Effects of extrusion parameters on physicochemical properties of flaxseed snack and process optimization

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Abstract: In order to optimize the extrusion process of flaxseeds snacks, the influence of different extrusion conditions on flaxseed production were studied by using the general four-factor quadratic designs of rotary combination and response surface methodology (RSM). Four extrusion conditions, the extrusion temperature (100-160°C), screw speed (60-180 r/min), feeding speed (18.35-54.95 kg/h) and moisture content (14%-30% w/w) were used as variables to detect the change of *in vitro* protein digestibility, expansion index, bulk density and texture (hardness and brittleness) of extruded productions. Through superimposed RSM contour map, it was found that the optimum extrusion conditions could be obtained at feed composition with flaxseed content of 20%, moisture content of 17.37%-22.43%, extrusion temperature of 134.3-156.1°C, screw speed of 114-165.7 r/min and feeding speed of 34.38-45.95 kg/h, respectively. Moreover, the composition and content of fatty acid in flaxseed-maize mixture changed rarely after extruded process, which indicated that extrusion had little impact on fatty acid. Under the optimum extrusion conditions, the flaxseed-maize blends can be extruded into acceptable snack foods.

Keywords: flaxseed, extrusion, optimization, physicochemical property, *in vitro* digestibility
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1 Introduction

China grows large quantities of flaxseed, which takes 20% of the global total yield, next to Canada. Flaxseed is a kind of important oil crops. Flaxseed oil is regarded as an abundant source of linolenic acid[1,2], which accounted for 30%-45% of flaxseed weight[3,4]. Recent research declared that edible flaxseed could help to increase linolenic and long-chainω-3 fatty acid in plasma and erythrocyte fat, whilst enhance the output of thiocyanate in piss; furthermore, the content of serum total cholesterol and low density lipopmtein cholesterol would decrease to varying degrees[5]. Research by Dev showed that compared with soybean protein, more asparaginic acid, glutamic acid, leucine and arginine were contained in flaxseed protein[6]; moreover, the physiological function of flaxseed was nothing less than soybean protein and casein, even superior to these two proteins in certain functions[7,8]. Besides, abundant phytoestrogen which refers to flaxseed lignans contained in flaxseed could reduce the density of serum low density lipopmtein cholesterol of menopausal female, then retard climacteric syndrome[9].

Extruded process is combined with high temperature

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and high pressure, accompanying with the increases of temperature, pressure and shear, the physical property changes from powdery to pasty, starch gelatinization and splitting decomposition, protein denature and recombine, fiber occurring partial digestion and refining. Moreover, pathogenic bacteria were killed when toxic constituents inactivate. A lot of researches focused on the processing technology of cereal and vegetable protein by extrusion cooking[10-15].

At present, few researches can be found on the flaxseeds' integrated utilization. In this study, with traditional extrusion process, flaxseed powder was made into new-style snacks. By analyzing the snacks' physical property changes and structure reengineering, the relationship of technological parameters and product feature can be found; thereby the interaction of different factors can be determined and the technological conditions can be optimized.

Based on single-factor experiment, optimum concentration of flaxseed was chosen to do optimizing experiment. Four factors were detected by quadratic general rotary unitized design, respectively extrusion temperature, screw speed, feed rate and moisture content.

After quadratic repression analysis and response surface methodology (RSM), the mathematical model of each response indicators were established; moreover, ideal point method created a mathematical model which contains multi-response indicators. By optimizing this model, the optimal extraction parameters of flaxseed snack can be gained. This experiment provides credible theoretical foundation to develop extrusion flaxseed functional food.

2 Materials and methods

2.1 Materials

Flaxseed (moisture content of 5.6%, protein content of 7.56%) was purchased from a local market in Hebei Province of China. Maize flour (moisture content of 9.0%, protein content of 25.32%) was purchased from a local market in Beijing. The moisture and protein (Tecator Kjeltec Auto 2300 Analyzer, protein factor: 6.25, Kjeltec™ 2300, Foss, Sweden), fat (Soxhlet standard extraction mode, B-811, Büchi Labortechnik AG, Switzerland) and ash contents of the flaxseed samples were determined according to approved methods described in AOAC (930.04, 992.23, 996.01 and 930.05, 1990).

The main equipment (Figure 1) included a twin-screw extruder (SLG67-18.5, Beijing Shilian Machinery Factory), a colorimeter (WSC-S, Shanghai Precision Scientific Instrument co., LTD), a scanning electron microscope (S-3400N, Hitachi (China) co., LTD), and a dynamic rheometer (AR2000ex, TA Instruments Companies of United States), etc.

Figure 1 SLG67-18.5 twin-screw extruder

2.2 Methods

2.2.1 Materials preparation

Mixing flaxseed with maize flour completely and feed into feeding device, then start extruded process after debugging every technological parameter. Extrusion productions were cut into subparagraphs of 60 mm long, and drying 8 h at 60°C, in order to reach homogeneous water balance.

2.2.2 Expansion index (EI)

The measuring method of EI refers the method of Kumagai[16]. Calculation formula is as below:

$$EI = \frac{D_p}{D_d} \times 100\% \tag{1}$$

where, EI is expansion index, %; D_p is the production diameter, mm; D_d is the die orifice diameter (5.2 mm).

2.2.3 Texture (hardness and brittleness)

The test of texture was conducted with three-point bending clamp of universal materials testing machine (Instron 4411, Instron Co. Ltd., UK). In this experiment, the detector moved down to break samples in a constant speed of 2 mm/s; regarded the stress peak as hardness and the distance of detector's movement as brittleness at samples' breaking point.

2.2.4 Bulk density (BD)

The measuring method of BD refers to the method of Alvarez-Martinez[17]. Calculation formula is as below:

$$BD = \frac{4m}{\pi D_p^2 L} \tag{2}$$

where, BD is bulk density, g/cm^3; m is the mass of samples, g; L is the length of samples, mm.

Extrusion samples were randomly selected and each sample had 10 parallel tests, the average of them was finally used.

2.2.5 In-vitro protein digestibility (IVPD)

1) Degrease: join 200 g extrusion powder with 1 L petroleum ether, keep stirring for 6 h, then remove extracting solution by suction filtration, and repeat three times to gain degrease extrusion powder.

2) Preparation of protein: mix extrusion powder with tris buffered solution (pH 8.1) at the rate of 1:6 (W/V) at room temperature. After stirring the mixture for an hour, place the uniform suspension liquid in refrigerator, set temperature to 4°C and extract for 24 h. Afterwards, centrifuge the extract for 30 min at 600 r/min, acid precipitate supernatant by HCl (0.1 mol/L), centrifuge again and neutralize the sediment, protein can be obtained after final freeze drying.

3) Titration measurement: heating and stirring the protein solution in water bath of 37°C, adjust pH value to 8.0, whereas the pH value of enzyme solution (trypsin) also adjusted to 8.0. Join enzyme and protein solution in proportion of 1:10 (V/V, enzyme/protein), standing for 10 min under room temperature. Measure the mixture's pH value, substitute into the formula below and calculate the IVPD (x=pH value).

$$y=210.464-18.10x \tag{3}$$

2.2.6 Fatty acid measurement by Gas chromatography

Based on Soxhlet extraction, extract grease from extruded samples, methyl esterification handing methods according to ISO standard (ISO: 5509)[18]. Separation and detection by gas chromatograph, then calculate the relative amount of constituent use peak area normalization method.

2.3 Experimental designs and statistical analyses

This experiment adopt single-factor experiment, respectively research the influence of extrusion temperature (80-160°C), screw speed (60-180 r/min) , feeding speed (15.5-54.95 kg/h), moisture content (11.3%-30.2% w/w) and flaxseed mass fraction (0-50%) on the EI and texture (hardness and brittleness) of extrusion flaxseed production.

Based on single-factor experiment, four factors five levels quadratic orthogonal general rotary unitized design was used to analysis data in this study. Fixing the flaxseed amount on 30%, respectively survey extrusion temperature (100-160°C, X_1), screw speed (60-180 r/min, X_2), feeding speed (15.5-54.95 kg/h, X_3) and moisture content (14%-30% w/w, X_4) impact on the characteristics of extrusion food. The characteristics include five response values, $IVPD$ (Y_1), EI (Y_2), BD (Y_3), hardness (Y_4) and brittleness (Y_5). Table 1 unfolds coded level for each independent variable.

Statistic analysis use SAS Analysis software (Version 6.12, Cary, NC, USA), Duncan variance analysis method was used to distinguish the significant difference between various results when the confidence coefficient was 5%. All tests were repeated three times and average values were used in final analysis.

Table 1 Coded levels for the independent variables

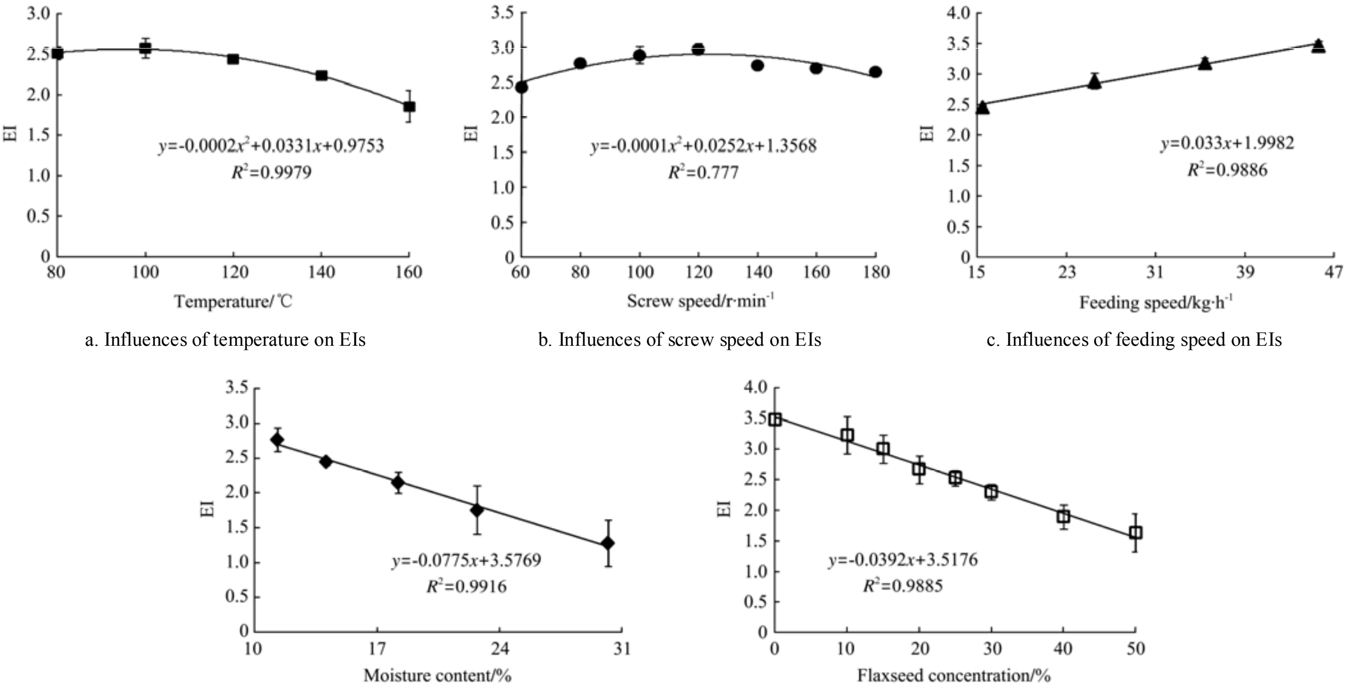
Variable	Code level				
	-2	-1	0	1	2
X_1: extrusion temperature/°C	100	115	130	145	160
X_2: screw speed/r·min^{-1}	60	90	120	150	180
X_3: feeding speed/kg·h^{-1}	18.35	27.5	36.65	45.8	54.95
X_4: moisture content/%	14	18	22	26	30

3 Results and discussion

3.1 Impact on characteristics of extrusion flaxseed snack

3.1.1 Impact of extrusion parameters on EI

It can be seen from Figure 2 that accompanying with the increase of temperature, EI had a quadratic decrease. This is because as temperature rises to a high level, materials rapidly reach molten state and the melt viscosity was relatively small, the generation of bubble reduced[19]. Extrusion production in this condition had uniformity porosity and small EI. As for moisture content, EI linearly declined when it rose, since the lubrication action of water cut down the melt viscosity, shortening the time to shear and heat-up materials; on the other hand, high moisture also reduced the extruded pressure, thereby flash evaporation drop and EI decreased together[20]. At low screw speed (60-120 r/min), EI increased along with screw speed, at this time, both shear force and rubbing action are small, vaporizable water could not distribute uniformly into feeding, porosity uneven and unfolded hard texture. However, when screw speed became higher (120-180 r/min), the enhancement of shear force and rubbing action lead to uniform moisture distribution. The same conclusion was presented in the study of Altan[21]. High temperature, high shear force expanded starch and protein structure recombined to new three-dimensional stability polymer network structure[22]. When mass fraction kept on rising, fat inside the mixture sharply increased; those excess fat may be filled in holes, which decreased EI. Lastly, EI lineally went up along with feeding speed. Low feeding speed resulted in an instauration condition inside extrusion machine, therefore resistance, shear force and rubbing action were all too weak to create sufficient molten mass.



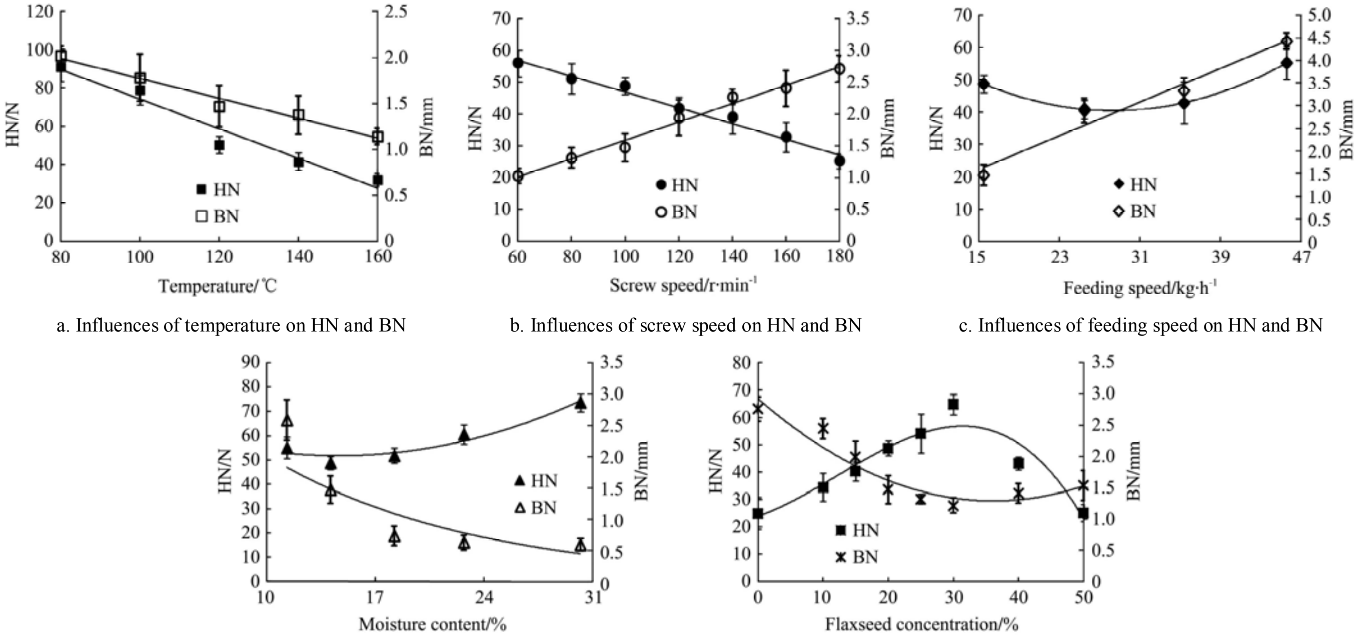
a. Influences of temperature on EIs b. Influences of screw speed on EIs c. Influences of feeding speed on EIs

d. Influences of moisture content on EIs e. Influences of flaxseed concentration on EIs

Figure 2 Influences of extrusion conditions on EIs of extruded samples

3.1.2 Impact of extrusion parameters on texture (hardness and brittleness)

The hardness and brittleness both decreased with the rise of temperature; maturing process enhanced inside the machine cavity, moisture rapidly evaporated and more bubble created, as a result, samples gained thinner porous walls and crisp taste (Figure 3). Altan et al.[21] and Ryu and Walker[23] also obtained the similar conclusion in their research of wheat and barley. As screw speed went up, the hardness decreased and brittlenes increased, shear force and pressure in machine increasingly high and the productions became porous. Along with the feeding speed increased, the hardness of food productions decreased first and then rose up; this indicated that appropriate feed amount was helpful to form multi-hole cellular structure. However, when feeding speed kept on rising higher than 35.4 kg/h, the efficiency of extrusion machine was strongly intensified, thereby samples were incompletely sheared and worse expanded. As moisture content grew up, hardness increased but brittleness significantly dropped down. These may because water remitted extrusion effect and the extruded samples had compact structures. Accompanying with the increasingly addition of flaxseed, hardness grew up at beginning and then reduced; because starch, proteins and fats generated new strong 3-D grid architectures under high temperature and shear force during extrusion process, furthermore, became compact porous extrusion productions.



a. Influences of temperature on HN and BN
b. Influences of screw speed on HN and BN
c. Influences of feeding speed on HN and BN
d. Influences of moisture content on HN and BN
e. Influences of flaxseed concentration on HN and BN

Figure 3 Influences of extrusion conditions on hardness (HN) and brittleness (BN) of extruded samples

3.2 Establishment of regression model

By quadratic commonly spinning regression experiment can gain regression equation as Equation (4). The experimental results and regression equations were shown in Tables 2 and 3.

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i x_i + \sum_{i=1}^{3} \beta_{ii} x_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} x_i x_j \tag{4}$$

where, Y: response value; β_0: constant term; β_i: linear coefficient; β_{ii}: quadratic coefficient; β_{ij}: interaction coefficient; x_i and x_j: true value of independent variables.

Table 2 Experimental results of quadratic regressive rotary design

Test number	x_1	x_2	x_3	x_4	IVPD (Y_1)/%	EI (Y_2)	BD (Y_3)/(g·cm^{-3})	HN (Y_4)/N	BN (Y_5)/mm
1	115	90	27.5	18	74.55	2.591	0.1883	76.07	2.42
2	115	90	27.5	26	73.24	1.803	0.2989	87.05	2.61
3	115	90	45.8	18	75.15	2.186	0.2880	70.17	1.99
4	115	90	45.8	26	73.83	1.679	0.3474	92.83	2.21
5	115	150	27.5	18	75.16	2.591	0.1566	67.60	2.35
6	115	150	27.5	26	73.84	1.933	0.2848	86.12	2.52
7	115	150	45.8	18	75.77	2.679	0.1793	70.42	1.84
8	115	150	45.8	26	74.44	1.928	0.2775	78.77	2.05
9	145	90	27.5	18	75.73	2.097	0.1383	36.63	1.53
10	145	90	27.5	26	74.45	1.644	0.2247	58.65	1.75
11	145	90	45.8	18	76.36	2.013	0.1903	61.08	1.38
12	145	90	45.8	26	75.03	1.597	0.2625	71.73	1.50
13	145	150	27.5	18	76.37	2.101	0.1145	28.90	1.32
14	145	150	27.5	26	75.05	1.530	0.2527	69.54	1.72
15	145	150	45.8	18	76.96	1.890	0.1529	62.12	1.22
16	145	150	45.8	26	75.66	1.548	0.2307	71.23	1.52
17	100	120	36.65	22	73.64	2.207	0.2371	99.90	2.28
18	160	120	36.65	22	75.38	2.257	0.1749	68.87	1.85
19	130	60	36.65	22	75.26	1.860	0.3328	79.48	1.99
20	130	180	36.65	22	75.64	2.333	0.2103	84.07	1.74
21	130	120	18.35	22	75.05	2.111	0.2248	74.78	2.37
22	130	120	54.95	22	74.93	2.219	0.2499	90.58	2.41
23	130	120	36.65	14	73.84	2.268	0.1551	49.35	1.66
24	130	120	36.65	30	73.16	1.630	0.2652	119.12	2.65
25	130	120	36.65	22	75.65	2.275	0.1882	87.68	1.66
26	130	120	36.65	22	75.67	2.208	0.2030	89.88	1.58
27	130	120	36.65	22	75.64	2.199	0.1943	88.23	1.66
28	130	120	36.65	22	75.66	2.273	0.1762	90.21	1.55
29	130	120	36.65	22	75.68	2.283	0.1943	88.24	1.57
30	130	120	36.65	22	75.69	2.294	0.1858	87.23	1.63
31	130	120	36.65	22	75.62	2.210	0.1953	89.07	1.61

Table 3 Response values corresponding regression equations

Response value (Y)	Regression equation	R^2
IVPD/%	Y_1=41.81461+0.272645x_1−1.4×10$^{-4}x_2$+0.097115x_3+1.135454x_4−9.16×10$^{-4}x_1^2$+3.2×10$^{-5}x_2^2$−10.27×10$^{-4}x_3^2$−28.656×10$^{-3}x_4^2$+4.167×10$^{-6}x_1x_2$+4.554×10$^{-6}x_1x_3$+5.2×10$^{-5}x_1x_4$+2.277×10$^{-6}x_2x_3$−1.6×10$^{-5}x_2x_4$−8.5×10$^{-5}x_3x_4$	0.8639
EI	Y_2=-0.42341+0.016558x_1+0.035792x_2−5.599×10$^{-3}x_3$+0.058884x_4−1.09×10$^{-4}x_1^2$+0.65×10$^{-4}x_2^2$−0.494×10$^{-3}x_3^2$−0.5961×10$^{-2}x_4^2$−0.16×10$^{-3}x_1x_2$+0.56×10$^{-4}x_1x_3$+0.96×10$^{-3}x_1x_4$+0.125×10$^{-3}x_2x_3$−0.82×10$^{-4}x_2x_4$+0.775×10$^{-3}x_3x_4$	0.8268
BD/g·cm^{-3}	Y_3=0.205453+0.1724×10$^{-7}x_1$−0.006926x_2+0.011607x_3+0.019741x_4−0.11×10$^{-4}x_1^2$+0.16×10$^{-4}x_2^2$+0.65×10$^{-4}x_3^2$−0.87×10$^{-4}x_4^2$+0.22×10$^{-4}x_1x_2$−0.26×10$^{-4}x_1x_3$−0.23×10$^{-4}x_1x_4$−0.47×10$^{-4}x_2x_3$+0.59×10$^{-4}x_2x_4$−0.266×10$^{-3}x_3x_4$	0.9355
HN/N	Y_4=-201.457+1.659728x_1+0.55796x_2+1.107372x_3+11.75602x_4−0.017394x_1^2−0.004657x_2^2−0.047358x_3^2−0.223513x_4^2+0.035105x_1x_2+0.035105x_1x_3+0.022823x_1x_4−0.001601x_2x_3+0.00537x_2x_4−0.07068x_3x_4	0.8002
BN/mm	Y_5=18.61483−0.129019x_1−0.012931x_2−0.205357x_3−0.268601x_4+0.323×10$^{-3}x_1^2$+0.25×10$^{-4}x_3^2$+1.839×10$^{-3}x_3^2$+5.953×10$^{-3}x_4^2$+0.12×10$^{-4}x_1x_2$+0.505×10$^{-3}x_1x_3$+0.26×10$^{-3}x_1x_4$−0.11×10$^{-4}x_2x_3$+0.172×10$^{-3}x_2x_4$−0.222×10$^{-3}x_3x_4$	0.7986

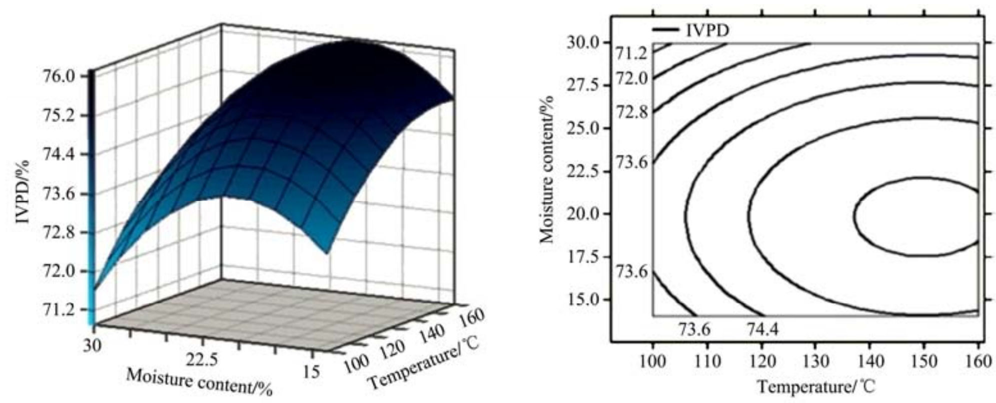
3.3 Response surface analysis of extrusion parameters

3.3.1 Protein in-vitro digestibility coefficient

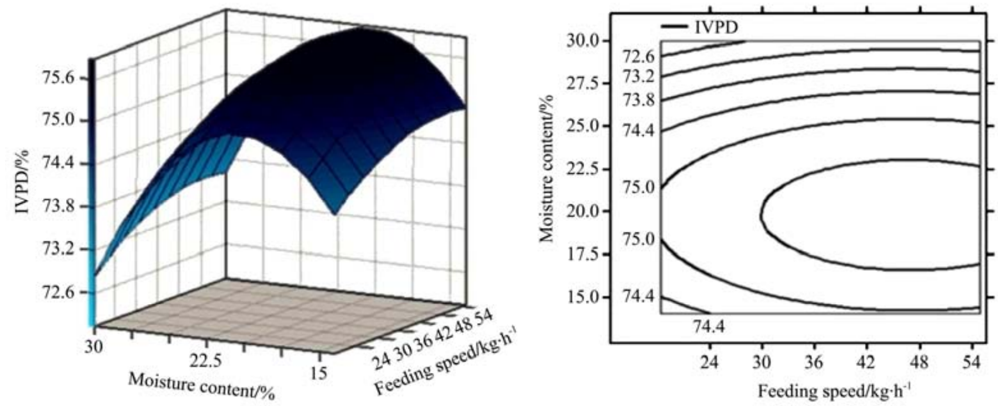
Digestibility is regarded as the most determinant factors of protein's nutritive value. In this study, the digestibility of protein without extrusion was 68.47%, whereas that of extruded protein could reach a peak of 77.53%. Several other researches also showed the similar results[24-26].

1) The interaction of extrusion temperature and moisture content

From Figure 4a, it can be concluded that accompanying with temperature increased, the digestibility of protein also grew up, which indicated the increase of temperature can effectively enhances the passivation of protease inhibitors in mixture. Some papers also prove this conclusion[27,28]. When temperature reached 160°C, the increase tendency of IVPD slowed down, that means overheat may cause part of protein to react sharply and carbonize. Figure 4 also showed that along with the rise of moisture content, IVPD went up first and then dropped back. This might because excess moisture rapidly reduced the rubbing action between cylinder, screw and materials, thereby decreasing the mechanical energy and thermal energy; as a result, the essential reaction energy of samples was cut and IVPD decreased.



a. Response surface figure and contour map of moisture content and temperature



b. Response surface figure and contour map of moisture content and feeding speed

Figure 4 Effects of feeding rate and feed moisture content on IVPD of extruded samples

2) The interaction of feeding speed and moisture content

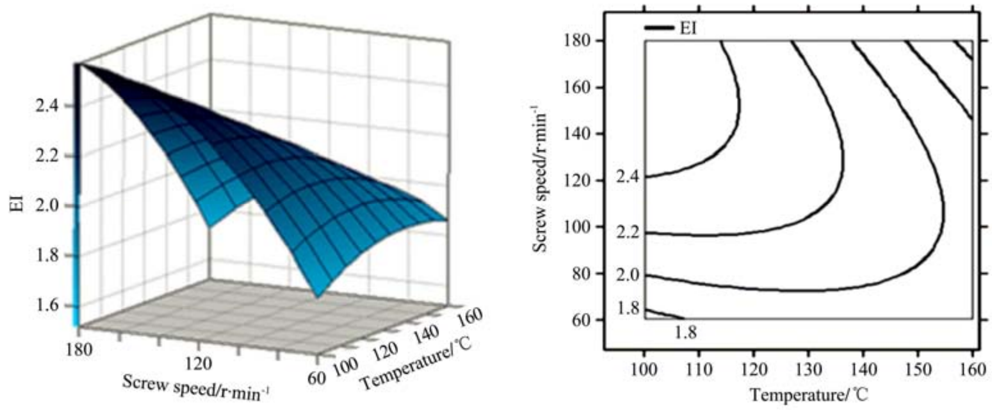
Figure 4b unfolded the interaction of extrusion temperature and moisture content on IVPD. Along with feeding speed increased, the IVPD kept growing as well as the compactedness inside the cylinder; therefore materials were adequately sheared and extruded. In this period, hydrogen bond, Van der Waals force, ionic bond and disulfide bond were all destroyed; higher protein structures could not maintain anymore and changed to uniform fibrous structures, so the digestibility increased. Similar conclusion can be found in studies of Bhattacharya et al.[28] and Camire[29]. At the maximum of feeding speed, IVPD reached the top when moisture content was 22%.

3.3.2 EI

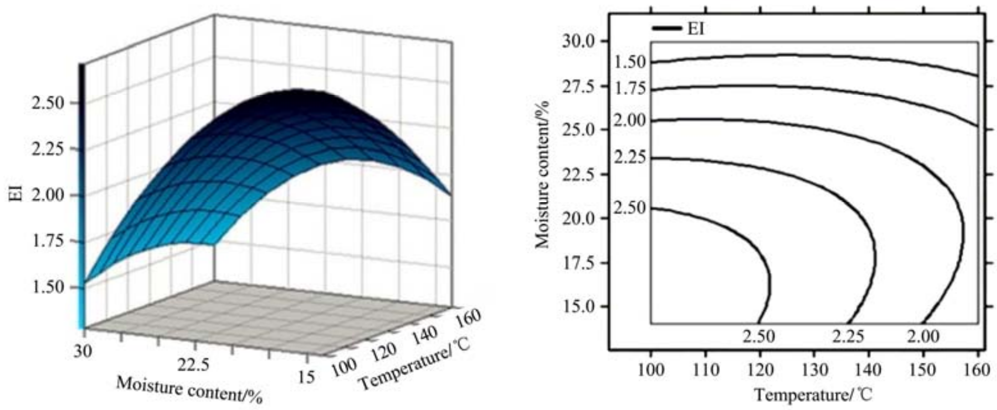
EI is an important indicator to measure the expanded effectiveness. Powdery become pasty because of moisture, starch dextrinization and splitting, protein denaturation and structural reorganization, etc. when material erupted from die, the release of pressure made water content sharply vaporize; therefore creating loose structure and porous crisp extrusion food.

1) The interaction of extrusion temperature and screw speed

Figure 5a showed that EI rose along with the increase of temperature, this tendency slowed down when temperature reached 130°C and then decreased. At high screw speed, EI remarkably dropped when temperature increased, which might be because material rapidly formed molten condition, and the viscosity reduced; by high shear force, molten mess was uniformly mixed and created porous expand effect[30].



a. Response surface figure and contour map of screw speed and temperature



b. Response surface figure and contour map of moisture content and temperature

Figure 5 Effects of extrusion temperature and screw speed on EIs of extruded samples

2) The interaction of extrusion temperature and moisture content

From Figure 5b, it can be found that EI increased first but then decreased accompanying with the growth of extruded temperature. High temperature accelerated the starch gelatinization and protein denaturation. As temperature was increasingly high, starch crystal melting and viscosity of molten mess reduced; furthermore, the rupture of hydrogen bonds in amylopectin molecules speeded up, therefore the expand effect dropped off. According to the research of Padmanabhan and Bhattacharya[31], the elasticity of samples and bubbles created by water vapor pressure can influence the EI. At high extrusion temperature, the EI rose along with moisture content at the very beginning and then decreased. High temperature and low water content would lead to incomplete starch dextrinization and protein denaturation. As for low temperature, EI dropped when moisture content increased.

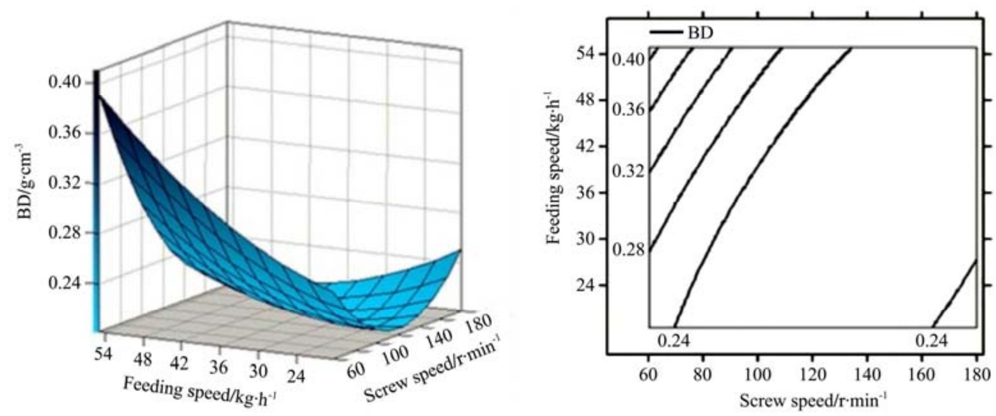
3.3.3 BD

1) The interaction of screw speed and feeding speed

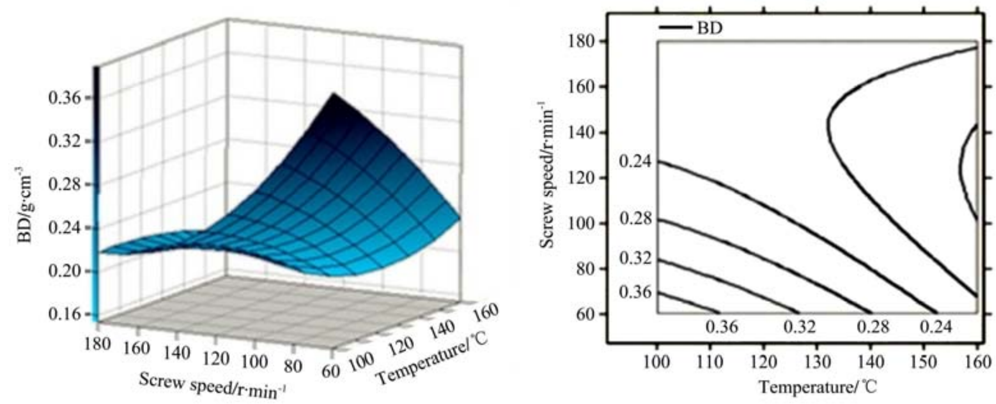
In Figure 6a, it can be seen that BD decreased when screw speed kept increasing. The growth of screw speed was beneficial to generate stable porous structure[20]. BD rose together with feeding speed at low screw speed, because overmuch materials increased the burden of machine and hinder the structure recombination. Moreover, high shear force could totally meet the requirement of material extrusion forming.

2) The interaction of extrusion temperature and screw speed

Based on Figure 6b, as for low extrusion temperature, BD decreased accompanying with the increase of screw speed. Since Maillard reaction occurred at high temperature and high screw speed shorten the extruded period; therefore the produced food had compact structure. Generally, high BD production presented low EI[32,33].



a. Response surface figure and contour map of feeding speed and screw speed



b. Response surface figure and contour map of screw speed and temperature

Figure 6 Effects of feed moisture content and screw speed on BDs of extruded samples

3.4 Optimization of extrusion parameters

By changing extrusion parameters to maximum increase the IVPD was the main aim of optimizing process. Based on the results of single-factor and orthogonal general rotary combination and overlap optimized method, extrusion parameters could be optimized analysis. Main constraint condition was high IVPD (>76%), low BD (<0.2 g/cm^3), high EI (>2), low hardness (<90 N) and high brittleness (<1.5 mm). Figure 7 is contour maps of SAS optimization analysis; the overlapped areas are optimization condition which extrusion productions can unfold good quality characteristics. The optimized scopes were extrusion temperature of 134.3-156.1°C; screw speed of 114.0-165.7 r/min; feeding speed of 34.38-45.95 kg/h; moisture content 17.37%-22.43%.

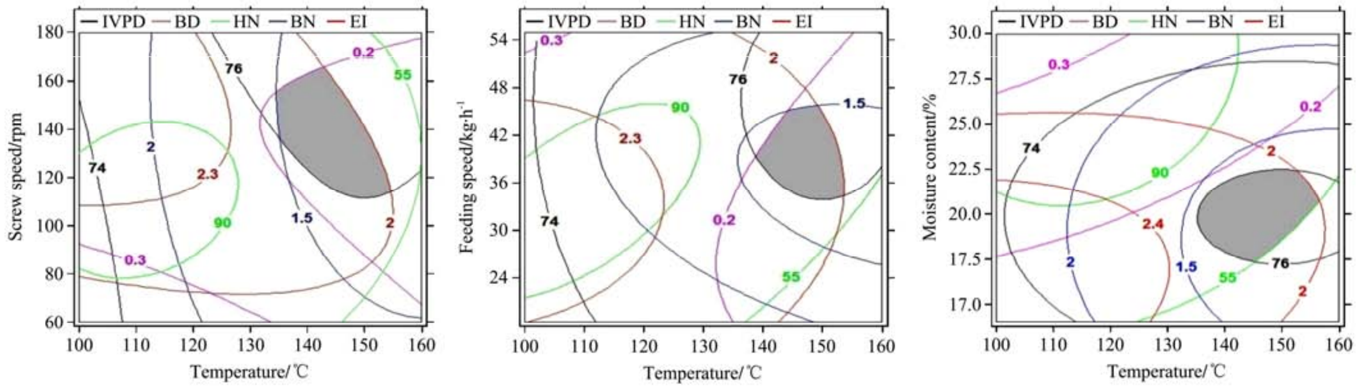


Figure 7 Superimposed contour maps (master contour map) for product responses

3.5 Influence of extrusion on the fatty acid composition

From Table 4, it can be concluded that extrusion process better retained the fatty acid composition of mixed oil of linseed oil with corn oil. As the results showed, extrusion process reduced the content of unsaturated fatty acid to some extent. Fat was easy to occur hydrolysis and oxidative rancidity during extrusion period, the double bond in fat had conjugated reaction, isomerized natural cis-fatty acids to trans acids, thereby the content of unsaturated fatty acid in oil reduced[34,35].

Table 5 Comparative analysis fatty acid composition (% of total fatty acids) of oil in extruded and raw sample

Fatty acid	Fatty acid composition	Raw sample/%	Extruded sample/%
Palmitic acid	C16:0	56.788±0.045	55.831±0.065
Stearic acid	C18:0	17.085±0.032	18.082±0.037
Oleic acid	C18:1	17.466±0.021	17.525±0.039
Linoleic acid	C18:2	2.929±0.005	2.773±0.006
Linolenic acid	C18:3	5.732±0.012	5.789±0.009

4 Conclusions

Single-factor experiments indicated that along with the change of extrusion conditions and the appending proportion of flaxseed, the physicochemical properties of extrusion productions changed significantly. This mainly depends on the generation of porous structure and Maillard reaction during extruded process.

As for the four main factors that influence the final quality of extrusion products, respectively extrusion temperature, screw speed, moisture content and feeding speed, four-factor quadratic orthogonal general rotary combination design was adopted, and five model equations of response indexes, respectively protein in vitro digestibility coefficient, EI, BD, hardness and brittleness were established; Upon inspection, the regression mathematics models had good matching.

By using regression equation and SAS analysis software, the response surface figure and contour map of response indexes can be drawn; moreover, the interaction and influence rule of every extrusion parameters were systematically analyzed after experiments.

As for the research of the quality requirement of extrusion products, IVPD was regarded as main optimizing index. After comprehensively optimizing the extrusion process parameters and conditions, the appropriate conditions were determined, which defined the temperature of 134.3-156.1°C, screw speed of 114-165.7 r/min, feeding speed of 34.385-45.95 kg/h, and moisture content of 17.37%-22.43%. Furthermore, the determination of fatty acids unfolded that extrusion process better retained the fatty acid composition of mixed oil of linseed oil and corn oil.

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