LWT - Food Science and Technology 165 (2022) 113686

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Influence of substituting wheat flour with quinoa flour on quality characteristics and *in vitro* starch and protein digestibility of fried-free instant noodles

Jianlou Mu [a,*], Yiwen Qi [a], Kexin Gong [c], Zhizhou Chen [e], Margaret A. Brennan [b,d], Qianyun Ma [a], Jie Wang [a], Yanlou Gen [f], Wei Lv [f], Charles S. Brennan [b,**]

[a] College of Food Science and Technology, Agricultural University of Hebei, Baoding, 071001, China
[b] College of Science, RMIT University, Melbourne, Australia
[c] Jinmailang Food Co. LTD, Xingtai, Hebei, 100001, China
[d] Department of Food, Wine, and Molecular Bioscience, Lincoln University, Christchurch, New Zealand
[e] College of Mechanical and Electrical Engineering, Agricultural University of Hebei, Baoding, 071001, China
[f] National Engineering Research Center for Semi-arid Agriculture, Shijiazhuang, Hebei Province, China

A R T I C L E I N F O

Keywords:
Texture
Quality characteristics
Gluten-free
In vitro digestion
Sensory

A B S T R A C T

Wheat flour (WF) was substituted with different level of quinoa core flour (QCF), quinoa whole flour obtained by grinding mill (GQWF) and flour mill (RQWF) equipment separately, to develop QCF, GQWF and RQWF-formulated fried-free instant noodles. Tensile properties and quality attributes of dough, and cooking qualities, texture properties and sensory analysis of noodles were investigated. Substitution with quinoa flour decreased optimal cooking time and iodine contrast index of noodles, while cooking loss was not affected by quinoa flour. Water absorption capacity of RQWF30-noodle was lower than that of WF-noodle. The hardness of QCF and RQWF formulated noodles was significantly higher than that of WF-noodle, while the hardness, chewiness, elasticity and resilience of GQWF-noodle were inferior to WF-noodle. Microstructure results showed that quinoa flour containing-noodles had larger and uneven pores than that of WF-noodles. The sensory indicators of noodles were better when substitution level of quinoa flours was ≤20%. Substitution with quinoa whole flour decreased protein digestibility and reducing sugar released during *in vitro* starch digestion of noodles. These findings revealed that substitution with quinoa flours (≤20%) may have the potential to develop noodles with both low reducing sugar released and desirable textural attributes.

1. Introduction

Quinoa (*Chenopodium quinoa* Willd) is a pseudo-cereal widely used in the food industry, and represents a current trend in the human diet due to its excellent nutritional and nutraceutical values as a gluten-free grain (Xu, Luo, Yang, Xiao, & Lu, 2019). Quinoa contains 14–18% protein (Chatain, Pernollet, Pralong, & Leccia, 2019), high quality lipids and a large number of vitamins, minerals, dietary fiber, polyunsaturated fatty acids as well as a diversity of bioactive compounds (Abugoch James, 2009). Chlopicka, Pasko, Gorinstein, Jedryas, and Zagrodzki (2012) revealed that polyphenols in quinoa flour improved the antioxidant capacity of quinoa-bakery products. Joye, Lamberts, Brijs, and Delcour (2011) also indicated that γ-aminobutyric acid from quinoa flour significantly lowered blood pressure.

Most frequently, quinoa is considered a healthy ingredient to produce diverse gluten-free products. Therefore, it is rational that quinoa can be used to develop food products with its unique functional and rheological properties, sensory characteristics, and nutrient profiles. An increasing number of studies have been reported on quinoa applications for food product development and evaluated the effect of quinoa flour substitution or supplements on the nutritional and functional properties of food products such as bakery and pasta products (Czekus et al., 2019; Gostin, 2019; Tiga, Kumcuoglu, Vatansever, & Tavman, 2021; Wang, Lao, Bao, Guan, & Li, 2021). Torres, Lema, and Galeano (2021) reported

* Corresponding author.
** Corresponding author.
E-mail address: jianloumu2022@163.com (J. Mu).

https://doi.org/10.1016/j.lwt.2022.113686
Received 26 March 2022; Received in revised form 13 June 2022; Accepted 20 June 2022
Available online 24 June 2022

that the quinoa flour increased the protein content in the formulated pasta, and the physicochemical and structural were changed significantly due to the molecular interaction of protein with the starch in quinoa formulated pasta.

The popularity of instant noodles rapidly spreads across the world. In 2019, the global instant noodle market expanded rapidly, reaching 100 billion servings (Parvathy, Bindu, & Joshy, 2017). Instant noodles are a type of pre-cooked noodle normally supplied in individual packets or bowls. They are steamed, dried, fried for dehydration, cooled, and then packed individually. Its main ingredients are typically flour, starch, water, and salt. However, consuming instant noodles may have serious consequences for health such as gastric cancer, heart disease and stroke, due mainly to the low fiber and protein, and high in sodium in instant noodles. Hence, it is necessary to improve the instant noodle processing to improve its nutritional values. Tiga et al. (2021) reported that increasing replacement level of quinoa flour resulted in the increased nutritional values, and decreased degree of gelatinization of extruded instant noodles. Schoenlechner, Drausinger, Ottenschlaeger, Jurackova, and Berghofer (2010) revealed that addition of quinoa increased cooking loss of gluten-free pasta. These previous studies clearly illustrated that quinoa flour could improve the nutritional properties of wheat products. A desired consuming quality of food products along with

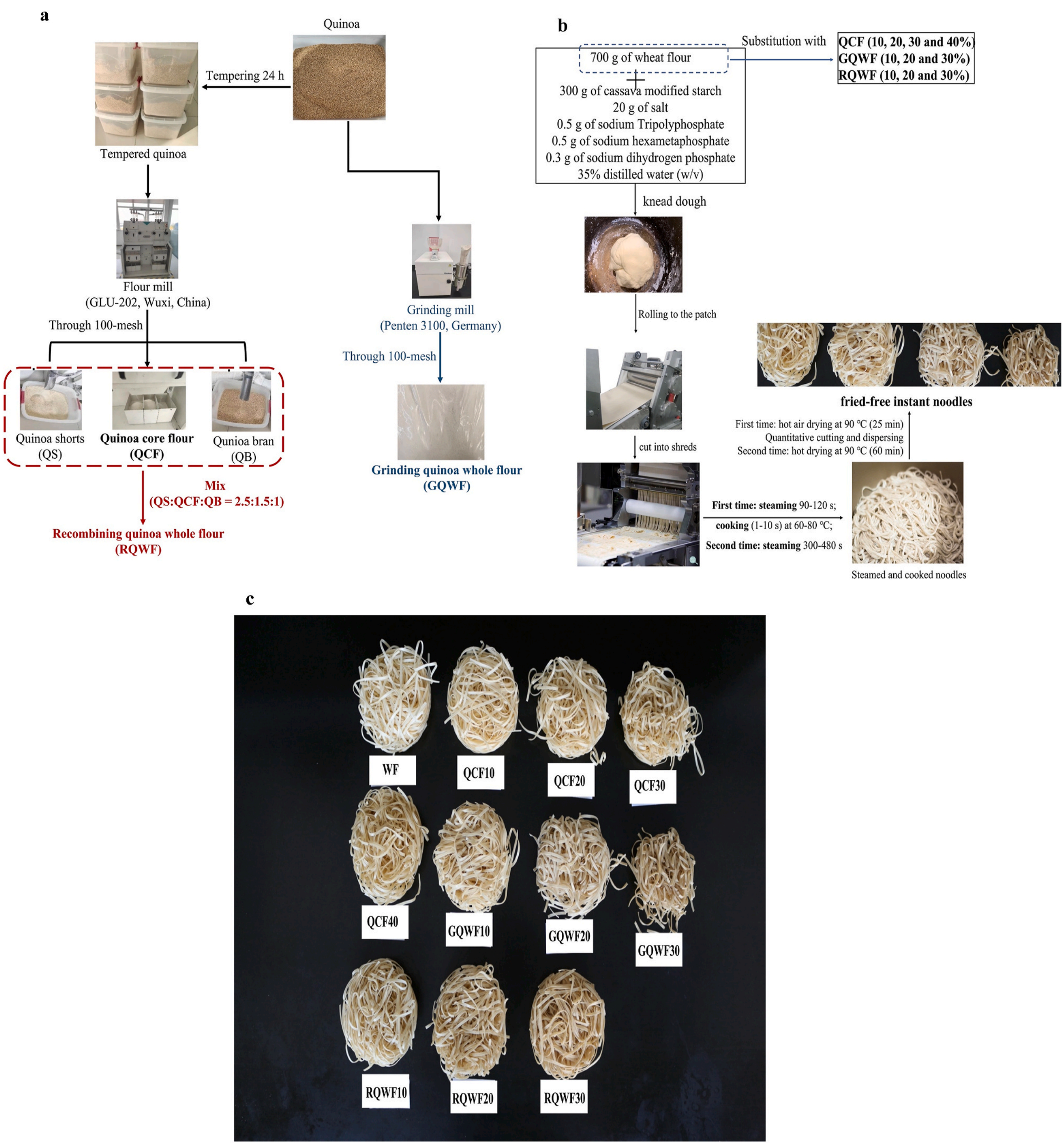

Fig. 1. (a) Preparation of quinoa core flour (QCF) and quinoa whole flours obtained using a grinding mill (GQWF) and a flour mill by recombining method (RQWF) separately. **(b)** Preparation of fried-free instant noodles produced by wheat flour (WF), QCF, GQWF, and RQWF with different substitution levels. **(c)** Appearance of fried-free instant noodles produced by wheat flour (WF), QCF, GQWF, and RQWF at different substitution levels.

acceptable physicochemical properties is essential for quinoa application to develop novel food products. Therefore, quinoa flour-containing products should either be sound in sensory attributes or exhibit similar characteristics with that of WF-containing products.

However, limited studies reported the substitution of quinoa flour and improved its production processing to improve the nutritional values of instant noodles. In this study, quinoa core flour, and quinoa whole flours produced by grinding mill and flour mill equipment separately, were utilized to substitute WF in different proportions to produce fried-free instant noodles. The effects of quinoa flour substitution on quality characteristics and sensory analysis of noodles were investigated. Besides, *in vitro* starch and protein digestibility of noodles were studied.

2. Materials and methods

2.1. Materials and reagents

All-purpose WF was provided from Jinmailang Food Co., LTD (Baoding, China). Quinoa seeds were kindly provided by a local plantation (Zhangjiakou, China). D(+)-glucose standard solution was purchased from Sigma-Aldrich (MA, USA). Porcine pancreatic α-amylase, glucoamylase, pepsin and trypsin were bought from Yuanye Technology Company (Shanghai, China). Total starch (AA/AMG) assay kit and total dietary fiber assay kit were purchased from Megazyme International Co., Ltd (Bray, Wicklow, Ireland).

2.2. Preparation of quinoa flour and fried-free instant noodles

As shown in Fig. 1a, quinoa seeds were ground using a grinding mill (3100, Penten Co., LTD, Germany) and through a 100-mesh sieve to obtain quinoa whole flour (GQWF). Besides, quinoa seeds were tempered for 24 h to make sure the moisture content being approximately 15%. The tempered quinoa seeds were stored in a wet warehouse for 12 h, and was ground using a flour mill (GLU-202, Buller Machinery Manufacturing Co., LTD, Wuxi, China) to obtain quinoa shorts, quinoa core flour (QCF, through 100-mesh sieve), and quinoa bran. They were mixed by recombining method according to the ratio of 2.5:1.5:1 to obtain the quinoa whole flour (RQWF). QCF, GQWF and RQWF were substituted WF with different proportions. The blended flours were mixed with 300 g of cassava modified starch, 20 g of salt, 0.5 g of sodium tripolyphosphate, 0.5 g of sodium hexametaphosphate, and 0.3 g of sodium dihydrogen phosphate thoroughly. The mixture was added to 35% (w/v) distilled water to make dough. The dough was rolled out to the patch, cut into shreds, and then was steamed, cooked, dried, cooled, and packed individually to produce fried-free instant noodles, as shown in Fig. 1b. Appearances of noodle samples are shown in Fig. 1c. The dried noodles were stored in sealed aluminum bags for further analysis.

2.3. The proximate compositions and total phenol content (TPC) and total flavonoid content (TFC) in flours

The moisture content of noodles was determined according to AACC method 44-15A (AACC, 2000a, 2000b, 2000c, pp. 50–65). The crude protein content was determined using the AACC method (conversion factor of 6.25) (AACC, 2000a, 2000b, 2000c, pp. 50–65). The dietary fiber content was analyzed using a Total Dietary Fiber Assay Kit. The gluten content was measured according to a previous study (Kaushik, Kumar, Sihag, & Ray, 2015). Flour samples (500 mg) was extracted using a three-step extraction procedure (50% methanol, 1% HCl in 50% methanol, and 80% acetone). The supernatants from all steps were combined and stored at −20 °C for TPC and TFC analysis. TPC of flours was determined using Folin-Ciocalteau reagent, and was calculated as gallic acid equivalents in mg/g of dry mass (Singleton, Orthofer, & Lamuela-Raventós, 1999), while TFC was evaluated using $NaNO_2$–$Al(NO_3)_3$ colorimetric method, and was calculated as rutin equivalents in mg/g of dry mass.

2.4. Farinographic and tensile properties of dough

The dough was produced and its farinographic properties tests were measured using a Farinograph-E (Brabender, Germany) equipment with a mixer for 50 g of flours. Water absorption capacity (WAC, the amount of water required to center the farinogram on 500 BU, as shown in Fig. S1), development time (the time between the first addition of water and the development of the maximum consistency of the dough) (Wang et al., 2022), stability time (the difference in time between the point at which the top of the curve first intercepts and leaves 500 BU), softness (the difference between the consistency value of the curve center at the end of the developing time and 10 min after starting the test), and quality index (the lengths along the timeline from the first addition of water until the point where the curve center is 30 FU lower than at the development time) of dough were evaluated (standard code: GB/T 14614–2019). Dough with 2% NaCl addition (w/w) was prepared using Farinograph-E with a larger mixer for 300 g of flours to measure its tensile property by an Extensograph-E equipment (model 860702, Brabender, Germany), followed by the standard procedure (ICC 114/1). Extensograph curves were recorded for proving times of 45, 90, and 135 min.

2.5. Optimal cooking time (OCT), WAC, cooking loss and iodine contrast index (ICI) of fried-free instant noodles

Noodles (30 g) were cooked in 500 mL of boiling water. OCT was defined by the required time to fully hydrate the noodles, and was determined by observing the time of disappearance of the central opaque core in noodles during cooking (every 5 s) by squeezing the noodles between two transparent glass slides (AACC, 2000a, 2000b, 2000c, pp. 50–65). WAC of noodles was referred to the total amount of water that can be absorbed, and was evaluated according to the method of Niu, Hou, Wang, and Chen (2014), the boiled noodle samples were put on filter paper to drain surface moisture of noodles. The mass of the boiled and dried noodles was weighed separately. WAC was calculated according to formula (1).

$$WAC = \frac{G_1 - G}{G \times (1 - W)} \times 100\% \quad (1)$$

where G_1 was the mass of boiled noodle (g); G was the mass of dried noodle (g); W was the moisture content of noodle (%).

The cooking loss indicates guarantee of quality in terms of water retention after being cooked, and was determined according to AACC Method 66–50 (AACC, 2000a, 2000b, 2000c, pp. 50–65). The boiled noodle samples were removed from cooking water. The cooking water was then collected in a volumetric flask and made the volume up to 500 mL. A volume of 50 mL was poured into a 100 mL of pre-dried beaker to a constant weight. Afterwards, the beaker was placed in a 105 °C air oven until a constant weight was obtained. The residue was weighed and reported as a percentage of the starting material (dry basis). Cooking loss was calculated followed by formula (2).

$$Cooking\ loss\ (\%) = \frac{5 \times M}{G \times (1 - W)} \times 100\% \quad (2)$$

where M was the mass of residue in cooking water (g); G was the mass of starting material in cooking material (g); W was the water content (%).

ICI is an important index to evaluate the gelatinization degree and the quality of flour products (Hansen & Godfrey, 2017). It was measured according to the standard method (SB/T 10250–95: instant noodle). Briefly, 2 g of sample (defatted by petroleum ether) was mixed with 20 mL of distilled water at 50 °C for 30 min. The mixture was centrifugated at 5000 g for 10 min. Supernatant (1 mL) was collected to mix with 5 mL of phosphate buffer solution (pH = 5.8) and 1 mL of 0.05 mol/L iodide-potassium iodide solution and made up to 50 mL with distilled water. The ICI was calculated according to the following formula:

$$ICI = 4 \times A \times \frac{1.00}{V} \quad (3)$$

where A is the OD value detected at 570 nm using a spectrophotometer, and V depicts the volume of supernatant.

2.6. Color, texture, and microstructure of fried-free instant noodles

L^* (luminance), a^* (red and green index), and b^* (blue and yellow index) values of noodle samples were determined by CR-400 tristimulus colorimeter (Konica Minolta Inc., Tokyo, Japan). The whiteness value was measured using a whiteness meter WSD-III (Kangguang Instrument Co., LTD, Beijing, China). The textural properties of boiled noodles were determined using a food physical analyzer TMS-Pro (Food Technology Corporation, VA, USA). The noodles were cooked to the OCT, and measurements were carried out for 5 min after cooking. The superficial water on noodle strands was blotted with filter paper. Each boiled noodle strand was cut to a length of 2.5 cm. Sample was placed on the base plate and compressed with a cylindrical probe (P/36R) by using a 10 kg load cell (calibration distance 25 mm, trigger force 5 g, and time interval 1 s). The compression strain was 75% of the noodle strand thickness. The measurements were carried out 10 times for each sample. Parameters of hardness (the force necessary attain a given deformation, F_N), resilience (the ratio of the area before the deformation target to the area after the deformation target when the first depression was applied), elasticity (the height that the noodle sample were recovered between the end of the first bite and the beginning of the second mouth), tackiness (hardness × cohesiveness, F_N), and chewiness (the energy required to masticate a sample to a state ready for swallowing, mJ) were recorded. Small specimens of dried noodles were coated with gold particles in an automated critical point drier (model SCD 050, Leica Vienna). Microstructure of samples was examined by Scanning electron microscope (SEM) (LEO EVO 40, Zeiss, Germany) with a 20 kV acceleration voltage and magnifications of 100× and 500 × for samples.

2.7. Sensory analysis

A sensory evaluation group consisting of 10 trained laboratory professionals (20–30 years of age from both genders) was selected to conduct sensory evaluation on fried-free instant noodles. Each sample had a code of 3 letters. Each panelist was tasted 2 g of each sample and had a test sheet corresponding with the same code. The sensory assessment focused on evaluating the color, appearance, palatability, toughness, stickiness, smoothness, and taste of noodles, and the grading criteria was indicated in Table 1 (standard code: GB/T 25005–2010). The noodles were served on plates and were presented to the sensory panel immediately after cooking using the optimal cooking time.

2.8. In vitro starch digestion assay

In vitro starch digestion assay was carried out according to a previous method (Başkan, Tütem, Akyüz, Özen, & Apak, 2016). Dried noodle sample (1 g) was weighted into a 100 mL of conical flask and dispersed with 20 mL of sodium acetate (0.2 mol/L, pH = 5.2) and 6 glass beads. The mixture was put into the boiling water to paste them for 30 min. Afterwards, 5 mL of porcine pancreatic α-amylase and glucoamylase were added to incubate at a 37 °C water bath shaker. At the beginning of 20, 60, 100, 120, and 180 min, 0.5 mL of digestive solution was taken out to mix with 10 mL of anhydrous ethanol to stop the reaction. Then the mixture was centrifuged at 25,000×*g*. The supernatant was collected, and the reducing sugar produced during *in vitro* digestion was determined by DNS (3,5-dinitrosalicylic acid) method.). Each aliquot (25 μL) was solubilized in 75 μL of distilled water, then 1 mL of DNS solution was added. The mixture was shaken and incubated in the boiling water bath for 5 min, then 1 mL of 40% sodium potassium tartrate (w/v) was added, and it was immediately cooled in ice bath for 15 min. The absorbance was recorded at 540 nm using a spectrophotometer. A linear regression equation was obtained using D(+)-glucose standard solution.

Table 1
Sensory analysis indicators.

Indicators	Score	Grading Criteria
Color	**10**	• White luster: 8.5–10 • Burnish of general: 6–8.4 • Brown matte: 1-6
Appearance	**10**	• Tight and smooth: 8.5–10 • Slight defect in appearance: 6.0–8.4 • Tough and shape change: 1-6
palatability	**20**	• Moderate: 17-20 • Harder or softer: 12-17 • Too hard or too soft: 1-12
Toughness	**25**	• Palatable and good elasticity: 21-25 • Moderate: 15-21 • Poor palatability and poor elasticity: 1-15
Stickiness	**25**	• Tasting good when chewing: 21-25 • Sticky: 15-21 • Clammy: 1-15
Smoothness	**5**	• Smooth: 4.3–5 • Moderate: 3–4.3 • Poor smoothness: 1-3
Taste	**5**	• Fresh scented: 4.3–5 • free from extraneous odor: 3–4.3 • unpleasant odor: 1-3

Refer to GB/T 25005-2010.

2.9. Protein digestibility

In vitro protein digestion was determined by gastric-trypsin method (Vázquez et al., 2020). Pepsin (0.1 g) was dissolved in 1 L of hydrochloric acid (pH = 1.5) to obtain the gastric juice, while 0.533 g of trypsin was dissolved in 1 L of phosphate buffer (pH = 8.0) to obtain the intestinal fluid. One gram of sample was dissolved in 15 mL of simulated gastric juice and incubated in a water bath shaker at 37 °C for 1 h at a speed of 150 r/min. pH was adjusted to 7.0 with 0.2 mol/L NaOH and then the mixture was incubated for 10 min. Afterwards, 15 mL of intestinal fluid was added to incubate for 1 h, and then 5 mL of 15% trichloroacetic acid was added to stop the reaction. After 1 h, the mixture was centrifuged at 5000×*g* for 30 min. The supernatant was collected, and the protein concentration was determined by Bicinchoninic acid (BCA) kit (Beyotime, Shanghai, China).

2.10. Statistical analysis

The data is presented as mean ± standard deviation (SD) and was subjected to one-way analysis of variance (ANOVA) using Minitab Statistical Software (Version 14.12.0, MINITAB, State College, PA, USA). Pearson's correlation was performed between dough quality and sensory evaluations using Graphpad Prism 8.0 software (CA, USA). Statistical significance was set at a probability level of $p < 0.05$.

3. Results and discussion

3.1. The proximate and polyphenol contents of flours

The moisture, protein and dietary fiber, starch, and gluten contents of WF, QCF, GQWF, and RQWF are shown in Fig. 2a. The moisture contents of GQWF and RQWF were 11.50 ± 0.02%, and 12.77 ± 0.04%, respectively, which were lower than that of WF. The protein content in WF and QCF was significantly different ($p < 0.05$) from each other. The highest content of protein was observed in GQWF (13.42 ± 0.67%) and

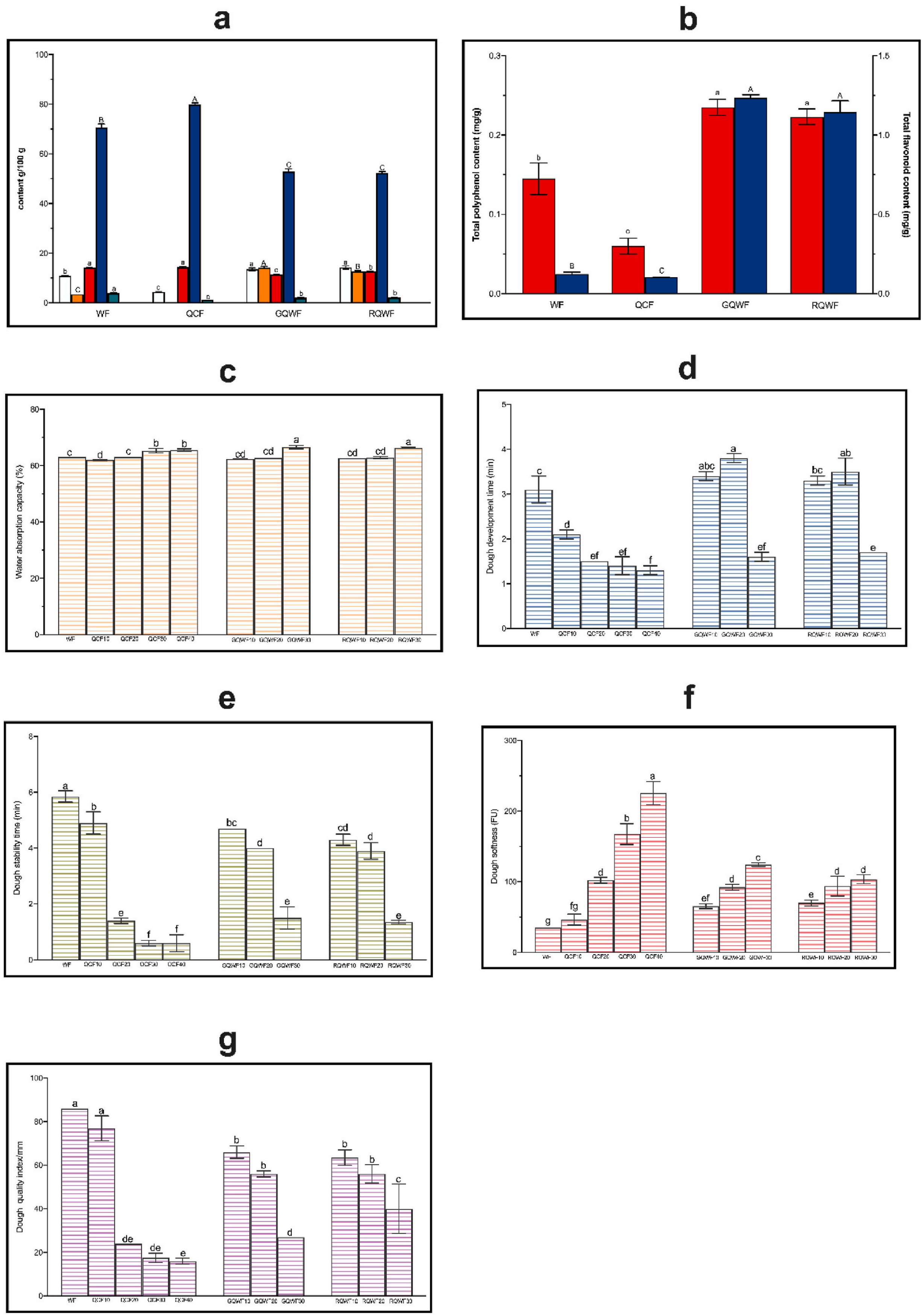

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Fig. 2. **(a)** The protein (white histogram), dietary fiber (tangerine histogram), moisture (red histogram), and starch (blue histogram) and gluten (green histogram) contents of flours; **(b)** The total phenol content (red histogram) and total flavonoid content (blue histogram) of flours; The effects of different amount of quinoa flour substitution on dough qualities **(c)** dough water absorption capacity; **(d)** dough formation time; **(e)** dough stabilization time; **(f)** dough softness; **(g)** dough quality index. Values are mean ± standard deviation, n = 3. Bars with different letters represent statistical difference between each other ($p < 0.05$). WF = wheat flour; QF10-40 = substitution of wheat flour with quinoa core flour at 10, 20, 30, and 40% levels, respectively; GQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a grinding mill at 10, 20, and 30% levels, respectively; RQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a flour mill by recombining method at 10, 20, and 30% levels, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

RQWF (14.20 ± 0.66%). This observation suggested that substitution of WF with quinoa flour could increase the protein content of final products, producing more shelf stable products due to their lower moisture content. The highest dietary fiber content was observed in GQWF (14.04 ± 0.02%), followed by RQWF (12.60 ± 0.03%). Compared with WF (70.66 ± 1.39%), QCF had a higher starch content (80.01 ± 0.52%), while the composite flour had a significantly lower starch content of approximately 50%. Gluten plays an important role in the elasticity and strength of dough by forming linear structures through intermolecular disulfide bonds. Herein, substation of WF with quinoa flour decreased the gluten content in GQWF (2.01 ± 0.19%) and RQWF (2.05 ± 0.20%) ($p < 0.05$). QCF (1.20 ± 0.00%) had the lowest gluten content among four types of flours. The TPC and TFC of flours are indicated in Fig. 2b. The TPC of GQWF and RQWF were significantly higher than that in WF ($p < 0.05$). The lowest TPC was observed in QCF (0.03 ± 0.01 mg/g), which was obviously lower than that of WF. The TFC in GQWF (1.15 ± 0.05 mg/g) and RQWF (1.07 ± 0.03 mg/g) were significantly higher than that in WF and QCF ($p < 0.05$). These results revealed that substitution WF with quinoa flour could be a promising strategy to improve the nutritional values and antioxidant properties of quinoa formulated noodle products.

3.2. Farinographic properties of dough

The influence of quinoa substitution on WAC of dough is shown in Fig. 2c. When the substitution level of QCF was 30–40%, the WAC of dough was significantly higher than that of WF ($p < 0.05$), which might be due to the high starch content in QCF. The starch granular in QCF swelled, increasing the WAC of composite flours. When the substitution level of QCF reached to 30%, the WAC in GQWF and RQWF significantly increased to 66.6 ± 0.57% and 66.4 ± 0.21%, respectively ($p < 0.05$). This might be related to dietary fiber contained in GQWF and RQWF. Dietary fiber contains a large number of hydrophilic groups, and has strong water holding capacity, which improves the dough WAC (Zheng et al., 2022). Fig. 2d presents the dough development time. The dough development time decreased to 1.6 ± 0.1 and 1.7 ± 0.0 min in GQWF and RQWF dough, respectively, as the substitutional level increased to 30%, which were significantly lower than that of WF-dough ($p < 0.05$). The gluten content in QCF, GQWF, and RQWF was lower than that in WF, which resulted in a shorter time to form the gluten network, thus shortening the development time of quinoa containing dough.

Dough stability time is an indication of dough strength, referring to as "tolerance" of the flour to over- and undermixing (Liu et al., 2019). Substitution with QCF, GQWF and RQWF decreased the stability time from 5.9 ± 0.21 to 0.6 ± 0.28, 1.5 ± 0.24 and 1.4 ± 0.07 min, respectively, which was significantly lower than that of WF dough ($p < 0.05$) (Fig. 2e). Weak gluten flour normally has a shorter stability time than strong gluten flour. This is agreement with the observation in our study. As the gluten content in GQWF and RQWF was lower than that of WF (Fig. 2a), which resulted in a shorter stability time compared to WF dough. Quinoa flour substitution diluted the gluten in WF, leading to the gluten strength dropped, thus reducing its stability time. In addition, the gluten content in GQWF and RQWF was higher than that of QCF, leading to their longer stability time at the same substitutional level compared with WCF dough ($p < 0.05$). Dough softness represents the resistance of the dough to mechanical mixing and is inversely related to the dough strength (Mtelisi Dube, Xu, & Zhao, 2020). It can be seen from Fig. 2f that when substitution levels of quinoa flours increased, the dough softness of composite flours increased, indicating that quinoa flours decreased the dough strength. The dough quality index of flours is shown in Fig. 2g. Increasing substitution amount of quinoa flour significantly decreased the dough quality index of composite flours. When substitution amount of QCF reached to 40%, the dough quality index decreased from 86 ± 0.00 to 16 ± 0.41 mm. When the substitution amount was 30% in GQWF and RQWF, the dough quality index was 27 ± 0.00 and 40 ± 11.31 mm, respectively.

3.3. Dough tensile properties

The dough tensile properties can reflect the processing properties of dough after fermentation (Guo et al., 2022). The tensile energy, tensile resistance and maximum tensile resistance of the dough increased with fermentation, while the elongation did not change significantly (Table 2). When the fermentation time increased from 90 to 135 min, the dough stretching curve did not change significantly, indicating that the appropriate dough fermentation time was 90 min. When the dough fermentation time was prolonged, the energy and tensile resistance of dough did not change significantly. At the same fermentation time, increasing quinoa flour substitutional levels in the range of 10–20% significantly decreased the dough energy, tensile resistance, and maximum tensile resistance ($p < 0.05$). The maximum dough tensile resistance decreased by 68.2, 70.6 and 67.6% in QCF, GQWF and RQWF, respectively. When the substitution level of quinoa flours was ≥20%, the tensile resistance and the maximum tensile resistance increased slightly. The gluten content was lower in composite flours compared with WF, which hindered the formation and cross-linking of protein molecular chains in dough, thus reducing the tensile resistance. 30–40% substitution amount of quinoa flours increased the viscosity of composite flours, leading to a slightly increased maximum tensile resistance. When the substitutional levels of GQWF and RQWF reached to 30%, the soluble dietary fiber content of flour bran was significantly increased, and its strong water holding capacity was beneficial to the maintenance of gluten network structure. As a result, the tensile resistance and maximum tensile resistance increased. When the substitution level of QCF, GQWF and RQWF was 30%, the elongation decreased to 69 ± 2.12, 71 ± 8.49 and 72 ± 9.19 mm, respectively, which was significantly lower than that of WF ($p < 0.05$). This might be related to the bran contained in GQWF and RQWF, and the low gluten content in quinoa flours, both of which affected the mechanical strength and processing properties of dough. Soluble dietary fiber in wheat bran can interact with gliadin and glutenin during dough fermentation to change the gluten network structure (Feng, Ma, & Wang, 2020; Sivam, Sun-Waterhouse, Quek, & Perera, 2010; Teng, Liu, Bai, & Liang, 2015), thus affecting the dough tensile properties.

3.4. Color of fried-free instant noodles

Color is consumers' visual impression of noodles (Samant et al., 2015). According to Table 3, when the substitution level of QCF was 30–40%, L^* value of QCF-noodles decreased significantly compared to WF-noodle ($p < 0.05$), indicating the brightness of QCF-noodles was darkened. The L* values of GQWF- and RQWF-noodles were lower than that of WF-noodle, while the a^* value of noodles increased by increasing substitution levels of quinoa flours. This means the color of quinoa flour

Table 2
The tensile properties of dough.

Samples	Stretch area/cm^{2}			Stretch resistance/BU			Extensibility/mm			Maximum stretch resistance/BU		
	45min	90min	135min	45min	90min	135min	45min	90min	135min	45min	90min	135min
WF	46 ± 2.83^{a}	56 ± 0.71^{a}	53 ± 0.71^{a}	243 ± 0.00^{a}	296 ± 12.02^{ab}	292 ± 11.31^{ab}	117 ± 2.83^{a}	119 ± 5.66^{a}	115 ± 3.54^{a}	281 ± 13.44^{a}	327 ± 4.24^{a}	331 ± 7.78^{a}
QCF-10	35 ± 2.12^{b}	50 ± 2.12^{b}	49 ± 0.71^{b}	205 ± 15.56^{bc}	313 ± 4.24^{a}	323 ± 5.66^{a}	108 ± 1.41^{ab}	109 ± 9.19^{ab}	103 ± 2.12^{b}	216 ± 21.21^{bc}	321 ± 9.19^{ab}	331 ± 7.78^{a}
QCF-20	33 ± 2.12^{bc}	39 ± 2.83^{c}	36 ± 0.71^{d}	191 ± 5.66^{c}	260 ± 7.07^{cd}	265 ± 7.07^{bc}	112 ± 9.19^{ab}	104 ± 2.12^{b}	96 ± 3.54^{bc}	197 ± 0.00^{cd}	262 ± 8.49^{d}	267 ± 7.07^{b}
QCF-30	25 ± 3.54^{de}	32 ± 2.12^{d}	34 ± 2.83^{de}	192 ± 8.49^{c}	271 ± 28.28^{bc}	299 ± 24.75^{ab}	81 ± 10.61^{ef}	78 ± 3.54^{c}	79 ± 5.66^{d}	212 ± 5.66^{bcd}	298 ± 23.33^{bc}	324 ± 12.73^{a}
QCF-40	28 ± 0.71^{cd}	27 ± 1.41^{de}	26 ± 1.41^{g}	230 ± 5.66^{a}	228 ± 24.75^{def}	215 ± 1.41^{e}	70 ± 2.12^{f}	69 ± 2.12^{c}	67 ± 0.71^{e}	300 ± 4.95^{a}	301 ± 7.07^{abc}	300 ± 2.83^{a}
GQWF-10	38 ± 0.71^{b}	40 ± 0.00^{c}	45 ± 0.71^{c}	222 ± 3.54^{ab}	275 ± 14.85^{bc}	313 ± 11.31^{a}	112 ± 1.41^{ab}	101 ± 6.36^{b}	102 ± 4.24^{b}	230 ± 7.07^{b}	280 ± 11.31^{cd}	319 ± 12.02^{a}
GQWF-20	21 ± 4.24^{e}	30 ± 0.00^{de}	33 ± 2.12^{def}	143 ± 16.26^{e}	218 ± 0.00^{ef}	253 ± 17.68^{cd}	95 ± 9.90^{cd}	96 ± 3.54^{b}	89 ± 1.41^{c}	144 ± 16.26^{e}	219 ± 0.71^{e}	256 ± 16.26^{b}
GQWF-30	22 ± 2.12^{e}	28 ± 0.71^{de}	29 ± 1.41^{fg}	166 ± 21.92^{de}	247 ± 9.19^{cde}	249 ± 2.83^{cde}	83 ± 0.00^{de}	71 ± 8.49^{c}	75 ± 6.36^{de}	190 ± 13.44^{d}	287 ± 21.92^{cd}	322 ± 14.85^{a}
RQWF-10	34 ± 1.41^{b}	40 ± 0.00^{c}	43 ± 2.83^{c}	197 ± 2.83^{c}	254 ± 13.44^{cd}	294 ± 26.87^{ab}	114 ± 4.95^{ab}	107 ± 7.07^{ab}	103 ± 1.41^{b}	205 ± 2.83^{bcd}	261 ± 14.85^{d}	300 ± 26.16^{a}
RQWF-20	25 ± 1.41^{de}	32 ± 0.71^{d}	29 ± 2.83^{fg}	161 ± 7.78^{de}	205 ± 3.54^{f}	223 ± 16.97^{de}	103 ± 1.41^{bc}	106 ± 3.54^{ab}	93 ± 0.71^{c}	161 ± 8.49^{e}	205 ± 2.83^{e}	224 ± 15.56^{c}
RQWF-30	23 ± 0.00^{de}	26 ± 1.41^{e}	30 ± 0.00^{efg}	184 ± 2.83^{cd}	229 ± 0.00^{def}	264 ± 12.73^{bc}	79 ± 1.41^{ef}	72 ± 9.19^{c}	71 ± 2.83^{de}	213 ± 2.12^{bcd}	275 ± 9.19^{cd}	318 ± 10.61^{a}

Values are mean ± standard deviation, n = 3. Values in the same column with different letters represent statistical difference between each other ($p < 0.05$). WF = wheat flour; QCF10-40 = substitution of wheat flour with quinoa core flour at 10, 20, 30, and 40% levels, respectively; GQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a grinding mill at 10, 20, and 30% levels, respectively; RQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a flour mill by recombining method at 10, 20, and 30% levels, respectively.

Table 3
The color characteristics of noodles.

Samples	*L**	*a**	*b**	Whiteness
WF	86.21 ± 0.71^{a}	0.72 ± 0.14^{f}	13.16 ± 1.08^{def}	59.30 ± 0.14^{ab}
QCF-10	85.61 ± 0.89^{ab}	0.97 ± 0.16^{e}	12.68 ± 0.92^{fg}	59.95 ± 0.07^{a}
QCF-20	85.61 ± 0.91^{ab}	1.00 ± 0.16^{de}	12.53 ± 0.95^{fg}	60.15 ± 0.35^{a}
QCF-30	84.7 ± 0.53^{c}	1.13 ± 0.14^{d}	13.03 ± 0.78^{efg}	58.90 ± 0.28^{b}
QCF-40	84.83 ± 0.6^{c}	1.04 ± 0.14^{de}	12.55 ± 0.68^{fg}	58.60 ± 0.42^{b}
GQWF-10	83.76 ± 0.56^{d}	1.11 ± 0.11^{d}	13.53 ± 0.41^{cde}	55.65 ± 0.07^{c}
GQWF-20	83.1 ± 0.54^{e}	1.29 ± 0.09^{c}	13.7 ± 0.38^{cd}	54.20 ± 0.28^{d}
GQWF-30	81.44 ± 0.76^{f}	1.56 ± 0.13^{b}	14.49 ± 0.51^{ab}	50.00 ± 0.00^{f}
RQWF-10	85.27 ± 0.3^{bc}	1.05 ± 0.05^{de}	12.41 ± 0.25^{g}	60.35 ± 0.07^{a}
RQWF-20	82.81 ± 0.5^{e}	1.33 ± 0.11^{c}	14.12 ± 0.46^{bc}	52.80 ± 0.14^{e}
RQWF-30	80.75 ± 0.73^{g}	1.69 ± 0.16^{a}	14.98 ± 0.54^{a}	48.25 ± 0.07^{g}

Values are mean ± standard deviation, n = 3. Values in the same column with different letters represent statistical difference between each other ($p < 0.05$). WF = wheat flour; QCF10-40 = substitution of wheat flour with quinoa core flour at 10, 20, 30, and 40% levels, respectively; GQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a grinding mill at 10, 20, and 30% levels, respectively; RQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a flour mill by recombining method at 10, 20, and 30% levels, respectively.

formulated noodles was becoming dark and red, which would reduce the color score in sensory analysis. The *b** value of GQWF- and RQWF-noodles was higher than that of WF-noodle, suggesting substitution with quinoa whole flour made noodles more yellowness. The whiteness value of GQWF- and BQWF-noodles was significantly lower than that of WF- and QCF-noodles ($p < 0.05$), mainly due to a large amount of bran in quinoa whole flour.

3.5. Texture properties of fried-free instant noodles

The texture properties of noodles are shown in Table 4. The hardness of QCF- and RQWF-noodles was significantly higher than that of WF-noodle ($p < 0.05$), while the hardness of GQWF20- and GQWF30-

Table 4
The effect of quinoa flour substitution on the texture properties of fried-free instant noodles.

Samples	Hardness/N	Resilience	Elasticity	Tackiness/N	Chewiness/mJ
WF	25.93 ± 0.97^{c}	0.23 ± 0.01^{bc}	0.31 ± 0.02^{ab}	5.2 ± 0.52^{bc}	1.92 ± 0.40^{a}
QCF10	27.09 ± 0.70^{bc}	0.24 ± 0.01^{ab}	0.29 ± 0.02^{bcd}	5.0 ± 0.54^{c}	1.71 ± 0.25^{ab}
QCF20	29.68 ± 0.83^{a}	0.21 ± 0.02^{cd}	0.29 ± 0.02^{bcd}	5.6 ± 0.32^{abc}	1.75 ± 0.13^{ab}
QCF30	27.10 ± 1.30^{bc}	0.21 ± 0.03^{d}	0.29 ± 0.01^{cd}	5.7 ± 0.56^{ab}	1.50 ± 0.15^{bc}
QCF40	28.10 ± 0.82^{ab}	0.24 ± 0.03^{b}	0.30 ± 0.03^{bcd}	5.8 ± 0.57^{ab}	1.48 ± 0.32^{bc}
GQWF-10	28.30 ± 1.43^{ab}	0.24 ± 0.02^{b}	0.30 ± 0.02^{bcd}	5.5 ± 0.43^{abc}	1.79 ± 0.13^{ab}
GQWF-20	22.13 ± 0.75^{d}	0.17 ± 0.01^{e}	0.28 ± 0.02^{d}	5.4 ± 0.55^{bc}	1.30 ± 0.26^{cd}
GQWF-30	21.12 ± 0.90^{d}	0.17 ± 0.01^{e}	0.26 ± 0.01^{e}	5.4 ± 0.28^{bc}	1.10 ± 0.12^{d}
RQWF-10	26.44 ± 0.85^{c}	0.26 ± 0.01^{a}	0.30 ± 0.03^{bcd}	5.4 ± 0.55^{abc}	1.65 ± 0.27^{ab}
RQWF-20	28.51 ± 1.47^{ab}	0.23 ± 0.01^{bc}	0.32 ± 0.01^{a}	5.9 ± 0.51^{a}	1.50 ± 0.24^{bc}
RQWF-30	28.72 ± 2.58^{ab}	0.22 ± 0.01^{bcd}	0.31 ± 0.02^{abc}	5.6 ± 0.76^{abc}	1.32 ± 0.37^{cd}

Values are mean ± standard deviation, n = 10. Values in the same column with different letters represent statistical difference between each other ($p < 0.05$). WF = wheat flour; QCF10-40 = substitution of wheat flour with quinoa core flour at 10, 20, 30, and 40% levels, respectively; GQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a grinding mill at 10, 20, and 30% levels, respectively; RQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a flour mill by recombining method at 10, 20, and 30% levels, respectively.

noodles was lower than WF-noodle ($p < 0.05$). When the substitution level of quinoa flour was 10%, the resilience of noodles was significantly higher than that of WF-noodles. The elasticity of GQWF20- and GQWF30-noodles was significantly lower than that of WF-noodle ($p < 0.05$). However, the elasticity of QCF- and GQWF-noodles had no obvious difference. Substitution with quinoa flours significantly reduced the gluten content, decreasing the water holding capacity of noodles, and increasing this substitution level improved the stickiness of noodles but decreased the chewiness of noodles.

3.6. Sensory analysis of fried-free instant noodles

Sensory evaluation results of noodles depict in Table 5. Quinoa flour had obvious effects on the color, apparent, palatability, toughness, stickiness, smoothness, taste, and sensory scores of noodles. When substitution level of QCF was 10–20%, there was no significant difference in sensory score between QCF-noodles and WF-noodle. When the substitution level of GQWF and RQWF was 10%, the sensory scores of noodles were 81.7 ± 1.6 and 84.1 ± 2.9, respectively. Increasing substitution level of quinoa flours significantly decreased the sensory score and the acceptance of noodles ($p < 0.05$).

Pearson's correlation was performed between dough quality and sensory indicators. In Fig. 3, sensory scores of noodles are significantly positively correlated with stability time, extensibility, and quality index of dough ($r = 0.862$, 0.866 and 0.670, respectively, $p < 0.05$), while significantly negatively correlated with WAC and softness of dough ($r = -0.785$ and -0.656, respectively, $p < 0.01$). Substitution with quinoa flour reduced dough strength, and adversely affected the sensory score of noodles. The WAC showed a significant negative correlation with sensory indicators such as appearance and palatability. Hence, it is necessary to control the WAC when making noodles. The appearance of noodles was positively correlated with the tensile energy, tensile resistance, and elongation of dough ($r = 0.817$, 0.671 and 0.666, respectively, $p < 0.05$). The surface of noodles produced from flour with strong strength and extensibility was smooth and was not easy to be deformed. Palatability was positively correlated with tensile energy and extensibility of dough ($r = 0.749$ and 0.677, respectively, $p < 0.05$). The toughness and stickiness of noodles were positively correlated with the dough stability time, quality index, tensile energy, and extensibility but was negatively correlated with the dough softness. The possible reason is that the high gluten content improved the continuity of gluten network structure, thus increasing the elasticity and toughness of noodles. Besides, there was a significant positive correlation between smoothness and softness of noodles and dough stability time, tensile energy, and extensibility, whilst the smoothness and taste of noodles were negatively correlated with dough softness. A strong dough strength could increase the elasticity and toughness of noodles, leading to better sensory indicators of smoothness and taste of noodles.

3.7. Microstructures of fried-free instant noodles

SEM was used to observe the effect of the substitution amount of quinoa flours on the microstructure of noodle samples at magnification of 100× (Fig. 4a) and 500 × (Fig. 4b). Fig. 4a reflects the distribution of holes formed by intense movement of the water and bubbles wrapped in the wet noodles after drying, which is conducive to the rapid rehydration of noodles. The cross section presents a spotty spongy, continuous, and crisp hollow structure. Addition of quinoa flours destroyed the gluten network, especially when the substitutional level was 30–40%. Obvious gluten network faults and pores were observed. This is similar with previous studies (Liu et al., 2019; Wang et al., 2021), probably due to the lack of gluten in quinoa flour. In Fig. 3b, the WF-noodle had a uniform, continuous and dense network structure. Large holes appeared when the WF was substituted with different amount of quinoa flours. Simultaneously, the network structure of gluten became loose, the internal texture became thicker, and was even broken, leading to loose structure of quinoa flour-noodles. This could be due to the high starch content in QCF, low gluten content and high dietary fiber content in GQWF and RQWF. Low gluten content in composite flours resulted in its incomplete network structure that could not coat starch granules. Besides, due to the destruction of network structure, the noodles would be easily broken and shattered during the cooking process. Therefore, excessive substitution with quinoa flours would have an adverse effect on the structure of noodles. Herein, 10–20% would be the ideal substitution levels for its maintenance of network structure.

3.8. Cooking qualities of fried-free instant noodles

The OCT of WF-noodle was 3.92 ± 0.00 min (Fig. 5a). Substitution with quinoa flours significantly decreased the OCT of noodles ($p < 0.05$) as quinoa flours weakened the binding strength of protein, starch, and other macromolecules in the dough, leading to a sparse structure in noodles. During the cooking process, water was easier to enter inside the molecules, thus reducing the OCT and cooking resistance of noodles. The moisture content of noodles ranged from 8.30 to 10.70%, which was beneficial to the noodle storage. The WAC of RQWF30-noodles was significantly lower than that of WF-noodles ($p < 0.05$) (Fig. 5b). Cooking loss is considered as an index of resistance to disintegration during cooking process (Fu, 2008). Herein, there was no significant difference in the cooking loss between noodles produced from different flours, indicating that quinoa flour-noodle had a good cooking quality in the OCT condition. In Fig. 5c, compared with the WF-noodle, the ICI of QCF30-, GQWF30- and RQWF30-noodles significantly decreased from 1.11 ± 0.01 to 0.74 ± 0.01, 0.48 ± 0.03 and 0.39 ± 0.01, respectively. The ICI of GQWF- and RQWF-noodles was significantly higher than that of QCF-noodle ($p < 0.05$). Quinoa whole flour contains a large amount of dietary fiber that can compete with starch for water, which have adverse

Table 5
Sensory evaluation values of fried-free instant noodles (fraction).

Samples	Color	Appearance	Palatability	Toughness	Stickiness	Smoothness	Taste	Sensory score
WF	9.1 ± 0.4^{a}	8.4 ± 0.8^{a}	18.1 ± 1.1^{a}	20.5 ± 1.4^{a}	21.1 ± 1.9^{a}	4.2 ± 0.4^{a}	4.0 ± 0.1^{ab}	83.9 ± 2.7^{a}
QCF-10	8.8 ± 0.4^{ab}	8.1 ± 0.5^{a}	18.3 ± 0.6^{a}	20.2 ± 0.7^{a}	19.4 ± 0.5^{bc}	4.1 ± 0.3^{ab}	4.1 ± 0.1^{a}	83 ± 2.2^{a}
QCF-20	8.8 ± 0.3^{ab}	8.4 ± 0.6^{a}	18.0 ± 0.8^{ab}	18.6 ± 0.5^{b}	19.5 ± 0.6^{bc}	4 ± 0.3^{abc}	4.2 ± 0.2^{a}	81.3 ± 2.5^{a}
QCF-30	8.7 ± 0.5^{ab}	7.9 ± 0.5^{a}	17.6 ± 0.5^{ab}	17.6 ± 0.8^{bc}	18.1 ± 0.3^{cde}	3.7 ± 0.3^{bcde}	3.7 ± 0.2^{c}	77.3 ± 1.2^{b}
QCF-40	8.3 ± 0.3^{bc}	7.6 ± 0.4^{ab}	16.8 ± 0.6^{bc}	16.5 ± 0.5^{c}	17.4 ± 0.5^{de}	3.2 ± 0.3^{e}	3.2 ± 0.2^{de}	73.1 ± 2.4^{c}
GQWF-10	8.2 ± 0.3^{bc}	8.2 ± 0.4^{ab}	17.6 ± 0.5^{ab}	20.4 ± 0.7^{a}	19.5 ± 0.5^{bc}	3.9 ± 0.3^{abc}	3.8 ± 0^{bc}	81.7 ± 1.6^{a}
GQWF-20	8 ± 0.5^{cd}	6.8 ± 0.6^{bc}	15.8 ± 0.8^{cd}	18.1 ± 0.5^{b}	18.1 ± 0.5^{cde}	3.8 ± 0.3^{abcd}	3.4 ± 0.2^{d}	73.9 ± 0.8^{c}
GQWF-30	6.8 ± 0.3^{e}	6.5 ± 0.5^{c}	15.4 ± 0.7^{d}	17.5 ± 0.6^{bc}	17.1 ± 0.4^{e}	3.2 ± 0.3^{e}	3.1 ± 0.1^{e}	69.5 ± 1.1^{cd}
RQWF-10	8.8 ± 0.3^{ab}	8.3 ± 0.4^{a}	17.9 ± 0.7^{ab}	20.9 ± 1.0^{a}	20.5 ± 0.6^{ab}	3.9 ± 0.3^{abc}	3.8 ± 0.1^{c}	84.1 ± 2.9^{a}
RQWF-20	7.5 ± 0.4^{d}	7.6 ± 0.4^{a}	17.6 ± 0.4^{ab}	18.5 ± 0.6^{b}	19.1 ± 0.5^{c}	3.6 ± 0.2^{cde}	3.7 ± 0.1^{c}	77.6 ± 2.1^{b}
RQWF-30	6.8 ± 0.5^{e}	7.2 ± 0.5^{bc}	16.1 ± 0.4^{d}	17.8 ± 0.3^{bc}	18.6 ± 0.4^{cd}	3.3 ± 0.2^{de}	3.4 ± 0.2^{d}	72.9 ± 0.6^{d}

Values are mean ± standard deviation, n = 3. Values in the same column with different letters represent statistical difference between each other ($p < 0.05$). WF = wheat flour; QCF10-40 = substitution of wheat flour with quinoa core flour at 10, 20, 30, and 40% levels, respectively; GQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a grinding mill at 10, 20, and 30% levels, respectively; RQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a flour mill by recombining method at 10, 20, and 30% levels, respectively.

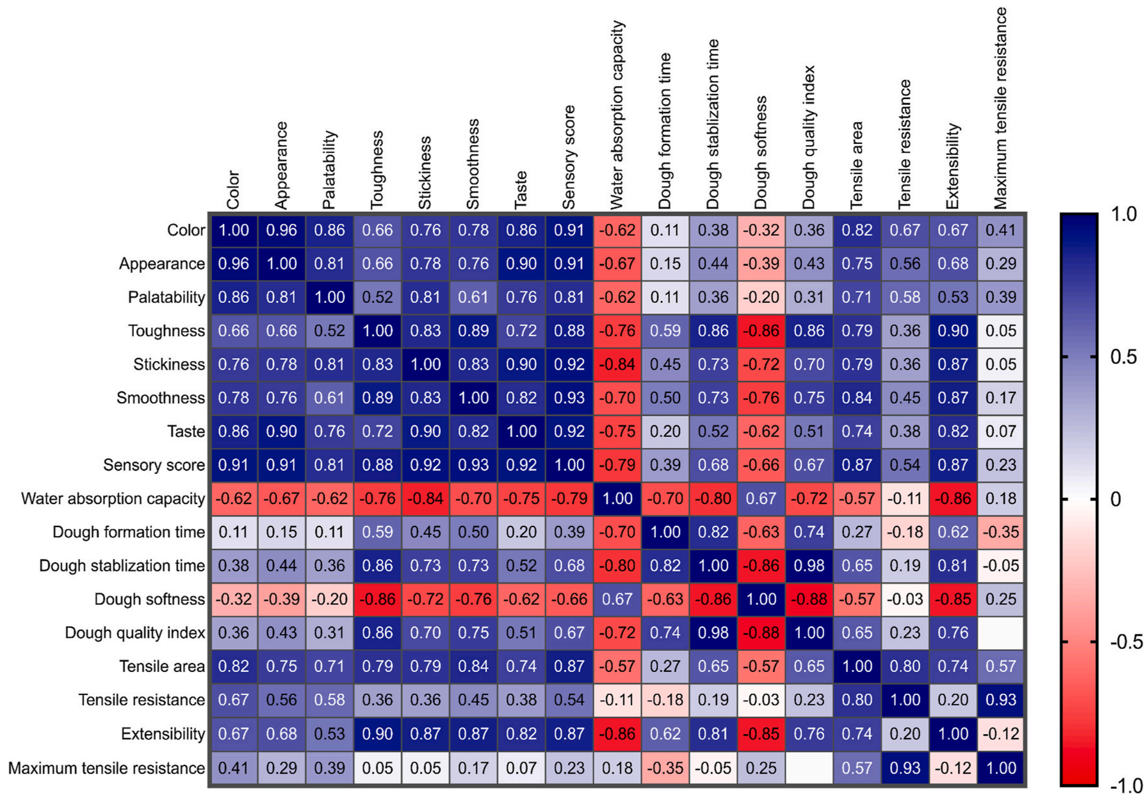


Fig. 3. Pearson's correlation between sensory indicators and quality and tensile properties of dough.

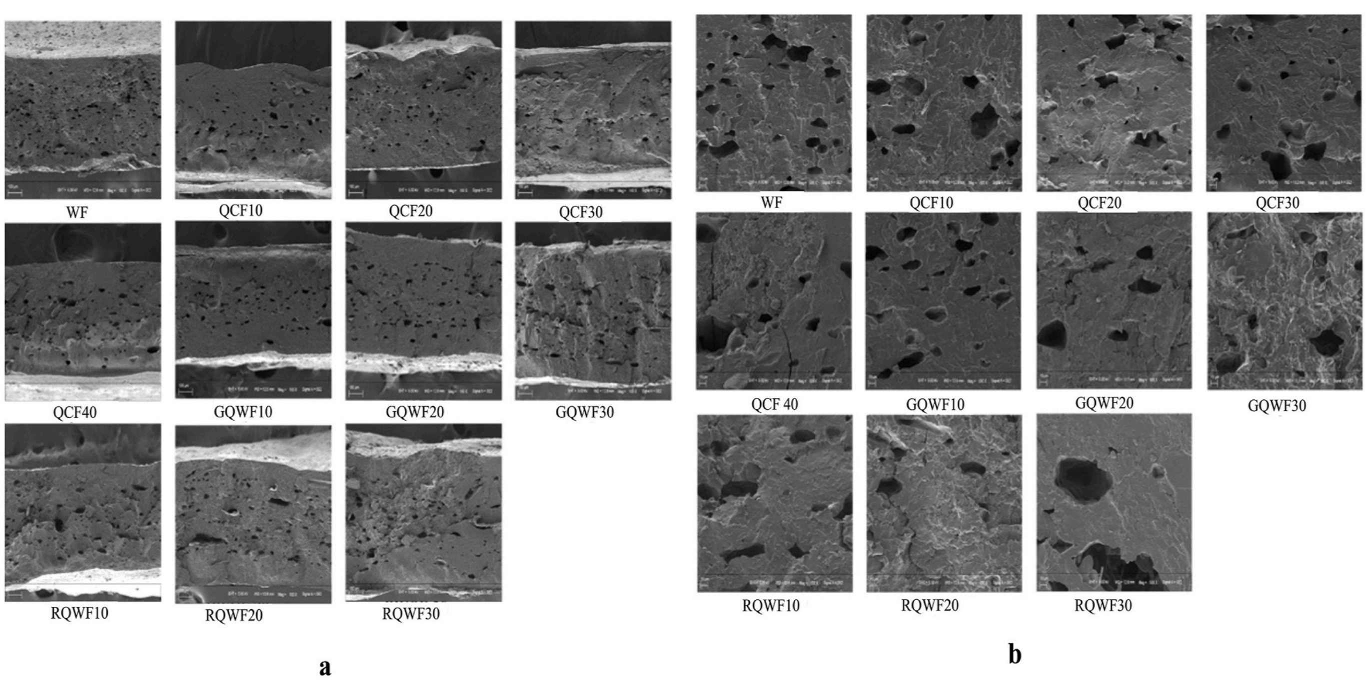
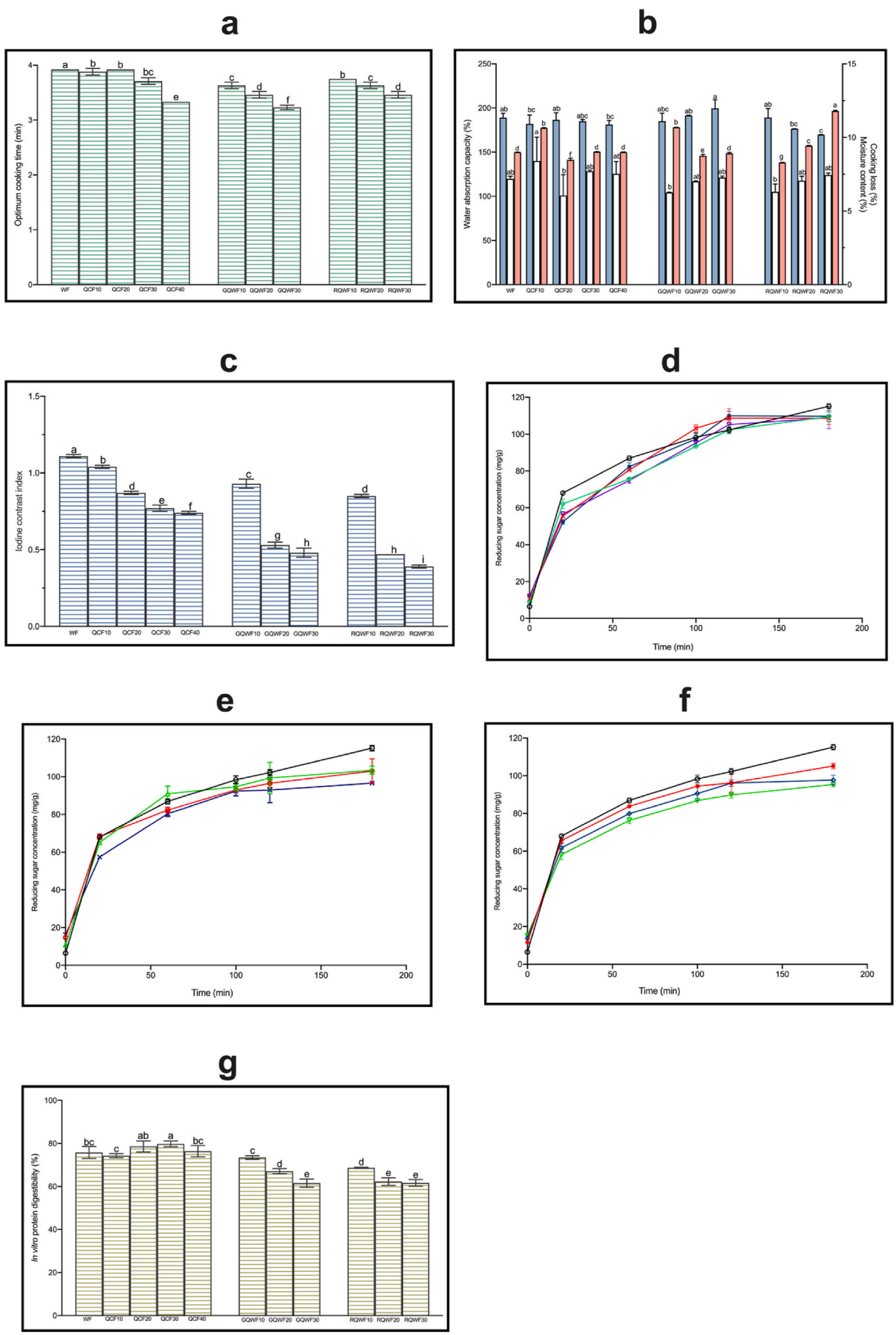


Fig. 4. Microstructures of gluten in composite flours by SEM analysis at magnifications of 100× **(a)** and 200 × **(b)** images.

effects on starch gelatinization in products. This observation revealed that the quinoa flour could retard the starch degradation. This is agreement with the results of dough WAC.

3.9. *In vitro starch digestibility*

The reducing sugar released from noodles during *in vitro* digestion is shown in Fig. 5d–f. Reducing sugar released from noodles increased significantly in the first 20 min of digestion, slowly increased between 20 and 120 min, then gradually levelled off after 120 min. The reducing sugar values at different time point were provided in Tables S1–S3. There was no significant difference in digestion rate between QCF-noodles and WF-noodle (Fig. 5d). According to Fig. 5e–f, the amount of reducing sugar released in GQWF- and RQWF-noodles was



(caption on next page)

Fig. 5. The effects of different amount of quinoa flour substitution on cooking qualities and *in vitro* protein and starch digestibility. **(a)** Optimum cooking time (min); **(b)** water absorption capacity (blue histogram), moisture content (white histogram) and cooking loss (pink histogram) (%) of fried-free instant noodles; **(c)** Iodine contract index of fried-free instant noodles; **(d)** Reducing sugar released (mg/g) of WF- and QCF-noodles during *in vitro* digestion (black line for WF; green line for QCF10; red line for QCF20; purple line for QCF30 and blue line for QCF40); **(e)** Reducing sugar released (mg/g) of WF- and GQWF-noodles during *in vitro* digestion (black line for WF; green line for GQWF10; red line for GQWF20 and blue line for GQWF30); **(f)** Reducing sugar released (mg/g) of WF- and RQWF-noodles during *in vitro* digestion (black line for WF; red line for RQWF10; blue line for RQWF20 and green line for RQWF30); **(g)** *In vitro* protein digestibility (%) of fried-free instant noodles. Values are mean ± standard deviation, n = 3. Bars with different letters represent statistical difference between each other ($p < 0.05$). WF = wheat flour; QF10-40 = substitution of wheat flour with quinoa core flour at 10, 20, 30, and 40% levels, respectively; GQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a grinding mill at 10, 20, and 30% levels, respectively; RQWF10-30 = substitution of wheat flour with quinoa whole flour obtained using a flour mill by recombining method at 10, 20, and 30% levels, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

significantly lower in than that of WF-noodle. Increasing substitution levels of GQWF and RQWF decreased the reducing sugar amount ($p < 0.05$) as it decreased the content of digestible starch in noodles and slowed down its digestion rate. GQWF and RQWF are rich in dietary fibers that compete with starch for water, inhibiting the gelatinization of starch during instant noodles processing. This makes α-amylase more difficult to reach the starch, thus inhibiting the starch hydrolysis and slowing down the digestion rate (Abderrahim et al., 2015). Additionally, dietary fiber has been shown to inhibit starch digestion by increasing the viscosity of the gastrointestinal contents, impeding the contact of digestive enzymes with substrates, and reducing the diffusion rate of small molecules such as glucose. Besides, quinoa whole flours contain high TPC that have been revealed to retard the starch degradation by inhibiting digestive enzymes such as α-amylase and α-glucosidase (Hui et al., 2020; Zhu, 2015).

3.10. In vitro protein digestibility

In Fig. 5g, the protein digestibility is 79.81% in QCF30-noodle, which is significantly higher than that of WF-noodle ($p < 0.05$), while there was no significant difference between QCF10-20 and WF-noodle. Moreover, the protein digestibility of GQWF- and RQWF-noodles was obviously lower than that of WF-noodle ($p < 0.05$). The protein digestibility of GQWF- and RQWF-noodles decreased to 61.52 and 61.64%, respectively. Shi et al. (2020) studied the protein digestibility of quinoa flour and its protein isolates. The results revealed that the protein digestibility of quinoa whole flour was lower than that of its protein isolates, which was agreement with the observation in this study. This could be due to the fact that quinoa whole flour contained more saponins, which hindered the binding of protease to protein. In addition, the dietary fiber and lipids in quinoa flour would affect the rate of protein hydrolysis.

4. Conclusion

Substitution with quinoa flours significantly decreased the optimal cooking time of noodles. The hardness, chewiness, elasticity, and resilience of GQWF-noodle were inferior to that of WF-noodle. Quinoa flour formulated noodles was a good source of protein. When the substitution level was ≤20%, the sensory indicators of noodles showed no difference from that of WF-noodle, which was acceptable for consumers. Besides, substitution with quinoa whole flour decreased *in vitro* protein digestibility and reducing sugar released during *in vitro* digestion. These findings might be a valuable guidance for the industrial application of quinoa flour with decreased reducing sugar content as well as suitable cooking qualities and texture properties.

Funding

This work was funded by the Key R&D Program of Hebei Province: Development and application of key technologies of Quinoa industrialization in Bashang (No.19227527D); Key Technology of Multi-grain Instant Nutrition Powder Processing with Low glycemic Index (No. C20200333); Introduction of foreign intelligence project in Hebei Province in 2021: Key technology research and function evaluation of coarse grain convenience food processing.

Declaration of competing interest

The authors declare that they have known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Jianlou Mu: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Writing – original draft. **Yiwen Qi:** Conceptualization, Methodology, Project administration, Validation, Visualization, Writing – review & editing. **Kexin Gong:** Validation, Methodology, Formal analysis, Investigation. **Zhizhou Chen:** Validation, Data curation, Writing – review & editing. **Margaret A. Brennan:** Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. **Qianyun Ma:** Validation, Data curation, Writing – review & editing. **Jie Wang:** Writing – review & editing. **Yanlou Gen:** Writing – review & editing. **Wei Lv:** Data curation, Writing – review & editing. **Charles S. Brennan:** Conceptualization, Supervision, Data curation, Formal analysis, Investigation, Validation, Visualization, Writing – review & editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2022.113686.

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