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Optimization of Formula of Matsutake Highland Barley Biscuit by Response Surface Methodology

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Abstract Taking refined flour, matsutake powder, and highland barley powder as main raw materials, this experiment studied the optimal formula of matsutake highland barley biscuit. Besides, single factor experiment was carried out for the amount of highland barley powder, white granulated sugar, and shortening. Then, the response surface optimization analysis was made on crispness and sensory score of the biscuit. The experiment indicates that taking the refined flour as the base 100 g (100%), the formula of 20% highland barley powder, 25% white granulated sugar, and 26% shortening can bake crisp biscuit with complete shape, pure flavor and high quality.

Key words Response surface optimization, Matsutake, Highland barley, Biscuit

1 Introduction

Matsutake, also known as matsutake mushroom, belongs to basidiomycete, has fat and fresh pulp, and fragrant flavor, fresh meat, as well as high food value and medicinal value. According to the relevant literature, matsutake can strengthen the body and improve the health, is helpful for stomach and kidney, and eliminating the phlegm, can be used for curing the diabetes and inhibit the proliferation of cancer cells, thus is reputed as the king of mushroom[1]. Matsutake also contains many beneficial chemicals, such as polysaccharides, steroids, saponins, anthraquinones, terpene ester compounds, phenols, tannins, alkaloids, coumarins, fats, triterpenes, sterols, eight kinds of amino acids and vitamins[2].

The highland barley is staple food of Tibetan plateau people[3]. Its content of β-glucan[4] ranks first in the barley of the world. It has reasonable nutritional structure beneficial for human health and longevity and the feature of "three highs and two lows"[5], namely, high protein content, high soluble fiber content, high vitamin content, and low fat and low sugar. Besides, the highland barley is rich in selenium[6], has high nutritional and therapeutic value. Selenium deficiency may lead to many kinds of diseases[7], so highland barley is a best choice of cereal crops for most people. Highland barley food is favored by the broad masses and can solve the problem of deficiency of nutrition. In addition, highland barley also contains tocol, dietary fiber, and sugar.

Response Surface Methodology (RSM) explores the relationships between several explanatory variables and one or more response variables, is used to determine the influence of interaction of various factors on dependent variables[8], precisely express the relationship between factors and response value, including the experimental design, model establishment, test of model fitting, and seeking the optimal conditions. Through conducting the regression fitting[10], response surface optimization, and plotting of contour chart for the functional relation between factors and response values using the multivariate quadratic equation, it is convenient to calculate the optimal response value of each factor level. Thus, it is an effective approach of reducing the production and development costs, optimizing the characteristics of processing conditions, improving the quality of production technology, and solving the problems in the process of production.

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2 Materials and methods

2.1 Materials and equipment Refined flour (Shandong Luwang Group); highland barley powder (local highland barley in Tibet, fried, ground to powder); matsutake powder (local matsutake ground to powder); white granulated sugar (Guangzhou Huaqiao Sugar Factory); shortening (Tianjin Namchow Oil & Fat Co., Ltd.); vegetable oil (Yihai (Shijiazhuang) Grain and Oil Industrial Co., Ltd.); skimmed milk power (Nouriz (Shanghai) Fine Food Co., Ltd.); sodium bicarbonate (Shanghai Qiaochu Trade and Business Co., Ltd.); TBHQ (Guangdong Food Industry Research Institute); HPMC (Henan Siyuan Biotechnology Co., Ltd.); baking oven (Beowulf BO-K45R); mould (Kayuan Household Article Monopolized Store); Texture Analyzer (SMSTA.XTPlus).

2.2 Basic formula Refined flour 100 g, highland powder 20 g, matsutake powder 10 g, white granulated sugar 25 g, skimmed milk power 10 g, and sodium bicarbonate 1 g.

2.3 Technological process Raw material premixing → dough preparation → placing → rolling → arranging and shaping → baking → cooling → arranging → inspection → packaging → finished product.

2.4 Experiment methods

2.4.1 Raw material processing. Pretreatment of raw materials according to the experimental requirements.

2.4.2 Dough preparation. Mixing the refined flour, matsutake

powder, and highland powder, adding the vegetable oil, TBHQ, HPMC, and adding other raw materials in sequence.

2.4.3 Placing. Placing 30 min.

2.4.4 Arranging and shaping. Pressing the biscuit mould onto the pastry with uniform force.

2.4.5 Baking. Baking at low temperature for a long time, and then baking at 150 ℃ to 180 ℃ for 15 min to 20 min.

2.4.6 Cooling. Placing the baked biscuit in the pancake tray and letting it cool down naturally.

2.5 Experiment design

2.5.1 Single factor experiment. Taking the refined flour as the base (the mass fraction is 100%), the amount of other raw materials in the basic formula is not changed. The amount of highland barley powder was 15%, 20%, 35%, and 30%; the amount of white granulated sugar was 18%, 24%, 30%, and 36%; the amount of shortening was 16%, 22%, 28%, and 34%. We evaluated the effects of these three factors on the crispness and sensory score of the matsutake highland barley biscuit.

2.5.2 Sensory evaluation. The evaluation team consisted of ten professional food technicians. The sensory evaluation was scored in accordance with relevant evaluation standard. The full score was 100 points, and the average value was taken as the final score[11-12]. Specific evaluation indicators were listed in Table 1.

Table 1 Sensory evaluation of the biscuit

Sensory evaluation	Good	General	Poor
Tissue (15 points)	12 – 15	9 – 11	<9
	The internal structure was dense and uniform, neat appearance, clear levels, free of impurities	Few big holes, clear levels, coarse tissue, few stains	Stiff texture, many impurities, moldy and rotten
Taste (30 points)	26 – 30	21 – 25	<21
	Crisp, tasty, pure, not tooth sticking	Soft, slightly tooth sticking, or slightly soft	Slightly hard and astringent, tooth sticking, rancid flavor
Appearance (15 points)	12 – 15	9 – 11	<9
	Complete appearance, uniform thickness, not shrank, not deformed, not blistered	Biscuit appearance not level, slightly broken	Small blistered on the surface, seriously broken
Odor (20 points)	17 – 20	12 – 16	<12
	Strong fragrance, no smell	Slight fragrance	Slight fragrance and slight smell
Color and luster (20 points)	17 – 20	12 – 16	<12
	Brown or golden yellow, basically uniform color and luster	Color and luster not uniform, slight caramel color	Color and luster not uniform, yellowish brown, too white

2.5.3 Response surface test. Based on the results of the single factor experiment, we adopted central composite test Box-Behnken design. The amount of highland powder, white granulated sugar, and shortening was denoted with A, B, and C respectively, and the variable level was expressed as 1, 0, and −1. The sensory score considered the influence of single factor highland barley powder, white granulated sugar, and shortening. Taking the highland barley powder, white granulated sugar, and shortening as independent variables, and sensory score and crispness of the matsutake highland barley biscuit as response values, we designed the response surface analysis experiment with three factors, three levels, and 17 experimental points[14], the experimental factors and levels were shown in Table 2.

Table 2 Levels and cords of response surface experiment factors

Level	Factor		
	A	B	C
	Amount of highland barley powder//g	Amount of white granulated sugar//g	Amount of shortening//g
−1	15	18	16
0	20	24	25
1	25	30	34

2.5.4 Determination of texture characteristics. We used the texture analyzer was used. TPA mode was used, and the parameter was probe P50.

3 Results and analyses

3.1 Single factor experiment

3.1.1 Effect of the amount of highland barley powder on the biscuit quality. From Table 3, it can be known that the results of the single factor experiment of the amount of highland barley powder. With the gradual increase in the highland barley powder, the crispness of the biscuit gradually became stronger. However, when too much highland barley powder was added, the dough was hard to be shaped and the baked biscuits were too crisp and not easy to be shaped. In addition, the effect of amount of highland barley powder on the biscuit sensory quality was mainly reflected in the color and flavor, the color was light yellow. When the amount of highland barley powder was too low, the taste of highland barley powder was light and the original characteristics of biscuit got lost; when the amount of highland barley powder was 20%, the biscuit was bright colored and the taste was strong.

3.1.2 Effect of the amount of white granulated sugar on the biscuit quality. From Table 4, we can see the results of single factor experiment amount of white granulated sugar. The amount of white granulated sugar had certain effect on all aspects of the biscuit. When the amount of white granulated sugar was 18%, the biscuits were slightly sweet, or even not sweet, and the chewiness and crispness were

insufficient. When the amount of white granulated sugar was 24%, the biscuit sweetness was moderate, and both the chewiness and crispness reached the maximum value. When the amount of white granulated sugar was 30%, the biscuit was too sweet. There were cracks and blisters on biscuit surface. Besides, the caramelization during baking deepened the color of the biscuits and made the appearance of the biscuits not pleasing to the eye. Thus, the most appropriate amount of white granulated sugar was 24%.

Table 3 Effect of the amount of highland barley powder on sensory score and crispness of biscuit

Amount of highland barley powder//%	15	20	25	30
Sensory description	Biscuits easy to shrink, large shape change	Clear cross section levels	Slight taste of highland barley, small holes on cross section	Regular appearance, very clear cross section levels
Sensory score//points	82	90	86	83
Crispness	29980.2	44389.8	37895.5	39645.4

Table 4 Effect of the amount of white granulated sugar on sensory score and crispness of biscuit

Amount of white granulated sugar//%	18	24	30	36
Sensory description	Not sweet, but clear cross section	Moderately sweet, sufficient flavor of matsutake highland barley	White sugar flowing out, too sweet	Easy caramelized, too sweet
Sensory score//points	83	89	84	82
Crispness	32176.3	44509.8	32451.5	39341.2

3.1.3 Effect of the amount of shortening on the biscuit quality. Table 5 showed the results of single factor experiment amount of shortening. When the amount of shortening was 16%, the dough was dry during preparation. After baking, cracks appeared on the biscuit surface. When the amount of shortening was 28%, biscuit surface was smooth, shape was excellent, and the biscuit quality reached the optimal level. When the amount of shortening was 34%, the taste of oil was deep and exceeded the original flavor of biscuit. Thus, the most appropriate amount of shortening was 28%.

Table 5 Effect of the amount of shortening on sensory score and crispness of biscuit

Amount of shortening//%	16	22	28	34
Sensory description	Biscuit surface dry, many cracks	Slightly crisp, slightly rough	Crisp, regular appearance, no crack	No blister, deep oil taste
Sensory score//points	84	86	90	83
Crispness	33567.1	39816.9	45213.8	40014.6

3.2 Analysis of response surface test results

3.2.1 Box-Behnken design scheme. On the basis of the single factor analysis, according to Box-Behnken design (BBD) scheme, we carried out three-factor three-level response surface analysis experiment and the experimental results were shown in Table 6.

Table 6 Design and results of Box-behnken experiment

Experiment No.	A	B	C	Sensory score//points	Crispness
1	1	0	−1	86.4	25046.3
2	0	−1	−1	86.1	34301.3
3	0	0	0	90.2	44788.7
4	1	0	1	87.3	28161.6
5	−1	0	−1	81.0	26091.7
6	0	0	0	90.0	46425.9
7	0	−1	1	83.5	21388.5
8	0	0	0	90.0	44087.9
9	−1	0	1	83.4	33310.6
10	0	0	0	91.0	46207.3
11	1	1	0	87.6	19242.6
12	−1	1	0	85.1	34552.5
13	0	0	0	90.4	45046.6
14	1	−1	0	86.4	31553.9
15	−1	−1	0	81.2	24164.5
16	0	1	−1	85.5	28161.2
17	0	1	1	88.2	37664.4

3.2.2 Model establishment and significance test. Using the BBD response surface analysis method, we carried out the variance analysis on the model fitted by experimental results, and the analysis results were shown in Table 7 and Table 8.

It can be seen from Table 7 that the F value of the RSM stereoscopic model was 50.16, $P < 0.0001$, indicating that this model was significant. The lack of fitting F value was 3.34 and P value was $0.1371 > 0.05$, the difference was not significant, and the degree of fitting of regression equation was good. In this model, $R^2 = 0.9847$, $R^2_{Adj} = 0.9651$, indicating that this model had a good fit with the actual experiment, and the linear relationship between each factor and the response value was significant. The model can be used to predict the sensory score of the matsutake highland barley biscuits, to determine the optimal formula of the biscuit[15].

Taking the sensory score (X) of the matsutake highland barley biscuits as the response value, through regression fitting, the effect of experimental factors on response values can be denoted using the following regression equation:

$$X = 90.32 + 2.13A + 1.15B + 0.43C - 0.68AB - 0.38AC + 1.32BC - 3.27A^2 - 1.97B^2 - 2.52C^2.$$

It can be seen from Table 8 that the F value of the RSM stereoscopic model was 21.98, $P < 0.0001$, indicating that this model was significant. The lack of fitting F value was 14.49 and P value

was 0.083 > 0.05, the difference was not significant, and the degree of fitting of regression equation was good. In this model, R^2 = 0.9660, R^2_{Adj} = 0.9229, indicating that this model had a good fit with the actual experiment, and the linear relationship between each factor and the response value was significant. The model can be used to predict the sensory score of the matsutake highland barley biscuits, to determine the optimal formula of the biscuit.

Taking the crispness (Y) of the matsutake highland barley biscuits as the response value, through regression fitting, the effect of experimental factors on response values can be denoted using the following regression equation:

$$Y = 45311.28 - 1764.36A + 1026.56B + 865.57C - 5674.82AB - 1025.9AC + 5604BC - 10079.6A^2 - 7853.3B^2 - 7079.13C^2.$$

Table 7 Variance analysis results of sensory score-regression equation

Variation source	Square sum	Degree of freedom	Mean square	F value	P value	Significance
Model	155.61	9	17.29	50.16	< 0.0001	* *
A-highland barley powder	36.12	1	36.12	104.80	< 0.0001	* *
B-white granulated sugar	10.58	1	10.58	30.69	0.0009	*
C-shortening	1.45	1	1.45	4.19	0.0005	*
AB	1.82	1	1.82	5.29	0.0550	
AC	0.56	1	0.56	1.63	0.2422	
BC	7.02	1	7.02	20.37	0.0028	
A^2	45.09	1	45.09	130.81	< 0.0001	* *
B^2	16.38	1	16.38	47.52	0.0002	*
C^2	26.79	1	26.79	77.72	< 0.0001	* *
Residual error	2.41	7	0.34	–	–	
Lack of fit	1.72	3	0.57	3.34	0.1371	
Pure error	0.69	4	0.17	–	–	
Total error	158.02	16		R^2 = 0.9847	R^2_{Adj} = 0.9651	

Note: * * denotes extremely significant difference (P < 0.01), and * denotes significant difference (P < 0.05).

Table 8 Variance analysis results of crispness-regression equation

Variation source	Square sum	Degree of freedom	Mean square	F value	P value	Significance
Model	1.30E +09	9	1.44E +08	21.98	0.0003	*
A-highland barley powder	2.49E +07	1	2.49E +07	3.80	< 0.0001	* *
B-white granulated sugar	8.43E +06	1	8.43E +06	1.29	0.0012	*
C-shortening	5.99E +06	1	5.99E +06	0.92	0.0004	*
AB	1.29E +08	1	1.29E +08	19.60	0.0031	
AC	4.21E +06	1	4.21E +06	0.66	0.4500	
BC	1.26E +08	1	1.26E +08	19.23	0.0033	
A^2	4.28E +08	1	4.28E +08	65.11	< 0.0001	* *
B^2	2.60E +08	1	2.60E +08	39.51	0.0004	*
C^2	2.11E +08	1	2.11E +08	32.16	0.0008	*
Residual error	4.61E +07	7	6.58E +06	–	–	
Lack of fit	4.22E +07	3	1.41E +07	14.49	0.083	
Pure error	3.89E +06	4	9.71E +05	–	–	
Total error	1.35E +09	16		R^2 = 0.9660	R^2_{Adj} = 0.9229	

Note: * * denotes extremely significant difference (P < 0.01), and * denotes significant difference (P < 0.05).

3.2.3 Response surface analysis and optimization of matsutake highland barley biscuit. According to regression result analysis in Table 7 and Table 8, we plotted the response surface chart, the response surface chart of sensory score was shown in Fig. 1 to Fig. 3, and the response surface chart of crispness was shown in Fig. 4 to Fig. 6.

These two charts visually reflect the interaction of various factors and show that there are extreme values in this range, namely, the highest point of the response surface, or the center of the minimum ellipse[16].

Through RSM, we obtained the optimal value of 0.957. The optimal formula of matsutake highland barley biscuit was 20% highland barley powder, 25% white granulated sugar, and 26% shortening.

Fig. 1 to Fig. 3 are the response surface charts for interaction of factors taking the sensory score as the response value, while Fig. 4 to Fig. 6 are the response surface charts for interaction of factors taking the crispness as the response value.

4 Conclusions

(i) In the single factor experiment, the optimal formula for crispness and sensory score of matsutake highland barley biscuit is 20% highland barley powder, 24% white granulated sugar, and 28% shortening.

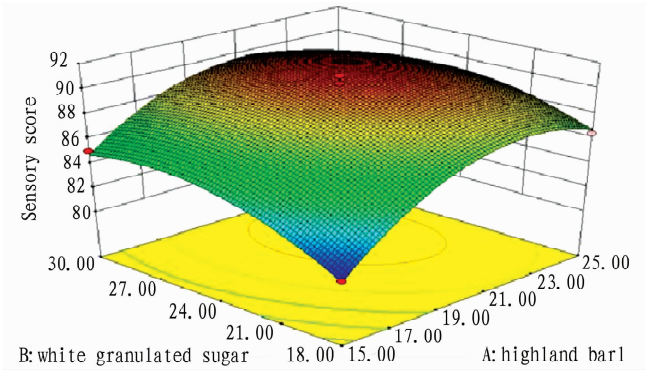

Fig. 1 Response surface of sensory score = (B, A)

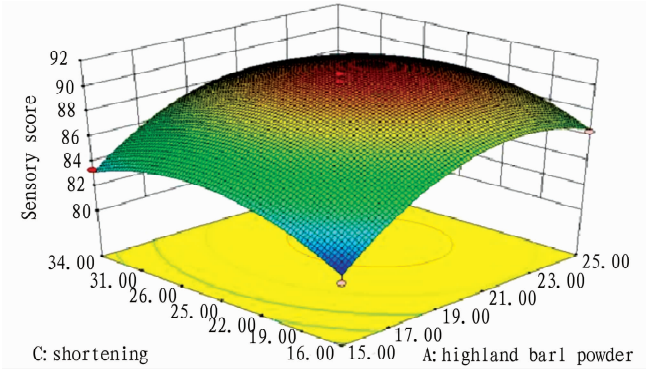

Fig. 2 Response surface of sensory score = (C, A)

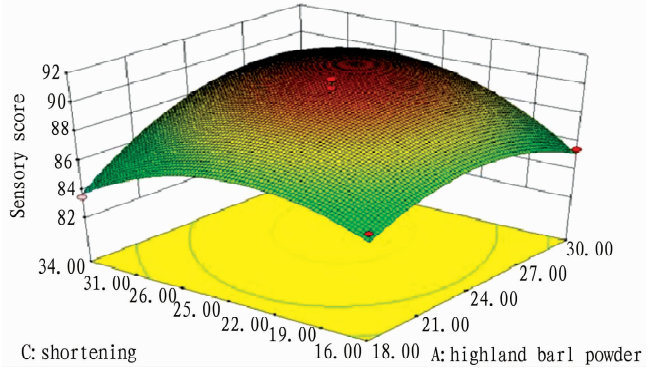

Fig. 3 Response surface of sensory score = (C, B)

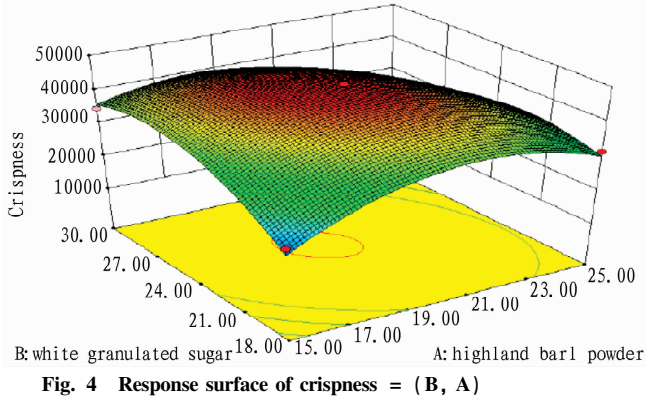

Fig. 4 Response surface of crispness = (B, A)

(ii) Through professional review of the evaluation team, the highest score of the biscuit is 91 points and the lowest score is 81 points. Biscuits can be stored for a long time[13], and are easy to take and store, so they are favored by the broad masses of the people.

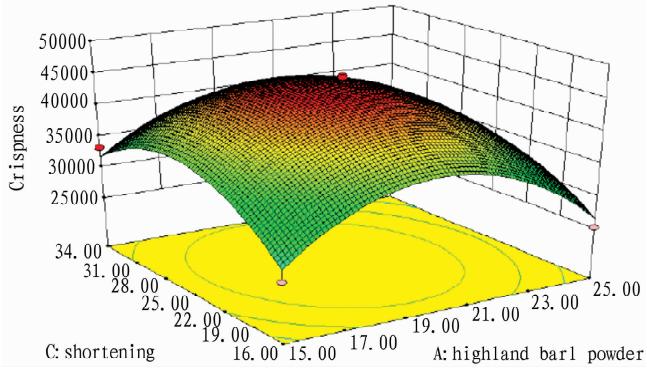

Fig. 5 Response surface of crispness = (C, A)

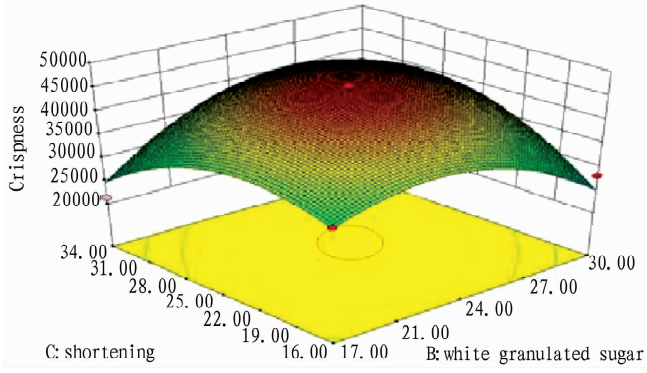

Fig. 6 Response surface of crispness = (C, B)

(iii) On the basis of the response surface analysis, the optimal formula of matsutake highland barley biscuit is as follows: taking 100 g refined flour as the base (the mass fraction is 100%), 20 g highland barley powder (20%), 10 g matsutake powder (10%), 26 g shortening (30%), 1 g sodium bicarbonate (1%), 20 g eggs (20%), 5 mL vegetable oil, 0.25 g TBHQ (0.25%), 25 g white granulated sugar (25%), and 10g whole milk powder (10%). The biscuit is golden yellow, regular appearance, free of oil smell, no peculiar smell or bitter taste. Inside the biscuit, there are small dense holes, the levels are clear. Besides, the taste is excellent, the flavor is pure, and crispness is moderate.

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cooling effect; sunshade + fan + cooling pad has obvious cooling effect, which can well meet the cooling needs in the summer greenhouse.

4.2 Discussions (i) For the northern agricultural greenhouse, the skylight + fan combination is an ideal cooling measure in high-humidity environment, and its cooling effect is even better than that of cooling pad + fan. It can make the indoor and outdoor temperature difference stabilized at 2 ℃ - 3 ℃, the cooling effect lasts long, and the indoor temperature rises slightly.

(ii) In a high temperature dry environment, the sunshade + fan + cooling pad way can make the indoor and outdoor temperature difference be 0 and even minus, that is, the indoor temperature is lower than the outdoor temperature, which can well satisfy the growth requirements of summer crops.

(iii) The sunshade can block sunlight, but it also will block the heat exchange inside and outside the greenhouse through the skylight, thus affecting the cooling capacity of other equipments, so we try not to expand the sunshade when the skylight is opened.

(iv) When the rapid cooling is not required, opening the skylight alone can continue to reduce the indoor temperature, and the energy consumption is low, so it is a good choice.

(v) The three ways (opening fan alone, opening sunshade alone, opening fan + sunshade) have poor cooling capacity, but they can be used as auxiliary cooling measures.

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