IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 13, Issue 8 Ser. II (August 2020), PP 55-61
www.iosrjournals.org

Effect of Extrusion on Soluble Dietary Fiber of Soy Sauce Residue

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Abstract: *Soy sauce residue (SSR) is rich in nutrients such as 20-30% crude proteins, 10-15% carbohydrates, 21-30% coarse fiber and 7-10% crude lipids and so on, and these residues are mainly disposed of using low-cost methods, such as for feeds and fertilizers which cause a lot of waste of resource, resulting serious pollution to the environment, and disrupting the ecological balance.*

Extrusion is thermal processing that involves the application of high heat, high pressure, and shear forces. Extrusion technology is an economical processing method, and it can achieve protein, starch, and cellulose polymer transformation directly or indirectly in a short time. Therefore, moisture content and mechanical parameters of affect the physical, chemical and nutritional quality of the extruded food product. The content of soluble dietary fiber(SDF) increased, but insoluble dietary fiber (IDF) and total dietary fiber (TDF) decreased upon extrusion cooking.

The extruding technology has been successfully applied to improve the content of SDF in soy sauce residue. Response surface methodology (RSM) was used to optimize the effects of extrusion conditions, namely feed moisture (30-36%), extrusion temperature (90-110 °C) and screw speed (90-110 rpm). According to the regression on coefficients of the quadratic polynomial model, the optimum extrusion parameters were as follows: feed moisture of 34%; extrusion temperature of 107 °C; and screw speed of 97 rpm. Under these conditions, the SDF content of SSR could reach to 3.6%, which increased 100% compared with the unextruded SSR (1.8%).

Key words: *Soy sauce residue, Extrusion, Soluble dietary fiber, Response surface methodology*

Date of Submission: 12-08-2020 Date of Acceptance: 28-08-2020

I. Introduction

Soy sauce is a conventional condiment in Asia and has been used in China for more than 2500 years. Nowadays, it is popular in the western part of the world as a condiment due to its unique taste and aroma. The annual production of soy sauce in China is approximately 6 million tons, accounting for over 65% of the total world production[1]. With the rapid development of soy sauce industry, the recycling and utilization of soy sauce residue (SSR) have attracted much attention because of the environmental problems and a great waste of resources[2]. At present, there is no treatment method to make SSR better used, and at the same time, lead to greater waste of resources[3]. Therefore, it is desired to develop an effective SSR process for the production of some useful materials, which can reduce the burden of the waste treatment of the soy sauce industry[4]. However, few related reports have been found up to now.

Extrusion is thermal processing that involves the application of high heat, high pressure, and shear forces. Extrusion cooking can significantly change the physical, chemical properties and nutritional quality of the product[5]. Zhang[6] et al. reported that the extrusion process improves some properties of SDF from oat bran. Moreover, studies showed that the feed moisture content and extrusion temperature are the most important factors that have an extreme effect on the extruded product properties[7].

According to literature, little information has been reported for extrusion on SSR. Therefore, the objective of this work was to study the effect of extrusion on SDF of SSR, to gain a comprehensive understanding of the relationship between extrusion and changes of fiber structure of SSR. The target was also to find a new way to deeperly utilize soy sauce residue and to improve economic benefits of SSR.

II. Material And Methods

2.1 Sample preparation

SSR was kindly provided by Shandong Yutu Food Co., Ltd (Zibo, China). The initial moisture content of fresh SSR was 84.4±0.3 g/100 g. The SSR was dried in the sun for 4 days to obtain a moisture content of 7.2±0.1 g/100 g. After dried sample was ground to a partical size of 0.5 mm, the resulting SSR power was tightly packaged in a polyethylene bag prior to use.

2.2 Extrusion experiments

Soy sauce residue sample was extruded with a single screw laboratory extruder (Shandong university of technology agricultural products intensive processing center, China). The barrel diameter and length were 79 mm and 1295 mm, respectively, and the screw speed went up to 1200 rpm. A die head with a diameter of 10 mm was used. The parameters for extrusion were optimized using response surface methodology (RSM) with Central Composite Design (CCD). The three independent variables included feed moisture (X1; 30, 32, 34, 36, 38 g/100 g dry basis), barrel temperature (X2; 80, 90, 100, 110, 120℃), and screw speed (X3; 80, 90, 100, 110, 120 rpm). After extrusion, the extruded sample was kept in the oven to obtain a constant moisture content, and was analyzed within 30 days.

A total of 20 experiments were designed based on the six replicates of the midpoint and each experiment was performed in triplicate (Table 1). Regression analysis was performed for the experiment data and the following equation was expressed by the empirical second-order polynomial model:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j \qquad (1)$$

Where Y is the predicted response; β_0 is a constant; β_i is the linear coefficient; β_{ii} is the quadratic coefficient; β_{ij} is the interaction coefficient of variables *i* and *j*; and X_i and X_j are independent variables.

2.3 Soluble dietary fiber (SDF)

Previous studies have based their criteria for selection on precipitating with four volumes of ethanol. SDF content was measured by the method of Rashid[8] with a slight change. The sample (1 g) was weighed in a 50 mL centrifuge tube, added 15 ml of distilled water, adjusted the pH value to 5.5, added 12% cellulase, and reacted in a constant temperature water bath for 4 h. After the reaction, the mixture was centrifuged at 3500g for 10 minutes to obtain a supernatant, and 4 times the volume of 95% ethanol was added to precipitate overnight. The precipitate was collected and dried to obtain soluble dietary fiber.

2.4 Statistical analysis

All experiments were carried out in triplicates. Analysis of variance of the results was performed using the Design-Expert 8.0.5 software. The data were analyzed with an analysis of variance method (ANOVA) with SPSS 25. A probability of $p < 0.05$ was used to determine a significant result. All calculations were performed using the Origin 9.0 software. The data were reported as mean values with corresponding standard deviations.

Table 1 Design and results of experiment.

Run	Feed moisture X_1	Extrusion temperature X_2	Screw speed X_3	The content of SDF (%)
1	1.68	0	0	2.2
2	1	-1	1	2.9
3	1	1	-1	3.0
4	-1	1	1	3.1
5	0	0	0	3.5
6	-1	1	-1	3.4
7	0	0	0	3.4
8	0	1.68	0	3.3
9	0	0	-1.68	2.9
10	0	0	0	3.6
11	1	1	1	2.7
12	0	0	0	3.6
13	-1	-1	1	2.5
14	0	0	0	3.5
15	0	0	0	3.7
16	-1	-1	-1	2.8
17	1	-1	-1	2.5
18	-1.68	0	0	2.3
19	0	-1.68	0	2.7
20	0	0	1.68	3.1

III. Results and discussion

3.1 single factor tests

3.1.1 Effect of the moisture content on SDF

It could be seen from Fig.1 that the SDF content first increased and then decreased with the increase of the moisture content. When the moisture content was 34%, the SDF reached the maximum value of 3.5%. The possible reason was that the humidity of the material increased under the condition of high moisture content, caused the lubricity increased, which reduced the friction between the material and the extruder, shortened the residence time of the material in the extruder. The material did not reach a molten state, and the fiber high polymer molecules were not easy to break, resulting in a decrease in the SDF content[9, 10]. Therefore, the material moisture content of 34% is appropriate.

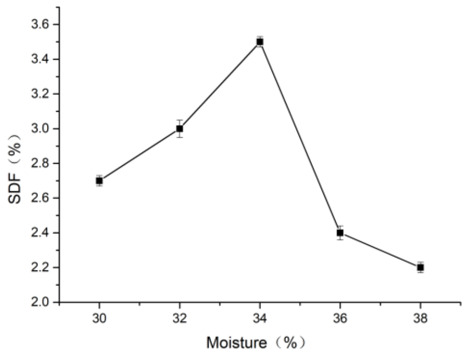


Fig.1 Effect of the moisture content on SDF

3.1.2 Effect of the extrusion temperature on SDF

As the extrusion temperature increased, the SDF content first increased and then decreased from Fig.2. When the extrusion temperature was 100℃, the SDF content reached the maximum value of 3.54%. The possible reason was that the temperature gradually increased, the degree of fiber damage increased, which was beneficial to the conversion of insoluble fibers to soluble fibers; when the extrusion temperature continued to increase, the SDF content tended to decrease, which may be due to excessive high temperature, resulting in rapid evaporation of the moisture in the material[11, 12], so the extrusion temperature was selected as 100 ℃.

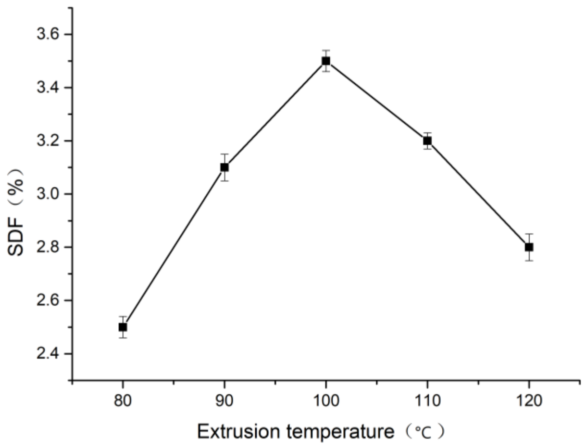


Fig.2 Effect of the extrusion temperature on SDF

3.1.3 Effect of the screw speed on SDF

It could be seen from Figure 3 that as the screw speed increased, the SDF content of the soy sauce residue first increased and then decreased. When the screw speed was 100 rpm, the SDF content of the reached the highest value of 3.51%. The possible reason was the screw speed was low, the material stayed in the cavity of the extruder for a long time, which could make the high-polymer fiber molecules in the material be fully subjected to pressure, shear, friction, and generate more oligomeric fiber molecules for full conversion to soluble fiber; when the screw speed continued to increase, the SDF content showed a downward trend, which may be due to the short residence time of the material in the barrel, so that part of the semi-fiber does not fully achieve the extrusion effect, and the cellulose did not degrade during the extrusion process[13, 14], caused the SDF content decreased, so the screw speed was selected as 100 rpm.

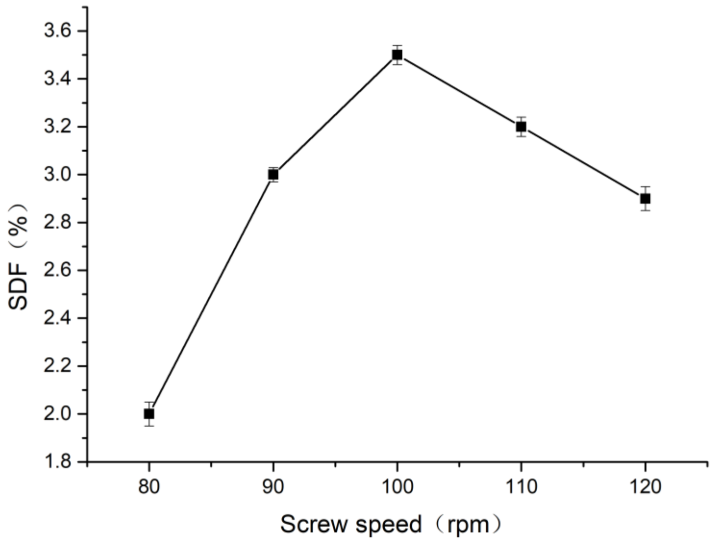


Fig.3 Effect of the screw speed on SDF

3.2. Response surface optimization of extrusion conditions
3.2.1. Model fitting

Table 2 presents the value of responses (content of SDF) at different experimental combination for coded variables. By applying multiple regression analysis on the experimental data, the response variable and the test variables are related by the following second-order polynomial equation:

$$Y=0.0354-0.0006X_1+0.0018X_2-0.0001X_3-0.0011X_1X_2+0.0009X_1X_3-0.0009X_2X_3 -0.0043X_1^2-0.0016X_2^2-0.0016X_3^2 \quad (2)$$

The results of the analysis of variance for the CCD are shown in Table 2. The coefficient of determination (R^2) of the model was 0.9348, which indicated that only 6.52% of the total variation was not explained by the model. The value of the adjusted determination coefficient (Adj R^2=0.8762), coefficients of variance (C.V.) values <10% and lack of fit values >0.1 also confirmed that the model was extremely significant. These parameters can be analyzed to determine the suitability of a model. In addition, Table 2 also shows the regression coefficients of the intercept, linear, and interaction terms of the model and the significance of each coefficient was determined using P-value. The P-value was used as a tool to check the significance of each coefficient, and the smaller the P-value was, the more significant the corresponding coefficient was6. According to Table 2, it was evident that the linear coefficients (X_2), and cross product coefficients ($X1^2$, $X2^2$, $X3^2$) were significant, with very small P-value ($P<0.05$). The other term coefficients were not significant ($P>0.05$).

Table 2 Analysis of variance (ANOVA) for the experiment results.

Source	Sum of squares	Estimated coefficients	df	Mean square	F value	Prob>F
Model	0.000373		9	0.0000414	15.94	< 0.0001
X_1	0.000006	-0.0006	1	0.000005519	2.13	0.1756
X_2	0.000046	0.0018	1	0.0000461	17.75	0.0018
X_3	0.000000	-0.0001	1	0.0000001961	0.076	0.7891
X_1X_2	0.00001	-0.0011	1	0.00001012	3.9	0.0766
X_1X_3	0.000006	0.0009	1	0.000006125	2.36	0.1556
X_2X_3	0.000006	-0.0009	1	0.000006125	2.36	0.1556
X_1^2	0.000261	-0.0043	1	0.0002611	100.54	< 0.0001
X_2^2	0.000037	-0.0016	1	0.00003711	14.29	0.0036
X_3^2	0.000037	-0.0016	1	0.00003711	14.29	0.0036
Residual	0.000026		10	0.000002597		
Lack of Fit	0.00002		5	0.000004094	3.72	0.0878
Pure Error	0.000006		5	0.0000011		
Cor Total	0.000399		19			
R^2	0.9348					
Adj R^2	0.8762					
C.V. %	5.31					

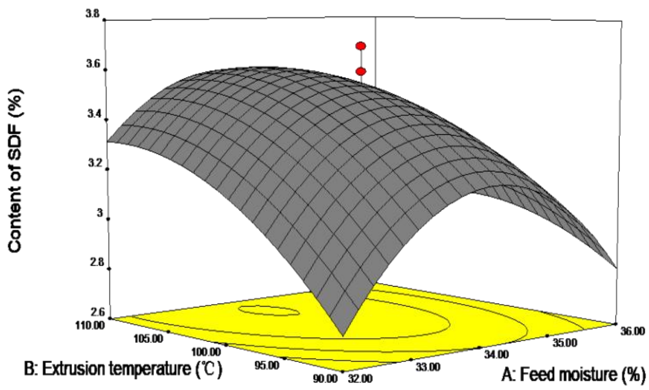
3.2.2. Analysis of response surfaces

The three-dimensional surface plots were obtained according to Eq. (2) that it can be used to determine optimal levels of the variables, and the results of content of SDF affected by feed moisture, extrusion temperature, and screw speed are presented in Fig. 4. Fig. 4A shows the content of SDF affected by different feed moisture and extrusion temperature, when the screw speed was fixed at 0 level. It can be seen that the content of SDF increased with feed moisture and extrusion temperature increasing, and the maximum content of SDF can be obtained when feed moisture and extrusion temperature were 33.60% and 107.21℃, respectively. Fig. 4B shows the effect of the feed moisture and screw speed on the content of SDF at a fixed extrusion temperature of 100℃. With the increasing of screw speed, the content of SDF increased and reached the peak value rapidly at screw speed 97.12 rpm, then followed by a decline with the further increase of screw speed. Fig. 4C shows the effect of the extrusion temperature and screw speed on the content of SDF at a fixed feed moisture of 34%. The content of SDF increased from 2.7% to its peak value of 3.7% and then decreased to 3.1% as screw speed increased from 90 to 110 rpm. The result was in agreement with Huang[10], showing that SDF in extruded orange pomace significantly increased with increasing screw speed and reached a peak value at a screw speed of 299 rpm, and the feed moisture and extrusion temperature used both had a positive impact on the content of SDF.

According to the regression coefficients significance of the quadratic polynomial model, the optimal extrusion conditions were obtained by using response surface methodology as follows: feed moisture, 33.60%; extrusion temperature, 107.21 ℃; and screw speed, 97.12 rpm.

In order to verify the actual production, the modified optimal conditions were set as follows: feed moisture, 34%; extrusion temperature, 107 ℃; and screw speed, 97 rpm. Under these conditions, the average value of SDF is 3.55±0.03%, obtained from experiments, while the predicted value was 3.62%, demonstrated the validity of the RSM model and the model was adequate for the extrusion process, since there was no significant ($P > 0.05$) differences between them.

A



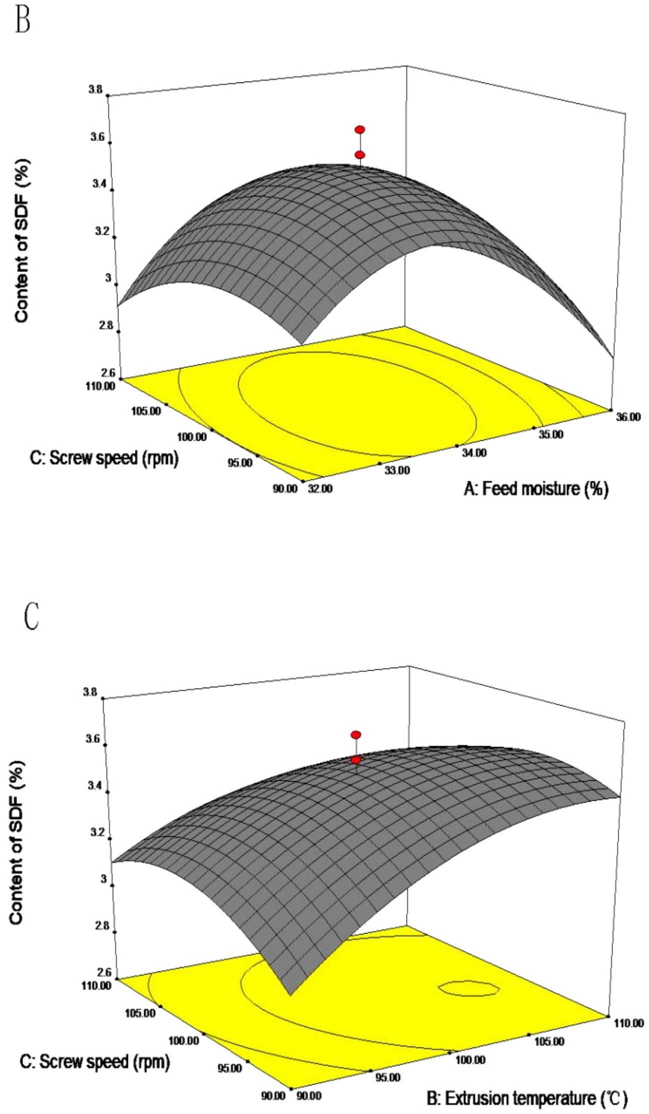


Fig. 4. Response surface plots showing effect of the extrusion parameters on the SDF content from SSR at varying feed moisture and extrusion temperature (A); at varying feed moisture and screw speed (B); at varying extrusion temperature and screw speed (C).

IV. Conclusion

In this study, an extrusion technology was successfully applied to SSR to increase its SDF content under optimal conditions. The optimum extrusion parameters were as follows: feed moisture of 34%; extrusion temperature of 107 °C; and screw speed of 97 rpm, the content of SDF (3.6%) prepared from extruded SSR was significantly higher than the content of SDF (1.8%) prepared from unextruded SSR. It indicated that the extrusion technology can significantly improve the content of SDF in SSR.

References

[1]. Zhao Haifeng, Wang Yaqin, Zou Yang, et al. Natural occurrence of deoxynivalenol in soy sauces consumed in China[J]. Food Control, 2013, 29(1):71-75.
[2]. Chen Xiangrong, Luo Yijie, Qi Benkun, et al. Simultaneous extraction of oil and soy isoflavones from soy sauce residue using ultrasonic-assisted two-phase solvent extraction technology[J]. Separation and Purification Technology, 2014, 128(13):72-79.
[3]. Feng Konglong, Huang Zaocheng, Peng Bo, et al. Immobilization of *Aspergillus niger* lipase onto a novel macroporous acrylic resin: Stable and recyclable biocatalysis for deacidification of high-acid soy sauce residue oil[J]. Bioresource Technology, 2019, 298:1-10.
[4]. Chen Pengfei, Song Hang, Wang Yan, et al. Homogeneous acetylation of hemicelluloses from soy sauce residue in imidazolium-based ionic liquid[J]. Journal of Material Cycles and Waste Management, 2015, 17(3):574-582.
[5]. Kamau Elijah Heka, Nkhata Smith G., Ayua Emmanuel Owino. Extrusion and nixtamalization conditions influence the magnitude of change in the nutrients and bioactive components of cereals and legumes[J]. Food Science and Nutrition, 2020, 8:1753-1765.

[6]. Zhang Min, Bai Xin, Zhang Zesheng. Extrusion process improves the functionality of soluble dietary fiber in oat bran[J]. Journal of Cereal Science, 2011, 54(1):98-103.
[7]. Yuan Guoqi, Pan Yuxiang, Li Weiwei, et al. Effect of extrusion on physicochemical properties, functional properties and antioxidant activities of shrimp shell wastes protein[J]. International journal of biological macromolecules, 2019, 136(1):1096-1105.
[8]. Rashid Summer, Rakha Allah, Anjum Faqir M, et al. Effects of extrusion cooking on the dietary fibre content and Water Solubility Index of wheat bran extrudates[J]. International Journal of Food Science and Technology, 2015, 50(7):1533-1537.
[9]. Bader Ul Ain H, Saeed F, Arshad MU, et al. Improving the bioactive functionality of barley dietary fibre by chemical treatments in combination with extrusion process[J]. International Food Research Journal 2019, 26(1):313-318.
[10]. Huang Ya-Ling, Ma Ya-Sheng. The effect of extrusion processing on the physiochemical properties of extruded orange pomace[J]. Food Chemistry, 2016, 192(1):363-369.
[11]. Zhang Guang, Sun Zhihui, Shi Yanguo, et al. Research on changes of dietary fiber in bean dregs during extrusion process[J]. Advances in Engineering Research, 2018, 173:430-434.
[12]. Andersson Annica AM, Andersson R, Jonsäll Anette, et al. Effect of different extrusion parameters on dietary fiber in wheat bran and rye bran[J]. Journal of food science, 2017, 82(6):1344-1350.
[13]. Singha Poonam, Muthukumarappan Kasiviswanathan. Single screw extrusion of apple pomace-enriched blends: Extrudate characteristics and determination of optimum processing conditions[J]. Food Science and Technology International 2018, 24(5):447-462.
[14]. Ge Qing, Mao Jian-Wei, Cai Chenggang, et al. Effects of twin-screw extrusion on physicochemical properties and functional properties of bamboo shoots dietary fiber[J]. Journal of Biobased Materials and Bioenergy, 2017, 11(4):385-390.

Zhang Haijing, et. al. "Effect of Extrusion on Soluble Dietary Fiber of Soy Sauce Residue." *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, 13(8), 2020, pp. 55-61.