

Effects of Salt, Moisture Content and Microwave Power on Puffing Qualities of Puffed Rice

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ABSTRACT

In this study, the effects of salt, moisture content and microwave power on the puffing qualities of puffed rice were investigated. Paddy rice was adjusted with water and 2% salt solution at four moisture levels 10, 13, 16 and 19% (wb) and puffed with microwave power at 600, 700 and 800 watts. The results showed that all the main factors and their interactions significantly ($p < 0.05$) affected the puffing qualities of total puffed yield, fully puffed yield, small puffed yield, expansion volume, texture, color and microstructure. Paddy rice soaked in 2% salt solution produced a higher puffed yield than paddy rice soaked in water. Higher moisture content and microwave power produced puffed rice with higher puffed yield and expansion volume, but lower hardness. Puffing paddy rice at low moisture content (10%) with low microwave power (600 watts) produced the hardest puffed rice texture. Puffing at low moisture content and high wattage decreased the lightness of the puffed rice. Puffing paddy rice at 19% moisture content with 600-700 watts produced the highest fully puffed yield, but the lowest total puffed yield. The results suggested that high puffed yield and expansion volume with moderate hardness was produced using soaked paddy rice at 2% salt solution, 13% moisture content and puffed with 700 or 800 watts microwave power.

Key words: puffing, puffed rice, microwave, microwave puffing

INTRODUCTION

Puffed rice is commonly used in ready-to-eat breakfast cereals, cereal drinks, infant foods and snack products, such as granola bars. Puffed rice can be created in several ways, but in Thailand hot air and hot oil puffing are the two processes that are generally used. However, the important qualities of puffed rice are puffing ability and expansion volume. The puffing ability of puffed rice has been studied for a long time. To date, most researchs have studied process conditions and their effect on expansion volume. Corazon and Juliamo (1987) found that the moisture content of pre-

gelatinized milled rice puffed in hot oil ranged from 10 to 13% at 210°C, while gun puffing had a pre-moisture content ranging from 13 to 15% at about 200-210°C, with 11.3 kg/cm³ pressure. Chinnaswamy and Bhattacharya (1983) found that the optimum moisture content for puffing with hot sand at 250°C for milled rice was 10.5% and for milled, parboiled rice was 10.5 to 11%. Murugesan and Bhattacharya (1986) reported that the optimum moisture content ranged from 13.5 to 14.5% for both hot sand (200°C) and hot air (225°C) puffing. Similarly, Simsriskul (1991) indicated that the maximum puffed yield and expansion volume by hot air puffing was achieved with 13% moisture

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content at 250°C. Moreover, Chinnaswamy and Bhattacharya (1983) reported that adding salt solution to the milled rice increased the expansion ratio, not only with sodium chloride, but also with other salts (KCl, CaCl₂ and NaHSO₃). Marugesan and Bhattacharya (1986) found that soaking paddy rice in salt solution increased puffing ability and expansion volume, but the optimum moisture content was 17% with salt. At present, research on microwave puffing of snack foods has increased because the convenience to consumers and microwave cooking are still developing as a means of food processing. Previous studies on microwave puffing have focused mainly on popcorn to investigate puffing conditions. The focus has been on moisture content and its effect on the puffed yield and expansion volume of corn grains because water vapor pressure inside the grains created the force for bursting and expanding the corn (Lin and Anantheswaran, 1988; Pordesimo *et al.*, 1990; Mohamed *et al.*, 1993; Singh and Singh, 1999; Allred-Coye *et al.*, 2000a; Gokmen, 2004). Moreover, Allred-Coye *et al.* (2000b) found that high microwave power levels produced higher expansion volume of popcorn, while increases in the salt content in the formulation produced lower expansion volume. There has been few researches on the effects of microwave puffing on paddy rice. Therefore, the purpose of this study was to investigate the effect of three independent variables (salt solution, moisture content and microwave power) on the puffing qualities of paddy rice following microwave puffing.

MATERIALS AND METHODS

Materials

A variety of waxy paddy rice (RD6) was purchased from the Ubon Ratchatani Rice Research Center, Ubon Ratchatani province, harvested during the period September 2006 to December 2006. The sample was cleaned, dried

and stored in a plastic bag at 12-15°C. The experiment was conducted 5 to 6 months after harvesting.

Sample preparation

Paddy rice was soaked in distilled water and 2% salt solution (NaCl) for 24 h. The paddy rice was dried at 45±3°C using a tray-dryer, until the moisture content was 19, 16, 13 and 10% (wb). Each sample was stored in a glass bottle for 2 d before puffing was carried out with some modifications using the methods of Murugesan and Bhattacharya (1986) and Simsrisakul (1991).

Microwave puffing operation

The microwave oven used in this experiment was a standard domestic microwave oven (Model M1712N SAMSUNG, THAILAND) with different microwave power settings (600, 700 and 800 watts) at 2,450 MHz. The actual power output of the microwave oven was determined by weighing 1,000 g of deionized water (19 to 21°C) in a beaker and heating it for 62 sec at high power. When heating was completed, the final temperature of the water was measured with an electronic thermometer. Equation 1 (Allred-Coye *et al.*, 2000b) was used to estimate the output wattage.

$$P = 70.0 \cdot T \quad (1)$$

where, P = power in watts and T = change in temperature in °C

To puff the rice, paddy rice (30 g) was put into a paper bag (size 16 × 30 cm), placed in the middle of the microwave oven and heated at 600, 700 and 800 watts for 130, 110 and 90 sec, respectively. When the paddy rice grains started puffing, the time was recorded and at the completion of heating, the temperature of the puffed rice was measured by infrared thermometer (Chino, Japan). After each test, the oven was opened for 3 min to cool down the chamber. The data were averaged from triplicate observations.

Product evaluations

Puffed yield (%)

The husk and unpuffed paddy rice were separated by hand picking and weighed. Puffed yield or the puffing ability of the paddy rice was evaluated by dividing the heated product into two shapes, namely fully puffed and small puffed rice, by modifying the method of Maisont and Narkrugs (2009). The puffed yield of the rice was expressed as a weight percentage, as determined by Simsrisakul (1991).

Expansion volume

The volume of the puffed rice was determined by the method of Simsrisakul (1991), with some modifications. Puffed rice was placed in a beaker with known volume. The remaining space in the beaker was filled with black sesame of known volume. The volume of puffed rice was calculated by subtracting the volume of black sesame from the beaker volume. Expansion volume was calculated using Equation 2:

Expansion volume (mL/g) =

$$\frac{\text{vol. of puffed rice (mL)}}{\text{wt. of paddy rice (g)}} \quad (2)$$

Color

The color of the puffed rice was determined using a Minolta CR 300, based on the CIE system. The color was recorded using L*, a* and b* values that represented the lightness, redness and yellowness, respectively, of the puffed rice. Six replications of the ground puffed rice obtained under each set of puffing conditions were used for the color tests.

Texture

Textural analysis based on the hardness of the puffed rice was carried out on a texture analyzer (model TA-XT2i), using the mode of measuring force in compression, a test speed of 5.0 mm/s, a post-test speed of 10.0 mm/s and an Ottawa cell with a wire plate probe. Six replications of the puffed rice obtained under each set of puffing conditions were used for the texture

test (Stable Micro System, 1995).

Microstructure

The microstructure of the puffed rice was examined using a scanning electron microscope (JEOL model JSM 6301F). The puffed rice under each set of puffing conditions was fixed on a specimen by double-sided adhesive tape and sputter-coated with gold. The samples were viewed under high vacuum conditions at an accelerating voltage of 15 kV, by modifying the method of Mariotti *et al.* (2006).

Experimental design

To study the puffing conditions of puffed rice, a 2×4×3 full factorial experimental design was employed to show the effect of salt solution (0 and 2%), moisture content of the paddy rice (10, 13, 16 and 19%) and microwave power (600 watts for 130 sec, 700 watts for 110 sec and 800 watts for 90sec) on the puffing qualities of puffed rice. Data were analyzed using the SPSS software. The analysis of variance was performed by ANOVA and the level of significance was set at 0.05. The effects of puffing condition on each quality attribute of puffed rice were plotted as a surface plot, using the STATISTICA software.

RESULTS AND DISCUSSION

Table 1 shows the results of the different salt and moisture contents and microwave power on the puffed product.

Paddy rice soaked in salt solution at all moisture content levels started puffing faster than paddy rice soaked in water. It was possible that the dielectric properties of the salt facilitated the absorption of the microwave energy and converted it to heat faster and better than water could. At 10% moisture content, the paddy rice took longer to start puffing than at 13, 16 and 19% moisture content, despite soaking in water or salt solution. This may have been caused by the inner part of the paddy rice grains having low moisture content,

so that when heated, only a low vapor pressure was produced and consequently it took longer to generate sufficient vapor pressure to explode the grains. At all power levels, paddy rice soaked in salt solution took less time to start puffing than the paddy rice soaked in water. In particular, when puffing at 800 watts, the time to start puffing was significantly less than for 600 and 700 watts. At 19% moisture content, the puffing time of paddy rice was less than at 10, 13 and 16% moisture content, respectively. At high moisture content, paddy rice was heated rapidly and the water converted to vapor pressure rapidly. Another factor might have been that the heat softened the aleurone layer. Soaking the paddy rice with water loosened interlocking in the husk (lemma-palea) (Maisont and Narkrugsa, 2009). In the aspect of the temperature of puffed rice after completed time of puffing, found that each condition of puffing increased the temperature corresponding the time of the paddy rice started puffing. Paddy rice soaked in the salt solution made it puff more quickly than the paddy rice soaked in water because the salt solution absorbed heat better than water.

Consequently, at the completed time of puffing, the final temperature was higher, especially for paddy rice soaked in salt solution and heated at 800 watts.

The independent variables of the puffing process (salt solution, moisture content and microwave power) and their interactions affecting the puffing qualities of puffed rice are shown with their F values in Table 2.

Puffed yield

Puffed yield was used to compare the puffing ability of the paddy rice under different processing conditions. The salt solution, moisture content and microwave power and their interaction each had a significant ($p < 0.05$) effect on total puffed yield, fully- and small-puffed yield, as shown in Table 2. Figure 1a shows the effects of salt solution and moisture content on total puffed yield heated at 800 watts. At all moisture content levels, paddy rice samples soaked in the salt solution showed higher puffed yields than samples soaked in water. Salt has greater dielectric properties than water, which might change the

Table 1 Effects of salt, moisture content and microwave power on the time taken for paddy rice puffing to commence and the temperature of puffed rice at completion.

Microwave power(watt)	Moisture content (%)	Water		2% Salt solution	
		Time of starting puffing paddy rice (sec.)	Temperature of puffed rice(°C)	Time of starting puffing paddy rice (sec.)	Temperature of puffed rice(°C)
600	10	62-69	162-167	63-68	170-177
	13	59-63	172-176	58-59	174-179
	16	60-66	164-167	55-58	164-169
	19	60-64	162-169	59-63	169-173
700	10	58-59	190-193	43-47	180-189
	13	55-57	176-180	46-50	182-186
	16	56-59	168-174	46-48	173-178
	19	57-59	165-170	53-57	168-174
800	10	48-50	193-194	40-44	196-198
	13	45-48	190-194	39-42	193-197
	16	45-48	182-190	43-46	186-192
	19	45-47	178-184	46-48	180-183

thermal properties of the grain when absorbing microwave power. When the moisture content increased from 10 to 13%, the total puffed yield increased for both paddy rice soaked in water and salt solution. Soaking paddy rice in the salt solution gave a total puffed yield higher than from soaking in water. At 16% moisture content, the paddy rice soaked in the salt solution gave a higher total puffed yield than the paddy rice soaked in water. However, for paddy rice soaked in the salt solution, there was no significant difference in total puffed yield at 13% moisture content compared with 16% moisture content. However, at 19% moisture content, total puffed yield from both methods decreased significantly. This may have been due

to the higher moisture in the grains loosening the interlocking in the husk (lemma-palea), which resulted in insufficient internal steam pressure being maintained to cause puffing (Maisont and Narkruga, 2009). Another cause may have been that the starch granules could increase their absorption and subsequent expansion when the moisture content increased, resulting in less space between the husk and the grain and thus lower expansion (Srinivas and Desikachar, 1973). At every level of microwave power used in puffing, the puffed rice from rice soaked in the salt solution had a higher total puffed yield than the puffed rice soaked in water. Increasing microwave power apparently increased the total puffed yield.

Table 2 Effects of salt, moisture content and microwave power on the puffing qualities of puffed rice.

Source of variation	df	F-value							
		Puffed Yield (%)			Expansion volume	Hardness	Color		
		Total puffed	Fully puffed	Small puffed			L*	a*	b*
A	1	103.87#	128.29#	362.15#	49.35#	10.16#	72.16#	21.64#	10.18#
B	3	178.87#	667.91#	160.34#	34.67#	203.20#	61.49#	30.53#	11.44#
C	2	16.67#	48.19#	16.70#	12.79#	14.90#	0.96	3.10#	2.73
AB	3	29.95#	5.00#	8.74#	2.37	3.34#	14.32#	4.83#	2.07
AC	2	10.82#	8.39#	9.12#	2.69	4.30#	1.49	1.55	1.87
BC	6	1.76	12.65#	19.84#	2.17	3.44#	2.29#	1.81	0.67
ABC	6	4.26#	13.39#	11.99#	2.37#	0.35	1.00	1.01	1.62

Note:

A = salt solution; B = moisture content; C = microwave power; # = significant at $p < 0.05$.

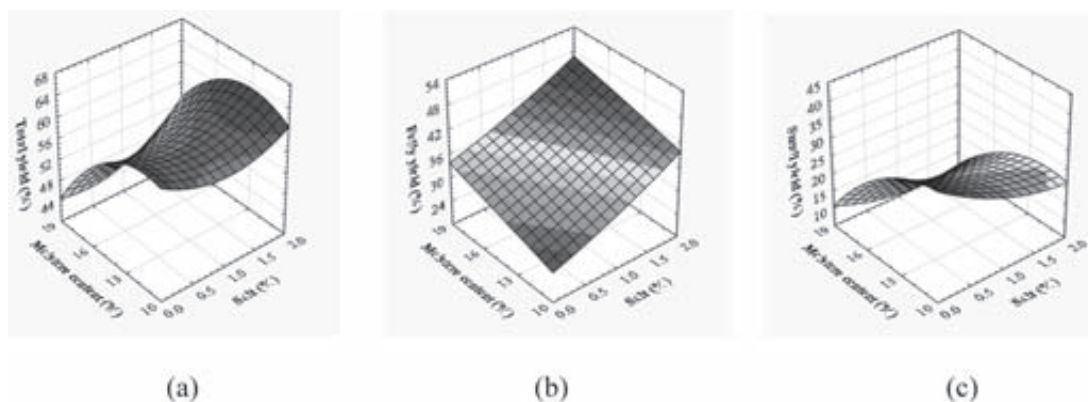


Figure 1 Effects of salt solution and moisture content on puffing ability or puffing yield at 800 watts microwave power for: (a) total puffed yield; (b) fully puffed yield; and (c) small puffed yield.

The effects of salt solution and moisture content on fully- and small-puffed yield are shown in Figures 1b and 1c. Paddy rice soaked in salt solution had a higher fully puffed yield than rice soaked in water. At 10% moisture content, the fully puffed yield was significantly ($p < 0.05$) less than the small puffed yield. When the moisture content increased from 10 to 13%, the fully puffed yield from both soaking methods increased more than the small puffed yield. The results agreed with the research of Murugesan and Bhattacharya (1986), who reported that at very low moisture content, most of the puffed grains remained cylindrical in shape without opening up or popping, probably due to a lack of adequate steam pressure or water vapor pressure needed for bursting. At 600 watts, the effects of salt solution and microwave power produced a lower fully puffed yield than soaking in water. However, paddy rice soaked in salt solution at 800 watts had a higher fully puffed yield than for paddy rice soaked in water. At 700 watts, there was no difference in the fully puffed yield from either method.

The effects of moisture content and microwave power are shown in Figures 2a and 2b. When the moisture increased from 10, 13, 16 and 19%, at all power levels, the fully puffed yield increased and small puffed yield decreased because at high moisture levels, the starch granules absorbed the water resulting in higher expansion

(as well as there being greater water vapor pressure), which made the fully puffed yield higher. With a moisture content of 13-16%, the paddy rice soaked in water and heated at 600 watts had a higher fully puffed yield than at 700 and 800 watts. The paddy rice soaked in salt solution and puffed at 800 watts had a higher fully puffed yield than at 600 and 700 watts. Interestingly, 19% moisture content and heating at 700 watts produced the highest fully puffed yield in both soaking methods.

Expansion volume

The expansion volume of puffed rice was expressed as the degree of expansion when paddy rice was puffed. Salt solution, moisture content, microwave power and the interaction between salt solution, moisture content and microwave power significantly affected the expansion volume ($p < 0.05$). Figure 3a shows the effects of salt solution and moisture content on the expansion volume of rice puffed at 800 watts.

The expansion volume of puffed rice from paddy rice soaked in salt solution was more than paddy rice soaked in water. The expansion volume of puffed rice was higher when the moisture content increased from 10 to 13%, but was lower when the moisture content was 16 and 19%. Figure 3b shows that at every level of microwave power, paddy rice soaked in salt

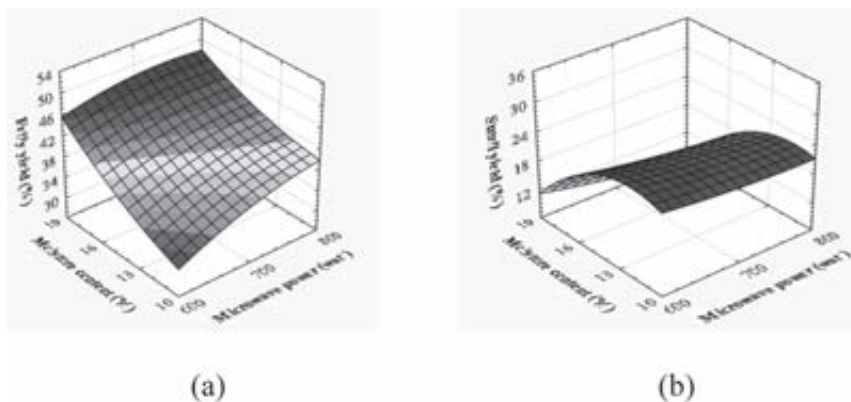


Figure 2 Effects on rice soaked in 2% salt solution of moisture content and microwave power on: (a) fully puffed yield; and (a) small puffed yield.

solution gave a higher expansion volume than paddy rice soaked in water. Puffing at 600 and 700 watts did not produce any difference in the expansion volume, while puffing at 800 watts produced an expansion volume significantly ($p < 0.05$) higher than at 600 and 700 watts. Simsrisakul (1991) reported that puffed rice produced using hot air at 220°C and 250°C, gave an expansion volume higher than heating at 280°C. Moisture content plays an important role in the expansion volume of puffed rice. The moisture present in the paddy rice is converted to superheated vapor, providing the driving force for expansion (Chinnaswamy and Bhattacharya, 1983). Thus, when microwave-puffing paddy rice, not only the moisture content, but also the microwave power and salt solution are important in determining the expansion volume of the puffed rice.

Hardness

The texture of puffed rice was described by hardness, which was defined as the maximum peak force generated during the breaking test. Salt solution, moisture content, microwave power and their interaction had significant ($p < 0.05$) effects on the hardness of puffed rice. Figure 4a illustrates the effects of salt solution and the moisture content

on the hardness of puffed rice at 800 watts microwave power; paddy rice soaked in salt solution showed lower hardness than paddy rice soaked in water. When the moisture of paddy rice was increased, the hardness of puffed rice tended to steadily decrease with both soaking in water and salt solution. In general, when the moisture of the starch increased, the ability of the starch to expand improved. A decrease in hardness was found at higher moisture contents, which agreed with Phuaksawat (2002), who found that the hardness of puffed rice decreased as the moisture content increased over the range from 10 to 20%.

Figure 4b shows the effects of salt solution and microwave power. Puffing the paddy rice soaked in salt solution at 800 watts produced puffed rice with the lowest hardness, while at 700 and 600 watts, respectively, hardness increased. In contrast, puffing the paddy rice soaked in water at 600 watts produced puffed rice with the lowest hardness and at 700 watts and 800 watts, respectively, hardness increased. The paddy rice soaked in salt solution and puffed with high microwave power induced good expansion volume and thus the hardness of the puffed rice was low.

Figure 4c shows the effects of moisture content and microwave power, with the puffed rice produced from paddy rice soaked in water and with

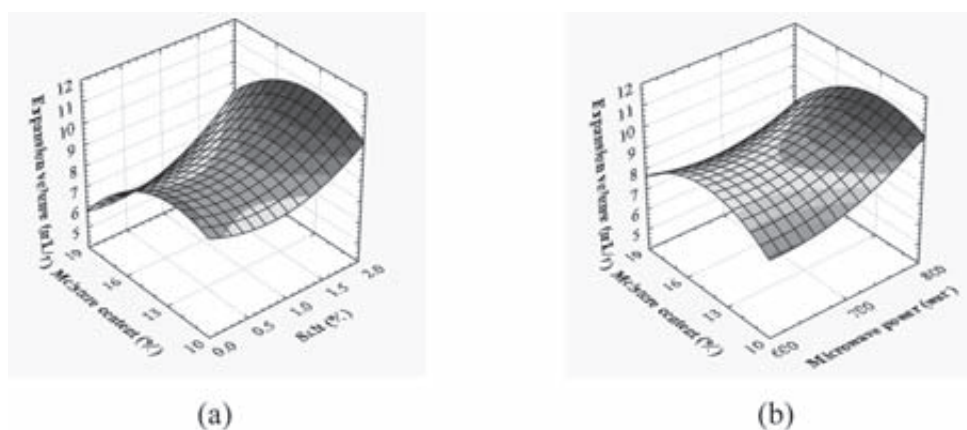


Figure 3 (a) Effects of salt solution and moisture content on expansion volume of puffed rice at 800 watts microwave power; and (b) effects of moisture content and microwave power on expansion volume of puffed rice soaked in 2% salt solution.

a moisture content of 10%, having the lowest hardness. In contrast, paddy rice soaked in salt solution and puffed at low microwave power produced puffed rice with the highest hardness. Even though the moisture content was higher, the hardness tended to decrease when the microwave power was higher. Thus, when puffed paddy rice was heated at low microwave power, there was a chance of case hardening in the aleuron layer that affected the hardness of the puffed rice. At high moisture content, the salt solution worked as an electrolyte, which absorbed microwave power and induced better heat transfer than water. Where there was high expansion volume, the hardness of the puffed rice was lower, because a larger volume of air cells formed inside the individual puffed rice kernels.

Color

The salt solution, moisture content, salt and moisture content, moisture content and microwave power had a significant effect on the lightness (L^*) of the puffed rice. The salt solution, moisture content, microwave power, salt and moisture content had a significant effect on the redness (a^*), while the salt solution and moisture content had a significant effect on the yellowness (b^*) of puffed rice as shown in Table 2. Figure 5a shows the effects of salt solution and moisture

content on the lightness of puffed rice heated at 800 watts microwave power; paddy rice soaked in salt solution had lower lightness than the puffed rice soaked in water. However, when the moisture content increased from 10 to 13%, lightness tended to increase also. At 16 and 19% moisture content, there was no difference in the lightness of the puffed rice. Figures 5b and 5c show that paddy rice soaked in salt solution and puffed at 800 watts microwave power had higher redness and yellowness values than puffed rice soaked in water. However, as the moisture content was increased, redness and yellowness values were lower, with the lowest values at 19% moisture content. The lower moisture content and longer heating time significantly increased the browning reaction, which appeared to have contributed to the lightness, redness and yellowness of the puffed rice.

Microstructure

The microstructure of puffed rice heated at 800 watts power is shown in Figures 6a-6d for paddy rice soaked in water and in Figures 7a-7d for paddy rice soaked in salt solution, respectively, at different moisture contents. The microstructure of puffed rice made from paddy rice soaked in water had smaller air cells than the paddy rice soaked in salt solution. At 10% moisture content,

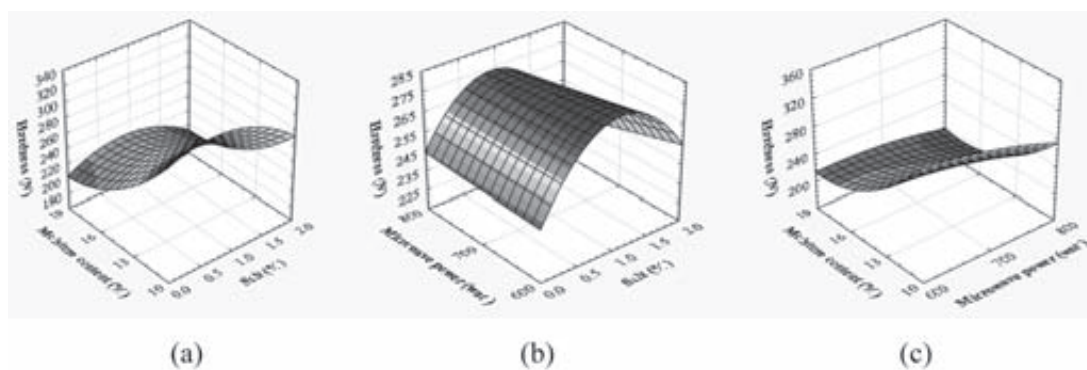


Figure 4 (a) Effects of salt solution and moisture content on hardness of puffed rice heated at 800 watts microwave power; and (b) effects of salt solution and microwave power on hardness of puffed rice soaked in 2% salt solution and 13% moisture content; and (c) effects of moisture content and microwave power on hardness of puffed rice soaked in 2% salt solution.

the microstructure of the two methods was slightly different. However, the size of the air cells in puffed rice kernels seemed to be closely correlated with the moisture content. The air cells were smaller in the puffed rice that was made from rice with a lower moisture content (Figures 6a and 7a). The size of the holes on the surface was larger when the moisture content increased. The air cell holes were thin, but at 19% moisture content, the size of the air cell holes was largest and most deformed. These results agreed with Jin *et al.* (1995) who concluded that the greater the

expansion in the extrudate, the larger the air cell holes were and the thinner the cell walls. Accordingly, if there was less expansion in the extrudate, then there were smaller cells with thicker cell walls. It is proposed that the results of puffing are caused by the vaporization of superheated water. The simultaneous flash-off of vapor expands the grains, resulting in a porous, sponge-like structure within the product. Therefore, moisture content plays an important role in the texture of puffed rice (Moraru *et al.*, 2003).

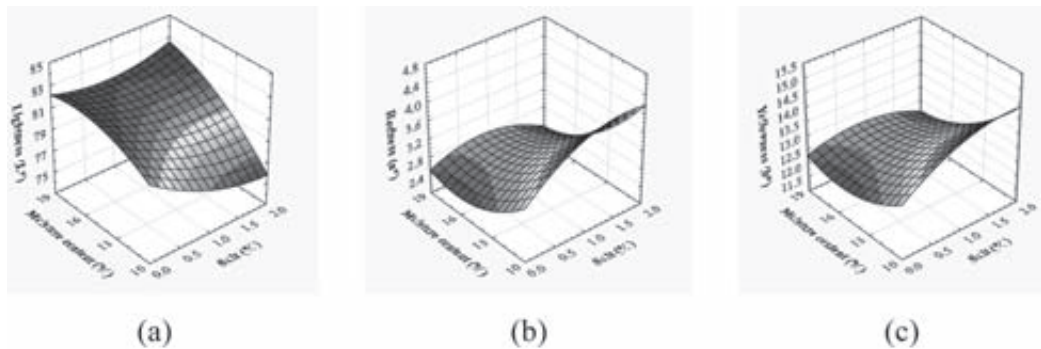


Figure 5 Effects on puffed rice heated at 800 watts microwave power of salt solution and moisture content on: (a) lightness; (b) redness; and (c) yellowness.

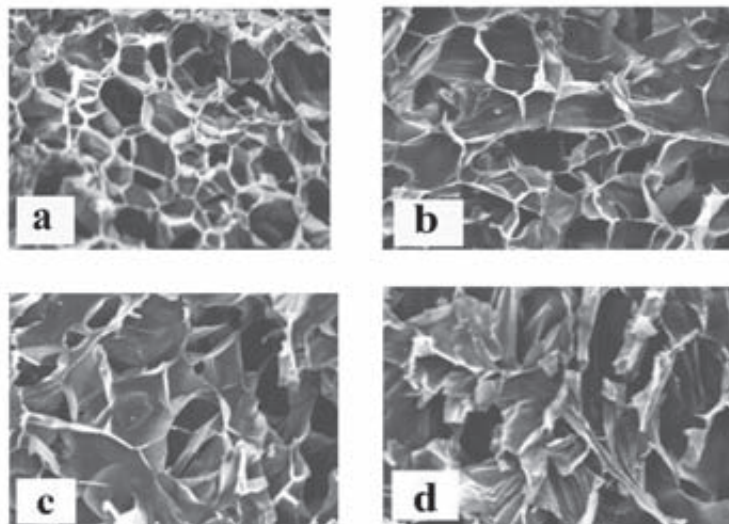


Figure 6 Scanning electron micrographs of puffed rice made from paddy rice soaked in water and heated at 800 watts microwave power with a moisture content of: (a) 10%; (b) 13%; (c) 16%; and (d) 19%.

Table 3 presents the correlations between puffing factors and the qualities of puffed rice. Salt solution had a highly significant ($p<0.01$) positive relationship with the total puffed yield, fully puffed yield, the expansion volume, a^* value and b^* value, while the small puffed yield and L^* value had a highly significant ($p<0.01$) negative relationship. In contrast, most of the moisture content levels had a highly significant ($p<0.01$) negative relationship with the total puffed yield, small puffed yield, a^* value, b^* value, expansion volume and hardness of puffed rice, while the fully puffed yield and the L^* value had a highly significant ($p<0.01$) positive relationship. The

wattage used for heating in the puffing process had a significant ($p<0.05$) positive relationship only with the expansion volume.

CONCLUSION

The salt solution, moisture content and microwave power significantly affected the puffing quality of puffed rice. Paddy rice soaked in salt solution gave a higher total puffed yield and expansion volume. However, at lower moisture content (10%) and higher microwave power, the lightness was lower, while the redness and yellowness were higher. The moisture content

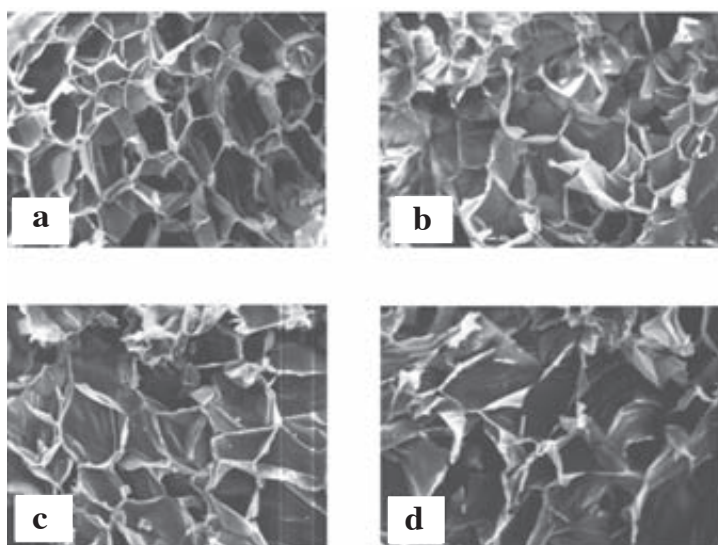


Figure 7 Scanning electron micrographs of puffed rice made from paddy rice soaked in salt solution and heated at 800 watts microwave power with a moisture content of: (a) 10%; (b) 13%; (c) 16%; and (d) 19%.

Table 3 Pearson's correlation coefficients (r) for the puffing factors and the qualities of puffed rice.

Factors puffing	Puffing qualities of puffed rice							
	Puffed yield (%)			Color			Expansion vol.	Hardness
	Total puffed	Fully puffed	Small puffed	L^*	a^*	b^*		
Salt solution	0.487**	0.699**	-0.325**	-0.440**	0.327**	0.289*	0.430**	-0.120
Moisture content	-0.484**	0.460**	-0.701**	0.692**	-0.661**	-0.484**	-0.376**	-0.855**
Watt power	0.208	0.195	-0.047	0.068	-0.174	-0.198	0.278*	-0.194

Note:

* = significant at $p < 0.05$; ** = highly significant at $p < 0.01$.

was the most important parameter affecting puffing quality. A moisture content of 13% gave the highest puffed yield and highest expansion volume, however the hardness of the puffed rice grains was lower. At low moisture content (10%), the small puffed yield was significantly higher than the fully puffed yield. At high moisture content (19%), the puffed yield and the expansion volume were lower, especially for the puffed rice soaked in water. This relationship was considered to be related to the microstructure of the puffed rice. Using 800 watts microwave power gave the highest expansion volume, while 600 watts gave the lowest expansion volume.

LITERATURE CITED

- Allred-Coyle, T.A., R.B. Toma, W. Reiboldt and M. Thakur. 2000a. Effects of bag capacity, storage time and temperature, and salt on the expansion volume of microwave popcorn. **J. Sci. Food Agric.** 81: 121-125.
- _____. 2000b. Effects of moisture content, hybrid variety, kernel size, and microwave wattage on the expansion volume of microwave popcorn. **J. Food Sci. Nutr.** 51: 389-394.
- Chinnaswamy, R and K.R. Bhattacharya. 1983. Studies on expanded rice. Optimum condition processing conditions. **J. Food Sci.** 48: 1605-1608.
- Corazon, P.V. and B.O. Juliano. 1987. Varietal differences in quality characteristics of puffed rices. **J. Cereal Chem.** 64(4): 337-342.
- Gokmen, S. 2004. Effects of moisture content and popping method on popping characteristics of popcorn. **J. Food Eng.** 65: 357-362.
- Jin, Z., F. Hsieh and H. E Huff. 1995. Effects of soy fiber, salt, sugar and screw speed on physical properties and microstructure of corn meal extrudate. **J. Cereal Sci.** 22: 185-194.
- Lin, Y.E. and R.C. Ananteswaran. 1988. Studies on Popping of Popcorn in a Microwave Oven. **J. Food Sci.** 53(6): 1746-1749.
- Maisont, S and W. Narkrugs. 2009. Effects of some physicochemical properties of paddy rice varieties on puffing qualities by microwave. **Kasetsart J. (Nat. Sci.)** 43(3): 566-575.
- Mariotti, M., C. Alamprese, M.A. Pagani and M. Lucisano. 2006. Effect of puffing on ultrastructure and physical characteristics of cereal grains and flours. **J. Cereal Sci.** 43: 47-56.
- Mohamed, A.A., R.B. Ashman and A.W. Kirleis. 1993. Pericarp Thickness and Other Kernel Physical Characteristics Relate to Microwave Popping Quality of Popcorn. **J. Food Sci.** 58(2): 342-346.
- Moraru, C.I. and J.L. Kokini. 2003. Nucleation and expansion during extrusion and microwave heating of cereal foods. **J. Comp. Rev. Food Sci. Food Safety.** 2: 120-138.
- Murugesan, G. and K.R. Bhattacharya. 1986. Studies on puffed rice I. Effect of processing conditions. **J. Food Sci. Tech.** 23: 197-202.
- Phuaksawat, P. 2002. **Microwave Puffed Rice Processing for Granola Bar**. M. Sc. Thesis. King Mongkut's Institute of Technology Ladkrabang, Bangkok.
- Pordesimo, L.O., R.C. Ananteswaran, A.M. Fleischmann, Y.E. Lin and M.A. Hanna. 1990. Physical properties as indicators of popping characteristics of microwave popcorn. **J. Food Sci.** 55 (5): 1352-1355.
- Stable Micro System. 1995. **Texture Analyzer**. Stable Micro System, Surrey, England. 77 pp.
- Simsrisakul, M. 1991. **Important Factors Affecting Puffing Quality of Paddy and Properties of Puffed Rice Flour**. M. Sc. Thesis. Chulalongkorn University, Bangkok.
- Singh, J. and N. Singh. 1999. Effects of different ingredients and microwave power on popping characteristics of popcorn. **J. Food Eng.** 42: 161-165.
- Srinivas, T. and H.S.R. Desikachar. 1973. Factors affecting the puffing quality of paddy. **J. Sci. Food Agric.** 24: 883-891.