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Optimization of Extrusion Technology and Quality Analysis of Lotus seed-Lentinus edodes Compound Rice

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Abstract:
In this study, compound rice with broken rice, lotus seeds and lentinus edodes were used as the main raw materials, and the lotus seed-lentinus edodes compound rice was prepared by twin-screw extrusion process. The sensory quality and protein digestibility in vitro of lotus seeds-lentinus edodes compound rice were evaluated by single factor test and response surface test. The effects of different extrusion parameters on sensory quality and protein digestibility in vitro of lotus seeds-lentinus edodes compound rice were investigated. Single factor test and response surface test were used to investigate the effects of different extrusion parameters on sensory quality and protein digestibility in vitro of lotus seed-lentinus edodes compound rice. The results showed that under the conditions of extrusion temperature of 131.28 ℃, screw speed of 144.49 r/min and moisture content of 25.34%, the sensory score reached 79.65, which was close to that of ordinary rice, and the protein digestibility in vitro reached 62.35%. The compound rice tasted mellow and had unique fragrance of lotus seed and lentinus edodes. It greatly improved the degree of human digestion and absorption, and had high nutritional value.

Key Word*: twin-screw extrusion; lotus seed-lentinus edodes compound rice; sensory quality; protein digestibility in vitro*

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I. Introduction

Compound rice is broken rice, rice flour or other starch matrix raw materials as the main ingredients, adding other quality amendments or nutrients, and then crushed, mixed, extrusion molding under high temperature and high pressure conditions [1]. Therefore, compound rice has been paid attention to by many researchers. Steel [2] took whole wheat flour and corn flour as the main raw materials and used the twin-screw extrusion technology to find that under the conditions of adding 80% whole wheat flour, the temperature range of the third and fourth zones was 90℃-110℃, and the moisture content was 16%, the profile expansion index and bulk density of breakfast cereal were greatly improved. Using oat flour, apple pomace and potato starch as the main raw materials. De [3] found that the optimal extrusion conditions were 140℃ and 25%-26% moisture content by single-screw extrusion technology, and the grain obtained had high phenolic compounds content and antioxidant activity under such conditions.

Lotus seeds are rich in protein, carbohydrate, vitamin and trace elements such as Ca, Fe and Zn [4]. The amino acid composition of lotus seeds is complete, and the total essential amino acids account for 28% of the total amino acids. The composition and content of gluten, albumin, globulin and gliadin in lotus seeds are basically in line with the FAO/WHO recommended values of amino acids [5]. Lentinus edodes is rich in protein, amino acids, minerals and vitamins and other nutrients, as well as contains polysaccharides and other bioactive ingredients [6]. Lentinus edodes has the effects of lowering cholesterol, blood pressure, anti-bacteria, anti-virus, enhancing immunity, regulating intestinal microorganisms and so on [7-11]. Lentinus edodes has high nutritional, health and medicinal value, and has been paid more and more attention by researchers. Therefore, adding a certain amount of lotus seeds-lentinus edodes to broken rice and making compound rice by means of extrusion and recombination technology can make up for the defects of less types and low content of amino acids in ordinary rice. [12].

Compound rice was prepared by twin-screw extrusion technology, and the effects of extrusion parameters on sensory quality and protein digestibility of compound rice were investigated. Through single factor test and response surface test, the data were fitted by polynomial regression using the Design-Expert 8.0.6 data analysis software to optimize the optimal process parameters and conditions of lotus seed-lentinus edodes compound rice with good quality and conducive to human digestion and absorption.

II. Material And Methods

Materials

Broken rice, (Xuzhou Xintian Grain and Oil Co., LTD, Xuzhou, Jiangsu, China). Lotus seeds, lentinus edodes (Peizheng Grain Store, Zibo, Shandong, China); Monostearate triglyceride (Shandong Yusuo Chemical Technology Co., LTD, Linyi, Shandong, China).

Preparation of rice

Lotus seed-lentinus edodes compound rice (10g) was weighed and placed in a metal goo. According to the ratio of solid to liquid 1:1, 10 mL of distilled water was added, and then stirred quickly. After the water in the electric boiler was boiled, the sample was placed in the steamer and steamed for 15min.

Single factor experiment arrangement of Lotus seed - lentinus edodes compound rice extrusion

Lotus seed powder: lentinus edodes powder: rice powder 5:3:2 ratio mix well. The addition amount of triglyceride monostearate was determined to be 0.5% of the total mass of mixed flour, the solid feeding speed was 15 kg/h, and the speed of extruder cutter was 1500 r/min. The temperature of zone II of the fixed extruder cavity was 60℃, zone III was 90℃, zone V was 70℃, and zone VI was 70℃. extrusion temperature (zone IV), screw speed and moisture content were selected as test factors for single factor test. The factor level coding table of single factor test was shown in Table 1.

Table no 1: Factor level coding table of single factor test

level	extrusion temperature（℃）	screw speed（r/min）	moisture content（%）
1	110	100	20
2	120	120	23
3	130	140	26
4	140	160	29
5	150	180	32

Response surface test arrangement of lotus seed-lentinus edodes compound rice extrusion

The optimal extruded gelatinization temperature (zone IV), screw speed and moisture content obtained from the single factor experiment were taken as the intermediate level to design a three-factor and three-level response surface test. The coding table of test factors and levels was shown in Table 2.

Table no 2: Response surface factors and level design

level	factors		
	X_1 extrusion temperature（℃）	X_2 screw speed（r/min）	X_3 moisture content（%）
1	120	120	23
2	130	140	26
3	140	160	29

Sensory quality evaluation

The sensory evaluation method in food was based on some modification of the reference (GB/T 15682-2008). Samples were prepared as described in 2.2 " Preparation of rice". Select 10 experienced evaluators to form an evaluation group. The samples were randomly numbered and evaluated independently and objectively by the evaluator. During the evaluation, each member carried out the evaluation independently, without contact or communication with each other, and rinsed with water during the evaluation [13]. The average fractions of the samples prepared with different extrusion parameters were compared and calculated. The evaluation included 20 points for aroma, 20 points for appearance with color, luster and integrity, 30 points for taste with stickiness, hardness and elasticity, 25 points for taste, and 5 points for cold rice texture, with a maximum of 100 points.

Determination of protein content

The determination of protein in food was based on some modification of the reference (GB 5009.5-2016).

Determination of protein digestibility in vitro

The crushed and screened sample (1.00 g) was accurately weighed and evenly dispersed and dissolved in 25mL acetic acid buffer solution (0.2mol/L, PH=8). 10mL HCl (0.2mol/L) was added and placed in a 37℃ water bath for preheating for 5min. After preheating, Pepsin (75 mg/mL) prepared by HCl (0.01 mol/L) was added and placed on a thermostatic oscillator with a preset temperature of 37℃ for 120 min. After that, NaOH (1 mol/L) was used to adjust the PH to 7.0 to terminate the digestion reaction, and then trypsin solution (120 mg/L) was rapidly added and digested for 120 min at 37℃ on a constant temperature water bath oscillator. After centrifugation at a speed of 4000 r/min for 15 min, the supernatant was discarded after filtration. After drying the filter paper containing the filter residue, the remaining protein content was determined using the determination of protein content method [14, 15].

The in vitro digestibility of protein was calculated using the following Equation (1).

$$X(\%)=\frac{(M-m)}{M}\times100\% \quad (1)$$

Where: X is protein digestibility in vitro, %; M is the total protein content in the sample, %; m is the undigested protein content, %.

Statistical analysis

Excel and Design-Expert software were used for data processing, and Origin software was used for mapping.

III. Result and discussion

Effects of extrusion temperature on the quality of lotus seed-lentinus edodes compound rice

As shown in Figure 1(a) and (b), the sensory score and protein digestibility in vitro of lotus seed-lentinus edodes compound rice increased first and then decreased with the increase of extrusion temperature, and the sensory score and protein in vitro digestibility reached the highest at 130℃, which was significantly different from that at other extrusion temperatures. When the extrusion temperature was low, the starch in the rice mixed with lotus seed-lentinus edodes compound rice could not be fully gelatinized, the starch structure was loose, the rice grains were not full, the chewability became poor, and the sensory score was low [16]. Under low extrusion temperature, material moisture evaporation was less, starch gelatinization degree was low and material subjected to small shear force. Protein could not form the molten body well, so less Maillard reaction occurred between protein and starch degraded sugars [17]. The protein structure was extended and reorganized, and the sites that were easy to be digested by digestive enzymes were exposed. The protein digestibility in vitro increased gradually with the increase of temperature. However, at high temperature, the environment of high temperature and high pressure in the cylinder leaded to ammonia carbonylation reaction between amino acids and some carbonyl compounds and reduced sugars in the raw materials. The loss of amino acids in the protein and the darkening of the surface color caused the decrease of the sensory quality and the in vitro digestibility of the protein. Overall consideration, the extrusion temperature of the response surface test should be selected between 120℃ and 140℃.

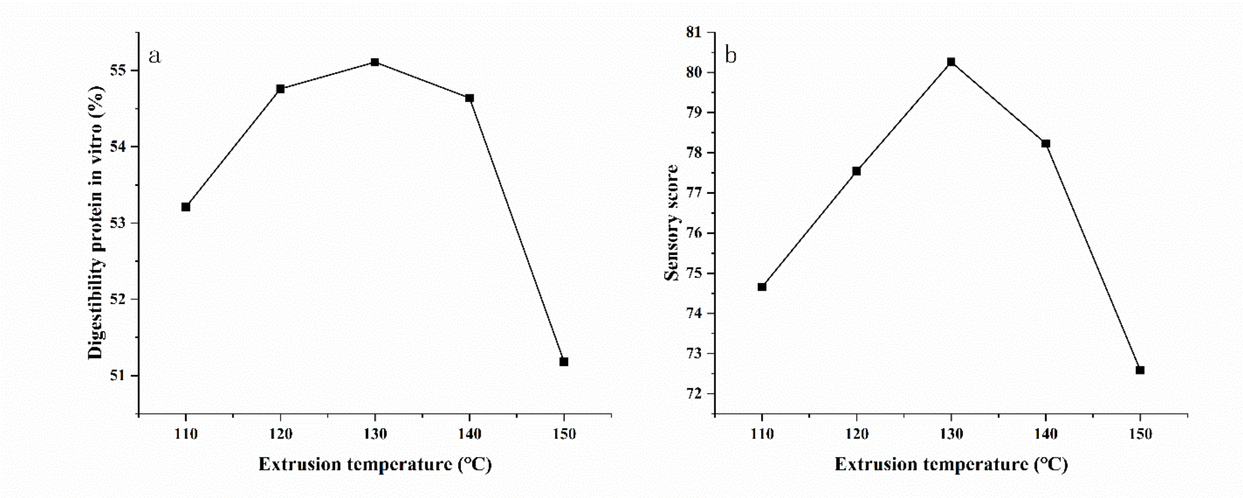

Figure 1: Effect of extrusion temperature on protein digestibility in vitro and sensory quality

Influence of screw speed on the quality of lotus seed-lentinus edodes compound rice

According to Figure 2 (a) and (b), the sensory score and protein digestibility in vitro of lotus seed-lentinus edodes compound rice increased first and then slightly decreased with the increase of screw speed, and the sensory score and protein in vitro digestibility reached the maximum when the screw speed was 140 r/min, which was significantly different from that of the lower screw speed. Under the low screw speed, the shear force and friction force of the screw were small, and the degree of starch gelatinization and cross-linking was low [21], resulting in the hardness of the compound rice and poor chewability and sensory score. At the same time, incomplete expansion of the material leaded to low damage degree of hydrogen bond, van der Waals force, disulfide bond and ionic bond, which maintain the advanced structure of the protein. The protein structure could not be fully expanded, and the material could not form a fiber protein system with uniform texture, resulted in low protein digestibility in vitro. With the increase of screw speed, the shear effect of the screw on the material gradually increased, and the friction between the material and the wall of the extruder cavity and the screw gradually increased, so that the degree of gelatinization and cross-linking of starch gradually increased. As a result, the hardness of the compound rice decreased and the sensory quality and protein digestibility in vitro increased gradually. However, when the screw speed was too large, the material would be subjected to high shear force and friction, which would also lead to a shorter retention time of the material in the extruder chamber, the degree of starch cross-linking and protein denaturation would be reduced, and then its sensory quality and protein digestibility in vitro would be reduced. Overall consideration, the screw speed of the response surface test should be chosen to be about 140 r/min.

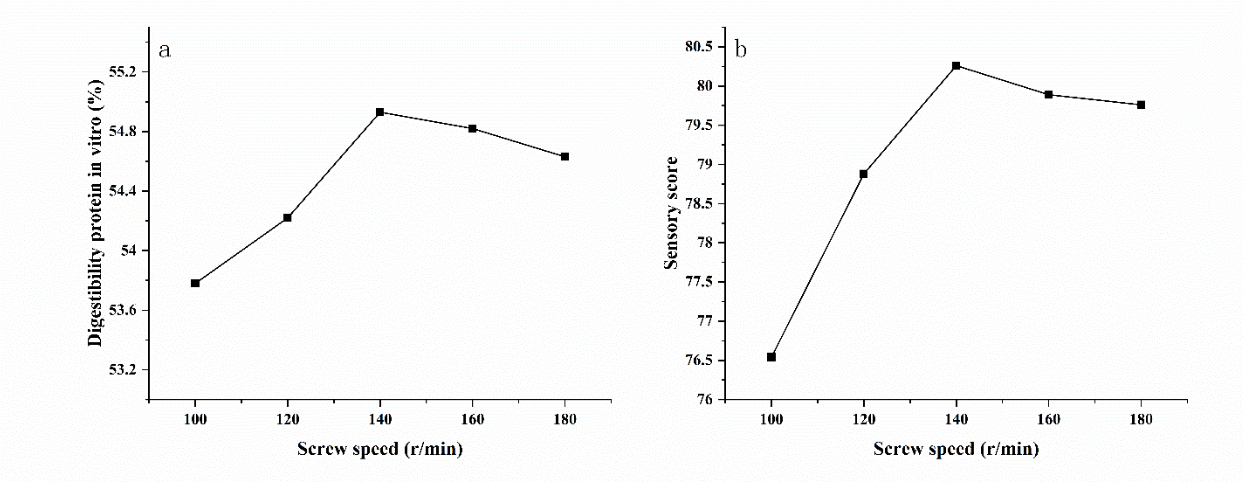

Figure 2: Effect of screw speed on protein digestibility in vitro and sensory quality

Effects of moisture content on quality of lotus seed-lentinus edodes compound rice

According to Figure 3 (a) and(b), the sensory score and protein digestibility in vitro of lotus seed-lentinus edodes compound rice increased first and then decreased with the increase of material moisture content, and the sensory score and protein digestibility in vitro reached the highest when moisture content was 26%. Too low moisture content was not conducive to the destruction of orderly starch chains in starch particles [22], and the gelatinization degree was low, resulted in the degradation of sensory quality of the product. With the increase of moisture content, the destruction degree of orderly starch chain in extruded starch granule was aggravated, the gelatinization degree of starch was improved, and the sensory quality was gradually increased. On the other hand, the degree of Maillard reaction between proteins and sugars degraded by starch could be reduced by increasing the moisture content under low moisture condition, and a certain moisture content could promote the thermal denaturation of proteins at the same temperature [23, 24]. Therefore, in a certain range, the protein digestibility in vitro of compound rice increased with the increase of material moisture content. However, excessive moisture would make the material not formed when it flows out of the die mouth, which reduced the friction between the material and the screw barrel [25], thus reduced the time that the material stayed in the barrel and the gelatinization degree, resulted in a significant decrease in the sensory score of the material and the protein digestibility in vitro. In conclusion, the moisture content of the material in this response surface test should be selected between 23%-29%.

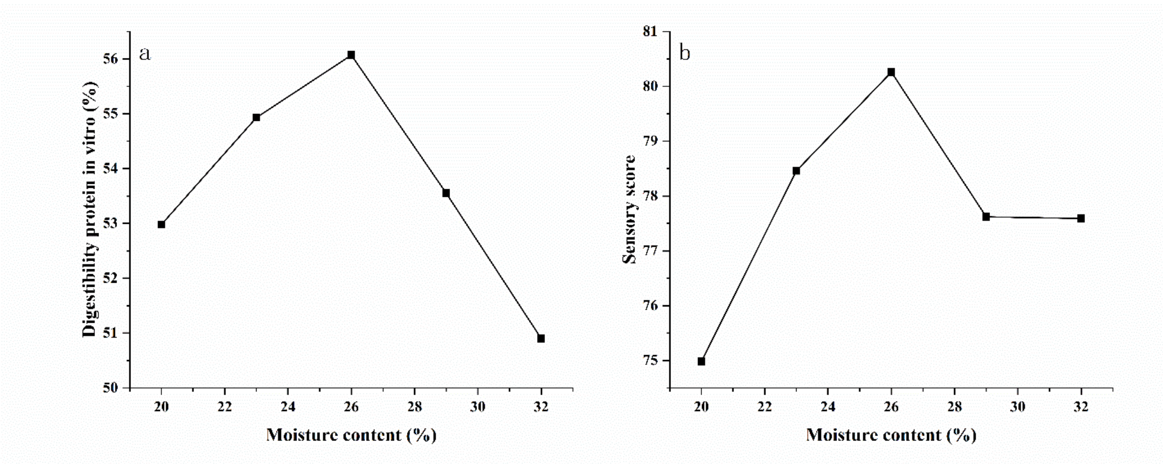

Figure 3. Effect of moisture content on protein digestibility in vitro and sensory quality

Response surface results for protein digestibility in vitro

Table 3 showed the response surface test arrangement and results of protein digestibility in vitro of lotus seed-lentinus edodes compound rice. After the analysis by Design-Expert software, the analysis results of the regression model of protein in vitro digestibility were shown in Table 4. The response surface and contour plot of the interaction between two factors of protein digestibility in vitro were shown in Figure 4.

Table no 3: Response surface test arrangement and results

test number	A	B	C	Y
1	-1	-1	0	53.22
2	1	-1	0	53.92
3	-1	1	0	52.98
4	1	1	0	56.02
5	-1	0	-1	54.13
6	1	0	-1	55.03
7	-1	0	1	52.00
8	1	0	1	53.24
9	0	-1	-1	56.90
10	0	1	-1	58.08
11	0	-1	1	55.94
12	0	1	1	56.16
13	0	0	0	60.44
14	0	0	0	60.31
15	0	0	0	59.98
16	0	0	0	59.85
17	0	0	0	59.26

* A is extrusion temperature, ℃; B is screw speed, r/min; C is the moisture content of the material, %; Y is protein digestibility in vitro, %

Table no 4: Regression model analysis of protein digestibility in vitro

origin	quadratic sum	degree of freedom	mean square	F-value	Prob>F	significance
model	130.8864	9	14.5429	76.1564	< 0.0001	**
A	4.3218	1	4.3218	22.6318	0.0021	**
B	1.3285	1	1.3285	6.9566	0.0335	*
C	5.7800	1	5.7800	30.2679	0.0009	**
AB	1.3689	1	1.3689	7.1685	0.0317	*
AC	0.0289	1	0.0289	0.1513	0.7088	NS
BC	0.2304	1	0.2304	1.2065	0.3084	NS
A^2	87.2259	1	87.2259	456.7724	< 0.0001	**
B^2	8.0360	1	8.0360	42.0816	0.0003	**
C^2	13.8934	1	13.8934	72.7548	< 0.0001	**
residuum	1.3367	7	0.1910			
Lack of fit	0.4817	3	0.1606	0.7510	0.5762	NS
Net error	0.8551	4	0.2138			
summation	132.2232	16				

The results of protein digestibility in vitro were fitted by quadratic polynomial model using Design-Expert software, and the fitting equation of protein in vitro digestibility (Y) on the independent variables extrusion temperature (A), screw speed (B) and material moisture content (C) was as follows: $Y=59.97+0.74A+0.41B-0.85C+0.58AB+0.085AC-0.24BC-4.55A^2-1.38B^2-1.82C^2$.After correction $R2_{adj}$ = 0.9769, indicating that 97.69% of the data could be explained by this model (Table 4), the regression model was extremely significant ($P < 0.01$), and the misfit term was not significant ($P > 0.05$), indicating that the model had a good fit, which could well indicate the relationship between the three factors and the in vitro digestibility of protein. At the same time, it can be seen from Table 4 that factor A (extrusion temperature) and factor C (material moisture content) had extremely significant effects on protein digestibility in vitro of lotus seeds-mushroom complex rice ($P < 0.01$), and factor B (screw speed) had significant effects on protein digestibility in vitro ($P < 0.05$), and F value and P value showed that, The significant order of influencing protein digestibility in vitro was factor C (material moisture content) > factor A (extrusion temperature) > factor B (screw speed). Among the interaction terms, the interaction effect of factor AB was significant ($P < 0.05$), while the interaction effect of other interaction terms was not significant ($P > 0.05$).

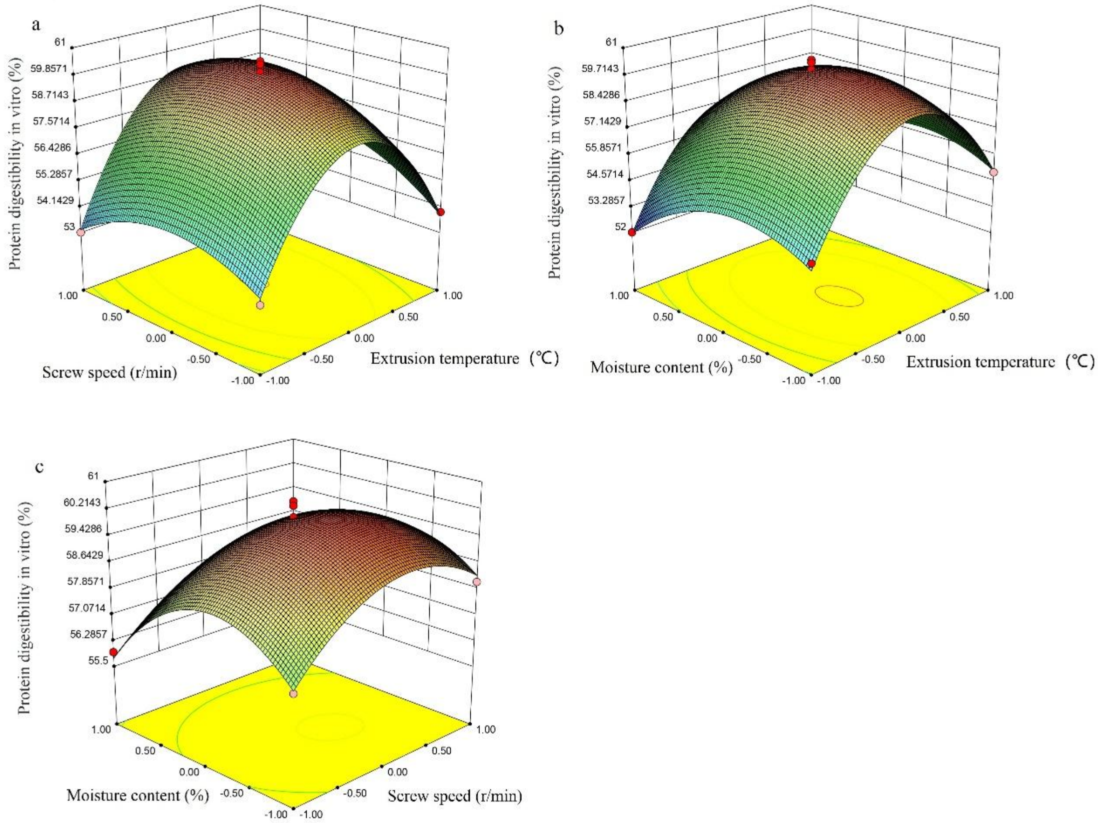

Figure 4: Response surface and contour plot of the influence of interaction of two factors on protein digestibility in vitro

Figure 4 (a) showed the interactive effects of factor A (extrusion temperature) and factor B (screw speed) on protein digestibility in vitro of lotus seed-lentinus edodes compound rice. When the screw speed was low, the protein digestibility in vitro increased first and then decreased with the increase of extrusion temperature, and reached the highest near the center point. At higher screw speed, with the gradual increase of material moisture content, the in vitro digestibility of protein also increased first and then decreased, reaching the highest near the center point. When the extrusion temperature was higher or lower, the protein digestibility in vitro also showed a trend of increasing first and then decreasing with the increase of extrusion temperature. According to the number of intersection points between contour lines, extrusion temperature and screw speed, extrusion temperature was the main factor affecting protein digestibility in vitro compared with screw speed (Figure 4(a)). When the extrusion temperature and material moisture content reached the center point at the same time, the response surface appeared the highest point, and the digestibility protein in vitro reached the highest.

Figure 4 (b) showed the interactive effects of factor A (extrusion temperature) and factor C (moisture content) on protein digestibility in vitro of lotus seed-lentinus edodes compound rice. When the extrusion temperature was low, the digestibility protein in vitro increased first and then decreased with the increase of material moisture content, and reached the highest near the center point. At higher extrusion temperature, with the gradual increase of moisture content, the protein digestibility in vitro also increased first and then decreased, reaching the highest near the center point. When the moisture content of the material was high or low, the in vitro digestibility of protein also showed a trend of increasing first and then decreasing with the increase of extrusion temperature. It could be seen from the intersection of contour lines with extrusion temperature and material moisture content that extrusion temperature was the main factor affecting protein digestibility in vitro compared with material moisture content (Figure 4(b)). When the extrusion temperature and material moisture content reached the center point at the same time, the response surface appeared the highest point, and the digestibility protein in vitro reached the highest.

Figure 4 (c) showed the interactive influence of factor B (screw speed) and factor C (material moisture content) on protein digestibility in vitro of lotus seed-lentinus edodes compound rice. When the screw speed was low, the protein digestibility in vitro increased first and then decreased with the increase of material moisture content, and reached the highest near the center point. When the screw speed was higher, with the gradual increase of material moisture content, the protein digestibility in vitro also increased first and then decreased, reaching the highest near the center point. When the moisture content of the material was high or low, the protein digestibility in vitro also showed a trend of increasing first and then decreasing with the increase of screw speed. As can be seen from the number of intersection points between contour lines and screw speed and material moisture content, compared with screw speed, material moisture content is the main factor affecting protein digestibility in vitro (Figure 4(c)). When the screw speed and material moisture content reached the center point at the same time, the response surface appeared the highest point, and the digestibility protein in vitro reached the highest.

Expert Design 8.0.6 analysis software was used to optimize the function. In order to achieve the highest protein digestibility in vitro of lotus seed-lentinus edodes compound rice, the regression model was established to optimize and evaluate, and the optimal extrusion process conditions were obtained as follows: extrusion temperature 131.28℃, screw speed 144.49 r/min, The moisture content of the material was 25.34%. At this time, the sensory score, protein digestibility in vitro of lotus seed - lentinus edodes compound rice reached the highest at the same time, which was 60.13%.

Verification Test

As shown in Table 5, the sensory score of lotus seed lentinus edodes compound rice extruded with the best technological parameters was close to that of ordinary rice, and the sensory quality was good. And its protein digestibility in vitro was much higher than that of ordinary rice. After extrusion at high temperature and pressure, the hydrogen bonds and van der Waals forces of the protein structure were destroyed, and more sites that were easily digested by digestive enzymes were exposed. At the same time, the high shear force was conducive to the formation of molten protein and uniform fiber protein system, so as to improve the in vitro digestibility of protein.

Table no 5: Comparison of the quality results between the lotus seed-lentinus edodes compound rice and the control rice under the optimal extrusion process parameters

Index	lotus seed-lentinus edodes compound rice	Subei rice
sensory score	79.65	84.58
Protein digestibility in vitro (%)	62.35	55.24

IV. Conclusion

Through single factor test, the center points of each factor were determined. On single factor test basis, through response surface test and Design Expert 8.0.6 analysis software optimization, it was concluded that the optimal extrusion conditions of lotus seed-lentinus edodes compound rice were extrusion temperature 131.28℃, screw speed 144.49 r/min, and moisture content 25.34%. Under these conditions, the rice mixed with lotus seed and mushroom was mellow and had good sensory quality, and the in vitro digestibility and gelatinization degree of protein were greatly improved, which was more conducive to human digestion and absorption.

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