Effects of Barley β-Glucan on Quality Characteristics of Twin-Screw Extruded Rice Noodles

Zhexin Hu^1, Sijin Gao^2, Hui Jin^2, Shuchang Li^2, Chuanshun Ren^2, Qiong Luo^2, Hongzhou An^2, Zehua Huang^2*

1. International Education College, Henan University of Technology, Zhengzhou 450001, Henan, China.

2. National Engineering Research Center for Wheat and Corn Deep Processing, College of Cereal and Oil Food Science, Henan University of Technology, Zhengzhou 450001, Henan, China.

Abstract:

Rice noodles are widely favored by consumers. In this study, rice noodles were prepared using twin-screw extrusion technology by incorporating barley β-glucan with physiological functionalities. The effects of different levels of BBG addition on the quality characteristics of rice noodles were investigated, including breakage rate, cooking loss, rehydration ratio, gelatinization degree, sensory attributes, as well as the texture and pasting properties. With increasing levels of BBG addition, the rehydration ratio, cooking loss, and breakage rate of extruded rice noodles increased, as well as the gelatinization degree gradually increased. The texture analysis revealed that the hardness, elasticity, chewiness, and overall resilience of extruded rice noodles decreased, while the stickiness increased with higher levels of BBG addition. RVA pasting curve analysis indicated that the setback value of extruded rice noodles decreased with increasing BBG addition, whereas peak viscosity, trough viscosity, final viscosity, and gelatinization temperature increased. Sensory evaluation results demonstrated that BBG addition within the range of 0% to 0.1% maintained a high level of acceptability. Based on the findings, it is recommended to add approximately 0.1% BBG to enhance the nutritional quality of rice products.

Keywords: barley β-glucan, rice noodle processing, twin-screw extrusion

Corresponding author: huangzh@haut.edu.cn.

Fundings:This research was supported by the National Natural Science Foundation of China (31772006), the Doctoral Startup Fund of Henan University of Technology (2020BS003), and the 2022 Undergraduate Innovation and Entrepreneurship Training Program (202210463001, 202210463002, 202210463003).

0 Introduction:

Rice noodles, refer to non-glutinous long and slender rice-based products that typically undergo processes such as milling, steaming, shaping, and cooling[1]. They are often referred to as rice flour noodles due to their resemblance to traditional wheat noodles[2]. Currently, the most prevalent processing technique for rice noodles in China is the twin-screw extrusion technology, which is typically conducted under high-temperature and high-pressure conditions [34]. Twin-screw extrusion technology offers advantages such as high production efficiency, low cost, diverse product range, minimal material loss **Error! Reference source not found.**8]. Twin-screw extruders, compared to single-screw extruders, exhibit better adaptability to raw material moisture content, enhanced self-cleaning capability, and more uniform heat distribution during the extrusion process, making them more widely applicable[10]. Consequently, extrusion technology has become a popular research direction with wide-ranging applications[9].

Since rice noodles primarily consist of starch, the quality of rice noodles is closely related to the gelatinization quality of starch. Rice products processed from rice with higher amylose content exhibited better appearance and eating quality[11]. Apart from amylose and amylopectin content, various components of rice noodles such as crude fat, protein content, and dietary fiber can also have different degrees of influence on the flavor and quality of processed rice noodles. Jetnapa et al. [12] found that the addition of cellulose derivatives and carrageenan to normal rice starch and waxy rice starch could alter the final viscosity and gelatinization temperature of starch, consequently affecting the aging process of starch. While konjac glucomannan was found be able to increase the hardness and elongation of rice-based products while effectively reducing cooking loss[14]. Srikaeo et al. [15] demonstrated that guar gum could enhance the texture and cooking quality of rice noodles. The addition of dietary fiber to bread could improve its viscosity, as well as enhance its eating quality and nutritional value[13].

Based on the above analysis, the addition of soluble polysaccharides is beneficial for improving the functional properties of rice noodles. Barley, which ranks fourth in global grain production, is rich in functional barley β-glucan (BBG) **Error! Reference source not found.**. BBG possess abundant physiological regulatory functions, such as blood sugar regulation[1618], immune-enhancing activity [19], and improvement of the gastrointestinal environment [20]. BBG can be used as an additive in the processing of convenient foods, such as rice noodles, to enhance the gelatinization properties of the products, and it can also act as a thickening agent, stabilizer, and fat substitute[21]. Therefore, the development of rice noodles enriched with BBG can help meet the current consumer demand for low-calorie, low-fat, and high dietary fiber foods.

In this study, five different levels of BBG addition were set: 0%, 0.05%, 0.1%, 0.5%, and 1.0%. The effects of BBG on the quality of rice noodles were investigated by comparing the breakage rate, cooking loss, rehydration ratio, gelatinization degree, and sensory attributes of rice noodles with different BBG levels. TPA (Texture Profile Analysis) and RVA (Rapid Visco Analyzer) tests were conducted to verify the experimental hypotheses and previous conclusions regarding rice noodles with added BBG.

1. Materials and Methods

1.1 Experimental Materials and Reagents

Rice: sourced from Tonghua Ecological Farm, Guangshan County.

BBG (Barley β-glucan oligosaccharides): obtained from Hangzhou Zhongzhikang Mushroom Biotechnology Co., Ltd.

Amylase: purchased from Beijing Aoboxing Biotechnology Co., Ltd.

Iodine: obtained from Tianjin Kemiou Chemical Reagent Co., Ltd.

Petroleum ether: purchased from Tianjin Zhiyuan Chemical Reagent Co., Ltd.

Unless otherwise specified, all reagents used in this study were of analytical grade.

1.2 Experimental Instruments and Equipment

CLEXTRAL Ev025 twin-screw extruder: provided by Clextral Group, France. TechMaster RVA rapid visco analyzer: obtained from Perten Instruments (Beijing) Co., Ltd. TA-XT plus texture analyzer: supplied by Stable Micro Systems Ltd., UK. Sartorius BSA224S electronic balance: purchased from Sartorius Scientific Instruments (Beijing)

Co., Ltd. FOSS Kjeltec8400 automatic Kjeldahl nitrogen analyzer: provided by FOSS Analytical Instruments (Denmark). HH-4 digital constant temperature water bath: obtained from Changzhou Tianrui Instrument Co., Ltd.

1.3 Experimental Methods

1.3.1 Basic Composition Analysis of Raw Materials

Moisture content: determined according to GB5009.3-2016 "Determination of Moisture in Foods" using the direct drying method. Ash content: analyzed following GB5009.4-2016 "Determination of Ash in Foods." Starch content: measured according to GB/T 15683-2008 "Determination of Amylose Content in Rice." Crude fat content: determined following GB 5009.6-2016 "Determination of Crude Fat in Foods." Protein content: analyzed following GB 5009.5-2016 "Determination of Protein in Foods" using the Kjeldahl method.

1.3.2 Production Process of Extruded Rice Noodles

Rice → Grinding → Sieving → Formulation → Setting of extruder parameters (moisture content of feed: 40%, feed rate: 2.2 kg/h, temperature: 30/50/70/90/100/100° C, screw speed: 180 r/min) → Extrusion and shaping → Aging treatment → Drying → Sealed storage

1.3.3 Determination of Cooking Loss Rate

Weigh a certain amount of uniformly extruded rice noodles. Fold the noodles into small strips approximately 10 cm in length and immerse them in boiling water in a ratio of 30 times the mass of the rice noodles. Using a stopwatch, remove one strip every 30 seconds and observe for the presence of a hard core by pressing with a glass slide. Stop the timing when no hard core is observed. After draining the samples for approximately 5 minutes, dry them in a 105°C oven until a constant weight is achieved, and then weigh them.

The calculation formula for cooking loss rate is as follows:

$$A=(W_1 - W_2)/W_1\times100\%$$

Where:

A is the cooking loss rate (%) of the tested sample, W1 is the mass of the tested sample before cooking (g), W2 is the mass of the tested sample after cooking (g). Rehydration time: conducted according to SN/T 0395-1995 (a Chinese standard for rehydration time determination).

1.3.4 断条率测定

Prepare the samples as in the cooking loss rate determination. When the cooking time is reached, stop the heating and use chopsticks to transfer the cooked rice noodles into a beaker filled with cold water. Once separated, pick out each broken rice noodle and count the number of broken pieces. The breakage rate is calculated using the following formula:

$$A=N_2/N_1\times100\%$$

Where: A is the breakage rate (%) of the tested sample, N1 is the total number of rice noodle strands tested, N2 is the number of rice noodle strands that break after cooking.

1.3.5 Determination of Rehydration Rate

Weigh a certain amount of extruded rice noodles and immerse them in boiling water, 30 times the mass of the rice noodles, for 5 minutes. Drain the noodles to remove surface moisture and weigh them. The rehydration rate is calculated using the following formula:

$A=(Q_1-Q_2)/Q_1\times100\%$.

Where: A is the rehydration rate (%) of the tested sample, Q1 is the mass of the dry rice noodles (g), Q2 is the mass of the rice noodles after rehydration and draining (g).

1.3.6 Determination of Gelatinization Degree

The gelatinization degree of extruded rice noodles is determined using the enzymatic method. The steps are as follows: Pass the powdered rice flour sample through an 80-mesh sieve and transfer it into a conical flask. Heat the sample for gelatinization, then cool it down and add 2 mL of diluted amylase enzyme. Maintain the flask in a constant temperature water bath at 50°C for 1 hour, shaking it intermittently. After 1 hour, remove the flask from the water bath and quickly add 2 mL of 1 mol/L hydrochloric acid to each flask to stop the enzymatic reaction. Dilute the solution to 100 mL with distilled water and filter it. Take three 250 mL iodine flasks and sequentially add 10 mL of the filtered solution, 10 mL of 0.05 mol/L iodine solution, and 18 mL of 0.1 mol/L sodium hydroxide solution. Allow the flasks to stand in the dark for 15 minutes, then immediately add 2 mL of 10% concentrated sulfuric acid. Titrate the solution in the iodine flask with 0.05 mol/L sodium thiosulfate solution until it turns colorless. Record the volume of sodium thiosulfate solution consumed for each titration to reach colorless endpoint.

$$A=(V_3-V_2)/(V_3-V_1)\times 100\%$$

Where: A is the gelatinization degree (%) of the tested sample, V1 is the volume of sodium thiosulfate solution consumed during the blank titration (ml), V2 is the volume of sodium thiosulfate solution consumed during the titration of the gelatinized sample solution (ml), V3 is the volume of sodium thiosulfate solution consumed during the titration of the non-gelatinized sample solution (ml).

1.3.7 Texture Profile Analysis

Approximately 40 strands of extruded rice noodle samples were taken, and they were boiled in boiling water at 100°C until the optimal cooking time was reached. The samples were then removed and drained for 2 minutes. Three cooked samples were placed in parallel on a carrier tray, with a certain gap left in the middle. Each sample was measured in 10 parallel groups, resulting in five sets of data: hardness, stickiness, chewiness, resilience, and elasticity. The Pasta Firmness/Stickiness Rig Code HDP/PFS probe was used. The instrument parameters were set as follows: pre-test speed: 2.00 mm/s, test speed: 1.00 mm/s, post-test speed: 1.00 mm/s, compression rate: 70%, time: 3.00 s, trigger force: 10.0 g.

1.3.8 RVA

This experiment followed the measurement of GB/T 24853-2010, using the rapid viscometer method.

1.3.9 Sensory Evaluation

Extruded rice noodles with different levels of BBG addition were separately cooked until the optimal cooking time was reached, and then they were removed. A sensory evaluation panel of 15 individuals was formed to conduct the sensory evaluation. The sensory evaluation criteria for rice noodles were modified based on the experiments conducted by Gao Xiaoxu[22] and are presented in Table 1.

Table 1 Rice noodles sensory evaluation form

Sensory indicators	Evaluation criteria	Scores
Color	Free from other impurities, white in color with excellent	7.1-10.0

（10）		appearance, and good transparency	
		White color is average, good transparency	4.1-7.0
		Multiple impurities, average transparency	1.0-4.0
Flavors（10）		Rich rice fragrance, no off-flavors.	7.1-10.0
		Average rice fragrance, slight off-flavor.	4.1-7.0
		Insufficient rice fragrance, noticeable off-flavor.	1.0-4.0
Tissue morphology（10）		Compact and delicate texture, no visible fractures.	7.1-10.0
		Slightly rough texture, some fractures are observable.	4.1-7.0.
		Rough texture, noticeable fractures	1.0-4.0
Soup（10）		Clear and transparent soup.	7.1-10.0
		Slightly cloudy soup.	4.1-7.0
		Significantly cloudy soup	1.0-4.0
Taste（60）	Soup（12）	Appropriate hardness.	8.1-12.0
		Harder or softer than desired.	4.1-8.0
		Too hard or too soft.	1.0-4.0
	Stickiness（12）	Minimal stickiness in rice noodles.	8.1-12.0
		Slight stickiness in rice noodles.	4.1-8.0
		Significant stickiness in rice noodles.	1.0-4.0
	Elasticity（12）	Noticeable elasticity.	8.1-12.0
		Lack of noticeable elasticity.	4.1-8.0
		Lack of elasticity, poor chewiness.	1.0-4.0
	Smoothness（12）	Smooth and silky mouthfeel.	8.1-12.0
		Average mouthfeel.	4.1-8.0
		Poor mouthfeel, insufficient silkiness.	1.0-4.0
	Chewiness（12）	Good chewiness experienced when tasting rice noodles.	8.1-12.0
		Average chewiness in the mouth.	4.1-8.0
		Poor chewiness experienced when tasting rice noodles.	1.0-4.0

1.3.11 Data statistics and analysis

Experimental data were organized and plotted using WPS Office 2019 software and Origin 2018. Data analysis was performed using SPSS 13.0 software, and a Duncan analysis was conducted for variance analysis (ANOVA) at a significance level of $p<0.05$. The results were presented in the form of mean ± standard deviation.

2. Results and Discussion

2.1 Analysis of Basic Composition of Raw Materials

Following the method described in section 1.3.1, the moisture content, ash content, amylose content, total starch content, crude fat content, and protein content of the raw materials were determined. The experimental data were averaged and summarized in Table 2.

Table 2 Basic ingredient list of raw materials

	Water	Ash	Amylose	Total Starch	Protein	Crude Fat
Content /%	12.07±0.18	0.39±0	18.94±0.04	73.86±0.02	6.33±0.21	2.35±0.07

2.2 The Influence of Different BBG Addition Levels on the Quality of Extruded Rice Noodles

2.2.1 Effects of Different BBG Addition Levels on Cooking Loss, Breakage Rate, and Rehydration Rate of Extruded Rice Noodles

Table 3 Effects of different BBG additions on the cooking loss rate, breaking rate and rehydration rate of extruded rice noodles

BBG Addition/%	rehydration /%	cooking loss /%	breaking rate /%
0	86.50±0.71^{c}	27.50±2.14^{c}	0±0^{c}
0.05	93.00±2.83^{b}	30.50±0.73^{c}	15.00±7.97^{b}
0.1	96.00±2.71^{b}	31.50±2.08^{c}	20.00±0^{b}
0.5	97.50±2.12^{b}	39.50±1.97^{b}	25.00±8.02^{b}
1.0	106.00±2.84^{a}	50.00±2.83^{a}	45.00±6.92^{a}

Note: Different letters indicate significant differences at $p<0.05$.。

From Table 3, it can be observed that as the BBG addition level increases, the cooking loss, breakage rate, and rehydration rate of the extruded rice noodles show varying degrees of increase. BBG possesses strong water absorption properties and exhibits thermal reversibility[23]. This characteristic of BBG affects both the distribution of moisture within the rice noodles and the retrogradation of starch. Additionally, the gelation of BBG during the cooking process can disrupt the viscoelastic structure of the rice noodles[24], resulting in an increased breakage rate. Moreover, the strong water absorption capacity of BBG leads to an increase in the rehydration rate of the rice

Due to its strong water absorption ability, BBG competes with starch for water, leading to the solubilization of a portion of starch during the cooking process. The solubilized components contribute to the turbidity of the rice broth, and the internal texture of the rice noodles becomes loose and porous, resulting in an elevated cooking loss[25] .

2.2.2The Impact of Different BBG Addition Levels on the Gelatinization Characteristics of Rice Noodles

Table 4 Effects of different amounts of BBG on the gelatinization degree of extruded rice noodels

BBG Addition/%	Gelatinization degree /%
0	79.95±2.38^{b}
0.05	82.01±4.40^{b}
0.1	94.28±0.31^{a}
0.5	95.15±0.07^{a}
1.0	96.13±0.60^{a}

Table 4 presents the effects of different BBG addition levels on the gelatinization degree of extruded rice noodles. Gelatinization degree refers to the ratio of gelatinized starch to total starch content and can reflect the degree of starch gelatinization in grain-based foods.

From Table 4, it can be observed that as the BBG addition level increases, the gelatinization degree of the extruded rice noodles gradually increases. The addition of BBG results in a higher system viscosity, increasing the shear force exerted on the starch granules' surface. Consequently, it leads to a greater extent of starch granule damage within the rice noodles[26]. Therefore, BBG may play a promoting role in the gelatinization of starch granules in the rice noodles.

2.2.3 Effects of different BBG additions on the texture of rice noodles

Table 5 Effects of different BBG additions on the texture of rice noodles

BBG Additon /%	Hardness/g	Elasticity/%	Stickiness/g.sec	Stickiness	Resilience/%
0	3410.62±329.24^{a}	0.87±0.03^{b}	-395.55±35.01^{c}	2047.14±153.14^{a}	0.36±0.02^{a}

0.05	2409.54±324.71^{b}	0.91±0.01^{a}	-160.52±33.74^{b}	1427.89±226.57^{b}	0.31±0.02^{ab}
0.1	1886.04±90.21^{d}	0.85±0.04^{b}	-63.96±3.84^{a}	934.61±53.33^{d}	0.29±0.01^{b}
0.5	2314.76±171.79^{bc}	0.85±0.02^{b}	-84.78±15.99^{a}	1208.61±126.25^{c}	0.28±0.01^{b}
1.0	2047.66±169.59^{cd}	0.84±0.03^{b}	-77.46±13.31^{a}	1070.70±116.76^{cd}	0.27±0.01^{b}

According to Table 5, it can be observed that the hardness of the rice noodles with added BBG is significantly lower than the control group. Within the range of BBG addition levels below 0.1%, the hardness increases with the increase in BBG addition. However, when BBG is added beyond 0.5%, the hardness shows a fluctuating decrease. The trend in hardness is consistent with the trend in chewiness, which is also supported by the study of Wang et al. **Error! Reference source not found.**. This phenomenon can be attributed to the addition of BBG altering the moisture migration rate within the rice noodles[27]. Additionally, BBG has strong water absorption properties, increasing the moisture content of the rice noodles, which leads to a reduction in hardness [29].

The stickiness of the extruded rice noodles is evaluated as the energy required for chewing and swallowing, assuming the rice noodles have no elasticity **Error! Reference source not found.**. The results indicate that within BBG addition levels of up to 0.1%, the stickiness of the rice noodles increases with the increase in BBG addition. However, when the BBG addition level exceeds 0.1%, the stickiness of the rice noodles gradually levels off. The elasticity of the rice noodles with added BBG shows an initial increase followed by a decrease with the increase in BBG addition. This suggests that adding a small amount of BBG (<0.05%) increases the elasticity of the rice noodles, but when the BBG addition level exceeds a certain threshold, it has an adverse effect on the elasticity of the extruded rice noodles. This may be attributed to the influence of BBG on the molecular rearrangement during starch gelatinization and retrogradation.

Resilience reflects the ability of the sample to recover its shape after the initial compression[30]. From Table 5, it can be observed that as the BBG addition level increases, the resilience of the extruded rice noodles gradually decreases, showing a negative correlation. This can be attributed to the strong water absorption and water retention properties of BBG, which affect the directional movement of water molecules within the system[31]. leading to changes in the distribution of moisture in the rice noodles [32], thereby significantly reducing their resilience.

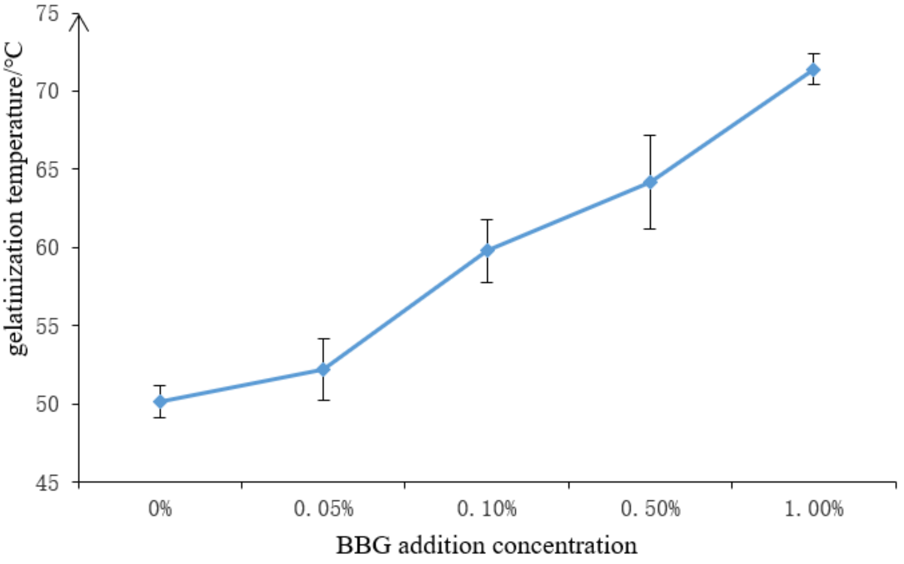
2.2.4 Sensory evaluation

Table 6 Sensory evaluation results

BBG / %	Color	Flavors	Tissue morphology	Soup	Elasticity	Hardness	Stickiness	Smoothness	Chewiness	Score
0	8.6	9.2	8.4	9	10.9	10.6	10.8	11	11.1	89.4
0.05	8.8	9.2	8.8	8.8	11.2	9.9	10.9	10.2	10.8	88.4
0.1	9	9.4	8.9	9.2	10.7	9.3	9.7	11.3	10.2	87.3
0.5	7.9	8.6	7.9	8.1	9.4	9.4	9.2	9.2	9	78.8
1	7.5	8.4	7.6	7.8	9.8	9.2	9.7	9	8.7	77.7

According to Table 6, it can be observed that the sensory scores of the rice noodles decrease with the addition of BBG. This may be due to the fact that BBG causes a more porous internal structure in the rice noodles. In the texture results (Table 5), the chewiness of the rice noodles is slightly reduced after the addition of BBG, which is consistent with the sensory evaluation results. However, even within the range of 0%-0.1% BBG addition, the scores are still above 85, indicating that BBG at lower than 0.1% can still maintain a high level of acceptability during consumption. On the other hand, within the range of 0.1%-1.0% BBG addition, the sensory quality of the rice noodles is significantly affected. Considering the rich physiological regulatory functions of BBG, it is recommended to add approximately 0.1% BBG to improve the nutritional quality of rice products while ensuring an enjoyable eating experience, meeting the higher expectations of increasingly diverse consumer groups for rice products.

2.3 添加不同剂量 BBG 对挤压米粉 RVA 糊化曲线的影响



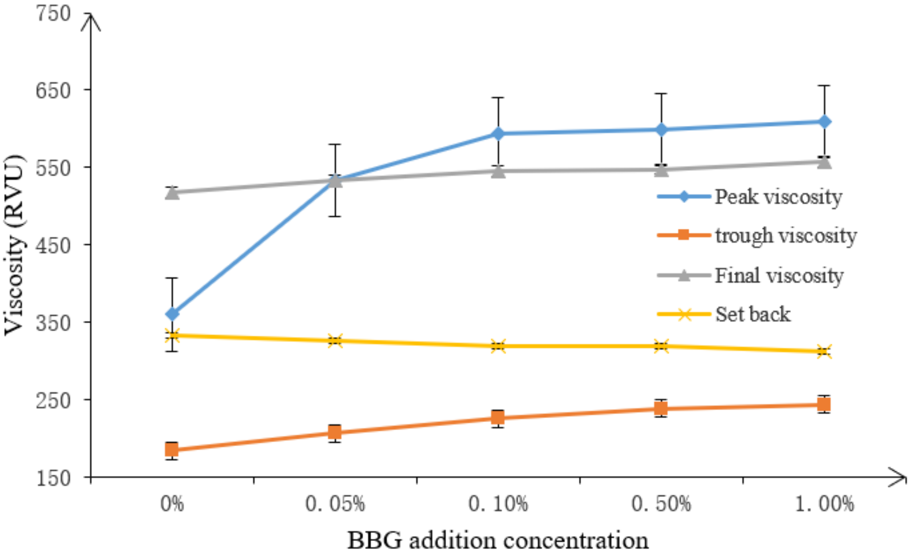


Figure 1 Effects of different BBG additions on the RVA index of rice noodles

As shown in Figure 1, the gelatinization temperature of extruded rice noodles increases with the increasing amount of BBG added. This could be attributed to the strong water-absorbing properties of BBG, which hinder the entry of water molecules into starch granules, thereby reducing the available water during the gelatinization process and inhibiting the swelling of starch granules, thus requiring a higher gelatinization temperature[26]. With the addition of BBG, the peak viscosity, minimum viscosity, and final viscosity of extruded rice noodles gradually increase. Studies have shown that hydrophilic colloid molecules interact with the leached-out amylose during the gelatinization process, and a portion of the amylopectin, especially its short side chains, also leaches out. These leached amylopectin molecules can interact with hydrophilic colloid molecules, thereby altering the viscosity of the system[33]. During the gelatinization process of extruded rice noodles, BBG may bind to the surface of starch granules through hydrogen bonding and promote the water absorption and swelling of starch granules, thus facilitating starch gelatinization and ultimately leading to an increase in peak viscosity, minimum viscosity, and final viscosity of starch paste [34]. The setback value reflects the degree of viscosity increase during the cooling process of extruded rice noodles and can be used to reflect the short-term retrogradation phenomenon of starch during cooling[35]. As shown in Figure 1, the setback value decreases with increasing BBG addition. Studies by Pan et al. [36] and CHARLES et al. [37] have shown that barley β-glucan and oat β-glucan can effectively inhibit the short-term retrogradation of starch, which is consistent with the results of this experiment.

3.3.2 XRD Analysis

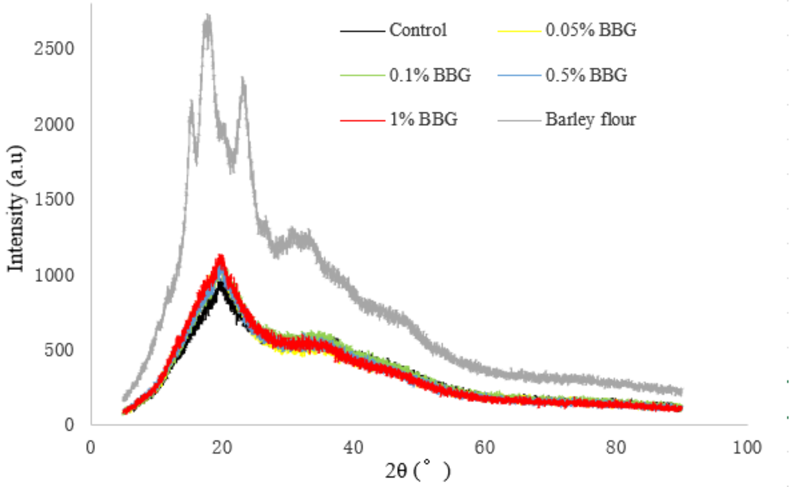


Figure 2 XRD curves of extruded rice noodles with different BBG additions

XRD is a commonly used method for evaluating the retrogradation effect of starch, and the height and width of the diffraction peaks are directly influenced by the crystallinity and size of the crystals. Therefore, higher and narrower peaks indicate a better retrogradation effect [29]. As shown in Figure 2, the untreated rice flour raw material exhibits three distinct characteristic diffraction peaks at around 15°, 18°, and 23°, which correspond to the typical A-type pattern, consistent with the findings of Ghaid et al. [28]. In contrast to the rice flour raw material, the XRD diffraction patterns of the extruded rice noodle samples with different amounts of BBG additives show concentrated peaks at around 20°, with significantly lower peak heights and reduced starch crystallinity, indicating an increase in the amorphous region. The increase in the amorphous region suggests the entry of starch chains from the crystalline structure of BBG-added rice noodles into an amorphous gel network**Error! Reference source not found.**[32].

3 Conclusion

By comparing the quality indicators such as breakage rate and cooking loss of rice noodles with different amounts of BBG additives, as well as the analysis of texture profile and RVA curve indicators, the following conclusions can be drawn: With the increase in BBG addition, the hardness, elasticity, chewiness, and recovery of extruded rice noodles generally decrease, while stickiness increases. The setback value of extruded rice noodles decreases with the increase in BBG addition, while peak viscosity, minimum viscosity, final viscosity, and gelatinization temperature increase. Due to the strong water-absorbing properties of BBG, it competes with the internal starch granules of rice noodles for water, inhibiting starch swelling and resulting in a decrease in the structural strength and hardness of rice noodles. The sensory evaluation results indicate that the addition of BBG within the range of 0% to 0.1% still maintains a high level of acceptability. Based on the above findings, adding BBG to rice-based food products will have an impact on taste and quality. Considering the rich physiological regulatory functions of BBG, it is recommended to add approximately 0.1% of BBG to enhance the nutritional quality of rice products.

References

[1] Fu B X. Asian Noodles: History, Classification, Raw Materials, And Processing[J]. Food research international. 2008, 41(9): 888-902.

[2] Li L.T., Cheng M.H. Production and Research Status of Rice Noodles [J]. Food and Machinery, 2000(03): 10-12..

[3] Miriam Mabel Selani,Solange Guidolin Canniatti Brazaca,Carlos Tadeu dos Santos Dias, et al.Characterisation and potential application of pineapple pomace in an extruded product for fibre enhancement[J].Food Chemistry,2014,163(Nov.15):23-30.

[4] Qi Phoebe X,Onwulata Charles I. Physical properties, molecular structures, and protein quality of texturized whey protein isolate: effect of extrusion temperature.[J]. Journal of agricultural and food chemistry,2011,59(9).

[5] Wei X.M., Zhang G., Liu L.L., et al. Influence of Extrusion Puffing Technology on the Nutrition of Breakfast Cereals [J]. Agro-Product Processing, 2016(7): 55-60.

[6] Ye Q.J., Yang G.M., Zhang Q.K., et al. Progress in the Application of Extrusion Puffing Technology [J]. Journal of Food Safety and Quality Inspection, 2013(5): 1329-1334.

[7] Yu G.M., Lu X.B., Wang C.Z., et al. Nutritional Evaluation of Extruded Puffed Foods [J]. Food Industry Science and Technology, 2003(2): 78-81.

[8] WOJTOWICZA, MOSCICKL. Effect of wheat bran addition and screw speed on microstructure and textural characteristics of common wheat precooked pasta-like products[J]. Polish Journal of Food and Nutrition Sciences, 2011, 61(2): 101-107.

[9] Chen S.P. Formation Mechanism and Quantitative Characterization of Wheat Gluten Extruded Tissues [D]. Zhengzhou: Zhengzhou University, 2019..

[10] Guo J.X. Production Process and Quality Improvement of Extruded Potato Rice Noodles[D]. Jiangnan University, 2016: 7-8.

[11] Dou H.X., Yang T.W., Zhao S.M., Zhu C.M., Albert Lomis, Yuan B.H., Chen G.X., Ding J.Z., Li K. Comparison of Chemical Composition, Gelation and Pasting Properties, and Processing Quality of Different Varieties of Indica Rice [J]. Journal of Chinese Cereals and Oils Association, 2014, 29(03): 1-6.

[12] Jetnapa Techawipharat,Manop Suphantharika,James N. BeMiller. Effects of cellulose derivatives and carrageenans on the pasting, paste, and gel properties of rice starches[J]. Carbohydrate Polymers,2007,73(3).417-426.

[13] Satrapai S, Suphantharika M. Influence of spent brewer's yeast β-glucan on gelatinization and retrogradation of rice starch[J]. Carbohydrate polymers, 2007, 67(4): 500-510.

[14] Wei Ping, Yang Mei, You Xiangrong, Zhang Yayuan, Sun Jian, Xie Xiaoqiang, Li Zhichun, Li Mingjuan. Influence of common food additives on the quality of potato rice noodles[J]. Journal of Southern Agriculture, 2017, 48(02): 314-322..

[15] Srikaeo Khongsak,Laothongsan Pronthip,Lerdluksamee Chutima. Effects of gums on physical properties, microstructure and starch digestibility of dried-natural fermented rice noodles.[J]. International journal of biological macromolecules,2018,109.

[16] Huang Zehua. Mechanism and application of thermal-induced solubilization and permeation of barley beta-glucan microgels on wheat protein cross-linking[D]. Jiangnan University, 2019.

[17] Wu Zhen, Liu Jia, Zheng Gang, et al. Research progress on the regulation of blood glucose by beta-glucan and its mechanism[J]. Journal of Chinese Cereals and Oils Association, 2010, 25(12): 44-48.

[18] Belobrajdic Damien P et al. Wholegrain barley β-glucan fermentation does not improve glucose tolerance in rats fed a high-fat diet.[J]. Nutrition research (New

York, N.Y.), 2015, 35(2) : 162-8.

[19] Fengmei Zhu and Bin Du and Baojun Xu. A critical review on production and industrial applications of beta-glucans[J]. Food Hydrocolloids, 2016, 52 : 275-288.

[20] Zhang Xuna, Ye Yang, Ren Guixing, et al. Study on the weight loss effect of barley beta-glucan[J]. Cereal & Oil, 2018, 31(01): 68-72.

[21] Huang Zehua, Zhu Kexue, Zhou Huiming. Research progress on gel characteristics and applications of barley beta-glucan[J]. Journal of Food Science and Technology, 2017, 35(05): 25-31.

[22] Gao Xiaoxu, Tong Litao, Zhong Kui, et al. Study on quality evaluation indicators of fresh rice noodles[J]. Journal of Nuclear Agricultural Sciences, 2014(09): 1656-1663.

[23] Bao Xuemei, Xie Huichun. Research progress on the main components and applications of Qingke [J]. Modern Food Science, 2019(2): 43-47.

[24] An Yanxia, Dong Yanmei, Zhang Jian, et al. Functional characteristics and application prospects of dietary fiber in the food industry[J]. Cereals & Feed Industry, 2019(6): 30-3.

[25] Wang Yonghui, Zhang Mingwei, Zhang Yehui, et al. Research progress on quality evaluation methods and raw material standards of rice noodles[J]. Guangdong Agricultural Sciences, 2012, 39(4): 70-72.

[26] Ji Jianhai, Gu Xiaoling, Cui Zhijun. Study on the correlation between wheat and flour composition and noodle quality[J]. Grain & Oil Processing, 2008(01): 81-84.

[27] Wang Weihua, Huang Li, Liu Chengmei, Liu Wei, Wan Jie. Effect of rice bran dietary fiber on the strengthening of rice texture[J]. Food and Machinery, 2011, 27(03): 16-18+31.

[28] Barcenas M E, Rosell C M.Effect of HPMC addition on the microstructure,quality and aging of wheat bread [J]. Food Hydrocolloids, 2005, 19 (6):1037-1043.

[29] Sharadanant R, Khan K. Effect of hydrophilic gums on the quality of frozen dough: II. Bread characteristics[J]. Cereal Chemistry, 2003, 80(6): 773-780.

[30] He Chengyun, Lin Xiangyang, Zhang Yongsheng. Study on the influence of xanthan gum on the texture of steamed buns[J]. Food Industry Science and Technology, 2010, 31(05): 313-315.

[31] Lai P,Li Y K,Lu Shin,et al. Physicochemical characteristics of rice starch supplemented with dietary fibre[J]. Food Chemistry, 2011, 127(1): 153-158.

[32] Li Anping, Jiang Yaqian, Zhou Yujie, Liang Zhenying. Effects of rice bran dietary fiber on the gelatinization characteristics of rice starch[J]. Journal of Jiangxi Agricultural University, 2015, 37(04): 725-732.

[33] Shi X,Bemiller J N. Effects of food gums on viscosities of starch suspensions during pasting[J]. Carbohydrate Polymers,2002,50(1): 7-18.

[34] Chen Long. Study on the influence and mechanism of pullulan on the properties of

rice starch[D]. Jiangnan University, 2015.

[35] Siddhesh N P,Kevin J E.Alginate derivatization: a review of chemistry properties and applications [J].Biomaterials,2012,33: 3279－3305.

[36] LI-HUA PAN, SHUI-ZHONG LUO, FEI LIU, et al. Comparison of rheological properties of dough and antistaling characteristics of Chinese Steamed Bread containing β-glucan from yeast or oat[J]. Cereal Chemistry,2018,95(1):149-157.

[37] CHARLES S. BRENNAN, LOUISE J. CLEARY. Utilisation Glucagel~® in the β-glucan enrichment of breads: A physicochemical and nutritional evaluation[J]. Food Research International,2007,40(2):291-296.