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Optimization of the Production Process of Rice Porridge Boiled With Pig Scapula Enzymolysis Soup

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ABSTRACT

This article uses pig scapula and rice as the main ingredients, with millet as an auxiliary ingredient. After enzymatic hydrolysis of the pig bones with papain, a nutritious and healthy pig bone rice porridge is prepared through high-temperature and high-pressure cooking. Single-factor experiments and orthogonal experiments were employed to optimize the process of making pig bone rice porridge. The study shows that the optimal process for making pig bone rice porridge is as follows: enzymatic hydrolysis of pig scapula for 4 hours, enzyme dosage of 18 g, cooking time of 45 minutes, cooking temperature of 110°C, and a rice-to-water ratio of 20:3. Under these conditions, the resulting pig bone rice porridge has a rich aroma, desirable texture, and a free amino nitrogen content of 0.25 g/100 g, with a sensory evaluation score of 84.5 points. This article provides an additional product option for the instant porridge industry and offers process parameter references for the further development of pig bone rice porridge.

KEYWORDS

Pig bone porridge; Process flow; Free amino acid nitrogen; Enzymatic hydrolysis

1. INTRODUCTION

The production, import and export volume and consumption of pork in China are large [1], and its consumption is much higher than that of beef, chicken and other livestock and poultry. At the same time, a large number of by-products will be produced in the process of pork production, accounting for about 11 % -35 % of the whole carcass [2-4]. Among them, bones are an important component of the carcass [5-6], accounting for about one-fifth of the total weight, and they are the main by-products generated during the processing of meat products [7]. Pig bones contain a variety of nutrients, including bio-calcium, peptides, nucleotides, collagen, fat, and organic acids [3, 8]. Some studies have found that certain nutrients in pig bones are even higher than those in pork and soft-shelled turtle[9]. For example, pig bones have a high calcium content that is more easily absorbed and utilized by the human body [9], it also contains eight essential amino acids required by the human body [7, 10]. Enzymatic treatment of pig bones can break down collagen into peptides and amino acids, thereby increasing the extraction rate of bone proteins [11]. Moreover, the proteins after hydrolysis have smaller molecular weights and higher solubility in water. Compared to large molecular weight proteins, they produce a stronger stimulation of the taste buds and have a more pronounced flavor-enhancing ability [12]. Compared to pig bones from other parts of the body, the scapular bones have less residual meat, lower hardness, and lower utilization rates. They are mostly discarded or used to feed animals, which makes them relatively inexpensive [10]. Given that the nutritional components of pig bones from different parts are similar, considering both the comprehensive nutritional value and the economic cost, the scapular bone is chosen as the main raw material.

With the improvement of people's living standards and the increasing acceptance of a healthy lifestyle, food that is safe, high-quality, natural, and healthy has become increasingly popular. One of the major trends in this regard is the preference for light and stomach-friendly diets. Porridge is a traditional delicacy in China, Japan, South Korea, and Southeast Asian countries [13]. It is also one of the many types of breakfasts in China [14-15]. Generally, it is made by simmering grains with legumes or dried fruits in water over low heat, resulting in a porridge through the process of starch gelatinization [16]. The flavor and texture of cereal products are primarily formed by changes in cereal biopolymers and flavor-active compounds during processing [17]. These products are highly appreciated by consumers for their rich nutrition and unique flavor [18]. Moreover, porridge has a smooth and tender texture, making it easy to chew and digest [13], and facilitating absorption by the human body [19]. It is known for its ability to nurture the stomach and intestines and is regarded as a symbol of healthy and wellness-oriented eating. Using the enzymatic hydrolysate of pig scapula to cook porridge can enhance the utilization rate of pig scapula, reduce the waste of resources, and promote the development of multiple aspects of the industry. It is expected to provide a theoretical basis for the industrialization of pig bone rice porridge.

2. MATERIALS AND METHODS

2.1. Materials

Pig shoulder blades, rice, millet and salt were purchased in Yibin City, Sichuan Province, China. The papain was from the Institute of Grain Crops, Xinjiang Academy of Agricultural Sciences.

2.2. Method of Making Pig Bone Rice Porridge

The fresh pig scapulae were washed with clean tap water at room temperature, and then the residual meat and fat were trimmed off with a knife [9]. The bones were then cut into pieces of approximately 1 cm in size and soaked in clean water for about 30 minutes [20]. Remove pork bones, rinse and drain, add scallions, ginger, garlic and pure water, blanch for 5 minutes to remove blood water, then drain [21-22]. Weigh 200 g of the treated pork bone pieces, add pure water to the beaker according to the ratio of 1:6, then weigh and add the required amount of papain, and put the beaker into a constant temperature water bath preheated at 55℃ for enzymatic hydrolysis [10]. Weigh the rice and millet, wash them thoroughly, drain the water, and place them into a container. Add the enzymatically hydrolyzed pig bone broth according to the rice-to-water ratio. Using an autoclave, set the corresponding cooking time and conditions to cook the mixture. Finally, mix the well-prepared seasonings evenly into the cooked pig bone rice porridge.

2.3. Single Factor Experimental Design

The basic formulation and cooking process for pig bone rice porridge are as follows: 200 g of pig scapula bones are added to pure water at a ratio of 1:6 along with 10 g of papain, and subjected to enzymatic hydrolysis for 4 hours at a constant temperature of 55°C. After hydrolysis, 200 g of the bone broth is weighed out, combined with 20 g of rice and 1 g of millet, and cooked in an autoclave at 110°C for 30 minutes. On this basis, single-factor experiments were conducted to investigate the effects of cooking temperature (80°C, 90°C, 100°C, 110°C, 120°C), cooking time (20 min, 30 min, 40 min, 50 min, 60 min), enzyme dosage (5 g, 10 g, 15 g, 20 g, 25 g), enzymatic hydrolysis time (2 h, 3 h, 4 h, 5 h, 6 h), and rice-to-water ratio (20:1, 20:2, 20:3, 20:4, 20:5) on the sensory properties and free amino nitrogen content of the pig bone rice porridge.

2.4. Orthogonal Design of Experiment

Based on the results of the single-factor experiments, enzyme dosage (A), cooking time (B), and rice-to-water ratio (C) were selected as the influential factors. The optimal experimental points from the single-factor experiments and their adjacent levels were chosen as the value ranges. An L9(33) orthogonal experimental design was employed to determine the optimal process conditions, using the content of free amino nitrogen and the average sensory evaluation results as criteria. The factors for the orthogonal experiment of pig bone rice porridge are shown in Table 1.

Table 1. Factor level table of orthogonal test of pig bone rice porridge

	Factor		
Level	A (Enzyme dosage /g)	B (Cooking time /min)	C (Rice-to-water ratio)
1	12	35	20:2
2	15	40	20:3
3	18	45	20:4

2.5. Sensory Scoring Requirements

The sensory evaluation criteria for pig bone rice porridge were designed based on the sensory requirements in the standard SB/T 10652-2012 "Rice and Rice Gurel and Rice Flour Products. " Ten students majoring in food science (five males and five females) were invited to serve as sensory evaluators. The sensory evaluation is based on a 100-point scale, with the following scoring criteria: the presence of impurities in the porridge, the degree of rice grain expansion, and the extent of damage (0-20 points); the flavor and texture of the porridge (0-30 points); the uniformity of the porridge's texture and the absence of stratification (0-30 points); the uniformity and milky white color of the porridge (0-20 points).

2.6. Determination of Amino Acid Nitrogen Content

Referring to the national standard GB 5009.235-2016 "Food Safety National Standard: Determination of Amino Nitrogen in Foods," the formaldehyde potentiometric method was used. The specific procedure is as follows: Before measurement, the sample is processed and homogenized using a blender. The sample is then placed in a beaker and titrated with 0.1 mol/L standard sodium hydroxide solution. Once the pH meter indicates a pH value of 8.2, 10 mL of neutral formaldehyde is added. The magnetic stirrer is then activated. Subsequently, the sample is titrated with the standard sodium hydroxide solution until the pH reaches 9.2, which is the endpoint. The volume (in milliliters) of the standard sodium hydroxide solution consumed after the addition of formaldehyde is recorded[23-24].

2.7. Data Analysis

All analyses were repeated in triplicate. The one-factor analysis of variance (ANOVA) was conducted by SPSS version 20 (SPSS Inc., Chicago, USA).

3. RESULTS AND DISCUSSION

3.1. Single Factor Test Results And Analysis

3.1.1. The effect of boiling time

The results are shown in Figure 1, the cooking time of the porridge has a significant impact on the sensory properties and nutritional value of pig bone rice porridge. If the cooking time is too short, the rice grains will not be fully gelatinized, failing to achieve the desired viscosity [25]. This results in insufficient aroma and an undercooked texture of the porridge, and also affects the breakdown of nutrients in the rice [26]. However, if the cooking time is too long, the porridge will have overcooked rice grains, deteriorated texture, and loss of nutritional value [26]. Relevant studies have shown that under high-temperature and high-pressure conditions, a cooking time of 30 to 40 minutes is relatively appropriate for porridge [16]. As shown in Figure 1, in this study, the cooking time of pig bone rice porridge had a highly significant impact on the content of free amino nitrogen and sensory evaluation ($P<0.01$), with both showing an initial increase followed by a decrease as the cooking time increased. When the cooking time was 20 minutes, the sensory score and the content of free amino nitrogen were relatively low. The porridge had insufficient aroma, poor texture, and a noticeable stratification. As the cooking time increased to 40 minutes, the content of free amino nitrogen and the sensory score reached their highest values, at 0.27 g/100 g and 80.50 points, respectively. At this point, the porridge had a natural color and better taste and texture. However, as the cooking time continued to increase, both the sensory score and the content of free amino nitrogen dropped sharply after 50 minutes of cooking. This may be because, under high pressure and temperature conditions, the longer the cooking time, the more severe the breakdown of the rice grains. The grains became overly mushy, reducing the porridge's viscosity and resulting in an undesirable texture with poor chewiness.

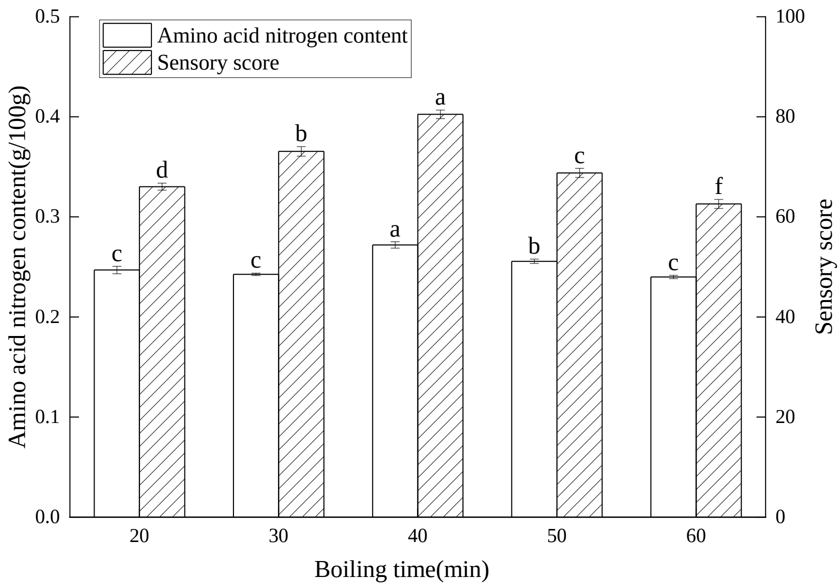

Figure 1. Effect of boiling time on free amino acid nitrogen content and sensory score of pig bone rice porridge

3.1.2. The effect of boiling temperature

Figure 2 shows the effects of different cooking temperatures on the content of free amino nitrogen and sensory evaluation in pig bone rice porridge. Cooking temperature is an important factor for starch gelatinization and has a significant impact on the digestibility of starch [27], but it has little effect on the solubility of free amino nitrogen. As shown in Figure 2, the cooking temperature shows an upward trend in the content of free amino nitrogen, but the difference is not significant ($P > 0.05$). However, there are significant differences in sensory scores with changes in temperature ($P < 0.01$). This is because a higher cooking temperature can accelerate the breakdown of rice grains during the cooking process, increase the viscosity of the porridge, and thereby enhance its sensory value. When the cooking temperature reaches 110°C, the resulting pig bone rice porridge has a natural rice aroma, low oiliness, no off-flavors, and a desirable texture. The content of free amino nitrogen reaches a relative maximum of 0.23 g/100 g, with a sensory score of 82.30 points. Under the same cooking conditions, when the temperature is below 100°C, the porridge tends to have a stronger oily flavor, an undercooked texture, and insufficient aroma, resulting in poor sensory quality. When cooked at 120°C, the rice grains are excessively broken down, leading to an undesirable texture. Generally, home-cooked porridge is prepared by simmering over low heat, with cooking temperatures not exceeding 100°C. This method is time-consuming. However, under high-temperature and high-pressure conditions, the cooking time can be significantly reduced, thereby saving time and effort.

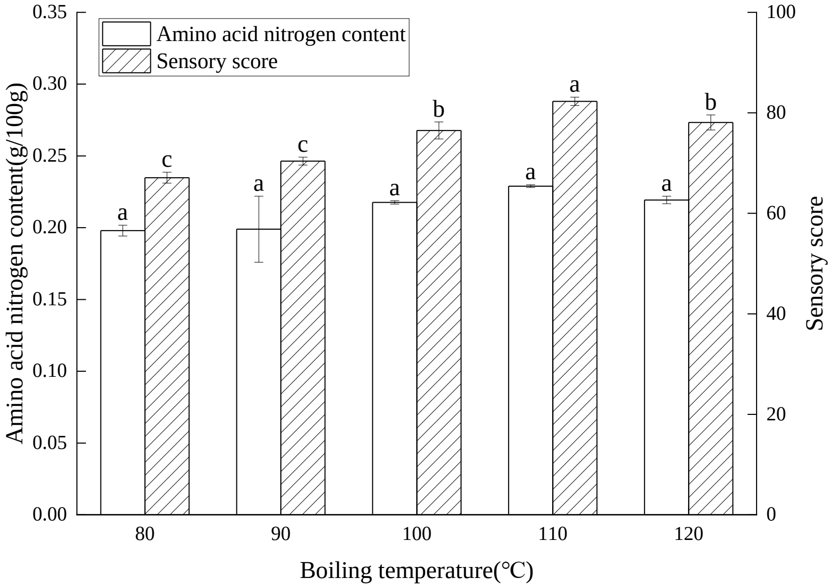

Figure 2. Effect of boiling temperature on free amino acid nitrogen content and sensory score of pig bone rice porridge

3.1.3. The effect of the amount of enzyme added

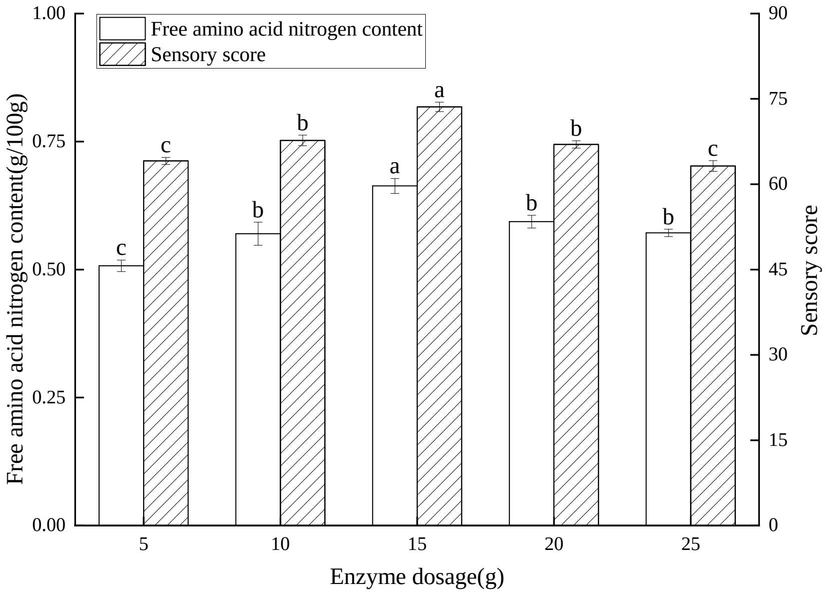

Figure 3. Effect of enzyme dosage on free amino acid nitrogen content and sensory score in pig bone rice porridge

The traditional method of cooking pig bone soup takes a long time and results in a low calcium solubility rate [11]. Enzymatic hydrolysis is an efficient way to utilize pig bone protein, it can hydrolyze the collagen in bones, thereby enhancing their nutritional value and functional properties [28]. Papain is an endopeptidase that possesses both protease and esterase activities. It has a strong hydrolytic capacity for proteins and peptides from both animal and plant sources [5]. Using papain to pre-treat pig scapula bones with enzymatic hydrolysis can increase the extraction rate of nutrients from pig bones. In this study, the content of free amino nitrogen in pig bone rice porridge was detected, and sensory evaluation was also conducted to analyze the effects of different papain dosages on the porridge. The results are shown in Figure 3. As indicated in Figure 3, the increase in papain dosage had a highly significant impact on the content of free amino nitrogen and sensory score in pig bone rice porridge (P<0.01). When the enzyme dosage was 15 g, the content of free amino nitrogen reached its maximum value of 0.66 g/100 g, with a sensory score of 73.60 points. As the dosage of papain continued to increase, both the content of free amino nitrogen and the sensory score showed an initial increase followed by a decrease. This indicates that within a certain range of enzyme addition, the solubility of free amino nitrogen can be increased. However, once a certain threshold is exceeded, the solubility decreases, and the sensory quality of the porridge also deteriorates.

3.1.4. Effect of enzymatic hydrolysis time

Enzymatic hydrolysis of bone proteins falls within the realm of high-tech applications [5]. Currently, there is a substantial body of research on enzymatic hydrolysis, and its food safety can be assured. Li [5] used a combination of papain and flavor protease to hydrolyze pig bone protein, and set the enzymatic hydrolysis time for bone broth protein at 4 hours. Qu [11] determined that the optimal hydrolysis time for pig bone protein using alkaline protease was between 3.5 and 4.5 hours. Zhang [10] investigated the preparation of antioxidant peptides from pig scapula using different proteases and determined the enzymatic hydrolysis time to be 4 hours. In this study, only papain was used to explore the effects of enzymatic hydrolysis time on the content of free amino nitrogen and sensory scores in pig bone rice porridge. The results are shown in Figure 4. As indicated in Figure 4, during the enzymatic hydrolysis process, the hydrolysis time had a significant effect on the content of free amino nitrogen ($P < 0.05$). The content of free amino nitrogen remained relatively stable between 2 and 4 hours of hydrolysis, and then showed a downward trend between 4 and 6 hours before gradually stabilizing again. The hydrolysis time had a highly significant impact on the sensory score ($P < 0.01$). Within the range of 2 to 4 hours, the sensory score increased with the hydrolysis time. However, between 4 and 6 hours, the sensory score decreased as the hydrolysis time increased. This was due to the slightly stronger oily flavor of the pig bone rice porridge, which negatively affected its sensory quality. At 4 hours of hydrolysis, the content of free amino nitrogen in the pig bone rice porridge reached a relative maximum of 0.40 g/100 g, and the sensory score reached its highest value of 79.10 points. Therefore, the enzymatic hydrolysis time was determined to be 4 hours.

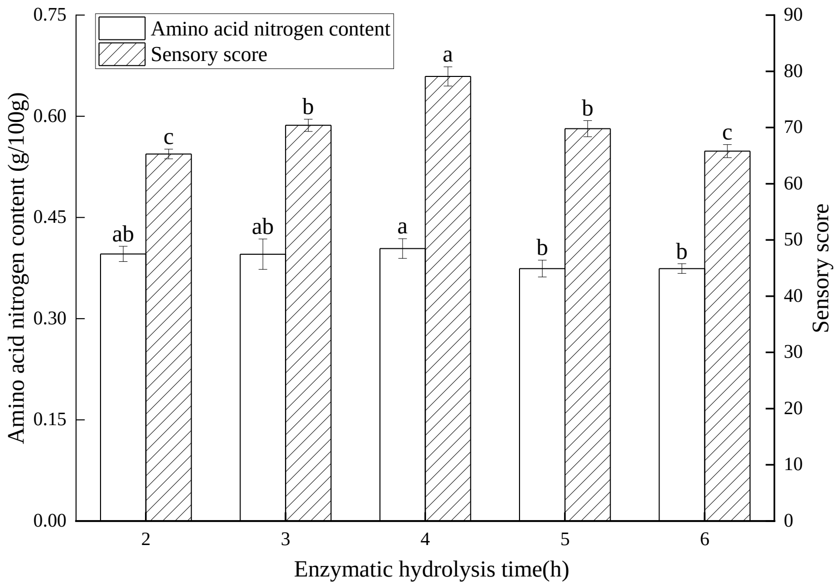

Figure 4. Effect of enzymolysis time on free amino acid nitrogen content and sensory score of pork bone rice porridge

3.1.5. Effect of enzymatic hydrolysis time

An appropriate rice-to-water ratio can give the porridge a better texture and appearance [19]. Add too little water, porridge will be too thick, does not meet the sensory standards of porridge [28]; Too much will lead to obvious stratification of rice porridge, decrease of fragrance, and excessive expansion of rice grains [27-28]. This study investigated the effects of the ratio of enzymatically hydrolyzed pork bone broth to rice on the content of free amino acid nitrogen and sensory scores in pork bone rice porridge. As shown in Figure 5, the variation in the rice-to-water ratio had a highly significant impact on the free amino acid nitrogen content and sensory scores of the porridge ($P < 0.01$). Within the range of 20:1 to 20:3 for the ratio of enzymatically hydrolyzed pork bone broth to rice, the free amino acid nitrogen content in the porridge showed an increasing trend. However, from 20:3 to 20:5, the content exhibited a decreasing trend. The maximum free amino acid nitrogen content of 0.37 g/100 g was achieved at a rice-to-water ratio of 20:3. On the other hand, the sensory score reached its peak of 83.8 points at a rice-to-water ratio of 20:2, after which it declined. When the rice content was too low, the porridge exhibited a clear separation of water and rice, resulting in a bland taste and excessive wateriness. Conversely, when the rice content was too high, the porridge became overly thick, making it difficult to stir and season, thereby negatively affecting the sensory score. At a rice-to-water ratio of 20:3, the porridge achieved the highest free amino acid nitrogen content. Although the sensory score was slightly lower than that at 20:2, the overall aroma, texture, and consistency were considered more balanced and suitable.

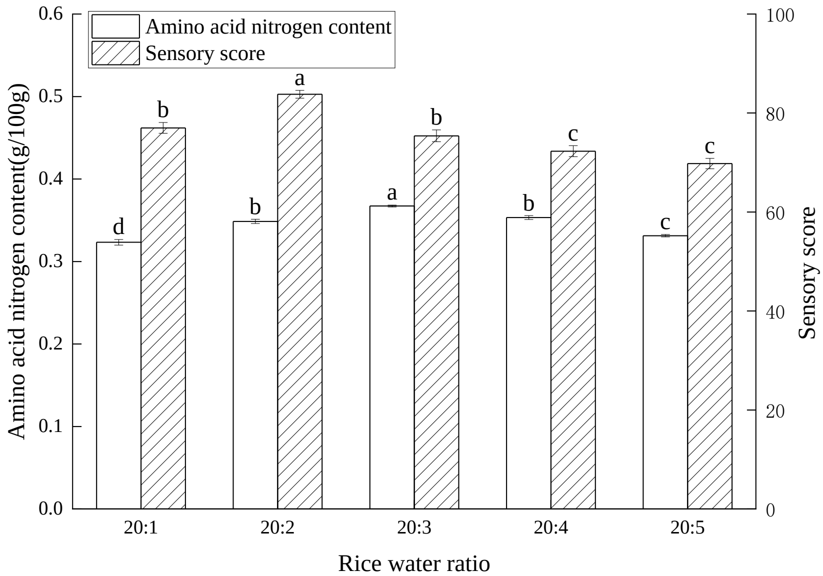

Figure 5. Effect of water ratio on the content of free amino acid nitrogen and sensory score of pork bone rice porridge

3.2. Orthogonal Test Results and Analysis

According to the optimized data selected from the single factor experiment results, orthogonal experiments were carried out on the free amino acid nitrogen and sensory scoring criteria for the three influencing factors of enzyme addition amount, cooking time and rice to water ratio. The results are shown in Table 2.

Table 2. Orthogonal analysis of experimental results

Test number	A	B	C	a Amino acid nitrogen content	b Sensory score
1	12	35	20:2	0.197	80.2
2	12	40	20:3	0.196	81.4
3	12	45	20:4	0.192	81
4	15	35	20:2	0.184	80.5
5	15	40	20:3	0.194	81.8
6	15	45	20:4	0.204	82.5
7	18	35	20:2	0.250	83.2
8	18	40	20:3	0.245	81.6
9	18	45	20:4	0.250	82.9
K_{a1}	0.174	0.210	0.214		
K_{a2}	0.194	0.212	0.217		
K_{a3}	0.248	0.215	0.207		
R_a	0.074	0.005	0.01		
K_{b1}	80.87	81.30	81.63		
K_{b2}	81.60	81.60	82.37		
K_{b3}	82.57	82.13	81.03		
R_b	1.7	0.8	1.3		
a Amino acid nitrogen content	$A_a>C_a>B_a$				
b Sensory score	$A_b>C_b>B_b$				

Through the orthogonal test results, we can clearly see that when the content of free amino acid nitrogen in pig bone rice porridge and sensory scores are taken as the indexes of orthogonal experiment evaluation, factor A has the most significant influence on the content of free amino acid nitrogen in pig bone rice porridge, while factor C and factor B have almost no influence on the content of free amino acid and sensory scores. Combined with the indexes, we can determine the main and secondary order affecting the content of free amino acid nitrogen and sensory score in pig bone rice porridge is the amount of enzyme > the ratio of rice to water > cooking time. According to K_a value and K_b value, $A_3B_3C_2$ is the best combination of free amino acid nitrogen leaching and sensory score, that is, the cooking time is 45 min, the amount of enzyme is 18 g, and the ratio of rice to water is 20:3.

3.3. Verification Experiment

In order to verify the results of the orthogonal test, a verification experiment was conducted on the optimal formula selected by the K value, that is, after enzymatic hydrolysis of pig shoulder blades with 18 g papain added for 4 h, the ratio of addition to rice was 20:3, the temperature was set at 110 °C, and the formula was boiled in a high-pressure high-temperature sterilization pot for 45 min. At this time, the content of free amino acid nitrogen was 0.25 g per 100 g of pig bone rice porridge, and the sensory score was 84.5 points. Therefore, through the detection of free amino acid nitrogen content and sensory scores compared with the results of orthogonal test, it is proved that the formula is indeed the best formula.

4. CONCLUSION

Pig bone is a by-product of pork slaughtering industry, which accounts for a large proportion of the whole pig. It has rich nutritional value, but its utilization rate is not high. Among them, the pig scapula is mostly used to feed animals because of its low price, and the resulting economic benefits are low. Enzymatic hydrolysis can increase the precipitation rate of nutrients in pig bone and increase the nutritional value of the product. Through single factor and orthogonal test, the content of free amino acid nitrogen and sensory evaluation in pig bone rice porridge were detected. It was found that the amount of enzyme had significant effects on the content of free amino acid nitrogen and sensory scores in pig bone rice porridge. The effect of cooking time on the ratio of rice to water is relatively low. Boiling temperature and enzymatic hydrolysis time had significant effects on sensory scores, but had no significant effects on free amino acid nitrogen, indicating that papain supplementation had a significant effect on the dissolution rate of free amino acid nitrogen. The best formula: enzyme dosage 18 g, enzymatic hydrolysis time 4 h, rice to water ratio 20:3, boiling temperature 110 ℃, boiling time 45 min. Under these conditions, the content of free amino acid nitrogen in pig bone rice porridge was 0.25 g/100 g, and the sensory score was 84.5 points. At present, more instant porridge has been sold in the market, and the market is broad. This study can provide parameters for the follow-up research and development of pig bone rice porridge.

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