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Research Article

Effect of Water Steam Treatment on Extrusion Texturization Product Properties

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Abstract: In this report, we mainly study the effect of water steam pretreatment conditions of raw materials on color, texture parameters, protein quality, solvent retention capacity and other properties of defatted soy flour extrusion texturization product and then trying to establish the regression model. The result shows that the correlation coefficients can be used for predicting the value of $L*$, hardness, cohesiveness, resilience, WSRC, LASRC, SCSRC and the interaction of covalent bond and non-covalent bond of extruded product of defatted soy flour steam treated. The effect of moisture content of raw material on hardness ($p = 0.0010$) and LASRC ($p = 0.0041$) is significant. The temperature of steam treatment on WSRC ($p = 0.0017$) and the interactions of covalent and non-covalent protein ($p = 0.0003$) is the most significant impact. The interactive effects of steam treatment temperature and moisture content on SCSRC of product is significant ($p = 0.0002$). The time of steam treatment has the most significant influence on $L*$ ($p = 0.0001$), cohesiveness ($p = 0.0019$) and resilience ($p = 0.0008$) of product.

Keywords: Extrusion texturization, regression model, water steam pretreatment

INTRODUCTION

The present study (Odell, 1966) focused on the vegetable protein, soybean protein, also include wheat protein, soy protein and rapeseed protein etc. Texturized protein has the higher nutritional value and the growing field of application for its similar structure of muscle, fiber characteristics and meat chewing feeling. However, texturized protein has the limitation in the field of application of emulsified meat products (Zheng, 2003).

Wang *et al*. (2005) found that protein content of protein isolated by hot water cooking process is less than 80%. This showed that some non-protein substances precipitated with protein isolated in the process of extraction. The soybean meal contains protein and carbohydrates and then Maillard reaction, a kind of non-enzymatic reactions, was likely to occur in food processing (Oliver *et al*., 2006). Thus, protein and carbohydrates occurred Maillard reaction so as to reduce the purity of the protein isolate. Meanwhile, it also showed that the structure of high temperature soybean meal protein had been changed in water steam treatment.

The raw materials of high pressure water steam treatment can make the protein denaturation, which affects some properties of extruded products. In this report, we mainly study the effect of water steam pretreatment conditions of raw materials on color, texture parameters, protein quality, solvent retention capacity and other properties of defatted soy flour extrusion textrization product and then trying to establish the regression model.

MATERIALS AND METHODS

Materials: Defatted soy flour with 39.4% protein, was obtained from the market. All other chemicals were analytical and the water were distilled water.

Methods: In this test, using SYSLG 32-Ⅱextrusion experiment machine with a cylinder temperature of 140°C and a screw speed of 175 r/min, we study the effects of pretreatment temperature, pretreatment time and moisture content of raw material on defatted soy flour extrusion texturization product properties and establish regression model of pretreatment conditions on extrusion texturization product properties. The experiment used the uniform design of three factors and ten levels and was arranged in the U_{10} (10^{10}) uniform design table. Specific test scheme was shown in Table 1.

Regression analysis is the main method for analysis of uniform design data. When the number of factor levels are (p+1) (p+2)/2 times more than the test factors, the quadratic polynomial regression model can be used for data analysis. There are three factors and ten levels in this experiment, therefore, the quadratic polynomial regression model can be used to analyze the effects of pretreatment of raw material on defatted soy flour extrusion texturization product properties. And then quadratic polynomial stepwise regression analysis

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Table 1: $U_{10}(10^{10})$ design of steam treatment on extrusion raw material

	Factor		
Test number	Temperature (°C) 1	Time (min) 5	Water content (%) 7
1	1(67)	5(15)	7(45)
2	2(74)	10(30)	3(25)
3	3(81)	4(12)	10(60)
4	4(88)	9(27)	6(40)
5	5(95)	3(9)	2(20)
6	6(102)	8(24)	9(55)
7	7(109)	2(6)	5(35)
8	8(116)	7(21)	1(15)
9	9(123)	1(3)	8(50)
10	10(130)	6(18)	4(30)

was adopted to analyze the correlation characteristic of extrusion texturization product by DPS 7.05.

Evaluation index:

Color: Color was one of the indexes to evaluate the quality of extruded products. And it reflected the level of chemical and nutritional changes in the process of extrusion texturization. The color of the samples was expressed in using uniform color space theory recorded in CIE (International Commission on illumination) (1976) as L^*, a* and b*. Coordinate L^*represents the luminance or lightness factor which indicates how light or dark the sample is. a* and b*, the chromaticity coordinates, represent the redness (+)/greenness(-) and yellowness (+)/blueness(-) color attributes. ∆E represents the color difference of samples with white board (Badescu *et al*., 1999; Sgaramella and Ames 1993; Fang *et al*., 2014). The smaller value indicates the smaller difference with white board and the analyte more bright and white.

This experiment made color analysis to dried samples of extrusion texturization product by automatic color measurement colorimeter DC-P3. Each sample does five parallel determination times and the results were showed in a "average value±standard deviation". The standard values for the white tile calibration were L*s = 97.13, a*s = 0.21, b*s = 1.87. Total color difference (∆E) values were calculated using the equation $\Delta E = [(L^*-L^*s)^2+(a^*-a^*s)^2+(b^*-b^*s)^2]\ 1/2$ (Sotillo and Hettiarachy, 1994).

Textural properties: Texture is the most important evaluation index of extrusion texturization and will vary greatly with small variation of production operation. It is necessary to predict its texture characteristics for the concern of the quality of the product acceptability. The textural properties of fresh extrusion texturization including the hardness, elasticity, cohesiveness, chewiness and resilience, etc. Hardness means the necessary force of sample reaching a certain deformation time. And the greater of the value means the higher of hardness of sample. Elasticity means the height or volume ratio the sample recover to the former of deformation from removing the deformation force. And the greater of the value means the higher of elasticity of sample. Chewiness means the required energy of chewing solid sample to the steady state of swallowing. And the smaller of the value means the better of the taste. Cohesiveness means the probe works to overcome the stickiness resistance of the sample surface moving upward. And the greater of the value means the higher of stickiness of sample. Adhesiveness can simulate the required energy of breaking semi solid sample the steady state of swallowing.

A 10 mm long pieces cut from fresh natural cooling extrusion texturization was compressed using a P/36R probe to 50% of its original thickness at a speed of 1 mm/s using a TA.XT Plus type matter, reciprocating 2 times at intervals of 5 sec. Each sample does three parallel determination times and the results were showed in an "average value ± standard deviation".

Determination of solvent retention capacity: Solvent Retention Capacity (SRC) is the ability of the flour keeping the solvent during a certain centrifugal force. And it is expressed as a percentage of keeping the solvent in 100 g flour of moisture content of 14% (mass fraction). Usually distilled water, 50% (w/w) sucrose solution, 5% (w/w) sodium carbonate solution and 5% (w/w) lactic acid solution are used to reflect the quality and functional properties of flour.

This test studied the solvent retention force characteristics of sample referring to the determination of flour (AACC, 2004). Quality and functional of the sample can be comprehensive reflected in four aspects; for instance, Sucrose Solvent Retention Capacity (SSRC) can reflect the characteristics of pentosan content and gliadin in the sample; Sodium Carbonate Solvent Retention Capacity (SCSRC) reflecting the damage degree of starch grains in the sample; Lactic Acid Solvent Retention Capacity (LASRC) reflecting the gluten properties in the sample; and Water Soluble Retention (WSRC) reflecting characteristics of all components in the sample.

The specific experimental procedures: weighing about 1.000 g sample powder in 50 mL covered the centrifuge tube, adding about 5.00 g distilled water, 50% sucrose, 5% sodium carbonate solution and 5% lactic acid solution respectively as a solvent. And the centrifugal should be shaken violently to mix sample powder and solvent evenly, static swelling for 20 min and mixing for 5 sec every 5 min during this period. After that, the centrifugal tube was arranged in a centrifuge, centrifuging at 3000 rpm for 15 min. After centrifugation, discarded the supernatant slowly. The centrifugal tube was inversed on the filter paper for 10 min and weighing with cover.

For every solvent:

$$SRC\ (\%) = [(W_3-W_1)/W_2*86/\ (100-M)-1]*100 \quad (1)$$

where,

W_1 = Mean the quality of samples
W_2 = The quality of centrifugal tube with a lid
W_3 = The quality of centrifugal tube with a lid and samples after drainage
M = The moisture content of samples

Protein solubility: The leaching solution was compounded with phosphate buffer solution (P), sodium dodecyl sulfate (SDS), sodium sulfite (N) and urea (U) (Adjusted to pH 7.6) (Liu and Hsieh, 2008, Chen *et al*., 2011, Hager, 1984):

0.02 mol/L (P)
0.02 mol/L (P) +1.5% (m/v) (S)
0.02 mol/L (P) +0.1 mol/L (N)
0.02 mol/L (P) +8 mol/L (U)
0.02 mol/L (P) +1.5% (m/v) (S)+0.1 mol/L (N)
0.02 mol/L (P) +1.5% (m/v) (S)+8 mol/L (U)
0.02 mol/L (P) +0.1 mol/L (N)+8 mol/L (U)
0.02 mol/L (P) +1.5% (m/v) (S) +0.1 mol/L (N) +8 mol/L (P)

Determination the moisture content of samples before digestion. Weighting about 0.2 g samples and mixed with 6 mL extraction solvent. The samples were water bath extraction at a temperature 40°C for 3 h and shaken every half hour. After that, centrifuging at 4000 rpm for 20 min, collecting the supernatant to constant volume to 10 mL. Then the soluble protein content was determined by Lowry method in wavelength 500 nm (Lin *et al*., 2000):

Protein solubility: PS (g/g) = X_1/X_2

where,

X_1 = The soluble protein content of samples in different extracting solution
X_2 = The content of total protein in the samples

The various chemical cross linking could be calculated based on the protein solubility of samples in different extracting solution (Zhang and Du, 2011).

Natural state role binding protein (PI), ①
Hydrophobic interaction binding protein (SI), ②-①
Role-binding protein disulfide bonds (NI), ③-①
Hydrogen bonds binding protein (UI), ④-①
Hydrophobic interactions and disulfide binding protein interactions (SNI), ⑤+①-②-③
Hydrophobic interactions and hydrogen bond interactions binding protein (SUI), ⑥+①-②-④
Disulfide bonds and hydrogen binding protein interaction (NUI), ⑦+①-③-④
Hydrophobic interaction, disulfide and hydrogen bonding interactions binding protein (SNUI), ⑧+②+③+④-①-⑤-⑥-⑦

RESULTS AND DISCUSSION

Effects of steam treatment on color qualities of extruded products: Color can reflect the level of chemical and nutritional changes in the process of extrusion texturization. Table 2 summarizes the results of the determination of color of extrusion texturization products of defatted soy flour steam treated. A regression equation of the steam treatment temperature, time and moisture content of defatted soy flour to color of extrusion texturization products can be tried to establish based on the statistical results.

The correlation coefficients of regression equation of lightness (L^*), redness (a*), yellowness (b*) and redness (ΔE) can be obtained by the quadratic polynomial stepwise regression analysis. Lightness (L^*):

$$L^* = 79.1904-0.0565X_1-2.9321X_2+0.3792X_3+0.0015X_1^2+0.0672X_2^2+0.0043X_3^2-0.0104X_1X_3+0.0158X_2X_3 \quad (2)$$

R = 1.0000, F = 39489.2887>F0.01 (8,1) = 5981 and the significant at p = 0.0039<0.01. The result shows that the correlation coefficients (2) can be used for predicting the value of lightness (L^*) of extruded product of defatted soy flour vapor treated. The effect of each factor on extrusion texturization of L^*can be ordered:

Table 2: Effects of steam treatment on color qualities of extruded products

Test number	X_1: Temperature (°C)	X_2: Time (min)	X_3: Water content (%)	*L**	*a**	*b**	*ΔE*
1	67(78*)	15	45	55.21	2.03	15.89	44.24
2	74(87*)	30	25	59.78	1.51	17.76	40.61
3	81(85*)	12	60	56.56	3.17	18.08	43.79
4	88	27	40	58.45	3.06	15.77	41.20
5	95	9	20	59.05	1.06	17.11	41.03
6	102	24	55	54.13	2.57	17.68	45.88
7	109	6	35	58.21	1.41	16.93	41.75
8	116	21	15	54.77	2.96	17.61	45.27
9	123	3	50	55.34	2.67	17.33	44.63
10	130	18	30	49.88	3.21	16.46	49.54

* Means the actual temperature in the vertical pressure steam sterilizer

Table 3: Significance of regression coefficient for L* of extruded product

Factor	Partial correlations	t-test value	Significant (p)
X_1	-0.9680	3.8549	0.0612
X_2	-1.0000	104.8209	0.0001
X_3	0.9999	60.2502	0.0003
X_1^2	0.9984	17.5472	0.0032
X_2^2	1.0000	116.2751	0.0001
X_3^2	0.9998	53.7171	0.0003
X_1X_3	-0.9999	92.6424	0.0001
X_2X_3	0.9999	67.7367	0.0002

$X_2 = X_2^2 = X_1X_3 > X_2X_3 > X_3^2 = X_3 > X_1^2 > X_1$ (Table 3)

Redness (a*): $R = 0.9704$, $F = 2.0185 < F_{0.05}$ (8, 1) = 239 and the significant at $p = 0.4985 > 0.05$. Yellowness (b*): $R = 0.9968$, $F = 19.5199 < F_{0.05}$ (8, 1) = 239 and the significant at $p = 0.1734 > 0.05$. Redness (△E): $R = 0.9491$, $F = 133.0063 < F_{0.05}$ (8, 1) = 239 and the significant at $p = 0.1734 > 0.05$. About them, the quadratic polynomial stepwise regression analysis is not applicable to predict the value of redness (a*), yellowness (b*) and redness (△E) of extruded product of defatted soy flour steam treated.

Effects of steam treatment on texture profile of extruded products: Texture is the most important evaluation index of extrusion texturization and will vary greatly with small variation of production operation. Table 4 summarizes the results of the determination of texture characteristics of extrusion texturization products of defatted soy flour steam treated. A regression equation of the steam treatment temperature, time and moisture content of defatted soy flour to texture characteristics of extrusion texturization products can be tried to establish based on the statistical results.

The correlation coefficients of regression equation of hardness, elasticity, cohesiveness, adhesiveness, chewiness and resilience can be obtained by the quadratic polynomial stepwise regression analysis.

Hardness:

$$\text{Hardness} = 10237.4391-127.2874X_1-300.0086X_2-65.4416X_3+0.5037X_1^2+4.0679X_2^2+0.5368X_3^2+1.2234X_1X_2+1.0299X_2X_3 \quad (3)$$

$R = 0.9999$, $F = 794.0900 > F_{0.05}$ (8, 1) = 239 and the significant at $p = 0.0274 < 0.05$. The results shows that the correlation coefficients (3) can be used for predicting the hardness of extruded product of defatted soy flour steam treated. The effect of each factor on extrusion texturization of hardness can be ordered:

$X_3 > X_1 = X_2X_3 > X_1^2 > X_3^2 > X_2^2 > X_2 > X_1X_2$ (Table 5)

Cohesiveness:

$$\text{Cohesiveness} = 7.0316-0.0872X_1-0.2893X_2+0.0004X_1^2+0.0041X_2^2+0.0002X_3^2+0.0012X_1X_2-0.0003X_1X_3+0.0007X_2X_3 \quad (4)$$

$R = 0.9999$, $F = 534.6724 > F_{0.05}$ (8, 1) = 239 and the significant at $p = 0.0334 < 0.05$. The results shows that the correlation coefficients (4) can be used for predicting the cohesiveness of extruded product of defatted soy flour steam treated. The effect of each factor on extrusion texturization of cohesiveness can be ordered:

$X_2 > X_2^2 > X_1 > X_1X_2 > X_1^2 > X_2X_3 > X_1X_3 > X_3^2$ (Table 6)

Resilience:

$$\text{Resilience} = 1.0151-0.0101X_1-0.0437X_2-0.0000X_3+0.00003X_1^2+0.0005X_2^2+0.0002X_1X_2-0.0000X_1X_3+0.0001X_2X_3 \quad (5)$$

$R = 1.0000$, $F = 3327.7697 > F_{0.05}$ (8, 1) = 239 and the significant at $p = 0.0134 < 0.05$. The results shows that the correlation coefficients (5) can be used for predicting the resilience of extruded product of defatted soy flour steam treated. The effect of each factor on extrusion texturization of resilience can be ordered:

$X_2 > X_2^2 = X_2X_3 > X_1X_2 > X_1 > X_1^2 > X_1X_3 > X_3$ (Table 7)

Elasticity: $R = 0.9885$, $F = 5.3324 < F_{0.05}$ (8, 1) = 239 and the significant at $p = 0.3236 > 0.05$.

Adhesiveness: $R = 0.9809$, $F = 3.1808 < F_{0.05}$ (8, 1) = 239 and the significant at $p = 0.4096 > 0.05$.

Table 4: Effects of steam treatment on texture profile of extruded products

Test number	X_1: Temperature (°C)	X_2: Time (min)	X_3: Water content (%)	Hardness (g)	Elasticity	Cohesiveness	Adhesiveness	Chewiness	Resilience
1	67(78*)	15	45	60.152	0.707	0.346	20.813	14.715	0.138
2	74(87*)	30	25	303.026	0.563	0.397	120.301	67.730	0.132
3	81(85*)	12	60	36.348	0.747	0.416	15.121	11.295	0.142
4	88	27	40	59.300	0.614	0.331	19.628	12.052	0.132
5	95	9	20	457.258	0.593	0.394	180.160	106.835	0.141
6	102	24	55	18.904	0.575	0.281	5.312	3.054	0.132
7	109	6	35	77.763	0.642	0.290	22.551	14.478	0.127
8	116	21	15	188.238	0.466	0.153	28.800	13.421	0.079
9	123	3	50	14.778	0.445	0.219	3.236	1.440	0.105
10	130	18	30	58.526	0.514	0.138	8.077	4.151	0.083

*Means the actual temperature in the vertical pressure steam sterilizer

Table 5: Significance of regression coefficient for hardness of extruded product

Factor	Partial correlations	t-test value	Significant (p)
X_1	-0.9994	28.5879	0.0012
X_2	-0.9989	21.2144	0.0022
X_3	-0.9995	32.0708	0.0010
X_1^2	0.9994	27.8494	0.0013
X_2^2	0.9992	24.9923	0.0016
X_3^2	0.9993	27.1058	0.0014
X_1X_2	0.9974	13.7980	0.0052
X_2X_3	0.9994	28.7312	0.0012

Table 6: Significance of regression coefficient for cohesiveness of extruded product

Factor	Partial correlations	t-test value	Significant (p)
X_1	-0.9986	18.5888	0.0029
X_2	-0.9990	22.8403	0.0019
X_1^2	0.9974	13.8110	0.0052
X_2^2	0.9990	21.8967	0.0021
X_3^2	0.9932	8.5066	0.0135
X_1X_2	0.9983	16.9646	0.0035
X_1X_3	-0.9939	9.0345	0.0120
X_2X_3	0.9956	10.6441	0.0087

Table 7: Significance of regression coefficient for resilience of extruded product

Factor	Partial correlations	t-test value	Significant (p)
X_1	-0.9994	29.9184	0.0011
X_2	-0.9996	35.5408	0.0008
X_3	-0.9389	2.7288	0.1121
X_1^2	0.9988	20.7994	0.0023
X_2^2	0.9996	33.3656	0.0009
X_1X_2	0.9995	32.2015	0.0010
X_1X_3	-0.9531	3.1473	0.0879
X_2X_3	0.9995	33.0540	0.0009

Chewiness: $R = 0.9782$, $F = 2.7732<F0.05\ (8, 1) = 239$ and the significant at $p = 0.4352>0.05$.

So, we know that the quadratic polynomial stepwise regression analysis is not applicable to predict the elasticity, adhesiveness and chewiness of extruded product of defatted soy flour steam treated.

Effects of steam treatment on solvent retention capacity of extruded products: WSRC: Distilled water solvent retention capacity, SSRC: Sucrose solvent retention capacity, SCSRC: Sodium solvent retention capacity carbonate, LASRC: Lactic acid solvent retention capacity.

Table 8 summarizes the results of the determination of solvent retention capacity of extrusion texturization products of defatted soy flour steam treated. A regression equation of the steam treatment temperature, time and moisture content of defatted soy flour to solvent retention capacity of extrusion texturization products can be tried to establish based on the statistical results.

The correlation coefficients of regression equation of WSRC, SSRC, SCSRC and LASRC can be obtained by the quadratic polynomial stepwise regression analysis.

WSRC:

$$WSRC = -478.9037+12.0581X_1+23.1002X_2-4.6020X_3-0.0603X_1^2-0.3307X_2^2-0.1059X_1X_2+0.0512X_1X_3-0.0398X_2X_3 \quad (6)$$

$R = 0.9997$, $F = 247.3924>F0.05\ (8, 1) = 239$ and the significant at $p = 0.0491<0.05$. The results shows that the correlation coefficients (6) can be used for predicting the WSRC of extruded product of defatted soy flour steam treated. The effect of each factor on extrusion texturization of WSRC can be ordered:

$X_{12}>X_1>X_3>X_1X_3>X_{22}>X_2>X_1X_2>X_2X_3$ (Table 9)

SSRC: $R = 0.9993$, $F = 94.2229<F0.05\ (8, 1) = 239$ and the significant at $p = 0.0795>0.05$. Thus the quadratic polynomial stepwise regression analysis is not applicable to predict the SSRC of extruded product of defatted soy flour steam treated.

LASRC:

$$LASRC = 564.0242-4.2846X_1-9.6991X_2-0.7024X_3+0.0249X_1^2+0.2268X_2^2+0.0465X_3^2-0.0384X_1X_3+0.0338X_2X_3 \quad (7)$$

$R = 0.9999$, $F = 494.5521>F0.05\ (8, 1) = 239$ and the significant at $p = 0.0348<0.05$. The results shows that the correlation coefficients (7) can be used for predicting the LASRC of extruded product of defatted soy flour steam treated. The effect of each factor on extrusion texturization of LASRC can be ordered:

$X_{32}>X_{22}>X_2>X_1X_3>X_1>X_{12}>X_2X_3>X_3$ (Table 10)

Table 8: Effects of steam treatment on solvent retention capacity of extruded products

Test number	X_1: Temperature (°C)	X_2: Time (min)	X_3: Water content (%)	WSRC	SSRC	LASRC	SCSRC
1	67(78*)	15	45	189.0	218.6	237.8	195.2
2	74(87*)	30	25	199.2	213.4	247.0	197.4
3	81(85*)	12	60	188.0	233.5	250.5	198.1
4	88	27	40	199.0	237.4	231.2	198.8
5	95	9	20	210.5	277.7	251.0	205.9
6	102	24	55	210.0	245.2	216.0	211.3
7	109	6	35	202.5	235.3	236.7	193.4
8	116	21	15	196.9	278.7	242.7	192.4
9	123	3	50	197.6	221.4	237.5	196.2
10	130	18	30	170.1	223.4	217.2	179.7

* Means the actual temperature in the vertical pressure steam sterilizer

Table 9: Significance of regression coefficient for WSRC of extruded product

Factor	Partial correlations	t-test value	Significant (p)
X_1	0.9987	19.4662	0.0026
X_2	0.9953	10.2292	0.0094
X_3	-0.9976	14.4368	0.0048
X_1^2	-0.9991	24.2092	0.0017
X_2^2	-0.9960	11.1232	0.0080
X_1X_2	-0.9934	8.6729	0.0130
X_1X_3	0.9972	13.4067	0.0055
X_2X_3	-0.9909	7.3562	0.0180

Table 10: Significance of regression coefficient for SCSRC of extruded product

Factor	Partial correlations	t-test value	Significant (p)
X_1	0.9997	40.6548	0.0006
X_2	0.9994	28.5685	0.0012
X_3	-0.9999	80.0082	0.0002
X_1^2	-0.9999	69.8156	0.0002
X_2^2	-0.9996	37.6745	0.0007
X_3^2	0.9998	46.6067	0.0005
X_1X_2	-0.9990	21.8581	0.0021
X_1X_3	0.9999	81.3237	0.0002

Table 11: Significance of regression coefficient for SCSRC of extruded product

Factor	Partial correlations	t-test value	Significant (p)
X_1	0.9997	40.6548	0.0006
X_2	0.9994	28.5685	0.0012
X_3	-0.9999	80.0082	0.0002
X_1^2	-0.9999	69.8156	0.0002
X_2^2	-0.9996	37.6745	0.0007
X_3^2	0.9998	46.6067	0.0005
X_1X_2	-0.9990	21.8581	0.0021
X_1X_3	0.9999	81.3237	0.0002

SCSRC:

$$SCSRC = 10.5064+4.0412X_1+10.8369X_2-4.8401X_3-0.0231X_1^2-0.1674X_2^2+0.0166X_3^2-0.0512X_1X_2+0.0369X_1X_3 \quad (8)$$

R = 1.0000, F = 3652.4896>F0.05 (8, 1) = 239 and the significant at p = 0.0128<0.05. The results shows that the correlation coefficients (8) can be used for predicting the SCSRC of extruded product of defatted soy flour steam treated. The effect of each factor on extrusion texturization of SCSRC can be ordered:

$X_1X_3 = X_3 = X_1^2>X_3^2>X_1>X_2^2>X_2>X_1X_2$ (Table 11 and 12)

Effects of steam treatment on protein solubility: The correlation coefficients of regression equation of covalent bond, non-covalent bond and interaction of covalent bond and non-covalent bond can be obtained by the quadratic polynomial stepwise regression analysis.

Covalent bond: R = 0.9984, F = 38.7479<F0.05 (8, 1) = 239 and the significant at p = 0.1236>0.05.

Non-covalent bond: R = 0.9995, F = 121.4566<F0.05 (8, 1) = 239 and the significant at p = 0.0701>0.05.

Thus the quadratic polynomial stepwise regression analysis is not applicable to predict the covalent bond and the non-covalent bond of extruded product of defatted soy flour steam treated.

Interaction of covalent bond and non-covalent bond:

$$PC = 42.4404-0.7377X_1-0.3288X_3+0.0041X_1^2+0.0068X_2^2+0.0035X_3^2-0.051X_1X_2-0.0007X_1X_3+0.0076X_2X_3 \quad (9)$$

R = 0.9999, F = 521.4128>F0.05(8, 1) = 239 and the significant at p = 0.0339<0.05. The results shows that the correlation coefficients (9) can be used for predicting the interaction of covalent bond and non-covalent bond of extruded product of defatted soy flour steam treated. The effect of each factor on extrusion texturization of interaction of covalent bond and non-covalent bond can be ordered:

$X_1>X_1^2>X_3>X_3^2>X_1X_2>X_2^2>X_2X_3>X_1X_3$ (Table 13)

CONCLUSION

The quadratic polynomial regression model can be used to analyze the effects of pretreatment of raw material on defatted soy flour extrusion texturization product properties and try to establish pretreatment conditions on the product characteristics index regression model. The results shows although the correlation coefficient of the regression equation R is large, close to 1, but that doesn't mean the quadratic polynomial regression model significant.

Table 12: Effects of steam treatment on protein due to various chemical cross-linking

Test number	X_1: Temperature (°C)	X_2:Time (min)	X_3: Water content (%)	Covalent bond	Non-covalent bond	Interaction of covalent bond and non-covalent bond
1	67(78*)	15	45	-0.073	0.654	0.207
2	74(87*)	30	25	0.027	0.704	0.146
3	81(85*)	12	60	-0.032	0.702	-0.358
4	88	27	40	0.054	0.610	0.152
5	95	9	20	0.069	0.738	0.247
6	102	24	55	0.027	0.614	-0.374
7	109	6	35	0.118	1.783	-0.931
8	116	21	15	-0.001	1.029	-0.504
9	123	3	50	-0.123	0.628	0.628
10	130	18	30	0.005	0.397	0.457

* Means the actual temperature in the vertical pressure steam sterilizer

Table 13: Significance of regression coefficient for protein due to interaction between covalent and non-covalent bond of extruded products

Factor	Partial correlations	t-test value	Significant (p)
X_1	-0.9998	55.7672	0.0003
X_3	-0.9996	37.2040	0.0007
X_1^2	0.9997	43.7877	0.0005
X_2^2	0.9988	20.0563	0.0025
X_3^2	0.9994	29.8744	0.0011
X_1X_2	-0.9990	22.8199	0.0019
X_1X_3	-0.9824	5.2551	0.0344
X_2X_3	0.9992	25.3606	0.0016

This study shows the correlation coefficients can be used for predicting the value of $L*$, hardness, cohesiveness, resilience, WSRC, LASRC, SCSRC and the interaction of covalent bond and non-covalent bond of extruded product of defatted soy flour steam treated. But it is not applicable to predict the value of a*, b*, ∆E, elasticity, Adhesiveness, chewiness, SSRC, Covalent binding protein and non-covalent binding protein. The effect of moisture content of raw material on the hardness and LASRC is significant. The temperature of steam treatment on WSRC and the interactions of covalent and non-covalent protein is the most significant impact. The interactive effects of steam treatment temperature and moisture content on SCSRC of product is significant. The time of steam treatment has the most significant influence on $L*$, cohesiveness and resilience of product.

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