlson, K. Larsoson and Y. Miezis. 1981b. Some effects of starch lipids on the thermal and theological properties of wheat starch. **Starch/Stärke** 33(4): 130–134.

Farkas, B.E. 1994. **Modeling Immersion Frying as a Moving Boundary Problem.** Ph.D. Dissertation. University of California. Davis, CA, USA.

Farkas, B. E., R.P. Singh and T.R. Rumsey. 1996. Modeling heat and mass transfer in immersion frying. I. Model development. **J. Food Eng.** 29(2): 211–226.

Faubion, J.M., R.C. Hoseney and P.A. Seib. 1982. Functionality of grain components in extrusion. **Cereal Foods World** 27: 212–216.

Fellows, P. J. 2000. **Food Processing Technology: Principles and Practices.** 2nd ed. Woodhead Publishing. UK. 575 pp.

Kilcast, D. 2004. **Texture in Food: Solid Food.** Volume 2. Woodhead Publishing. Cambridge, England 340 pp.

Kugimiya, M., J.W. Donavan and R.Y. Wong. 1980. Phase transitions of amylose-lipid complexes in starch: A calorimetric study. **Starch/Stärke** 32(8): 265–270.

Kyaw, Z.Y., S.Y. Yu, C.S. Cheow, M.H. Dzulkifly and N.K. Howell. 2001. Effect of fish to starch ratio on viscoelastic properties and microstructure of fish cracker (keropok) dough. **Int. J. Food Sci. Tech.** 36(7): 741–747.

Larsson, K. 1980. Inhibition of starch gelatinization by amylose-lipid complex formation. **Starch/Stärke** 32(4): 125–126.

Leissner, O. 1988. A comparison of the effect of different polymorphic forms of lipids in breadmaking. **Cereal Chem.** 65: 202–207.

Linko, P., P. Colonna and C. Mercier. 1981. High temperature, short time extrusion cooking, pp. 145–235. *In* Y. Pomeranz, (ed.). **Advances in Cereal Science and Technology. Vol. 4.** American Association of Cereal Chemists. USA.

MacRitchie, F. and P.W. Gras. 1973. The liquid phase of dough and its role in baking. **Cereal Chem.** 53(3): 318–326.

Maisont, S. and W. Narkrugsa. 2010. Effects of salt, moisture content and microwave power on puffing qualities of puffed rice. **Kasetsart J. (Nat. Sci.)** 44: 251–261.

Matz, S. A. 1984. **Snack Food Technology.** 2nd ed. AVI Publishing Co Inc., Westport, CT, USA. 415 pp.

Murugesan, G. and K.R. Bhattacharya. 1986. Studies on puffed rice I. Effect of processing conditions. **J. Food Sci. Tech.** 23: 197–202.

Ni, H., A.K. Datta and K.E. Torrance. 1999. Moisture transport in intensive microwave heating of biomaterials: A multiphase porous media model. **Int. J. Heat and Mass Trans.** 42(8): 1501–1512.

O'Brien, R.D. 2009. **Fats and Oils: Formulating and Processing for Applications.** CRC Press, Taylor & Francis Group. Florence, KY, USA. 680 pp.

Pareyt, B., S.M. Finnie, J.A. Putseys and J.A. Delcour. 2011. Lipids in bread making: Source, interactions and impact on bread quality. **J. Cereal Sci.** 54(3): 266–279.

Peri, C.,R. Barbieri and E.M. Casiraghi. 1983. Physical, chemical, and nutritional quality of extruded corn germ flour and milk protein blends. **J. Food Sci. Tech.** 18(1): 43–52.

Prasert, W. and P. Suwannaporn. 2009. Optimization of instant jasmine rice process and its physicochemical properties **J. Food Eng.** 95: 54–61.

Rakesh, V. and A.K. Datta. 2011a. Microwave puffing: Determination of optimal conditions using a coupled multiphase porous media–large deformation model. **J. Food Eng.** 107(2): 152–163.

Rakesh, V. and A.K. Datta. 2011b. Microwave puffing: Mathematical modeling and optimization. **Procedia Food Sci.** 1: 762–769.

Sahin, S. and S.G. Sumnu. 2006. **Physical Properties of Foods.** Springer Science and Business Media. New York, NY, USA. 272 pp.

Salvador, A., P. Varela, T. Sanz and S.M. Fiszman. 2009. Understanding potato chips crispy texture by simultaneous fracture and acoustic measurements, and sensory analysis. **LWT – J. Food Sci. Tech.** 42 (3): 763–767.

Schwab, E.C., G.E. Brown, K.L. Thomas and T.R. Harrington. 1994. High intensity microwave puffing of thick RTE cereal flakes. **U.S. Patent** 5338556.

Shachat, M.A. and S.J. Raphael. 1990. Process for making microwave puffed snack products. **U.S. Patent** 4950492.

Singh, R.P. and D.R. Heldman. 2008. **Introduction to Food Engineering.** 4th ed. Elsevier. Boston, MA, USA. 864 pp.

Smith, P.R. and J. Johansson. 2004. Influences of the proportion of solid fat in a shortening on loaf volume and staling of bread. **J. Food Process. Pres.** 28: 359–367.

Sumnu, G. and S. Sahin. 2005. **Recent Developments in Microwave Heating. Emerging Technologies for Food Processing.** Elsevier Academic Press. Boston, MA, USA. 792 pp.

Sweley, J.C., D.J. Rose, D.S. Jackson. 2012a. Hybrid and environment effects on popcorn kernel physiochemical properties and their relationship to microwave popping performance. **J. Cereal Sci.** 55(2): 188–194.

Sweley, J.C., M.C. Meyer, D.J. Rose and D. S. Jackson. 2012b. Effects of hybrid, environment, oil addition, and microwave wattage on popped popcorn morphology. **J. Cereal Sci.** 56(2): 276–281.

Taewee, T. K. 2011. Cracker “Keropok”: A review on factors influencing expansion. **Int. Food Res. J.** 18(3): 855–866.

Tunde-Akintunde, T.Y. and B.O. Akintunde. 2004. Some physical properties of sesame seed. **Biosystems Eng.** 88(1): 127–129.

Venkatesh, M.S. and G.S.V. Raghavan. 2005. An overview of dielectric properties measuring techniques. **Canadian Biosyst. Eng.** 47(7): 15–30.

Wang, S.W. 1997. Starches and starch derivatives in expanded snacks. **Cereal Foods World** 42(9): 734–745.

Watanabe, A., K. Yokomizo and A.C. Eliasson. 2003. Effect of physical states of non-polar lipids on rheology, ultracentrifugation, and microstructure of wheat flour dough. **Cereal Chem.** 80(3): 281–284.

Wu, H., S.A. Tasson, H. Jouhara and T.G. Karayiannis. 2010. Analysis of energy use in crisp frying processes. *In* **SEEP 2010 Conference Proceedings,** 29 June–2 July, Bari, Italy.

Yagua, C.V. and R.G. Moreira. 2011. Physical and thermal properties of potato chips during vacuum frying. **J. Food Eng.** 104: 272–283.