J Food Sci Nutr
Vol 13, p 340~347 (2008)
DOI: 10.3746/jfn.2008.13.4.340

J Food Science and Nutrition

Optimization of Iced Cookie with Dried Lotus Root Powder Using Response Surface Methodology

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Abstract

This study was conducted to develop a recipe for a nutritional cookie with lotus root powder that had the optimal composition of ingredients and texture resulting in high preference by all age groups. Wheat flour was partially substituted with lotus root powder to reduce its content. Response Surface Methodology was used to analyze the measured results, which showed 16 experimental points including 2 replicates for lotus root powder, sugar and butter. The compositional and functional properties were measured, and these values were applied to a mathematical model. A canonical form and perturbation plot showed the influence of each ingredient on the final mixture product. The sensory evaluation results showed significant values in color ($p< 0.01$), texture ($p< 0.05$) and overall quality ($p< 0.05$). As a result, the optimal sensory ratio was determined to be 22.59 g of lotus root powder, and 53.08 g of sugar for every 120 g of butter.

Key words: lotus root, cookie, response surface methodology, optimization, sensory evaluation

INTRODUCTION

Lotus root (*Nelumbo nucifera Gaertn*) is an aquatic vegetable. It contains an abundant amount of protein, amino acids, dietary fiber, carbohydrates and vitamins C, B1, and B2 (1). It is widely favoured by Asians because of its hard and crispy texture, special aroma and texture. It is often used to make instant lotus powder, as a drink, thickener or as an ingredient for making desserts (2). Lotus (*Nelumbo*) is used, not only as an ornamental plant, but also as a dietary staple in Eastern Asia, particularly in Korea and China. Lotus roots of the 'edible lotus' variant of *Nelumbo nucifera* (3,4), have been widely used and processed as a delicious and nutritional food, and are particularly popular in South Korea.

Cookies and biscuits are widely consumed food products, appreciated for their taste, versatility, convenience, long shelf life, texture and appearance. The use of natural ingredients, exhibiting functional properties and providing specific health benefits beyond traditional nutrients, is a very attractive way to design new food products, with an important market niche presently exhibiting pronounced growth (5).

The objectives of this study were to partially replace wheat flour in the formulation of cookies with different amount, of lotus root powder and to perform a systematic investigation of how different process conditions influence physicochemical properties of cookies with lotus root powder using response surface methodology (RSM), as well as to determine optimal conditions for producing lotus root cookies, and to provide reliable experimental data for the baking process in developing new types of functional foods (6).

MATERIALS AND METHODS

Material

The lotus root powder used in this experiment was obtained from Song-sang food (Seoul, Korea). Confectionary flour was from cake flour of Daehan Flour Mills (Daehan, Seoul, Korea). Also, salt-free butter (Seoulmilk, Seoul, Korea) was used for butter along with baking powder, brown sugar (CJ, Seoul, Korea), salt (Sempio, Seoul, Korea) and eggs (Younglim, Seoul, Korea).

Experiment design

Design Expert 7 program was used for all the research plans, data analysis and optimization analysis on cookies with lotus root powder. As for independent variables, three factors were chosen such as the content level of lotus root powder in partial replacement of flour, sugar and butter, and as for dependent variables, chromaticity (L, a, b), spread ratio, hardness and sensory evaluation (color, appearance, flavor, texture, and overall quality) were chosen. The maximum and minimum range of lotus root powder, sugar, and butter were determined to be

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10～30%, 20～46.6%, and 53.3～80% respectively against the total amount of flour through a preexamination. The experimental points of Central Composite consist of the most central point, ±α point (axial point) and ±1 level point (factorial point), and between these experimental points, there exists an iterative point for the selection of a model and the verification of fitness lack. Accordingly, when each established scope was inputted, forming 16 experimental points, and 2 iterative points were selected through the establishment of replication (7). The mixture ingredient and rate of the cookies added in lotus root powder are as seen in Table 1.

Cookie preparation and baking

Lotus root cookies were prepared according to the AACC method 10-52 (8) with modification. sugar, butter and salt were creamed in a mixer (model K5SS, Kitchen Aid Co., Joseph, Michigan, USA) equipped with a wire whip beater set at the 4th-speed setting for 3 min. And egg was added to the mix using a flat beater with intermittent scraping of the creamed mass every 1 min. Then, wheat flour, lotus root powder and baking powder were added the creamed mass over a period of 1 min to during mixing at a low speed setting of the machine. The completed dough was aged for 1 hour in a 4°C refrigerator and then sheeted to a thickness of 1 cm with the help of a rolling pin. The cookies were cut at with a cookie die of diameter 4 cm and transferred to a lightly greased baking tray. The cookies were baked at 180°C for 13 min in a convection oven (RSF-22, Rinnai Co., Incheon, Korea). The baked cookies were cooled to room temperature for 1 hour. The cookie samples were removed from the baking sheet and placed in a zippered plastic bag for analysis.

Table 1. Experimental design for lotus root cookie

Sample No.[1)]	Variable level[2)]		
	X_1	X_2	X_3
1	15	30	80
2	45	30	80
3	15	70	80
4	45	70	80
5	15	30	120
6	45	30	120
7	15	70	120
8	45	70	120
9	15	50	100
10	45	50	100
11	30	30	100
12	30	70	100
13	30	50	80
14	30	50	120
15	30	50	100
16	30	50	100

[1)]Sample No.: The number of experimental conditions by central composite design.
[2)]X_1: lotus root powder (15～45 g), X_2: sugar (30～70 g), X_3: butter (80～120 g).

Color measurement

The color values (L, a, and b value) of lotus root cookies are measured using a colorimeter (Colormeter CR-200, Minolta Co., Osaka, Japan). The colorimeter was calibrated using a standard white plate with L, a, and b values of 97.26, -0.07 and +1.86, respectively. Three measurements were made for each treatment.

Spread factor measurement

The spread factor was measured according to AACC 10-52 (8) and it was calculated as follows:

$$\text{Spread factor} = \frac{\text{Average diameter of cookie (cm/EA)}}{\text{Average height of cookie (cm/EA)}}$$

Texture analysis

A rheometer (Compac-100, Sun scientific Co., Ltd., Tokyo, Japan) mounted with a plunger (adapter No. 4) was used. The adapter was forced 0.5 cm into the centre of each sample, then moved upward to the plunger at a speed of 140 mm/min. The operating conditions of the rheometer is shown in Table 2. The hardness unit was expressed in dyne/cm^2.

Sensory evaluation

Sensory evaluation was done according to the seven-point hedonic scale. Processed lotus root cookie was evaluated for its sensory quality by a 16-student panel of Sookmyung woman's university. All cookies were conversant with the factors governing the quality of the product. The lotus root cookie prepared for each test sample was corded with a random 4 digit number.

The panelists were asked to evaluate the color, appearance, flavor, texture and overall quality of the cookies by giving a score ranging from 1 (dislike extremely) to 7 (like extremely).

Optimization

Through the numerical optimization of a Canonical model and graphical optimization, the quantity of lotus root powder, sugar and butter was chosen for the optimal result, by which the optimal point was selected by using

Table 2. Operating conditions for rheometer

Items	Conditions
Max wt	10 kg
Distance	50%
Table speed	120 mm/min
rupture	1 bite
probe	number 4 needle type

the point found through the point prediction. For the numerical optimization, the goal area was set with the highest point of the sensory test out of all reactions with the coefficients of the model using the standard canonical model.

The optimal points presented through numerical optimization, the optimal point showing the highest desirability was selected after acquiring the desirability through the following formula.

$$D = (d_1 \times d_2 \times \cdots \times d_n)^{\frac{1}{n}} = \left(\prod_{i=1}^{n} d_i\right)^{\frac{1}{n}}$$

Here, D is the overall desirability, d is each desirability and n is the number of reponses (9,10).

Statistical analysis

Statistical analysis of variance (ANOVA) and multiple regression were performed using the Design-Expert 7 program (Stat-Easy Co., Minneapolis, USA) to fit the equation. The results included the significance of the model and of each of its terms, the estimated model coefficients, the coefficient of determination, and the lack of fit test.

RESULTS AND DISCUSSION

Characteristics of rheology

According to Central Composite Design with the purpose to optimize the manufacturing conditions for lotus root powder cookies, the results of physical measurements from 16 conditions with 3 variables are as in Table 3. The model equations and, the coefficients of determination of the model equation are given in Table 4.

Color value

The values of L, a, and b were in the ranges of 55.74 ~67.64, 4.43~8.49, and 21.72~25.43, respectively. The analysis of L shows that lightness decreased significantly ($p<0.001$) with increased of lotus root powder and sugar. But, L value was reduced by adding butter. The evaluation of a values show that increased lotus root

Table 3. Experimental combinations and data under various conditions of lotus root powder, sugar, butter, and their responses

Sample No.[1)]	Variable level[2)]			Responses[3)]				
	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4	Y_5
1	15	30	80	67.64	4.43	23.87	4.42	549580.99
2	45	30	80	61.65	5.99	22.5	4.55	370062.27
3	15	70	80	63.23	6.54	25.43	5.13	1332069.89
4	45	70	80	60.14	7.59	22.36	4.96	1285760.77
5	15	30	120	67.12	4.82	23.23	5.15	257209.49
6	45	30	120	60.23	6.79	21.72	5.03	267369.98
7	15	70	120	63.28	7.19	24.85	6.45	608924.48
8	45	70	120	55.74	8.49	21.72	5.22	453134.85
9	15	50	100	66.54	5.20	23.99	5.21	686465.47
10	45	50	100	59.19	7.84	21.95	5.05	368211.94
11	30	30	100	64.76	5.56	22.37	4.80	239248.45
12	30	70	100	62.95	6.72	21.83	5.38	1052463.68
13	30	50	80	64.44	6.43	22.72	4.73	809839.49
14	30	50	120	63.87	6.21	22.78	5.11	737727.49
15	30	50	100	62.53	7.42	22.83	5.23	676658.88
16	30	50	100	62.85	7.22	22.99	4.91	738767.62

[1)]Sample No.: The number of experimental conditions by central composite design.
[2)]X_1: lotus root powder (15 g~45 g), X_2: sugar (30 g~70 g), X_3: butter (80 g~120 g).
[3)]Y_1: L (white +100↔0 black), Y_2: a (red +60↔−60 green), Y_3: b (yellow +60↔−60 blue), Y_4: spread ratio, Y_5: hardness.

Table 4. Analysis of predicted model equation for the quality characteristics of lotus root cookie

Responses[1)]	Model	R-squared	F-value	P-value Prob> F	Equation of on terms of pseudo component[2)]
Y_1	Linear	0.8853	30.86	$<0.0001^{**}$	$-3.09X_1-1.61X_2-0.69X_3+62.89$
Y_2	Linear	0.8389	20.83	$<0.0001^{**}$	$+0.85X_1+0.89X_2+0.25X_3+6.53$
Y_3	Linear	0.7573	12.48	0.005^{**}	$-1.11X_1+0.25X_2-0.26X_3+22.95$
Y_4	Quadratic	0.9149	16.12	0.0002^{**}	$-0.15X_1+0.32X_2+0.32X_3-0.18X_1X_2-0.16X_1X_3+0.0046X_2X_3+5.08$
Y_5	Linear	0.7912	15.16	0.0002^{**}	$-68971.05X_1+30490.005X_2-20230.005X_3+65210.005$

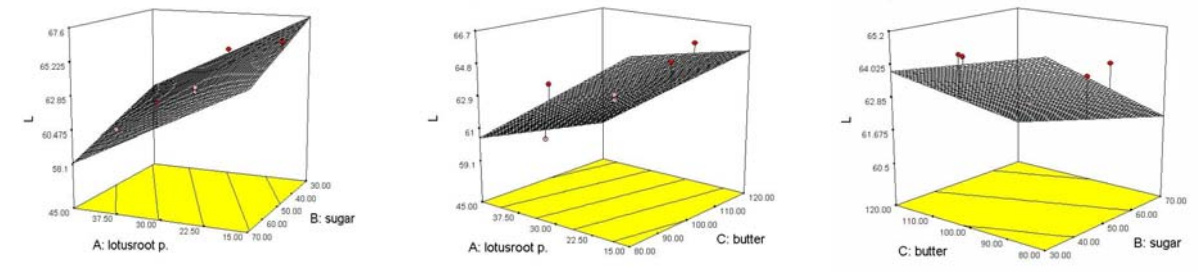
[1)]Y_1: L (lightness), Y_2: a (redness), Y_3: b (yellowness), Y_4: spread ratio, Y_5: hardness.
[2)]X_1: lotus root powder (g), X_2: Sugar (g), X_3: butter (g).
$^{*}p<0.05$, $^{**}p<0.01$.

powder, sugar and butter significantly ($p<0.001$) increased the cookies red color. The b values of cookies increased with increasing amounts of sugar and butter. Whereas, the b value was reduced by adding lotus root powder. The b value is also very significant ($p<0.001$). Shown in Fig. 1 is the response surface for the effect of lotus root powder, sugar and butter on color (L, a, b) on lotus root cookies.

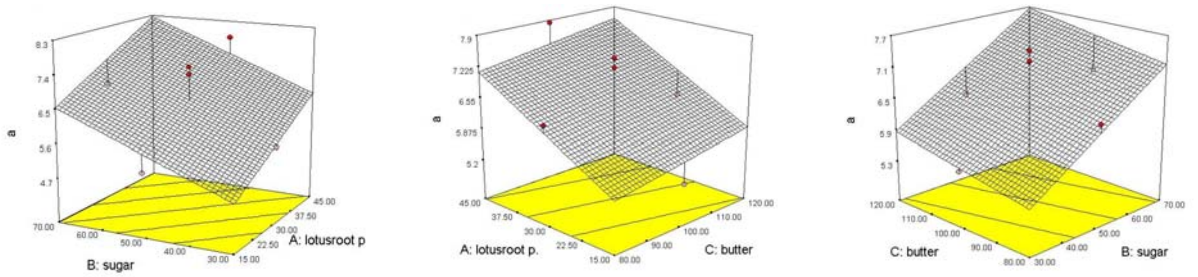
Spread ratio

Correlation with the spread ratio of cookies was significant ($p<0.001$), and it was shown that the more was added sugar and butter, the more the spread ratio of cookies increased (Fig. 2).

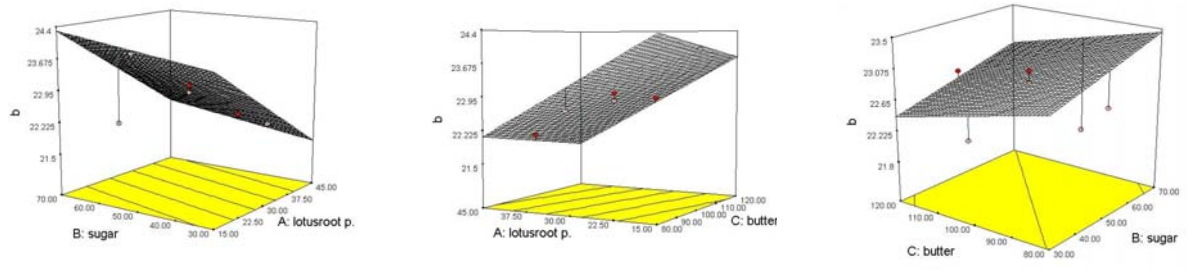
Singh and Mohamed (11) reported that the spread factor was decreased with increased protein in the cookies. Replacement of soft wheat flour with lotus root powder therefore resulted in cookies with higher spread factor. The spread factor was also influenced by dough rheological properties and moisture content. In addition, Ko and Joo (12) reported that substitution of Jinuni bean powder increased the cookie spread factor and suggested



Lotus root powder (A)×Sugar (B) Lotus root powder (A)×Butter (C) Sugar (B)×Butter (C)

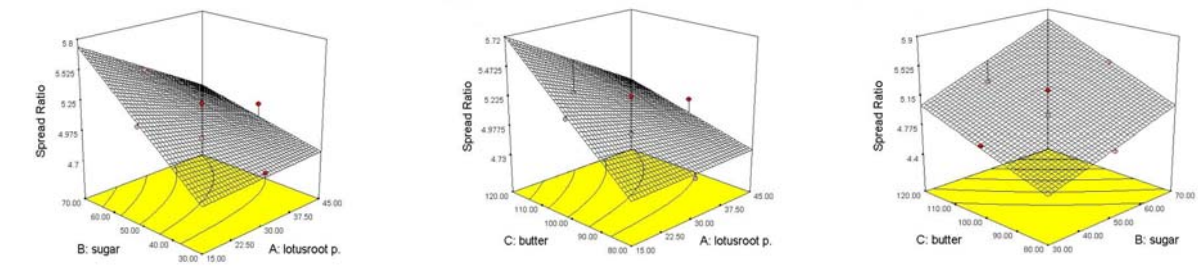


Lotus root powder (A)×Sugar (B) Lotus root powder (A)×Butter (C) Sugar (B)×Butter (C)



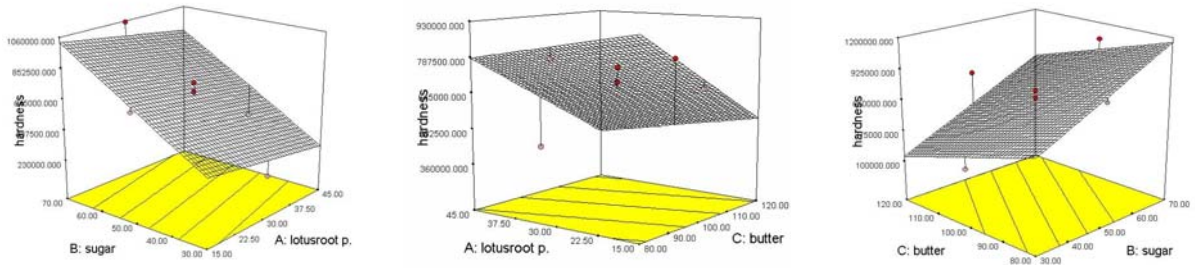
Lotus root powder (A)×Sugar (B) Lotus root powder (A)×Butter (C) Sugar (B)×Butter (C)

Fig. 1. Response surfaces for the effect of lotus root powder (A), sugar (B), butter (C) on the color (L, a, b) of lotus root cookies.



Lotus root powder (A)×Sugar (B) Lotus root powder (A)×Butter (C) Sugar (B)×Butter (C)

Fig. 2. Response surfaces for the effect of lotus root powder (A), sugar (B), butter (C) on the spread ratio of lotus root cookies.



Lotus root powder (A)×Sugar (B) Lotus root powder (A)×Butter (C) Sugar (B)×Butter (C)

Fig. 3. Response surfaces for the effect of lotus root powder (A), sugar (B), butter (C) on the hardness of lotus root cookies.

that the replacement might have interfered with gluten formation in the sample. A similar increase in the spread factor of cookies made with black rice flour was also reported (13).

Hardness

Correlation with the hardness of cookies was significant ($p<0.001$). It was shown that the hardness of cookies was in proportion to the added amount of sugar, but in inverse proportion to the added amount of butter (Fig. 3). According to Park et al. (14), cookie hardness results during manufacturing when it is influenced by moisture from supplemental Ingredients.

Sensory evaluation

The values of color, appearance, flavor, texture and overall quality were in the ranges of 2.0～5.3, 3.0～5.8, 3.5～5.2, 3.5～5.2, and 3.3～5.2, respectively (Table 5).

Table 5. Sensory evaluation combination and data under various condition of louts root powder, sugar, butter, and their responses

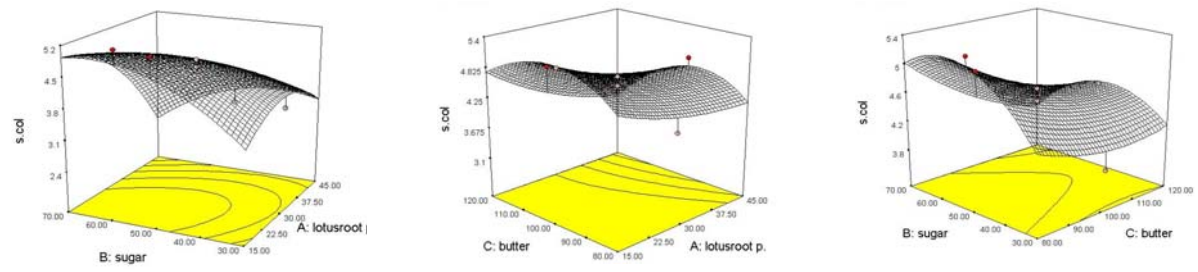
Sample No.[1)]	Variable level[2)]			Responses[3)]				
	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4	Y_5
1	15	30	80	3.50	4.17	4.00	3.83	3.67
2	45	30	80	4.17	4.67	4.17	3.67	3.83
3	15	70	80	5.33	5.83	4.83	4.00	4.50
4	45	70	80	3.33	3.00	3.50	3.50	4.17
5	15	30	120	3.83	3.83	4.17	4.67	4.00
6	45	30	120	3.50	3.67	4.00	4.83	4.17
7	15	70	120	4.50	3.00	4.83	5.00	4.67
8	45	70	120	2.00	3.00	3.83	3.83	3.33
9	15	50	100	5.17	4.33	4.83	5.17	4.50
10	45	50	100	3.17	4.00	4.00	4.50	3.67
11	30	30	100	3.83	4.33	4.50	3.67	4.00
12	30	70	100	4.67	4.50	4.83	3.83	4.67
13	30	50	80	5.33	5.00	5.00	4.83	5.17
14	30	50	120	4.50	4.17	3.83	4.83	5.00
15	30	50	100	4.50	4.67	4.50	5.20	5.17
16	30	50	100	4.67	4.83	5.17	5.17	5.00

[1)]Sample No.: The number of experimental conditions by central composite design.
[2)]X_1: lotus root powder (15～45 g), X_2: sugar (30～70 g), X_3: butter (80～120 g).
[3)]Y_1: color, Y_2: appearance, Y_3: flavor, Y_4: texture, Y_5: overall quality.

Table 6. Analysis of predicted model equation for the quality characteristics of lotus root cookie

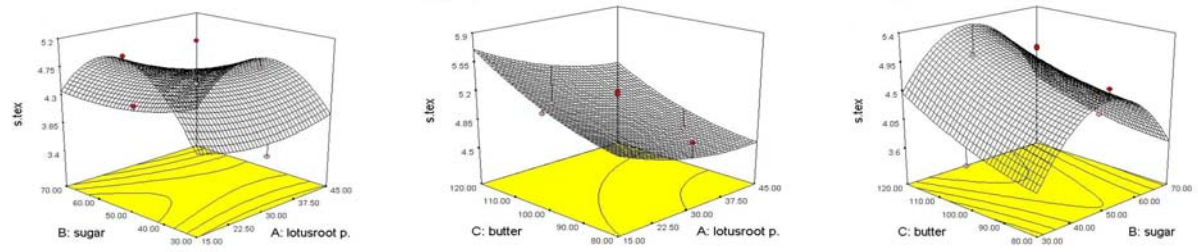
Responses[1)]	Model	R-squared	F-value	P-value Prob> F	Equation of on terms of pseudo component[2)]
Color	Quadratic	0.9393	10.32	0.0051**	$-0.62X_1+0.100X_2-0.33X_3-0.61X_1X_2-0.19X_1X_3-0.23X_2X_3-0.58X_1^2-0.05X_2^2+0.17X_3^2+4.69$
Texture	Quadratic	0.8602	4.10	0.0499*	$-0.23X_1-0.051X_2+0.33X_3-0.21X_1X_2-0.044X_1X_3-0.084X_2X_3+0.11X_1^2-0.97X_2^2+0.11X_3^2+4.88$
Overall quality	Quadratic	0.9072	6.52	0.0167*	$-0.22X_1+0.17X_2-0.017X_3-0.25X_1X_2-0.12X_1X_3-0.17X_2X_3-0.71X_1^2-0.46X_2^2+0.29X_3^2+4.89$

[1)]Y_1: color, Y_2: texture, Y_3: overall palatability. [2)]X_1: lotus root powder (g), X_2: sugar (g), X_3: butter (g). *$p<0.05$, **$p<0.01$.



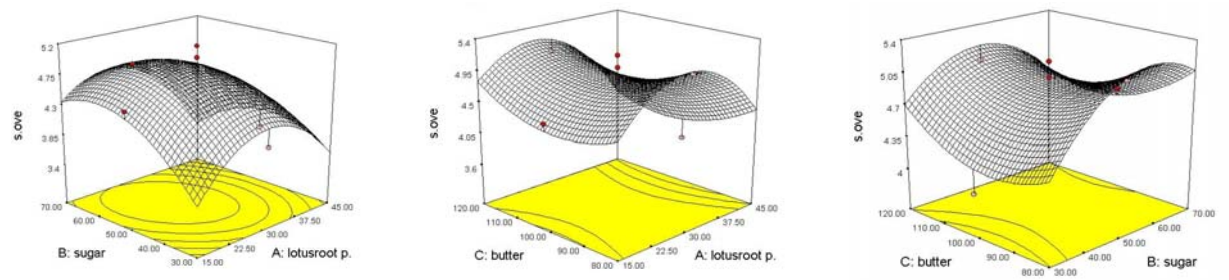
Lotus root powder (A)×Sugar (B) Lotus root powder (A)×Butter (C) Sugar (B)×Butter (C)

Fig. 4. Response surfaces for the effect of lotus root powder (A), sugar (B), butter (C) on sensory characteristics (color) of lotus root cookies.



Lotus root powder (A)×Sugar (B) Lotus root powder (A)×Butter (C) Sugar (B)×Butter (C)

Fig. 5. Response surfaces for the effect of lotus root powder (A), sugar (B), butter (C) on sensory characteristics (texture) of lotus root cookies.



Lotus root powder (A)×Sugar (B) Lotus root powder (A)×Butter (C) Sugar (B)×Butter (C)

Fig. 6. Response surfaces for the effect of lotus root powder (A), sugar (B), butter (C) on sensory characteristics (overall palatability) of lotus root cookies.

The lotus root cookies showed significant results ($p<0.05$) for color, texture, and overall quality. However, appearance and flavor were not significant ($p<0.05$). The model equations and coefficients of determination of the model equation are given in Table 6.

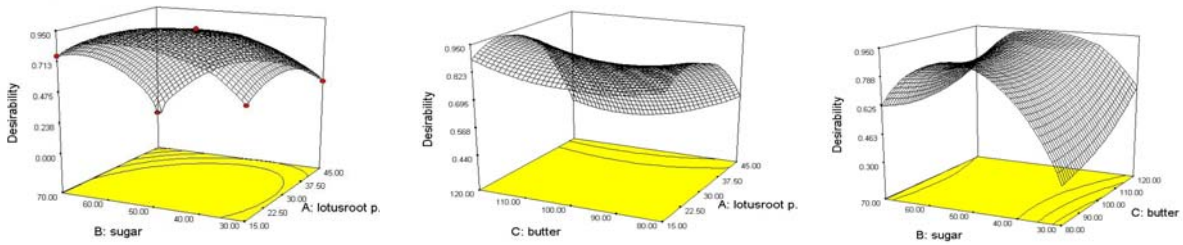
In color, it was shown that the more was added lotus root powder, the more the preference in color decreased (Fig. 4).

The texture of cookies was found to be influenced greatly by butter in general (Fig. 5). A similar result in the texture of cookies made with pine leaf powder was also reported (15).

In overall quality, it was shown that as more lotus root powder increased, the preference in overall quality decreased (Fig. 6). A similar result in the overall quality of cookies made with Yam powder was also reported (16).

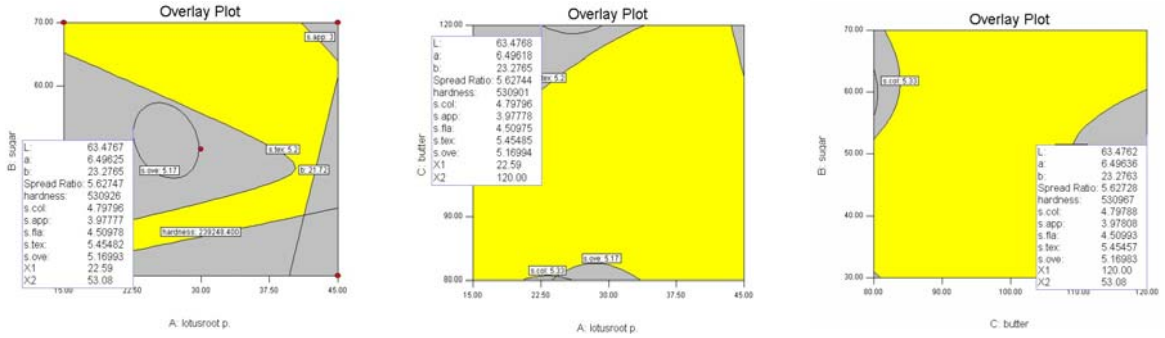
Optimization

The optimal amounts of lotus root powder, sugar and butter were selected through numerical optimization of a canonical model and through graphical optimization. All the significant items shown in the sensory evaluation were determined by their maxima, from which the response formula determined by the modeling acquired was utilized, and the numerical point was selected through numerical optimization (Fig. 7) and graphical optimization (Fig. 8). The optimal point with the highest desirability was deduced through point prediction, and



Lotus root powder (A)×Sugar (B) Lotus root powder (A)×Butter (C) Sugar (B)×Butter (C)

Fig. 7. Response surface plots for optimizing the mixture on desirability of lotus root cookies.



Lotus root powder (A)×Sugar (B) Lotus root powder (A)×Butter (C) Sugar (B)×Butter (C)

Fig. 8. Overlay plot of the common area for the optimization mixture of lotus root cookies.

the predicted optimal values were 22.59 g of lotus root powder, 53.08 g of sugar and 120 g of butter.

CONCLUSIONS

Central Composite Design was used for the purpose of optimizing the manufacturing conditions for lotus root powder cookies. The compositional and functional properties were measured, and these values were applied to a mathematical model. A canonical form and perturbation plot showed the influence of each ingredient on the final mixture product. The sensory evaluation results showed significant values in color ($p<0.01$), texture ($p<0.05$) and overall quality ($p<0.05$). As a result, the optimal sensory ratio was determined to be 22.59 g of lotus root power, and 53.08 g of sugar for every 120 g of butter.

Through the results of this study, lotus root cookies were considered to be competitive in functionality, quality and preference. Optimization to determine the mixing ratios to satisfy consumer's preferences and their evaluation will be the subject of further research needed.

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(Received May 30, 2008; Accepted December 16, 2008)