Optimization of Processing Conditions for the Production of Puffed Rice

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팽화미 제조 공정조건의 최적화

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Abstract

    The objective of this study was to optimize processing conditions for the production of an instant puffed rice product using response surface methodology (RSM) and contour analysis. Sensory and texture qualities, and physical properties of the puffed rice were analyzed with various processing conditions related to drying and puffing temperature, and moisture content. Preference, color intensity, cohesiveness, rehydration ratio, density and lightness of the puffed rice product significantly varied depending on the processing conditions. The responses showed high R^2 values (0.623, 0.852, 0.735, 0.688, and 0.790) and lack-of-fit. Rehydration ratio was found to have a negative correlation with density in the condition of drying and puffing temperature. Lightness and preference scores of the puffed rice increased as the moisture content increased. According to RSM, the preference scores were very highly related to the moisture content, and the optimum processing conditions of the puffed rice product were at 40℃ of drying temperature, with 11.0% of moisture content, and at 232.7℃ of puffing temperature.

    Key words: optimum processing, puffed rice, drying temperature, moisture content, puffing temperature, RSM

Ⅰ. Introduction

    Grains supply large amounts of dietary energy around the world and rice is well known for the

second major cereal in the human diets following wheat (Pimentel D & Pimentel M 2003; Shierly P & Robert HD 2007). It is one of the most important major staple food for more than half of the

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world's population with regard to human nutrition (Pakorn L et al 2008). It affords around 21% of per capita energy and 15% of protein to the global human population (Bhullar NK & Wilhelm G 2013). Due to surplus of rice on the market, there has been a growing interest in developing better processed rice products (Lee HJ et al 2012). Puffed rice might be an important ingredient of the instant *bibimbop*, one of the popular Korean traditional foods (Park KH et al 2011).

Nowadays, the accelerated pace of modern life style has encouraged new applications of staple rice products, which are easy to prepare for. In order to satisfy consumers' demand, various forms of instant rice products such as expanded, frozen, and dried forms were developed (Wang JP et al 2013). Instant rice, which is precooked and dehydrated, requires only 3 to 5 min of rehydration to prepare for serving (Shierly P & Robert HD 2007). Rehydration is a very important factor to product quality (Pakorn L et al 2008). There are two ways to rehydrate instant rice, one is to use hot water, and the other is to employ microwave. The texture of instant rice after rehydration is still not similar to that of fresh cooked rice with lower hardness and less stickiness because of organoleptic and nutritional loss during preparation (Prasert W & Prisana S 2009; Rewthong O et al 2011). High hydrostatic pressure can also change the characteristics of rice (Park SJ et al 2014). Puffing process is one of the most common methods used for rice rehydration, and is generally used to make breakfast cereals, cereal drinks, infant foods, and snack products (Joshi ND et al 2014; Semwal AD et al 1996). However, there were no research articles related to puffed rice, and little information is available in the literature about the effect of factors on the quality of puffing rice. The response surface methodology (RSM), empirical modeling technique, has been used to evaluate the relationship between the experimental and predicted values (Maran P & Manikandan S 2013).

In this study, RSM was used to estimate the relationship between a set of controllable experimental factors (Myers RH & Montgomery DC 2002). The effects of three processing factors (drying temperature, moisture content, and puffing temperature) for manufacturing dried instant rice on the sensory evaluation and physicochemical properties were investigated. The aim of this study was to optimize processing conditions for the production of dried instant rice with puffing process, focusing on the taste quality after rehydration of puffing rice.

Ⅱ. Materials and methods

1. Raw Materials

Sindongjin, a japonica rice, produced in 2013, was purchased at a local grocery store (Incheon, South Korea) on the day before the experiment with an initial moisture content of 12~13% (dry basis), and kept at 4℃ prior to use.

2. Preparation and Cooked Rice

For each experiment 10 kg of *Sindongjin* rice was washed thoroughly in water at ambient temperature in order to clean and remove dust particles. After cleaning, the sample was soaked in water for 12 h at room temperature (22±2℃). The soaked rice in a steam cooker (Hyunjung engineering, Korea) was cooked by steaming at 100℃ for 25 min under atmospheric pressure to pre-cook. Then pre-cooked rice was soaked for 3 min in water at ambient temperature to prevent burning. After soaking, steam process was re-applied at 100

℃ for 25 min under atmospheric pressure to fully gelatinize the rice.

3. Experimental Design

Puffing was performed under 27 different conditions with various drying temperatures, and moisture contents, and puffing temperatures through a 3^3 factorial design (Table 1). Based on the results of preliminary processing experiments, three quantitative variables were chosen: drying temperature, moisture contents before puffing, and puffing temperature. Cooked rice was dried using a tray dryer at temperatures of 40℃, 55℃ and 70℃ to obtain a dried sample with a moisture content of less than 7%. After drying, pre-determined amounts of tap water were sprayed on 10 kg of each sample at room temperature (22±2℃) followed by mixing by hand to allow uniform moisture level distribution throughout the sample for 15 min. Moisture content was determined using an infrared moisture balance (FD-610, Kett Electric Laboratory, Tokyo, Japan). Three moisture levels (7±0.32%, 9±0.23%, 11±0.35%) and puffing temperature levels (230℃, 235℃, 240℃) were selected.

4. Density

Puffed instant rice was put in 100 mL cylinder and tapped 25~30 times for compacting the grains uniformly, and the weight and volume of the instant rice were recorded. Density was calculated by the following formula:

$$\text{Density} = \text{weight of instant rice (g)} / \text{volume of instant rice (mL)}.$$

5. Rehydration Ratio

Ten g of dry instant rice with 100 mL water was heated by microwave for 4 min, draining the excess water for 5 min, followed by weighing. The rehydration ratio was calculated by the following formula:

$$\text{Rehydration ratio} = \text{weight of instant rice after cooking (g)} / \text{weight of instant rice before cooking (g)}$$

6. Color Measurement

Color values were measured by a Minolta colorimeter (CR300, Minolta Co., Osaka, Japan). Before measurement, the colorimeter was calibrated with standard white plate title, having L*=93.57, a*=0.06, and b*=0.24. The parameter L* is a measure of lightness, a* is an indicator of redness, and the parameter b* is a measure of yellowness. All experiments were performed three times.

7. Scanning Electron Micrographs (SEM)

SEMs of puffed rice samples were taken with a Jeol Model JSM 6335F at magnitude ×30. The puffed rice were coated with Pt for SEM.

8. Texture Profile Analysis (TPA)

Seventy g of instant rice was rehydrated with 140 mL boiling water, and microwaved for 3 min. The texture of the rice was evaluated with a Brookfield texture analyzer (model M08-373, Brookfield Engineering Laboratories, Inc., Middleboro, MA, USA). Ten g of rehydrated rice was molded into a block using a cylindrical container, and compressed to 60% by a rod-type probe (2.5 diameters) at 1.7 mm/s. Hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness were determined. All experiments were performed five times.

9. Sensory Evaluation

〈Table 1〉 **Coded levels for the independent variables used in developing experimental data (A) and variables in a 3^3 factorial design (B)**

(A)

Factor	Code	Level		
		−1	0	+1
Drying temperature(℃)	X_1	40	55	70
Moisture content(%)	X_2	7	9	11
Puffing temperature(℃)	X_3	230	235	240

(B)

Experiment	Drying temperature(℃)		Moisture content(%)		Puffing temperature(℃)	
	Code value	Real value	Code value	Real value	Code value	Real value
1	−1	40	−1	7	−1	230
2	−1	40	−1	7	0	235
3	−1	40	−1	7	+1	240
4	−1	40	0	9	−1	230
5	−1	40	0	9	0	235
6	−1	40	0	9	+1	240
7	−1	40	+1	11	−1	230
8	−1	40	+1	11	0	235
9	−1	40	+1	11	+1	240
10	0	55	−1	7	−1	230
11	0	55	−1	7	0	235
12	0	55	−1	7	+1	240
13	0	55	0	9	−1	230
14	0	55	0	9	0	235
15	0	55	0	9	+1	240
16	0	55	+1	11	−1	230
17	0	55	+1	11	0	235
18	0	55	+1	11	+1	240
19	+1	70	−1	7	−1	230
20	+1	70	−1	7	0	235
21	+1	70	−1	7	+1	240
22	+1	70	0	9	−1	230
23	+1	70	0	9	0	235
24	+1	70	0	9	+1	240
25	+1	70	+1	11	−1	230
26	+1	70	+1	11	0	235
27	+1	70	+1	11	+1	240

Ten panels were trained for the sensory evaluation. After three training sessions, the sensory attributes of rehydrated rice were evaluated. All the samples were served equally after being heated in a microwave oven for 4 min. The panelists rated the intensities of sensory attributes from 1 (extre-

mely weak) to 9 (extremely strong) on a 9-point hedonic scale. Preference was evaluated by 30 untrained panels.

10. RSM and Statistical Analysis

Regression analysis was performed based on the experimental data and was fitted to an empirical second order polynomial model as shown in the following equation:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j + e$$

where Y was the response variable, and B_0, B_i, B_{ii}, and B_{ij} were the regression coefficients of variables for intercept, linear, quadratic, and interaction terms, respectively. x_i and x_j were independent variables. In statistics, polynomial regression fits a nonlinear relationship between the value of x and the corresponding conditional mean of y, denoted $E(y \mid x)$, and has been used to describe non-linear phenomena and special case of multiple linear regression. Multiple regression analysis was conducted using Minitab (Minitab Inc., Pennsylvania, USA). Linear, quadratic, and interaction effects of the three independent variables (i.e., drying temperature, moisture content, and puffing temperature) on the various quality attributes of the samples were also determined using the same packages. RSM was used to schematically identify the relationships between the independent variables and the response variables. All data were expressed as averages of five replicate measurements.

Ⅲ. Results and Discussion

1. Process Optimization

In this study, RSM was used to analyze the relationship between controllable processing factors, and applied to optimize the production con-

ditions of instant puffed rice (Lee EY et al 2000; Pakorn L et al 2008). The selection of adequate response models were proceeded by model analysis as linear, quadratic, and cubic functions. Lack-of-fit test and R-square analysis were also considered to select adequate response. Lack-of-fit test was done through comparing between the residual error and pure error from replicated design points.

The 29 kinds of response variables including sensory qualities, textural and physical properties varied as the three independent variables were changed. As a result, five responses (sensory preference, color intensity, cohesiveness, rehydration ratio, and density) were selected with no significant lack-of-fit and higher R^2 value (Table 2). The results of the multiple regression analysis showed that the linear effects were generally more significant than the quadratic and interaction effects (Table 2).

As a consequence, sensory preference, color intensity, cohesiveness, rehydration ratio, and density were selected as important responses of RSM to evaluate the production of instant puffed rice.
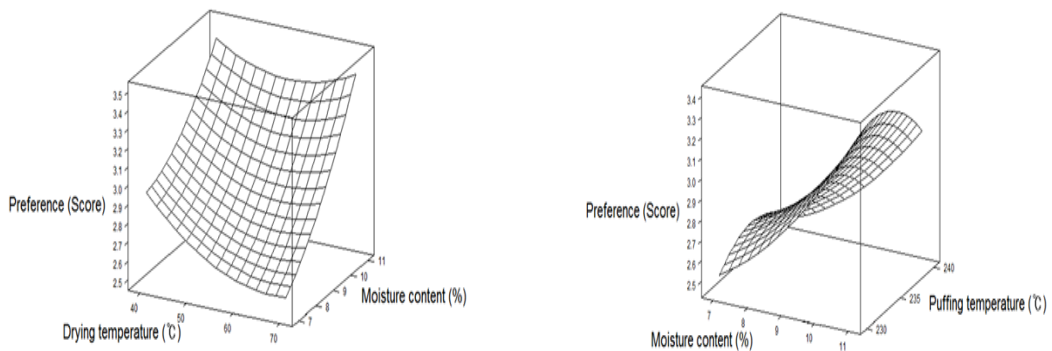
2. Effect on Preference

The resulted equations and response surface plots, which express the change in response variables (Y) as sensory preference with drying temperature (X_1), moisture content (X_2), and puffing temperature (X_3), are illustrated in ⟨Fig. 1⟩. The moisture content (X_2) greatly affected the dependent response variable as sensory preference, and this response tended to increase as the moisture content increased. The result of ⟨Fig. 1⟩ showed that sensory characteristic of preference was significantly driven by the moisture content rather than drying and puffing temperature based on the linear, quadratic, and interaction effects of the overall model.

〈Table 2〉 **Regression coefficient of the polynomial function and the coefficients of determination (R^2)**

Coefficient	Preference	Color intensity	Cohesiveness	Rehydration ratio	Density
β_0	2.8811	2.8667	0.3002	2.8785	41.6550
β_1	−0.1067	−0.0183	−0.0422***	−0.1006***	1.7580***
β_2	0.3411***	−0.5906***	0.0012	0.0189	0.4240
β_3	−0.0644	0.2522**	0.0177*	0.0611*	−1.0930**
β_{12}	0.0917	−0.1367	−0.0027	0.0733*	−1.2930**
β_{13}	−0.0083	−0.0458	−0.0062	−0.0358	−0.2870
β_{23}	−0.0542	−0.1683	0.0070	−0.0083	0.0920
β_{11}	0.1200	0.0683	0.0372	00828	−1.7490
β_{22}	0.0933	0.1017	0.0030	−0.0389	0.6730
β_{33}	−0.1233	0.1400	0.0223	−0.0022	−0.5790
R^2	0.6230	0.8520	0.7350	0.6880	0.790
Lack-of-fit	0.3127	0.2902	0.0326	0.1016	1.397

β_1=Drying temperature (℃), β_2=Moisture content (%), β_3=Puffing temperature (℃)
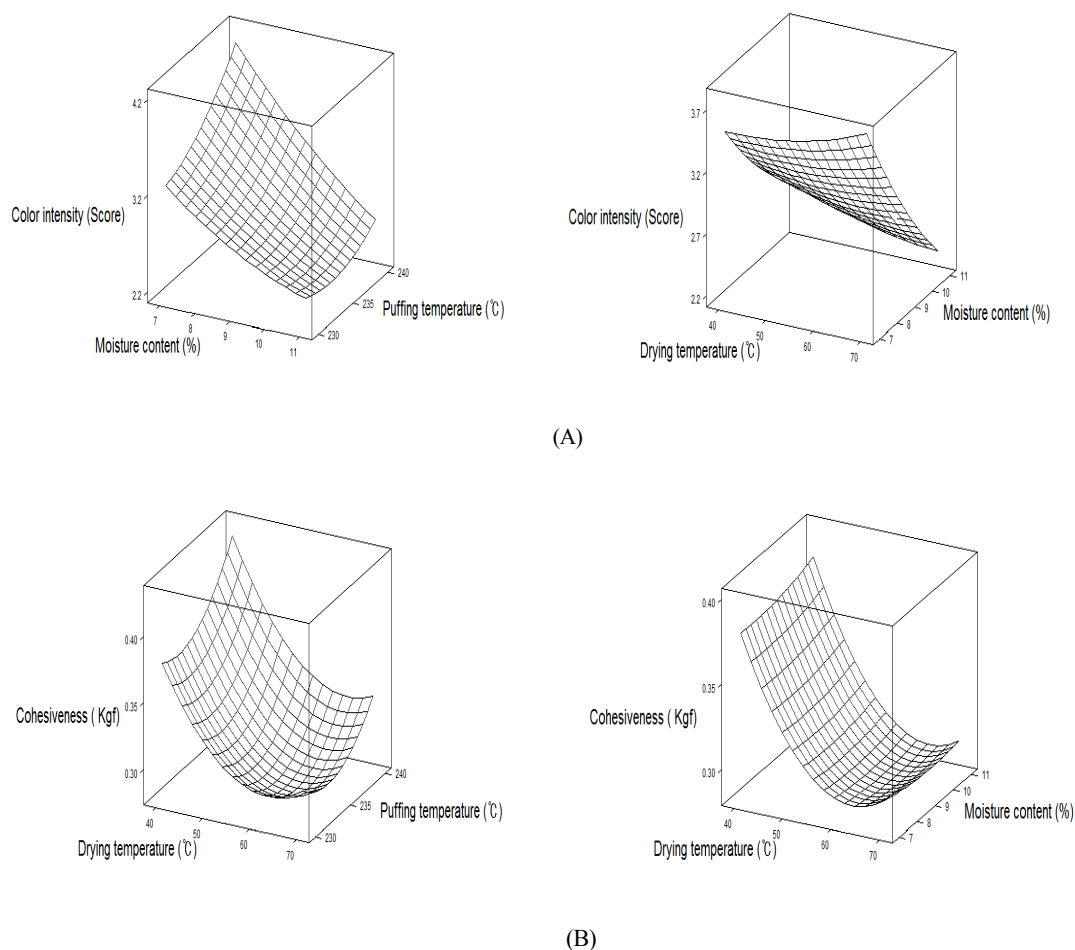* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

〈Fig. 1〉 **Contour plot of preference of rehydrated puffed rice as a function of processing conditions as drying temperature, moisture content, and puffing temperature.**

3. Effect on Color Intensity

The color intensity based on sensory evaluation was significantly affected by moisture content and puffing temperature (Fig. 2A). The effect of processing conditions on the value of color intensity was significant for two variables as moisture content and puffing temperature at the level of 1% (Table 2). The color intensity of sensory evaluation increased as the moisture content decreased and puffing temperature increased (Fig. 2A). The surface color of the puffed rice was influenced by puffing temperature rather than drying temperature due to Maillard reaction between the starch and amino acids in the rice under 230~240℃. Starch

(A)

(B)

⟨Fig. 2⟩ **Contour plot of color intensity (A) and cohesiveness (B) of rehydrated puffed rice as a function of processing conditions as drying temperature, moisture content, and puffing temperature.**

breaks down into dextrin, which reacts with basic amino acids such as lysine present in the rice, producing a brown pigment (melanoidin) that may in turn cause a decline in L value (Heo NK et al 2005; Rewthong O et al 2011).

4. Effect on Cohesiveness

The cohesiveness by texture analyzer was the most significant value ($p<0.05$ and R^2=0.735) in texture properties as hardness, adhesiveness, chewiness, gumminess, and springiness. The cohesive ness values were affected by drying and puffing temperatures. As shown in ⟨Fig. 2B⟩, the samples of rehydrated puffed rice became more cohesive with decreased drying temperature and increased puffing temperature. The change in cohesiveness was due mainly to the heat treatment by puffing and drying, which causes the gelatinization of starch and dissociation of protein in rice, resulted in a lower shear strain and reduced hardness and chewiness.

5. SEM
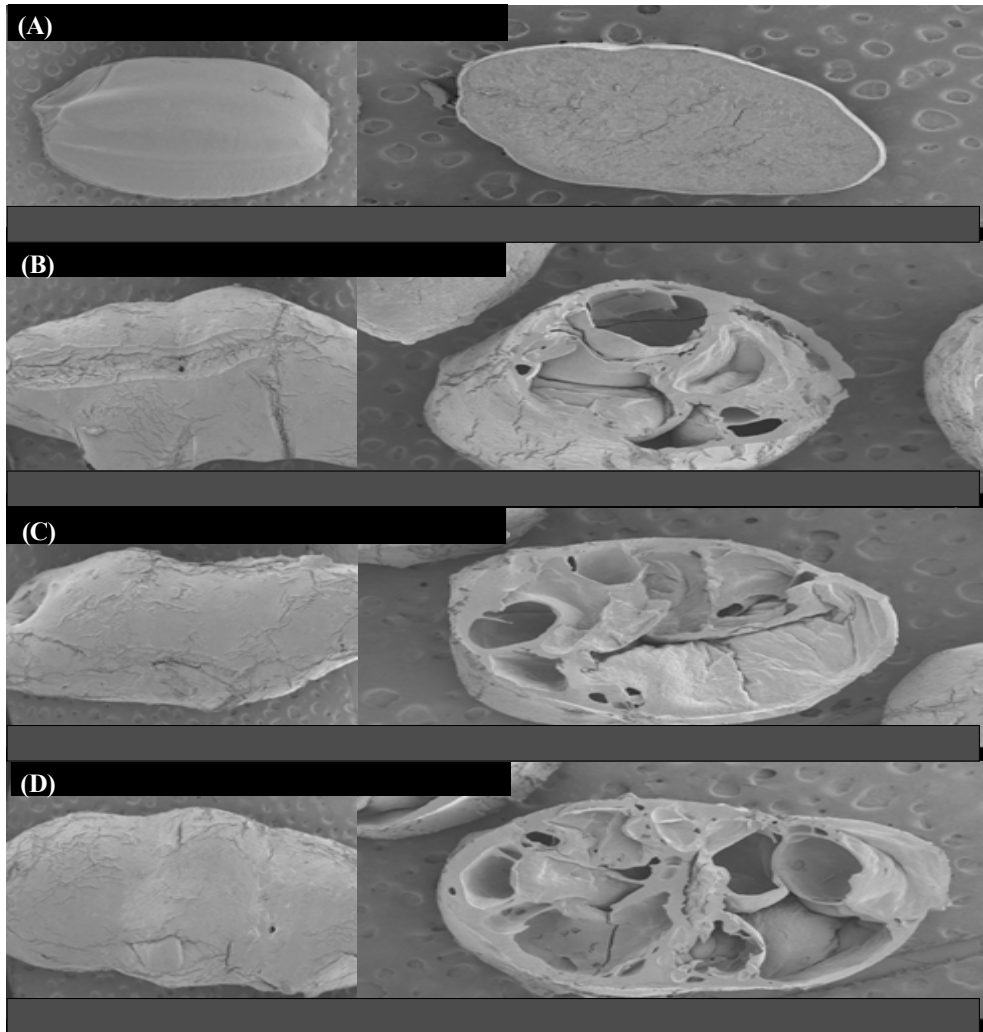
A : Rice after soaking
B : Puffed rice with moisture content 7% at puffing temperature 235℃
C : Puffed rice with moisture content 9% at puffing temperature 235℃
D : Puffed rice with moisture content 11% at puffing temperature 235℃

〈Fig. 3〉 **Scanning electron microphotographs of the surface and cross cut section of the rice.**

The SEM images showed that puffed rice had a hollow structure after puffing (Fig. 3). In the soaking step, the increase in grain dimensions has been attributed to the swelling of starch granules and subsequent widening of cracks in the grain by water diffusion (Ahromrit et al 2006). Puffed rice with moisture content of 11% could be seen larger than those of 7% and 9%, implying moisture content had a impact on a hollow structure in puffed rice.
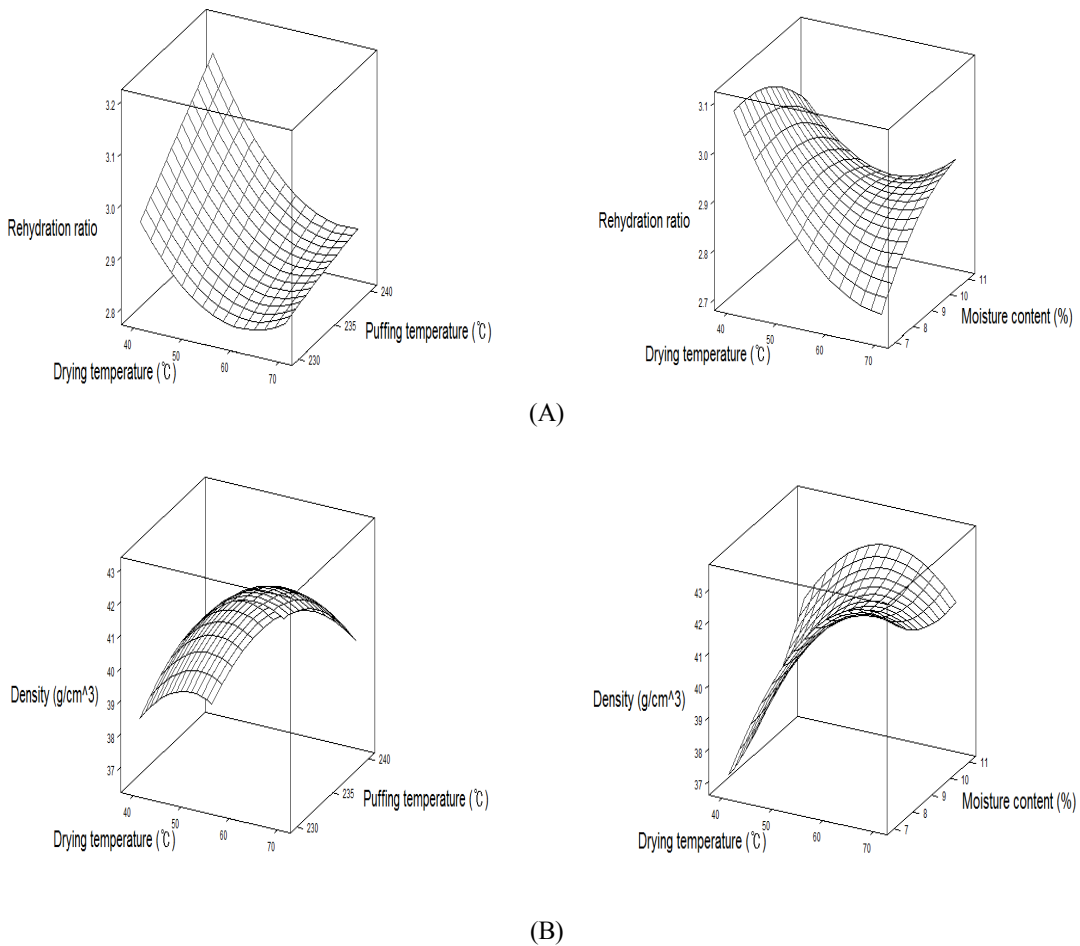
6. Effect on Rehydration Ratio and Density

In the case of rehydration ratio effect, drying and puffing temperatures were significantly affected at the 5% significance level (Table 2). For the interaction effects, drying temperature and moisture content were found to be significantly affected at the 5% level (Table 2). As shown in 〈Fig. 4A〉, the rehydration ratio tended to increase as the drying temperature decreased and puffing temperature increased. The rehydration ratio of sam-ples treated at a higher puffing temperature and lower drying temperature tended to be greater than those of the samples treated at a lower drying temperature and with a higher moisture content.

The response variables related to physical property such as density was significantly influenced by drying and puffing temperature at the 1% significance level and density was more strongly influenced by interaction effects as drying temperature and moisture content at the 1% level (Table 2). The RSM model including linear and interac-

(A)

(B)

〈Fig. 4〉 Contour plot of rehydration ratio (A) and density (B) of rehydrated puffed rice as a function of processing conditions of drying temperature, moisture content, and puffing temperature.

tion effects of processing temperature and moisture significantly affected the density of the samples (Fig. 4B). The density of the puffed rice treated with a higher drying temperature and middle puffing temperature was the greatest among the various processing conditions. As shown in ⟨Fig. 4B⟩, the density increased sharply with decreased drying temperature and reduced with a decrease in moisture content. These tendency might be due to the gelatinization of starch, denaturation of proteins in rice components, and destruction of the rice cells during drying and puffing process (Lee JE et al 2012; Maisont S & Woatthichai N 2009).
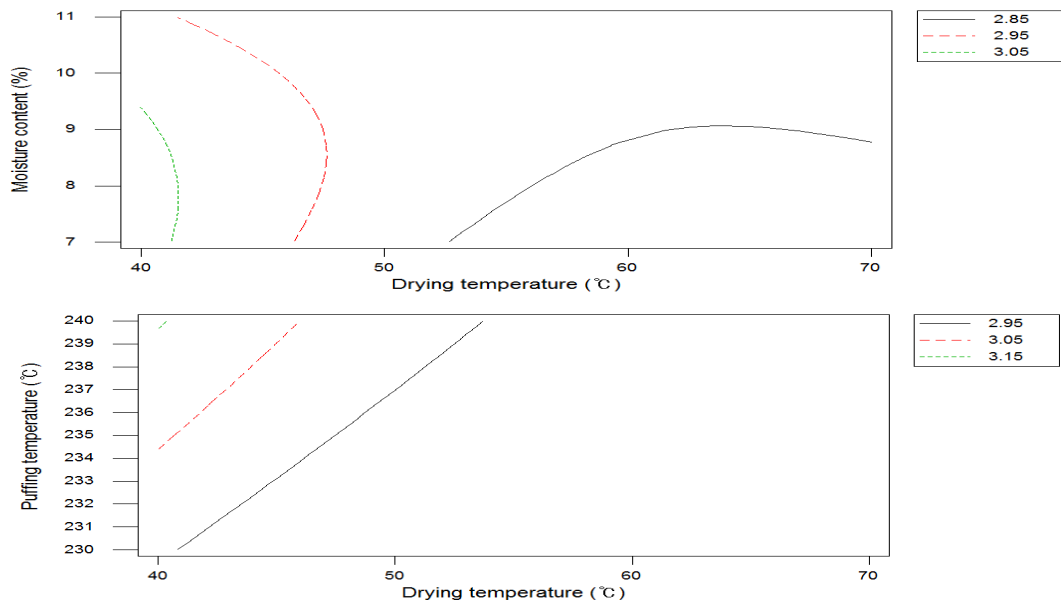
7. Optimum Processing Conditions

The optimum processing conditions were determined by checking the validity of the processing conditions through multiple regression analysis (Table 3A). The maximum values of each of response variables - preference, color intensity, co-

hesiveness, rehydration ratio, and density - of the samples were attained under difference conditions of processing (Table 3B).

Contour analysis was conducted to determine the optimum processing conditions of puffed rice products. The optimum conditions for rehydration ratio and preference of the samples were determined by superimposing the significant contour plotting lines of the selected physical properties and quality attributes. As a result of the contour analysis on the rehydration ratio, the optimum conditions were highly restricted due to low drying temperature. The optimal condition for rehydration ratio of puffed rice was approximately at 40℃ of drying temperature, 7.3% of moisture content, and 240℃ of puffing temperature (Fig. 5). The score of the preference based on the sensory attributes for the samples was very high and was sufficient to cover moisture content conditions in the experimental design. The optimum drying and puffing tempera-

⟨Table 3⟩ **Correlation coefficients between processing conditions and organoleptic and physical properties of instant puffed rice (A) and optimal conditions of processing factors for the response values (B)**

(A)

Properties	Drying temp. (℃)	Moisture content (%)	Puffing temp. (℃)
Preference	−0.0672	0.8554	2.3606
Color intensity	0.1500	3.4536	−2.3964
Cohesiveness	−0.0009	−0.1725	−0.4181
Rehydration ratio	0.0431	0.2458	0.0878
Density	2.2584	−2.5986	10.7922

(B)

Responses	Drying temp. (℃)	Moisture content (%)	Puffing temp. (℃)
Preference	40.0	11.0	232.7
Color intensty	70.0	7.0	240.0
Cohesiveness	40.0	11.0	240.0
Rehydration ratio	40.0	7.3	240.0
Density	70.0	7.0	230.0

〈Fig. 5〉 Optimal conditions of rehydration ratio of rehydrated puffed rice as a function of processing conditions of drying temperature, moisture content, and puffing temperature.
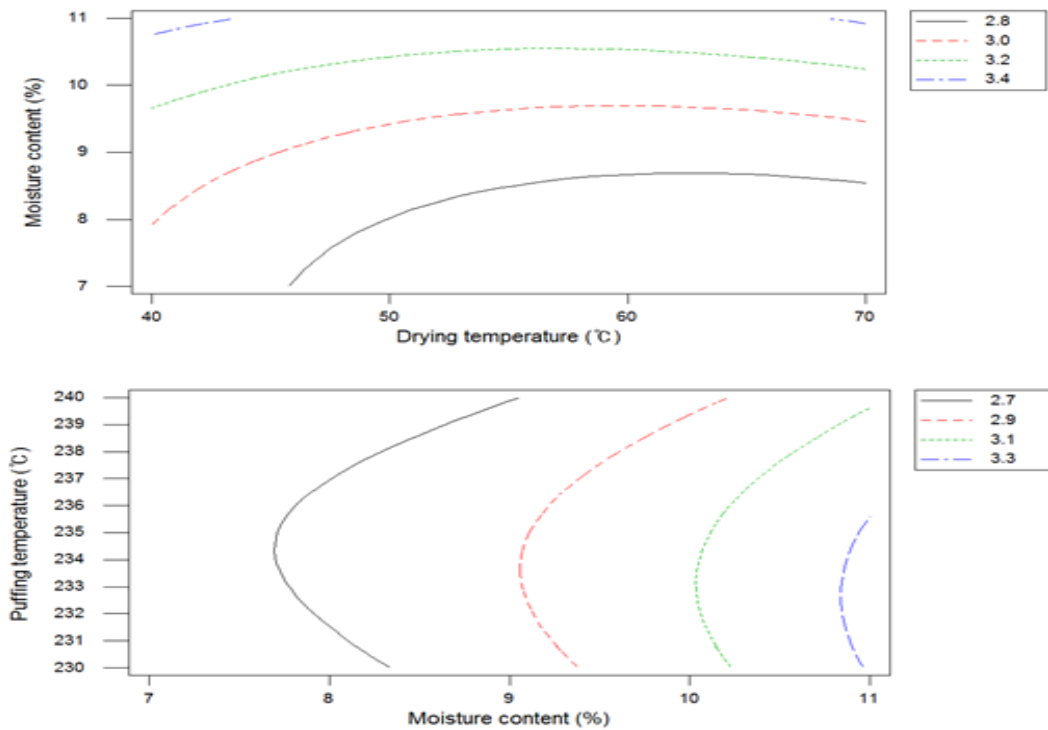
〈Fig. 6〉 Optimal conditions of preference of rehydrated puffed rice as a function of processing conditions of drying temperature, moisture content, and puffing temperature.

tures, and moisture content of the puffed rice were 40℃, 232.7℃, and 11.0%, respectively (Fig. 6). In this optimal processing conditions based on preference score (over 3.5), the optimum density was more than 40 and the optimum cohesiveness ranged from 0.37 to 0.4. The optimum rehydration ratio, color intensity, and L value were 2.75 to 3.0, less than 2.92, and more than 80.7, respectively.

Ⅳ. Conclusions

In this study, effects of processing factors for manufacturing puffed rice onsensory evaluation, and textural and physicochemical properties were investigated, while RSM was applied to optimize the quality of puffing rice. Many factors affected dried instant rice during drying and puffing process. The preference, color intensity, cohesiveness, rehydration ratio, and density of the puffed instant rice were significantly and variously affected by drying and puffing temperatures, and moisture content. According to the contour analysis on the rehydration ratio, the optimum conditions were highly restricted due to low drying temperature, and the score of the preference was very highly related to moisture content. L value was also found to be an important factor for evaluating the puffed rice. L value was related with the moisture content and puffing temperature. The optimum conditions of processing for puffed rice product with higher preference score were at 40℃ of the drying temperature, with 11.0% of the moisture content, and at 232.7℃ of the puffing temperature according to the RSM and contour analysis.

한글 초록

본 연구는 팽화미를 제조할 때 팽화미 품질에 영향을 미치는 세 가지의 조건인 건조 온도, 수분 함량, 퍼핑 온도를 달리하고, 반응표면분석법과 등고선분석법을 이용하여 팽화미의 최적 제조 조건을 검토한 연구이다. 팽화미 제조에 적합한 국내산 신동진미를 팽화미 원료로 사용했고, 총 27 가지 조건(3×3)에서 팽화미를 제조 후, 관능검사, 조직감, 색도, 밀도, 복원율, 크기 등 총 29개의 반응변수를 분석하였다. 그 결과, 공정에서 유의적으로 영향을 주는 반응변수는 선호도, 색의 강도, 밀도, 복원율, 명도, 응집성이었다. 반응표면분석과 등고선분석 결과, 기호도는 수분 함량, 명도는 수분 함량 및 퍼핑 온도와 상관관계가 높았다. 퍼핑 전과 퍼핑 후의 팽화미를 SEM 촬영을 통해 비교한 결과, 수분함량이 높을수록 쌀 단면 공극이 더 균일했으며, 기공이 많이 발생했다. 반응변수의 최적범위는 선호도 3.5 이상을 기본조건으로 하여 밀도는 40 이상, 응집성은 0.37부터 0.4까지, 그리고 복원율, 색의 강도, L value는 각각 2.75부터 3.0까지, 2.92 미만, 80.7 이상일 때 유효한 범위를 나타냈다. 팽화미 제조의 최적 공정조건은 건조온도 40℃, 수분함량 11%, 퍼핑온도 232.7℃ 이었다. 본 연구는 팽화미 제조에 영향을 미치는 요인들에 관한 기초 자료를 제공해 주며, 팽화미의 최적 조건을 활용하여 제조 시, 전자레인지 및 열수에 복원되는 팽화미의 품질의 향상이 기대된다.

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