Optimization of Processing Technology of Chinese Chestnut Stuffing by Response Surface Methodology

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Abstract: **[Objective]** To enrich the variety of Chinese chestnut products, promote the transformation of Chinese chestnut raw materials and increase added value, we developed a Chinese chestnut stuffing method and optimized the compounding process in order to provide a reference for the industrial development of Chinese chestnut stuffing. **[Method]** The degree of Chinese chestnut ripening, Chinese chestnut particle size, job's tear dosage, red bean dosage and date paste dosage were optimized through single-factor experiments; then orthogonal experiments were conducted for the dosage of job's tear, red bean and date paste. The Box-Behnken experimental results were then analyzed by response surface method. **[Results]** Firstly, it was determined that when the Chinese chestnut was steamed to the fifth to seventh degree of ripeness and crushed to 4-6 mesh size, the optimal amount of job's tear was 10 g/25 g chestnut, red bean 10 g/25 g chestnut, and red date paste was 6 g/25 g chestnut.. The results of the orthogonal experiment showed that the compounding effect was better with the barley dosage of 9 g/25 g chestnut, red bean 10 g/25 g chestnut and red date paste 7 g/25 g chestnut. Response surface analysis yielded the regression equation Y (sensory score) = $8.2-0.27\chi1 -0.059\chi2 +0.26\chi3 -0.22\chi1\ \chi2 +0.062\chi1\ \chi3 -0.46\chi2\ \chi3 -0.81\chi12 -0.41\chi22 - 0.32\chi32$. The model had a low coefficient of variation (CV= 0.023), indicating that the equations fit well with high confidence. **[Conclusion]** A better quality Chinese chestnut filling could be obtained by compounding diced chestnuts of five to seven minutes steam ripening and crushed in 4-6 mesh with job's tear, red beans and date paste in the ratio of 8.96 g/25 g, 9.77 g/25 g 7.37 g/25 g respectively. The error between the theoretical value (8.32 points) and the experimental value (8.28 points) was small (0.48%), indicating the optimized parameters are accurate and have practical value.

1 INTRODUCTION

Chinese chestnut is a traditional nut in China, with a unique "fragrant, sweet and glutinous" flavor which is known worldwide. Chinese chestnuts are rich in nutrition, traditionally cooked to replenish Qi and strengthen the spleen, and provide many other health benefits while being filling in the stomach (Wang, 2021)

China is the main producing country of Chinese chestnut and has the largest cultivation area and production of Chinese chestnut in the world (Gao, 2006). However, the required extensive processing of chestnut has outstanding problems such as few categories, single color and low conversion rate (Wang, 2015; Wang, 2011; Zeng, 2010; Zhu, 2020; Shi, 2014; Li, 2011), and is still mainly focused on fried chestnut and small package chestnut kernel. It is reported that the development of other processed chestnut products is being carried out continuously, including canned chestnut, chestnut powder, chestnut paste, and the like. Among them, the application of chestnut paste is relatively large, mainly used for baked goods (Zhang, 2018; Research and Markets.com, 2020; Li, 2021; Lee, 2016; Dai, 2020; Shen, 2014; Zeng, 2011; Wang, 2021; Zhou, 2021). Chestnut paste has a delicate and glutinous taste, though as it needs to be fried with cooking oil during the production process thereby increasing the fat content in the filling, it is therefore desirable to develop a high-quality chestnut filling with rich chestnut flavor without addition of cooking oil.

Japan has a well-developed chestnut processing industry, often combining chestnuts with red beans, which is expensive but still popular among consumers. Job's tear contains vitamin E, coixin, selenium trace elements and other nutrients, has the effect of postponing senility and invigorating the spleen to eliminate dampness. Red beans are used to induce diuresis and alleviate edema, as well as the detoxification and drainage of pus. Chinese traditional medicine often utilizes job's tear and red beans to help increase nutrition and reduce ‘dampness’. In addition, red dates are high in iron and have the effect of reducing iron defiency, calming the mind, and can enhance liver function, promote detoxification, improve myocardial nutrition (Li, 2014; Ge, 2018).

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This study combined Chinese chestnuts, job's tear, red beans and red dates to develop a Chinese chestnut stuffing for chestnuts in granular form, rich in sweet flavor, nutritionally fortified and without oil frying. This study hereby provides a reference for deep processing of Chinese chestnut products, which is beneficial to promote the healthy development of the Chinese chestnut industry and help rural revitalization.

2 MATERIALS AND METHODS

2.1 Materials

The Chinese chestnut variety selected was the 'Early Rich' variety, purchased from Qianxi Chestnut Demonstration Base. Job's tear, red beans and red dates were purchased from the supermarket near the school.

2.2 Methodology

Chinese chestnuts were selected to exclude bad or rotten nuts, then were shelled and had the inner skin removed. Red beans and job's tear were washed and had water added to soak for >6h. Chestnuts were then steam processed in a pot. Job's tear, red beans and red dates were then soaked in separate pots for ~1h. The steamed chestnuts were then broken and set aside. The red beans and Job’s tear were then beaten into paste, along with the steamed red dates. The Chinese chestnuts were then pureed and sieved to different ripeness and different mesh sizes for measuring.

2.3 Single-Factor Experiment Design

The appropriate degree of maturation and particle size were first determined by single-factor experiments. On this basis, 25 g of Chinese chestnut was used as the base each time, and other materials were added to optimize the compounding
ratio.

Table 1 Table of Factor Levels

Factors	Level				
Degree of maturation	Raw	Blanching	Medium	Medium well	Well done
Grain size	2 purposes	4 purposes	6 purposes	10 items	18 items
Job's Tears	0g	5g	10g	15g	20g
Red beans	5g	10g	15g	20g	25g
Red date paste	2g	4g	6g	8g	10g

2.4 Orthogonal Experiments

Based on the results of the single-factor experiment, reference L9 (34) three-factor three-level orthogonal experiment.

2.5 Response Surface Analysis

The results of the orthogonal experiments were further optimized using Box-Behnken and analyzed using response surface methodology. (Wei, 2015)

2.6 Sensory Scoring

A 15-member evaluation team was organized to evaluate the overall quality of the fillings using a weighted scoring method. Product sensory score = taste*40% + aroma*30% + looseness*30%. The sensory evaluation table is shown in the table.

Table 2 Chestnut stuffing sensory evaluation table

Score	Fragrance	Taste	Formation
8.1~10	Chestnut flavor is obvious	Sweet, soft and sticky, chestnut taste is obvious	Filling into a dough, not easy to fall apart
6.1~8.0	Chestnut fragrance in general, can cover other materials	Chestnut taste more, the filling is hard	Filling into a dough, more easily dispersed
0~6.0	Basically no chestnut flavor, other materials taste strong	Basic no chestnut taste, filling hard	No dough

3 RESULTS AND DISCUSSION

3.1 Single Factor Analysis

3.1.1.Effect of maturation degree on sensory scores

From 500g of chestnut kernels, 100 g was taken to make raw chestnut dice. The remaining 400 g of chestnut kernels were rinsed in boiling water for 2min, then 100 g was taken as a rinsed sample., The remaining 300 g of chestnuts were then steamed for 10 min, 15 min and 20 min respectively. The steamed samples were then made into diced chestnut filling to make buns (buns were steamed in cold water for 15min, and the filling was evaluated after the buns were cooked).

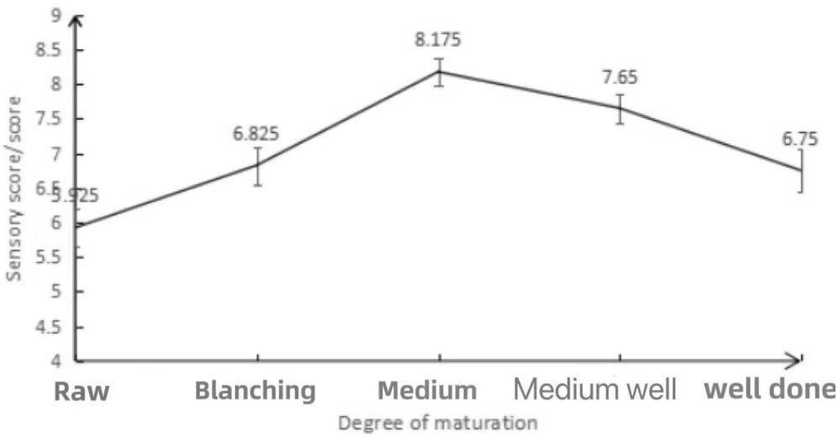

Figure 1 Sensory score of chestnut ripening degree

Figure 1 shows that the sensory scores of diced chestnuts at five, seven and fully cooked levels were all higher, and the difference between cooking levels was not significant. The fillings in the steamed buns all had a sweet taste. The five- and seven-percent ripened diced chestnuts were easy to form into a dough, which was convenient for making the buns. In addition, the filling was slightly loose and soft when the buns were ripe. Fully cooked diced chestnuts had no significant difference in taste and aroma from the five- and seven-percent-ripe fillings, and were also easy to form dough, though as the starch was completely pasted it easily stuck to the container, which affected the utilization rate of the filling. Raw diced chestnut, bleached diced chestnut, and those with a low degree of starch paste do not easily form a dough. In the production of buns when the operation time is restricted and the starch cannot be completely turned into a paste within the 15 minutes cooking time, simply extending the time will negatively affect the quality of the shape of the bun skin. Therefore, the chestnut filling production using pre-cooked chestnut cooked to five to seven minutes is more appropriate.

3.1.2.Effect of grain size on sensory scores of chestnut stuffing

Chestnuts from five to seven minutes ripe were crushed and sieved into five particle sizes of 2, 4, 6, 10 and 10 mesh for sensory evaluation.

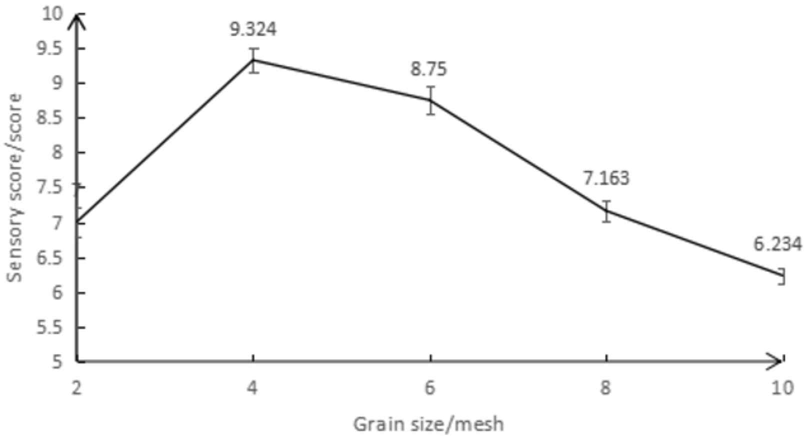

Figure 2 Sensory scores of chestnuts in different grain sizes

As shown in Figure 2, when the particle size of chestnut was graded to 4 and 6 mesh, the sensory evaluation score was higher and the difference was not significant, and the filling was easy to form a dough. Two-size mesh chestnut particles were large, loose and non-dough forming, and chewiness was poor. When the particle size reached 10 mesh, it was easy to produce a crumbly texture when tasting because of the small particle size. Considering the taste and operability, the particle size of chestnut stuffing is more suitable between 4 and 6 mesh.

3.1.3.Effect of barley on sensory scores of chestnut stuffing

The barley was divided into 5 parts by different weights, soaked for 6 h and then cooked. Following this, the barley was cooled and a small amount of water from the boiled barley was added and the mixture was beaten into a puree by a crusher, and combined with chestnuts in 5 levels. The optimal barley content for chestnut stuffing was then determined according to sensory score.

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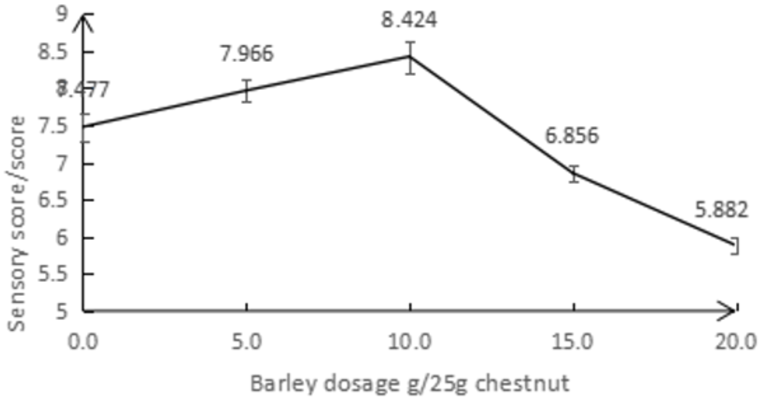


Figure 3 Sensory scores of different fillings with different amounts of job's tears addition

Cooked job's tears have a characteristic odor and the starch paste is more viscous, so the aroma, taste and dough-forming properties of the Chinese chestnut stuffing were affected by the addition of job's tears. Figure 3 shows that the sensory scores of the stuffing gradually decreased as the amount of job's tears increased, and the difference in sensory scores was not significant when the amount of job's tears was 5 g and 10 g. The stuffing of Chinese chestnut with 10 g of job's tears had better dough formation while the stuffing was looser when the amount of job's tears was 5 g, which affected the convenience of handling. Overall, 10 g of job's tears was found to be the optimum amount of job's tears addition.

3.1.4.Effect of red beans on sensory scores of chestnut stuffing

The red beans were divided into 5 parts by different weights, soaked for 6 hours and then cooked, cooled and broken in a crusher until they were pureed, and compounded with Chinese chestnuts in 5 levels. The Chinese chestnut fillings with different red bean additions were then assessed according to sensory scores.

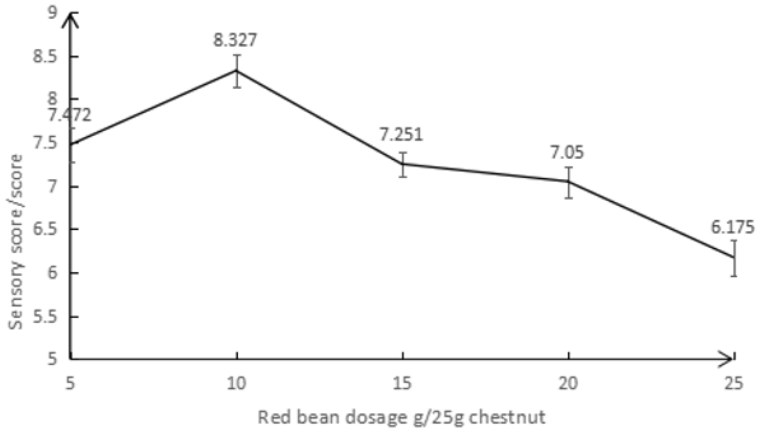


Figure 4 Sensory scores of fillings with different amounts of red beans added

The addition of red beans to Chinese chestnuts will make the filling red in color, sandy in texture and loose, preventing easy dough formation with dough-formation ability decreasing with increasing red bean content. Figure 4 shows the highest sensory score and the best overall quality of the filling were obtained when 10 g of red beans was added. Therefore, this was taken as the optimal level of red bean dosage.

3.1.5.Effect of red date paste on sensory scores of chestnut stuffing

The red dates were steamed, peeled, pitted and beaten into a puree then divided into 5 groups with 25 g of Chinese chestnuts for proportioning. Sensory evaluation of the compounded fillings was then performed to determine the optimum levels.

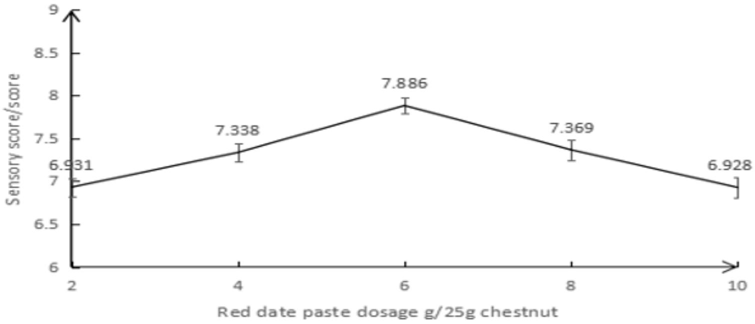


Figure 5 Sensory scores of fillings with different amounts of red date paste addition

The sweetness and rich pectin texture of the red date puree combined with the powder glutinousness of Chinese chestnuts gave the filling a unique flavor that was easy to form into a dough. However, the strong, sweet flavor of red dates and the larger amount of red date puree required tended to obscure the flavor of Chinese chestnuts. Figure 5 shows that adding 6 g of red date puree resulted in the best overall quality of the filling and the highest sensory score.

3.2 Results and Analysis of Orthogonal Experiments

Using the optimal level of each factor determined by the single-factor experiments as the center point, three levels of each factor were taken and orthogonal experiments were conducted with the results shown in Table 3.

Table 3 Factor levels and results of orthogonal experiments

Level	Experimental factors			Sensory score
	Job's Tears amount A (g/25g chestnut)	Red bean volume B (g/25g chestnut)	Amount of date paste C (g/25g chestnut)	
1	1(9)	1(9)	1(5)	7.0
2	1	2(10)	2(6)	8.3
3	1	3(11)	3(7)	8.5
4	2(10)	1	2	8.O
5	2	2	3	7.25
6	2	3	1	7.0
7	3(11)	1	3	7.38
8	3	2	1	7.0
9	3	3	2	6.0
K1	23.8	22.38	21	
K2	22.25	22.55	22.3	
K3	20.38	21.5	23.13	
k1	7.93	7.46	7.00	
k2	7.42	7.52	7.43	
k3	6.79	7.17	7.71	
R	1.14	0.35	0.71	
Factor Main Sub-order		A>C>B		
Excellent level	A1	B2	C3	
Excellent combination		A1 B2 C3		

Comparing the R values of the three factors, it can be inferred that job's tears dosage has the most influence on the results, followed by red date paste dosage, then red bean dosage. Comparison of the mean K values shows the optimum combination is A1 B2 C2; that is, the superior level of each factor is 9g/25g of job's tears dosage (chestnut), 10g/25g of red bean dosage (chestnut), and 7g/25g of red dates dosage (chestnut).

According to the results of the orthogonal experiment, five parallel replications of Chinese chestnut stuffing were carried out using samples with sensory scores of 8.6±0.2. To obtain better quality stuffing, a 3-factor, 3-level experimental design was carried out using Box-Behnken central combination, with job's tears dosage, red bean dosage and red date paste dosage as independent variables, and sensory scores as response values for further optimization.

3.3 Response Surface Optimization Experiments

3.3.1.Experimental design and results of response surface optimization

The factor level table determined from the orthogonal factor experiment is shown in Table 4, and the response surface fruit analysis was performed using Design-Expert 8.0.6 software, and the results are shown in Tables 5, 6, and 7.

Table 4 Experimental factor levels for response surface optimization

Factors	Level		
	-1	0	1
X1 job's tears dosage/(g/25g)	8.5	9	9.5
X2 Red bean dosage/(g/25g)	9.5	10	10.5
X3 Amount of sludge/(g/25g)	6.5	7	7.5

Table 5 Response surface experimental results

Experiment serial number	χ1	χ2	χ3	Sensory score
1	8.5	9.5	7.0	7.0
2	9.5	9.5	7.0	7.0
3	8.5	10.5	7.0	7.38
4	9.5	10.5	7.0	6.5
5	8.5	10.0	6.5	7.25
6	9.5	10.0	6.5	6.5
7	8.5	10.0	7.5	7.5
8	9.5	10.0	7.5	7.0
9	9.0	9.5	6.5	6.75
10	9.0	10.5	6.5	7.5
11	9.0	9.5	7.5	8.35
12	9.0	10.5	7.5	7.25
13	9.0	10.0	7.0	8.0
14	9.0	10.0	7.0	8.38
15	9.0	10.0	7.0	8.35
16	9.0	10.0	7.0	8.26
17	9.0	10.0	7.0	8.0

Using the sensory scores as the response values, the results were analyzed by quadratic regression based on the experimental results of the Box-Behnken design in Table 4, and the regression equation (predictive model for Y) was Y = 8.2-0.27χ1 -0.059χ2 + 0.26χ3 -0.22χ1 χ2 +0.062χ1 χ3 -0.46χ2 χ3 -0.81χ 12-0.41χ22 -0.32χ32.

The ANOVA results of the regression equations are shown in Table 6.

Table 6 Response surface analysis of variance

Source of variation	sum of squares	Degree of freedom	Mean Square	F-value	P-value
Regression model	6.53	9	0.73	24.49	0.0002
A	0.57	1	0.57	19.16	0.0032
B	0.028	1	0.028	0.93	0.3663
C	0.55	1	0.55	18.62	0.0035
AB	0.19	1	0.19	6.54	0.0377
AC	0.016	1	0.016	0.53	0.4911
BC	0.86	1	0.86	28.91	0.0010
A2	2.79	1	2.79	94.25	<0.0001
B2	0.72	1	0.72	24.38	0.0017
C2	0.44	1	0.44	14.70	0.0064
Residuals	0.21	7	0.030		
Loss of proposed items	0.069	3	0.023	0.66	0.6175

Pure Error	0.14	4	0.035
Total value	6.73	16	

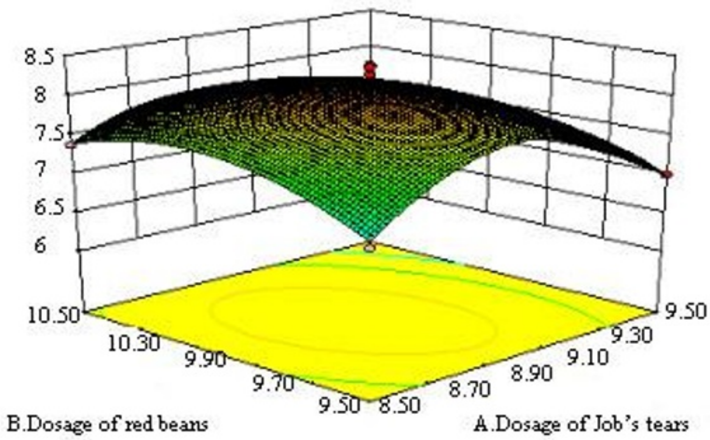
Table 7 Credibility analysis of the model

Average value	7.47
Compound correlation coefficient R2	0.9692
Corrected R2	0.9297
Model misfit error term	0.6175
The coefficient of variation CV of Y	0.0230

Table 6 shows that P<0.01 and F=24.49, indicating a significant relationship between the response values and the regression equation. The regression coefficient of the model R2 was 0.9692, indicating that 96.92% of the variation in the model response values (sensory scores) came from the values of the selected variables. With regard to the amount of job's tears puree, red bean puree and red date puree, the misfit error term was 0.6175, which was not significant and indicates that the equation fit was high and the regression equation could be used to determine the optimal process conditions. The coefficient of variation (CV) of Y indicates the accuracy of the experiment, with higher CV value corresponding to lower reliability of the experiment. The low CV(0.0230) in this experiment therefore indicates that results are credible. The optimal process conditions calculated by the software were 8.96g/25g chestnut for job's tears, 9.77g/25g chestnut for red beans, and 7.37g/25g chestnut for red dates, and the theoretical sensory score value could reach 8.32. The response surface and contour plot (Figure 6), the fitted response surface and contour plot obtained by the software can reflect the interaction between the factors more intuitively; all three response surfaces are convex surfaces with downward openings, and the amount of job's tears puree, red bean puree and red date puree can be parabolically related to the sensory score, and there are very low sensory scores in the investigated range.

3.3.2.Response surface and contour analysis

The software Design-Expert 8.0.6 was used to make 3D surface plots and contour plots of the effects of Chinese chestnut volume, job's tears volume, red bean volume and Chinese chestnut filling on sensory scores (See Figure 6).



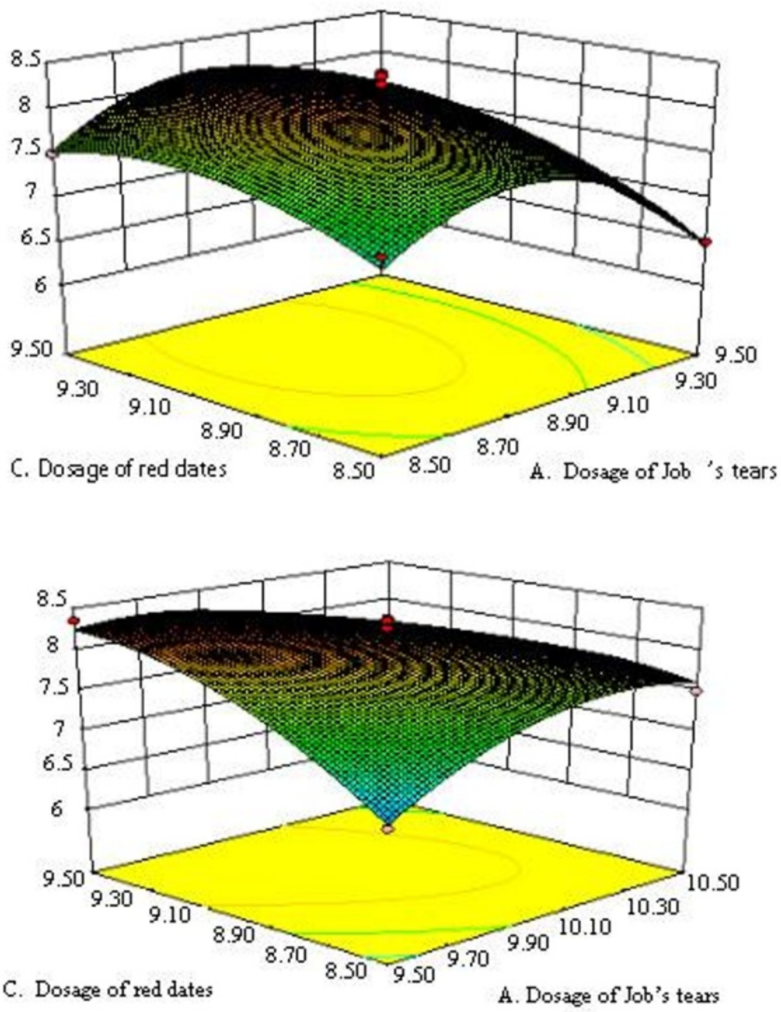


Figure 6 Response surface analysis contour plots and surfaces

The contour plots of all three experiments were elliptical and similar in sparsity, and the 3D surfaces were similar in inclination. The results indicated that some key? factors influenced the sensory evaluation of Chinese chestnut stuffing, but the interaction experiments of each group showed little effect on the sensory scores.

3.3.3.Validation experiments

The sensory score was 8.28 with an error of 0.48% in five parallel compounding tests on Chinese chestnut stuffing under the optimal conditions derived from response surface analysis.

4 CONCLUSION

The degree of Chinese chestnut ripening and crushing size were determined by single-factor experiments, and the amounts of job's tears, red beans and red date paste were optimized. The results of the orthogonal experiments determined that the optimal levels of job's tears dosage was 9g/25g chestnut, red bean dosage 10 g/25g chestnut and red date paste dosage 7g/25g chestnut. The Box-Behnken central combination experiment was analyzed by response surface method and the regression equation Y (sensory score) =8.2-0.27χ1 -0.059χ2 +0.26χ3 -0.22χ1 χ2 +0.062χ1 χ3 -0.46χ2 χ3 -0.81χ12 -0.41χ22 -0.32χ32, and the model term P=0.0002, F=24.49, indicated that the response value and regression equation was significant. The regression coefficient of the model R2 was 0.9692 and CV= 0.0230, which was very low and indicated the equations fit well and with high confidence. Finally, the optimum Chinese chestnut stuffing process was determined to be combining diced Chinese chestnuts of five to seven minutes ripe and of 4-6 mesh size with job's tears (8.96g/25g), red beans (9.77g/25g) and red date paste (7.37g/25g). The sensory score was theoretically 8.32, and the experimental sensory score was 8.28, with a small error of 0.48%. Therefore, the parameters obtained by optimization using the response surface method were accurate, reliable and of practical value.

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