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Optimization of stir-baked technology for Flos Sophorae Immaturus tea according to quadratic regression rotation-orthogonal design method and quality evaluation

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PAPER

Abstract

This study aimed to optimize the stir-baked technology for Flos Sophorae Immaturus tea (FSIT) and evaluate the quality of FSIT. The optimum stir-baked conditions were found to be as follows: amount, 3.9 kg; rotation speed, 400 r/min; and time required to reach the temperature of 120°C, 5 min and maintained for 3.9 min after adding 15 mL of 1% stevioside. The machine-made FSIT soup was clear and golden in color, with charred taste, no bitterness, no peculiar smell, and improved sensory quality under the above-mentioned conditions. Heavy metal contents and microorganisms did not exceed the national standards.

Keywords: Flos Sophorae Immaturus, quadratic regression rotation-orthogonal design, quality, stir-baked

Introduction

Flos Sophorae Immaturus (FSI), which originated from the flower buds of *Sophora japonica L.*, is a medicinal food homology crude drug planted throughout China. China, which has rich resources, is the origin of Flos Sophorae Immaturus. It is bitter, slightly cold, nontoxic, and distributed in the large intestine and liver channel. It is effective in cooling blood and stopping bleeding, clearing the liver, and reducing fire. Flos Sophorae Immaturus contains large amounts of flavonoids and glycosides, such as rutin, narcissoside, quercetin, isorhamnetin, kaempferol, genistein, total polysaccharides, saponin, tannin, sterol, and vitamin A (Liu *et al.*, 2016; Xie *et al.*, 2014; Krishna, *et al.*, 2012), and has good curative effect on myocardial circulation. Moreover, the drug clears body heat, detoxifies, lowers blood fat and blood pressure levels, softens the blood vessels, reduces inflammation, tones the kidney, prevents arteriosclerosis, and has beauty-holding and antiaging properties (Chua, 2013; He *et al.*, 2016). Flos Sophorae Immaturus has an extremely high nutritional value and contains 19 kinds of amino acids, including essential amino acids required for the human body. The protein content in Flos Sophorae Immaturus is as high as 19.03%, which is 2.2-fold that of common health food silver almond (Wang and Wang, 2009). With emphasis on healthcare, the research and development of functional foods containing Flos Sophorae Immaturus has become extensive, especially the development of Flos Sophorae Immaturus tea (FSIT), which has become a focus of research by the Flos Sophorae Immaturus processing industry.

The stir-baked method for Flos Sophorae Immaturus was first recorded in the Song dynasty, and the Chinese Pharmacopoeia (edition 2015) has also recorded

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stir-baked Flos Sophorae Immaturus. In Chinese medicine, stir-baked Flos Sophorae Immaturus can reduce the side effects of bitter cold, and is used in patients with spleen deficiency. The stir-baked substitute tea prepared from Flos Sophorae Immaturus has evident curative effects on diabetes, hypertension, vascular sclerosis, constipation, various hemorrhoids, pharyngeal dryness, sore throat, red eyes and heat, and heart irritability (Li *et al*., 2017). At present, domestic research on FSIT is primarily focused on handmade or simple mechanism and the development of new compound FSIT (Jiang and Chen, 2008), although scientific reports on the key technologies of the stir-baked process are relatively few. The evaluation method of FSIT is primarily limited to sensory evaluation, and the FSIT production cannot be evaluated through modern methods of measurement.

In the present study, the shape, soup color, aroma, and taste of FSIT are used as sensory indicators. Water extract content, total polysaccharides, total flavonoids, and rutin, narcisin, quercetin, and isorhamnetin contents are used as chemical indicators. The weight distribution was determined through projection pursuit clustering (PPC) with objective assignment, and comprehensive vector distance (*Ci*), used as an evaluation index, was obtained by analyzing the sensory and chemical indices through the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. On the basis of single factor, the quadratic regression rotation-orthogonal combination design was applied for the optimization of the process conditions for stir-baked FSIT, development of an FSIT variant with burnt flavor, and without bitterness and peculiar smell, and evaluation of sensory, physical, and chemical indices of production. This design can provide reference for the development and utilization of Flos Sophorae Immaturus and quality control of FSIT.

Materials and Methods

Materials and reagent

The Flos Sophorae Immaturus sample was collected in 2018 at the Flos Sophorae Immaturus base of Maojiawan, Changping Township, Wanzhou District, Chongqing City. The sample was identified as a dry flower bud of *S. japonica L.* by a researcher (Longyun Li) of Chongqing Academy of Chinese Materia Medica. Rutin reference substance (batch number: MUST−16070511, purity 99%), quercetin reference substance (batch number: MUST−16072203, purity 98%), and isorhamnetin reference substance (batch number: MUST−16092001; purity of 98%) were purchased from Chengdu Mansite Biotechnology Co. Ltd. Narcissoside reference substance (batch number: TAQT−LRLA; purity of 93.1%) was purchased from National Institutes for Food and Drug Control. As a standard solution, the lead (Pb) and cadmium (Cd) standard solutions were purchased from American Sigma Company. Acetonitrile, methanol, and acetic acid of chromatographic grade were purchased from TEDIA Company (USA). All other solvents and chemical reagents were of analytical grade or effective.

Instruments and equipment

Instruments and equipment included are as follows: Agilent 1263 HPLC (Agilent Company, USA), UV-2600 ultraviolet spectrophotometer (Shimadzu Corporation, Japan), Milli-Q Integral 5 pure water meter (Millipore Company, USA), BSA 124-S electronic scales (Sartorius Company, Germany), KQ-250 DB numerical control ultrasonic cleaning instrument (Kunshan Ultrasonic Instrument Co. Ltd., China), XMTB digital display electric thermostatic water bath (Shanghai Yuejin Medical Instrument Co. Ltd., China), G2X-9240 MBE electricity heat drum wind drying oven (Shanghai Boxun Industrial Co. Ltd., China), ZDHW temperature regulating electric heating sleeve (Beijing Zhongxing Weiye Instrument Co. Ltd., China), and CY-900 drum-type medicine stir-fry machine (Kanghua Pharmaceutical Machinery Co. Ltd., China).

FSIT preparation

High-quality Flos Sophorae Immaturus with full granules and large grain size was selected, cleaned, placed in a self-made sterilizing device (patent application number: 201920071851.3), piled up, steamed at a thickness range of 4–6 cm, and cooked for 15–20 min after boiling. Then it was taken out and dried for use. According to the stir-baked temperature, rotation speed, and time designed for the experiment, an appropriate amount of Flos Sophorae Immaturus was placed in a drum stir-baked machine for frying, and an appropriate amount of 1% stevia glycoside was added to it for flavor mixing. At the end of frying, after cooling for 1 h with a blower, the sample was placed for two times in a double-layer vibrating screening machine through 90-mesh screen. Finally, the sample was placed in the color selection machine for removing burnt paste and black Flos Sophorae Immaturus, and the finished product of FSIT was obtained.

Single factor design of stir-baked process for FSIT

Stir-baked amount

The fixed stir-baked temperature was 120°C, and the motor synchronous speed was 400 r/min. At 120°C, the selected stir-baked amounts were 2, 3, 4, 5, and 6 kg. We analyzed water extract, total polysaccharides, total flavonoids, and rutin, narcisin, quercetin, and isorhamnetin contents, and performed sensory evaluation for FSIT for determining preferred stir-baked amount.

Stir-baked temperature

The fixed stir-baked amount was 4 kg, the motor synchronous speed was 400 r/min, the selected stir-baked temperatures were 80, 100, 120, and 140°C. The sample was stir baked for 4 min after the target temperature was reached. Water extract, total polysaccharides, total flavonoids, and rutin, narcisin, quercetin, and isorhamnetin contents were analyzed, and sensory evaluation was performed for FSIT for determining the preferred stir-baked temperature.

Stir-baked rotation speed

The fixed stir-baked amount was 4 kg, and the stir-baked temperature was 120°C. The stir-baked time needed to reach the target temperature was 4 min, and the selected motor synchronous rotation speeds were 200, 300, 400, 500, and 600 r/min. We analyzed the water extract, total polysaccharides, total flavonoids, and rutin, narcisin, quercetin, and isorhamnetin contents, and performed sensory evaluation for FSIT to determine the preferred stir-baked rotation speed.

Stir-baked time

The fixed stir-baked amount was 4 kg, the stir-baked temperature was 120°C, and the motor synchronous rotated speed was 400 r/min. After stir-baking for 5 min and reaching 120°C, the stir-baked timings were 1, 2, 3, 4, 5, and 6 min for the test. We analyzed the water extract, total polysaccharides, total flavonoids, and rutin, narcisin, quercetin, and isorhamnetin contents, and performed sensory evaluation for FSIT to determine the preferred stir-baked time.

Secondary orthogonal rotating combination design of stir-baked process for FSIT

According to the results of the single factor test, four factors for stir-baking that is, amount, temperature, rotation speed, and time, were designed, thereby applying the quadratic regression rotation-orthogonal combination design with four factors and five levels to optimize the FSIT stir-baked process (Ye and Liu, 2017), see Table 1.

Deployment of flavor for FSIT

According to the best process parameters of the test, different volumes of 1% stevioside were sprayed with regard to time, and stir-baking was continued for a certain period. Ten professional tasters were invited to score different samples according to the sensory evaluation criteria mentioned in Table 2, and the average of the results was taken as the final sensory evaluation.

Table 1. Coding list of levels of various factors.

Levels code	Factors			
	Amount (kg) X_1	Temperature (°C) X_2	Time (min) X_3	Rotate speed (r/min) X_4
+2	6	140	6	600
+1	5	130	5	500
0	4	120	4	400
-1	3	110	3	300
-2	2	100	2	200

Determination of physical and chemical indicators for FSIT

Determination of moisture: Refer to the direct drying method in GB 5009.3-2016, 'Determination of moisture in foods'.

Determination of ash: Refer to the first method in GB 5009.4-2016, 'Determination of ash in foods'.

Determination of aflatoxin B1 content: Refer to the second method in GB/T 5009.22-2016, 'Determination of aflatoxin B and G in foods'.

Determination of lead, arsenic and cadmium content: Refer to the inductively coupled plasma-mass spectrometric method in GB/T 35876, Inspection of grain and oils—Determination of sodium, magnesium, kalium, calcium, chromium, manganese, iron, copper, zinc, arsenic, selenium, cadmium, and lead in cereals and derived products'.

Determination of water extract, total polysaccharides and total flavonoids: The sample processing and detection methods were tested according to the relevant methods furnished in the 2015 edition of the Pharmacopoeia of the People's Republic of China (National Pharmacopoeia Commission, 2015).

Determination of rutin, narcisin, quercetin, and isorhamnetin: Refer to the method introduced in a previous report (Tan *et al.*, 2018).

Determination of microbial indicators for FSIT

The total number of bacterial colonies and coliforms of salmonella and Staphylococcus aureus of S. japonica were determined with GB 4789-2016. Shigella assay was performed with GB 4789-2012.

Sensory evaluation of FSIT

According to GB/T 23776-2018, 'Methodology for sensory evaluation of tea', the method of password evaluation was adopted for sensory evaluation and score. The review procedure is as follows:

Sampling → comment on the shape → weighing 3 g → brewing 200 mL of boiling water → turn over the soup → look at the soup color → sniffing aroma → taste.

The product quality consisted of four factors, namely, shape, aroma, soup color, and taste, and each factor was evaluated at three levels, that is, poor, medium, and good. The scores were presented in percentage; the scores for shape, aroma, soup color, and taste were 25%, 30%, 10%, and 35%, respectively. Ten professional tasters were invited to evaluate taste according to the scoring criteria, and the average was taken as the final sensory score. The sensory score criteria are demonstrated in Table 2.

Weight determination by the projection pursuit clustering method

Pursuit Clustering is a new statistical method for processing and analyzing high-dimensional data. The basic idea is to project high-dimensional data onto low-dimensional subspace and determine the optimal projection direction reflecting data structure or characteristics in solving the comprehensive evaluation of high-dimensional problems (Tang, 2010). According to the size of the projection direction, the weight coefficient of each evaluation index can be determined. In this study, the weight of the quality index of FSIT was calculated by the PPC method in DPS software.

Application of technique for order preference by similarity to ideal solution (TOPSIS) method

TOPSIS, as proposed by Hwang and Yoon in 1981 (Hwang and Yoon, 1981), is a sorting method based on the proximity of finite evaluation objectives to ideal objectives. TOPSIS is an effective method that is used commonly in multi-objective decision-making analysis, whose basic idea is to explore optimal and worst solutions (represented by the optimal vector D_i^+ and worst vector D_i^-, respectively) in the finite solutions on the basis of normalized original matrix. Then the distance of each evaluation objective to the optimal and worst solutions is calculated. Thus, the relative proximity between the evaluation objective and optimal solution (represented by the C_i) as the basis of optimal or worst solution evaluation was obtained (Wang *et al.*, 2019; Tang, 2010). The specific method is as follows: *n* evaluation objectives and *m* evaluation indices are set, and the original data could be written as matrix $X = (X_{ij})_{n\times m}$. High- (the larger the better) and low-quality indices (the smaller the better), that is, $Z_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i-1}^{n} X_{ij}^2}}$ and $Z_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} (1/X_{ij})^2}}$, respectively, were normalized. The normalized matrix was $Z = (Z_{ij})_{n\times m}$, with the optimal and worst vectors comprising maximum and minimum values in each column labeled as $Z^+ = (Z_{max1}, Z_{max2} \dots Z_{max})$ and $Z^- = (Z_{min1}, Z_{min2} \dots Z_{min})$, respectively. The distances between the evaluation objective *i* and the optimal and worst solutions were $D_i^+ = \sqrt{\sum_{j=1}^{m} (Z_{max\,j} - Z_{ij})}^2$ and $D_i^+ = \sqrt{\sum_{j=1}^{m} (Z_{max\,j} - Z_{ij})^2}$, respectively. The relative proximity between the evaluation objective *i* and optimal solution is as follows: $C_i = D_i^- / (D_i^+ + D_i^-)$.

Table 2. Sensory scoring standards for FSIT.

Factor	Grade	Index
Shape (25%)	Good (18–25 points)	With charred taste, even and coking yellow in color, full grain, texture solid, crisp
	Middle (9–17 points)	Light fragrance, uneven color, brownish yellow, individual grain broken
	Poor (0–8 points)	Light yellow or brownish brown, with obvious burnt smell and severe grain breakage
Soup Color (10%)	Good (8–10 points)	Clear and golden, no turbidity, no scattered particles
	Middle (4–7 points)	Brownish yellow, no turbidity, no scattered particles
	Poor (0–3 points)	Light green or tan, turbid, with scattered particles
Aroma (30%)	Good (21–30 points)	Strong taste with charred smell
	Middle (11–20 points)	Light fragrance, no charred smell
	Poor (0–10 points)	With charred smell
Taste (35%)	Good (26–35 points)	No astringency
	Middle (13–25 points)	With astringency
	Poor (0–12 points)	With paste taste and strong astringency

Index weight was introduced into the TOPSIS of DPS; the weight coefficient of the chemical indices was calculated using PPC; and the quality indices of the stir-baked FSIT were evaluated comprehensively by combining with TOPSIS. The larger the value of C_i, the better the effect of experimental method.

Results

Single-factor test on stir-baked process of FSIT

The factors influencing the stir-baked process of FSIT primarily included stir-baked amount, temperature, time, and speed. The assignment of water extract, total polysaccharides, total flavonoids, and rutin, narcissoside, quercetin, and isorhamnetin contents, as well as the sensory score in the preparation of FSIT, were evaluated by the objective PPC method and analyzed through the TOPSIS method using DPS software. The results are demonstrated in Table 3. Water extract, total polysaccharides, total flavonoids, and rutin, narcissoside, quercetin, and isorhamnetin contents, as well as the sensory scores, were used as evaluation indicators. According to the ranking of C_i, the FSIT sample with the best quality was obtained after the stir-baked amount was 4 kg, stir-baked temperature was 120°C, stir-baked rotation speed was 400 r/min, and stir-baked time was 4 min at a temperature of 120°C or above. Therefore, the following tests selected the stir-baked amount of 4 kg, the stir-baked temperature of 120°C, the stir-baked speed of 400 r/min, and the stir-baked time of 4 min at zero level.

Optimization of stir-baked process of FSIT by quadratic regression rotation-orthogonal combination design

According to single-factor experiments, the quadratic regression rotation-orthogonal combination design with four factors and five levels was used to optimize the stir-baked process of FSIT. A total of 36 combinations at five levels for each factor were present, and the experimental design and results are demonstrated in Table 4.

According to the test results (Table 4), the statistical analysis software DPS 17.10 was used to obtain the quadratic regression model of C_i for four experimental factors, such as stir-baked amount, temperature, time, and rotation speed, as follows:

$$Y = -19.80272 + 0.64512X_1 + 0.25508X_2 + 0.98855X_3 + 0.00966X_4 - 0.11938X_1^2 - 0.00106X_2^2 - 0.1095\,2X_3^2 - 0.00001X_4^2 + 0.00189X_1X_2 - 0.00309X_1X_3 + 0.00021X_1X_4 - 0.00071X_2X_3 - 0.00001X_2X_4 - 0.00004X_3X_4$$

ANOVA was performed with F_1 = mean square loss/mean square error and F_2 = mean square regression/mean square residual. As demonstrated in Table 5, $F_{Lf} = F_1 = 0.3916 < F_{0.1(10,11)} = 2.25$ and the *P*-value was higher than 0.05 (0.9245), thereby suggesting that the lack of fit was not significant, that is, the regression equation fitted all the test points well, and no other unknown factors affected the results. $F_{regression} = F_2 = 11.2178 > F_{0.01\ (14,21)} = 3.03$ and $P = 0 < 0.\ 01$, thereby indicating that the regression equation was extremely significant, that is, the quadratic regression model was suitable. Among them, the influences of stir-baked temperature (X_2) and all quadratic terms on C_i were extremely significant at $a = 0.01$, stir-baked time (X_3) and stir-baked speed (X_4) were significant at a = 0.05, and the stir-baked volume (X_1) was significant at a = 0.1. However, all interaction terms were not significant. Therefore, at the significant level of $a = 0.1$, the regression equation was simplified by eliminating the nonsignificant terms as follows:

$$Y = -19.80272 + 0.64512X_1 + 0.25508X_2 + 0.98855X_3 + 0.00966X_4 - 0.11937X_1^2 - 0.00106X_2^2 - 0.1095\,2X_3^2 - 0.00001X_4^2$$

The *P*-value influenced by the main effect of each factor can reflect the importance of each factor to the test index. The smaller the *P*-value, the greater the influence of the factor on test result, that is, the greater will be the importance (Sun *et al.*, 2016). As demonstrated in Table 5, the primary and secondary influences of the four factors on C_i followed the following order: stir-baked temperature (X_2) > stir-baked time (X_3) > stir-baked rotation speed (X_4) > stir-baked amount (X_1). The stir-baked temperature had a significant influence on C_i, followed by the stir-baked time, and the effect of stir-baked rotation speed was relatively small, but all reached a significant level ($P < 0.05$), and the stir-baked amount had no significant effect on experimental results ($P > 0.05$). The relationship between various factors and C_i is demonstrated in Figure 1. As demonstrated in Figure 1, the relationship between stir-baked amount (X_1) and C_i was nearly linear, thereby indicating that the stir-baked amount had minimal influence on C_i. The three other factors (i.e., X_2, X_3, and X_4) also had the same trend with increase in temperature, time, and rotation speed. C_i established an upward trend, among which the changed trend of temperature was the most evident one, thereby indicating that temperature had the most significant influence on C_i.

The frequency analysis method was used to find the good stir-baked conditions, and the frequency analysis results are demonstrated in Table 6. As demonstrated in Table 6, in the 95% Confidence Interval (CI), the average of C_i was more than 0.50. The optimized stir-baked scheme is as follows: stir-baked amount = 3.9 kg, stir-baked temperature = 121°C, stir-baked time after reaching the target temperature = 3.9

Table 3. Results of single-factor test.

Factor	Parameter	Content (%)							Sensory-score	C_i	Rank
		Water extract	Total polysaccharides	Total flavonoids	Rutin	Narcissoside	Quercetin	Isorhamnetin			
Amount (kg)	2	32.30	1.18	31.41	25.99	0.79	0.49	0.34	56	0.04	5
	3	31.63	1.89	32.70	26.75	0.88	0.69	0.35	70	0.74	2
	4	35.39	1.89	32.89	27.57	0.93	0.69	0.35	83	0.99	1
	5	32.47	1.74	32.97	27.54	0.91	0.49	0.34	79	0.57	3
	6	30.85	1.88	32.53	26.44	0.81	0.50	0.33	72	0.51	4
Temperature (°C)	80	30.98	1.66	30.24	26.10	0.86	0.64	0.33	49	0.35	4
	100	31.63	1.89	32.70	26.75	0.88	0.69	0.35	70	0.79	3
	120	39.92	2.03	33.12	27.28	0.88	0.69	0.36	75	0.90	1
	140	35.08	2.14	34.48	26.67	0.85	0.69	0.34	65	0.79	2
	160	33.72	1.89	30.92	25.58	0.81	0.63	0.33	32	0.15	5
Rotate speed (r/min)	200	29.31	1.68	26.08	27.42	0.81	0.49	0.28	60	0.04	5
	300	31.63	1.89	32.70	26.75	0.88	0.69	0.35	70	0.67	4
	400	38.21	1.78	32.44	26.17	0.87	0.62	0.38	78	0.91	1
	500	38.70	1.50	35.06	26.16	0.88	0.61	0.35	78	0.73	2
	600	38.15	1.24	34.44	25.47	0.85	0.59	0.34	79	0.68	3
Time (min)	1	31.73	2.12	32.00	26.01	0.88	0.58	0.30	37	0.30	6
	2	33.99	1.63	32.18	26.51	0.89	0.59	0.32	50	0.31	5
	3	31.63	1.89	32.70	26.75	0.88	0.69	0.35	70	0.72	3
	4	39.62	1.90	34.48	27.40	0.92	0.63	0.38	78	0.84	1
	5	34.37	1.94	34.32	25.62	0.87	0.60	0.35	73	0.75	2
	6	33.84	1.66	32.74	26.24	0.79	0.47	0.33	69	0.55	4

Note: D_i^+ is the optimal vector distance; D_i^- is the distance of the worst vector; C_i is the relative proximity of optimal value.

Table 4. Experimental design and results of quadric regression orthogonal rotation combination with four factors and five levels.

Test number	X_1	X_2	X_3	X_4	Content determination (%)							Sensory score	C_i
					Water extract	Total polysaccharides	Total flavonoids	Rutin	Narcissoside	Quercetin	Isorhamnetin		
1	1	1	1	1	33.80	1.67	38.68	26.88	1.03	0.56	0.33	82	0.28
2	1	1	1	–1	34.55	1.34	38.43	31.16	1.00	0.53	0.29	81	0.20
3	1	1	–1	1	47.02	1.26	34.81	29.83	0.98	0.54	0.32	79	0.27
4	1	1	–1	–1	38.20	1.58	33.31	28.4	0.96	0.55	0.33	75	0.23
5	1	–1	1	1	37.00	1.31	33.75	27.61	0.94	0.47	0.30	72	0.16
6	1	–1	1	–1	35.74	1.45	33.21	26.79	0.97	0.47	0.32	80	0.19
7	1	–1	–1	1	35.58	1.73	30.67	27.34	0.95	0.5	0.31	78	0.24
8	1	–1	–1	–1	35.85	1.25	34.42	28.08	0.96	0.44	0.28	77	0.15
9	–1	1	1	1	39.16	1.42	37.15	27.38	0.96	0.43	0.28	81	0.21
10	–1	1	1	–1	34.99	1.81	38.18	30.53	1.07	0.42	0.27	69	0.30
11	–1	1	–1	1	35.53	1.43	34.71	30.72	1.10	0.44	0.28	80	0.23
12	–1	1	–1	–1	36.83	1.87	40.86	30.88	1.10	0.47	0.29	81	0.35
13	–1	–1	1	1	34.52	1.8	38.24	31.01	1.08	0.45	0.28	76	0.30
14	–1	–1	1	–1	33.25	1.74	37.4	30.56	1.10	0.48	0.30	75	0.30
15	–1	–1	–1	1	28.10	1.69	38.04	29.82	1.12	0.47	0.30	70	0.28
16	–1	–1	–1	–1	30.34	1.58	38.41	31.77	1.10	0.45	0.29	79	0.26
17	–2	0	0	0	28.96	1.31	39.13	31.54	1.07	0.46	0.29	81	0.21
18	2	0	0	0	31.51	1.97	41.88	31.85	1.09	0.43	0.27	78	0.35
19	0	–2	0	0	34.27	1.99	40.44	30.33	1.08	0.44	0.28	70	0.35
20	0	2	0	0	34.40	1.81	41.01	31.97	1.09	0.42	0.27	71	0.31
21	0	0	–2	0	31.70	1.67	41.88	32.09	1.15	0.40	0.26	78	0.31
22	0	0	2	0	34.30	1.86	40.47	28.49	1.06	0.53	0.31	75	0.33
23	0	0	0	–2	37.22	1.9	37.33	27.12	0.83	0.68	0.35	73	0.30
24	0	0	0	2	38.86	1.84	34.88	26.44	0.83	0.73	0.37	78	0.31
25	0	0	0	0	38.62	1.91	39.94	29.18	1.284	0.73	0.37	83	0.49
26	0	0	0	0	37.38	1.96	38.17	30.52	1.18	0.64	0.40	88	0.44

(*continues*)

Table 4. Continued

Test number	X_1	X_2	X_3	X_4	Content determination (%)							Sensory score	C_i
					Water extract	Total polysaccharides	Total flavonoids	Rutin	Narcissoside	Quercetin	Isorhamnetin		
27	0	0	0	0	39.93	1.83	44.62	30.79	1.94	0.58	0.37	85	0.73
28	0	0	0	0	39.56	1.91	42.9	35.67	1.97	0.58	0.37	89	0.74
29	0	0	0	0	38.80	1.97	39.21	30.44	1.97	0.58	0.37	80	0.73
30	0	0	0	0	37.20	1.925	43.38	29.34	1.97	0.59	0.37	85	0.73
31	0	0	0	0	38.58	2.15	44.84	31.3	1.96	0.62	0.39	81	0.77
32	0	0	0	0	38.68	1.89	44.19	33.17	1.77	0.94	0.49	82	0.79
33	0	0	0	0	37.62	1.96	41.98	34.22	1.74	0.99	0.52	83	0.78
34	0	0	0	0	38.33	1.96	39.97	30.08	1.74	0.93	0.47	81	0.77
35	0	0	0	0	39.13	2.06	43.69	31.01	1.85	0.74	0.44	80	0.80
36	0	0	0	0	37.85	2.16	42.04	30.03	1.78	0.93	0.49	80	0.81

Table 5. ANOVA table of regression model.

Sources of variation	Sum of squares	Degrees of freedom	Average square	Standard regression coefficient	*F*-values	*P*-values
X_1	9.9885	1	9.9885	2.3281	1.7559	0.0937
X_2	156.1570	1	156.1570	9.2051	5.4658	0
X_3	23.4535	1	23.4535	3.5674	2.6906	0.0137
X_4	22.4100	1	22.4100	3.4871	2.6301	0.0156
X_1^2	22.3462	1	22.3462	−3.4822	6.6377	0
X_2^2	156.1020	1	156.1020	−9.2035	5.9017	0
X_3^2	18.8064	1	18.8064	−3.1945	6.0894	0
X_4^2	19.8862	1	19.8862	−3.2849	6.2617	0
X_1X_2	1.3810	1	1.3810	0.8657	0.7441	0.4650
X_1X_3	0.0075	1	0.0075	−0.0637	0.1214	0.9045
X_1X_4	0.3599	1	0.3599	0.4419	0.8424	0.4091
X_2X_3	0.1944	1	0.1944	−0.3248	0.2791	0.7829
X_2X_4	0.4848	1	0.4850	−0.5129	0.4408	0.6638
X_3X_4	0.0133	1	0.0133	−0.0851	0.1622	0.8727
Regression		14	0.1161		$F_2 = 11.2178$	0
Surplus		21	0.0103			
Loss of quasi		10	0.0057		$F_1 = 0.3916$	0.9245
Error		11	0.0146			
Sum		35				

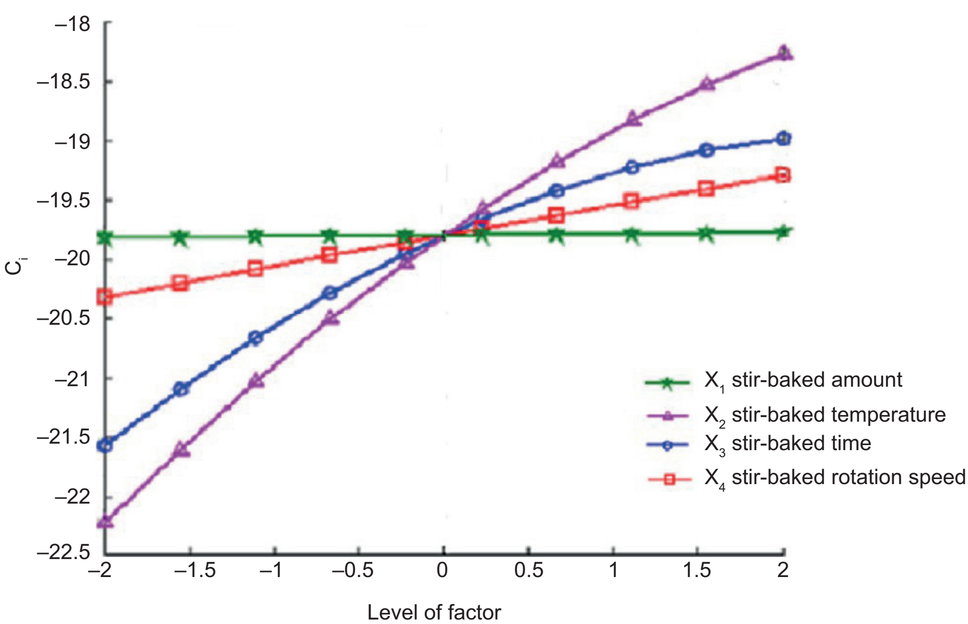

Figure 1. Influence of various factors on comprehensive vector distance (Ci).

min, and stir-baked rotation speed = 393 r/min. However, considering the practical operability of the equipment and production, the optimization scheme was appropriately modified. The modification scheme is as follows: stir-baked amount = 3.9 kg, stir-baked temperature w= 120°C, stir-baked time after reaching the target temperature = 3.9 min, and stir-baked rotation speed = 400 r/min.

Study on taste blending of FSIT

In Section 2.2.4, we obtained the best stir-baked process parameters, that is, the stir-baked amount was 3.9 kg, the stir-baked rotation speed was 400 r/min, and the stir-baked time after reaching 120°C was 5 min; 1% stevia glycoside of different volumes was added, and the stir-baked

Table 6. Value frequency distribution of stir-baked amount (X_1), temperature (X_2), time (X_3), and rotation speed (X_4).

Level	X_1 (kg)		X_2 (°C)		X_3 (min)		X_4 (r/min)	
	Number	Frequency	Number	Frequency	Number	Frequency	Number	Frequency
–2	0	0	0	0	0	0	0	0
–1	3	0.2	3	0.2	2	0.13	3	0.2
0	10	0.67	8	0.53	12	0.8	10	0.67
1	2	0.13	4	0.27	1	0.067	2	0.13
2	0	0	0	0	0	0	0	0
95% Confidence Interval (CI)	–0.3569~0.2236		–0.2774~0.4107		–0.2905~0.1571		–0.3569~0.2236	
Stir-baked conditions	3.63~4.22		117.22~124.11		3.71~4.16		364.31~422.36	
Average	3.9		121		3.9		393	

was conducted for 3.9 min. According to the results of scoring, the product obtained by adding 15 mL of 1% stevia glycoside tasted good. Therefore, the result of the taste blending scheme of FSIT is as follows: 15 mL of 1% stevia glycoside was added per 3.9 kg of Flos Sophorae Immaturus.

Study on quality of FSIT

The sensory evaluation of FSIT was conducted according to the requirements of sensory indices of the National Industry Standard of Substitute Tea. We observed the appearance of the obtained tea: the color was burnt yellow, the grain was full, the texture was firm and crisp, and the smell had a strong coke flavor. Under natural light, the soup of FSIT was clear and golden in color; had no turbidity; had no scattered particles; had no astringency; and had charred taste through watching, smelling, and tasting.

The physicochemical and microbial indicators of FSIT were determined according to the requirements of the Chinese Pharmacopoeia and the National Industry Standard on Physical and Chemical Indices of Substitute Tea and microbiological indicators on food microbial national standards. The results are demonstrated in Table 7; all the indicators complied with the relevant provisions of the industry standards, and the contents of all kinds of microorganisms did not exceed the values specified in the National Standards.

Table 7. Physical and chemical indices of FSIT.

Project	Index	Measured value
Total flavonoids (%)	>20	36.87 ± 0.38
Rutin (%)	>15	29.49 ± 0.72
Moisture (%)	≤13	2.43 ± 0.25
Total ash (%)	≤12	5.23 ± 0.25
Aflatoxin B_1 ($\mu g \cdot kg^{-1}$)	≤5	3.20 ± 0.10
Lead ($mg \cdot kg^{-1}$)	≤5	0.8 ± 0.10
Total arsenic ($mg \cdot kg^{-1}$)	≤0.5	0.13 ± 0.06
Cadmium ($mg \cdot kg^{-1}$)	≤0.5	0.26 ± 0.06
Total number of colonies ($cfu \cdot g^{-1}$)	≤30,000	17,000
Coliform ($MPN \cdot g^{-1}$)	≤30	15
Staphylococcus aureus	Not detected	Not detected
Salmonella	Not detected	Not detected
Shigella	Not detected	Not detected

Discussion

In this experiment, the sensory and chemical indices of the multicomponent content were used to: evaluate the stir-baked process of the new mechanism of FSIT comprehensively; optimize the best process; avoid the limitation and inaccuracy caused by the evaluation of single index; make the stir-baked process of FSIT reasonable; and perfect the quality evaluation system. For the selection of the content evaluation indices, water extract was the general term of soluble substances that could be dissolved in hot water in the tea soup and a comprehensive index that represented the overall level of flavor components in the tea soup (Liu *et al*., 2014). Flavonoids could not only enhance the capillary and has anti-inflammatory, antispasmodic, antiulcer, hypolipidemic, and other pharmacological effects but could also cool the blood to stop bleeding, clear the liver, and purge fire and heat. Flavonoids are one of the substances with evident biological activity and physiological functioning in FSIT (Liu *et al*., 2018). Although the total content of polysaccharides in Flos Sophorae Immaturus is not high but has anti-inflammatory and antiviral effects, maintains vascular resistance, is rouge, and inhibits aldose reductase. The total content of polysaccharides is also one of the basic substances involved in life activities (Zhou and Xia 2011).

The single-factor experiment selects PPC weight analysis combined with TOPSIS as a comprehensive evaluation method for initial screening and stir-baked conditions. Given the difference in the contribution of sensory and chemical indices in evaluating the quality of FSIT in the stir-baked process, the direct use of subjective valuation method to determine the weight coefficient is biased. The PPC method in DPS software is a relatively objective weight assignment method that avoids artificial interference factors of expert grading and eliminates grading steps. Therefore, single-factor experiment is more scientific, reasonable, and advantageous than the subjective weight assignment method. The TOPSIS method could provide effective solutions for the optimization of different evaluation indices and comprehensive evaluation of target groups (Ning *et al.*, 2018) and simplify the statistical analysis of multi-index variable data. The TOPSIS method could be used as an auxiliary analysis method to compare different cooking conditions of Flos Sophorae Immaturus in improving work efficiency and accuracy.

Orthogonal and uniform experiments are generally used to optimize the extraction or stir-baked process. Although these methods avoid a large number of repetitive experiments, they also have defects, such as poor precision and limited scope of application. In this experiment, four factors, including stir-baked amount, temperature, time, rotation speed, and five levels of each factor, were investigated in the stir-baked process of FSIT. The quadratic regression rotation-orthogonal combination design is the best choice. This design is a kind of experimental design method with orthogonal, regression, uniform, and high saturation. This design belongs to an advanced experimental design technique that not only overcomes the faults that the quadratic regression forecast variance in the regression orthogonal design depends on sites in the factor space position but also retains the advantages of the regression orthogonal design experiment (Ye and Liu, 2017) and provide scientific basis for industrialization production of FSIT.

Water extract and volatile components are the material basis of tea flavor. In this report, the descriptions of chemical characteristics of different tea soups prepared from the same fresh Flos Sophorae Immaturus with different stir-frying techniques are based on the relative content of each component. The fresh raw materials of tea and the biochemical composition of tea soup have their own unique index profiles. The multi-component chemical pattern recognition method of tea soup contributes to the better quality control of tea soup. The next step would be to study the overall change of the chemical profile of tea soups because of different fresh raw materials and the processing techniques. In addition, since there are various biochemical components in tea soups, it remains to be explored how to establish a stoichiometry scheme that correlates quality of the tea soup flavor with its main components (including sensory threshold).

Conclusions

The combined PPC-TOPSIS method with the quadratic orthogonal rotation combination design method was used to investigate the four factors, namely, stir-baked amount, temperature, time, and rotation speed, of the machine-made FSIT. The contents of seven components and sensory scores were taken as inspection indices to study the key technology of stir-baked FSIT, and the optimum stir-baked conditions are as follows: stir-baked amount: 3.9 kg, stir-baked rotation speed: 400 r/min, and time needed to reach the temperature of 120°C: 5 min and maintained for 3.9 min after adding 15 mL of 1% stevioside. The technology had high stability and simple operation, and the results established that the machine-made FSIT soup was clear and golden in color, with charred taste, no bitterness, no peculiar smell, and improved sensory quality under the above-mentioned conditions. The sensory, that is, physical and chemical indicators, and microbial indicators agreed with relevant national standards, and the technical standards for the production of stir-baked FSIT could be formulated accordingly. This research provides additional insight into the types of substitute teas and technical support for enterprises to develop the stir-baked technology of FSIT for industrial application, which has practical guiding significance.

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References

Chua, L.S., 2013. A review on plant-based rutin extraction methods and its pharmacological activities. Journal of Ethnopharmacology 150: 805–817. https://doi.org/10.1016/j.jep.2013.10.036

He, X.R., Bai, Y.J. and Zhao Z.F., 2016. Local and traditional uses, phytochemistry, and pharmacology of Sophora japonica L.: a review. Journal of Ethnopharmacology 187: 160–182. https://doi.org/10.1016/j.jep.2016.04.014

Hwang, C. L. and Yoon, K. P., 1981. Multiple attribute decision making: methods and applications. New York: Springer-Verlag.

Jiang, Q.B. and Chen, X.Z., 2008. Extraction of rutin by microwave irradiation with alkali-base and development of compound health care tea from pagoda-tree flowers. Journal of Central South University of Forestry & Technology 28(1): 158–161. http://dx.doi.org/10.3969/j.issn.1673-923X.2008.01.036

Krishna, P.M., Rao, K.N.V., Sandhya, S. and Banji, D., 2012. A review on phytochemical, ethnomedical and pharmacological studies on genus Sophora, Fabaceae. Rev. Bras. Farmacogn. Braz. J. Pharm. 22, 1145–1154. http://dx.doi.org/10.1590/S0102-695X2012005000043

Li, Q.H., Lung, Z.Q. and Wang, J.K., 2017. The chemical components, Chinese medicine processing and pharmacological effect on sophora flower bud. Acta Chinese Medicine and Pharmacology 45(3): 112–116. http://dx.doi.org/10.19664/j.cnki.1002-2392.2017.03.035

Liu, J.L., Li, L.Y. and He, G.H., 2016. Optimization of microwave-assisted extraction conditions for five major bioactive compounds from Flos Sophorae Immaturus (cultivars of Sophora japonica L.) using response surface methodology. Molecules 21: 296. https://doi.org/10.3390/molecules21030296

Liu, J.L., Li, L.Y., He, G.H., Zhang X., Song X.H., Cui G.L., et al. 2018. Quality evaluation of Flos Sophorae Immaturus from different habitats by HPLC coupled with chemometrics and anti-oxidant ability. Chinese Traditional and Herbal Drugs 49(19): 4644–4652. https://doi.org/10.7501/j.issn.0253-2670.2018.19.027

Liu, D.N., Nie, K.L., Du, X., Chang, J. and Li, S.L., 2014. Sensory evaluation and chemical composition of Matcha. Food Science 35(2): 168–172. http://dx.doi.org/10.7506/spkx1002-6630-201402031

National Pharmacopoeia Commission. 2015. Pharmacopoeia of the People's Republic of China: part I. China Medical Science and Technology Press, Beijing.

Ning, D.X., Yan, C.P., Zhao, Y.K, Yang, X., Yang, L.P., Li, N., et al. 2018. Study on agronomic, economic and qualitative characters of different peanut varieties with TOPSIS method evaluation. Journal of Shanxi Agricultural Sciences 46(12): 1986–1989. http://dx.doi.org/10.3969/j.issn.1002-2481.2018.12.04

Sun, R., Zhang, Z.M., Xing, Q.H., Liu, M.M. and Zhuo, W.Y., 2016. Optimization of breed processing technology for flour of wheat Pubing 9946. Journal of Northwest A & F University (Natural Science Edition) 44(5): 185–192. http://dx.doi.org/10.13207/j.cnki.jnwafu.2016.05.025

Tan, J., Li, L.Y., Wang, J.R., Ding, G. and Xu, J., 2018. Study on quality evaluation of Flos Sophorae Immaturus. Natural Product Research and Development 30: 2166–2174, 2202. http://dx.doi.org/10.16333/j.1001-6880.2018.12.021

Tang, Q.Y., 2010. DPS© data processing system. Science Press, Beijing, pp. 1231–1233.

Wang, H.D., Wang X.K., Bi, L.F., Wang, Y., Fan, J.L., Zhang, F.C., et al. 2019. Multi-objective optimization of water and fertilizer management for potato production in sandy areas of northern China based on TOPSIS. Field Crops Research 240: 55–68. https://doi.org/10.1016/j.fcr.2019.06.005

Wang, X.T. and Wang, X.H., 2009. Development of Sophora japonica L. and honey healthy compound beverage. Hubei Agricultural Sciences 48(11): 2827–2830. http://dx.doi.org/10.14088/j.cnki.issn0439-8114.2009.11.010

Xie, Z., Lam, S.C., Wu, J.W., Yang, D.P. and Xu, X.J., 2014. Chemical fingerprint and simultaneous determination of flavonidsoids in Flos Sophorae Immaturus by HPLC-DAD and HPLC-DAD-ESI-MS/MS combine with chemometrics analysis. Anal Methods 6: 4328–4335. https://doi.org/10.1039/C4AY00289J

Ye, X.Y. and Liu, Q.E., 2017. Optimization of extraction technology for protein from Boletel by quadratic regression rotation-orthogonal combination design [J]. Journal of Nuclear Agricultural Sciences 31(4): 728–735. http://dx.doi.org/10.11869/j.issn.100-8551.2017. 04.0728

Zhou, Y. and Xia, X.K., 2011. Research on extracting technology of total polysaccharide from Flos Sophorae Immaturus. Hubei Agricultural Sciences 50(15): 3161–3163. http://dx.doi.org/10.14088/j.cnki.issn0439-8114.2011.15.030