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Effects of whole quinoa flour addition on the pasting property, dough rheology, and steam bread textural property of wheat flour

*Feng, Y. Y., Zhu, Y. L., Wang, Z. and Li, X. L.

College of Biological and Food Engineering, Anyang Institute of Technology, Anyang, 455000 Henan, China

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Abstract

Addition of whole quinoa flour (WQF) into wheat flour is a promising approach to make quinoa food efficient, but the amount of WQF addition has a great influence on the quality of the quinoa food. The water-soluble index, swelling power, pasting property, dough rheological properties, and steam bread textural property of wheat flour containing 10 - 50% (w/w) WQF were investigated in the present work. Results showed that water soluble index and swelling power of mixed flour decreased gradually as the WQF content increased. Mixed flour containing higher WQF content (30 - 50%) had a lower peak viscosity, breakdown, and setback value than mixed flour containing lower content WQF (10 - 20%). Doughs containing 30 - 50% WQF had a weaker dough stability, less dough development time, but an increased water absorption and softening degree than the doughs containing 10 - 20% WQF. Dough's extension resistance increased and then decreased with the addition of WQF. Dough energy and extensibility of the mixed flour decreased with increasing level of WQF (10 - 50%). In addition, hardness and chewiness of steam bread made by mixed flour increased with increasing amount of WQF (10 - 50%). In view of the practical point, the maximum addition level of WQF was 20% when making a quinoa-wheat steam bread without any food additives.

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Introduction

Quinoa (*Chenopodium quinoa* Willd.) is a type of pseudocereal which can grow in nearly every continent around the world, including China (Tiga *et al*., 2021). The whole quinoa flour (WQF) is a perfect food material which contains well-proportioned nutritional composition, such as high-quality protein with ideal essential amino acid composition (especially abundant in lysine), higher lipid content abundant in unsaturated fatty acids, and higher dietary fibre content than other cereal. Due to its nutritional quality, it has become a trend to make coarse grain food made with WQF. However, the main content of quinoa protein is globulin and albumin; it has no gluten which can form a fermented dough structure in the production of cereal food. Therefore, there is a need to mix WQF with wheat flour to make a quinoa food.

Chinese steam bread (mantou), a traditional staple food in China, can be made only by wheat flour, water, and yeast, and then cooked by steaming. Mantou has become increasingly popular with the consumers around the world due to its health benefits, which contains less negative Maillard reaction products (acrylamide and furans) due to its lower manufacture temperature. However, the traditional steamed bread has limited healthy benefits because it contains only wheat flour, and using wheat flour alone to make steam bread cannot satisfy the growing nutritional requirements (Liu *et al*., 2021). Addition of other nutritious flour into steam bread is an effective method to amend its nutritional value (Fu *et al*., 2015; Zhu *et al*., 2016; Wu *et al*., 2018). It should be noted that although the addition of WQF can nutritionally enhance the quality of steam bread, it will decrease the texture and eating quality with increasing amount of WQF. The replacement of wheat flour by grain flour, such as calamondin fibre, sorghum, and WQF can result in a more rigid and less extensible dough, and the acceptable substitution of wheat flour is only less than 20% (Zhang *et al*., 2019; 2022; Demir and Bilgiçli, 2020; Barakat *et al*., 2022). The limited addition of WQF greatly restricts its

*Corresponding author.
Email: fyyyby2020@163.com

maximum nutritional benefits and popularisation in staple food. The WQF is different from wheat flour in several important aspects; so, a clear basic knowledge of its technical characteristics of mixed flour is required to facilitate its industrial application.

As the amount of WQF in quinoa-wheat flour increases, the technological property of mixed flour varies greatly. The property such as swelling power, water soluble index, pasting property, and dough farinographical and extensographical properties of mixed flour can well reflect the reaction between mixed flour and water, which can give us clear information on how changing situation of mixed flour affect the making properties of steam bread during its production. However, only limited information of these properties of mixed flour can be found, especially at higher addition (> 30%) of WQF. The addition of 10% quinoa flour did not influence the rheological properties, but higher additions (20 and 30%) led to significant changes of stability and elasticity of wheat flour (Tömösközi *et al*., 2011). All of these properties are key points to develop high quinoa content of steam bread in the future. In the present work, the water-soluble index, swelling power, pasting property, dough rheological properties, and the steam bread textural properties of the mixed flour (wheat flour containing 10 - 50% WQF) were studied systematically. These studies will provide scientific evidence for the application of quinoa processing in quinoa industrialisation.

Materials and methods

Materials and preparation of mixed flour samples

Wheat flour of brand "Fu Lin Men" was purchased from COFCO Group Co. Ltd. (Beijing, China). Its composition was 9.0% of protein, 1.5% of lipid, 75% of carbohydrate, and 14.5% of moisture content based on the label. The WQF was obtained from white quinoa seed (*Chenopodium quinoa*) grown in Qinghai province in China. The white quinoa seed was crushed into flour using a grinder, and passed through 0.150 mm sieve. The proximate composition of WQF was 8.1% of moisture, 2.1% of ash, 7.9% of lipid, 1.4% of fibre, 10.3% of protein, and 70.1% of carbohydrate. Six formulations of flour blends at WQF to wheat flour ratios (w/w) were prepared namely 0:100 (control, C), 10:90 (Q10), 20:80 (Q20), 30:70 (Q30), 40:60 (Q40), and 50:50 (Q50). All the samples were mixed uniformly in a Ziploc bag before determining the properties.

Water-soluble index and swelling power

Determination of water-soluble index (WSI) and swelling power (SP) of mixed flour samples were performed following the method descried by Li and Zhu (2016). In brief, flour sample (W_0, 0.25 g) was dispersed in 10 mL of deionised water, and stirred in a 50 mL centrifuge tube. The tube was heated at 95°C for 30 min, and oscillated for 10 s every 5 min on a vortex shaker. The sample did not produce eddy during the heating course. After heating, the samples were then cooled and centrifuged at 3,000 *g* for 10 min. The supernatant was dried at 105°C to a constant weight, and weighed (W_1). The residual sediment was weighed directly after wiping the surface water (W_s). All measurements were conducted in triplicate. The water-soluble index (%) and swelling power (g/g) of the mixed flour samples were calculated using Eqs. 1 and 2:

$$\text{WSI} = (W_1/W_0) \times 100\% \quad \text{(Eq. 1)}$$

$$\text{SP} = W_s/[W_0 \times (1 - WSI)] \quad \text{(Eq. 2)}$$

Pasting property

A rapid viscometer analyser (TechMaster RVA, Perten Instruments Inc., Sweden) was used to determine the pasting properties of the mixed flour following the method described by Jan *et al*. (2017). The mixed flour sample (3.0 g) was weighed into 25 mL of deionised water placed in the aluminium RVA pot. The pasting properties were measured by a standard procedure: the sample was first held at 50°C, then heated from 50 to 95°C in 3.75 min, followed by holding at 95°C for 2.5 min, and cooled to 50°C in 3.75 min. The pasting parameters evaluated included peak viscosity (PV), final viscosity (FV), trough viscosity (TV), breakdown viscosity (BD), and setback viscosity (SB). All measurements were conducted in triplicate.

Farinographical property

The dough mixing property of samples were determined using a Brabender Farinograph (Brabender OHG., Duisburg, Germany) following the AACC method. Based on Brabender©/ICC standard procedure, the flour samples (300 g) and moderate amount of water at 30°C were mixed in the farinograph bowl at a constant stirring rate of 63/min for 20 min. The dough farinographical properties such as dough development time (DT), water absorption (WA), stability (DS), and softening degree

(SD) were measured. All measurements were conducted in triplicate.

Extensographical characteristics

A Brabender Extensograph (Brabender GmbH &. Co. KG, Duisburg, Germany) was used to measure the dough stretching properties of samples following the method of AACC 54-10. The dough stretching properties in different formulations and fermentation times (45 - 135 min) such as extension resistance (ER), extensibility (E), and energy were measured. All measurements were conducted in triplicate.

Textural properties

The steam bread was prepared following the method described by Zhu *et al.* (2016) with minor modifications. Mixed flour (100 g), yeast (1 g), and moderate amount of water were kneaded for 3 min to make a smooth and uniform dough, then the dough was fermented at 37°C for 1 h in a constant temperature incubator, kneaded, and steamed for 30 min. The steam bread was cooled at room temperature conditions for 1 h before measuring the textural property. A texture analyser (TMS-PRO, Food Technology Corporation, USA) was applied to determine the textural properties of steam bread made by different mixed flour. The steam bread was cut into thin slices of 1 cm thickness, and placed on a flat sample tray. The texture profile analysis (TPA) of the two-cycle compression test was used following the method of Zhu *et al.* (2016). The compression mode was set as follow: test speed was 60 mm/min; strain was 70%; and trigger force was 0.03 N with a 35 mm cylinder prober. All measurements were conducted in five times.

Statistical analysis

Results were expressed in the form of mean ± standard deviation. An IBM SPSS version 21.0 software (SPSS Inc., Chicago, IL, USA) was used for analysis of variance and Duncan multiple-comparison test for statistical analysis. $p < 0.05$ was regarded as statistically significant.

Results and discussion

Water soluble index and swelling power

The interactions between mixed flour sample and water at 95°C were determined to illustrate the influences of wheat flour partially replaced by WQF. The water-soluble index is the percentage of soluble component released from the flour during heating (Lívia *et al*., 2012). As shown in Figure 1(a), the water-soluble index of mixed flour decreased from 14.58% (sample Q10) to 9.83% (sample Q50). This indicated that a higher replacement of wheat flour with WQF decreased the water-soluble index of the mixed flour. This behaviour might have been caused by the lower total starch and amylose contents in quinoa flour (Li and Zhu, 2016). In addition, the main proteins (albumins and globulins) which are bound tightly through disulphide bridges in quinoa flour might have also led to lower soluble index of quinoa flour as compared to wheat flour (Sathaporn *et al*., 2017). During the heating process, there were less starch (amylose) and soluble proteins leaching out from the mixed flour containing higher content of quinoa flour.

The influence of WQF addition on the swelling power of wheat flour are shown in Figure 1(b). Swelling power is an indicator of the amount of water absorbed by the flour particles during heating (Zhou *et al*., 2021). The swelling power of mixed flour showed a decreasing trend from 8.71 to 7.53 g/g with increasing WQF addition from 0 to 50% of the wheat flour. The swelling power of samples Q10 and C (wheat flour without WQF) were similar but significantly higher than other samples; this indicated that the higher addition of WQF decreased the swelling power of mixed flour samples. The higher lipid content in WQF may explain this phenomenon which can form helical complex with starch during the heating process (Sathaporn *et al*., 2017).

Pasting property

The pasting characteristics are helpful in understanding the viscosity changes of the flour-water system during heating and cooling, and the quality of mixed-flour products can also be predicted by the obtained pasting parameters (Jia *et al*., 2019). As shown in Table 1, the peak viscosity (PV) of mixed flour decreased from 1778.5 to 1513.5 cP with WQF addition amounts increasing from 10 to 50%. It seemed that the higher the quantity of WQF added, the lower the peak viscosity of the mixed flour. The peak viscosity can indicate the strength and viscous load of pastes which reflect the degree of swelling of starch granules (Li and Zhu, 2016).

The trough viscosity (TV) decreased from 1172.0 to 1164.0 cP, and the breakdown value

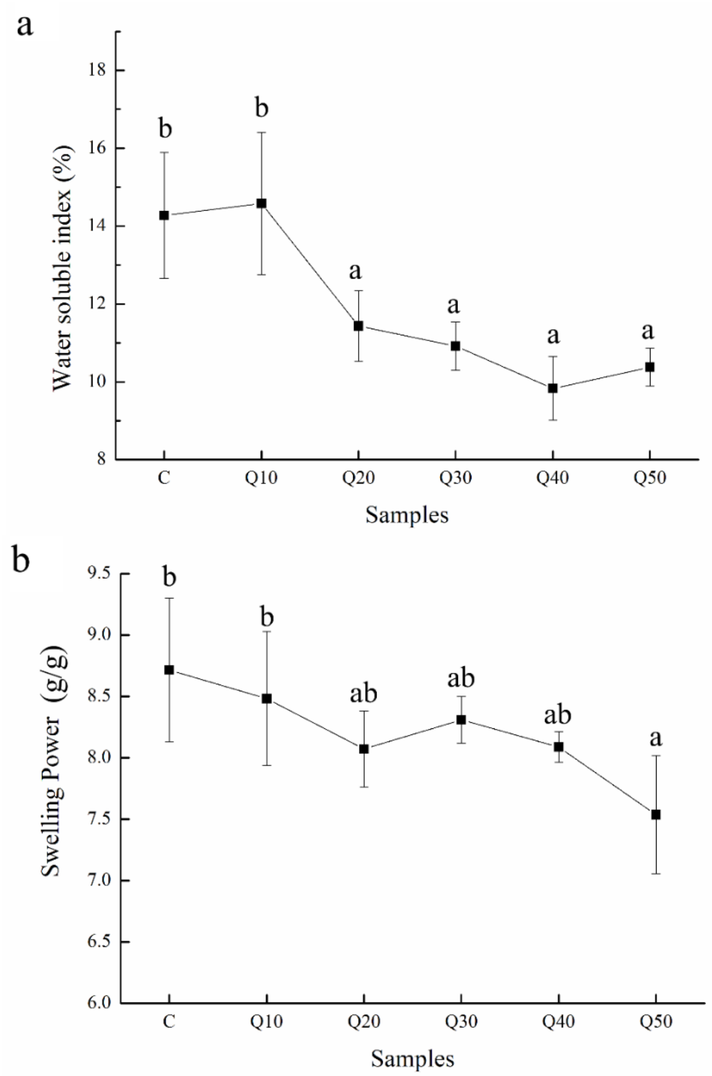

Figure 1. Water-soluble index **(a)** and swelling power **(b)** of mixed flour.

Table 1. Pasting properties of different mixed flour.

Sample	PV (cP)	TV (cP)	BD (cP)	FV (cP)	SB (cP)
C	1887.0 ± 9.8^{d}	1187.5 ± 4.9^{c}	699.5 ± 4.9^{e}	2496.0 ± 12.7^{d}	1308.5 ± 7.7^{e}
Q10	1778.5 ± 33.2^{c}	1172.0 ± 11.3^{b}	606.5 ± 21.9^{d}	2435.5 ± 12.0^{c}	1263.5 ± 23.3^{de}
Q20	1658.5 ± 6.36^{b}	1157.5 ± 6.3^{a}	501.0 ± 12.7^{c}	2395.5 ± 0.7^{bc}	1238.0 ± 7.1^{cd}
Q30	1580.0 ± 39.5^{ab}	1162.5 ± 21.9^{a}	417.5 ± 17.6^{b}	2358.5 ± 55.8^{b}	1196.0 ± 33.9^{bc}
Q40	1566.0 ± 14.1^{ab}	1163.5 ± 6.3^{a}	403.5 ± 20.5^{a}	2347.0 ± 26.8^{b}	1184.5 ± 33.2^{ab}
Q50	1513.5 ± 0.7^{a}	1164.0 ± 0.5^{a}	349.5 ± 0.7^{a}	2303.0 ± 0.5^{a}	1139.0 ± 0.5^{a}

Data are mean ± standard deviation of three replicates ($n = 3$). Means in the same column with different lowercase superscripts differ significantly ($p < 0.05$). PV: peak viscosity; TV: trough viscosity; BD: breakdown viscosity; FV: final viscosity; SB: setback viscosity; C: wheat flour without WQF; and Q10 - Q50: wheat flour with 10 - 50% addition of WQF.

decreased from 606.5 to 349.5 cP with WQF addition amounts increasing from 10 to 50% in the mixed flour. The breakdown value can reflect the stability of starch granules and paste viscosity during the heating-cooling-mixing process (Tömösközi *et al*., 2011). The lower the breakdown value, the higher the stability of starch to withstand shear stress and heating. Liu *et al*. (2014) also reported that a high breakdown value indicated that the swollen starch particles were relatively weak during heating and shearing, and a low breakdown value demonstrated that the starch had cross-linking characteristics.

The final viscosity (FV) can help determine the gel formation capacity of the flour sample during processing, while the setback viscosity (SB) can indicate the stability and possible degradation of the gel. The final viscosity decreased from 2435.5 to 2303.0 cP, and the setback value decreased from 1263.5 to 1139.0 cP with WQF addition amounts increasing from 10 to 50% in the mixed flour. Liu *et al*. (2014) also reported that the high setback value indicated that starch molecules were easily dispersed in hot paste, and easily recombined during cooling. The crystallinity and branch chain length of starch particles, and the higher fibre content in the WQF may reduce the water availability in the flour mixture, thus affecting the pasting properties.

Farinographical property

The farinographical properties of the doughs made by different mixed flour such as water absorption (WA), the dough development time (DDT), stability (DS), and softening degree (SD) are presented in Table 2.

Table 2. Farinographical properties of doughs made by different mixed flour.

Sample	WA (%)	DDT (min)	DS (min)	SD (FU)
C	57.95 ± 0.07[a]	5.70 ± 0.56[d]	8.90 ± 0.27[d]	42.00 ± 2.82[a]
Q10	58.60 ± 0.01[b]	4.66 ± 0.05[c]	6.86 ± 0.19[c]	61.00 ± 2.82[b]
Q20	58.75 ± 0.07[bc]	3.75 ± 0.00[b]	5.30 ± 0.14[b]	80.50 ± 3.53[c]
Q30	58.85 ± 0.07[bc]	3.15 ± 0.25[c]	5.02 ± 0.28[c]	84.50 ± 2.12[c]
Q40	58.75 ± 0.07[bc]	2.81 ± 0.02[c]	4.66 ± 0.75[b]	139.00 ± 4.24[d]
Q50	58.95 ± 0.07[c]	2.28 ± 0.19[a]	3.07 ± 0.06[a]	188.00 ± 4.24[e]

Data are mean ± standard deviation of three replicates ($n = 3$). Means in the same column with different lowercase superscripts differ significantly ($p < 0.05$). WA: water absorption; DT: dough development time; DS: dough stability; SD: the softening degree; C: wheat flour without WQF; and Q10 - Q50: wheat flour with 10 - 50% addition of WQF.

These can predict potential applications of WQF, and evaluate how the dough rheological properties can be changed by adding WQF into wheat flour. The WA of the mixed flour increased with the addition of WQF, from 57.95% for sample C, to 58.95% for sample Q50 (wheat flour containing 50% WQF), and the difference were significant ($p < 0.05$). This might have been due to the more quantity of protein, soluble dietary fibre, and amylopectin in WQF (Sathaporn *et al*., 2017). In general, the WA of dough is related to the protein content and the water binding capacity of starch and fibre (Li and Zhu, 2016). Adding fibre can enhance water absorption due to the hydrogen bonds that can bind water with hydroxyl group tightly in fibre (Nicoleta and Maria, 2021). Tsykhanovska *et al*. (2018) also reported that the water absorption of wheat flour dough increased with the addition of rye.

The dough development time (DDT) is the duration time when the dough has its maximum conformance under a non-cracking state. As shown in Table 2, The DDT for sample C was 5.70 ± 0.56 min, and decreased from 4.66 ± 0.05 min (sample Q10) to 2.28 ± 0.19 min (sample Q50); the increase in WQF in mixed flour dough caused a significant decrease in the DDT ($p < 0.05$). This might have been caused by the fact that the dough network structure was mainly built by gluten, and the main protein in WQF were albumin and globulin, which had no dough network structure forming ability. So, the addition of WQF will lead to a dilution of gluten network structure in mixed flour dough which will significantly decrease the DDT of mixed flour dough (Sánchez *et al*., 2019).

The dough stability (DS) can indicate the dough resistance of mixed flour to mixing and kneading. The DS of mixed flour decreased from 8.90

± 0.27 min (sample C) to 3.07 ± 0.06 min (sample Q50). Therefore, the addition of WQF could significantly decrease the DS of mixed flour, which formed a weak network structure due to the lack of gluten. Similar effects were reported by Sudha *et al*. (2006) where the DS decreased by 50% with the addition of 15% apple pomace fibre. Liu *et al*. (2016) also reported a decrease in DS from 6.18 to 1.40 min when 30% potato flour added into wheat flour.

The softening degree (SD) is measured by farinograms at 12 min when the curve arrived at the maximum value. The SD of mixed flour increased with the addition of WQF from 42.00 ± 2.82 FU (sample C) to 188.00 ± 4.24 FU (sample Q50), and the difference were significant based on ANOVA ($p < 0.05$). Similar conclusion had been reported by Nicoleta and Maria (2021) where 0.5 - 2.5% of rosehip powder added into wheat flour increased the SD of mixed flour from 58 to 91 BU, and Liu *et al*. (2018) also reported that the SD of mixed flour increased from 38 to 112 FU with 30% addition of WQF. The addition of WQF reduced the strength of protein network in the mixed dough. The destruction and weakening of gluten structure during the mixing process may lead to the decrease of plasticity of the mixed dough.

Extensographical parameters

The dough extensographical properties of mixed flour samples after fermented for 45, 90, and 135 min are presented in Figure 2. In Figure 2(a), when compared with sample C, the extension resistance value of mixed flour increased from 277.5 ± 16.2 to 384.5 ± 9.1 BU ($p < 0.05$) with 10 and 20% addition of WQF, but started to decrease from 384.5 ± 9.1 to 218.5 ± 14.8 BU ($p < 0.05$) at higher amount addition of WQF (at 30 - 50% level). Regarding the extension resistance values after fermented for 45, 90, and 135 min, the extension resistance of all samples tended to increase with the extension of fermentation time. In general, a greater tensile resistance indicated a better dough elasticity and rigidity, theoretically. This result indicated that lower addition of WQF (less than 20%) and fermentation improved the elasticity and rigidity of mixed flour dough to some extent; however, higher addition of WQF (more than 20%) led to an inverse trend that decreased the dough elasticity and rigidity. Similar conclusions had also been reported by Zhang *et al*. (2016) and Zuo *et al*. (2022).

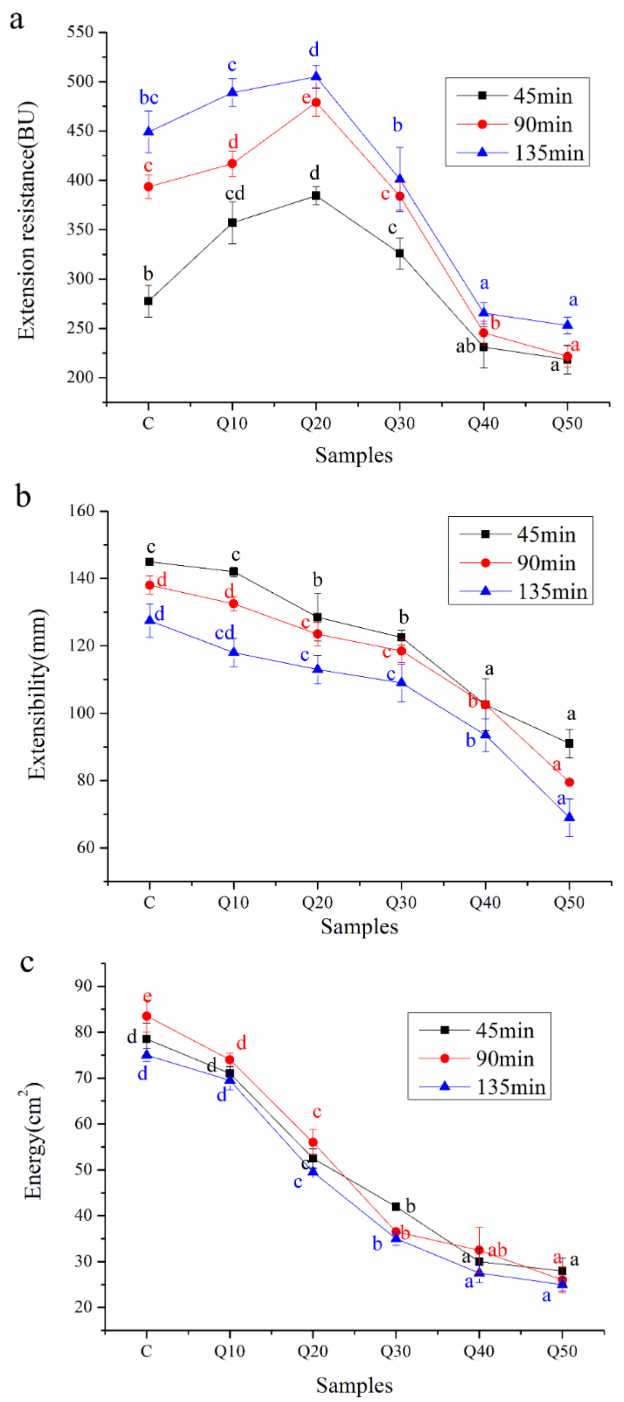

Figure 2. Dough extension resistance **(a)**, extensibility **(b),** and energy **(c)** of mixed flour.

In Figures 2(b) and 2(c), as compared to sample C, the dough extensibility and energy value of mixed flour exhibited a similar trend which decreased from 145.0 ± 1.0 to 91.0 ± 4.2 min as WQF was added in the mixed flour. This indicated that the WQF addition decreased the extensibility and energy of mixed flour. This might have been caused by the reduced gluten in mixed flour dough which formed a weak network structure with increased addition of

WQF. After fermented for 90 and 135 min, the extensibility of mixed dough was decreased to a slight degree. This might have been due to the solubilisation and polymerisation of the weak network structure formed by the limited gluten mixed flour dough during the fermentation (Kumar and Achutha, 2019). The extensibility represents the ductility and plasticity of the dough. Glutenin in wheat flour gives gluten good elongation, and gliadin gives gluten good elasticity (Diego and Alba, 2020). The energy value represents the total energy it takes to stretch the dough from the beginning until it breaks; a higher energy represents a stronger dough (Zhang *et al*., 2016). The addition of non-gluten flour such as WQF will dilute the gluten protein network, and cannot form a network that is strong enough to finish the latter process such as fermentation and heating, especially for a higher amount addition of WQF.

Textual properties of steam bread made by different mixed flour

Texture is a reliable way to evaluate the quality of steamed bread, and its reproducibility is better than sensory evaluation. The textual properties of steam bread made by different mixed flour are shown in Table 3. The hardness of steamed bread made by different mixed flour significantly increased with increasing WQF addition. The highest hardness (18.53 ± 4.13 N) was obtained in sample Q50 (wheat flour containing 50% WQF) and the lowest (12.95 ± 0.34 N) in sample C. The springiness value represents the change of elasticity of steam bread after adding WQF. The springiness value of steam bread showed a significant decrease with increasing addition of WQF in the mixed flour. The chewiness of steam bread exhibited a significant increase with increasing addition of WQF in mixed flour. The increase in chewiness makes the steam bread firmer (Putra and Abdillah, 2021). However, there was no significant effect on cohesiveness when WQF was added into wheat steam bread. This might have been due to the complex interaction of starch, protein, and lipids in quinoa flour, which can form high molecular complexes that may heighten the gluten network strength (Lu *et al*., 2009; Huang *et al*., 2022). In addition, the cross-section structures of the steamed bread samples Q30, Q40, and Q50 were more compact than that of samples Q20 and Q10, which meant that the steam bread made by mixed flour containing less than 20% WQF had acceptable product textural quality. The fine WQF interior could form a compact structure with wheat flour in the steam bread when it was added with more than 30% WQF.

Table 3. Textual properties of steam bread made by different mixed flour.

Sample	Hardness (N)	Springiness (mm)	Chewiness (mJ)	Cohesiveness
C	12.95 ± 0.34^{a}	3.90 ± 0.26^{d}	33.90 ± 1.16^{a}	0.84 ± 0.02^{a}
Q10	13.90 ± 0.26^{b}	3.50 ± 0.10^{c}	37.16 ± 1.46^{b}	0.83 ± 0.01^{a}
Q20	15.61 ± 1.59^{c}	3.34 ± 0.04^{bc}	45.33 ± 4.86^{cd}	0.83 ± 0.02^{a}
Q30	15.56 ± 1.65^{c}	3.21 ± 0.04^{b}	42.05 ± 5.43^{c}	0.82 ± 0.01^{a}
Q40	16.06 ± 1.47^{cd}	3.12 ± 0.06^{ab}	46.34 ± 5.29^{cd}	0.82 ± 0.01^{a}
Q50	18.53 ± 4.13^{d}	3.07 ± 0.20^{a}	48.09 ± 4.67^{d}	0.81 ± 0.02^{a}

Data are mean ± standard deviation of three replicates ($n = 3$). Means in the same column with different lowercase superscripts differ significantly ($p < 0.05$). C: wheat flour without WQF; and Q10 - Q50: wheat flour with 10 - 50% addition of WQF.

Conclusion

The present work revealed that the addition levels of WQF into wheat flour could significantly change the water-soluble index, swelling power, dough rheological behaviour, and steam bread textural property of mixed flour. The increased addition of WQF decreased the water-soluble index and swelling power of mixed flour. The dough rheology and steam bread textural properties indicated that the higher level of WQF addition (30 - 50%) would dilute the gluten network formed in the mixed flour dough, which mainly determine the texture and consumer acceptance of the steam bread. In view of the practical point, the maximum addition level of WQF was 20% when making a quinoa-wheat steam bread without any food additives. However, if the purpose of quinoa uses in steam bread making is the increase in the quinoa protein nutritive value, the steam bread with high quinoa flour may be made added with some appropriate food additives.

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