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Effect of xylooligosaccharides from rice husks on the pasting and rheological properties of dough and biscuit quality

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ABSTRACT

Rice husks are rich in xylan, which can be hydrolyzed by xylanase to form xylooligosaccharides (XOS). XOS is a functional oligosaccharide with stable physicochemical properties and physiological functions such as improving the structure and nutritional characteristics of flour products. Regarding the application of XOS in flour products, more attention was paid to the research of the characteristics of the product itself. In this study, the effect of adding XOS on the pasting and rheological properties of flours (1 g/100g, 3 g/100g, 5 g/100g) showed that with the increase of XOS content, the pasting temperature of flour increased and the retrogradation value decreased. With the increase of XOS addition, the storage modulus G′ and loss modulus G″ first increased and then decreased, and the dough elasticity decreased, indicating that the addition of XOS inhibited the formation of gluten network structure. The addition of XOS lead to an increase in biscuit diameter, with a maximum diameter of 39.63 mm for 5 g/100g XOS biscuits. The digestion results showed that the eGI value of the control biscuit was 59.27, and the eGI value of the 5 g/100g XOS biscuit was 56.98. Overall, XOS biscuits are the high-value utilization pathways for rice husks.

1. Introduction

Xylooligosaccharides (XOS), also known as xylooligosaccharides, are composed of 2–7 xylose molecules β-functional polysaccharide formed by the combination of 1,4 glycosidic bonds (Poletto et al., 2020; Pu, Zhao, Wang, Xiao, & Zhao, 2016). Compared with commonly used soy oligosaccharides, oligofructose, isomaltooligosaccharides, etc., XOS have unique advantages in selectively promoting the proliferation activity of intestinal *bifidobacteria*. Its bifidogenic function is 10–20 times that of other polymeric sugars (Finegold et al., 2014; Moura et al., 2007). XOS are difficult to break down by digestive enzymes in the human body, using saliva and gastric juice for digestion. Some experiments have proved that various digestive juices can hardly decompose XOS (Abasubong et al., 2019; Li, Peng, Lin, Xiong, & Huang, 2023; Martins, Silva, Ávila, Sato, & Goldbeck, 2021). Its energy increment is zero, which does not affect blood glucose levels, nor increase the contents of serum insulin, and does not form fat accumulation. It can play a role in low energy food, so as to meet the requirements of people who love sweets but worry about diabetes and obese people to the maximum extent (Khat-udomkiri, Toejing, Sirilun, Chaiyasut, & Lailerd, 2020; Santibáñez et al., 2021; Sheu, Lee, Chen, & Chan, 2008).

The main raw materials for the production of XOS are agricultural by-products with high levels of xylan, such as rice husks, corn cobs, wheat straw, sugarcane bagasse, cotton husks, etc (Mazlan, Samad, Yussof, Saufi, & Jahim, 2019; Samanta et al., 2015; Santibáñez et al., 2021). The earliest industrial production of XOS was achieved by Suntory Corporation in Japan (Yoshino, Higashi, & Koga, 2006). Compared with other oligosaccharides, XOS have good acid and thermal stability, are difficult to ferment, and their outstanding feature is their excellent stability (Silva, Arruda, Pastore, Meireles, & Saldaña, 2020; Silva et al., 2022). Even when heated to 100 °C under acidic conditions (pH = 2.5–7), it basically does not decompose, while some functional oligosaccharides are easily decomposed under acidic conditions, thereby reducing their activity in promoting the proliferation of bifidobacteria (Wang et al., 2022; Yan et al., 2022). Therefore, xylooligosaccharides can be widely used in food (Palaniappan, Antony, & Emmambux, 2021;

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Paschoa et al., 2024). However, the human clinical results showed that XOS had no adverse effect but there was gastrointestinal distress the only side effect that might be associated with XOS excessive consumption (Samanta et al., 2015).

In the food industry, XOS is usually used as a sweetener, gelling agent, viscosity regulator and foam stabilizer (Mensah et al., 2023; Palaniappan et al., 2021). Using XOS as a sweetener and stabilizer substitute in flour products can improve their sweetness and elasticity, as well as enhance their storage stability (Aachary & Prapulla, 2011; Deng et al., 2019). XOS have been proven to be a promising new alternative that can increase the dietary fiber content of cereal biscuits (Carlson, Erickson, Hess, Gould, & Slavin, 2017). XOS was widely used in baked goods due to its excellent acid stability and thermal stability. The moisturizing and water retention properties of XOS could alter the rheological properties of dough, control the optimal moisturizing effect, and thus alter the taste and appearance of baked goods (Juhász, Penksza, & Sipos, 2020; Zhu, Wang, Huang, Zheng, & Rayas-Duarte, 2010). Ayyappan et al. reported that the application of XOS in baked goods could significantly improve the taste and product quality of the food. Biscuits with added XOS had a soft and palatable taste, and were not sour or odor. Meanwhile, the biscuits had a smooth and clean surface, and no obvious powder particles, bubbles, cracks, or deformations (Ayyappan et al., 2016). Juhász et al. found that XOS could increase the sweetness and overall flavor intensity of biscuits, indicating that XOS played a role in enhancing flavor in baked products (Juhász et al., 2020). However, few research has focused on the effects of XOS on the physicochemical properties of dough and the digestion characteristics of biscuits. In this study, the effects of XOS on wheat flour quality were discovered through the analysis of flour properties, tensile properties, dynamic rheological properties and texture properties, providing reference for the application of XOS in flour products. The effects of different added amounts of XOS on the physical properties, nutritional characteristics, digestive characteristics, and antioxidant activity of biscuits were investigated, and its impact on the quality of biscuits was explored, providing reference for the application of XOS in baked goods.

2. Materials and methods

2.1. Materials

Low gluten flour was provided by Chen Keming Food Co., Ltd (Suiping, Henan, China). XOS from steamed explosion (SE) rice husks were prepared with xylanase by the laboratory itself (Yan, Tian, Du, & Wang, 2021). XOS enzymatic hydrolysis products were decolorized with D301 resin for reserved dough additives. Butter provided by Anchor (New Zealand). Milk was purchased from Inner Mongolia Yili Industrial Group Co., Ltd (Hohhot, China). 1,1-Diphenyl-2-picryl-hydrazyl (DPPH•) was purchased from Sigma Corporation of America (St Louis, USA). 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) was provided by Shanghai McLean Biochemical Technology Co., Ltd (Shanghai, China). All other reagents were analytical grade products.

2.2. Preparation of biscuits

The production of XOS biscuits follows the method of Juhász et al. with some modification (Juhász et al., 2020). XOS biscuit dough was made from a specialized formula that contained flour (50 g/100g), butter (25 g/100g), sugar (10 g/100g), and milk (15 g/100g), with XOS added in amounts of 1 g/100g, 3 g/100g, and 5 g/100g of the sugar substitute.

All raw materials (500g) were weighed according to the specified quantity. The butter and sugar/XOS was mixed until fluffy, and then added milk. The mixture was stirred until fluffy, and added a certain proportion of flour. The consistent dough was obtained through stirring evenly in a blender (Xuzhong SZH-20, Hangzhou, China). The stirring conditions were slow stirring for 3 min to form a dough, and fast stirring for 1 min to form a smooth dough. The biscuit dough was placed into a circular mold to form a circle, and baked at 185 °C for 20 min. The control biscuit was made of sucrose. Three batches of biscuits were prepared and analyzed using three levels of XOS (1 g/100g, 3 g/100g, and 5 g/100g) as a partial substitute for sucrose to make experimental biscuits.

2.3. Determination of pasting properties

Pasting properties of the low gluten flour and XOS flour with different addition ratios were determined using Rapid Visco Analyzer (RVA TecMaster, Perten Instruments, Sweden). In an RVA canister, the compound flour sample (3 g) was mixed with deionized water to make a 28 g slurry. The slurry was equilibrated at 50 °C for 1 min and then heated up to 95 °C for 3 min. The heated sample was held at 95 °C for 2.5 min and then cooled to 50 °C at a constant rate for 4 min. The pasting properties of the mixed flour samples added different proportions of XOS, including peak viscosity, breakdown, and final viscosity after gelatinization were determined.

2.4. Dynamic rheological properties

Dynamic rheological properties of the low gluten flour and XOS flour with different addition ratios were tested by a DHR-1 dynamic shear rheometer (TA Instrument (Watsch Technology) Co., Ltd, Shanghai, China) using a slightly modified method (Zhu et al., 2022). The dough was mixed with different proportions of XOS, and the linear viscoelastic zone was first determined through strain scanning tests. The experimental parameters were: a fixed frequency of 1 Hz and a strain of 0.1–20%. Then a frequency scanning test was conducted, with experimental parameters of 0.1–20 Hz frequency and 0.02% strain.

2.5. Determination of physical properties of biscuits

2.5.1. Determination of biscuit dimensions

The diameter, thickness, and weight of biscuits are measured using Ayyappan's method (Ayyappan et al., 2016). The diameter of biscuits was measured from end to end at the center point of the biscuits, while the thickness was measured from the base to the upper surface of the center point with the help of a measuring scale. The weight of biscuits was determined using a weighing balance (Shimadzhu, AY 220, Tokyo, Japan).

2.5.2. Determination of biscuit color

The determination of color difference for L^* value (brightness), a^* value (red green), and b^* value (yellow blue) was carried out using a CR-400 color colorimeter (Kefeng Instrument Co., Ltd, Hangzhou, China). Each group of 8 biscuits was measured, with 6 points measured for each biscuit.

2.5.3. Determination of biscuit texture

The textural properties of control biscuits and XOS biscuits were determinedusing a TA-XTplus Texture Analyzer (Stable Microsystems, Godalming, UK) equipped with a P/36R probe. The hardness of the control biscuit and the XOS biscuits was measured using the three-point bending method, and a force was applied at the center of the biscuit. The samples were placed on two support beams with a spacing of 2.5 cm and a weighing sensor of 10 kg. The test parameters were a pre test speed of 1.0 mm/s, a mid test speed of 3.0 mm/s, a post test speed of 10.0 mm/s, a distance of 5 mm, and a triggering force of 50 g.

2.6. Sensory evaluation of biscuits

Sensory evaluation of control biscuits and XOS biscuits was conducted by 20 trained panelists (10 males and 10 females) using the literature method (Owheruo et al., 2023). The evaluation was performed by 20 trained panelists that were between the ages of 25 and 55, and of appropriate sensory sensitivity (ISO 8586:2023). The quality descriptors and weighting coefficients to a five-point evaluation scale were chosen by assessors according to the procedure included in ISO 6658:2017. Biscuit samples were encoded with three digits and randomly presented to the trained panelists. Sensory attributes (color, taste, appearance, aroma, and overall acceptability) were evaluated using a 9-point hedonic scale (1 = extremely disliked, 5 = neither liked nor disliked, 9 = extremely liked). Sensory evaluation samples were first measured without adding XOS biscuits, and then the biscuits were progressively evaluated according to the amount of XOS added. After each evaluation, the flavour neutraliser used by the panelists was purified water.

2.7. Storage study of biscuits

The storage study was conducted for the control biscuits and XOS biscuits with best sensory attributes. The biscuits were cooled, wrapped in LDPE (100 μm) and sealed packages at room temperature for 21 d. The control biscuits and XOS biscuits were collected after every 7 d and were evaluated for peroxide value, color, moisture content.

2.8. Determination of estimated glycemic index (eGI)

The *in vitro* digestibility of biscuits was determined according to the methods of Englyst et al. with slight modifications. The porcine trypsin was dissolved in distilled water with a solute content of 12.5 g/100g. After thorough mixing and centrifugation, the supernatant was transferred to a container containing starch glucosidase solution, and mixed again to prepare a mixed enzyme solution for standby application. The starch glucosidase solution included 31.4 g/100g volume fraction of starch glucosidase, with a ratio of 1:2 to porcine trypsin. 4 mL of sodium acetate buffer with a pH value of around 5.2 was added to the test tube containing the sample, and heated it in a constant temperature water bath at 100 °C for 30 min to completely gelatinize the starch sample. After cooling to 37 °C, the mixed enzyme was added in a ratio of 1:5 between the mass of starch and the volume of the mixed enzyme solution, and continuously hydrolyzed at 37 °C and 200 rpm for 6 h. 0.1 mL of solution at different times (30, 60, 90, 120, 150, 180 min) was added to 4 mL of 70 g/100g alcohol solution to inactivate the enzymes in the sample solution. After centrifugation at 3000 rpm, 0.1 mL of the supernatant reacted with GOPOD and the absorbance was measured at 510 nm using a full wavelength ELISA reader. The percentage of starch hydrolysis at different times is calculated using the following formula:

$$C(\%) = \frac{A_t - A_0}{A_1 - A_2} \times 104 \times 0.9$$

Where C represents hydrolysis percentage of starch at different times; A_t, A_0, A_1, and A_2 respectively represent the absorbance of the sample at t min, the absorbance of the control group, the absorbance of the standard substance, and the absorbance of water. Based on the determination of *in vitro* digestion characteristics, the hydrolysis curve of biscuits was fitted according to the equation:

$$C = C_\infty \left(1\text{-}e^{-kt}\right)$$

The curve area (AUC) was calculated corresponding to the fitting curve for 0–180 min, and the glycemic index (eGI) was estimated using the following formula:

$$eGI = 39.71 + 0.549HI$$

Where k represents the hydrolysis rate constant; C represents the percentage of hydrolysis of t min, %; C_∞ represents the equilibrium concentration,%; HI represents the ratio of the fitting curve area of the sample to the fitting curve area of white bread.

2.9. Determination of biscuit X-ray diffraction (XRD)

Using a D8 Advance X-ray diffractometer (Thermo Fisher Scientific, USA) for detection, the detection parameters were: Copper target; Pipeline pressure pipeline flow rate: 40 kV/100 mA; Diffraction angle 2 θ Scanning range: 4°–60°; Scanning rate: 6°/min.

2.10. Statistical analysis

Data were reported as the mean ± standard deviation. Analysis of variance was conducted using SPSS 26.0, and analysis of variance (ANOVA) and Tukey post hoc tests were applied to compare the different groups. The Kolgomorov-Smirnov was required to test normality, which was one of the conditions for parametric ANOVA to be applicable. Origin 2023 software (Origin Lab Co., USA) was used for chart plotting. The data was taken as the average of the results of three parallel experiments.

3. Results and discussion

3.1. Effect of XOS on the pasting properties of flour

The pasting curves of flour blends with different amount of XOS were displayed in Fig. 1. As Table 1 showed, the addition of XOS (1–5 g/100g) resulted in significant increase in pasting temperature ($p < 0.05$), while the peak viscosity and breakdown presented decreasing tendency ($p < 0.05$).

With the addition of XOS, the decrease in breakdown indicated that XOS could effectively control the damage of starch particles caused by temperature rise and processing, and maintained the structural stability of starch. The possible reason was that the added XOS competes with starch for moisture reduced the available moisture of starch, inhibiting starch gelatinization which formed hydrogen bonds with starch molecules to encapsulate starch particles. Additionally, the added XOS surrounded starch particles, reducing the damage rate of starch during dough production (Yang et al., 2021).

As shown in Tables 1 and it could be seen that with the addition of XOS, the retrogradation value decreased, indicating that XOS could effectively improve the aging of starch. This might be due to the addition of XOS to aggregate water molecules, and an increase in the amount of XOS added increased the competition phenomenon of water molecules in the gelatinization process of starch molecules. This competition disrupted the binding of hydrogen bonds, making it difficult for linear starch to form a double helix structure, thereby slowing down the aging rate (Precup, Teleky, Ranga, & Vodnar, 2022; Zhu et al., 2010).

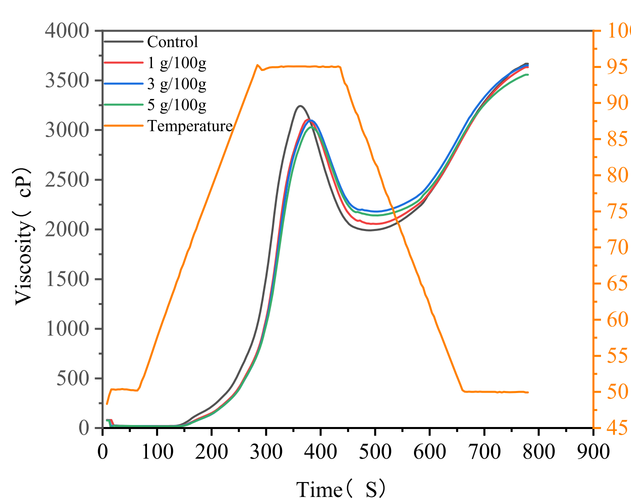


Fig. 1. The pasting curves of flour blends with different amount of XOS.

Table 1
Pasting properties of wheat flour with different addition amounts of XOS.

Sample	Peak viscosity (cP)	Breakdown (cP)	Final viscosity (cP)	Setback (cP)	Pasting temperature (°C)
Control	3239.00 ± 4.24[a]	1253.00 ± 4.24[a]	3653.00 ± 21.21[a]	1667.00 ± 12.73[a]	70.08 ± 0.04[b]
1 g/100g	3154.50 ± 68.59[ab]	1010.00 ± 56.57[b]	3638.00 ± 5.66[a]	1493.50 ± 119.50[ab]	80.33 ± 0.60[a]
3 g/100g	3084.50 ± 16.26[bc]	907.50 ± 13.44[bc]	3634.00 ± 24.04[a]	1457.00 ± 21.21[ab]	80.28 ± 0.53[a]
5 g/100g	2971.50 ± 79.90[c]	828.00 ± 82.02[c]	3496.00 ± 87.68[b]	1352.50 ± 89.80[b]	81.13 ± 1.73[a]

Data are expressed as mean ± standard deviation (n = 3). [a-c] Values labelled with different letter are significantly different ($p < 0.05$).

3.2. Effect of XOS on the dynamic rheological properties of dough

The dynamic rheological properties of the mixed dough were measured with a dynamic rheometer. As shown in Fig. 2, the storage modulus G′ of all the dough was greater than the loss modulus G″, which indicated that the interaction between the components in the dough formed a network structure, mainly an elastic gel. The addition of XOS changed the viscoelastic properties of the mixed dough. When the XOS dosage was 1 g/100g, the changes in dough G 'and G″ were not significant. However, as the dosage of XOS further increased, G′ and G″ first increased and then decreased, and the viscoelasticity of the dough decreases (Juhász et al., 2020; Torbica, Radosavljević, Belović, Djukić, & Marković, 2022). The viscoelasticity of 3 g/100g XOS dough was higher than that of the control group, which might be because XOS had strong water absorption, which increased the viscosity of the dough system. XOS made the viscoelasticity of the dough lower than that of the control group. This might because XOS filled the gluten network, which made the structure of the gluten network worse.

3.3. Effect of XOS on the physical properties of biscuits

3.3.1. Physical properties of biscuits

Heating is a key influence of size changes during the baking process of biscuits, and heating can lead to an increase in water vapor pressure (Mesias, Olombrada, González-Mulero, Morales, & Delgado-Andrade, 2021). The results listed in Table 2 indicated that the addition of XOS lead to an increase in biscuit diameter (Fig. 3), with a maximum diameter of 39.63 mm for 5 g/100g XOS biscuits. Conversely, as the amount of XOS increased, the biscuit thickness gradually decreased ($p < 0.05$).

The addition of XOS has a high water binding ability, which may lead to poor gas retention, resulting in a decrease in biscuit height (Samanta et al., 2015). At 5 g/100g XOS, the increase in diameter and the decrease in height were the largest. In biscuits containing different levels of XOS, weight decreases as XOS levels increased from 1 g/100g to 5 g/100g. The hardness of XOS biscuits was significantly lower than that of control biscuits ($p < 0.05$), which might be due to a decrease in biscuit thickness and an increase in diameter (Gallagher, O'Brien, Scannell, & Arendt, 2003). This result was consistent with the peak viscosity and breakdown of flour with different XOS addition amounts.

Table 2
Physical properties of biscuits with different XOS addition amounts.

Sample	Weight (g)	Diameter (mm)	Thickness (mm)	Hardness
Control	4.15 ± 0.00[a]	36.19 ± 0.12[a]	5.67 ± 0.02[a]	1344.17 ± 0.19[a]
1 g/100g	4.11 ± 0.01[b]	37.28 ± 0.40[b]	5.29 ± 0.03[b]	1252.92 ± 24.80[b]
3 g/100g	3.96 ± 0.01[c]	39.40 ± 0.12[c]	4.94 ± 0.14[c]	523.21 ± 29.30[c]
5 g/100g	3.93 ± 0.01[d]	39.63 ± 0.34[c]	4.92 ± 0.18[c]	310.85 ± 1.20[d]

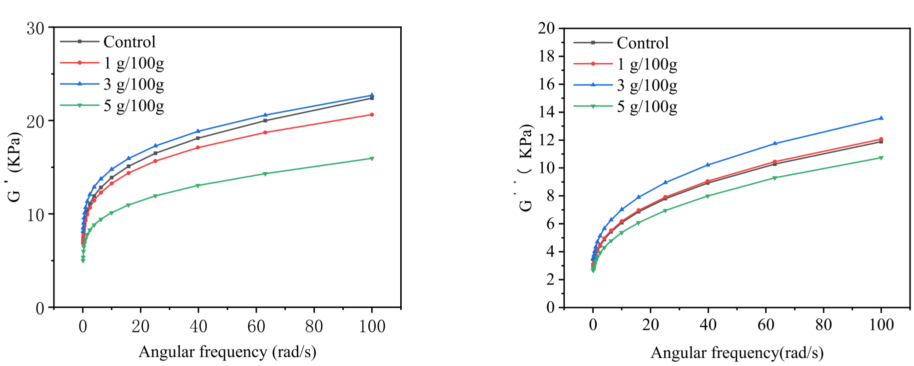
Data are expressed as mean ± standard deviation (n = 3). [a-d] Values labelled with different letter are significantly different ($p < 0.05$).

3.3.2. Color analysis of biscuits

As shown in Fig. 4, after adding XOS, the L* value of the biscuits decreased, while the a * and b * values increased. After adding 3 g/100g and 5 g/100g XOS, the surface color significantly darkened (as shown in Fig. 3) ($p < 0.05$). The color of biscuits underwent browning, which might be due to the Maillard reaction of reducing sugars in the dough, the Maillard reaction of sugar amino acid interactions, and the caramelization of direct sugar degradation, resulting in a darker color of biscuits during baking (Zanoni, Peri, & Bruno, 1995). Ayyappan et al. also reported that the addition of XOS enhances the browning of biscuits (Ayyappan et al., 2016).

3.4. Effect of XOS on the sensory characteristics of biscuits

Fig. 5 showed the sensory evaluation results of XOS biscuits. The sensory evaluation results showed that all biscuits with added XOS were acceptable. 1 g/100g XOS biscuits scored the highest in terms of aroma and appearance. Juhász et al. found that adding XOS to biscuits could enhance the overall aroma intensity of biscuits (Juhász et al., 2020). 5 g/100g XOS biscuits scored the highest in color and taste, and 1 g/100g XOS biscuit scored the highest in overall sensory evaluation. This indicated that appropriate XOS addition improved the overall sensory evaluation of biscuits.



(a) (b)

Fig. 2. Effect of XOS on the dynamic rheological properties of dough (a: storage modulus G'; b: loss modulus G″).

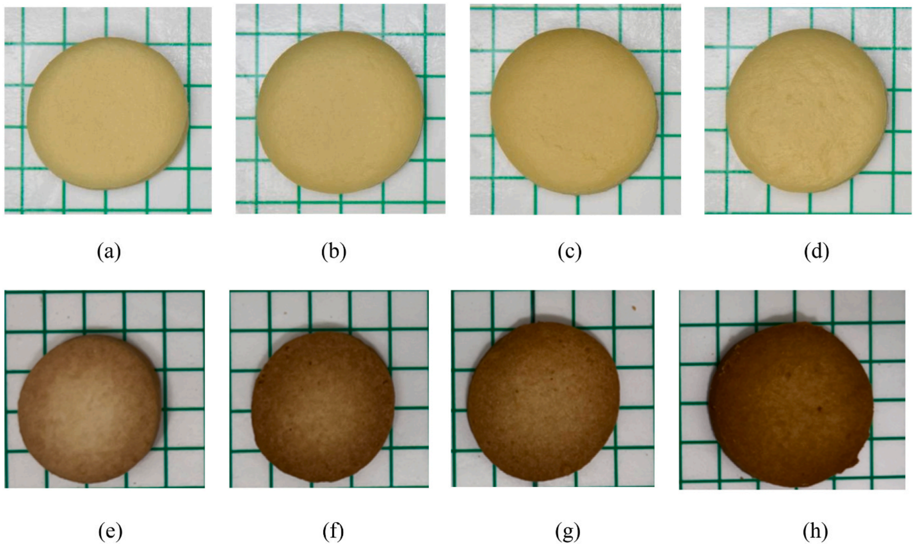


Fig. 3. Appearance of biscuits with different XOS addition. (a, e: Control; b, f: 1 g/100g; c, g: 3 g/100g; d, h: 5 g/100g).

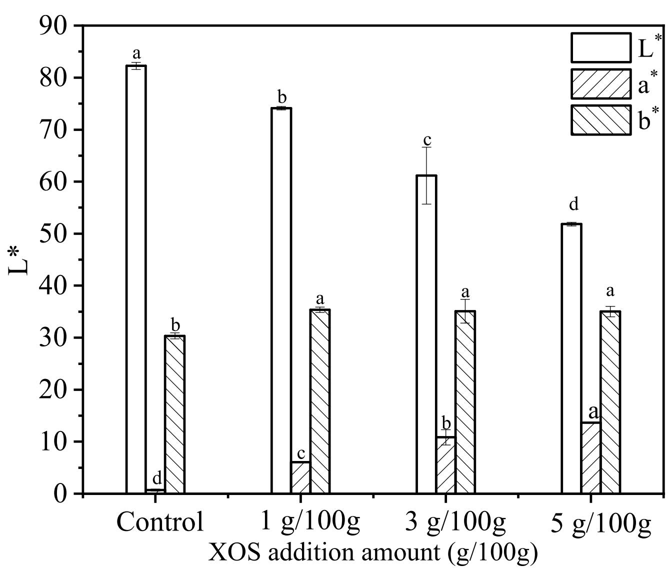


Fig. 4. Effect of different XOS addition on the color of biscuits. Different letters indicate the significant difference ($p < 0.05$).

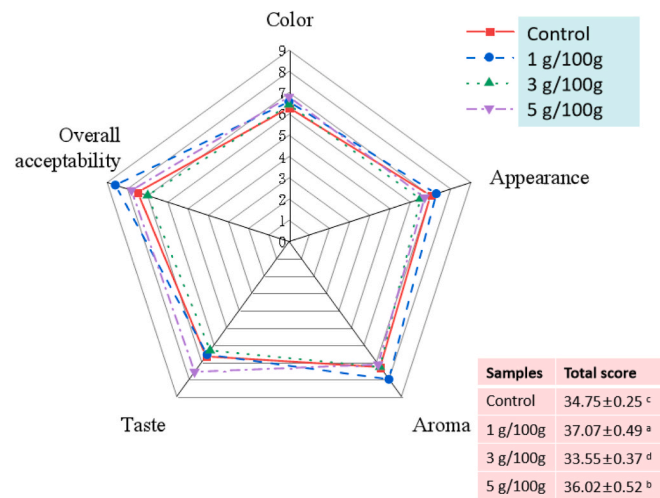


Fig. 5. Sensory characteristics of biscuits with different XOS addition levels.

3.5. *Effect of XOS on the storage characteristics of biscuits*

As shown in Fig. 6, during storage, the moisture content of the control biscuit and XOS biscuits slightly increased, and the hardness of XOS biscuits decreased. Under room temperature storage conditions, it was found that biscuits were stored stably. Even after 21 d of storage, no excess peroxide was detected in the control and XOS biscuits. Enrichment with XOS at 5 g/100g provided a product stable for 21 d at room temperature (25 ± 2 °C). The storage stability of biscuits with higher levels of XOS was less than the control (Ayyappan et al., 2016).

3.6. *Effect of XOS on the digestion characteristics of biscuits*

As shown in Fig. 7a, it could be seen that in the first 30 min of *in vitro* simulated digestion, the hydrolysis rate of XOS biscuits and control biscuits increased rapidly, but after 30 min, the hydrolysis rate of XOS biscuits increased slowly, with little change in hydrolysis rate between 120 and 180 min. At 120 min, the hydrolysis rate of adding 5 g/100g XOS biscuits was 37.39%. The hydrolysis rate of the control biscuit was 42.11%. This might be because the added XOS hindered the contact between starch crystals and amylase, reducing the hydrolysis rate (Marim, & Gabardo, 2021).

As shown in Fig. 7b, the results showed that the eGI vaule of the control biscuit was 59.27, and the eGI value of the 5 g/100g XOS biscuit was 56.98, which belonged to the food with a moderate glycemic index (55 < GI < 70). Adding XOS biscuits would lower its estimated blood glucose index (eGI value). According to reports, XOS did not rely on insulin for metabolism in the human body, which not only did not cause an increase in blood glucose, but also effectively controlled blood glucose levels, making it suitable for consumption by patients with high blood glucose (Ayyappan et al., 2016; Singh, Banerjee, & Arora, 2015; Moure, Gullón, Domínguez, & Parajó, 2006).

3.7. *Effect of XOS on the crystalline characteristics of biscuits*

As shown in Fig. 8, XOS biscuits had higher crystallinity. Crystallinity is an important indicator for evaluating the physical properties of food. A high crystallinity indicated a compact food structure that was not easily affected, resulting in a lower digestibility (Wang, Lin, Li, Zhuang, & Guo, 2024). The results were consistent with the conclusion that the *in vitro* starch digestibility of XOS biscuits was significantly

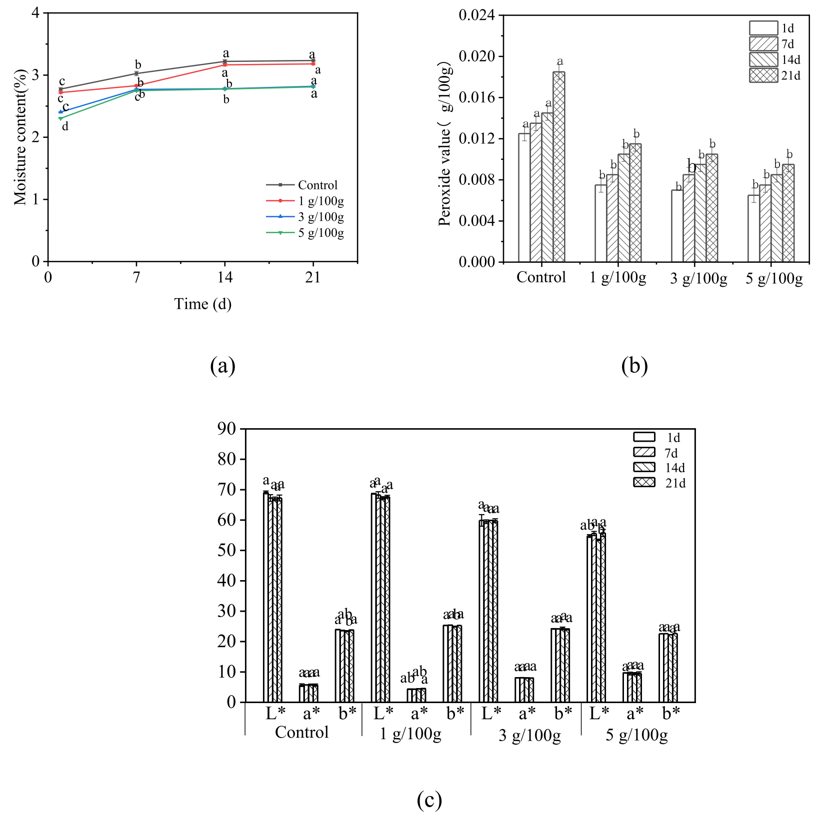


Fig. 6. Storage characteristics of biscuits with different XOS addition levels (a: Moisture content; b: Hardness; c: Color). Different letters indicate the significant difference with different storage time ($p < 0.05$).

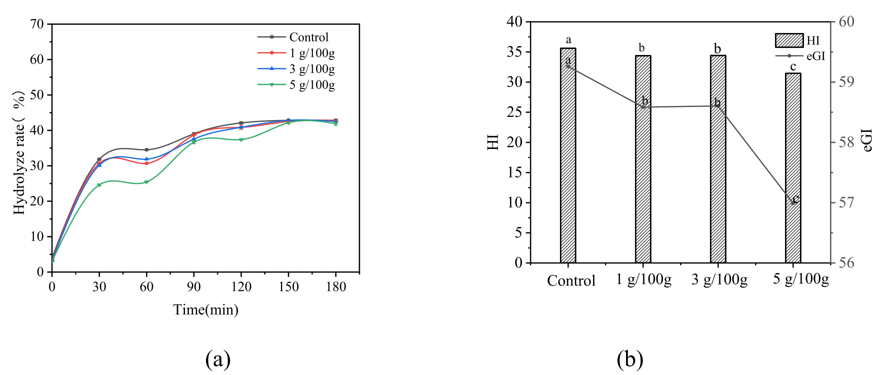


Fig. 7. Digestion characteristics of biscuits with different XOS addition amounts (a: hydrolysis rate; b: eGI value). Different letters indicate the significant difference ($p < 0.05$).

lower than that of control biscuits. According to the analysis and calculation of the relevant software MDIjade6, the crystallinity of 5 g/100g XOS biscuit was 8.64%. Compared with the control group, adding higher XOS biscuits resulted in narrower and sharper characteristic peak patterns near $2\theta = 22°$. This phenomenon was mainly due to the exposed crystalline region of XOS, which increased the absorption intensity and crystallinity (Sardabi, Azizi, Gavlighi, & Rashidinejad, 2021). The difference in crystal structure between XOS biscuits and control biscuits might be due to the addition of XOS, which made the biscuit structure more dense (Nara, 1978).

4. Conclusion

China is a major producer of rice, with abundant resources of rice husks as byproducts during rice processing. However, the current low bioavailability of rice husks in China requires finding new ways to utilize rice husks and increasing their added value. Rice husks are rich in xylan, which can be hydrolyzed by xylanase to form XOS. XOS is a functional oligosaccharide with stable physicochemical properties and physiological functions such as improving gut microbiota and antioxidant properties. Extracting XOS from rice husks is a high-value utilization pathway for rice husks. In this study, the effect of adding XOS on the pasting and rheological properties of flour (1–5 g/100g) showed that with the increase of XOS content, the pasting temperature of flour

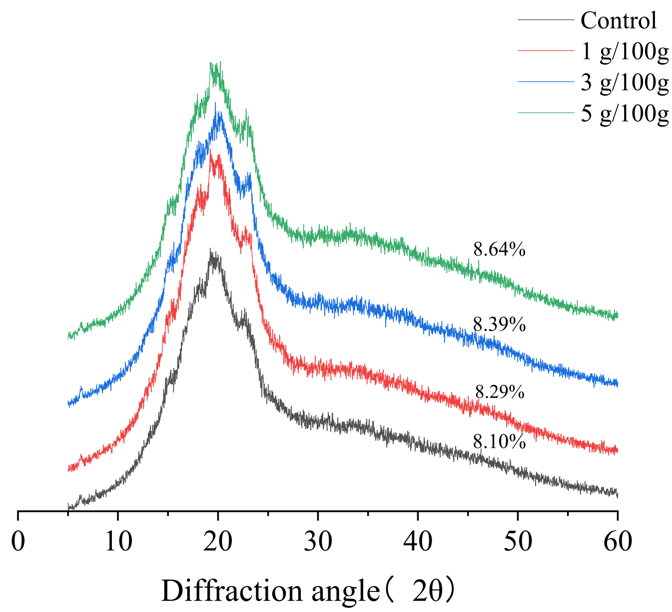


Fig. 8. Crystalline characteristics of biscuits with different XOS addition amounts.

increased and the retrogradation value decreased, indicating that the addition of XOS could inhibit starch gelatinization and weaken starch retrogradation. With the increase of XOS addition, the storage modulus G′ and loss modulus G″ first increased and then decreased, and the dough elasticity decreased, indicating that the addition of XOS inhibited the formation of gluten network structure. The biscuit made by adding XOS to flour had a larger diameter, lower thickness, lower hardness, darker color, better storage stability, and increased resistance to digestion. The digestion results showed that the eGI value of the control biscuit was 59.27, and the eGI value of the 5 g/100g XOS biscuit was 56.98. However, XOS biscuits have not yet reached low eGI levels, and in the future, they can be further optimized to achieve low eGI biscuits through formula optimization. In the probiotic functional research of XOS, only the proliferation effect of XOS on probiotics was studied, and further experiments are needed to explore the improvement effect of XOS on human gut microbiota, laying a foundation for the effective utilization of XOS. Overall, extracting XOS from rice husks to prepare biscuits is one of the high-value utilization pathways for rice husks. The reasonable utilization of XOS can bring greater economic benefits.

Statement on compliance with ethical standards

There was no formal approval from an ethical committee but the appropriate protocols for protecting the rights and privacy of all participants were utilized during the execution of the research, as there was no coercion to participate, full disclosure of study requirements and risks, written or verbal consent of participants was obtained, no release of participant data without their knowledge and participants were able to withdraw from the study at any time.

CRediT authorship contribution statement

Shuangqi Tian: Writing – review & editing, Supervision, Funding acquisition, Formal analysis, Conceptualization. **Ziyi Yang:** Writing – original draft, Investigation, Formal analysis. **Feng Yan:** Writing – original draft, Supervision, Investigation. **Zehua Liu:** Investigation. **Jing Lu:** Supervision, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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