Response Surface Optimization of Pure Natural Fairy Tofu Production Process

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Abstract: This experiment was centred on the concept of using pectin gel to manufacture fairy tofu in order to determine the ideal parameters for the creation of natural fairy tofu. Based on the single-factor test, The Box-Behnken central combination design approach was employed to investigate the optimal production process of fairy tofu. According to the findings, there were substantial changes ($P<0.05$) in the qualitative attributes of tofu at varied material-to-liquid ratios, drying temperatures (the leaves of *Premna microphylla Turcz*) and grinding temperatures during the production process. The optimal process parameters were: material-to-liquid ratio of 1:60 (g:g), drying temperature of 20 °C and a grinding temperature of 90 °C. The yield of fairy tofu produced under this process parameter was 46.02 g/g, which was 55.33% higher than the yield of fairy tofu produced by the unoptimized process. It indicated that the optimized process conditions for the production of pure natural fairy tofu are feasible and can produce a high-yield and high-quality of fairy tofu. This study provides a theoretical basis for the reuse of the leaves of *Premna microphylla Turcz.* and lays the foundation for the large-scale production of fairy tofu.

1 INTRODUCTION

Fairy tofu is a product formed by pectin gel extracted from the leaves of *Premna microphylla Turcz*, which is rich in pectin, protein, fat, fiber, isoflavones, vitamins, minerals and other nutrients (Shi, Zou, Song, 2022; Shi, Zou, Wang, 2022; Zhang, 2022). The processing of fairy tofu has a long history, and the process is diverse and complex, including the leaves of *Premna microphylla Turcz.* selection, cleaning, crushing, drying, grinding with water, filtering, coagulation, pressing, and other processes, of which pulping is the core key process in the production of fairy tofu (Ma, 2022; Chen, 2022). Diverse pulping procedures not only play a crucial role in the extraction rate and stability of nutrients in its water, but also boast a major impact on the quality as well as flavor of fairy tofu (Yu, 2022; Dong, 2022). The process of producing pure natural fairy tofu is to crush the dried leaves of *Premna microphylla Turcz*, add water and then grind and filter the residue to obtain the "pectin liquid", which is then solidified (Duan, 2022). This process method requires relatively little plant and equipment, and is easy to operate with high efficiency (Li, 2021; Song, 2021). It is the most prevalent technique of production employed by farmers and most businesses in China to manufacture tofu (Gong, 2021; Dong, 2022).

The response surface optimization method is an experimental statistical method, that is suitable for solving problems related to nonlinear data processing (Banerjee, 2016). The response value corresponding to the level of each factor may be easily discovered via fitting the regression to the process and visualizing the response surface and contour, as well as the ideal value of the anticipated response and the associated experimental conditions (Zhou, 2020; Huang, 2020). Therefore, this study will optimize the process of making pure natural divine tofu by response surface. it's based on the principle of pectin gelation to produce fairy tofu. With the fresh *Premna* as raw materials, the production process of pure natural fairy tofu was adopted (Pan, 2019; Elmaidomy, 2019). With the moisture content, water retention, and yield of fairy tofu as evaluation indicators, an analysis of single-factor experimental results by controlled variable statistical methods revealed the effects of material-liquid ratio, drying temperature (*Premna*), and grinding temperature on the quality of fairy tofu. The objective is to provide excellent technical assistance and a theoretical foundation for the standardized industrial production of natural fairy tofu so that it may become a popular household dish as soon as feasible.

2 Material and Method

2.1 Materials and reagents

Fresh *Premna microphylla Turcz* (harvested in August 2022 from Zuolong Village, Zuolong Town, Langao County, Ankang City, Shanxi Province); deionized water.

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2.2 Instruments and equipment

JA2203N type electronic balance: Shanghai Minqiao Precision Scientific Instruments Co., Ltd; GZX-9140MBE type electric blast dryer: Shanghai Boxun Industrial Co., Ltd; 3205 FP3010 Braun grinder: Hungarian Machinery Company; 100~1000 μL pipette gun: Shaoxing Yuecheng District Xiaoke Instrument and Equipment Trading Company.

2.3 Experimental methods

2.3.1.Single-factor test setup.

The Box-Behnken concept was employed to create the experimental technique. Using response surface analysis, the material-liquid ratio, drying temperature (*Premna*), and grinding temperature were founded as single factors, and the second-order multinomial nonlinear regression equation as well as a data model were established to optimize the fairy tofu production process, with the yield of fairy tofu as the index. Five material-to-liquid ratios (1:40, 1:45, 1:50, 1:55, and 1:60 (g:g)) were selected; five drying temperatures (*Premna*) (10 °C, 20 °C, 30 °C, 40 °C, 50 °C) were preferred; and five grinding temperatures (20 °C, 40 °C, 60 °C, 80 °C, and 100 °C) were chosen. The effect of one of the factors on the yield, water retention, and moisture content of tofu was investigated by changing one of the factors by the controlled variable method, while ensuring that all other factors remained constant.

2.3.2.Process of producing fairy tofu by pure natural fairy tofu process.

Premna → selection → washing → drying → crushing → adding water to grind (grind) → separation of pulp and dregs → solidification → resting → fairy tofu

2.3.3.Determination of the yield of fairy tofu.

Each group received three parallel samples, and the dried leaves of *Premna* prepared employing various production procedures were precisely weighed and documented with the fairy tofu. The yield of fairy tofu is the ratio of the wet weight of the fairy tofu to the weight of the dry powder of *Premna*'s leaves.

2.3.4.Determination of moisture content of fairy tofu.

Three 5.0 g samples of fairy tofu were taken from each group, and then they put it into a weighing bottle, dried to a constant weight, weighed precisely, and recorded, placed it in a drying oven for drying (101-105 °C), removed it after 4 h of drying, cooled it in a desiccator for 30 min, repeated the drying to a constant weight, weighed, and recorded the mass. The ratio of the difference between the before and after masses and the mass of fairy tofu is the moisture content.

2.3.5.Determination of water retention of fairy tofu.

Three 5.0 g samples of fairy tofu were captured from each group and positioned in a 50 mL centrifuge tube with skimmed cotton at the bottom, centrifuged at 1000 r/min for 10 min, and thereafter weighed and recorded the mass of fairy tofu. The weighed fairy tofu was slightly crushed and dried at 105 °C for 4 h before being removed, weighed, and documented. Use the equation to figure out the water retention of fairy tofu.

2.3.6.Response surface optimization test.

Design Expert 12, Origin Pro 2021, among other software, were used for statistical analysis and plot processing. On the basis of a single factor, the factors with greater influence in material-liquid ratio, drying temperature (*Premna*), and grinding temperature were selected for the response surface test, and the test optimization was carried out with the yield of fairy tofu as the reference index, and three replicate tests were conducted for each group.

2.3.7.Validation test.

Each group was replicated three times to evaluate the discrepancies in fairy tofu yield between the experimental groups using the response surface optimization scheme as well as process parameters set up in the production of pure natural fairy tofu prior to and following the optimization of the two experimental groups to create fairy tofu.

2.4 Processing and Analysis

Experimental data were expressed as "mean value". The statistical analysis and ANOVA were performed using SPSS 22.0, Origin 2018 and Design-Expert 8.0, with significant and highly significant levels set at $p<0.05$ and $p<0.01$, respectively, to identify significant differences between groups.

3 Results and Analysis

3.1 Analysis of Single-Factor Experimental Results

3.1.1.Effect of material-to-liquid ratio on the quality characteristics of fairy tofu

Figure 1 depicts the effects of various material-to-liquid ratios on the qualitative features of the pure natural fairy tofu production process. The yield, moisture content, and water retention of fairy tofu rose and subsequently fell when the material-to-liquid ratio decreased. There was a substantial association between the production of fairy tofu and the material-to-liquid ratio of 1:55. The explanation for this might be that while the grinding water is low, the pectin concentration in the serous fluid is high, and as the water level rises, the material-liquid ratio approaches the ideal ratio of 1:55. The pectin component in the serous fluid is diluted and lowered as the grinding water increases, causing a fall in fairy tofu. The moisture content and water retention of fairy tofu start to decrease when the material-liquid ratio exceeds 1:55, probably because the slurry is too dilute and the pectin content is not sufficient to make fairy tofu form a gel. Therefore, 1:50, 1:55, and 1:60 (g:g) material-to-liquid ratios were selected for response surface testing for further optimization.

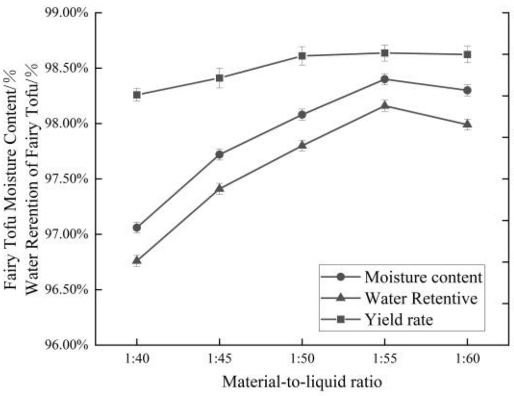


Figure 1. Influence of material-to-liquid ratio on the quality characteristics of pure natural fairy tofu

3.1.2.Effect of drying temperature (tofu firewood leaves) on the quality characteristics of fairy tofu

The effects of different drying temperatures on the quality characteristics of tofu in the production process of pure natural fairy tofu are shown in Figure 2. The yield, moisture content, and water retention of fairy tofu surged and subsequently decreased with increasing drying temperature, all reaching their maximum benefits at 20 °C, demonstrating that the optimal drying temperature in the manufacturing of pure natural fairy tofu is approximately 20 °C. It is assumed that the reason for this is that on the one hand, it is probably the closest to the ambient temperature at which the pectin in the *Premna microphylla Turcz* can be retained to the maximum extent, and on the other hand, due to the increase in drying temperature of the *Premna microphylla Turcz*, the internal molecules of pectin are cleaved and the pectinase activity is inhibited (Onuegbu, 2019; Kalyniukova, 2021), so that the yield of fairy tofu increases first and then decreases, resulting in a decrease in the yield of fairy tofu (Pu, 2018). Therefore, response surface tests at drying temperatures of 10 °C, 20 °C, and 30 °C were selected for further optimization.

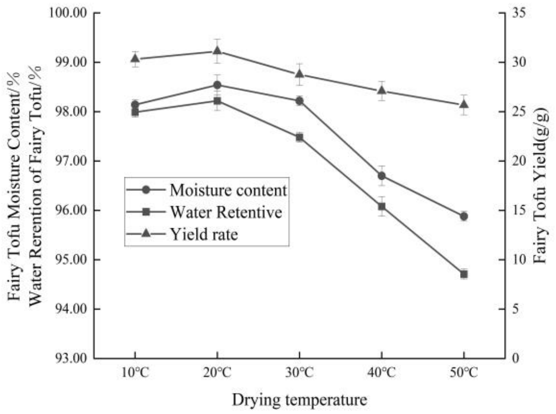


Figure 2. The influence of drying temperature on the quality characteristics of pure natural fairy tofu

3.1.3.Effect of grinding temperature on the quality characteristics of fairy tofu

Figure 3 depicts the impact of various grinding temperatures on the qualitative attributes of fairy tofu in the manufacturing of natural fairy tofu. Fairy tofu production, moisture content, and water retention rose and subsequently declined as cooking temperature increased, with the yield of fairy tofu peaking at 80 °C and attaining a maximum value of 33.90 g/g. It is possible that the majority of the polygalacturonic acid leaches out when the grinding temperature rises, boosting the production of fairy tofu. The growth rate of the fairy tofu rate steadily drops, possibly since when the temperature is more than 50 °C, the enzyme activity is hindered, the pectin dissolving becomes slower, and therefore the growth rate of the fairy tofu rate decreases. When the temperature is too high, the pectin molecules start to cleave, which eventually leads to a decrease in all the quality characteristics of tofu (Levitin, 2005). Therefore, 60 °C, 80 °C and 100 °C grind pulp temperatures were selected for response surface testing for further optimization.

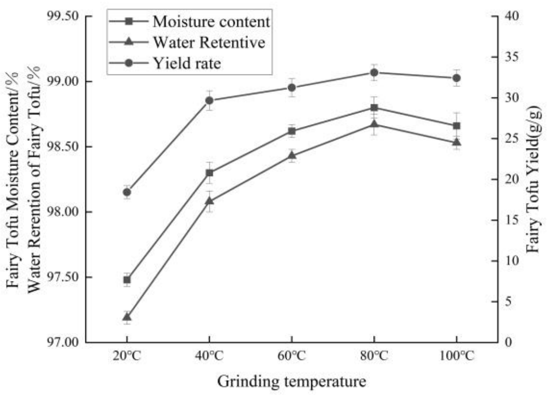


Figure 3. Influence of grinding temperature on the quality characteristics of pure natural fairy tofu

3.2 Response Surface Test Results Analysis

3.2.1.Response surface test results.

Based on the results of single-factor experiments, the yield of fairy tofu was optimized by Box-Behnken's response surface design method. Table 2 discussed the layout and outcomes of the 17 experimental combinations as well as the response surface test, which was performed at three levels for three factors: material-to-liquid ratio (*A*), drying temperature (*B*), and grinding temperature (*C*), and the test was optimized using the fairy tofu yield and as the reference index. The quadratic polynomial regression equation for the yield of fairy tofu (*Y*) was obtained as: Y=44.70+0.89A-0.49B+5.20C-1.66AB-0.98AC+3.12BC -0.76A^2 -3.66B^2 -3.80C^2.

Table 1. Level table of the test factors of the response surface

Level	*A* material to liquid ratio (m:m)	*B* Drying temperature/℃	*C* Grinding temperature/℃
-1	1:50	10	60
0	1:55	20	80
1	1:60	30	100

Table 2. Test results of process optimization response surface

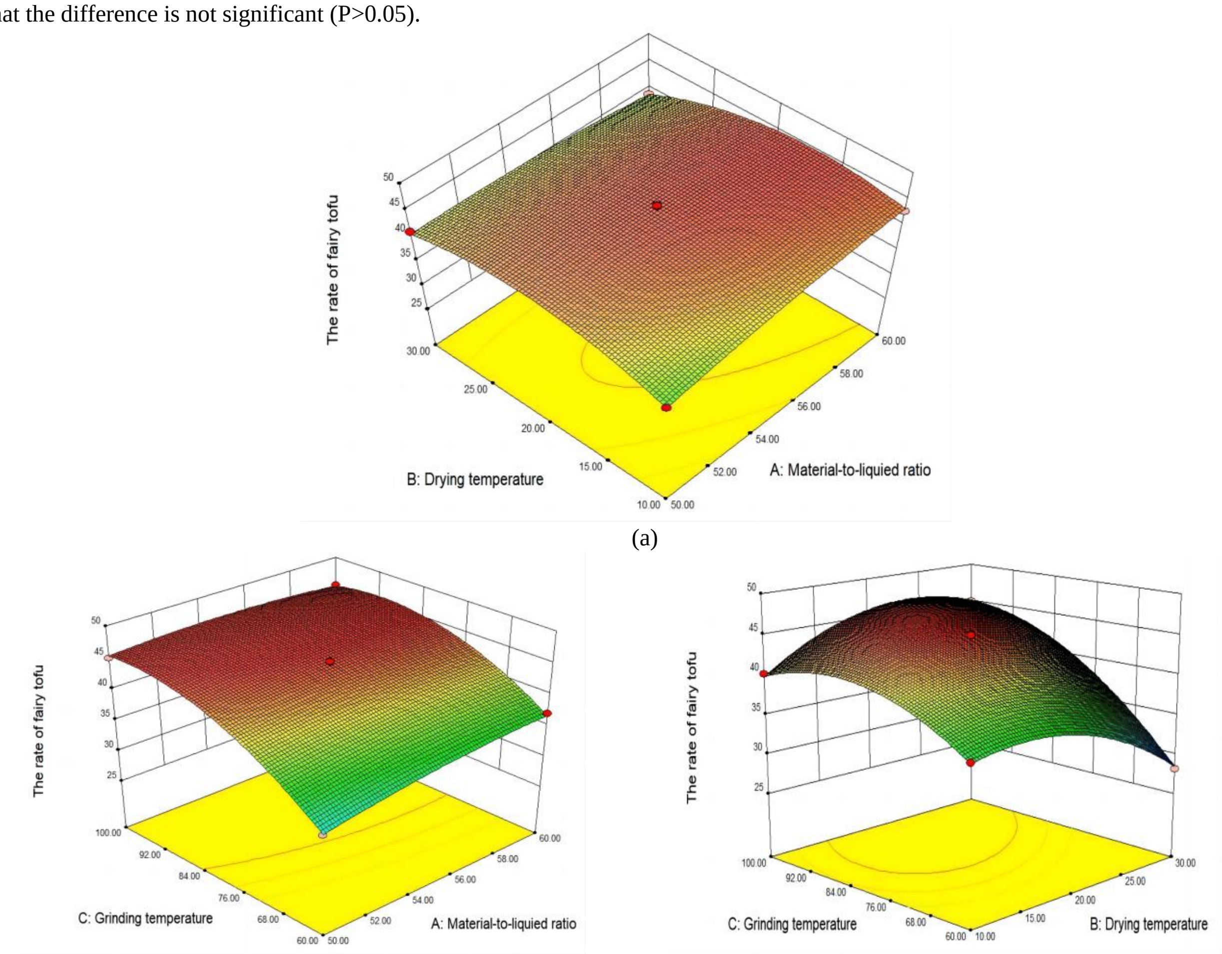
Test number	*A* Material to liquid ratio（m:m)	*B* Drying temperature/℃	*C* Grinding temperature/℃	*Y* The rate of fairy tofu/(g/g)
1	1:50	10	80	38.221
2	1:60	10	80	42.857
3	1:50	30	80	41.017
4	1:60	30	80	39.021
5	1:50	20	60	32.912
6	1:60	20	60	37.121
7	1:50	20	100	45.105
8	1:60	20	100	45.411
9	1:55	10	60	35.799
10	1:55	30	60	28.112
11	1:55	10	100	40.135
12	1:55	30	100	44.931
13	1:55	20	80	44.602
14	1:55	20	80	44.821
15	1:55	20	80	44.132
16	1:55	20	80	45.011
17	1:55	20	80	44.932

Table 3. Table of variance analysis of experimental results of immortal tofu

Source of variance	Square and	Degree of freedom	Mean Square	*F-value*	*P-value*	Significance
Models	408.24	9	45.36	223.36	< 0.0001	**
A Material to liquid ratio	6.40	1	6.40	31.51	0.0008	**
B Drying temperature	1.93	1	1.93	9.51	0.0177	*
C Grinding temperature	216.72	1	216.72	1067.12	< 0.0001	**
AB	11.00	1	11.00	54.14	0.0002	**
AC	3.81	1	3.81	18.75	0.0034	**
B^2	56.30	1	56.30	277.24	< 0.0001	**
C^2	60.75	1	60.75	299.15	< 0.0001	**
Residuals	1.42	7	0.20			

Misfit error	0.92	3	0.31	2.48	0.2007
Pure Error	0.50	4	0.12		
total deviation	409.66	16			
C.V.%=1.10; R^2=0.9965; R^2_{adj}=0.9921					

Note: "*"indicates a significant difference (0.01<P<0.05), "**"indicates a highly significant difference (P<0.01), Blank cells indicate that the difference is not significant (P>0.05).



(a)

(b) (c)

Figure 4. The effect of the interaction of the two factors on the yield rate of the divine tofu

In accordance with the variance assessment of the response surface test findings in Table 3, the model of the yield of fairy tofu, P, is less than 0.01, implying that the regression model effect is extremely noteworthy (P<0.01). The loss of fit term P=0.2007>0.05, it can be seen that the model's loss of fit term is not significant, indicating that the model is reliable. The experimental correction coefficient R^2 =99.65% and the correction coefficient R^2 =99.21% indicate that the equation can respond well to the relationship between each single factor, with an incredible fit and little experimental error, and can explain 99.21% of the variation in the response value of the fairy tofu yield, which can be used for analysis and prediction of the fairy tofu process.

By analyzing the model regression equation and ANOVA results, it can be seen that each factor affects the yield of fairy tofu in the following order: C (grinding temperature) > A (material-liquid ratio) > B (drying temperature), indicating that the grinding temperature has the greatest influence on the yield of fairy tofu, followed by the influence of the material-liquid ratio. When the grinding temperature is too low, the pectin in the *Premna microphylla Turcz* cannot be completely precipitated to promote gel formation; when the grinding temperature is too high, it will cause the pectin to crack, resulting in a decrease in the yield of fairy tofu.

3.2.2.Interaction analysis.

The response surface model may visibly and starkly illustrate the interaction of two variables (factors) as well as represent the effect of other variables (factors) on a certain trait index. Figure 4 depicts the impact of the material-to-liquid ratio, drying temperature, as well as grinding temperature, on the yield of fairy tofu. The graphic indicates that the overall parabolic connection between the two components expands and then drops, and there is an extreme value, which is the response surface's ideal value. Simultaneously, the steeper the curve in the 3D surface plot, the more significant the impact of the component on tofu yield or protein content. The interaction effects between A (material-to-liquid ratio) and B (drying temperature), A (material-to-liquid ratio) and C (grinding temperature), and B (drying temperature) and C (grinding temperature) on the yield of fairy tofu were highly significant ($P<0.01$), which was consistent with the results of the significance test of each partial regression coefficient in the regression equation Y.

3.2.3.Optimal conditions and verification experiments.

According to the optimization scheme derived from Design Expert 8.0 software, the best process parameters for tofu yield are: material-to-liquid ratio of 1:60, a drying temperature of 19.32 °C, and a grinding temperature of 90.57 °C; by comparing the R^2 size and considering the actual operation, the process conditions were changed to a material-to-liquid ratio of 1:60, a drying temperature of 20 °C, and a grinding temperature of 90 °C. The findings are in agreement with the projected value and boost tofu yield by approximately 53.33% as compared to before the experimental optimization.

4 Conclusion

In accordance with the principle of pectin gel to produce pure natural fairy tofu, the impact of various process conditions on the quality characteristics of pure natural fairy tofu was explored in this experiment, and response surface optimization assessments were tailored to determine the most effective process conditions for the production of pure natural fairy tofu. It was found that the material-to-liquid ratio, drying temperature (*Premna*) and grinding temperature had significant effects on the yield of fairy tofu, with the grinding temperature having the most significant effect on the yield of fairy tofu. Based on the results of the single-factor test, quadratic regression equation fitting, ANOVA and interaction analysis were performed using the response surface method to determine the optimal process parameters for the production of pure natural fairy tofu as the material-liquid ratio of 1:60 (g:g), the drying temperature (*Premna*) of 20 °C and the grinding temperature of 90 °C. The yield of pure natural fairy tofu created according to the specified process parameters was 46.02 g/g, an improvement of 55.33% over the yield of pure natural fairy tofu manufactured without optimal processing technology. The results of this analysis can offer practical technical assistance as well as a theoretical foundation for standardized industrial production of high-quality, high-yield pure natural fairy tofu.

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