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Study on the Optimization of the Soluble Dietary Fiber Content of Soybean Residue by Steam Explosion Pretreatment

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ABSTRACT

Because a large amount of soybean residue(SR) what is the byproduct of tofu and soymilk industries is produced annually in the world and is a byproduct with a rich nutritional profile, particularly in proteins, fibers, lipids, and bioactive components, a lot of researchers intensify the study on the SR and the processing and utilization of its have attracted more and more attention due to the increased consumption of SR in recent years. Especially the soluble fiber of SR lowers blood cholesterol and triglyceride levels by binding to cholesterol and helping to pass it out of the body, therefore, the composition proportion of soluble components in dietary fiber is an important factor affecting its physiological function. Steam explosion (SE) is a kind of physical method recently used in food pretreatment. In this study, the insoluble dietary fiber of SR converted to soluble dietary fiber by SE treatment and increased the content of soluble dietary fiber, and optimized the condition of SE treatment processing by response surface methodology(RSM). The results showed that the optimum conditions was: moisture content of 76.3%, steam explosion time of 88S， steam explosion pressure of 1.7MPa; on the conditions，the content of SDF was 36.5%. Through the analysis on the physicochemical properties of SE treated SR in the optimum condition, determined that water solubility of SR increased significantly, while swelling capacity, oil and water holding capacities decreased after SE treatment.

Keywords : Soybean residue, Steam explosion, Soluble dietary fiber, response surface method

I. INTRODUCTION

Soybean residue(SR), also named Okara, is the by-pro duct of tofu and soymilk industries. A large amount of SR is produced annually in the world, but only a smal l amount is utilized with the increase of soybean cons umption [1]. However, the utilization of SR is very lo w, and most of them are used as feed or discarded as waste disposal [2]. Dry SR contains about 50% dietary fiber and 20% protein, plus considerable isoflavone, s aponin, mineral elements and other nutrients [3]. Die tary fiber is defined to be plant components that are n ot broken down by human digestive enzymes. In SR t he dietary fiber mainly consists of cellulose, hemicell ulose and pectin. Dietary fiber is the primary component and bioactive constituent of SR. Based on the differences of solubility, dietary fiber can be divided into insoluble dietary fiber (IDF) and soluble dietary fiber (SDF). The two kinds of dietary fibers perform different functions in the human body. IDF can increase the volume of feces and promote intestinal peristalsis, thus preventing constipation, diarrhea and bowel cancer. SDF plays a more important role in modulating metabolic function, and has physiological functions such as enhancing glucose tolerance and lowering cholesterol level [4]. Diabetes researchers believe that consuming large amounts of soluble fiber may help control blood sugar levels after meals by slowing down the rate of carbohydrate absorption in the intestine. Soluble fiber also lowers blood cholesterol and triglyceride levels by binding to cholesterol and helping to pass it out of the body. Therefore, the composition proportion of soluble components in dietary fiber is an important factor affecting its physiological function. It has been suggested that dietary fiber containing 30%–50% of SDF possesses good quality. The portion of SDF in SR is very low, no more than 5% of total dietary fiber. This affects the development and utilization values of SR. Therefore, increasing the SDF content is an important way to improve the quality and enhance the utilization of SR. Methods for increasing the SDF content and improving the properties of SR have been reported, including chemical, enzymatic, fermentation and physical [5]. Among these, physical methods present many advantages, such as short time, simple treatment, low cost and free of chemical residues. Steam explosion (SE) is a kind of physical method recently used in food pretreatment. The sample material is placed into a closed environment with high temperature and high pressure, and the pores of material are filled with steam. When the high pressure is released instantaneously, the superheated steam in the pores will rapidly gasify and the volume will drastically expand, resulting in the "explosion" of cells. The cell walls burst into porous and low molecular weight substances are released from inside of cells. During SE treatment, the actions of acid-like hydrolysis, thermal degradation, mechanical fracture and hydrogen bonds destruction could degrade and destroy the cellulose and hemicellulose into SDF [6]. SE technology has been in existence for more than 80 years and is most used in the pretreatment of wood fiber to improve the accessibility of cellulose to enzyme and chemicals. In recent years, there are also a few reports of SE used in foods, such as increasing the extract yield of flavonoids from fruits [7], and enhancing the SDF content of orange peel [5]. But the research results on steam explosion treatment for dry SR were published, but were not published on the research results of increasing the ratio of soluble components by steam explosion treatment for wet SR. If the wet SR produced in the soybean processing such as tofu and soybean milk is treated by steam explosion, not only a lot of energy for drying can be saved, but also the content of soluble dietary fiber can be increased. In this study, was evaluated the physicochemical properties of wet SR after determining the moisture content and the optimum steam explosion treatment conditions that maximize the content of soluble dietary fiber by Response Surface Methodology(RSM).

II. METHODS AND MATERIAL

2.1 Materials

① Materials

The SR of different moisture content was used the by product of tofu and soymilk processing in 2019. 5.

② Instruments

QBS-80 type steam explosion machine

DZF-6050 type vacuum drier

③ Period for experiment

From July 2019 to December 2019

2.2 Method

① Preparation of SR sample

The sample to treat by steam explosion was prepared two class of wet SR of different moisture content and dried SR. Due to the high moisture content and high viscosity, wet SR is difficult to dry by the traditional dr ying methods. Therefore, vacuum drying technique w as applied to dry SR. In this method the sample was dr ied to prepare the dry SR by a vacuum drier and grou nd into powder and was sieved.

② Selection of sample class for steam explosion treat ment

The dried SR and the wet SR was loaded into the reac tor of QBS-80 steam explosion machine, and then wat er steam was allowed to enter the reactor until 1.5 M Pa and was kept for 90s, then the pressure was release d instantaneously. The SE treated SR samples were col lected, dried by a vacuum drier, ground and sieved wi th 80 mesh. The analysis of chemical composition on t he SE treated SR sample was carried out.

③ Determination of chemical components of steam e xplosion treated SR

Moisture content was measured by oven drying at 95–100 °C (AOAC 934.01)[8]. Protein content was estima ted by the Kjeldahl method (AOAC 960.52)[8]. Crude fat content was analyzed by the Soxhlet extraction me thod (AOAC 960.39)[8]. The ash content was determi ned by the method of combustion (AOAC 923.03)[8]. The contents of total dietary fiber (TDF), insoluble di etary fiber (IDF) and soluble dietary fiber (SDF) were assayed by the enzymatic-gravimetric method (AOAC 991.43)[8].

④ Single factor experiments

—Selection of moisture content

The wet SR of different moisture content(60%, 65%, 70%, 75%, 80%, 85%) was loaded into the reactor of QBS-80 steam explosion machine, and then water stea m was allowed to enter the reactor until 1.5 MPa and was kept for 90s, then the pressure was released insta ntaneously. The SE treated SR samples were collected, dried by a vacuum drier, ground and sieved with 80 mesh. The analysis of the contents of soluble dietary f iber (SDF) on the SE treated SR sample was carried ou t.

—Selection of steam explosion treatment time

The wet SR of moisture content 75% was loaded into the reactor of QBS-80 steam explosion machine, and t hen water steam was allowed to enter the reactor unti l 1.5 MPa and was kept for 30s, 60s, 90s, 120s and 150 s, respectively, then the pressure was released instanta neously. The SE treated SR samples were collected, dr ied by a vacuum drier, ground and sieved with 40–80 mesh. The analysis of the contents of soluble dietary f iber (SDF) on the SE treated SR sample was carried ou t.

—Selection of steam explosion pressure

The wet SR of moisture content 75% was loaded into the reactor of QBS-80 steam explosion machine, and t hen water steam was allowed to enter the reactor unti l the setting pressure(0.5MPa, 1.0MPa, 1.5 MPa, 2.0M Pa and 2.5MPa) and was kept for 90s, then the pressur e was released instantaneously. The SE treated SR sam ples were collected, dried by a vacuum drier, ground a nd sieved with 80 mesh. The analysis of the contents of soluble dietary fiber (SDF) on the SE treated SR sa mple was carried out.

⑤ Experimental methodology

RSM(response surface method) is a statistical method that used quantitative date from appropriate experime ntal design to determine optimal conditions. Therefor e, RSM with Box–Behnken was employed to determin e the optimum conditions for steam explosion treatme nt. The experimental factors were ascertained on the basis of the results of single factor experiments. In this work, the relationships between the responses and th e three selected variables were approximated by the f ollowing second order polynomial function:

$$Y = \beta_0 + \sum_{i=1}^{a} \beta_i X_i + \sum_{i=1}^{a} \beta_{ii} {X_i}^2 + \sum_{ij=1(i\neq 1)}^{a} \beta_{ij} X_i X_j \quad (1)$$

Where Y is the calculated response function and X_i is the corresponding actual value of variable. β_0 is the es timated regression coeffificient of the fitted response at the center point of the design; β_i is the regression c oeffificient for liner effect terms; β_{ij} is interaction effe cts; and β_{ii} is quadratic effects.

The response of experiment design is the contents of soluble dietary fiber (SDF) on the SE treated SR sample according to each experiment condition of design.

A Box–Behnken design was used to estimate the model coefficients. The levels of the three retained variables are indicated in Table 1.

Table 1. Experimental domain of the Box–Behnken design

Factors	Coded symbols	Levels		
		-1	0	+1
Moisture/%	X_1	65	75	85
Pressure Time/S	X_2	80	90	100
Explosion pressure/MPa	X_3	1	1.5	2

⑥ Determination of physicochemical properties of SE treated SR in the optimum condition

—Water solubility

Water solubility has an important impact on the development and application of dietary fiber [12]. Higher water solubility can expand the application of SR in water-soluble food systems (such as beverages) and improve its physiological functions. The water solubility (WS) was determined according to the method of [9] with minor modification. SE treated SR (0.5 g) was gently mixed with 50 mL of distilled water in a beaker. The mixture was then stirred at 90 °C for 30 min in thermostat water bath followed by centrifugation at 3000 rpm for 15 min. The supernatant was collected and dried by a vacuum drier. The residue was weighed. The WS was calculated as follows :

$$WS(\%) = \frac{W_1}{W} \times 100 \quad (2)$$

Where W_1 and W are the weights of the residue after drying and sample, respectively.

—Water-holding capacity

The water-holding capacity (WHC) was determined according to the method of [10] with minor modification. Briefly, 0.2 g of sample was mixed with 10 mL distilled water at room temperature (25 °C) for 1 h. After centrifugation at 3000 rpm for 20 min, the supernatant was removed and the sediment with centrifuge tube was weighed. The WHC was calculated as follows:

$$WHC(g/g) = \frac{W_1}{W} \quad (3)$$

Where W_1 is the weight of the sediment minus sample, and W is the weight of sample.

—Oil-holding capacity

The oil-holding capacity (OHC) was determined according to the method[9] with minor modification. Briefly, 1.0 g of sample was mixed with 5 mL soybean oil at 25 °C for 30 min, shaking once every 5 min. Then it was centrifuged at 4500 rpm for 25 min. The upper free oil was removed and the residue with centrifuge tube was weighed. The OHC was calculated as follows:

$$OHC(g/g) = \frac{W_1}{W} \quad (4)$$

Where W_1 is the weight of the residue minus sample, and W is the weight of sample.

—Swelling capacity

The swelling capacity (SC) was measured according to the method[11] with minor modification. 1.0 g of sample was placed in a test tube, 10 mL of water was added and it was hydrated for 24 h at 25 °C. Thevolume of the sample was recorded. The SC was calculated as follows:

$$SC(mL/g) = \frac{V}{W} \quad (5)$$

Where V is the final volume occupied by sample and W is the weight of sample.

2.3 Statistical analysis

All experiments were triplicated. Analysis of variance (ANOVA) of the results was performed using Design-Expert version 11. The statistical significance of the model terms was determined by calculating the F-value at confidence levels of 95% ($P < 0.05$) and 99% ($P < 0.01$). Data were subjected to analysis of variance (ANOVA) using the software package SPSS version 26 for Windows. Significant differences ($p < 0.05$) of means were determined by the Duncan's multiple range test.

III. RESULTS

3.1 Effect of steam explosion on the composition and content of dietary fiber of SR

The SDF content in SR was very low, which affects its nutritional value and application range. Therefore, increasing SDF content is one of the key measures for improving the quality of SR. SE treatment was applied to increase SDF content of SR in this work and the effects of SE strength (explosion pressure and keep time) on the composition and content of dietary fiber of SR were studied.

Table 2. The change of the composition and content of dietary fiber of SR by steam explosion treatment/%

Material	Crude Ash	Crude Protein	Crude Fat	TDF	IDF	SDF
Dried SR	4.65±0.43[b]	20.41±0.21[b]	13.27±0.24[b]	55.62±0.61[b]	33.16±0.46[a]	22.49±0.66[b]
Wet SR	4.65±0.26[a]	20.36±0.32[a]	13.2±0.45[a]	55.65±0.43[a]	30.39±0.57[b]	25.26±0.79[a]

※ Data with different small letters (a~b) in a column are significantly different at $p<0.05$ by Duncan's multiple range test.

The change of chemical composition and content of dietary fiber of dried SR and wet SR by steam explosion treatment is shown in Table 1. As shown Table 1, the composition and the TDF content of dried SR and wet SR was no different after steam explosion treatment, but on the SDF content, the wet SR was higher than the dried SR. The reason is that a lot of low molecular is produced and released the hydrophilic group, the content of soluble material is increased through the polymerization degree of IDF is decreased and the polymer is dissolved. Thus, the appropriate moisture content should be chosen to get maximum SDF content. The reason for SDF content enhancement is that SE treatment of wet SR was more effective loosen the tight structure of fiber than dried SR.

3.2 The results of single factor experiments

① Determination of SR moisture content

The change of SDF content according to SR moisture content in the steam explosion treatment is shown in Figure 1.

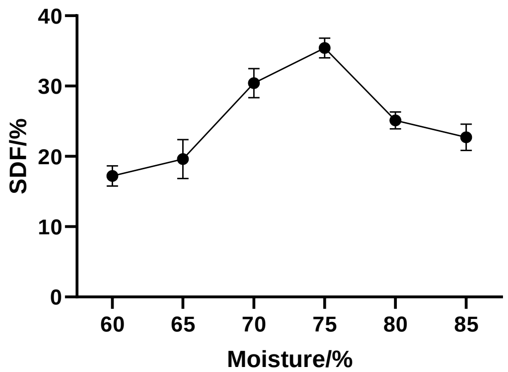


Figure 1. The change of SDF content according to SR moisture content in the steam explosion treatment

As can be seen from Figure 1, in the steam explosion treatment the SDF content of wet SR was rapidly increased from moisture content 70% and when the moisture content was higher than 80%, the SDF content was gradually decreased. Thus, the SDF content was highest in the moisture content 75%, therefore the moisture content of SR selected 75% to carry out the following studies.

② Determination of steam explosion treatment time

The change of SDF content according to steam explosion treatment time is shown in Figure 2.

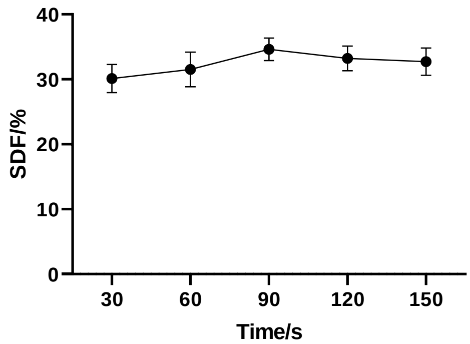


Figure 2. The change of SDF content according to steam explosion treatment time

As can be seen from Figure 2, with the prolong of steam explosion treatment time, the SDF content gradually increased, reaching the highest when steam explosion treatment time was 90s, and then the content decreased slightly. Therefore, 90s was selected as the steam explosion treatment time.

③ Determination of steam explosion pressure

The change of SDF content according to steam explosion pressure is shown in Figure 3.

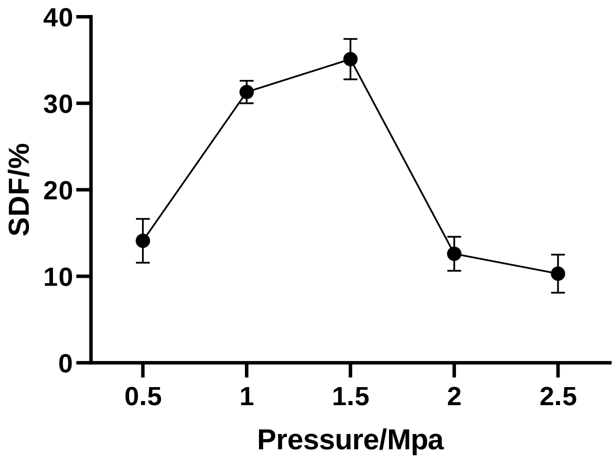


Figure 3. The change of SDF content according to steam explosion pressure

As can be seen from Figure 3, with the increasing of steam explosion pressure, the SDF content increased rapidly, reaching the highest when steam explosion pressure was 1.5MPa, and then the content decreased rapidly. Therefore, 1.5MPa was selected as the steam explosion pressure.

3.3 The results and analysis of response surface experiment

① Response measurements

Experimental values obtained for SDF content of SE treated wet SR are shown in Table 2. The SDF content ranged from 33.65% to 36.49%

Table 3. Box–Behnken design and SDF content

Runs	Factors			SDF content/ %
	X_1:Moisture /%	X_2:Pressure time/S	X_3:Explosion pressure/MPa	
1	65	80	1.5	34.29
2	85	80	1.5	34.61
3	65	100	1.5	33.65
4	85	100	1.5	34.68
5	65	90	1	34.08
6	85	90	1	34.86
7	65	90	2	34.54
8	85	90	2	35.08
9	75	80	1	35.46
10	75	100	1	35.02
11	75	80	2	35.68
12	75	100	2	35.42
13	75	90	1.5	36.49
14	75	90	1.5	36.45
15	75	90	1.5	36.5
16	75	90	1.5	36.46
17	75	90	1.5	36.44

※ Center points is 5

② Estimated model

RSM was used to evaluate the effects of variables on the SDF content, then build a model to find the best setting of the variables that maximize the SDF content and study the combined relationships between the conditions and the SDF content. The second-order models in term of coded variable are given by the following equation.

$$Y = 36.47 + 0.3327X_1 - 0.1594X_2 + 0.1604X_3 + 0.1781X_1X_2 - 0.06X_1X_3 + 0.0463X_2X_3 - 1.46X_1^2 - 0.7023X_2^2 - 0.3696X_3^2 \quad (6)$$

The correction coefficient of the model R^2=0.9997 and R_{Adj}^2 =0.9993 indicate that the model has good fitting degree and small experimental error, so the model is suitable. The results of analysis of variance (ANOVA) for SDF content are given in Table 4. As can be seen, t he model F-value of 2460.51 with a low probability P-value of less than 0.0001 indicted high significance of the model. The lack of fit for an F-value of 1.46 meant that this term was not significantly relative to the pure error, the nonsignificant value of lack fit (<0.05) showed that the quadratic model was valid for this study.

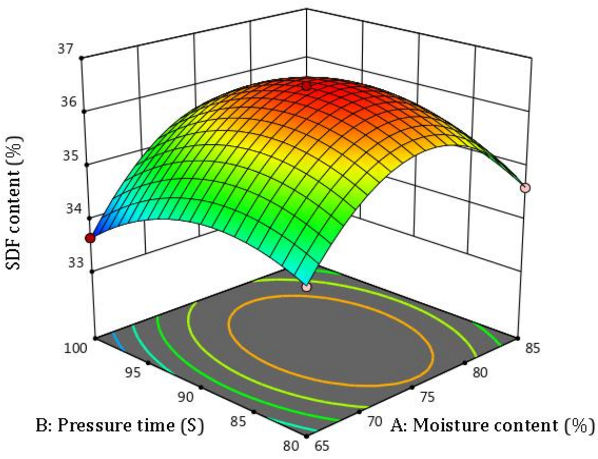
From the results in Table 4, the liner coefficient, the interaction and the quadratic coefficient of all factors were significant by t-test at a level of 0.01. The all of moisture, pressure time and explosion pressure had shown to be the important variable of this model.

Table 4. Analysis of variance of Box-Behnken design (BBD)

Source	Sum of Squares	df	Mean Square	F-value	P-value	Significant
Model	13.97	9	1.55	2460.51	< 0.0001	**
X_1-Moisture	0.8854	1	0.8854	1403.00	< 0.0001	**
X_2-Pressure time	0.2034	1	0.2034	322.29	< 0.0001	**
X_3-Explosion pressure	0.2059	1	0.2059	326.29	< 0.0001	**
X_1X_2	0.1269	1	0.1269	201.16	< 0.0001	**
X_1X_3	0.0144	1	0.0144	22.85	0.0020	**
X2X3	0.0086	1	0.0086	13.56	0.0078	**
X_1^2	8.95	1	8.95	14186.42	< 0.0001	**
X_2^2	2.08	1	2.08	3290.47	< 0.0001	**
X_3^2	0.5751	1	0.5751	911.36	< 0.0001	**
Residual	0.0044	7	0.0006			
Lack of Fit	0.0023	3	0.0008	1.46	0.3514	not significant
Pure Error	0.0021	4	0.0005			
Cor Total	13.98	16				

③ Analysis of response surface

The relationships between the experimental variables and the responses are illustrated in three dimensional representations of the response surfaces. These plots are presented in Figure 4, respectively. The main goal of response surface is to track efficiently for the optimum values of the variables such that the response is maximized. By analyzing the plots, the best response range can be calculated.



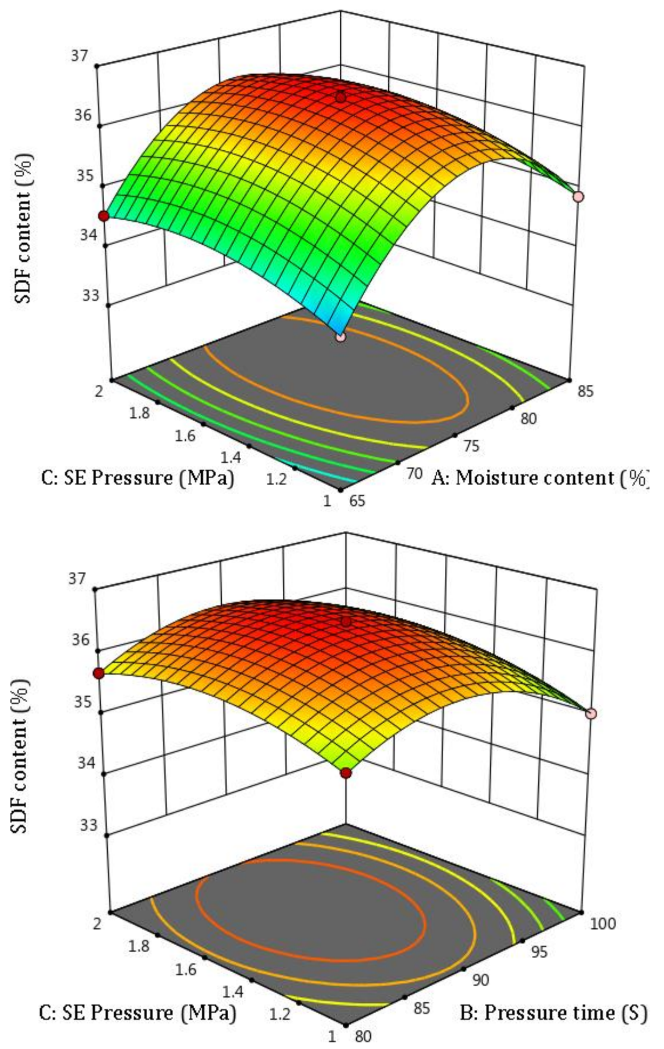


Figure 4. Response surface plots and contour lines of effects of interaction between each factor

Figure 4 shows the three-dimensional response surface plot for SDF content of SE treated SR. It can be seen from Figure 4A, 4B and 4C that the SDF content increases firstly, and decreases afterwards with the increase of pressure time, SE pressure and moisture content, it could be observed that general trends of the three factors are similar. The significant negative linear effect of X_2 (pressure time) and the negative square effect of X_1^2 (moisture content), X_2^2 (pressure time), X_3^2 (SE pressure) in the SDF content were presented in Figure 4A. Therefore, the maximal SDF content was obtained at the low level of pressure time (88S), the middle level of moisture content(76.3%), the middle level of SE pressure(1.7MPa). The effects of the three independent variables on the response value (SDF content) were visually described by the 3-D plot (Figure 4A-4C). The results showed that the low level of pressure time (88S), the middle level of moisture content(76.3%), the middle level of SE pressure(1.7MPa), led to the optimal results.

3.4 The physicochemical properties of SE treated SR in the optimum condition

The physicochemical properties of SE treated SR in the optimum condition is shown in Figure 5.

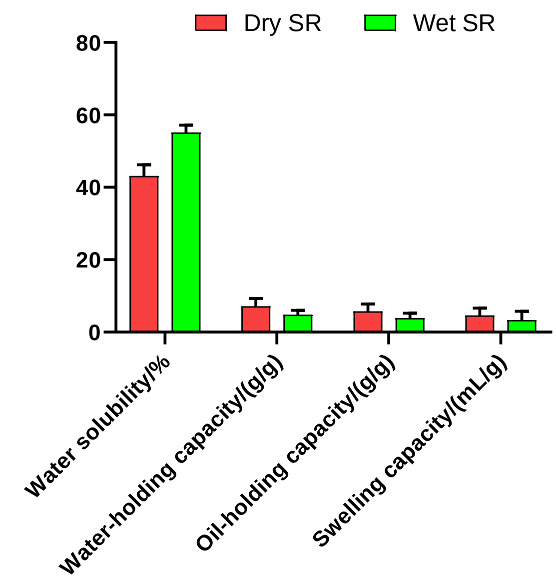


Figure 5. The analysis result on the physicochemical properties of SE treated SR in the optimum condition

As can be seen from Figure 5, the water solubility of wet SR increased than dry SR after SE treatment. This may be due to the fact that SE treatment more effective loosened the tight structure of dietary fiber in SR of high moisture content and degraded some insoluble dietary fiber, resulting in more hydrophilic groups being exposed, thus much enhancing the water solubility of SR. The swelling capacity of wet SR decreased after SE treatment. This might be caused that the original structure of dietary fiber was easily destroyed after SE treatment in the high moisture content of substance, and the amount of macromolecular substances reduced, both leading to the decrease of swelling capacity. T he oil holding capacity of SR decreased after SE treat ment, caused that SE treatment is effective depolymer ized proteins of wet SR, which might lead to the decr ease of oil holding capacity. Furthermore, the porous structure and large specific surface area are beneficial for the absorption property of dietary fiber. The water holding capacity of wet SR decreased after SE treatm ent. The reason is that the SDF of wet SR is more incr eased than the dry SR after SE treatment, on the contr ary, because the IDF of wet SR is decreased, the water holding capacity of wet SR is decreased.

IV. DISCUSSION

Soybean residue(SR) is a by-product of soymilk produ ction with a rich nutritional profile, particularly in pr oteins, fibers, lipids, and bioactive components. SR ha s the potential for value-added production and utilizat ion choices that, at the same time, deliver on the pro mise of increased economic advantages along with a r eduction in environmental pollution. However, the ut ilization of SR is very low, and most of them are used as feed or discarded as waste disposal. Dry SR contains about 50% dietary fiber and 20% protein, plus consid erable isoflavone, saponin, mineral elements and othe r nutrients. SDF lowers blood cholesterol and triglyce ride levels by binding to cholesterol and helping to pa ss it out of the body. Therefore, the composition prop ortion of soluble components in dietary fiber is an im portant factor affecting its physiological function. The portion of SDF in SR is very low, no more than 5% of total dietary fiber. Therefore, increasing the SDF cont ent is an important way to improve the quality and en hance the utilization of SR. Methods for increasing th e SDF content and improving the properties of SR hav e been reported, including chemical, enzymatic, ferm entation and physical. Steam explosion (SE) is a kind of physical method recently used in food pretreatmen t. During SE treatment, the actions of acid-like hydrol ysis, thermal degradation, mechanical fracture and hy drogen bonds destruction could degrade and destroy t he cellulose and hemicellulose into SDF. In this study, the insoluble dietary fiber of SR converted to soluble dietary fiber by SE treatment and increased the conte nt of soluble dietary fiber, and optimized the conditio n of SE treatment processing by response surface met hod(RSM). Firstly, ascertained the effect of the SE tre atment on the wet SR sample, the result was shown t hat the SE treatment on wet SR has more excellent in the improvement of SDF content, SDF content increa sed than the dried SR. Secondly, optimized the SE tre atment on wet SR. Through the single factors experim ents, determined the optimal blocks of each factor, on the basis of these, the experimental design carried out by Response Surface Methodology and obtained the o ptimum condition. As can be seen from Figure 4 and t able 4, the results showed that the optimum conditio ns was: water content of 76.3%, steam explosion time of 88S，steam explosion pressure of 1.7MPa; on the c onditions，the theoretical content of SDF was 36.5%. Through the analysis on the physicochemical propert ies of SE treated SR in the optimum condition, determ ined that water solubility of SR increased significantly, while swelling capacity, oil and water holding capaci ties decreased after SE treatment. The water solubility of wet SR increased than dry SR after SE treatment. T his may be due to the fact that SE treatment more effe ctive loosened the tight structure of dietary fiber in S R of high moisture content and degraded some insolu ble dietary fiber, resulting in more hydrophilic groups being exposed, thus much enhancing the water solub ility of SR. The swelling capacity of wet SR decreased after SE treatment. This might be caused that the origi nal structure of dietary fiber was easily destroyed afte r SE treatment in the high moisture content of substa nce, and the amount of macromolecular substances re duced, both leading to the decrease of swelling capaci ty. The oil holding capacity of SR decreased after SE t reatment, caused that SE treatment is effective depoly merized proteins of wet SR, which might lead to the d ecrease of oil holding capacity. Furthermore, the poro us structure and large specific surface area are benefic ial for the absorption property of dietary fiber. The w ater holding capacity of wet SR decreased after SE treatment. The reason is that the SDF of wet SR is more increased than the dry SR after SE treatment, on the contrary, because the IDF of wet SR is decreased, the water holding capacity of wet SR is decreased.

V. CONCLUSION

In this study, ascertained the effect of the SE treatment on the wet SR sample, the result was shown that the SE treatment on wet SR has more excellent in the improvement of SDF content, SDF content increasedthan the dried SR. And optimized the SE treatment on wet SR, through the single factors experiments, determined the optimal blocks of each factor, on the basis of these, the experimental design carried out by Response Surface Methodology and obtained the optimum condition. The results showed that the optimum conditions was: water content of 76.3%, ，steam explosion time of 88S，steam explosion pressure of 1.7MPa; on the conditions，the theoretical content of SF was 36.5%. Through the analysis on the physicochemical properties of SE treated SR in the optimum condition, determined that water solubility of SR increased significantly, while swelling capacity, oil and water holding capacities decreased after SE treatment. Further research works will be done to investigate the change of bioactivities of SE treated SR and the application effects on foods such as flour products, beverages, etc.

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