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The Influence Of Baking Process Parameters On The Sensory Quality Of Potato Flour Biscuit

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Abstract
In order to improve the sensory quality of potato flour biscuit, the effects of baking process (kneading time, upper heating temperature, lower heating temperature, baking time) on the texture characteristics (hardness, crispy degree, brittleness) and sensory score of 30% potato flour biscuit were studied through single-factor experiments and response surface experiments. The optimal baking process conditions were obtained as follows: kneading time of 24 minutes, upper heating temperature of 148 °C, lower heating temperature of 158 °C, and baking time of 15 minutes. Under these conditions, the hardness of the biscuit was 2678.69 g, the crispy degree was 4.67, the brittleness was 5.33, and the sensory score was 69.00 points. Under the optimized process conditions, the biscuit have a moderate hardness, a golden color, a crispy taste, and a relatively high comprehensive quality.
Keywords: *Baking process; Potato flour; Texture characteristics; Sensory score; Biscuit*

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I. Introduction

Potatoes have attracted much attention in the field of food processing in recent years due to their rich nutritional value and good processing properties[1, 2]. Potato flour is made by dehydrating potatoes and retains its unique flavor and nutritional components. It is a natural additive and an excellent raw material for the production of potato products.

Traditional biscuit is mainly made by wheat flour as the raw material, and their nutritional components are relatively single[3, 4]. In order to enrich their nutritional components and develop gluten-free products, more and more studies have been devoted to adding natural food components that are complementary to wheat flour in the biscuit formula. However, due to the different characteristics of potato flour, a higher addition amount often leads to an increase in the hardness of biscuit and a decrease in crispy degree and taste[5].

For baked foods, their quality depends to a large extent on the baking temperature, baking time, and other baking conditions[6]. During the baking process, biscuit undergo a ripening reaction at a high temperature, and the internal structure forms a microporous sponge-like structure, making the biscuit taste more porous[7-9]. In this study, on the basis of adding 30% potato flour, the effects of kneading time, upper heating temperature, lower heating temperature, and baking time on the hardness, crispy degree, brittleness, and sensory score of biscuit were discussed, and the baking conditions of biscuit were optimized to improve the quality of potato flour biscuit.

II. Materials And Methods

Experimental Materials

Potato snowflake flour was provided by Xisen Potato Industry Group Co., Ltd., and its starch, protein, and dietary fiber contents were 72.60%, 7.66%, and 2.60%, respectively.

Wheat flour was provided by Linyi Hongtai Flour Manufacturing Co., Ltd., and its starch, protein, and dietary fiber contents were 78.40%, 10.48%, and 0.60%, respectively.

White sugar, butter, eggs, whole milk powder, salt, and baking soda were purchased from Mingji Baifu supermarket.

Experimental Methods

Preparation of Dough

Based on the mass of the mixed powder of wheat flour and potato flour, potato flour was used to replace 30% of the wheat flour and mixed thoroughly with it before being kneaded into a dough.

Biscuit Formula

Based on 100% of the weight of the wheat flour and potato flour, the proportions of other auxiliary materials were shown in Table 1 below.

Table 1 Biscuit formula

Accessories	Whole milk powder	Egg liquid	Butter	Ammonium bicarbonate	White granulated sugar	Salt	Water
Proportion	10.00%	7.50%	8.00%	1.50%	20.00%	0.25%	60.00%

Preparation of Biscuit

(1) Weighing of raw materials and auxiliary materials: Weigh the required potato flour (30%), wheat flour (70%), and the masses of the auxiliary materials in the above formula.

(2) Mixing and dough modulation: Thoroughly mix wheat flour, potato flour, ammonium bicarbonate, white sugar, and salt, then add egg liquid and melted butter, and finally slowly add water for thorough modulation. The dough absorbs water and swells. The kneading time was controlled during the dough preparation process.

(3) Standing: Place the kneaded dough at 25 °C for 15 minutes to eliminate its internal tension, reduce the viscoelasticity of the dough, and make the dough less likely to deform[10].

(4) Rolling and forming: Roll the treated dough into a uniformly thick and thin sheet with a thickness of 3 mm, and make uniformly sized biscuit blanks through a biscuit mold.

(5) Placing and baking: Place the biscuit blanks neatly on a baking tray with an appropriate spacing and then bake. The upper heating temperature, lower heating temperature, and baking time were controlled during the baking process.

(6) Cooling: The biscuit after baking was cooled at room temperature for 30 minutes, and then the texture characteristics were measured and the sensory score was determined.

Determination of the Texture Characteristics of Biscuit

The biscuit was analyzed according to the method of Pedersen et al[11]. A texture analyzer was used to analyze the texture of tough biscuit, and a P2 probe was used to perform a puncture test on tough biscuit[12]. The test parameters were set as follows: pre-test speed of 2.0 mm/s, test speed of 3.3 mm/s, post-test speed of 10.0 mm/s, compression amount of 75%, trigger force of 5.0 g, and compression time interval of 5.0 s. The probe moves downward until the biscuit was pierced, and the texture characteristics (hardness, crispy degree, and brittleness) of different layers from the outer layer to the inner layer of the biscuit can be measured.

Determination of the Sensory Score of Biscuit

The scoring panel consisted of 10 professionally trained personnel, including 5 men and 5 women[13]. Each member of the scoring panel scored the shape, color, flavor, taste, and organizational structure of tough biscuit respectively, and each index had a full score of 20 points. The scoring standards were shown in Table 2. The sensory requirements of biscuit refer to the General Rules for Biscuit Quality (GB/T 20980-2021).

Table 2 Sensory rating scale

Indicator	Evaluation indicator details	Score (points)
Shape	Appearance intact, consistent thickness, no shrinkage, no deformation, no blistering.	15-20
	Relatively intact appearance, basically consistent thickness, slightly shrunk, slightly deformed, slightly blistered.	7-14
	Damaged appearance, inconsistent thickness, severe shrinkage, large deformation, many blisters.	0-6
Color	Golden yellow, very uniform in color, no scorching or whitening.	15-20
	Dark yellow, basically uniform in color, no scorching or whitening.	7-14
	Dark brown, uneven in color, with scorching or whitening.	0-6
Flavor	No peculiar smell, appropriate potato flavor and appropriate biscuit fragrance.	15-20
	With peculiar smell, relatively weak or strong potato flavor and relatively weak biscuit fragrance.	7-14
	Excessive peculiar smell, too weak or strong potato flavor, and no biscuit fragrance.	0-6
Taste	No peculiar smell, appropriate potato flavor and appropriate biscuit fragrance.	15-20
	With peculiar smell, relatively weak or strong potato flavor and relatively weak biscuit fragrance.	7-14
	Excessive peculiar smell, too weak or strong potato flavor, and no biscuit fragrance.	0-6
Texture	The cross-section structure was porous with a sense of layering, no holes and no cracks.	15-20
	The cross-section structure was porous with average layering, few holes and few cracks.	7-14
	The cross-section structure was not porous, with poor layering, large and numerous holes and many cracks.	0-6

Single-factor Experimental Design

By measuring the texture characteristics and sensory scores of 30% potato flour biscuit, the effects of dough kneading time (18, 21, 24, 27, 30 minutes), upper fire temperature (130, 140, 150, 160, 170 °C), lower fire temperature (140, 150, 160, 170, 180 °C), and baking time (11, 13, 15, 17, 19 minutes) on the quality of potato flour tough biscuit were investigated.

Response Surface Optimization Experimental Design

By analyzing the results of single-factor experiments, the central levels of four factors (kneading time (A), upper heating temperature (B), lower heating temperature (C), baking time (D)) were selected, and the hardness, crispy degree, brittleness, and sensory score of biscuit were taken as response indicators to design a four-factor three-level central combination experiment to optimize the baking process parameters of potato flour tough biscuit.

Table 3 Response surface optimization test factor level

Level	因素			
	A Kneading time (min)	B Upper heating temperature (℃)	C Lower heating temperature (℃)	D Baking time (min)
-1	21	140	150	13
0	24	150	160	15
1	27	160	170	17

Data Processing

All index measurements were repeated three times, and the results were averaged. Design-Expert.V8.0.6 was used to design the response surface optimization experiment. Origin 2018 software was used to draw graphs.

III. Results And Discussions

Single-factor Experimental Results

The Effect of Kneading Time on the Hardness, Crispy degree, Brittleness, and Sensory Score of Biscuit

The test results were shown in Figure 1. As the kneading time increases, the hardness of the biscuit first decreases and then increases, while the crispy degree and brittleness first increase and then decrease. When the kneading time was less than 24 min, the dough does not fully form gluten, and the hard dough leads to an increase in the hardness of the biscuit[14-16].

When the kneading time was 24 min, the raw materials were mixed evenly, and the kneaded dough has good gas-holding properties, and the baked biscuit have the lowest hardness and the largest crispy degree and brittleness. When the kneading time exceeds 24 min, the protein fully absorbs water and swells, resulting in excessive formation of gluten, causing the dough to shrink easily, and the biscuit do not expand well during baking, ultimately increasing the hardness of the baked biscuit, decreasing the crispy degree and brittleness, and deteriorating the taste[17, 18]. This phenomenon was consistent with the research results of Li Ying.

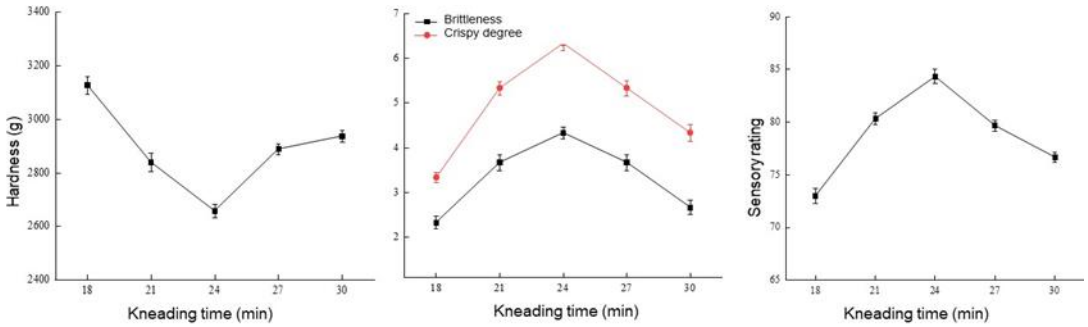

Figure 1 The effect of kneading time on the sensory quality of biscuit

As the kneading time was extended, the sensory score of the biscuit first increases and then decreases. When the kneading time was 24 min, the sensory score of the biscuit was the highest. The kneaded dough has a smooth surface, and the baked biscuit have a complete shape, no deformation or shrinkage, uniform thickness, a golden color, and a good potato flavor. When the kneading time was less than 24 min, the dough was difficult to form, the biscuit has a poor layer structure, the biscuit flavor was weak, and the sensory score was reduced. When the kneeding time was higher than 24 min, the dough temperature rises, the dough was sticky, the prepared biscuit blank shrinks severely, the baked biscuit were deformed, the thickness was uneven, and the flavor was poor, and

the sensory score was reduced[19]. It can be seen that the optimal kneading time for biscuit was 24 min, so kneading times of 21 min, 24 min and 27 min were selected for the response surface optimization experiment.

The Effect of Upper Heating Temperature on the Hardness, Crispy degree, Brittleness, and Sensory Score of Biscuit

Appropriate baking temperatures not only increase the taste of biscuit, but also promote Maillard and caramelization reactions to generate a large number of flavor substances, changing the flavor and color of food. Figure 2 shows that as the upper heating temperature increases, the hardness of the biscuit gradually increases, while the crispy degree and crittleness first increase and then decrease. When the upper heating temperature was less than 140 °C, the biscuit were not cooked, the color was white, the water content was large, and the crispy degree and crittleness were low; when the upper heating temperature exceeds 160 °C, the biscuit were darkened, the edges of the biscuit were burnt, and the biscuit have a poor taste; when the upper heating temperature was 150 °C, the crispy degree and brittleness of the biscuit were the highest, and the color was relatively uniform[20]. The optimal upper heating temperature for biscuit was 150 °C, so upper heating temperatures of 140 °C, 150 °C、160 °C were selected for the response surface optimization experiment.

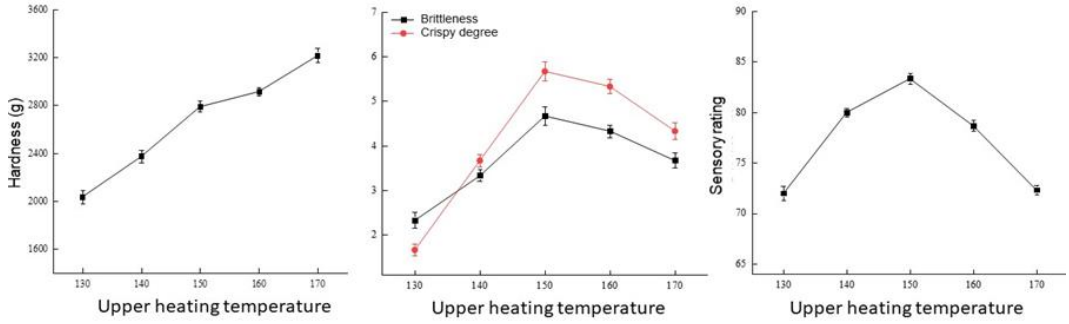

Figure 2 The effect of upper heating temperature on the sensory scores of biscuit

The Effect of Lower Heating Temperature on the Hardness, Crispy degree, Brittleness, and Sensory Score of Biscuit

The baking temperature can control the expansion ratio of biscuit, and the expansion process directly affects the crispy degree of biscuit. The larger the expansion ratio, the crispier the taste of biscuit. As shown in Figure 3, when the temperature was less than 160 °C, the biscuit have an uneven thickness, the bottom was soft and the color was white, and the hardness, crispy degree and brittleness were low. This was because the low temperature leads to insufficient expansion of the biscuit blank, and carbon dioxide and water were not easily released from the inside.

when the lower heating temperature was 160 °C, the biscuit has a complete shape, uniform thickness, a relatively uniform color, and a good crispy degree; when the lower heating temperature exceeds 160 °C, the biscuit were darkened and burnt, resulting in a continuous increase in the hardness of the biscuit, a decrease in the crispy degree and short properties of the biscuit. When the lower heating temperature was less than 150 °C, the carbon dioxide and water in the biscuit blank were not fully released, the central organizational structure of the biscuit was tight, not in an expansion state, resulting in soft biscuit, a white color, a poor flavor and taste, and a low score; when the lower heating temperature was 160 °C, the biscuit have a uniform color and no burnt bottom, and the sensory score was highest[21]. when the lower heating temperature exceeds 170 °C, the baked biscuit has many bubbles, an uneven thickness, a poor layer structure, and a dark color. It can be seen that the optimal lower heating temperature for biscuit was 160 °C, so lower heating temperatures of 150 °C、160 °C、170 °C were selected for the response surface optimization experiment.

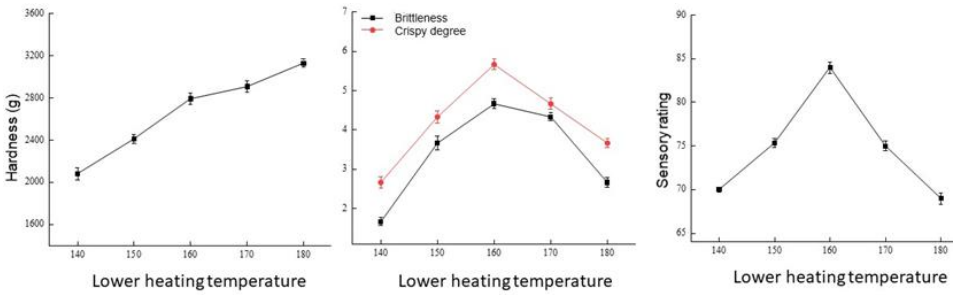

Figure 3 The effect of lower heating temperature on the sensory scores of biscuit

Effect of baking time on the hardness, Crispy degree, Brittleness and sensory score of biscuit

The length of baking time has a significant impact on the overall quality of flour products. If the baking time was too short, the biscuit dough cannot be fully matured, and its quality characteristics such as color, aroma and taste cannot reach the ideal state. On the contrary, if the baking time was too long, the biscuit dough will be overly matured, resulting in excessive loss of moisture and the biscuit will appear dry and hard or even burnt. As shown in Figure 4, with the increase of baking time, the hardness of biscuit increases, and the crispy degree and brittleness first increase and then decrease. If the baking time was less than 15 minutes, components such as starch, lipids and proteins inside the biscuit do not have time to fully undergo the browning reaction in a short time, resulting in insufficient gelatinization of starch. The biscuit was not fully baked and the taste was therefore not good. When the baking time was 15 minutes, the biscuit has a crisp taste and uniform color, and good brittleness. When the baking time was higher than 15 minutes, the biscuit lose too much moisture, causing the biscuit to become scorched, increasing the hardness of the biscuit and reducing the crispy degree and brittleness[22]. The overall biscuit shrinks and deforms. The optimal baking time for biscuit was 15 minutes. Therefore, baking times of 13 minutes, 15 minutes and 17 minutes were selected for the response surface optimization test.

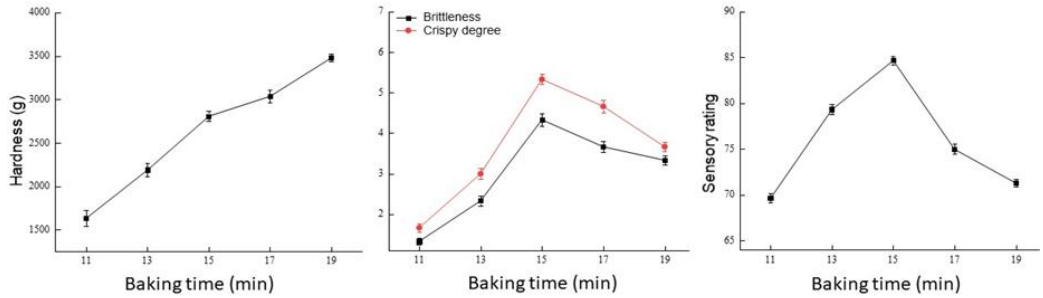

Figure 4 The effect of baking time on the sensory scores of biscuit of biscuit

Response Surface Optimization Experimental Results

According to the experimental arrangement in Table 3, the process was optimized with sensory evaluation as the consideration, and the results were shown in Table 4 below.

Table 4 Response surface optimization test arrangement and results

NO.	A	B	C	D	Y
1	0	0	0	0	68.00
2	0	0	0	0	70.67
3	0	0	0	0	69.33
4	0	1	-1	0	55.00
5	1	0	-1	0	54.33
6	0	-1	-1	0	58.00
7	0	0	0	0	67.33
8	0	0	-1	1	56.00
9	0	1	0	1	50.00
10	-1	0	1	0	57.00
11	0	0	1	1	54.00
12	0	1	1	0	56.00
13	0	-1	0	1	52.33
14	0	0	0	0	68.33
15	-1	0	0	-1	52.00
16	-1	1	0	0	58.00
17	0	-1	1	0	54.00
18	-1	0	0	1	55.00
19	-1	-1	0	0	53.00
20	1	0	0	1	50.67
21	1	1	0	0	51.00
22	1	0	1	0	53.00
23	0	1	0	-1	51.00
24	0	0	1	-1	52.00
25	0	-1	0	-1	47.33
26	0	0	-1	-1	52.00
27	1	0	0	-1	46.00
28	-1	0	-1	0	62.00
29	1	-1	0	0	49.00

Note: A was kneading time (min); B was upper heating temperature (°C); C was lower heating temperature (°C); D was baking time (min); Y1 was sensory score (points).

By fitting and analyzing the sensory score data of biscuit, the regression equation of sensory score (Y4) was obtained as follows:

$$Y4 = 68.73 - 2.75A + 0.61B - 0.94C + 1.47D - 0.75AB + 0.92AC + 0.42AD + 1.25BC - 1.50BD - 0.50CD - 7.52A^2 - 8.31B^2 - 4.73C^2 - 10.35D^2$$

From Table 4, the regression model of sensory score has $P < 0.0001$, indicating that the model was extremely significant, the simulation effect was good, the experimental error was small, and it can better reflect the effect of process parameters on the sensory score of biscuit; the lack-of-fit term was not significant ($P = 0.6595 > 0.05$), indicating that the model was established; $R2 = 0.9845$, indicating that the regression equation was effective and reliable, and the experiment has a high credibility. By analyzing the F value, the influence degree of each factor of baking conditions on the sensory score of biscuit was A (kneading time) > D (baking time) > C (lower heating temperature) > B (upper heating temperature).

Table 5 Analysis of variance for regression model of sensory scores

Source	Sum of squares	Degrees of freedom	Mean square	F value	Prob > F	Significance Model
Model	1273.03	14	90.93	63.64	< 0.0001	**
A	90.75	1	90.75	63.51	< 0.0001	**
B	4.49	1	4.49	3.14	0.098	
C	10.7	1	10.7	7.49	0.0161	*
D	26.02	1	26.02	18.21	0.0008	**
AB	2.25	1	2.25	1.57	0.2301	
AC	3.37	1	3.37	2.36	0.147	
AD	0.7	1	0.7	0.49	0.4963	
BC	6.25	1	6.25	4.37	0.0552	
BD	9	1	9	6.3	0.025	*
CD	1	1	1	0.7	0.4169	
A^2	366.67	1	366.67	256.62	< 0.0001	**
B^2	448.04	1	448.04	313.57	< 0.0001	**
C^2	144.95	1	144.95	101.45	< 0.0001	**
D^2	695.15	1	695.15	486.52	< 0.0001	**
Residual	20	14	1.43			
Lack of fit	13.23	10	1.32	0.78	0.6595	
Pure error	6.78	4	1.69			
Total variation	1293.03	28				
R^2	0.9845					

According to the response surface optimization experimental results, the optimal process parameters for biscuit were determined as follows: kneading time of 23.8 min, upper heating temperature of 148 °C, lower heating temperature of 158 °C, and baking time of 14.8 min. Under these conditions, the hardness of the tough biscuit was 2680.81 g, the crispy degree was 4.80, the brittleness was 5.19, and the sensory score was 68.19 points. In order to test the feasibility of the model and consider the convenience of operation comprehensively, the optimal baking process conditions were adjusted to: kneading time of 24 min, upper heating temperature of 148 °C, lower heating temperature of 158 °C, and baking time of 15 min.

According to these process parameters, three verification experiments were carried out, and the hardness of the tough biscuit was 2678.69 g, the crispy degree was 4.67, the brittleness was 5.33, and the sensory score was 69.00 points. The actual values of various indicators were close to the predicted values, indicating that the response surface model was reliable.

IV. Conclusion

This study optimized the baking process of 30% potato whole flour tough biscuit and systematically explored the effects of dough mixing time, upper fire temperature, lower fire temperature and baking time on the texture characteristics and sensory scores of biscuit. Through single-factor experiments, it was found that a dough mixing time of 24 minutes, an upper fire temperature of 150 °C, a lower fire temperature of 160 °C, and a baking time of 15 minutes were the preliminary process conditions with better performance. Under these conditions, the biscuit had lower hardness and showed higher levels of crispy degree, brittleness and sensory scores. Based on single factors, the process parameters were further optimized by using a four-factor and three-level response surface analysis method.

Through variance analysis and regression analysis, the final optimal baking process conditions were obtained as follows: dough mixing time of 24 minutes, upper fire temperature of 148 °C, lower fire temperature of 158 °C, and baking time of 15 minutes. Under these optimized conditions, the hardness of biscuit was 2678.69 g, the crispy degree was 4.67, the brittleness was 5.33, and the sensory score was 69.00 points. The actually measured values were consistent with the model predicted values, proving that the optimization scheme was reasonable and effective. Compared with the unoptimized process, the comprehensive quality of biscuit was significantly improved.

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