Study on the Deep Processing of Extrusion Modification and Gelatinization Degree of Millet Powder

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Abstract. This paper takes millet powder as the test object, adopts extrusion modification treatment, optimizes the technological parameters of the modification by single factor and response interview. The results show that the best technological parameters of the modified rice powder are: the water content is 22%, the extrusion temperature is 140 °C, the particle size of millet powder is 142 μm, and the screw speed is 20Hz. Under this condition, the gelatinization degree of millet flour was 93.2%. The factors influencing the paste degree of millet powder were: water addition > extrusion temperature > grain size of millet powder > screw speed. This paper aims to provide reference for developing healthy food of cereal powder and provide basis for the deep processing and utilization of millet powder.

Keywords: millet flour, extrusion modification, single factor, response surface

1. Introduction
Millet has a long history of planting in China and was once the main food crop[1]. Millet is rich in nutrition and has an appropriate nutrient ratio. It mainly contains carbohydrates, high-quality hypoallergenic proteins, amino acids, vitamins, etc.[2], with appropriate ratios of various nutrients, is a good source of food nutrition[3], millet also contains a lot of dietary fiber The dietary fiber in millet cannot be digested and absorbed by the human body, but it can promote the peristalsis of the intestinal tract and has a preventive effect on digestive tract diseases [4]. The food processed by millet also has high nutritional value [5], so it is very popular among consumers. Millet is rich in vitamins and is easily absorbed by the human body, with a digestibility rate of over 90% [6]. The protein content of millet is higher than that of rice, and it has the effects of invigorating the stomach, clearing away heat and detoxifying [7]. The protein in millet is extremely low in allergy, and its digestibility and biological value are higher than that of wheat and rice; the carbohydrate content is lower than that of rice, wheat and rice. Corn, and the main ingredient is starch, the content is 63% to 70% [8]. This article aims to analyze the physical and chemical properties of millet powder after extrusion modification. Extrusion treatment can reduce the level of anti-nutritional factors in grains and improve the availability of nutrients [9]. The final millet extruded modified powder can be used for research and development. The production of compound grain nutritional powder provides base material, which will increase the added value of grain resources [10].
2. Materials and Methods

2.1. Raw materials and reagents
Millet Flour (Jiangxi Chunsi Food Co., Ltd.)

2.2. Instruments and equipment
UV-6100 UV-Vis Spectrophotometer, Changzhou Best Instrument Co., Ltd.; YP2001B Electronic Analytical Balance, Lichen Technology Co., Ltd.; DHG-9000 Electric Heating Constant Temperature Blast Drying Box, Shanghai Yiheng Technology Co., Ltd.; JP-2000C -8 type high-speed crusher, Jiupin Industry and Trade Co., Ltd.; MB-45 type fast moisture analyzer, American Ohaus Instruments Shanghai Co., Ltd.; SYSLG30-IV twin-screw extrusion tester, Shandong Saibainuo Machinery Co., Ltd. the company.

2.3. Millet extrusion modification process
Water ↓
Millet powder → moisturizing → twin screw extrusion → crushing and drying → sieving → testing → millet modified powder

2.4. Modified single factor test of millet flour

2.4.1. Effect of Water Addition on Gelatinization Degree of Modified Millet Flour. Under the conditions of extrusion temperature of 140 °C, millet powder particle size of 140μm, screw speed of 20 Hz, and water addition of 18%, 20%, 22%, 24% and 26%, the modified millet powder is used to gelatinize The degree is the evaluation index to investigate the influence of the amount of water added on the gelatinization degree of millet modified powder.

2.4.2. The effect of extrusion temperature on the gelatinization degree of millet modified powder. When the water content is 22%, the millet powder particle size is 140μm, the screw speed is 20 Hz, and the extrusion temperature is 130, 135, 140, 145, and 150 °C, the gelatinization degree of the modified millet powder is used as the evaluation index. , To investigate the influence of extrusion temperature on the gelatinization degree of millet modified powder.

2.4.3. Effect of the particle size of millet flour on the gelatinization degree of modified millet flour. When the water content is 22%, the extrusion temperature is 140 °C, and the screw speed is 20 Hz, when the particle size of the millet powder is 100, 120, 140, 160 and 180μm, the gelatinization degree of the modified millet powder is used as the evaluation index. , To investigate the effect of millet powder particle size on the gelatinization degree of millet modified powder.

2.4.4. The effect of screw speed on the gelatinization degree of millet modified powder. Under the conditions of 22% water addition, 140°C extrusion temperature, 140μm millet powder particle size, and screw speeds of 16, 18, 20, 22 and 24 Hz, the gelatinization degree of millet modified powder is used as the evaluation index. The effect of screw speed and rice noodle particle size on the gelatinization degree of millet modified powder.

2.5. Optimization of Millet Flour Extrusion Modification Process
Comprehensively investigate the single factor test results, take the amount of water added (A), extrusion temperature (B), millet powder particle size (C), screw speed (D) as factors, and take the modified millet powder gelatinization degree (α) as the response Value, design a response surface with four factors and three levels to determine the best process parameters for the extrusion of millet modified powder.
3. Results and Analysis

3.1. Single factor experiment results and analysis of millet extruded modified powder

3.1.1. Effect of Water Addition on Gelatinization Degree of Millet Extrusion Modified Powder. The effect of water addition on the gelatinization degree of millet extruded modified powder is shown in Figure 1.

![Figure 1. Effect of water addition on the pasting degree of millet extrusion modified powder](image)

It can be seen from Figure 1 that when the amount of water added is 18%, the degree of gelatinization of the millet extruded modified powder is low, and as the amount of water added gradually increases, the degree of gelatinization gradually increases. When the amount of water added is 22%, the gelatinization degree reaches the best. As the amount of water added increases again, the degree of gelatinization also decreases. This may be because the amount of water added is too small and the gelatinization degree is not reached, so the gelatinization degree is low. When the amount of water added is too much, the stability of the starch decreases, so the degree of gelatinization is low. Therefore, 20%, 22%, and 24% are selected as the response surface experimental research level.

3.1.2. The effect of extrusion temperature on the gelatinization degree of millet extruded modified powder. The effect of extrusion temperature on the gelatinization degree of millet extrusion modified powder is shown in Figure 2.
Figure 2. Effect of extrusion temperature on the degree of gelatinization of millet extruded modified powder

It can be seen from Fig. 2 that when the extrusion temperature is 100°C, the gelatinization degree is relatively low. As the extrusion temperature gradually increases, the gelatinization degree of the millet extruded modified powder also gradually increases. When the extrusion temperature is 140°C, the gelatinization degree reaches the best. As the extrusion temperature increases again, the degree of gelatinization also decreases. This may be because when the extrusion temperature is too low, it is difficult to gelatinize completely, so the degree of gelatinization is low. When the extrusion temperature is too high, the millet powder will stick to the extrusion screw and affect the gelatinization of the millet powder. Therefore, 120°C, 140°C, and 160°C were selected as the extrusion temperature as the research level of response surface experiments.

3.1.3. The effect of millet powder particle size on the gelatinization degree of millet extruded modified powder. The effect of millet powder particle size on the gelatinization degree of millet extruded modified powder is shown in Figure 3.

Figure 3. Effect of particle size of millet flour on paste degree of extruded modified millet flour
It can be seen from Fig. 3 that when the particle size of millet powder is 100 μm, the gelatinization degree is relatively low. As the particle size of the millet powder gradually increases, the gelatinization degree also increases. When the grain size of millet flour is 140μm, the gelatinization degree reaches the best. As the particle size of millet flour increases again, the degree of gelatinization also decreases. The reason may be that when the particle size is too small, the millet powder cannot fully contact with water molecules, resulting in insufficient gelatinization, and when the particle size is too large, the millet powder slips in the extruder, which also causes the millet powder to gelatinize too low. Therefore, the particle size of millet powder is selected as 120μm, 140μm, and 160μm as the research level of response surface test.

3.1.4. The effect of screw speed on the gelatinization degree of millet extruded modified powder. The effect of screw speed on the gelatinization degree of millet powder extrusion modification is shown in Figure 4.

![Figure 4. Effect of screw speed on pasting degree of millet extrusion modified powder](image)

It can be seen from Figure 4 that when the screw speed is 16 Hz, the degree of gelatinization of millet flour is the lowest. As the screw speed increases, the gelatinization degree of millet flour gradually increases. When the screw speed is 20 Hz, the gelatinization degree reaches the highest, and the screw speed continues to increase, and the gelatinization degree begins to decrease rapidly. The reason may be that when the screw speed is low, the material moves slowly, and the material loses water quickly, resulting in insufficient gelatinization; when the screw speed is too fast, the material in the extrusion cavity has a shorter time, resulting in incomplete gelatinization. Therefore, the screw speed is to choose 18Hz, 20Hz, 22Hz as the response surface test research level.

3.2. Optimizing Extrusion Modification Process of Corn Meal by Response Test

3.2.1. Establishment of Mathematical Model and Significance Test. Using single factor results, according to the principle of response surface test, select the water content (A), extrusion temperature (B), millet powder particle size (C), screw speed (D) as the factors, and select the gelatinization degree (Y) as the evaluation Indicators and response surface results are shown in Table 2.
Table 2. Box Behnken central composite experimental design and results

| Experiment number | A Water addition/% | B Extrusion temperature/℃ | C Millet powder particle size/μm | D Screw speed/Hz | Gelatinization% |
|-------------------|-------------------|--------------------------|---------------------------------|-----------------|----------------|
| 1                 | -1                | -1                       | 0                               | 0               | 79.57          |
| 2                 | 1                 | -1                       | 0                               | 0               | 85.44          |
| 3                 | -1                | 1                        | 0                               | 0               | 85.73          |
| 4                 | 1                 | 1                        | 0                               | 0               | 85.91          |
| 5                 | 0                 | 0                        | -1                              | -1              | 82.18          |
| 6                 | 0                 | 0                        | 1                               | -1              | 87.80          |
| 7                 | 0                 | 0                        | -1                              | 1               | 85.62          |
| 8                 | 0                 | 0                        | 1                               | 1               | 88.11          |
| 9                 | -1                | 0                        | 0                               | -1              | 86.63          |
| 10                | 1                 | 0                        | 0                               | -1              | 88.81          |
| 11                | -1                | 0                        | 0                               | 1               | 88.58          |
| 12                | 1                 | 0                        | 0                               | 1               | 89.48          |
| 13                | 0                 | -1                       | -1                              | 0               | 78.11          |
| 14                | 0                 | 1                        | -1                              | 0               | 81.42          |
| 15                | 0                 | -1                       | 1                               | 0               | 81.28          |
| 16                | 0                 | 1                        | 1                               | 0               | 82.14          |
| 17                | -1                | 0                        | -1                              | 0               | 79.38          |
| 18                | 1                 | 0                        | -1                              | 0               | 86.41          |
| 19                | -1                | 0                        | 1                               | 0               | 86.56          |
| 20                | 1                 | 0                        | 1                               | 0               | 86.78          |
| 21                | 0                 | -1                       | 0                               | -1              | 79.08          |
| 22                | 0                 | 1                        | 0                               | -1              | 84.78          |
| 23                | 0                 | -1                       | 0                               | 1               | 84.72          |
| 24                | 0                 | 1                        | 0                               | 1               | 84.87          |
| 25                | 0                 | 0                        | 0                               | 0               | 92.57          |
| 26                | 0                 | 0                        | 0                               | 0               | 93.10          |
| 27                | 0                 | 0                        | 0                               | 0               | 93.20          |
| 28                | 0                 | 0                        | 0                               | 0               | 92.22          |
| 29                | 0                 | 0                        | 0                               | 0               | 93.11          |

Use response surface software to make regression fitting, significance test and variance analysis of Table 2 to get the degree of gelatinization of the quadratic equation $Y = 92.84 + 1.36A + 1.39B + 1.63C + 1.01D - 1.42AB - 1.70AC - 0.32AD - 0.61BC - 1.39BD - 0.78CD - 2.32A^2 - 6.85B^2 - 5.25C^2 - 2.15D^2$

The significance of the model is tested, and the analysis of variance can be obtained as shown in Table 3, and the credibility analysis of the model is shown in Table 4.

According to Table 2 and Table 3, the response model $p < 0.0001$, which shows that the response surface is extremely significant, and the relative error between the theoretical value and the actual value is extremely small. Therefore, the test results can be analyzed using this equation, $R^2 = 97.89\%$, indicating that the theoretical value and the actual value can fit well, the correlation is high, and the data is true. According to the results of the analysis of variance, the interaction terms AB, AC, and BD square terms A2, B2, C2, and D2 of the primary terms A, B, C, and D have a significant impact on the results. The largest impact on millet extrusion modified powder is the amount of water added, followed by extrusion temperature, millet powder particle size, and screw speed.
Table 3. Regression equation and analysis of variance

| Level | Degree of freedom | Sum of squares | Mean square | F value | P value | Significance |
|-------|------------------|----------------|-------------|---------|---------|--------------|
| A     | 22.36            | 1              | 22.36       | 27.29   | 0.0001  | **           |
| B     | 23.10            | 1              | 23.10       | 28.20   | 0.0001  | **           |
| C     | 31.85            | 1              | 31.85       | 38.87   | < 0.0001| **           |
| D     | 12.2             | 1              | 12.2        | 14.89   | 0.0017  | **           |
| AB    | 8.09             | 1              | 8.09        | 9.88    | 0.0072  | **           |
| AC    | 11.59            | 1              | 11.59       | 14.15   | 0.0021  | **           |
| AD    | 0.41             | 1              | 0.41        | 0.50    | 0.4911  |              |
| BC    | 1.5              | 1              | 1.50        | 1.83    | 0.1974  |              |
| BD    | 7.7              | 1              | 7.70        | 9.40    | 0.0084  | **           |
| CD    | 2.45             | 1              | 2.45        | 2.99    | 0.1058  |              |
| A²    | 53.46            | 1              | 34.85       | 42.54   | < 0.0001| **           |
| B²    | 355.17           | 1              | 304.07      | 371.12  | < 0.0001| **           |
| C²    | 218.74           | 1              | 179.07      | 218.56  | < 0.0001| **           |
| D²    | 47.23            | 1              | 29.86       | 36.44   | < 0.0001| **           |
| Model | 532.02           | 14             | 38.00       | 46.38   | < 0.0001| **           |
| Residual | 11.79         | 14             | 0.84        |         |          |              |
| Lack of fit | 10.74       | 10             | 1.07        | 5.91    | 0.0508  |              |
| Pure error | 0.73        | 4              | 0.18        |         |          |              |
| sum   | 543.49           | 28             |             |         |          |              |

Note: *, the difference is significant (P<0.05); **, the difference is extremely significant (P<0.01)

Table 4. Reliability analysis of regression model

| Project | Response Surface Results Average | Multiple Correlation Coefficient r²/% | Modified Correlation Coefficient R²Adj/% | Coefficient of Variation of Y/% |
|---------|----------------------------------|--------------------------------------|----------------------------------------|-------------------------------|
| Result  | 85.99                            | 97.89                                | 95.78                                  | 1.05                          |

3.2.2. Optimize the process parameters of millet extruded modified powder. According to the analysis of response surface software, the optimal process parameters of millet extruded modified powder are: water content 22.52%, extrusion temperature 140.27°C, millet powder particle size 142.08μm, screw speed 20.28Hz. The gelatinization degree of the millet extruded modified powder prepared in this way was 93.2014%. Under actual conditions, in order to facilitate the operation, the parameters are revised to: 22% water addition, 140°C extrusion temperature, 142μm millet powder particle size, and 20Hz screw speed. If three parallel tests are carried out with the revised process parameters, the final gelatinization degree is 93.2%. The influencing factors of the gelatinization degree of millet powder extruded modified powder in descending order are: water content>extrusion temperature>millet powder particle size>screw speed.

4. Conclusions
The optimal process parameters of millet extruded modified powder are: water content 22%, extrusion temperature 140°C, millet powder particle size 142μm, screw speed 20Hz. Under these conditions, the gelatinization degree of millet extruded modified powder is 93.2%. The factors affecting the gelatinization degree of millet powder extruded modified powder in descending order are: water content>extrusion temperature>millet powder particle size>screw speed. According to the experimental results and data analysis, the millet extruded modified powder prepared with the best process parameters has an ideal effect.
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References
[1] Ligen Wu, Lingbo Qu. Research progress on nutritional function and processing of millet [J]. Food Research and Development, 2018, 39(15): 191-196.
[2] Xiaofang Liu, Anna Wang, Ligen Wu. Response surface method to optimize the optimal ratio of coarse cereal steamed bread [J]. Journal of Henan University of Technology (Natural Science Edition), 2021, 42(01): 42-48.
[3] Anna Wang, Xiaofang Liu, Ligen Wu, et al. Effects of millet flour and millet flour on the rheological properties of dough [J]. Journal of Henan University of Technology (Natural Science Edition), 2019, 40(06): 7-13.
[4] Munan Li, Fengying Lan. Research progress on the nutritional components and health functions of millet [J]. Journal of Hebei North University (Natural Science Edition), 2017, 33(07): 56-60.
[5] Guiying Zhang, Xiwen Zhang, Ruiling Shen, et al. Comprehensive evaluation of the rheological properties of the dough based on the principal component of millet-wheat mixed flour[J].Science and Technology of Food Industry, 2018, 39(07): 35-39.
[6] Yujie Liu, Yinhuan Chen, Xiushi Yang, et al. Research progress on the nutrition and functional components of millet [J]. Food and Oils, 2020, 33(05): 1-3.
[7] Lanlan Liang, Mengxian Li. Optimization of processing technology of rice noodles with whole grains [J]. Food Science and Technology, 2020, 45(12): 150-155.
[8] Liyuan Ma, Yang Li, Yana Zhang, et al. The processing technology of compound enzyme hydrolyzed grains millet flour [J]. Food Industry, 2020, 41(05): 77-81.
[9] Nikmaram N, Leong S Y, Koubaa M, et al. Effect of extrusion on the anti-nutritional factors of food products: An overview [J]. Food Control, 2017, 79(79): 62-73.
[10] Jingxue Jing, Tingting Gao, Fenglin Li, et al. Optimization of key process of extrusion modification of naked oat flour by response surface experiment [J]. Food Industry, 2019, 40(10): 80-84.