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Comparison Between Traditional Deep-Oil and Microwave Puffing for Physical and Eating Qualities of Puffed Pork Rind

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ABSTRACT

The effects were characterized and compared of pretreatment process conditions (boiling at different sodium chloride solutions of 0, 3, 4 and 5 % and drying at different dehydration times of 4, 5 and 6 hr) on the moisture content prior to puffing (MCP), volume expansion (VE), the moisture loss after puffing (ML), hardness and the color difference between microwave puffing (MWP) and deep-oil frying puffing (DOFP). The optimal pretreatment process conditions were selected by means of response surface methodology that considered the desirability and was validated by sensory evaluation. It appeared that the addition of salt increased the MCP associated with the puffing processes. The VE and hardness were affected differently by the two techniques with the values of DOFP being better than those of MWP values in general. MWP resulted in samples with a higher lightness but a lower color intensity when compared to those of DOFP. The results suggested that gelatin together with MCP might play an important role in MWP. Although being inferior compared to DOFP at different pretreatment conditions, MWP showed some comparable efficiencies in the puffing process and sensory evaluation under the optimal conditions which consisted of boiling in 3% salt and drying for 5 hr for MWP, while for DOFP, the optimum conditions were boiling in 0.003% salt (approximately water only) and drying for 6 hr when compared to the commercial product.

Keywords: microwave puffing, dehydration, puffed pork rind, volume expansion, sensory evaluation

INTRODUCTION

Pork skin (pork rind) has been used as a raw material for meat products or has been satisfactorily applied in connective gel in reduced-fat bologna (Satterlee and Zachariah, 1973; Puolanne and Ruusunen, 1981; Osburn *et al.*, 1997). Nowadays, pork rind plays an important role in many products, especially in snack foods. It has been mentioned in patents that the use of pork skin to make pork rind products as a healthy snack food, which contains low carbohydrates, low fat, low calories and high protein (Villar, 1994). Normally, pork rind is deep fried in oil to create the desired texture which is soft, crispy and "pops up".

Traditional deep-fat frying has good texture with huge volume expansion and crispness; however, it contains a lot of excess oil which may concern some consumers. The amount of fat in the human diet has increased greatly due to the apparent relationship between the amount and type

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of fat consumed and the incidence of coronary heart disease (Swinburn *et al*., 2004). For this reason, increased public concern over deep-fat-fried snack foods has motivated the food industry and research communities to explore new products with lower fat or no fat with many researchers focusing on the reduction of oil absorption in fried products (García *et al*., 2002; Mellema, 2003; Daniela *et al*., 2009). Microwave heating is as an alternative method for improving the quality of dehydrated products as the positive vapor pressure from internal microwave heating produces puffed products (Yan *et al*., 2010). Supporting healthy food claims, if the puffed pork rinds are produced by the microwave puffing method, the oil content will probably be reduced in the final product. A microwave puffing technique has been used to achieve the desired final product with a low fat content in snack products (Villar, 1994; Rakesh and Datta, 2011a and b).

The moisture content prior to puffing (MCP) is a critical factor in a puffing product that influences volume expansion and texture during microwave puffing. Microwave heating can generate heat for food materials through rapid heating and volumetric mass transfer; its mechanism consists of ionic polarization and dipole rotation which occur between the dielectric material and microwave energy (Ni *et al*., 1999; Sahin and Sumnu, 2006; Singh and Heldman, 2008; Thao *et al*., 2013). On the other hand, microwave power levels also affect the puffing process. A low microwave power level may affect the puffing volume and quality of pork rind due to the lack of appropriate pressure levels (Thao *et al*., 2013). Moreover, low microwave power may result in a lower temperature, which prolongs the puffing process and subsequently reduces product quality (Maisont and Narkrugsa, 2010. Otherwise, case hardening may be increased and this affects shrinkage or results in poor air cell generation inside puffed pork rind (Frederick, 1975. Therefore, pre-treatments are considered as an important step in microwave puffing.

Brining is one of factors influencing the efficiency of microwave methods and the final qualities of puffed pork products as it relates to the moisture content and protein properties. Sodium chloride (NaCl) has been traditionally used in the curing processes acting as a preservative and modifying the water holding capacity of the proteins (Sofos, 1986; Siró *et al*., 2009). Some functions of NaCl in meat products are: meat particle binding, fat emulsification and water holding, and thus it reduces cooking losses and improves the quality and texture (Sofos, 1986). With pork rind, a gelatin process together with a suitable moisture content prior to puffing are likely to be important factors facilitating the puffing process. Moreover, the gelatin is a traditional functional protein of high interest and value, having the ability to form transparent gels under specific conditions (Eastoe and Leach, 1977; Gennadios *et al*., 1994; Djagny *et al*., 2001). Gelatin has been proposed as a preservative coating for meat and other foods (Klose *et al*., 1952) and may play a role in the coating layer and enhancing the puffing process.

Due to the various effects of microwave energy on different types of food material and the advantages in reduced processing time and the provision of energy savings, specific conditions are required for certain foods (Thostenson and Chou, 1999; Venkatesh and Raghavan, 2004). Chandrasekaran *et al*. (2013) reported that in spite of the complex nature of microwave-food interactions, more research needed to be carried out for a better understanding of the process which would be useful for industrial applications.

The aim of this study was to characterize and compare the effects of the pretreatment processing conditions involving different boiling and dehydration processes on the physical properties and eating qualities of puffed pork rind produced using either microwave puffing or traditional deep-oil frying.

MATERIALS AND METHODS

Sample preparation

Pork skin from the belly area was used and purchased from the Amornphan market, Bangkok, Thailand. The samples were stored in a freezer (-22 °C) prior to the experiment. The hairs and the fat on the skin were removed using a sharp knife. The pork skin samples were washed and cut into small pieces, 1 × 5 × 0.2 cm (width by length by height). A salt meter (ATAGO S-28, ATAGO Co., Ltd; Tokyo, Japan) was used to measure the salt concentration of samples after boiling.

Pretreatment process conditions

Twenty pork skin pieces were used for each set of processing conditions: 1) no boiling (NB); 2) boiling in water (BW); 3) boiling in 3% sodium chloride solution at 99% purity (B3%); 4) boiling in 4% sodium chloride solution (B4%); and 5) boiling in 5% sodium chloride solution (B5%).

Boiling was undertaken for 40 min at 97 °C using an automatic electric rice cooker (Model SR-3NA-S; Panasonic; Bangkok, Thailand). After boiling, a sample of each process was dried at 75 ± 2 °C in a dehydration machine (Dorr-Automat; ABC Electro; Haldenwang, Germany) for varying times (4, 5 and 6 hr). The moisture contents after dehydration (prior to puffing) were measured using the method of Association of Official Analytical Chemists (2000) with 5 g of each sample dried at 105 °C for 24 hr.

Microwave puffing process

After pretreatment processing, the samples were placed in a ceramic container with a microwavable plastic cover and then puffed using a microwave oven (Model KOG-3725; Daewoo; Bangkok, Thailand) at a microwave power output of 1,200 W for 3 min. After microwave puffing, the products were stored in sealed polyethylene plastic bags and kept for 24 hr before further use.

Frying process

After drying under the different pretreatment conditions, the samples were fried at 190 °C for 3 min using an electric fryer of 1.5 L capacity (Fryer Pro; Princess; Tilburg, the Netherlands). Twenty pretreated samples were placed in an excess amount of hot oil. The palm oil used in frying was bought from the Morakot Industry Company (Bangkok, Thailand). The optimal temperature and time for frying were preliminarily tested based on volume expansion, texture analysis and appearance. The pork rind samples puffed by deep-oil frying were placed on tissue paper to reduce the excess surface oil before later inspection.

Experimental design and analysis

A 4 × 3 full factorial experimental design with four processing conditions (salt concentrations of BW, B3%, B4% and B5%) and three drying times (at 75 °C for 4, 5 and 6 hr) was employed to determine the effects of processing conditions on the puffing qualities of the puffed pork rind samples. NB was also conducted as a control to compare with other treatments.

Mathematical models were developed to describe the relationship between the response variables and independent variables using a 4 × 3 full factorial design according to several major steps described by Benlloch-Tinoco *et al.* (2012). The response surface plots of each response were plotted as a function of different processing conditions to describe their effects and to determine optimal points using the software package Stagraphic Centurion (version XV; (StatPoint Technologies, Inc.; Warrenton, VA, USA). an analysis of variance (ANOVA) table was used to partition the variability in each attribute into separate components for every effect. The statistical significance of each effect was tested by comparing the mean square against an estimate of the experimental error ($P \leq 0.05$; $P \leq 0.01$; and $P \leq 0.001$, respectively). The differences in mean values were compared by application of ANOVA and least significant difference multiple range testing at the 95% confidence level. The MCP, hardness, volume expansion and sensory score were expressed as means ± SD.

Optimization process

To conduct the multiple response optimizations, a model for each response was constructed separately and conducted with optimization for each response prior to combining multi-responses. The multiple-optimization was based on the desirability function expressing the desirability of a response value equal to Y on a scale of 0 to 1 (Corzo *et al*., 2008). Several critical responses regarding commercial product purchased from Amornphan market, Bangkok, Thailand were used to target the optimization process.

The overall desirability of the response values was calculated using Equation 1 and the method of Corzo *et al*. (2008):

$$D=\left\{d_1\left(\hat{Y_1}\right)\times d_2\left(\hat{Y_2}\right)\times d_3\left(\hat{Y_3}\right)\times\ldots\times d_k\left(\hat{Y_k}\right)\right\}^{1/k} \tag{1}$$

where $d\left(\hat{Y}\right)$ is the desirability of each response (the formula depends on the objective type which might be maximization, minimization or a target) and k is the number of responses.

Physical properties and eating qualities

Volume expansion determination

The percentage of volume expansion before and after the puffing process was determined by the seed displacement method (modified from Sahin and Sumnu, 2006; Thao *et al.,* 2013). The known density of dried black sesame seeds (Thai Cereals World Company; Bangkok, Thailand) with a moisture content of 5.6% on a wet basis was used. The puffed pork rind was placed in a container of known volume and then filled up with sesame seeds. The volume of the sample was calculated using the known total volume of the container and of the sesame seeds inside. The volume of the sesame seeds was determined using the known weight of the seeds in the container and the seed density (Thao *et al.,* 2013).

Color measurement

The surface color of powder puffed pork rind samples was measured using a Mini Lab colorimeter (Chromameter model CR-300; Minolta Camera Co. Ltd., Osaka, Japan**)** using the CIE color system (Le *et al*., 2014) with the color of samples expressed as L* and BI, where "L*" represents lightness (whiteness), BI is the color intensity and was calculated using Equation 2 (Roy *et al*., 2008)**:**

$$\mathrm{BI}=\sqrt{(\mathrm{a}^*)^2+(\mathrm{b}^*)^2} \tag{2}$$

where a* represents red/green opposing colors and b* represents yellow/blue opposing colors

Prior to each measurement, the calorimeter was calibrated using a standard white and black plate. The measurements were performed in two replications and repeated five times per replicate of puffed sample.

Texture analysis

A TA-XT.Plus Texture Analyzer (Stable Micro Systems; Godalming, UK) was used to measure the hardness of the fried and puffed pork rind samples. The testing conditions were modified from Salvador *et al*. (2009). The texture analyzer was set up with a Warner-Bratzler blade corresponding with a heavy duty platform (HDP/90) and a force/displacement measurement of a 25 kg load cell. The pre-test speed and post-test speed were determined at 1 mm.s^{-1} and 10 mm.s^{-1}, respectively. Puffed pork rind samples were tested under the conditions of a 20 g trigger force and 30 mm travel distance of the blade. The peak (maximum force) was recorded and was used to represent the hardness.

Microstructure of puffed pork rinds

The microstructure of puffed pork rinds was determined using a stereomicroscope (Leica S8APO; Leica Microsystems; Wetzlar, Germany) equipped with a digital image program

(Dewinter Software; New Delhi, India). The total magnification was 20 for image capture.

Sensory evaluation for validation

Samples derived using the optimal processing conditions for the desirability technique were used sensory evaluation. Forty panelists comprising fourth year bachelor degree students, teachers and other 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 three-digit encoded samples with questionnaires and evaluation instructions. The evaluation of the appearance, flavor, crispness, and hardness of samples was done using a 9-point hedonic scale.

RESULTS AND DISCUSSION

Effect of pretreatment process on physical properties and eating qualities of pork rind puffed by microwave

Table 1 shows the influence of two factors as the main and interaction effect on the properties of microwaves and fried-puffed pork rind. The boiling process had a great effect on most attributes, especially on the moisture content and lightness ($P \leq 0.001$) while there was no significant effect on the VE and hardness for MWP. With DOFP, the effect of boiling was evident in almost attributes except for hardness and lightness. The dehydration time showed its effect on the VE ($P \leq 0.001$) and hardness ($P \leq 0.01$, $P \leq 0.001$) in both puffing methods. The MCP, lightness and color intensity of MWP samples were not significantly affected by the dehydration time. Similarly, the dehydration time did not influence any attributes except for the color intensity ($P \leq 0.05$) of DOFP.

The interaction between two factors was only revealed with the hardness ($P \leq 0.001$) in the case of MWP and with the color intensity ($P \leq 0.05$) in the case of DOFP. The quadratic effect of the boiling process was shown with the hardness, lightness and color intensity for MWP while with DOFP it was apparent with almost all attributes except for hardness (not significant). In addition, the quadratic effect of the dehydration time also was evident for all attributes for DOFP while it was not for the hardness, lightness and color intensity of MWP.

The statistical model of each response was analyzed as shown in Table 3. The models satisfactorily represented the data in the

Table 1 Regression coefficient and analysis of variance, adjusted correlation coefficient (Adj. R^2) and standard error of estimate (SEE) values.

	MCP (% wet basis)	VE (%)	Hardness (N)	Lightness	Color intensity
Constant	62.13(61.64)	-34.82(-53.68)	228.00(320.7)	68.76(18.25)	32.7(63.02)
X_1	$1.261^{***}(2.055^{***})$	$-7.606^{ns}(-16.82^{***})$	$-48.47^{ns}(-1.696^{ns})$	$-1.231^{***}(-5.642^{ns})$	$1.199^{*}(5.394^{**})$
X_2	$-19.78^{ns}(-19.64^{ns})$	$40.78^{***}(56.58^{***})$	$-39.08^{**}(-122.1^{***})$	$0.0058^{ns}(24.05^{ns})$	$-5.163^{ns}(-17.33^{*})$
X_1X_1	$-0.0901^{ns}(-0.204^{*})$	$0.3212^{ns}(2.42^{***})$	$2.169^{**}(-0.2476^{ns})$	$0.5197^{***}(0.875^{***})$	$-0.2017^{*}(-0.5893^{***})$
X_1X_2	$0.0054^{ns}(-0.597^{ns})$	$1.034^{ns}(0.0925^{ns})$	$7.394^{***}(0.9423^{ns})$	$0.00^{ns}(0.2946^{ns})$	$0.0105^{ns}(-0.4042^{*})$
X_2X_2	$1.956^{***}(1.956^{***})$	$-5.164^{*}(-6.268^{*})$	$1.503^{ns}(13.14^{**})$	$-0.0083^{ns}(-2.477^{***})$	$0.5125^{ns}(1.771^{***})$
Adj. R^2 (%)	73.28(69.62)	50.57(75.46)	61.92(53.82)	76.67(77.31)	17.66(79.9)
SEE	1.073(1.144)	6.781(6.69)	9.839(10.58)	1.444(1.486)	1.354(1.141)

VE = Volume expansion; MCP = Moisture content prior to puffing; X1 = Boiling processing condition, X2 = Dehydration time. Numbers in parentheses are for traditional deep-oil frying puffing.

* = $P \leq 0.05$; ** = $P \leq 0.01$; *** = $P \leq 0.001$; ns = Not significant.

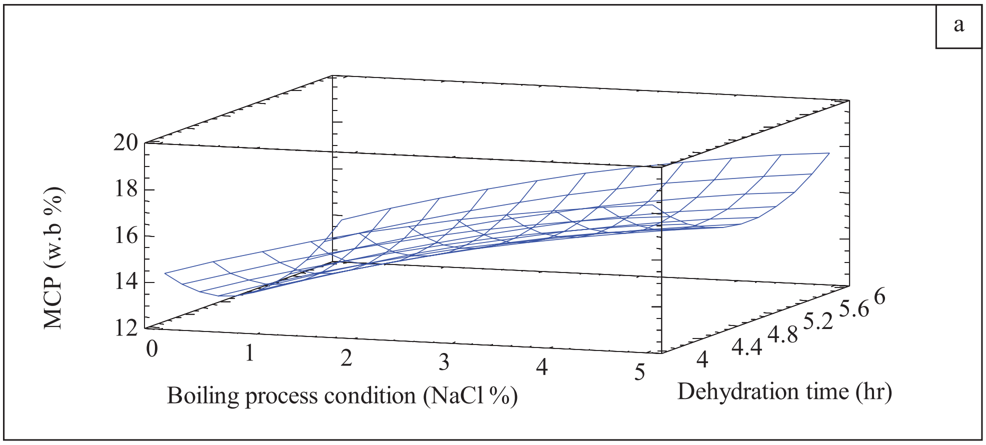
experimental domain where the correlation coefficient (R^2) values range between 70 and 90%. However, the models were not well-fitted by such a second order function for VE, hardness and color intensity for MWP while this model was quite a good fit for those attributes for DOFP. Moreover, together with the low R^2, the standard error of estimate (SEE) values in this study was quite large for VE and hardness either of the two methods of puffing although MWP seemed to be better fitted than DOFP for hardness. This implied that the two attributes were considerably changed during puffing. Such changes may have been due to variation in the preparation of samples such as cutting into pieces. During puffing, there might have been other influential factors besides those chosen in this study.

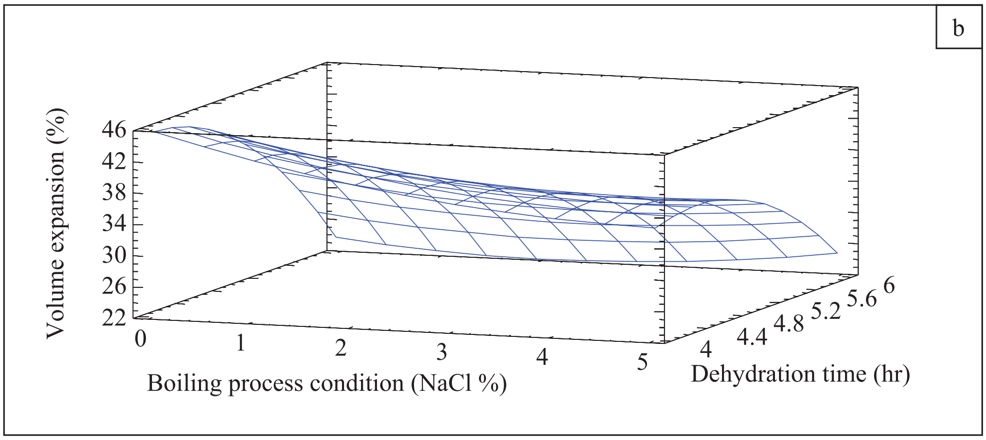
The physical properties and eating qualities of pork rind puffed by microwave and traditional deep-oil frying seemed to demonstrate the different trends of effect by the pretreatment processing conditions on different attributes according to Table 1 and Figure 1

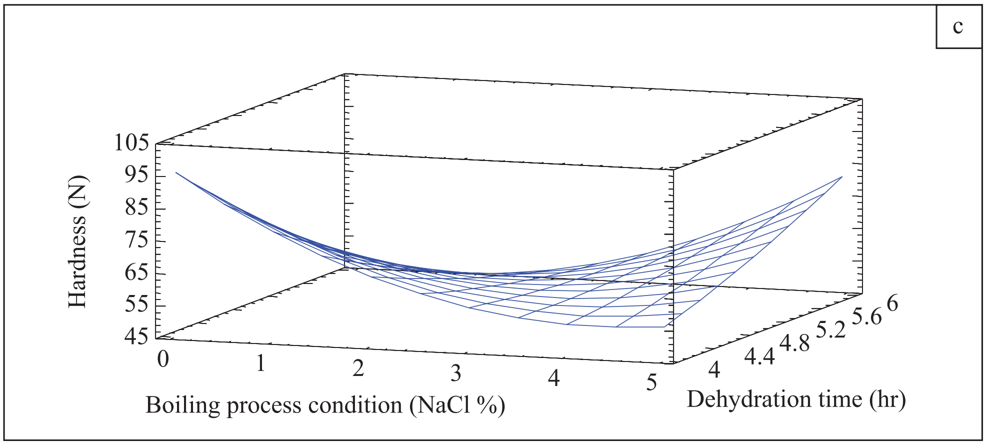
The MCP was the lowest for the control (no boiling) compared with boiled in water and with salt added. The MCP increased with the concentration of salt while it fluctuated as the dehydration time increased as seen in Figure 1a. The lowest MCP occurred after drying for 5 hr (Figure 1a) because there might have been a difference in the gelatinization process in the presence of salt, which led to differing water holding capacities after dehydration.

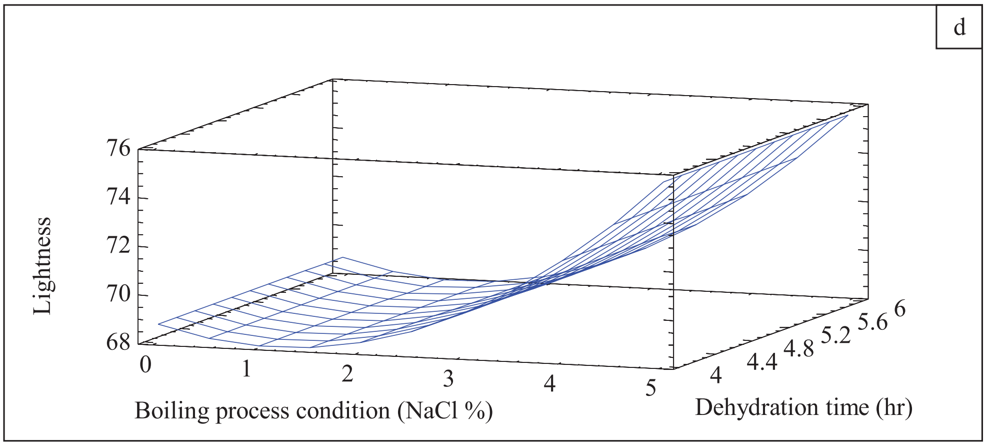
There was a noticeable effect of dehydration time on the volume expansion and hardness in the two techniques. The VE decreased as the salt concentration and dehydration time increased for both MWP and DOFP, with the VE of DOFP being higher than that of MWP (Figures 1b and 1c). For MWP, an increased dehydration time resulted in a sharp decrease in the VE while that of DOFP decreased slightly. The higher the VE value, the lower the hardness for DOFP while there was an interaction effect between the two factors, boiling process conditions and dehydration time, on the hardness for MWP. The hardness of MWP decreased at short dehydration time either at a low or at a high salt concentration. The hardness of DOFP increased as the dehydration time increased and as the boiling process with salt concentration increased. There was a region where the hardness of MWP and DOFP was comparable as seen in Figures 1d and 1e.

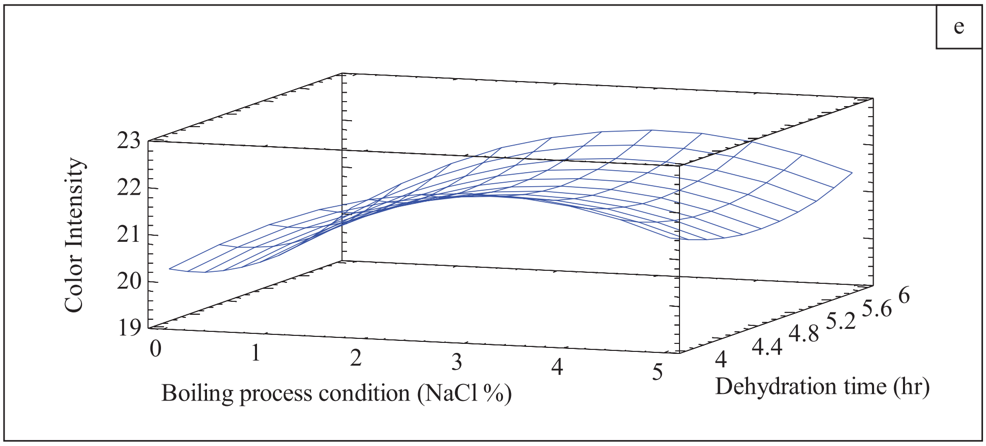
For MWP, the lightnesss sharply increased as the concentration of salt increased from 3 to 5% while for DOFP, the lightness had an inversion point in the middle of the graph corresponding to a salt concentration range of 3–5%. The color intensity of the two puffing methods changed inversely as the salt concentration and dehydration time increased. The lightness of MWP samples was higher than that of DOFP samples whereas the

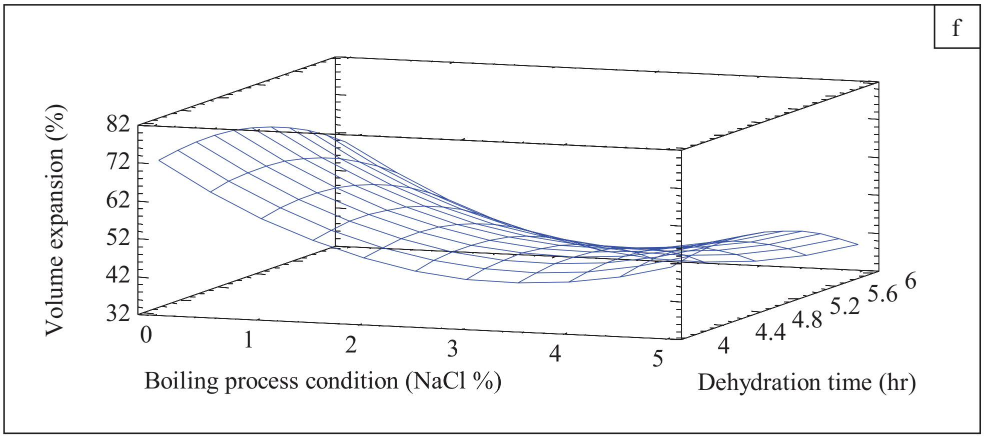


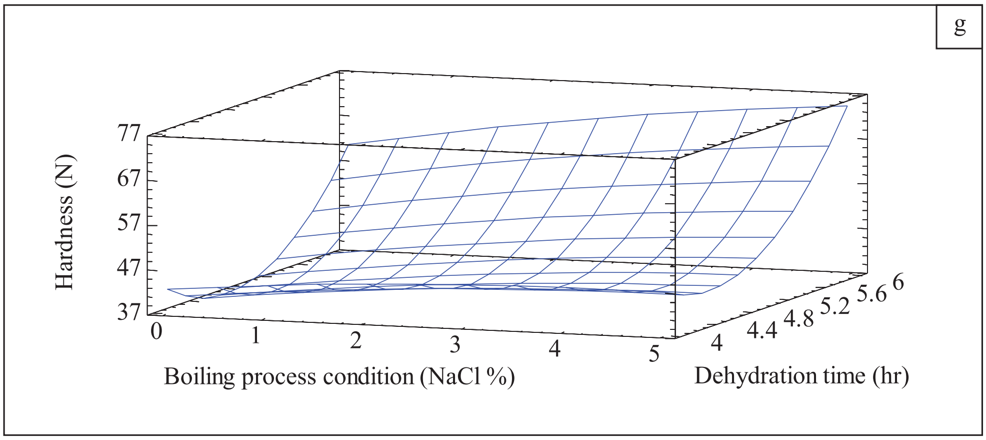

b
Volume expansion (%)
46
42
38
34
30
26
22
0
1
2
3
4
5
Boiling process condition (NaCl %)
4
4.4
4.8
5.2
5.6
6
Dehydration time (hr)

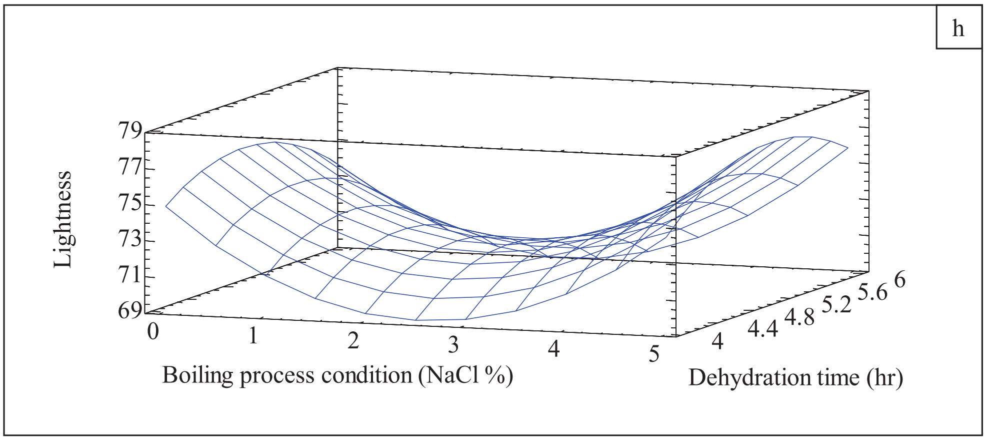

c
Hardness (N)
105
95
85
75
65
55
45
0
1
2
3
4
5
Boiling process condition (NaCl %)
4
4.4
4.8
5.2
5.6
6
Dehydration time (hr)


d
Lightness
76
74
72
70
68
0
1
2
3
4
5
Boiling process condition (NaCl %)
4
4.4
4.8
5.2
5.6
6
Dehydration time (hr)


e
Color Intensity
23
22
21
20
19
0 1 2 3 4 5
Boiling process condition (NaCl %)
4 4.4 4.8 5.2 5.6 6
Dehydration time (hr)


f
Volume expansion (%)
82
72
62
52
42
32
0 1 2 3 4 5
Boiling process condition (NaCl %)
4 4.4 4.8 5.2 5.6 6
Dehydration time (hr)


g
Hardness (N)
77
67
57
47
37
0 1 2 3 4 5
Boiling process condition (NaCl %)
4 4.4 4.8 5.2 5.6 6
Dehydration time (hr)



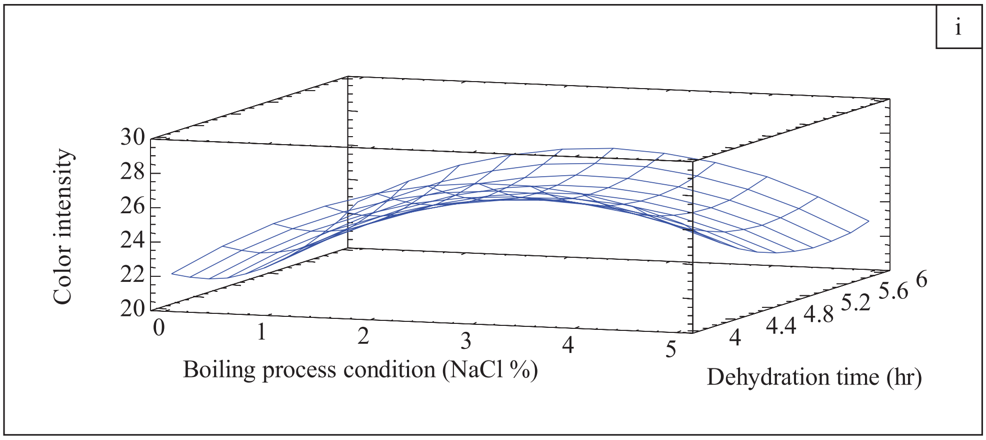


Figure 1 Response surface plot of different attributes of microwave and traditional deep oil puffing as a function of boiling process and dehydration time: (a) MCP = Moisture content prior to puffing (w.b. = Wet basis); (b) Volume expansion of microwave puffing (MWP); (c) Hardness of MWP; (d) Lightness of MWP; (e) Color intensity of MWP; (f) Volume expansion of deep-oil frying puffing (DOFP); (g) Hardness of DOFP; (h) Lightness of DOFP; (i) Color intensity of DOFP.

color intensity was noticeably lower. The absence of salt led to decreased MCP and color of samples after MWP. In the BW sample, the lightness was lower than that with increased salt concentration when the dehydration time increased. The higher color intensity of DOFP was due to the effect of a browning reaction when deep-oil frying at elevated temperature. Nevertheless, the MWP resulted in samples with less browning. The higher the salt concentration, the lighter the color of the MWP samples.

Table 2 shows the results of the comparison between NB and BW for DOFP and MWP. The VE values after no boiling were significantly lower while the hardness was higher compared with those of BW. The lower VE vlaues also meant that ML was also less than that of BW. The L* values of NB were significantly lower while the BI values were higher than those of BW.

Table 2 Comparison between microwave cooking and frying with no boiling and boiling with water.

Dehydration condition		MCP (% wet basis)	VE (%)		ML		Hardness (n)		L*		BI	
		MWP = DOFP	MWP	DOFP	MWP	DOFP	MWP	DOFP	MWP	DOFP	MWP	DOFP
4h	NB	$10.11^{b} \pm 0.05$	$14.07^{b} \pm 0.46$	$35.49^{a} \pm 4.57$	$6.63^{b} \pm 0.31$	$6.04^{a} \pm 0.06$	$157.06^{e} \pm 10.61$	$116.09^{c} \pm 6.63$	$65.10^{b} \pm 0.09$	$72.46^{c} \pm 0.46$	$22.89^{d} \pm 0.20$	$20.48^{a} \pm 0.78$
	BW	$14.03^{d} \pm 0.20$	$53.23^{f} \pm 0.23$	$78.73^{d} \pm 1.95$	$9.31^{d} \pm 0.08$	$10.29^{c} \pm 0.35$	$92.21^{c} \pm 2.16$	$49.65^{ab} \pm 2.72$	$69.64^{d} \pm 0.08$	$73.56^{c} \pm 0.48$	$19.76^{a} \pm 0.19$	$21.18^{a} \pm 0.65$
5h	NB	$7.58^{a} \pm 0.43$	$21.68^{c} \pm 0.28$	$34.37^{a} \pm 0.97$	$5.66^{a} \pm 0.03$	$4.78^{a} \pm 0.28$	$221.36^{f} \pm 2.94$	$134.02^{cd} \pm 9.74$	$64.00^{a} \pm 0.13$	$66.27^{a} \pm 0.62$	$24.25^{e} \pm 0.02$	$26.34^{d} \pm 0.29$
	BW	$13.15^{c} \pm 0.17$	$28.96^{e} \pm 0.70$	$60.82^{b} \pm 2.81$	$8.37^{c} \pm 0.17$	$9.75^{c} \pm 0.23$	$74.59^{b} \pm 3.04$	$34.92^{a} \pm 0.80$	$67.31^{c} \pm 0.27$	$78.34^{d} \pm 0.74$	$21.04^{b} \pm 0.01$	$21.05^{b} \pm 0.19$
6h	NB	$10.15^{b} \pm 0.24$	$8.70^{a} \pm 0.07$	$36.14^{a} \pm 2.86$	$5.43^{a} \pm 0.05$	$8.15^{b} \pm 1.76$	$109.52^{d} \pm 1.27$	$152.32^{d} \pm 25.24$	$65.10^{b} \pm 0.09$	$67.79^{b} \pm 1.26$	$22.24^{c} \pm 0.45$	$24.99^{c} \pm 1.04$
	BW	$13.14^{c} \pm 0.17$	$26.66^{d} \pm 1.22$	$68.29^{c} \pm 1.36$	$9.41^{d} \pm 0.20$	$9.55^{c} \pm 0.26$	$49.04^{a} \pm 8.59$	$64.95^{b} \pm 4.70$	$69.64^{d} \pm 0.08$	$73.57^{c} \pm 0.56$	$19.60^{a} \pm 0.35$	$22.87^{b} \pm 0.36$

MCP = Moisture content prior to puffing; VE = Volume expansion; ML =Moisture loss; L* = Lightness; BI = Color intensity; MWP = Microwave puffing; DOFP = Deep-oil frying puffing; NB = No boiling; BW = Boiling with water

Values shown are mean ± SD.

Means with different lowercase superscript letters within the same column differ significantly ($P \leq 0.05$).

The VE, ML, hardness and color of puffed samples were clearly affected by the two puffing methods and the dehydration time. Morover, it was clearly seen that the two puffing methods were influenced by no boiling (NB) and boiling (BW) suggesting the role of the gelatinization process with regard to the puffing qualities. The samples with lower hardness also had higher volume expansion and more air cells inside the samples. However, it was noted that the hardness and VE of MWP could be decreased due to the fact that even when the pork rind was not puffed, the texture could achieve well-done cooked values by the heating effect of the microwaves.

Optimization of individual response

The values in this experiment for boiling were from 0 (BW) to 5 (5% salt) with a dehydration time range from 4.0 hr to 6.0 hr. By using response surface methodology, the process of optimization was compared with the control sample. The individual response for each attribute was independently optimized and the results are shown in Table 3. For different attributes, the optimal operating processing parameters were different but were within the range of the experimental settings. Moreover, the optimum values of the two different puffing methods were also different for each attribute. For example, for MWP, the optimum value for VE was 0 for the boiling process corresponding with boiling at 0% and 4.0 hr for the dehydration while those values for DOFP were 1.59% salt and 5.03 hr dehydration. The difference indicates that the pretreatment processes did affect the qualities of the puffing products that led to different values of the processing conditions between the two puffing methods.

Optimizing multi-responses by desirability methodology

Based on the desirability methodology, the optimal settings of the experimental factors involving the VE, hardness, lightness and color intensity of puffed pork rind were obtained at B3% for 5 hr for MWP while those for DOFP were B0.003% (≈ 0%) for 6 hr. At these settings, the response variables generated a desirability index of 88.93% for MWP and 85.53% for DOFP when compared to commercial puffed pork rind products.

The desirability plots as a function of the boiling process and dehydration time are shown in Figure 2. The surface had a well-defined maximum near the higher salt concentration for MWP while the maximum values were at both very low and high salt concentrations for DOFP. The optimum locations of the two puffing methods were clearly seen within the selected levels of the two chosen factors which were determined at B3% for 5 hr for MWP and at BW for 6 hr for DOFP. These processing conditions were validated through the sensory evaluation compared with the commercial product.

Sensory evaluation for validation

The results of the sensory acceptability from optimal conditions for both puffing methods are presented in Table 4. The two optimal sets of conditions (B3% for 5 hr for MWP, and BW for 6 hr for DOFP) were used to compare with the commercial fried pork rind in terms of the appearance, flavor, crispness and hardness by sensory evaluation. The results showed that there was no significant difference in the acceptability of the appearance, flavor, crispness and hardness between samples puffed by DOFP and the commercial product. The hardness values of samples of MWP and the commercial product were not significantly different but there were significant differences in the appearance, flavor, and crispness. Although there were differences in acceptability between MWP and DOFP, the panelists accepted the final products from both puffing methods (MWP and DOFP). Except for the appearance, most attributes of MWP had a higher acceptability than for the commercial product. In addition, the acceptability of the flavor and crispness of DOFP seemed to be higher than those of the commercial product. The acceptability of the sensory evaluation of MWP was better than that of the DOFP and the commercial product. The results indicated that the panelists seemed to prefer the MWP sample to the deep-oil frying samples which might have been due to the presence of the excess oil on the surface as well as inside the fried samples after puffing using deep-oil frying. The pretreatment processes may lead to a reduced oil content in the final product for DOFP when compared to the commercial product, whereas the final product from MWP contained no such oil. The response of the consumers was similar to that reported in the research of Pedreschi and Moyano (2005) and Thao *et al*. (2013) where

Table 3 Optimal operating process conditions for physical and eating properties of puffed pork rind from microwave and deep-oil frying methods.

Factor	Optimum values of processing conditions					
	Setting values		VE (%)	Hardness (N)	Lightness	Color intensity
Boiling process condition (% salt concentration)	0 (low)	5(high)	0.00(1.59)	0.95(0.0)	1.18(2.21)	3.08(3.20)
Dehydration time (h)	4.00	6.00	4.00(5.03)	6.00(4.65)	6.00(6.00)	4.00(4.00)
Optimum value of response			45.69(52.45)*	45.75(36.99)*	68.04(69.12)*	22.16(28.11)*

VE = Volume expansion

* = These values were obtained from commercial product for setting optimization targets.

Values in parentheses are for deep-oil frying puffing.

consumer preference was for low-fat and fat-free products. Moreover, the addition of salt might create a better taste for the final product in the case of MWP. According to the sensory evaluation, the optimum conditions for the best eating qualities such as appropriate appearance, higher crispness, suitable hardness and better flavor were B3% for 5 hr puffing by microwave heating.

Images from digital photography and stereomicroscopy

Figure 3 indicates that the commercial product had an uniform, porous structure or air cell distribution (Figure 3d) while that of MWP was not as uniform (Figure 3f). The appearance of pork rind from MWP (Figure 3c) was denser than that from DOFP (Figure 3b) and the commercial product (Figure 3a). However, for DOFP with BW and 6 hr, the air cell bubbles were also nonuniform in shape and very large in size. An additional problem was that these air cells were not stable after DOFP. This might have been due to the fact that DOFP could increase the air cell diameter while the outer layer of the air cell was not sufficiently strong to keep a stable frame.

The gelatin extent corresponding to BW and B3% salt provided different qualities under the two puffing methods. For MWP, boiling with 3% salt led to increased MCP and ionic polarization facilitating the puffing process in

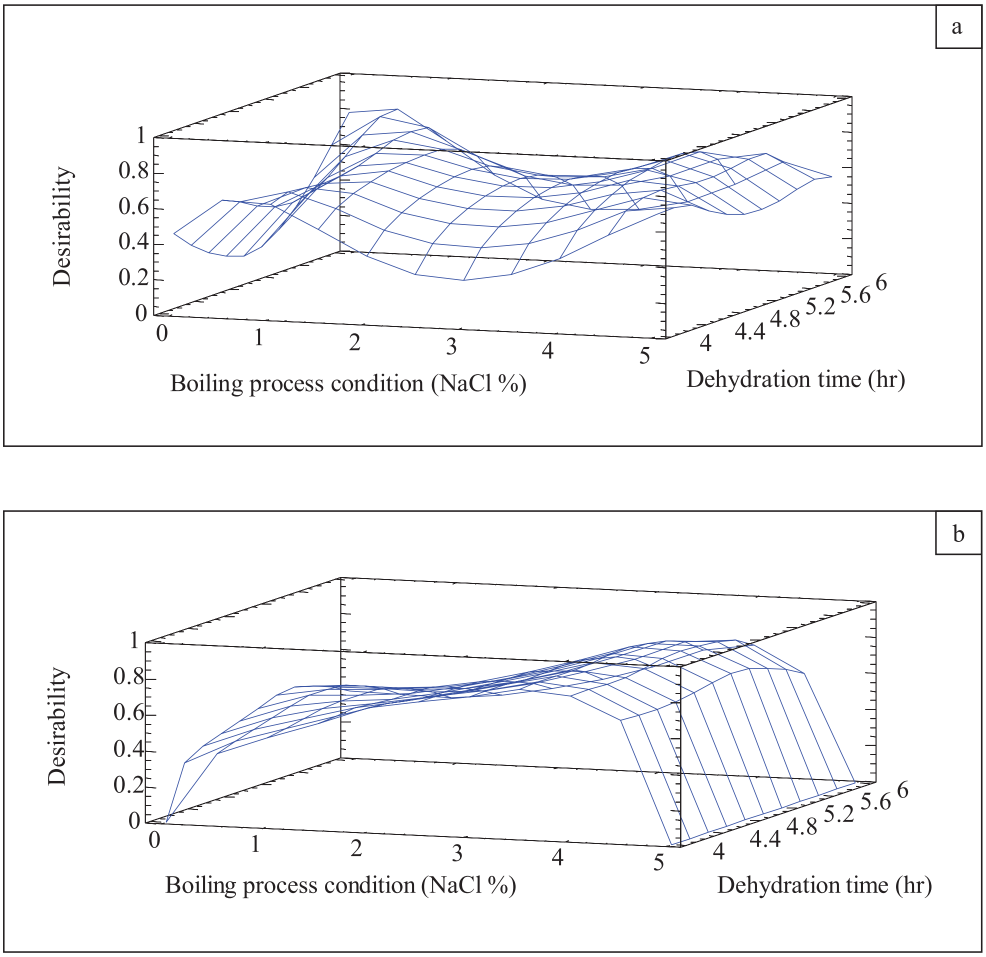


Figure 2 Desirability plot for multi-optimization of puffed pork rind as a function of different processing conditions: (a) Microwave puffing and (b) Deep-oil frying puffing.

terms of expanding the air cell size; however, the air cell size was not uniform. The traditional frying method could provide a smoother surface on the puffed pork rind than MWP. Although the puffed pork rind from the different methods varied in flavor and eating qualities, the consumers accepted puffed pork rind from both MWP and DOFP; however, they seemed to prefer samples from MWP. The research of Thao *et al*. (2013) indicated that consumers are conscious of the oil content in puffed products. Even though the hardness and crispness of MWP were less compared to those of DOFP, the consumers still preferred the new form of product with less or no oil content.

According to this study, the amount of gelatin produced by boiling played an important role in the ready-to-eat product after a short puffing time using microwaves. The no-boiling results (Table 2) were only suitable for DOFP since this process could increase gelatin, flavor and thus

Table 4 Validation using comparison of qualities between deep-oil frying and optimal microwave pretreatment process for puffed pork rind samples with commercial product.

Sample	Fried pork rind	Fried pork rind	Microwave puffed pork rind
	Commercial	BW(0.003%) for 6 hr	B3% for 5 hr
Appearance	$6.96^{a} \pm 1.37$	$6.33^{ab} \pm 1.05$	$6.54^{b} \pm 0.72$
Flavor	$5.75^{a} \pm 0.94$	$6.08^{a} \pm 0.76$	$7.83^{b} \pm 0.82$
Crispness	$6.71^{a} \pm 0.86$	$6.88^{a} \pm 0.90$	$7.42^{b} \pm 0.97$
Hardness	$6.98^{ab} \pm 1.12$	$5.83^{a} \pm 0.75$	$7.21^{b} \pm 0.43$
Acceptability	Control	Acceptable	Acceptable

BW (0.003%) = Boiling with water; B3% = Boiling with 3% NaCl.
Values are based on a 9-point hedonic scale and are shown as mean ± SD; n = 40.
Means with different lowercase superscript letters within the same row differ significantly (P ≤ 0.05) using 95% least significant differences.

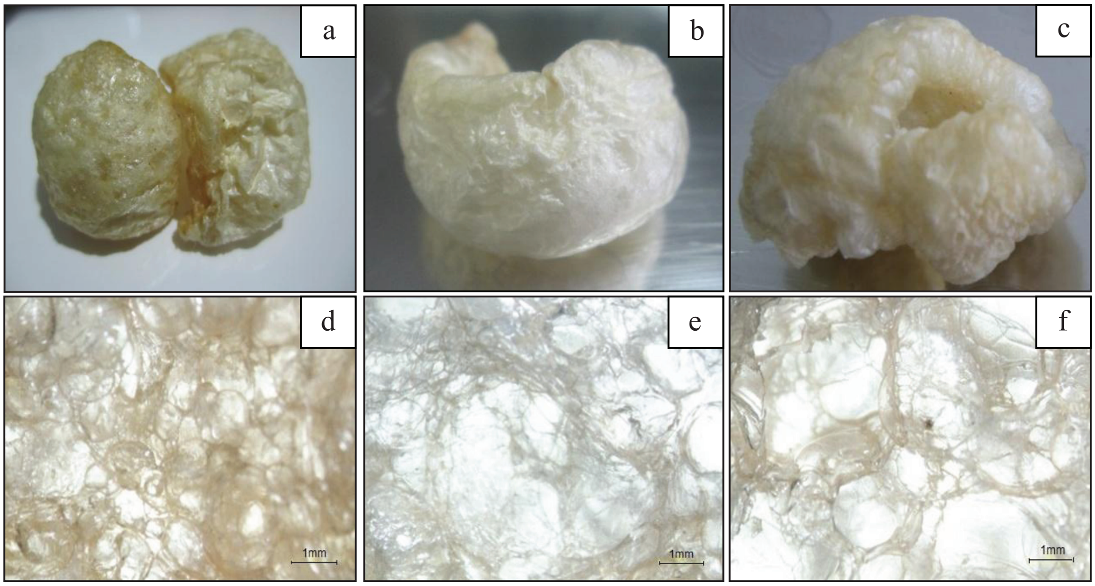


Figure 3 Images of puffed pork rind from: (a) Commercial product; (b) Boiled with water and dried for 6 hr; (c) Boiled with 3% salt and dried for 5 hr;. (d), (e), and (f) are stereo microscope micrographs of puffed pork rind corresponding to (a), (b), and (c), respectively.

eating qualities by its nature.

CONCLUSION

The volume expansion, hardness and color change of samples were noticeably affected by the pretreatment process conditions; however, the effect of boiling and dehydration on those attributes had different impacts. Increased salt levels led to an increase in the moisture content prior to puffing. The result of no boiling or boiling with water were only suitable for DOFP since this process could increase the flavor and eating qualities by its nature. Thus, the gelatin played an important role in determining the puffing qualities for MWP. MWP provided a whiter appearance in the puffed pork rind compared with deep-oil frying and the commercial product. The microstructure of puffed pork rind after MWP was different from that of DOFP and the commercial product. The commercial product had a more uniform air cell size compared to MWP and DOFP. Samples boiled with 3% salt and dried for 5 hr with puffing using MWP provided acceptable qualities compared with the commercial product. The most acceptable conditions for puffing using DOFP were boiling in water and drying for 6 hr. Validation by sensory evaluation indicated that a desirability technique was useful for selecting the optimal conditions. The samples prepared using the optimal conditions were acceptable to the panelists. The results indicated that an appropriate quality of puffed pork rind could be obtained using different optimal salt concentrations and dehydration times if puffed using a suitable method.

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