

MICROWAVE PUFFING OF VARIOUS PADDY VARIETIES: EFFECTS OF MOISTURE CONTENT AND CALCIUM CHLORIDE

*Nirandom CHANLAT and Sirichai SONGSERMPONG

*Department of Food Science & Technology, Faculty of Agro-Industry, Kasetsart University
Chatuchak, Bangkok 10900, Thailand*

Corresponding author: Sirichai SONGSERMPONG. E-mail: sirichai.so@ku.ac.th

ABSTRACT

Microwave-puffing technique is more efficient and faster than traditional method. However, there is a limited information about microwave puffing of rice. In this study, five varieties of Thai paddy rice were selected, including glutinous (RD6, RD16 and SPT1) and non-glutinous rice (RD 33 and RBR). Face-centered central composite design with three levels of grain moisture contents (10, 13 and 16% wb) and three levels of calcium chloride concentrations (0, 1.5 and 3.0%) was studied. The paddy was soaked in calcium chloride solution by vacuum-infusion technique before puffing in a home microwave oven at 2,450 MHz with 800 Watt output. The results showed that the amylose content (4.78-13.46%) was negatively correlated with puffed yield of all puffed rice. Results of ANOVA showed that the effect of moisture content was significant ($p \leq 0.05$) on puffing yield, expansion ratio and density of RD6, RD 16, RD 33, and SPT1 while the calcium chloride significantly affected on expansion ratio of RD6, RD16 and SPT1 ($p \leq 0.05$). RD6 had highest yield while RBR had lowest yield than other varieties. Puffed rice was classified into two types, butterfly-shaped (fully puffed) and rugby-shaped (small puffed) were observed. The optimal condition was found to be 13% moisture content and 1.5-3.0% calcium chloride.

Keywords: Microwave; Paddy; Expansion ratio; Calcium Chloride; RSM

INTRODUCTION

Puffed rice or popped rice has been produced for a long time in many countries in Asia. Puffed rice in Thailand is known as “Khao Tok or Khao Pong”. It is a whole grain puffed products from paddy, parboiled rice or milled rice, generally prepared by preconditioning of rice grain, followed by drying and puffing [6,12]. There are several methods to produce the puffed rice, such as puffing with hot-sand roasting, frying in hot oil, puffing in hot air and gun-puffing methods [10]. Puffing of cereal grains involves the release or expansion of vapor inside the grains, while it is subjected to intensive heating for a short time. This technique can expand an internal structure and rupture an original structure [5,10]. In Thailand, roasting in hot sand and frying in hot oil are generally used. Roasting has the risk of burning and producing a lot of defects, while the oil can be easily turns rancid [6]. In India, puffed rice is mostly produced by sand roasting method, heating of the sand is achieved by the husk or wood chips fired furnace that poses

serious environmental hazard along with a risk of adherence of silica with the puffed product [10,12]. Therefore, there is a need of using clean and convenient energy for processing that addresses the environmental and health issues as well as convenient production.

At present, there is an increasing trend to use microwave for food processing, because the microwave heating has several benefits over traditional methods such as quick start-up time, faster heating rate, energy efficient, space saving, selective heating, and final products with improved nutritive quality [1, 3, 4, 7, 11]. Now a day, retail pack microwav-eable popcorn in consumer market is increas-ing [5]. A similar approach for production of microwaveable puffed rice will be possible if optimized process parameters related to maximized puffing yield and expansion are available. The objective of this research is to investigate the effects of moisture contents and calcium chloride concentrations on the characteristics of puffed rice from different paddy varieties.

MATERIALS AND METHODS

Materials

Five Thai Paddy varieties, RD6 and RD16 were purchased from Chiang Rai Rice Research Center, RD33 was purchased from Ubon Ratchathani Rice Research Center, SPT1 was purchased from Chiang Mai Rice Research Center and RBR was obtained from Rice Science Center, Kasetsart University, Kamphangsaeen Campus. Thailand. All paddies were harvested during December 2013 – February 2014.

Methods

1. Chemical Analysis

The paddy was dehusked and ground. Then, the brown rice flour was sieved through a 100-mesh sieve. The crude protein was determined according to [14] and Kjeldahl protein using the factor 5.95. The amylose content was determined according to [13]. A standard curve was established using amylose from potato (Sigma).

2. Sample Preparation

The paddy were sorted to remove any foreign materials and to separate the immature paddy by soaking in tap water. After that, the mature paddy (submergence) was drained for 3 min, blotted with muslin cloth to remove the surface water [15]. Vacuum-infusion technique was applied. The 500 gram of mature paddy was soaked in 2 liters of calcium chloride (CaCl₂) solution at different concentration following experimental design in Table 1. The vacuum condition was set at 600 mmHg for 60 minutes at room temperature (27 ± 3 °C). After that, the soaked paddy was dried in hot air oven at 50° C until the grain moisture content were decreased to 10, 13 and 16% (wb).

3. Puffing Method

Home microwave oven (Model KOG-3725, Daewoo, Malaysia) with power output of 800 W at 2450 MHz was used. Paddy of 10 grams were placed in a Perti dish (12 cm in diameter) and puffed for 70-80 sec. Then, puffed and unpuffed rice were separated by sieving and hand picking.

4. Puffing Quality Measurements

The unpuffed grains were handpicked and the weight of puffed rice was recorded. The puffed yield was calculated as the weight percentage [4,5,9].

$$\text{Puffed yield (\%)} = \frac{\text{weight of total puffed rice}}{\text{weight of paddy after puffing}} \times 100 \quad \dots(1)$$

Expansion ratio was determined by measuring the volume of paddy before puffing and puffed rice, using 100 ml of graduated cylinder [4,5,9].

$$\text{Expansion ratio} = \frac{\text{volume of puffed rice (g)}}{\text{volume of paddy (g)}} \quad \dots(2)$$

The density was calculated using the following equation 3: [4,5,9].

$$\text{Density (g/ml)} = \frac{\text{weight of total puffed rice (g)}}{\text{volume of puff rice (ml)}} \quad \dots(3)$$

5. Statistical Analysis

Response surface methodology was employed. Face-centered central composite design (FCCD) with two factors (grain moisture content and calcium chloride concentration) and three levels were used. Experimental values and code of FCCD design are shown in Table 1.

Table 1 Face-centered composite design (FCCD)

| Factors | Code | -1 | 0 | +1 |
|--------------------------------------|----------------|----|-----|-----|
| Moisture Content (%) | X ₁ | 10 | 13 | 16 |
| CaCl ₂ Concentration. (%) | X ₂ | 0 | 1.5 | 3.0 |

The responses were analyzed by Minitab program version 16 to fit a second-order polynomial equation 4 [16].

$$Y = \beta_0 + \sum \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum \beta_{ij} X_i X_j \quad \dots(4)$$

Chemical compositions were conducted using analysis of variance (ANOVA). Significant calculated mean values were compared using Duncan's new multiple range test at α = 0.05 level of significance.

RESULTS AND DISCUSSIONS

Chemical Compositions of Paddy Varieties

Chemical compositions of paddy varieties are shown in Table 2. The crude protein and amylose content of rice were in the range of 10.83-13.62% and 4.85 – 13.67%, respectively. The crude protein content of RBR was different significantly (p ≤ 0.05). RBR had highest protein of 13.62%, whereas the lowest was RD33 for 10.83%.

Amylose content was different significantly ($p \leq 0.05$) and could be classified into two groups; non-waxy rice and waxy rice. Non waxy rice includes RD33 and RBR had amylose of 13.11-13.67% and RD6, RD16 and SPT1 had amylose of 4.85-5.45%, respectively.

Table 2 Chemical compositions of rice grain

| Variety | Chemical compositions | |
|---------|-----------------------|--------------|
| | Protein (%) | Amylose (%) |
| RD6 | 10.87 ± 0.76 b | 5.45±0.11c |
| RD16 | 11.39 ± 0.76 b | 5.27±0.05c,d |
| RD33 | 10.83 ± 0.80 b | 13.67±0.29 a |
| SPT1 | 11.41 ± 0.18b | 4.85±0.11d |
| RBR | 13.62 ± 0.36 a | 13.11±0.34 b |

Average from triplication ± standard deviation.
 Different superscript letters are significantly different ($p \leq 0.05$).

Appearance of Puffed Rice

The puffed rice obtained in microwave puffing were classified into four groups (Fig.1). There were unpuffed (Fig.1A), puffed with improper expansion (Fig.1B), puffed without rupture in shape (Fig.1C) and fully puffed with open shape (Fig.1D). The last two groups of puffed rice were calculated in the puffing quality.

Puffing Qualities

The effects of grain moisture contents and calcium chloride concentrations on puffing qualities are shown in Table 3, Analysis of variances are shown in Table 4 and The contour plots of puffed rice qualities are shown in Fig. 2, respectively.

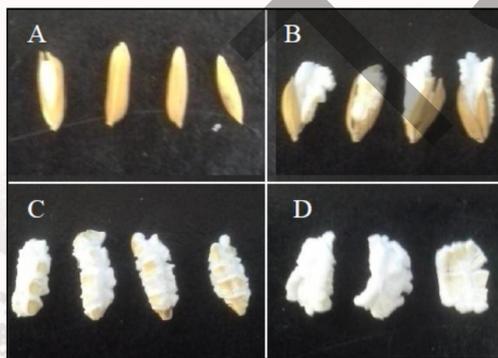


Fig. 1 Appearance of puffed rice at different stage of microwave puffing, A) Unpuffed rice, B) Puffed rice with improper expansion, C) Small puffed rice and D) Fully puffed rice.

Puffed yield shows the puffing ability of paddy. The percentage of puffed yield varied from 42.46% -77.61% at different moisture contents and CaCl₂ concentrations. The highest puffed yield was found in RD6 followed by SPT1, RD16, RD33 and RBR, respectively.

The percentage of puffed yield in RD6 varied from 53.62% - 77.61%. The maximum

puffed yield was found at 13% mc and 1.5% CaCl₂ and minimum was found at 16% mc and 1.5% CaCl₂.

For RD16, puffed yield was varied from 49.94%-60.16%, the highest puffed yield was found at 13% mc and 1.5% CaCl₂ and the lowest was found at 16% mc and 0% CaCl₂.

For RD33, puffed yield was varied from 46.33%-57.63%, the highest of puffed yield was found at 13% mc and 3.0 %CaCl₂ and the lowest was found at 10% mc and 1.5% CaCl₂.

For SPT1, puffed yield was varied from 49.24% -76.02%, the highest puffed yield was found at 13% mc and 3.0 % CaCl₂ and the lowest was found at 10% mc and 0% CaCl₂.

For RBR, puffed yield was varied from 42.46% - 49.16%, the highest puffed yield was found at 16% mc and 1.5% CaCl₂ and the lowest was found at 10% mc 0% CaCl₂ and 13% mc and 1.5% CaCl₂. According to this study when the moisture content was increasing tend to higher puffed yield; however, when the moisture increased to 16% yields lower puffed yield. These results correlated with the previous studies [9,10] which reported the optimum moisture content for maximum expansion was 14%. The drop in the puffed yield at low moisture content could be due to lack of enough pressure to burst the husk, on the other hand when the moisture content is high, the pressure inside the grain at puffing moment is lower causing less expansion and lower puffed yield. This study shows that optimal level of moisture in the grain is essential for puffing, in this case 13% (wb). This study supported by [8] that at high moisture level, starch structure collapse producing lesser expansion due to nucleation during corn popping process.

Expansion ratio was expressed as the degree of expansion when the paddy was puffed. Expansion ratio varied from 1.75-3.00. The highest expansion ratio was found in SPT1 followed by RD6, RD16, RD33 and RBR, respectively.

The expansion ratio in RD6 varied from 1.98-3.00. The maximum expansion ratio was found at 13% mc and 1.5% CaCl₂ and minimum was found at 10% mc and 0% CaCl₂.

In RD16, expansion ratio was varied from 1.90-2.50 the highest expansion was found at 13% mc and 1.5% CaCl₂ and lowest was found at 10% mc and 0% CaCl₂.

In RD33, expansion ratio was varied from 1.73-1.90 the highest expansion was found at

13% mc and 1.5% CaCl₂ and lowest was found at 10% mc and 0% CaCl₂.

In SPT1, expansion ratio was varied from 2.18-3.00 the highest expansion was found at 13% mc and 3.0% CaCl₂ and lowest was found at 10% mc and 0% CaCl₂.

In RBR, expansion ratio was varied from 1.86-2.06 the highest expansion was found at 16% mc and 1.5 % CaCl₂ and lowest was found at 10% mc and 0% CaCl₂.

According to ANOVA in Table 4, CaCl₂ had significant effect on expansion ratio of on SPT1, RD6 ($p \leq 0.01$) and RD16 ($p \leq 0.05$) because CaCl₂ increases the dielectric properties than the water alone, it could generate more heat in the grain when absorbing microwave power. Resulting, quickly and simultaneously transfer the heat to the grain and build internal pressure of the grain for puffing [2,9].

Amylopectin in SPT1, RD6 and RD16 leads to light, elastic and homogeneously expanded texture while amylose leads to hard texture and less expansion [4,8].

The density has been linked with the expansion ratio in describing the degree of puffing in product. The density of the puffed rice varied between 0.088-0.144 g/ml. The lowest density value was obtained in RBR and

RD33, whereas the highest value was obtained in SPT1 and RD6. The moisture content had high significant effect with density ($p \leq 0.01$). However, it was not affected by the calcium chloride.

Water plays an important role in expansion. The moisture in the grain is converted to superheated vapor, providing the driving force for expansion. Thus, when microwave-puffing, not only moisture content but also microwave power, time and dielectric properties of material are important in determining the expansion and other quality of puffed rice [2,9,15].

CONCLUSIONS

Puffed yield and expansion are two major criteria for deciding the effectiveness of microwave-puffing. This study provided some information of characteristics of puffed rice from paddy by microwave. The moisture content had a highly significant effect on puffed yield, expansion ratio and density of puffed rice from paddy. The calcium chloride concentration had a significant effect on expansion ratio. The puffed yield of RD6 SPT1 RD16 RD33 and RBR were 76.61%, 76.02%, 60.16%, 57.63 and

Table 3 Face-centered composite design arrangement and responses.

| Trial | Independent variables | | RD6 | | | RD16 | | | RD33 | | | SPT1 | | | RBR | | |
|-------|-----------------------|----------------|------------------|--------------|----------------|------------------|--------------|----------------|------------------|--------------|----------------|------------------|--------------|----------------|------------------|--------------|----------------|
| | X ₁ | X ₂ | Puffed yield (%) | Expan. ratio | Density (g/ml) | Puffed yield (%) | Expan. ratio | Density (g/ml) | Puffed yield (%) | Expan. ratio | Density (g/ml) | Puffed yield (%) | Expan. ratio | Density (g/ml) | Puffed yield (%) | Expan. ratio | Density (g/ml) |
| 1 | 10 | 0.0 | 56.72 | 1.98 | 0.109 | 51.08 | 1.90 | 0.118 | 50.85 | 1.73 | 0.130 | 49.24 | 2.18 | 0.088 | 42.46 | 1.86 | 0.113 |
| 2 | 16 | 0.0 | 57.18 | 2.20 | 0.099 | 49.94 | 2.00 | 0.110 | 49.72 | 1.80 | 0.122 | 55.67 | 2.27 | 0.095 | 45.81 | 1.97 | 0.115 |
| 3 | 10 | 3.0 | 60.39 | 2.26 | 0.101 | 54.48 | 2.10 | 0.114 | 49.72 | 1.80 | 0.122 | 54.50 | 2.36 | 0.090 | 45.81 | 2.00 | 0.114 |
| 4 | 16 | 3.0 | 63.26 | 2.43 | 0.098 | 57.89 | 2.10 | 0.121 | 50.85 | 1.85 | 0.122 | 55.79 | 2.36 | 0.092 | 46.93 | 1.94 | 0.120 |
| 5 | 10 | 1.5 | 58.90 | 2.13 | 0.105 | 56.75 | 1.95 | 0.128 | 46.33 | 1.80 | 0.114 | 50.64 | 2.27 | 0.087 | 45.81 | 2.00 | 0.114 |
| 6 | 16 | 1.5 | 53.62 | 2.22 | 0.092 | 57.89 | 2.15 | 0.119 | 50.85 | 1.85 | 0.122 | 55.44 | 2.41 | 0.089 | 49.16 | 2.06 | 0.119 |
| 7 | 13 | 0.0 | 66.13 | 2.41 | 0.104 | 51.08 | 2.15 | 0.105 | 50.85 | 1.75 | 0.129 | 60.94 | 2.55 | 0.093 | 45.81 | 1.94 | 0.117 |
| 8 | 13 | 3.0 | 74.05 | 2.96 | 0.095 | 57.89 | 2.35 | 0.109 | 57.63 | 1.77 | 0.144 | 76.02 | 3.00 | 0.098 | 46.93 | 1.97 | 0.118 |
| 9 | 13 | 1.5 | 75.77 | 2.96 | 0.097 | 59.02 | 2.35 | 0.111 | 53.11 | 1.75 | 0.134 | 71.93 | 2.82 | 0.099 | 48.04 | 1.89 | 0.126 |
| 10 | 13 | 1.5 | 77.04 | 2.85 | 0.102 | 60.16 | 2.40 | 0.110 | 54.24 | 1.90 | 0.126 | 72.63 | 2.86 | 0.099 | 43.58 | 2.00 | 0.108 |
| 11 | 13 | 1.5 | 77.61 | 3.00 | 0.098 | 59.02 | 2.35 | 0.111 | 54.24 | 1.88 | 0.128 | 72.05 | 2.91 | 0.096 | 42.46 | 1.92 | 0.110 |
| 12 | 13 | 1.5 | 77.27 | 2.96 | 0.099 | 59.02 | 2.40 | 0.108 | 54.24 | 1.85 | 0.130 | 70.18 | 2.82 | 0.097 | 43.58 | 1.92 | 0.113 |
| 13 | 13 | 1.5 | 77.50 | 2.98 | 0.099 | 60.16 | 2.50 | 0.106 | 55.37 | 1.88 | 0.131 | 69.59 | 2.86 | 0.094 | 42.46 | 1.94 | 0.109 |

X₁ is moisture content, X₂ is CaCl₂ Concentration

Table 4 Regression coefficients and coefficient of determination of puffing qualities for each variety

| Coefficient | Regression coefficients | | | | | | | | | | | | | | |
|-------------------------------|-------------------------|--------------|----------|--------------|--------------|---------|--------------|--------------|----------|--------------|--------------|----------|--------------|--------------|---------|
| | RD6 | | | RD16 | | | RD33 | | | SPT1 | | | RBR | | |
| | Puffed yield | Expan. ratio | Density | Puffed yield | Expan. ratio | Density | Puffed yield | Expan. ratio | Density | Puffed yield | Expan. ratio | Density | Puffed yield | Expan. ratio | Density |
| Constant | 75.648** | 2.905** | 0.098** | -59.337** | 2.382** | 0.109** | 54.003** | 1.842** | 0.129** | 70.784** | 2.849** | 0.096** | 44.654** | 1.948** | 0.114** |
| X ₁ | -0.325 | 0.079 | -0.004** | 0.567 | 0.05 | -0.001 | 0.753 | 0.029 | -0.000 | 2.086 | 0.037 | 0.002 | 1.303 | 0.018 | 0.002 |
| X ₂ | 2.946 | 0.177** | -0.002* | 3.026 | 0.083* | 0.001 | 1.129 | 0.025 | 0.001 | 3.411 | 0.127** | -0.000 | 0.931 | 0.023 | 0.001 |
| X ₁ ² | -15.917** | -0.625** | -0.000 | -1.663** | -0.289** | 0.011** | -4.831** | 0.002 | -0.012** | -16.517** | -0.496** | -0.006** | 1.252 | 0.042 | -0.000 |
| X ₂ ² | -2.082 | -0.115 | 0.001 | -4.501** | -0.089 | -0.004* | 0.818 | -0.060 | 0.006 | -1.079 | -0.064 | -0.000 | 0.134 | -0.027 | 0.001 |
| X ₁ X ₂ | 0.602 | -0.010 | 0.001 | 1.135** | -0.025 | 0.003* | 0.365 | -0.006 | 0.001 | -1.287 | -0.022 | -0.001 | -0.558 | -0.041 | 0.001 |
| R ² (%) | 91.38 | 94.01 | 79.49 | 98.29 | 92.49 | 89.33 | 75.05 | 55.44 | 66.98 | 93.89 | 95.80 | 81.18 | 37.63 | 52.74 | 18.30 |

R² - Coefficient of determination.

X₁ is moisture content, X₂ is CaCl₂ Concentration.

*, ** Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively.

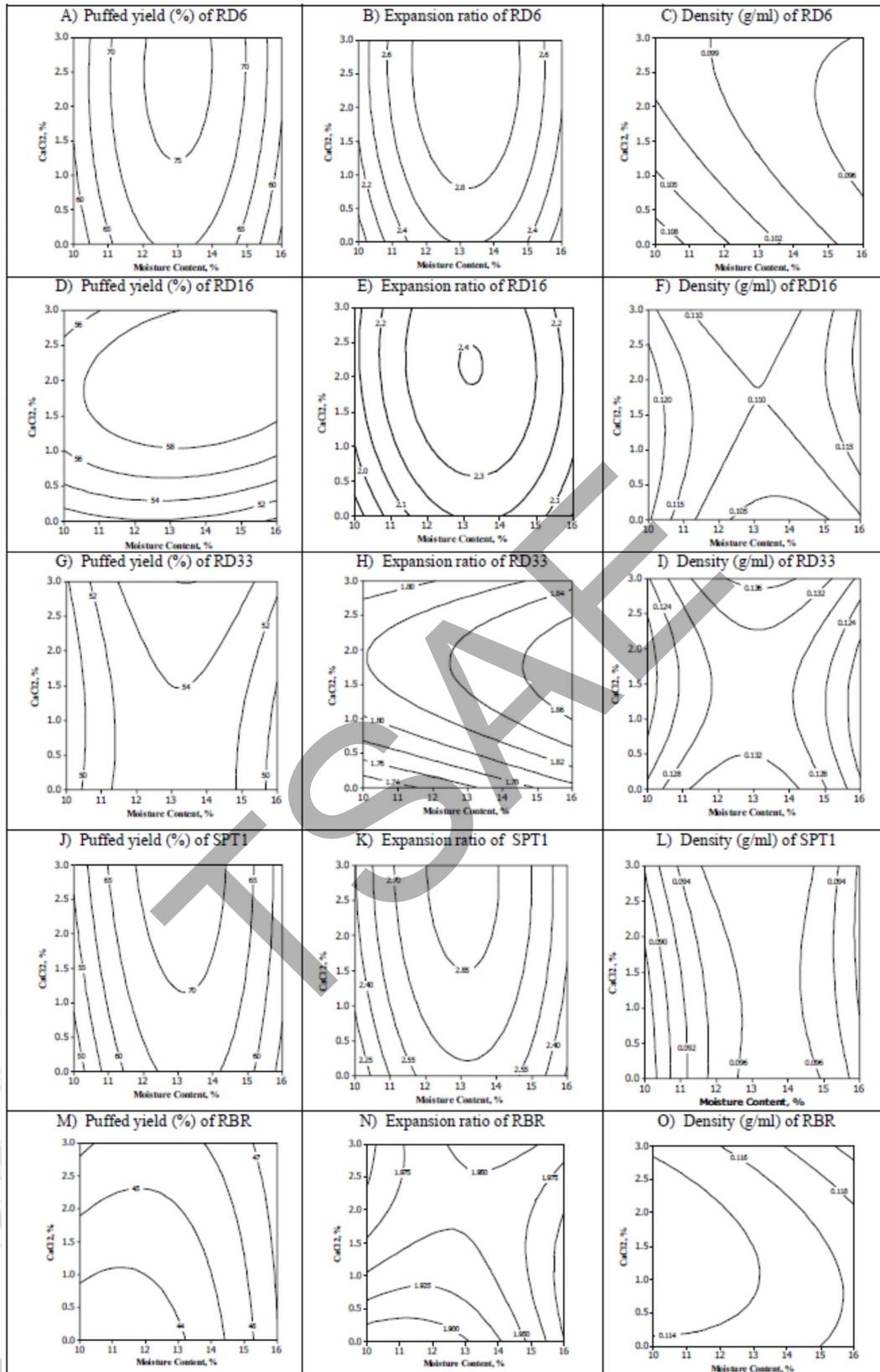


Fig. 2 The contour plots of puffed yield, expansion ratio and density of different puffed rice varieties as affected by moisture contents and calcium chloride concentrations.

49.16%. RD6 has high potential for microwave puffing more than other varieties. The optimum conditions for puffing by microwave was 13% mc and 1.5-3.0%CaCl₂.

ACKNOWLEDGMENTS

This research was financially supported by the Researchers and Research for Industry Grant (RRi) under Thailand Research Fund (TRF) and Royal Richy Rice Co.,Ltd., Bangkok, Thailand and thanks to Bureau of Rice Research and Development, Rice Department for providing paddy.

REFERENCES

- [1] Regier, M. and Schubert, H. Introducing Microwave Processing of Food: Principles and Technology, pp.3-21. In H. Schubert and Regier,M. (Ed). The Microwave Processing of Foods. CRC Press, Boca Raton (2005)
- [2] Tang, J. Dielectric properties of foods, pp. 22-40, in H. Schubert and M. Regier (Ed.) The Microwave Process of Food, CRC Press, Boca Raton (2005)
- [3] Joshi, N.D., Mohapatra, D., Joshi, D.C. and Sutar, R.F. Puffing Characteristics of Parboiled Milled Rice in a Domestic Convective-Microwave Oven and Process Optimization. Food Bioprocess Technol. 7:1678-1688 (2014)
- [4] Maisont, S and Narkrugsa, W. Effects Of Salt, Moisture Content And Microwave Power on Puffing Qualities Of Puffed Rice. Kasetsart J (Nat.Sci.). 44:251-261 (2010)
- [5] Swarnakar, A.K., Devi, M.K. and Das, S.K. Popping Characteristics of Paddy Using Microwave Energy and Optimization of Process Parameters. International Journal of Food Studies 3:45-59 (2014)
- [6] Simsriskul, M. Important Factors Affecting Puffing Quality of Paddy And Properties Of Puffing Rice Flour. M.S. Thesis. Chulalongkorn University, Bangkok (1991)
- [7] Sumnu, G. A Review on Microwave Baking of Foods. International Journal of Food Science and Technology 36: 117-127 (2001)
- [8] Moraru, C. I., and Kokini, J. L. Nucleation and Expansion During Extrusion and Microwave Heating of Cereal Foods. Comprehensive Reviews in Food Science and Food Safety 2:147-165 (2003)
- [9] Gokmen, S. Effects of Moisture Content and Popping Method on Popping Characteristics of Popcorn. Journal of Food Engineering 65:357-362 (2004)
- [10] Hoke, K., Housova, J and Houska, M. Optimum Conditions of Rice Puffing-Review. Czech Journal of Food Science. 23:1-11 (2005)
- [11] Boffler, C. R.. Microwave Cooking and Processing: Engineering Fundamentals for The Food Scientist. AVI Book, New York (1993)
- [12] Chinnaswamy, R and Bhattacharya, K.R. Studies on Expanded Rice: Optimum Processing Conditions. Journal of Food Science 48: 1604-1608 (1983)
- [13] Juliano, B.O. A Simplified Assay Milled Rice Amylose. J. Cereal Sci-Today. 16:334-340 (1971)
- [14] AOAC. Official Analytical Methods of Analysis, 17th Ed., The Association of Official Analytical Chemists, Washington, D.C. (2000)
- [15] Chanlat, N and Songsermpong, S. Effect of Calcium Chloride and Moisture Content on Microwave Puffing of Rice Grains. Proc. of the 4th International Rice Congress, Bangkok, (2014)
- [16] Myers, R. H., and Montgomery, D. C. Response Surface Methodology: Process and Product Optimization Using Designed Experiments. 2nd Ed., Wiley, New York (2002)