Effects of dough mixing time before adding konjac glucomannan on the quality of noodles

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Revised: 5 August 2017 / Accepted: 23 August 2017 / Published online: 6 October 2017
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Abstract In this study, effects of 5% konjac glucomannan (KGM) blended with low-protein flour at different dough mixing duration on the properties of dough and noodles were investigated. To prepare the KGM noodle samples, 5% KGM was added after low-protein flour mixed with water for 0, 2 and 4 min, respectively. The three samples above were defined as T₀ KGM, T₂ KGM and T₄ KGM noodle samples, respectively. The results revealed that the elastic modulus (G') and viscous modulus (G'') of dough both increased with extending dough mixing time before adding KGM. T₄ KGM samples showed the least cooking loss. Textural properties including hardness, cohesiveness and tensile strength of KGM noodles had a tendency to increase with a longer dough mixing time before adding KGM. Microstructure of dough and noodles confirmed that a longer dough mixing time before adding KGM made microstructure more compact with a thickened gluten matrix. The sensory quality of the T₂ KGM and T₄ KGM samples was better than that of the T₀ KGM samples.

Keywords Konjac glucomannan · Textural properties · Confocal laser scanning microscopy · Scanning electron microscopy · Sensory characteristics

Introduction

Nowadays, with a dramatic increase in the problem of over-nutrition around the world, diets with adequate amounts of dietary fiber supplementation, low in calories, cholesterol and fat are more and more popular (Elleuch et al. 2011). Fiber enriched foods are of high demand because of their associated health benefits, including protection from degenerative diseases (such as obesity, diabetes and coronary heart disease), and their technological properties that result in texture modification and enhancement of the stability of the food during production and storage (Tudorica et al. 2002).

Noodle is one of the most important staple foods in many Asian countries, and account for at least one eighth of the total consumption of global wheat production (Bui and Small 2007). Traditional noodles are typically produced from ordinary wheat flour, which is lack of dietary fiber, due to the flour refinement (Choo and Aziz 2010; Bui and Small 2007). As noodle is a common staple food in Asian diet, it may be a convenient food to deliver dietary fiber of high concentrations. Recently, some types of noodle products were produced by using enriched fiber flours substituting for a portion of wheat flour, and have been shown to present acceptable textural and sensory properties (Heo et al. 2013; Choo and Aziz 2010).

Konjac glucomannan (KGM) is a water-soluble dietary fiber obtained from the tubers of *Amorphophallus konjac* (Fang and Wu 2004). KGM is an essentially linear polysaccharide composed of blocks of β -D-(1 $\rightarrow$ 4)-linked

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mannose and glucose residues in a ratio of 1.6:1, with O-acetate every 9–19 sugar units (Katsuraya et al. 2003). It has been suggested that KGM is one of the most viscous dietary fibres known because of its extraordinarily high water-holding capacity (Chua et al. 2010). When taken as an edible *Amorphophallus* konjac-based food, KGM could delay gastric emptying and slow small-bowel transit time by increasing the viscosity of gastrointestinal content that retard absorption of the nutrients in food (Kök et al. 2009; Keithley and Swanson 2005). The promotion of satiety is thought to be the possible mechanism of action of KGM for helping with weight loss when used in conjunction with either a normal caloric or a hypo-caloric diet (Chua et al. 2010; Keithley and Swanson 2005; Fang and Wu 2004).

Considering its functional value and technological properties, KGM as a low calorie flour substitute is expected to be useful in the development of fiber-enriched noodles. In previous study, the effects of KGM (1, 2, 3, 4 and 5%) on noodles made from low-protein wheat flour were evaluated (Zhou et al. 2013). The results showed that, at a low level addition, KGM contributed to higher cooking yield and lower cooking loss for the resultant noodles, and affected textural properties of hardness and springiness with developing a more compact and continuous gluten network in microstructure. However, with 5% KGM incorporated, sharp changes in textural parameters and adversely affects in sensory properties of noodles appeared.

The previous study of KGM noodle properties mostly focused on the role of raw materials and application of additions. Nevertheless, despite the variation of formulation, the noodle-making processing including dough mixing, dough sheet formation and noodle strand formation also determine the quality of the final product (Carini et al. 2009; Man et al. 2012). In noodle manufacturing, mixing is the first step, contributing to the dispersion of ingredients and their interactions through the beating action of the blades (Carini et al. 2009). It is hypothesized that the mixing processing may affect water–solid interactions, the degree of gluten development, and consequently, affect the quality of the final noodle product (Fu 2008).

In this study, aiming to relieve the adverse effects of high KGM substitution on noodle properties, effects of 5% KGM blended with low-protein flour at different dough mixing time point on the properties of dough and noodles were investigated.

Materials and methods

Materials

Commercial noodle flour was purchased locally from De Jiafu Flour Mills, Guangdong, China. Analysis (moisture,

ash, protein and wet gluten) of wheat flour was performed according to approved methods of AACC (2000) (methods 44-15, 08-01, 46-13 and 38-12, respectively) in triplicate and the results were expressed as average. The contents of moisture, ash, crude protein and wet gluten were 11.95 g/100 g, 0.69 g/100 g, 8.73 g/100 g, and 19.58 g/100 g (dry basis, w/w), respectively. Konjac glucomannan (KGM $\geq$ 95%) was supplied by Yuanli Biotechnology Co., Ltd (Hubei, China).

Dynamic rheological measurements

Dynamic rheological measurements of the dough were determined on the AR1000 rheometer (TA Instruments, New Castle, DE) according to (Ribotta et al. 2004). Dough samples were prepared by stirring with a spatula. Optimum amount of water for different formulated flours is pre-determined through farinographic test. Using 54% water absorption of commercial low-protein wheat flour (Control) for desirable noodle dough as a reference. Water absorption values from farinograph assays were 64% for the dough with 5% KGM. 103 mL distilled water was added to the base wheat flour (190 g) and mixed uniformly for 0, 2, 4 min, respectively (There could not be a uniform dough with 5% KGM added after more than 4 min mixing). Then 20 g KGM and another 25 mL distilled water were added and continued to mix for 10, 8, 6 min, respectively. All dough samples were cut into $1 \times 1 \times 1 \text{ cm}^3$ cubes. The measuring system consisted of parallel plate geometry (40 mm diameter, 1 mm gap). The dough sample was placed between the plates within 30 min after making, and excess dough protruding from the edge of the plate was coated with a thin layer of silicon oil to prevent evaporation during the measurements. The test was started after 2 min, so that stresses generated during sample loading could relax. The temperature was kept constant at 25 °C. The linear viscoelastic zone was determined by stress sweeps at 1 Hz frequency. Frequency sweep tests were performed from 0.1 to 10.0 Hz to determine the storage modulus (G') and loss modulus (G'') as a function of frequency.

Noodle preparation

Noodles were prepared using the method previously described by Zhou, et al. (2013) with some modifications. The stiff dough obtained as Step 2.2 was allowed to rest 10 min at room temperature. Then the dough was sheeted three times using 3, 2, and 1 mm roll gap settings respectively in a noodle-making machine (Kenwood, UK). The final dough sheet was cut by cutting blades (Kenwood, UK) to produce 3 mm-wide and 20 cm-long noodle strands. The

raw noodles were placed in a zip-lock plastic bags before cooking.

Cooking properties

The cooking yield and cooking loss of noodles were determined as previous study (Zhou et al. 2013) with some modifications. The optimum cooking time (the time necessary to obtain complete gelatinization of starch) for each noodle was determined using AACC Method 66-50 (AACC 2000). Noodles (10 strips, 20 cm in length) were weighed and then cooked to their optimum cooking time in a beaker containing about 200 ml of boiling water with slight agitation. The cooked noodles were rinsed with 50 ml distilled water for 30 s and drained for 5 min before weighting. Cooking yield was calculated as the weight increase of noodles and expressed as a percentage of the uncooked noodles. Cooking loss was determined by evaporating the combined cooking and rinse water in a pre-weighed glass beaker in an air oven at 105 °C to constant weight. The residue was weighed and reported as a percentage of the weight of dry noodles before cooking.

Texture profile analysis (TPA)

The textural properties of cooked noodles were evaluated by texture profile analysis (TPA) and tensile strength analysis using a TA-XT2i texture analyzer (Stable Micro Systems, UK) according to the description of Wu and Corke (2005). Noodle strands (10 cm in length) were cooked to the optimal cooking time and then rinsed with cold water to cool down for 2 min and drained for 5 min. The hardness, cohesiveness, springiness, and adhesiveness of cooked noodles were tested by an R/36 R probe and calculated based on texture profile analysis (TPA) at 25 °C under ambient relative humidity. The noodles were placed parallel on a flat metal plate and compressed twice to 75% of their original height. The pre-test speed, test speed and post-test speed were set at 1.0, 0.8 and 3 mm/s, respectively. The trigger type is 'auto' with trigger force of 5.0 g. The pause between the first and second compression was 2 s. The tensile force and tensile distance of cooked noodles were tested by an A/SPR probe and calculated based on tensile strength analysis at 25 °C under ambient relative humidity. The pre-test speed, test speed and post-test speed were set at 2.0, 3.0 and 10 mm/s, respectively. The distance between the parallel friction rollers was set at 10 cm. Noodles were tested individually by positioning through slots and winding around parallel friction rollers to anchor the noodle end. For all texture profile analysis and tensile strength analysis, five replicate samples were tested and the highest and lowest values were discarded.

Confocal laser scanning microscopy (CLSM)

Dough samples were analyzed by confocal laser scanning microscopy (CLSM). The noodle dough was pre-stained by adding a mixture of fluorescein isothiocyanate (FITC) (0.1% of flour weight) and Rhodamine B (0.1% of flour weight) into distilled water for non-covalent labeling before mixing. FITC preferentially stain starch and Rhodamine B preferentially stain protein. This allowed simultaneous observation of starch and protein under confocal laser scanning microscopy (CLSM). After mixing, dough samples were immediately frozen at −18 °C. The frozen dough samples were sectioned into 1-mm-thick slices with dissecting blades, placed on glass slides, and observed under a Leica TCS SP5 Confocal Laser Scanning Microscope (Heidelberg, Germany) with dual excitation. The objective used for all experiments provided a 20 (HCPLAPO 20x/0.70 IMM/CORRCS) magnification with a zoom of 4. The excitation/emission wave lengths for FITC and Rhodamine B were 488/518 and 568/625 nm, respectively.

Scanning electron microscopy (SEM)

The cooked noodles were examined with scanning electron microscopy (SEM). Noodles were cut transversally to expose the cross-sectionals surface and then lyophilized. All samples were coated with gold–palladium (Au/Pd) with a sputter coater SCD 005 (BAL-TEC, Germany) for 60 s. The samples were then observed in the Scanning Electron Microscope (HITACHI, Japan). The micrographs were taken at 500× magnification.

Sensory evaluation

The sensory evaluation for each sample was determined according to the description of Choo and Aziz (2010). Twelve panelists comprising six females and six males were recruited and selected from the College of Food Science and Nutritional Engineering of China Agricultural University. The sensory panel was professionally trained for the use of rating test and terminology for each attribute (Table 2). Samples were cooked as described above, then valuated for firmness, elasticity and stickiness. All samples were evaluated under red light using a nine point scale with “1” equaling “extremely low” and “9” equaling “extremely high”. The overall acceptability was evaluated by using a nine point hedonic scale with “1” equaling “dislike extremely” and “9” equaling “like extremely”. All samples were presented individually in randomized order in plastic trays. Panelists rinsed their mouths with deionized water between samples.

Results and discussion

Dynamic rheological measurements

The elastic modulus (G'), loss modulus (G'') and complex shear viscosity (η^*) as a function of the oscillation frequency (Hz) for dough samples are shown in Fig. 1. Dough is a viscoelastic system, which exhibits intermediate viscoelastic behavior between the purely viscous fluid and purely elastic solids (Petrofsky and Hosney 1995). With increasing frequency, the dynamic moduli increased for all the samples. All dough samples showed higher G' values than G'' values in the entire range of frequency, indicating a predominance of elastic properties over viscous properties, which agrees with previous reported findings (Ribotta et al. 2004; Bárcenas 2009; Kaur et al. 2016).

The addition of 5% KGM at different dough mixing time (0, 2, 4 min) decreased the G' , G'' and η^* of dough samples. The reduction in viscoelastic properties of dough

seems to be due to the decrease in dough consistency as a result of large KGM substitution. A continuous gluten network is critical for the viscoelastic properties of wheat dough (Huang et al. 2010). Hydrocolloids are able to modify gluten quantity and quality, mainly affecting the hydration properties of gluten (Bárcenas 2009). According to our previous work, dry gluten and wet gluten both decreased with 5% KGM substitution of wheat flour, resulting from the reduction of the total protein content in the formulated flours (Zhou et al. 2013). KGM had the highest water absorption among the flour constituents. The competition between KGM and gluten for water during the dough making process might affect the gluten formation and properties.

With the extension of dough mixing time before adding KGM, G' , G'' and η^* of the dough samples increased. During dough mixing, proteins may have separated from the flour particles forming a continuous matrix with starch granules embedded in it. This result suggested that the gluten formation before adding KGM was very significant and actually restrained the decrease in the modulus observed when KGM was added to dough. During hydration and mechanical abrasion, water is necessary for gluten proteins to fully hydrate and plasticize, contributing to the supra molecular organization of dough structure (Zhou et al. 2014). KGM interfere with gluten formation indirectly by competing for water and thus changing conditions for gluten development (Sim et al. 2011). Insufficient hydration caused by the large amount of KGM results into dough that resembles the structure of a discontinuous protein network containing number of inadequately hydrated flour particles and result in lower moduli values. Presence of pre-mixing without KGM addition in the T₂ KGM sample and T₄ KGM sample might be responsible for the relieved structural damage in gluten and accounting for the higher moduli values compared with the T₀ KGM sample. The T₄ KGM sample samples showed the greater viscoelastic properties among the KGM dough.

Effects of KGM on cooking properties

Cooking yield and cooking loss are important cooking properties of noodle. High cooking yield is considered to be connected to high cooking properties. Cooking loss can be regarded as an indication of the resistance to disintegration during the cooking of noodles. High cooking loss results in sticky surface and is not desirable.

The results of the cooking yield and cooking loss of the samples at optimum cooking time are presented in Fig. 2. Significant increase ($P < 0.05$) in cooking yield for cooked noodles with 5% KGM was observed according to Fig. 2a. It indicated that an additional water soluble polysaccharide can provide more water absorption and that can be

Fig. 1 Frequency sweep of wheat flour dough: **a** elastic modulus (G') and loss modulus (G'') versus frequency for dough samples; **b** complex shear viscosity (η^*) versus frequency for dough samples

Fig. 2 Cooking properties of all noodles: **a** cooking yield; **b** cooking loss. Compared with the control, * $P < 0.05$

attributed to the hydroxyl groups in the hydrocolloid structure which allow more water interactions through hydrogen bonding (Guarda et al. 2004). According to Sasaki et al. (2000), non-starch polysaccharide adding to a starch suspension would absorb water and induce a higher concentration in the continuous phase. During the cooking of noodles, the starch granules absorb water and swell, and the gelatinization of starch is the main reason for increasing the water absorption of the samples during cooking (Delcour et al. 2000). Starch's gelatinization can be modified by hydrocolloids addition, suggesting that swelling of granules is enhanced in their presence, and that might promote the water absorption of the noodle samples (Charles et al. 2007).

The results showed that cooking loss of the samples increase with the addition of 5% KGM, but start to decline when the dough mixing time extended before adding

KGM. The T₄ KGM noodle samples showed the least cooking loss. During the cooking of noodle in water, some soluble components including amylose (the principle component), non-starch polysaccharides and protein escape from the network during starch granule gelatinization, due to a weak or discontinuous gluten matrix (Kishk et al. 2011). It showed that large KGM substitution of wheat flour at the start of dough mixing increased the cooking loss of noodle samples, suggesting that a greater amount of exudates escaped from the dough system during starch granule gelatinization. Similar results were reported by Charles et al. (2007). They mentioned that the noodles prepared using wheat flour and high non-starch polysaccharide had higher soluble loss apparently due to the ease of swelling and instability of gelatinized mucilage granule. Except of the instability of KGM gel at high concentration, another possible explanation to this result was that amount of KGM that was incorporated caused the dilution of gluten fraction and negative effects on the formation of continuous protein matrix or starch-protein complexes.

Adding KGM to the dough after a period of dough mixing time showed a to decrease in cooking loss when compared to T₀ KGM noodles. It indicated that the gluten network formed during the dough mixing without the weakening effect resulted from KGM at high concentrations contributed to some stability to the interface dough system. Yoshimura et al. (1998) revealed that the addition of konjac-glucomannan may increase the effective starch concentration because of the immobilization of water. This suggests that addition of the KGM fractions affect starch concentration, developing a matrix network that formed a protective network around starch granules, thereby reducing spontaneous rupture of the swelling granules.

Texture profile analysis of cooked noodles

The results of texture profile analysis (TPA) and tensile strength analysis of cooked noodles made from original wheat flour and reconstituted flour with 5% KGM are compared in Table 1.

Noodle structure is developed by shear and tensile forces resulted from mixing and sheeting, where large amount of gluten protein coalesce and form a continuous network, modified by a high loading of filler, the starch present as granules (Park et al. 2003). During cooking, gluten protein reabsorbs water and strengths the network, imparting elasticity and springiness to the noodles and preventing the starch dissolving from the noodle. Table 1 showed that the incorporation of 5% KGM significantly ($P < 0.05$) decreased the hardness and cohesiveness of cooked noodles without making significant changes to the springiness. Noodle surface hardness is a property that would reduce when surface starch, especially damaged starch, is

Table 1 Texture parameters of all noodle samples

	Hardness (g)	Cohesiveness (g s)	Springiness (radio)	Adhesiveness (g)	Tensile force (g)	Tensile distance (mm)
T ₀ Control	7067 ± 108.6 ^a	0.68 ± 0.02 ^a	0.95 ± 0.02 ^b	82 ± 18.7 ^b	64 ± 1.7 ^a	61 ± 3.3 ^a
T ₀ KGM	5943 ± 123.7 ^c	0.54 ± 0.02 ^c	0.96 ± 0.02 ^b	92 ± 17.1 ^a	58 ± 2.9 ^b	45 ± 2.0 ^b
T ₂ KGM	6001 ± 189.6 ^c	0.62 ± 0.03 ^b	1.05 ± 0.03 ^a	88 ± 21.7 ^a	63 ± 0.9 ^a	57 ± 2.2 ^a
T ₄ KGM	6479 ± 179.7 ^b	0.67 ± 0.12 ^a	1.06 ± 0.02 ^a	83 ± 15.5 ^b	64 ± 3.4 ^a	58 ± 3.7 ^a

Results are presented as mean values ± standard deviation of 3 replicates. Different letters superscripted on the results indicate significant difference ($P < 0.05$) between each parameter tested

dissolved and separated from the protein network (Hu et al. 2007). Cohesiveness of cooked noodles depend on the proteins that are concentrated at the starch/matrix interface and how they control adhesion. The results indicated that KGM at high level appeared to be detrimental to the continuity of gluten matrix, leading to more starch granules escaped from the noodle network. Compared to the T₀ KGM noodles, the texture profile analysis (TPA) parameters, including hardness, cohesiveness and springiness of noodles would tend to increase when KGM was added to the dough after a period of dough mixing time. The values of these three parameters of T₄ KGM noodle samples were all the highest (6479 g, 0.67 g s, 1.06 respectively) among all the KGM noodles. The results were similar with dynamic rheological measurements, reconfirming that a longer mixing time before adding KGM gives a continuous viscoelastic network to KGM noodles.

The results of adhesiveness of cooked noodles showed an inverse tendency with the hardness and cohesiveness parameters. The higher values obtained for adhesiveness compared to the control may be explained by the physicochemical nature of KGM. KGM is hygroscopic and competes with the starch and protein for water upon hydration. KGM hydrates more quickly than the starch and protein components of flour, leading to starch and protein fractions of the noodles being more discrete and less incorporated in a matrix. On cooking, the starch is not encapsulated within a protein matrix and may form a “starchy” layer at the surface of the product, resulting in higher levels of surface stickiness (adhesiveness) (Tudorica et al. 2002). Mixing a period of time before adding KGM reduced the competition among KGM, starch and protein for water during the dough making process, resulting in the reduction in adhesiveness.

Texture strength analysis (tensile strength and tensile distance) assesses the breaking strength and extensibility of the cooked samples. The results of and tensile strength analysis of cooked noodles analysis were similar with the TPA parameters of hardness and cohesiveness. The weaker network formation by incorporating 5% KGM also resulted in deteriorating the elasticity and extensibility of the

noodles, which was determined based on the tensile strength and tensile distance. It found that protein content, which involved in the formation of well-developed network, had a positive relationship with tensile strength of cooked noodles (Oh et al. 1986). Chung et al. (2012) reported that the addition of non-gluten flour in the fabrication of wheat noodles diluted the gluten strength and retarded the formation of strong gluten matrices of the noodles, resulting in the substantial decrease in hardness and tensile strength of cooked noodles. The significant increase in tensile strength and tensile distance were found in T₂ KGM and T₄ KGM noodles when compared with T₀ KGM noodles. Results revealed that the extension of mixing time before adding KGM could improve the texture qualities of KGM noodles closer to the range of wheat noodles.

Effect of KGM on structural analysis

Confocal laser scanning microscopy (CLSM)

The microstructures of fully developed dough prepared with original wheat flour and reconstituted flour with 5% KGM were examined by CLSM (Fig. 3). In dough samples, gluten protein (stained in yellow) stretched out and formed a continuous network with discontinuous granules (stained in green) embedded in. The adding of KGM led to a less connected matrix, where starch and protein fractions more discrete and less incorporated into the matrix (Fig. 3b). This result of the present study was in accordance with Aravind et al. (2012), who noted from CLAM that 20% inulin incorporation appears to disrupt the protein-starch matrix, possibly because large addition of inulin hydrate quicker than other components before starch gelatinization that disrupt the protein-starch matrix, thus changing the polymeric structure. According to our previous work, KGM might disrupt the glutenin aggregation, then promote the formation of a weaker gluten network (Zhou et al. 2014). These pictures confirm what was observed in the rheological measurements, where

Fig. 3 Confocal micrograph of uncooked dough samples: **a** T₀ Control; **b** T₀ KGM; **c** T₂ KGM; **d** T₄ KGM. Size bar 25 µm

significant decline of G' value and G'' value was seen in the dough when 5% KGM was added.

The T₂ KGM and T₄ KGM images were not that different from the T₀ Control, except the green-stained areas had more small granules, that might be because starch and KGM both could be labelled by fluorescein isothiocyanate (FITC) (Abhyankar et al. 2011). In the T₂ KGM sample, the intensity of the protein network was increased and the protein-starch matrix appeared to be more uniform than that in T₀ KGM samples (Fig. 3c). The T₄ KGM sample is similar to T₂ KGM. The granules were visible and clearly surrounded by a more extensive matrix than observed in the T₀ KGM (Fig. 3d). The microstructure images reiterated the tendency towards a more strong protein network with a period time of dough mixing before adding KGM as indicated by dynamic rheological measurements. The CLSM analysis indicated that premixing of dough revealed a beneficial effect on formation and stretching of protein network, and therefore a film like structure could be formed with 5% KGM incorporated.

Scanning electron microscopy (SEM)

Microstructure of the cross-section of cooked noodles were investigated using SEM. As shown in Fig. 4, the gluten matrix was observed to present a mesh-like structure with gelatinized starch granules in a tangled state, which in accordance with the microstructure of noodles οβσερπεδ εαρλιερ (Kumar and Prabhasankar 2015). In the absence of the hydrocolloids, differences in pore size are distinguished, where average pore size is reducing with high KGM substitutions, giving rise to a highly porous structure (Fig. 4b). The open and porous structure might attribute to the incorporated fiber, which hindered the interaction between the starch granules and protein (Niu et al. 2014; Tudorica et al. 2002). This change in the noodle structure may explain the increased cooking yield (Fig. 2a) and significantly decreased firmness and cohesiveness in texture profile analysis (Table 1).

KGM incorporated after a period of dough mixing time appeared to cause a thickening of the matrix with coarser

Fig. 4 Scanning electron micrographs of the cross-section of cooked noodle samples: **a** T_0 Control; **b** T_0 KGM; **c** T_2 KGM; **d** T_4 KGM. Size bar 100 μ m

and less oriented gluten fibrils when compared with T_0 KGM samples. Micrograph of T_4 KGM (Fig. 4d) show a highly compacted structure where gluten fibrils were cross linked regularly and starch granules seemed to be encapsulated within the protein-KGM network. These results appeared to be a support of the lowest cooking loss (Fig. 4b) and highest tensile strength (Table 1) of T_4 KGM samples among all the KGM noodle samples. These findings in microstructures reconfirmed the presumption that KGM additions after a period of dough mixing time could modify the gluten network, which might be caused by the effects on the relationship between protein and starch.

Sensory evaluation

The sensory evaluation of all noodle samples is shown in Table 2. In view of firmness, T_4 KGM sample gained the majority of attention, followed by the control and T_2 KGM sample, while T_0 KGM sample scored lowest. Regarding the elasticity of the cooked salted noodles, the control and T_4 KGM samples appeared to have a desirable noodle quality which indicated significantly higher ($P < 0.05$) elasticity than others. No significant difference in stickiness

of cooked noodle was detected among all samples (ranged from 3.9 to 4.7), even though the T_0 KGM samples scored higher than the other three samples. Overall, no significant difference was detected between the control and T_4 KGM samples in the scores of overall acceptability, while the T_0 KGM and T_2 KGM samples scored lower than the other two samples. This indicated that adding 5% KGM as a proportional substitution after 4 min of dough mixing could obtain the similar quality and pleasant appearance as regular wheat noodles.

Conclusion

The combination of 5% KGM flour substituted in wheat noodles at different dough mixing time (0, 2, 4 min, respectively) resulted in changes in rheological properties, textural properties, microstructure and other quality parameters of dough as well as fresh cooked noodles. The rheological properties of the dough samples revealed that the elastic modulus (G') and viscous modulus (G'') significantly decreased by 5% KGM incorporated, while all increased with the extension of dough mixing time before

Table 2 Sensory scores of all noodle samples

	Firmness	Elasticity	Stickiness	Overall acceptability
T ₀ Control	5.4 ± 0.73 ^b	7.0 ± 0.75 ^b	4.4 ± 1.09 ^a	7.4 ± 0.82 ^b
T ₀ KGM	4.1 ± 0.61 ^a	5.8 ± 0.85 ^a	4.7 ± 0.79 ^a	5.2 ± 0.94 ^a
T ₂ KGM	5.4 ± 0.85 ^b	5.8 ± 1.16 ^a	4.3 ± 0.92 ^a	5.8 ± 0.99 ^a
T ₄ KGM	5.8 ± 0.83 ^b	6.5 ± 1.10 ^{ab}	3.9 ± 0.84 ^a	6.8 ± 0.72 ^b

Results are presented as mean scores. Different letters superscripted on the results indicate significant difference ($P < 0.05$) between each attribute tested

adding KGM. Improved cooking yield were due to 5% KGM flour substitution. The T₄ KGM noodle samples showed the least cooking loss. Compared to the T₀ KGM noodles, textural properties including hardness and cohesiveness, as well as tensile strength and tensile distance of noodles have a tendency to increase, as a period time of dough mixing before adding KGM affected gluten network development and make microstructure more compact with a thickening gluten matrix. In general, 5% KGM incorporation after 4 min of dough mixing could obtain the similar noodle quality and pleasant appearance as regular wheat noodles.

Acknowledgements This work was supported by the grants from National Science Foundation of China (31571791), China Agriculture Research System - Green Manure and National Key-technologies R&D Project (2016YFD0400402) during the 13th 5-year Plan of the People's Republic of China.

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