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Effects of Onion Powder and Baking Temperature on the Physicochemical Properties of Cookies

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Abstract

Response surface methodology (RSM) was used for the optimization of the baking process of cookies made with onion powders (onion cookie). Experiments were carried out according to a central composite design, selecting onion powder content (1.15～8.86%) and baking temperature (155.9～184.1°C) as independent variables and pH, titratable acidity, moisture content, density, spread factor, CIE color parameters (*L-, *a**-, and *b**-values), and hardness as response variables. pH decreased with increasing amount of onion powder and baking temperature. Moisture content also decreased as the baking temperature increased. *L**- and *b**-values decreased but *a**-values increased with increasing onion content and baking temperature. Most polynomial models developed by RSM were highly effective to describe the relationships between the studied factors and the responses. Overall optimization, conducted by overlaying the contour plots under investigation, was able to point out the optimal range of the independent variables within which the six responses were simultaneously optimized. The point chosen as representative of this optimal region corresponded to 4.01% onion powder content and 161.84°C baking temperature. The predicted dependent or response values in the optimal region were: pH＝6.87, moisture content＝2.77%, *L**-value＝68.45, *a**-value＝1.98, *b**-value＝34.64, and spread factor＝9.41.**

Key words: cookie, onion powder, optimization, response surface methodology

INTRODUCTION

Onion (*Allium cepa* L.) is considered to be one of the most important and widely consumed crops in many countries (1-3) and its production ranked third in the world among seven major vegetables, namely onion, garlic, cauliflower, green peas, cabbage, tomato, and green beans (3). Onion has long been used as both spice and food during processing and cooking because of its distinctive flavor and taste (4,5).

Flavonoids, particularly quercetin derivatives, have received special attention as dietary constituents due to their possible role in preventing cardiovascular diseases and cancer. Onion contains very high level of flavonids, especially quercetin and its glycosides (1). Onion ranked highest in quercetin content in a survey of 28 vegetables and nine fruits (6). These flavonoids showed antibacterial (1), antioxidative (7), anti-inflammatory (8), and antiangiogenic (9) effects, and they were believed to prevent or delay cancer and cardiovascular disease (10,11). These activities seem to be related to the free radical scavenging antioxidant activity (12).

Onion usage in both fresh and dried forms is widespread and dried onions in the form of flakes or powder are in extensive demand in world trade (13). Onion is used in a wide range of food formulations as flavor additives. With the functional properties of onion known, researchers have attempted to develop new types of processed foods containing onion, such as white bread (14), strawberry jam (15), extruded snack (16), sponge cake (17), and *kochujang* (18) to name a few.

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

MATERIALS AND METHODS

Preparation of raw materials

Fresh onions, harvested in June 2006, were obtained from Daelim Farm of Changnyeong-Gun, Gyeongnam, Korea. The soft wheat flour (ranked 1st; CJ Corp., Seoul,

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Korea), granulated sugar (CJ Corp., Incheon, Korea), butter (Seoul Milk Corp., Yongin, Gyeonggi, Korea), baking powder (Samjin Foods Co., Ltd., Jincheon, Chungbuk, Korea), salt (Hanju Co., Ltd., Ulsan, Korea), and eggs were procured from a local market and stored at room temperature before use. One hundred grams of the soft wheat flour contained 77 g of carbohydrates, 5 g of protein, 1.5 g of lipids, and 10 mg of sodium.

Prewashed onions were shredded using a food processor (model RVSA, Whirlpool Corp., St. Joseph, Michigan, USA) with a rotary slicer attachment, dried at room temperature for 2 hours, then lyophilized using a freeze dryer (FDU-1100, Tokyo Rikakikai Co., Japan) at a vacuum pressure of 8.5 Pa after being frozen at -50°C for 48 hours in a deep freezer (VLT 1450-3-D-14, Thermo Electron Corp., Asheville, NC, USA). Dehydrated onions were milled using an analytical mill (DA-282, Daesung Artlon Co., Ltd., Paju, Gyeonggi, Korea) at maximum speed for 90 s and sieved to yield particle sizes less than 297 μm (50 mesh). Onion powders were placed in a desiccator containing saturated LiCl solution prior to cookie making which took within a day.

Cookie preparation and baking

Ingredients were mixed in a Kitchen Aid mixer (model 5K5SS, Whirlpool Corp., St. Joseph, MI, USA) using a flat beater attachment as described in AACC method 10-52 (19) by substituting 1.145～8.855% (based on the total weight of the soft wheat flour and onion powder mixture) of onion powder according to the formulation given in Table 1. The dough was aged for 20 min in a -4°C freezer and then sheeted to a thickness of 0.5 cm with the help of a rolling pin. The cookies were cut with a cookie die of diameter 4.5 cm and transferred to a lightly greased baking tray. The cookies were baked at 155.85°C～184.14°C for 14 min in a multi-functional convection oven (model GOR-704C, TongYang Magic Corp., Seoul, Korea). The baked cookies were cooled to room temperature for 1 hr and packed in airtight bags. The levels of the independent variables used in the baking experiments were fixed by a central composite experimental design (Table 2).

pH and titratable acidity measurement

A total of 5 g of onion cookie was blended with distilled water (cookie : water = 1:9, w/w) for 1 min. The pH of the sample was determined using a PHM210 Standard pH meter (Radiometer Analytical, Lyon, France). The same sample was used to measure titratable acidity: the amount of 0.1 N NaOH solution to titrate the sample beyond pH 8.3. The results were calculated as a percentage of malic acid [(mL NaOH×0.1 N / weight of sample titrated)×0.067×100] (20). All measurements were done in triplicate.

Moisture analysis and density measurement

Moisture content of the baked cookies was determined using a convection oven at 105°C overnight. Density of the cookies was measured by the rapeseed displacement method as described by AACC. The reported values were means of three separate cookies.

Spread factor measurement

The spread factor was measured according to AACC 10-52 (19) and it was calculated as follows:

$$\text{Spread factor} = \frac{\text{Average diameter of cookies (mm)}}{\text{Average height of 6 cookies (mm)}} \times 10$$

Table 1. Formulation of cookie on substitution of onion powder for flour

Ingredients (g)	Sample				
	1.145%	2.5%	5.0%	7.5%	8.855%
Soft wheat flour	296.56	292.50	285.00	277.50	273.43
Onion powder	3.44	7.50	15.00	22.50	26.57
Granulated sugar	135	135	135	135	135
Butter	180	180	180	180	180
Baking powder	7.5	7.5	7.5	7.5	7.5
Salt	0.3	0.3	0.3	0.3	0.3
Egg	30	30	30	30	30
Total	652.8	652.8	652.8	652.8	652.8

Table 2. Independent variables and their levels in the central composite design

Independent variables	Unit	Symbol	Coded levels				
			$-\sqrt{2}$	-1	0	1	$\sqrt{2}$
Onion powder	%	x_1	1.145	2.5	5	7.5	8.855
Baking temperature	°C	x_2	155.85	160	170	180	184.14

Color and texture analysis

CIE color characteristics (L^*, a^*, and b^*) of baked cookies were determined using a Chromameter (model CR-200, Minolta Co., Osaka, Japan) calibrated with a calibration plate using $Y=94.2$, $x=0.3131$, and $y=0.3201$. The Chromameter used xenon pulse-diffused illumination (D65 illuminant) with three response detectors set at 0^o viewing angle. In addition, the machine was preset to use the 2^o observer. Color was measured at the same location (one in center and 3 measurements at the edges) using three baked cookies for each treatment and mean values were reported.

Ten cookies were evaluated measuring the peak breaking force (N) using the three-point break (triple beam snap) technique with a computer-controlled Advanced Universal Testing System (model LRX*Plus*, Lloyd Instrument Ltd., Fareham, Hampshire, UK) at room temperature. The crosshead speed was 1 mm/s and span between the two platforms was 40 mm.

Experimental design

The experimental design was a central composite design with two factors and five levels. In this experimental design, there were five coded factor levels: $-\sqrt{2}$, -1, 0, 1, and $\sqrt{2}$. The factor and respective coded and uncoded levels are given in Table 2. The effect of two independent responses (Y) was modeled using a polynomial response surface. Table 3 shows the actual design of experiments which contain 12 randomized experimental runs, including four replicates at the center point for evaluating the experimental error and the suitability of the mathematical model. The second-order response function for the experiments was predicted by the following equation:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2$$

where β_0 is the value of the fixed response at the central point of the experiment which is the point (0,0); β_1 and β_2 are linear; β_{11} and β_{22} are quadratic, and β_{12} is interaction coefficient, respectively.

Statistical analysis

Statistical analysis of variance (ANOVA) and multiple regression were performed suing the Design-Expert v.7.0 software (21) 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

Statistical analysis on model fitting

The independent and dependent variables were fitted to the second-order model equation and examined for the goodness of fit. Regression analysis and ANOVA were conducted for the model to examine the statistical significance of the model terms. ANOVA of the effect of onion powder substitution and baking temperature for preparing cookies as linear, quadratic, and interaction terms on the response variables are shown in Table 4. The results indicated that the model for pH, moisture content, spread factor, CIE L^*-, a^*-, and b^*-values is highly adequate with their satisfactory levels of R^2 (0.85∼0.94) and model significance. It has been suggested that the model with R^2 greater than 0.8 indicate a good fit (22).

The density and hardness results showed low coefficients of determination R^2 (57% and 76%, respectively) and the two models were not significant ($p>0.05$). This could be due to the range studied in this study. The models may not truly represent the data; thus, the models with significance at 5% level were included

Table 3. The observed responses in the central composite experimental design on onion powder cookies

Independent variables		Responses								
Onion powder (coded)	Baking temperature (coded)	pH	Acidity (g acid/ 100 g)	Moisture content (%, d.b.)	Density (g/mL)	Spread factor	Color			Texture
							L^*-value	a^*-value	b^*-value	Hardness (N)
0	-1.41	6.93	164.49	2.91	1.46	8.76	61.80	6.04	35.45	29.48
-1	1	6.91	140.42	1.85	1.28	7.91	66.28	2.15	34.22	40.76
0	0	6.76	156.47	2.69	1.43	9.60	60.45	5.63	34.21	30.79
1.41	0	6.71	373.12	2.21	1.49	8.36	48.99	10.90	29.78	34.71
0	0	6.66	160.48	2.60	1.38	9.33	61.65	5.15	33.95	33.74
1	1	6.68	180.54	1.70	1.27	8.44	43.15	10.80	24.57	48.84
0	1.41	6.47	186.56	1.27	1.29	7.79	41.66	10.08	22.08	41.38
-1	-1	7.03	138.41	2.40	1.38	9.32	75.43	-4.21	32.24	28.38
1	-1	7.03	176.53	2.51	1.37	8.73	61.10	7.01	35.94	36.45
0	0	6.69	158.47	2.72	1.33	9.52	61.83	4.94	34.04	35.33
-1.41	0	6.99	126.38	1.51	1.15	7.97	71.79	-0.49	33.35	37.82
0	0	6.71	158.47	2.82	1.31	9.34	57.87	6.57	33.08	33.49

Table 4. Analysis of variance on the independent variables as linear, quadratic and interaction terms on the response variables

Source	df	Sequential sum of squares								
		pH	Acidity (g acid /100 g)	Moisture (%)	Density (g/mL)	Spread factor	Color			Texture
							L*-value	a*-value	b*-value	Hardness (N)
Regression	5	0.2985*	0.7613	3.0408**	0.0544	4.5452**	1095.1850**	203.3074**	189.5462**	274.6415
Linear	2	0.2102**	0.5755	1.8027**	0.0502	0.9539*	993.2943***	193.2824***	115.1841**	233.6400*
Square	2	0.0759	0.1858	1.2205**	0.0042	3.0865***	82.5196	8.3674	29.7619*	41.0015
Interaction	1	0.0125	0.0001	0.0176	0.0001	0.5048*	19.3710	1.6577	44.6001**	0.0001
Residual error	6	0.0510	0.3709	0.3102	0.0407	0.3393	72.5291	20.3082	17.1415	86.5646
Lack-of-fit	3	0.0464*	0.3708***	0.2860*	0.0327	0.2862	62.5151	18.7353*	16.3676*	75.9338
Pure error	3	0.0046	0.0001	0.0242	0.0080	0.0531	10.0140	1.5728	0.7739	10.6308
Total	11	0.3495	0.8123	3.3510	0.0951	4.8845	1167.7141	223.6156	206.6877	361.2061
R-Sq (%)		0.85	0.67	0.91	0.57	0.93	0.94	0.91	0.92	0.76

***Significant at $p \leq 0.001$, **Significant at $p \leq 0.01$, *Significant at $p \leq 0.05$.

in discussion.

Effects on pH

Minimum pH (6.47) was found with an onion powder content of 5% and baking temperature of 184.14°C while maximum pH (7.03) was recorded at an onion powder content of 2.5% and 7.5% and baking temperature of 160°C (Table 3). Titratable acidity ranged from 126.38∼373.12 g acid/100 g. It can be observed from ANOVA that substitution of onion powder and baking time were significant factors (at 95% confidence level) for pH (Table 4). The regression model explained 85% of the total variability in pH of onion cookies. From Table 5, it may be observed that baking temperature had a linear negative effect on pH. Cookies containing a higher amount of onion powder had a lower pH (Fig. 1a). It is probably due to the low pH of onion power itself, which is 5.25. Similar reduction results with the substitution of onion powder were reported for wheat flour dough (23) and the substitution of ethanol-extract of onion on fried fish paste (24). Maximum (6.93) and mini-

Table 5. Regression coefficients of the second-order polynomial for the response variables

Coefficients	pH	Acidity (g acid/100 g)	Moisture (%)	Density (g/mL)	Spread factor	Color			Texture
						L^{*}-value	a^{*}-value	b^{*}-value	Hardness (N)
β_0	6.7042***	155.4725***	2.7060***	1.3604***	9.4465***	60.4504***	5.5721***	33.8196***	33.3381***
β_1	-0.0780	53.3979*	0.1172	0.0578	0.0231	-8.7124***	4.4972***	-1.3750	1.4690
β_2	-0.1421**	4.6540	-0.4601**	-0.0541	-0.3445**	-6.9466**	1.9839*	-3.5367***	5.2007**
β_{11}	0.1083*	32.2231	-0.3875**	-0.0251	-0.5648***	1.3282	-0.8576	-0.7332	2.1526
β_{22}	-0.0558	-4.8894	-0.2748*	0.0001	-0.5088**	-3.0031	0.5695	-2.1337*	1.7351
β_{12}	0.0325	0.5000	-0.0663	-0.0009	0.3553*	-2.2001	-0.6438	-3.3392**	0.0032

***Significant at $p \leq 0.001$, **Significant at $p \leq 0.01$, *Significant at $p \leq 0.05$.

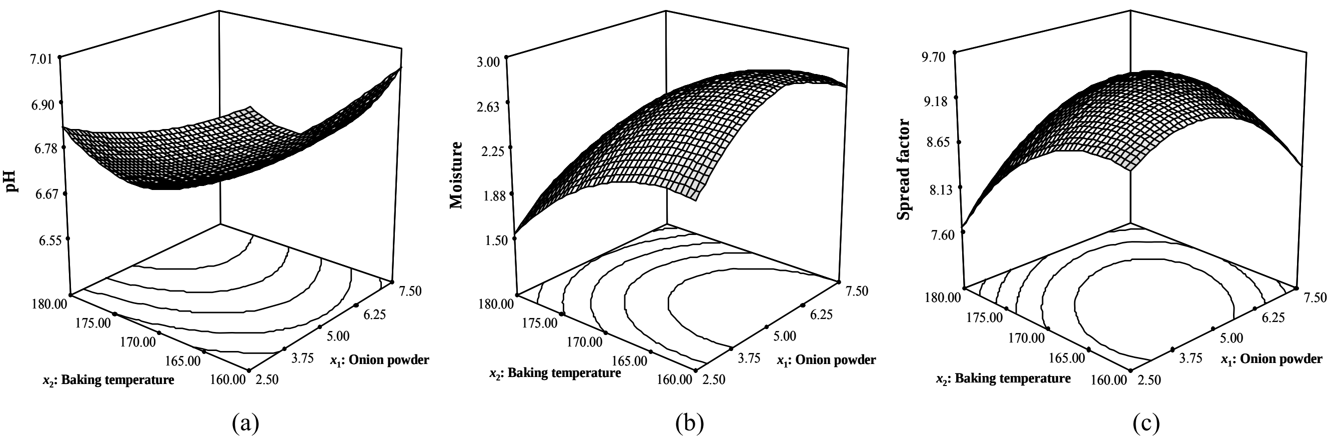


Fig. 1. The contour plots of cookies as affected by onion powder and baking temperature: (a) pH, (b) moisture content, and (c) spread factor.

mum (6.63) values of pH were observed at onion powder content = 2.50 ~ 3.46% / baking temperature = 160.0 ~ 165.7°C and onion powder content = 4.45 ~ 7.75% / baking temperature = 175.9 ~ 180.0°C (Fig. 1a), respectively.

Effects on moisture content

Moisture content was affected significantly by the variables from which the cookies were formulated but density was not (Table 4). Minimum moisture content (1.27%, d.b.) occurred with an onion powder content of 5% and baking temperature of 184.14°C while maximum moisture content (2.91%, d.b.) was recorded at an onion powder content of 5% and baking temperature of 155.85°C (Table 3). Minimum (1.76%, d.b.) and maximum (2.69%, d.b.) values of moisture content were observed at onion powder content = 2.50 ~ 3.34% / baking temperature = 177.3 ~ 180.0°C and onion powder content = 3.69 ~ 7.50% / baking temperature = 160.0 ~ 170.6°C (Fig. 1b), respectively.

ANOVA revealed that onion powder content and baking temperature are significant parameters linearly affecting moisture content ($p<0.05$), quadratic term of baking temperature ($p<0.05$) and quadratic term of onion content ($p<0.01$). The positive coefficient of the first order term of onion powder content (Table 5) indicated that moisture content increased with increase in onion powder content. The regression model explained 91% of the total variability ($p<0.01$) in moisture content of onion cookies. Moisture content of the cookies increased as the concentration of onion powder increased, but the change was not significant when baking temperature was high, indicating an interaction effect between the variables (Fig. 1b).

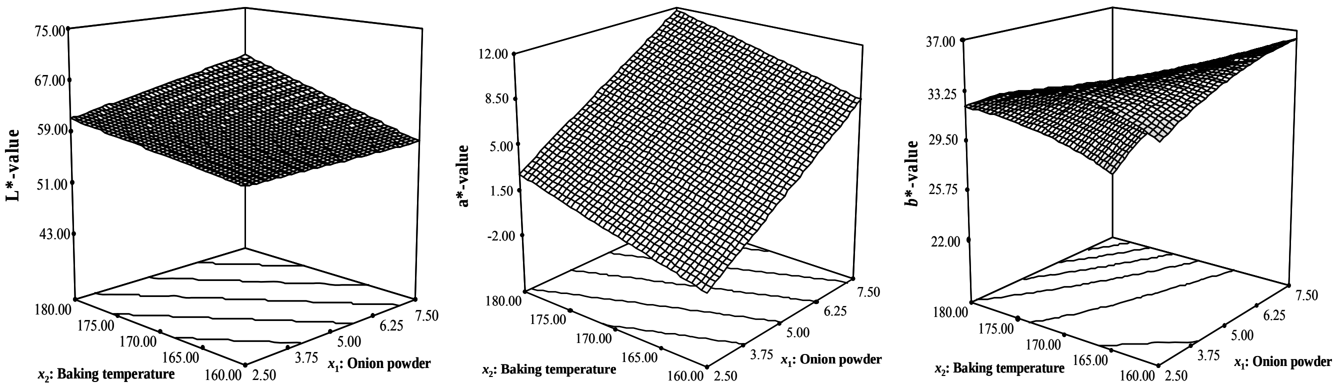
Effects on spread factor

Minimum spread factor (7.79) was found to be at an onion powder content of 5% and baking temperature of 184.14°C (Table 3). Spread factor was affected by the process conditions and baking temperature had a negative linear effect which was significant at $p<0.01$. As the baking temperature increased, spread factor decreased significantly. Minimum (7.96) and maximum (9.20) values of spread factor were observed at onion powder content = 2.50 ~ 3.05% / baking temperature = 178.1 ~ 180.0°C and onion powder content = 3.05 ~ 5.49% / baking temperature = 160.0 ~ 174.5°C (Fig. 1c), respectively.

Onion substitution increases the nutritional value of cookie, but at the same time it usually alters the rheological properties of dough and, thus the quality of the cookie. The reduction in cookie diameter, which affects the spread factor directly, is dependent on the amount of gluten in the blend. Singh and Mohamed (25) reported that the spread factor was decreased with increased protein in the cookies. Replacement of soft wheat flour with onion powder therefore resulted in cookies with higher spread factor. The spread factor was also influenced by dough rheological properties and moisture content. Han et al. (26) reported that the spread factor of the functional cookies made with potato peel increased with the amount of potato peel in the blend, probably due to the increased moisture content. This finding was in accordance with the present study. In addition, Ko and Joo (27) reported that substitution of Jinuni bean powder increased the cookie spread factor and suggested that the replacement might have interfered gluten formation in the sample. A similar increase in the spread factor of cookies made with black rice flour was also reported (28).

Effect on color

The effects of onion power and baking time on cookie color and texture are also given in Table 3. The values of L^*, a^*, and b^* were in the ranges of 41.66 ~ 75.43,



(a) (b) (c)

Fig. 2. The contour plots of cookies as affected by onion powder and baking temperature: (a) L^*-, (b) a^*-, and (c) b^*-values.

-4.21～10.90, and 22.08～35.94, respectively.

As shown in Table 5, the L^*-values of onion cookies were significantly affected by the first-order (linear) term of x_1 ($p<0.001$) and x_2 ($p<0.01$). The contour plot in Fig. 2a indicated significant decreases in L^*-values with increasing amount of onion powder. Similar findings were reported for onion extract-substituted fried fish paste (24) and white bread with onion powder substituted for flour (23). The substitution of onion powder increased the total sugar content, which may have resulted cookies with lower L^*-values after baking.

The a^*-values of cookie were significantly ($p<0.001$) affected by the first-order (linear) term of x_1 while their b^*-values were significantly ($p<0.001$) affected by linear term of x_2. The a^*-values of cookie increased as the concentration of onion powder and baking temperature increased (Fig. 2b). The b^*-values of cookie decreased with increasing amount of onion powder and baking temperature (Fig. 2c). Similar increases in a^*-values were also reported for onion powder (or extract) substituted for ingredients in wheat flour dough (23), fried fish paste (24), and white bread (23).

Optimization

Numerical and graphical optimizations were carried out for the process parameters for cookie baking. The desired goals for each variable and response were chosen as summarized in Table 6. Table 6 also shows software-generated optimum conditions of independent variables with the predicted values of responses, at onion powder content = 4.01% and baking temperature = 161.84°C for achieving the highest value of pH = 6.87, moisture content = 2.77%, spread factor = 9.41, L^*-value = 68.45, a^*-value = 1.98, and b^*-value = 34.64.

From the set of constraints and outputs given in Table 6, contour plots of relevant and statistically significant responses were generated and the overlaying plots are

Table 6. Criteria and outputs of the numerical optimization of the all the responses affected by onion powder and baking temperature

Criteria	Goal	Limit
x_1: Onion powder (%)	In the range	2.50～7.50
x_2: Baking temperature (°C)	In the range	160～180
Y_1: pH	In the range	6.47～7.03
Y_2: Moisture (%)	Maximize	2.40～2.91
Y_3: Spread factor	Maximize	9.30～9.60
Y_4: L^*-value	Maximize	67.00～75.43
Y_5: a^*-value	Maximize	0.00～10.90
Y_6: b^*-value	Maximize	32.00～35.94

Outputs

No.	x_1	x_2	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
1	4.01	161.84	6.87	2.77	9.41	68.45	1.98	34.64

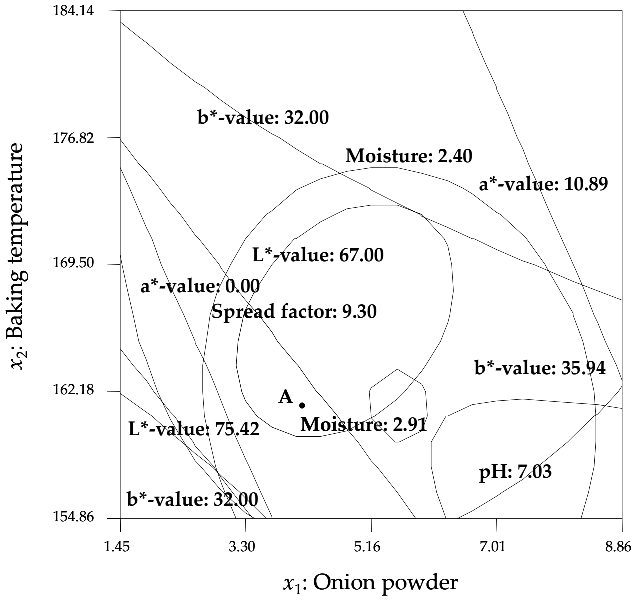


Fig. 3. Superimposed contour plot for significant responses as affected by onion powder and baking temperature.

displayed in Fig. 3. The shaded area in Fig. 3 represents the x_1-x_2 domain satisfying the imposed criteria. Thus, optimum baking conditions can be drawn from this delimited area to achieve a specific goal. For example, point A in Fig. 3 determines the following criteria and goals: onion powder content = 4.01%, baking temperature = 161.84°C, pH = 6.87, moisture content = 2.77%, spread factor = 9.41, L^*-value = 68.45, a^*-value = 1.98, and b^*-value = 34.64.

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