

Understanding the quality changes and underlying mechanism of wheat-stewed dough during storage

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Abstract

This study investigated the quality changes and their underlying mechanisms in wheat-stewed dough during storage at 4°C for various durations. Total plant count (TPC), pH, water activity (A_w), water distribution, texture properties, brightness (L^*), microstructure; contents of free sulfhydryl groups (SH), disulfide bonds (S–S), glutenin macropolymers (GMP), secondary protein structure, and turbidity were evaluated. With prolonged storage time, the TPC of wheat-stewed dough increased by 8.53%, whereas pH and L^* decreased gradually, with increase in free water content. On the first day of storage, A_w was the highest, whereas pH decrease fastest at 1.47%. On the third day of storage, maximum breaking distance (119.25 mm) took place. Conversely, the contents of S–S bonds, GMP, and β -sheets exhibited an initial increase, followed by a decrease. The β -sheet content peaked on the fifth day (28%), coinciding with the lowest contents of S–S bonds and random coils. GMP content transitioned from accumulation to degradation on fifth day. The turbidity of noodles also reached its minimum on the fifth day. On the seventh day of storage, hardness, springiness, cohesiveness, and recovery of wheat-stewed dough decreased by 34.40%, 16.22%, 42.32%, and 28.58%, respectively. Based on the changes in S–S bond breakage, GMP depolymerization, β -sheet transformation, and turbidity, the critical point of dough proofing was established in 5 days.

Keywords: fresh wet noodles; low-temperature storage; quality changes; wheat-stewed dough

Introduction

Noodles have been popular in China since ancient times. Noodles mainly consists of a basic recipe of flour, water, and salt, which are then shaped by kneading, proofing, rolling, and cutting into strips (Chen *et al.*, 2024). Noodles are one of the main flour-based products consumed in China, Japan, and South Korea (Li *et al.*, 2020, Xu *et al.*, 2019). According to storage requirements, noodles are classified as dried and fresh wet noodles. Fresh wet noodles are made when flour is processed

into dough and cut into strips of appropriate size and packaged immediately. They typically have a moisture content of approximately 28–32% with a smooth, chewy texture (Chen *et al.*, 2023). Stewed noodles, as a typical food made from Chinese handmade fresh wet noodles, mainly consist of high-gluten flour and are produced through the process of ‘kneading and resting the dough three times each’ (Gu *et al.*, 2024). As a common practice in Chinese restaurants, the prepared stewed dough is left to rise for a certain period, then cooked and sold on the spot. However, when stored at room temperature,

the dough undergoes browning because of its high moisture and rich nutrient content. The main external manifestations are the darkening of the surface color and irregular color distribution, which diminish the edibility of noodles (Wang *et al.*, 2023a). Compared with storing at room temperature, low-temperature storage could lower water activity (A_w) and reduce the activity of both microorganisms and enzymes, thus prolonging the shelf life of noodles (Kondakci *et al.*, 2015). Yan *et al.* (2012) studied the effects of storage at 25°C, 4°C, and -18°C on the quality of fresh wet noodles and found that storage at -18°C sufficiently retained the quality of noodles, even after 8 days of storage. Generally, the quality of the noodles remained good with storage under 4°C. However, long-term frozen storage can cause detrimental effects, including mechanical damage caused by ice crystals, moisture migration, and yeast inactivation (Liu *et al.*, 2022).

Although low temperatures can maintain the edible quality of fresh wet noodles to a certain extent, the quality of noodles nevertheless changes. Furthermore, the dough would still be rising during the early stage of storage. Several food additives are used to improve noodle quality. Wang *et al.* (2015) found that adding 2%–3% of gluten could improve the tensile strength of wheat-stewed dough and significantly increased the sensory score, hardness, adhesiveness, and chewiness of stewed noodles. Yao *et al.* (2024) found that thymol could inhibit the growth of spoilage bacteria and reduce cooking loss rate of fresh wet noodles. Furthermore, a composite improver comprising chitosan, nisin, and tea polyphenols can extend the shelf life of fresh wet noodles from 12 h to 48 h (Ma *et al.*, 2024).

In a previous preliminary study, we investigated extruded wheat bran and the effects of adding gluten, glucose oxidase, or guar gum on the quality of bran-fortified stewing noodles (Li *et al.*, 2022). We found that the bran-fortified stewing noodles had better tensile characteristics, brightness, and sensory scores if the wheat gluten, glucose oxidase, and guar gum contents were 6.67%, 28 mg/kg, and 0.22%, respectively (Li *et al.*, 2024). However, the quality changes of wheat-stewed dough containing these additives during storage at 4°C remained unclarified. Moreover, few studies have specifically investigated the low-temperature storage of wheat-stewed dough and stewed noodles. We hypothesized that low-temperature storage would maintain dough quality up to a critical proofing point identifiable by biochemical and textural markers. Therefore, this study investigated the quality changes and underlying mechanisms in improved stewed dough during storage at 4°C for 0, 1, 3, 5, and 7 days to determine the critical point of dough proofing. The findings of this study would provide a theoretical basis for quality control, storage, and transportation of fresh wet noodles.

Materials and Methods

Materials

High-gluten wheat flour, comprising 11.46% protein and 13.65% water, was purchased from the Yihai Kerry Arawana Holdings Co. Ltd. (Shanghai, China). Wheat bran was supplied by Sanjie Co. Ltd. (Wuhan, China). Gluten powder, glucose oxidase (100,000 units/g), and guar gum were supplied by Henan Wanbang Chemical Technology Co. Ltd. (Zhengzhou, China). Iodized refined salt (Hubei Salt Industry Group Co. Ltd., Shanghai, China) was obtained from a local supermarket in Wuhan, China.

Preparation of samples

Extruded wheat bran

Extruded wheat bran was prepared as described by Li *et al.* (2022). A twin-screw extruder (FMHE-24 type; Hunan Fuma Food Engineering Technology Co. Ltd., Hunan, China) was used. The feed moisture content, feeding speed, and rotation speed were 17%, 17 kg/h, and 160 rpm, respectively. Temperatures of heating zones were maintained at 60°C, 90°C, 120°C, 140°C, and 130°C. The extrudate was placed in an oven (DHG-9240A; Shanghai Jinghong Laboratory Equipment Co. Ltd., Shanghai, China) and dried at 40°C for 24 h. Then, it was cooled to 25°C, crunched, and passed through an 80-mesh sieve.

Wheat-stewed dough and stewed noodles

The mixing flour (300 g) included 6% extruded wheat bran over 80 mesh, 6.67% gluten, 28-mg/kg glucose oxidase, 0.22% guar bean gum, and high-gluten wheat flour. The optimal compounding ratio of the three improvers was determined through preliminary quality enhancement experiments on wheat-stewed dough (Li *et al.*, 2024). This involved evaluating wheat-stewed dough based on tensile properties, color characteristics, and sensory scores, using single-factor testing, response surface methodology optimization, and a comprehensive weighted scoring method. The wheat-stewed dough was prepared as described by Li *et al.* (2024). Mixed flour (300 g) was poured into an automatic mixer (SPI-11, VMI, Montaigu-Vendee, France), followed by 153-g water and 6-g salt. The ingredients were stirred at a constant speed (100 revolutions/min) for 10 min until the powder was blended completely and a smooth dough was formed. The dough was kneaded into cylindrical strips with a diameter of 25 mm, height of 20 mm, and weight of 30 g. The dough strips were arranged in a proofing box for proofing, performed thrice, and rolling, performed twice. The proofing conditions were as follows: temperature, 30°C; humidity, 80%; and duration, 30 min. For the

first rolling, the roller width was 5 mm, while for the second rolling, it was 3 mm. Rolling was performed continuously for five times for both first and second rollings.

The prepared wheat-stewed dough was cut into noodles with a width of 2 cm, thickness of 1.2 mm, and length of 10 cm.

Low-temperature storage

The wheat-stewed dough and fresh wet noodles were placed in food-grade trays, covered thoroughly with plastic wrapper, and stored in a refrigerator at 4°C for 0, 1, 3, 5, and 7 days. To avoid temperature fluctuations in the refrigerator, only experimental samples of this study were stored in the 4°C compartment for storage period. The sampling process was conducted by minimizing door opening range and maximizing sampling speed while guaranteeing that no other personnel would open the refrigerator.

Determination of total plant count (TPC)

The TPC of wheat-stewed dough was determined according to the method described by Xing *et al.* (2021). Samples (20 g) were stretched and mixed with 225 mL of 0.85% sterile physiological saline. Then the mixture was homogenized for 60 s using a stomacher (Lab-b Lender 400; Seward Laboratory, China). A series of dilutions was prepared with 0.85% sterile physiological saline, from which 1 mL was collected and transferred onto a sterile plate count agar plates for TPC detection. The plates were incubated at 36°C for 48 ± 2 h.

Measurement of pH

Wheat-stewed dough (10 g) was placed in a sterile homogenization bag and added with 90-mL deionized water. The sealing mouth was pressed shut, and the dough was homogenized for 60 s using a homogenizer (JX-05, Shanghai Jingxin Industrial Development Co. Ltd., Shanghai, China). The pH value was determined using a pH meter (ST5000, Ohaus Instruments Co. Ltd., Changzhou, Chang). pH calculations were calibrated using distilled water before measuring the pH (Hong *et al.*, 2021).

Determination of texture properties

The texture properties of wheat-stewed dough were determined using a texture analyzer (TA-XTPlus; Stable Micro Systems Ltd. London, UK). Wheat-stewed dough

was cut into 2.5 cm × 2.5 cm squares (mass difference ≤ 0.1 g). Tensile tests were performed with P/45 probe at pretest, test, and post-test speeds of 1 mm/s, 0.2 mm/s, and 1 mm/s, respectively. The run program was set up for a trigger force of 5.0 g, the strain was set at 50%, and the interval time was 5 s (He *et al.*, 2018). Each sample was tested for 10 times.

A Surface Plasmon Resonance (SPR) probe was used to determine tensile properties. The optimal test conditions were as follows: pretest speed, 1.0 mm/s; test speed, 1.0 mm/s; post-test speed, 10 mm/s; and distance, 160 mm. Each sample was tested for 10 times (Shao *et al.*, 2019).

Determination of brightness

The color of wheat-stewed dough was measured using a colorimeter (CS-10; Hangzhou Chroma Technology Co. Ltd., Hangzhou, China). Each sample of stewed dough was cut into three pieces. The upper, middle, and lower pieces were measured for three times and for nine times in parallel. The L* value obtained indicated the degree of brightness.

Determination of water activity

Sample's A_w was measured using LabMaster-Aw (Novasina, Lachen, Switzerland). Wheat-stewed dough was cut into 1-g pieces with a particle size of approximately 1–2 mm. The optimal test conditions were as follows: temperature, 25°C and relative humidity (RH), 75%. After the instrument was fully balanced, each sample was measured for three times (Allan *et al.*, 2019).

Determination of water distribution

Wheat-stewed dough was flattened into a circle with a diameter of 3.5 cm and weighing approximately 3.0 g (mass difference ≤ 0.1 g). It was wrapped with a special nuclear magnetic film and quickly placed into a 40-mm diameter low-field nuclear magnetic resonance analyzer tube (Q001, Suzhou Niumai Analytical Instruments Co. Ltd., Suzhou, China) with the following measurements: Sweep width (SW) = 200 kHz; Time window (TW) = 1,000 ms; Time domain (TD) = 59,996; Echo time (TE) = 0.10 ms; Echo Count (EC) = 3,000; and Number of scans (NS) = 8 (Yan and Lu, 2021).

Determination of free sulfhydryl group (SH) and disulfide bond (S–S) contents

The contents of free SH group and S–S bonds were measured as described by Sun *et al.* (2021) with slight

modifications. The wheat-stewed dough was dried in a vacuum freeze-drier (EYELA, Tokyo, Japan), crushed into powder, and passed through a 0.150-mm sieve. Prepared powder (50 mg) was dissolved in 1-mL buffer (0.086-M Tris, 0.092-M glycine, 0.004-M ethylenediaminetetraacetic acid [EDTA], pH 8.0), added with 4.7-g guanidine hydrochloride, and further diluted to 10 mL with buffer.

The free SH content was determined by mixing together 1 mL of the prepared solution, 4 mL urea–guanidine hydrochloride solution (8-M urea and 5-M guanidine hydrochloride), and 0.05-mL 5,5'-dithio-2-nitrobenzoic acid (DTNB; 4% w/v in buffer). The absorbance of the mixture was measured at 412 nm. To determine total SH content, 1 mL prepared solution was added to 4-mL urea–guanidine hydrochloride solution and 0.05-mL 2-mercaptoethanol. The mixture was reacted for 1 h and centrifuged at a rotational speed of 5,000 rpm for 10 min. Supernatant was discarded and precipitate was washed twice with 5 mL of 12% trichloroacetic acid and centrifuged at 5,000 rpm for 10 min. The precipitate was dissolved in 10 mL of 8 mol/L urea; then it was added with 0.08-mL DTNB with a mass concentration of 4 mg/mL. A 1-mL aliquot of this solution was collected and added with 5 mL buffer solution. The absorbance of the mixture was measured at 412 nm. The SH and S–S contents were calculated according to Equations 1 and 2, as follows:

$$\text{SH} \left(\frac{\mu\text{mol}}{\text{g}} \right) = 73.53 \times A_{412} \frac{D}{C}, \quad (1)$$

where A_{412} is the absorbance of the sample at 412 nm; C is the protein concentration of samples (mg/mL); and D is the dilution coefficient.

$$\text{SS} \left(\frac{\mu\text{mol}}{\text{g}} \right) = \frac{N_1 - N_2}{2}, \quad (2)$$

where N_1 is the volume of total SH groups, and N_2 is the volume of free SH groups.

Determination of secondary protein structure of wheat-stewed dough

The secondary protein structures of gluten were determined using a Fourier transform infrared (FTIR) spectrometer (IS-10, Thermo Nicolet Corp., Madison, WI, USA). The sample was combined with potassium bromide (mass ratio 1:100) at a scanning range was 400–4,000 cm^{-1} , with a total of 32 scans. The data were processed using the Omnic 8.0 software (Thermo Fisher Scientific, Madison, WI, USA) and Peakfit 4.12 (Systat Software, San Jose, CA, USA). The absorbance

peak positions and areas in the amide I region (1,600–1,700 cm^{-1}) were determined using Fourier self-deconvolution and second derivative methods. The secondary structure components of the samples were calculated using the ratio of the corresponding area to the total amide I band area. The test was performed at least in triplicate.

Determination of glutenin macropolymers (GMP)

The sample (0.5 g) was dispersed in 10 mL of 1.5% sodium dodecyl sulfate (SDS) extraction solution, and the protein was extracted by constant temperature oscillation at 30°C for 1 h. The extract was centrifuged at 9,500 $\times g$ at 20°C for 15 min. The supernatant was removed, and the extraction process was repeated. Precipitate's protein content was determined using the Kjeldahl method for approximate GMP content. Each group of samples was measured thrice in parallel (Weegels *et al.*, 1996).

Scanning electron microscopy (SEM)

The wheat-stewed dough was freeze-dried, cut to an appropriate size, and pasted onto the sample stage. Observed under a scanning electron microscope (EVO MA 15, Carl Zeiss AG, Jena, Germany) after ion sputtering and gold spraying. The section magnification was 500 \times .

Determination of turbidity in stewed noodles

Stewed noodles (10 g) were placed in 250-mL water, boiled for an optimal time, removed, and then rinsed thrice with water. The noodle soup was cooled to room temperature and transferred into a 250-mL volumetric bottle for constant volume mixing. The light absorption value was determined at 460 nm with an ultraviolet spectrophotometer (UV-1800PC, Shanghai Mapada Co. Ltd. Shanghai, China) as described by Wang *et al.* (2023b).

Statistical analysis

Data were analyzed by one-way analysis of variance, followed by Duncan's multiple range test using the SPSS 17.0 Statistical Software Program (SPSS Incorp., Chicago, IL, USA). Probability $p < 0.05$ was considered statistically significant. The data were plotted using the Origin2019b software (OriginLab Inc., USA). Results were expressed as mean \pm standard deviation (SD) of triplicate experiments.

Results and Discussion

Analysis of TPC and pH

Changes in the TPC and pH of wheat-stewed dough during storage at 4°C are shown in Figure 1. The TPC showed an increasing trend with prolonged storage period. On the seventh day, the TPC increased by 8.53% at 3.80 lg CFU/g. Microorganisms in wheat-stewed dough were mainly contained in wheat flour and introduced during the production process (Jiang, 2019). Part of the flour was replaced by extruded bran, which reduced the survival rate of microorganisms after extrusion, thereby reducing the number of microorganisms introduced into the raw material powder. During first 3 days of storage, the TPC increased slowly because of the inhibitory effect of low temperature on growth of microorganisms as well as competition between microorganisms for the same nutrients. On the fifth day of storage, the TPC increased faster; this could be due to the emerging dominance of some microorganisms in dough (Gram *et al.*, 2002). Ghaffar *et al.* (2009) recommended 6 lg CFU/g as the cutoff point for the level of incipient spoilage in fresh noodles. According to NY/T 1512-2014 'Green Food—Uncooked Processed Food Made of Cereal', the TPC limit is $\leq 3.0 \times 10^5$ CFU/g (equivalent to 5.45 lg CFU/g). Exceeding this threshold indicates that fresh wet noodles have reached their shelf-life limit. Under experimental conditions, the TPC of stewed dough samples was below this threshold, demonstrating compliance with the safety standards for microbial indicators in fresh noodle consumption.

Potential of Hydrogen (pH) is a key indicator of food spoilage. In the study, the pH showed a decreasing trend

with prolonged storage period, and the highest decrease rate on the first day was 1.47%. On the last day of storage, the pH of wheat-stewed dough decreased from 6.25 to 6.01. The change in pH was related to microbial metabolism. During storage, microorganisms continued to grow and metabolize via carbohydrate metabolism in dough to produce acidic substances, thereby decreasing the pH (Huang *et al.*, 2022). During prolonged storage, the pH did not change significantly, which might be ascribed to the accumulation of acidic substances in stewed dough combined with low temperature, thereby restraining the growth and metabolism of microorganisms. Consequently, the production of acidic substances and change in pH decreased (Li *et al.*, 2011). pH decreased significantly on the seventh day because of the increased number of microorganisms in dough.

Analysis of water activity (A_w) and water distribution

The A_w of wheat-stewed dough during storage is shown in Table 1. A_w increased significantly on the first day of storage, but no significant changes were observed with increasing storage period. Early during storage, the number of microorganisms was relatively low, with increased free water content. With time, the number of microorganisms proliferates significantly, consuming the moisture present in dough, resulting in decreased A_w . The quality and stability of fresh noodles are closely related to the moisture content (Carini *et al.*, 2010). T_{21} , T_{22} , and T_{23} represented the relaxation time of bound, weakly bound, and mightily bound water (Chen *et al.*, 2020). The transverse relaxation time reflected the binding capacity with water, and a shorter relaxation time indicated a stronger binding capacity with water (Liu *et al.*, 2019).

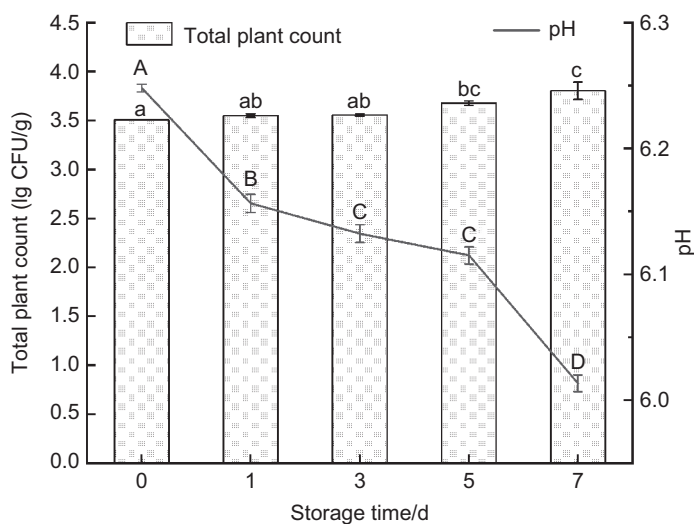


Figure 1. Total plant count and pH of wheat-stewed dough during storage. Different superscripted alphabets indicate significant differences ($p < 0.05$).

As shown in Table 1, with increasing storage time, T_{21} , T_{22} , T_{23} , and A_{22} of wheat-stewed dough showed a decreasing trend, whereas A_{21} and A_{23} showed an increasing trend. These patterns indicated that the weakly bound water was converted to strongly bound and free water, and the gluten network structure was strengthened during storage. These changes showed that the dough structure was adequately maintained and was constantly proofing during the storage period. Moisture in the dough was tightly bound to the gluten network, gradually enhancing water-binding capacity.

Analysis of texture and brightness properties

The textural properties of wheat-stewed dough, namely, hardness, springiness, adhesiveness, recovery, and break distance during storage are shown in Table 2. The hardness, springiness, cohesiveness, and recovery values decreased by 34.40%, 16.22%, 42.32%, and 28.58%, respectively, similar to the results obtained by Huang *et al.* (2022). In the early stage of storage, the reproduction rate of microorganisms was high, with a large number of microorganisms affecting protein peptide chain and destroying gluten network structure. Furthermore, the hydrolase generated by microbial metabolism may catalyze the decomposition of high molecular weight proteins and destroy

protein structure, thereby diminishing the texture characteristics of dough (Baik *et al.*, 1994). In the later stage of storage, the contents of S–S bond and β -folding in dough decreased, reducing the strength of gluten network and its ability to wrap starch particles, thereby reducing the quality of texture properties (Li, 2014). The breaking distance of wheat-stewed dough increased initially and then decreased, reaching maximum value on the third day of storage and significantly decreasing on the fifth day of storage ($p < 0.05$). This may be caused by S–S bonds, which serve as primary covalent ‘scaffolding’ within gluten network. Their increase enhances protein connectivity, creating a structure that efficiently resists and recovers from deformation and requires significant force and elongation to break. Conversely, loss of S-S bonds dismantles this scaffolding, leading to a network incapable of elastic recovery that ruptures easily under minimal extension (Wang *et al.*, 2023c).

Browning is an important process affecting the storage and palatable quality of fresh wet noodles. The color of noodles directly affects consumers’ judgment on noodle quality (Morris, 2013). The L^* value of wheat-stewed dough decreased significantly on the first day of storage, indicating that browning begins on the first day of storage. However, the L^* value did not change significantly with further increase in storage period, signifying that

Table 1. Water activity (A_w) and water distribution of wheat-stewed dough during storage.

Storage time/d	A_w	T_{21} (ms)	T_{22} (ms)	T_{23} (ms)	A_{21} (%)	A_{22} (%)	A_{23} (%)
0	0.94 ± 0.00 ^a	0.14 ± 0.00 ^a	12.33 ± 0.00 ^a	333.52 ± 68.76 ^a	7.63 ± 0.36 ^c	92.31 ± 0.34 ^a	0.06 ± 0.03 ^d
1	0.95 ± 0.00 ^b	0.11 ± 0.01 ^b	10.72 ± 0.00 ^b	145.39 ± 6.60 ^b	12.58 ± 0.14 ^a	86.39 ± 0.17 ^d	1.03 ± 0.04 ^{a,b}
3	0.95 ± 0.00 ^b	0.10 ± 0.00 ^b	10.72 ± 0.00 ^b	159.58 ± 7.59 ^b	9.73 ± 0.47 ^b	89.13 ± 0.49 ^b	1.14 ± 0.04 ^{a,b}
5	0.95 ± 0.00 ^b	0.10 ± 0.00 ^b	10.72 ± 0.00 ^b	83.20 ± 3.78 ^b	11.68 ± 0.53 ^a	87.70 ± 0.38 ^c	0.62 ± 0.16 ^c
7	0.95 ± 0.00 ^b	0.10 ± 0.00 ^b	9.79 ± 0.47 ^c	79.42 ± 3.78 ^b	10.18 ± 0.38 ^b	88.98 ± 0.37 ^b	0.84 ± 0.05 ^{b,c}

Note: Different superscripted alphabets in the same column indicate significant differences ($p < 0.05$). Data are expressed as mean ± standard deviation (SD).

Table 2. Texture and brightness of wheat-stewed dough during storage.

Storage time (d)	Hardness (g)	Springiness	Cohesiveness	Adhesiveness (g)	Recovery	Break distance (mm)	L^* value
0	3577.86 ± 29.38 ^a	0.37 ± 0.01 ^a	0.44 ± 0.02 ^a	1591.70 ± 42.91 ^a	0.07 ± 0.00 ^a	100.66 ± 3.37 ^b	70.46 ± 0.41 ^a
1	3409.37 ± 87.71 ^a	0.34 ± 0.01 ^a	0.42 ± 0.01 ^{a,b}	1445.83 ± 42.30 ^b	0.07 ± 0.00 ^{a,b}	112.92 ± 3.54 ^{a,b}	68.56 ± 0.30 ^b
3	2584.02 ± 91.02 ^b	0.36 ± 0.00 ^a	0.46 ± 0.01 ^a	1176.75 ± 10.56 ^c	0.06 ± 0.00 ^{b,c}	119.25 ± 3.58 ^a	68.59 ± 0.16 ^b
5	2378.45 ± 62.27 ^{b,c}	0.31 ± 0.00 ^b	0.42 ± 0.02 ^{a,b}	998.70 ± 24.02 ^d	0.06 ± 0.00 ^{c,d}	117.51 ± 1.65 ^a	68.62 ± 0.21 ^b
7	2347.15 ± 44.05 ^c	0.31 ± 0.02 ^b	0.39 ± 0.02 ^b	918.06 ± 68.58 ^d	0.05 ± 0.00 ^d	115.02 ± 6.87 ^a	68.16 ± 0.16 ^b

Note: Different superscripted alphabets in the same column indicate significant differences ($p < 0.05$). Data are expressed as mean ± standard deviation (SD).

the color could be maintained, and browning could be inhibited to a certain extent. Studies have shown that when the L^* value of noodles was more than 45, it did not affect people's perception of noodle quality and noodles' shelf life (Wang, 2000). Thus, if the L^* value of dough was >60 during storage, the perceived quality of noodles was not affected.

Analysis of scanning electron microscopy

The microstructure of wheat-stewed dough is shown in Figure 2. The continuous part of SEM shows the protein network of dough. Here, the initial gluten network structure can better wrap starch particles. On the third day of storage, the gluten network structure became denser, indicating that the dough was still rising and the gluten network was still strengthening. On the fifth day of storage, small holes appeared on the surface of dough, and up to the last day of storage, more starch particles were exposed and the visible gluten network structure became more discontinuous and porous. This was because the strength of gluten network and consequently its ability to wrap starch granules decreased during storage, causing crumbling of starch granules (Li et al., 2024).

Analysis of S–S bond and SH group

S–S bonds are important for the formation of gluten network in dough. S–S bonds, SH groups, and mutual

transformation between them have a significant impact on dough quality. When S–S bonds are transformed into SH groups, the gluten network structure becomes loose, causing a decrease in the quality of dough and flour products. Therefore, the strength of gluten network and protein stability is characterized by measuring S–S bond and SH group contents (Xiao et al., 2021).

As shown in Figure 3, the SH group content showed an increasing trend with increasing storage period, indicating that the degree of cross-linking of S–S bond in dough decreased during storage, which adversely affected the tensile properties of dough. The S–S content increased initially but then decreased. This was because during the early stage of storage, the dough was still rising, promoting S–S cross-linking S–S and the formation of a more compact gluten network structure, thereby improving the tensile characteristics of dough. However, during the later stage of storage, the S–S content decreased continuously. This was because the pH of dough during the later stage of storage decreased, and the ionization of SH group, which generates $-S^-$ anions ($-S^-$), was inhibited to a certain extent, reducing the $-S^-$ content and its participation in the formation of S–S bond and the exchange reaction rate between S–S bond and SH group (Koehler, 2003). Therefore, the formation of S–S bonds decreased, which weakened protein network integrity, thus weakening the formation of gluten network and reducing the tensile characteristics of dough.

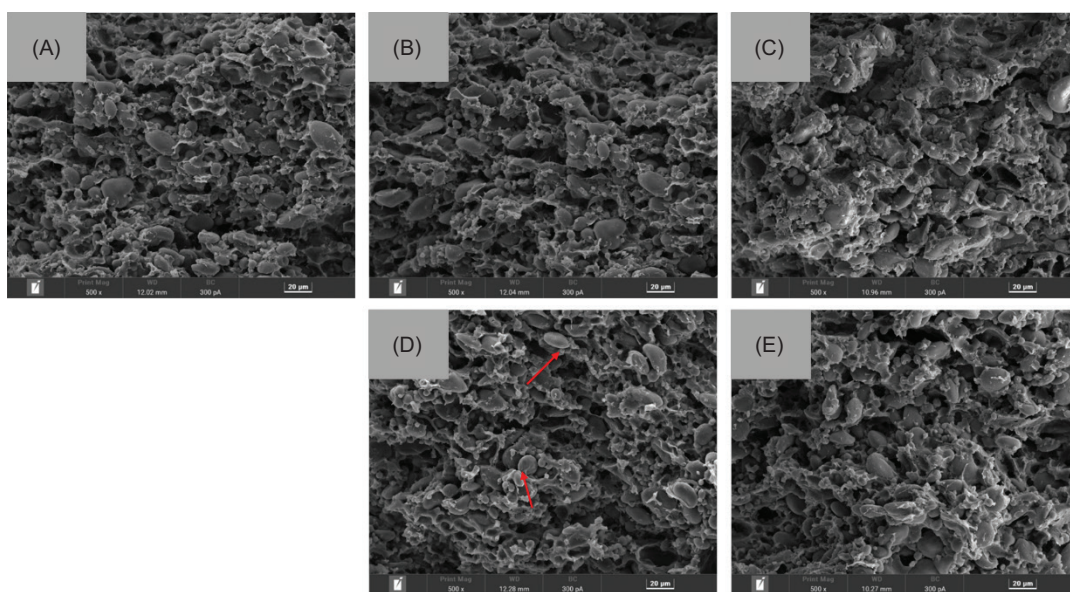


Figure 2. Scanning electron microscopy (SEM) of wheat-stewed dough during storage. (A–E) Images of dough structure on 0, 1, 3, 5, and 7 day of storage.

Analysis of protein secondary structure

According to the position of spectral peak, the protein structure was divided into four types by fitting the FTIR spectroscopy data. The wavelength ranges of β -folding, random curling, α -helix, and β -turn are mainly found in 1620–1640, 1640–1650, 1650–1658, and 1660–1700 cm^{-1} , respectively (Huang *et al.*, 2023). Of these, the β -folding and α -helix have highly ordered structures, which increased protein disorder, β -turn, and random curling structures (Niu *et al.*, 2018). Changes in the secondary structure of stewed dough protein during low-temperature storage are shown in Figure 4.

During storage, the β -sheet content showed an overall downward trend, the random curling content showed an overall increasing trend, and the α -helix and β -turn contents showed no observable changes, indicating unfolding of the ordered β -sheet structures into less ordered random coils.

Analysis of glutenin macropolymers

The gluten network structure is mainly composed of wheat glutenin and gliadin. As a component of glutenin, the GMP content reflects the degree of aggregation of

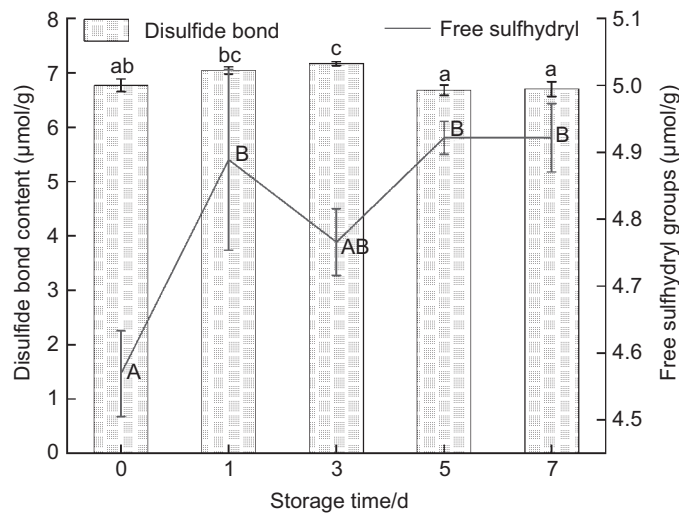


Figure 3. S–S disulfide bond and free sulfhydryl (SH) group contents of wheat-stewed dough during storage. Different superscripted alphabets indicate significant differences ($p < 0.05$).

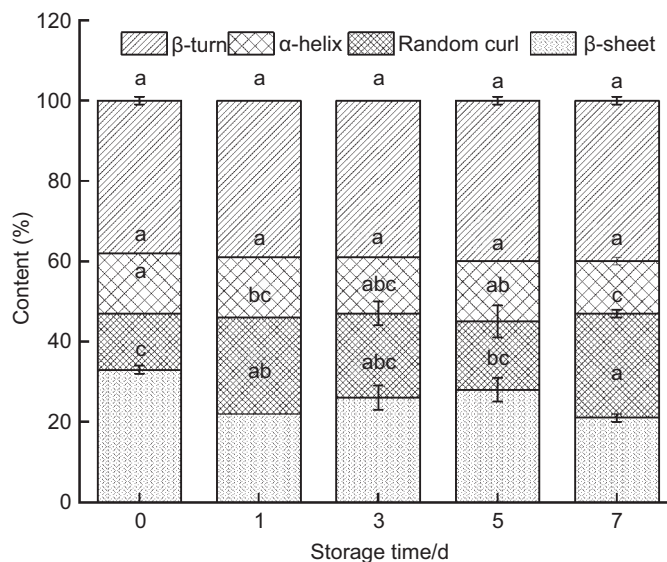


Figure 4. Secondary protein structure of wheat-stewed dough during storage. Different superscripted alphabets indicate significant differences ($p < 0.05$).

glutenin (Su *et al.*, 2023). Changes in the GMP content of wheat-stewed dough during low-temperature storage is shown in Figure 5. With increasing storage period, the GMP content of wheat-stewed dough increased initially but then decreased, with the maximum value obtained on the third day of storage. This was consistent with the change in S–S bond content, confirming that the dough had the best tensile characteristics on third day. This behavior was primarily caused by the gradual shrinkage and subsequent aggregation of proteins into a larger polymer when the dough rose in the early stage of storage. This indicates an increase in the degree of cross-linking of –S–S–,

which increased GMP content and promoted the formation of a more continuous and dense gluten network structure. In the later stage of storage, microorganisms and proteases in dough destroyed connections between protein subunits, reducing the degree of –S–S– cross-linking S–S (Wang *et al.*, 2012), thereby reducing the GMP content.

Analysis of turbidity

Change in turbidity during storage is presented in Figure 6. With prolonged storage period, the turbidity decreased

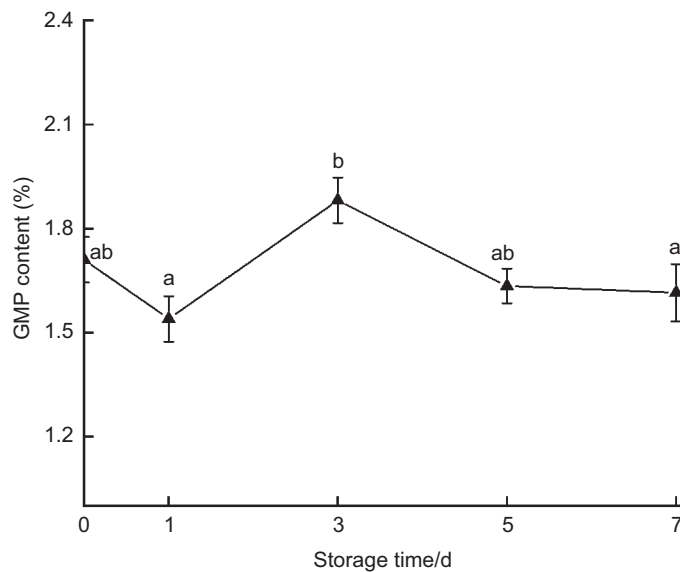


Figure 5. Glutenin macropolymer content of wheat-stewed dough during storage. Different superscripted alphabets indicate significant differences ($p < 0.05$).

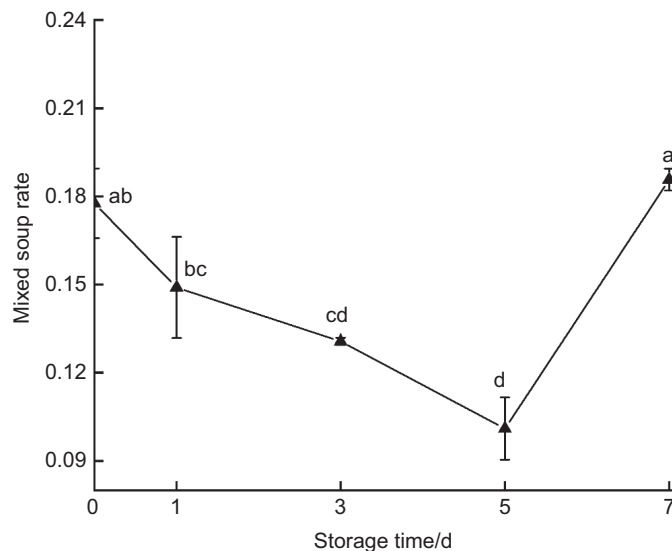


Figure 6. Turbidity of stewed noodles during storage. Different superscripted alphabets indicate significant differences ($p < 0.05$).

initially, then increased. The turbidity of stewed noodles was lowest on the fifth day of storage. Initially, turbidity decreased due to improved gluten cohesion. During the later stage of storage, the S–S and GMP contents in dough decreased, the number of microorganisms increased, the damage to the gluten network structure increased, with a large amount of starch dissolved into noodle soup during cooking, resulting in increased turbidity.

Conclusions

The present study explored the quality change mechanism and proofing critical point of wheat-stewed dough during storage at 4°C for 0, 1, 3, 5, and 7 days. The results indicated that with the prolongation of storage, the TPC of wheat-stewed dough increased gradually and lead to decreased pH from 6.25 to 6.01. On the first day, A_w increased significantly, but no significant changes occurred with increasing storage time ($p < 0.05$). With increased storage time, the bound water in wheat-stewed dough was released gradually, and the content of free water increased to 0.84%. Furthermore, the hardness, springiness, cohesiveness, and recovery decreased by 34.40%, 16.22%, 42.32%, and 28.58%, respectively. On the third day of storage, the maximum breaking distance (119.25 mm) occurred. Conversely, the contents of S–S bonds, GMP, and β -sheets exhibited an initial increase, followed by a decrease. The β -sheet content peaked on the fifth day (28%), coinciding with the lowest contents of S–S bonds and random coils. GMP content transitioned from accumulation to degradation on fifth day. The turbidity of noodles also reached its minimum on the fifth day. Moreover, holes began to appear on the surface of wheat-stewed dough, and the gluten network structure decreased gradually. These findings demonstrated that the quality of wheat-stewed dough was retained during storage at 4°C for 5–7 days. Based on the changes in S–S bond breakage, GMP depolymerization, β -sheet transformation, and turbidity, the critical point of dough proofing was established in 5 days.

Data Availability

The original data used to support the findings of this study are available from the first author and corresponding author upon request.

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Author Contributions

Xiwu Jia: supervision, and writing—review and editing. Xiaohua Luo: data curation, formal analysis, and writing. YiBo Li: investigation, methodology, data curation, and writing—original draft. Zhili Ji: supervision and review. Wangyang Shen: supervision and review. Hongjian Zhang: methodology and resources.

Conflict of Interest

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

References

- Allan, M.C., Grush, E.N., Rajwa, B.P., Butzke, C.E. and Mauer, L.J. 2019. Determination of the water activities of wines and spirits. *Food Anal. Methods*. 12(12):2753. <https://doi.org/10.1007/s12161-019-01632-2>
- Baik, B.K., Czuchajowska, Z. and Pomeranz, Y. 1994. Role and contribution of starch and protein contents and quality to texture profile analysis of oriental noodles. *Cereal Chem*. 71(4):315.
- Carini, E., Vittadini, E., Curti, E., Antoniazzi, F. and Viazzani, P. 2010. Effect of different mixers on physicochemical properties and water status of extruded and laminated fresh pasta. *Food Chem*. 122(2):462. <https://doi.org/10.1016/j.foodchem.2009.05.031>
- Chen, Q.Q., Li, X.L. and Zhang, H.M. 2024. Study on process optimization of saline-alkali fresh wet noodles. *Cereal Food Ind*. 31(04):23.
- Chen, Z.L., Wang, J.X., Li, X.C. and Su, K.R. 2023. Effects of curdlan on the quality of fresh wet noodles made from high- and low-gluten flours. *Food Res Dev*. 44(13):34.
- Chen, Y., Zhang, Y.F., Jiang, L., Chen, G.Y., Yu, J.J., Li, S.H. and Chen, Y. 2020. Moisture molecule migration and quality changes of fresh wet noodles dehydrated by cold plasma treatment. *Food Chem*. 328:127053. <https://doi.org/10.1016/j.foodchem.2020.127053>
- Ghaffar, S., As, A., Abu Bakar, F., Karim, R. and Saari, N. 2009. Microbial growth, sensory characteristic and pH as potential spoilage indicators of Chinese yellow wet noodles from commercial processing plants. *Am J Appl Sci*. 6(6):1059–1066. <https://doi.org/10.3844/ajassp.2009.1059.1066>
- Gram, L., Ravn, L., Rasch, M., Bruhn, J.B., Christensen, A.B. and Givskov, M. 2002. Food spoilage—interactions between food spoilage bacteria. *Int J Food Microbiol*. 78(1–2):79. [https://doi.org/10.1016/s0168-1605\(02\)00233-7](https://doi.org/10.1016/s0168-1605(02)00233-7)
- Gu, S.C., Liu, C., Zheng, X.L. and Guan, E.Q. 2025. Relationship between wheat flour quality and resistance to resting of stewed noodles dough. *Food Ferment Ind*. 51(14):159–166. (In Chinese)
- He, L.D., Guo, X.N. and Zhu, K.X. 2019. Effect of soybean milk addition on the quality of frozen-cooked noodles. *Food Hydrocoll*. 87:187–193. <https://doi.org/10.1016/j.foodhyd.2018.07.048>

- Hong, T.T., Zhao, Q.Y., Xu, D., Yuan, Y.R., Ma, Y., Wu, F.F. and Xu, X.M. 2021. Effect of heat-treated flour on the quality and storage stability of fresh noodles. *Food Sci Technol (LWT)*. 146:111463. <https://doi.org/10.1016/j.lwt.2021.111463>
- Huang, J.N., Qi, Y.J., Faisal Manzoor, M.F., Guo, Q. and Xu, B. 2022. Effect of superheated steam treated wheat flour on quality characteristics and storage stability of fresh noodles. *Food Control*. 133:108666. <https://doi.org/10.1016/j.foodcont.2021.108666>
- Huang, X.Q., Wang, N.J., Yu, M.F., Wei, S.W., Xu, D., Jin, Y.M., Xu, X.M. and Wu, F.F. 2023. Impact of glucose oxidase on characteristics of corn dough with different frozen storage times. *Int J Food Sci Technol*. 58(7):3876. <https://doi.org/10.1111/ijfs.16489>
- Jiang, D.H. 2019. Study on microbial control and quality-keeping of fresh wet noodles. Jiangnan University, Wuxi, China.
- Koehler, P. 2003. Effect of ascorbic acid in dough: reaction of oxidized glutathione with reactive thiol groups of wheat glutenin. *J Agric Food Chem*. 51(17):4954. <https://doi.org/10.1021/jf026061t>
- Kondakci, T., Zhang, J.W. and Zhou, W. 2015. Impact of flour protein content and freezing conditions on the quality of frozen dough and corresponding steamed bread. *Food Bioprocess Technol*. 8(9):1877. <https://doi.org/10.1007/s11947-015-1544-6>
- Li, M. 2014. Deterioration mechanisms of fresh noodles and the regulation Technology Thereof. Jiangnan University, Wuxi, China.
- Li, S.H., Tang, D., Liu, S.T., Qin, S.S. and Chen, Y. 2020. Improvement of noodle quality: the effect of ultrasonic on noodles resting. *J Cereal Sci*. 96:103089. <https://doi.org/10.1016/j.jcs.2020.103089>
- Li, Y.B., Yao, G.Q., Shen, W.Y., Wang, Z., Guo, C. and Jia, X.W. 2024. Optimizing the quality of bran-fortified stewing noodles using extruded wheat bran and improvers. *Ital J Food Sci*. 36(2):1. <https://doi.org/10.15586/ijfs.v36i2.2496>
- Li, Y.B., Yao, G.Q., Zhao, K.M., Shen, W.Y., Wang, Z., Fan, K. and Jia, X.W. 2022. Effects of extruded wheat bran on the physicochemical properties and edible quality of stewing noodles. *Cereal Chem*. 100(2):500. <https://doi.org/10.1002/cche.10633>
- Li, M., Zhu, K.X., Guo, X., Peng, W. and Zhou, H.M. 2011. Effect of water activity (aw) and irradiation on the shelf-life of fresh noodles. *Innov. Food Sci., Emerg. Technol*. 12(4):526. <https://doi.org/10.1016/j.ifset.2011.06.005>
- Liu, Q., Guo, X.N. and Zhu, K.X. 2019. Effects of frozen storage on the quality characteristics of frozen cooked noodles. *Food Chem*. 283:522. <https://doi.org/10.1016/j.foodchem.2019.01.068>
- Liu, H., Guo, X.N. and Zhu, K.X. 2022. Effects of freeze-thaw cycles on the quality of frozen raw noodles. *Food Chem*. 387:132940. <https://doi.org/10.1016/j.foodchem.2022.132940>
- Ma, H., Li, Y., Wu, J., Li, J.S. and Liu, C.J. 2024. Influence of composite biopreservatives on the preservation effect and quality changes of fresh wet noodles. *Sci Technol Cereals Oils Foods*. 32(03):125–131. <https://doi.org/10.16210/j.cnki.1007-7561.2024.03.013>
- Morris, C.F. 2018. Determinants of wheat noodle color. *J Sci Food Agric*. 98(14):5171. <https://doi.org/10.1002/jsfa.9134>
- Niu, M., Xiong, L.C., Zhang, B.J., Jia, C.H. and Zhao, S.M. 2018. Comparative study on protein polymerization in whole-wheat dough modified by transglutaminase and glucose oxidase. *Food Sci Technol (LWT)*. 90:323. <https://doi.org/10.1016/j.lwt.2017.12.046>
- NY/T 1512-2014. *Green food—Uncooked processed food made of cereal* [Standard]. Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2014. [in Chinese]
- Shao, L.F., Guo, X.N., Li, M. and Zhu, K.X. 2019. Effect of different mixing and kneading process on the quality characteristics of frozen cooked noodle. *Food Sci Technol (LWT)*. 101:583. <https://doi.org/10.1016/j.lwt.2018.11.078>
- Su, T., Liu, H.F., Li, F., Dai, M.Y. and Zhang, B. 2023. Review on the changes of glutenin macropolymer in wheat dough processing. *J Chin Inst Food Sci Technol*. 23(04):481.
- Sun, J., Chen, M., Hou, X.X., Li, T.T., Qian, H.F., Zhang, H., Li, Y., Qi, X.G. and Wang, L. 2021. Effect of phosphate salts on the gluten network structure and quality of wheat noodles. *Food Chem*. 358:129895. <https://doi.org/10.1016/j.foodchem.2021.129895>
- Wang, Z.C. 2000. *Grain, Oil and Food Quality Analysis*. China Light Industry Press, Beijing, China.
- Wang, L., Chen, J., Lu, Y.G. and Bian, K. 2015. Effects of gluten on dough rheological properties and quality of stewed noodles. *Food Sci Technol*. 06:182.
- Wang, R., Lin, J.T., Yue, Q.H., Song, A.Q., Song, X.Y. and Su, D.M. 2023a. Effect of microwave treatment on the browning and characteristics of fresh and wet noodles. *Mod Food Sci Technol*. 39(9):187.
- Wang, L.S., Yu, X.S., Wang, K.X., Huo, J.J., Ma, X.Q., Duan, Y.M., Xiao, Z.G. and Wang, P. 2023b. Insights into the modulation of the multi-scale structure of glutenin on the textural properties of reconstituted rice. *Innov Food Sci Emerg Technol*. 87:103405. <https://doi.org/10.1016/j.ifset.2023.103405>
- Wang, H., Zhang, J., Han, L., Cao, J., Yang, J., Zhang, Y. and Hu, B. 2023c. Calcium ion regulation of sodium alginate in pure buckwheat noodles shown by *in vitro* simulated digestion. *Front Nutr*. 9:1105878. <https://doi.org/10.3389/fnut.2022.1105878>
- Wang, X., Zhang, T.L. and Zhou, H.M. 2012. Research on the effects of microencapsulated glucose oxidase on the oxidation of dough. *J Chin Inst Food Sci Technol*. 27(07):17–41.
- Weegels, P.L., van de Pijpekamp, A.M., Graveland, A., Hamer, R.J. and Schofield, J.D. 1996. Depolymerisation and re-polymerisation of wheat glutenin during dough processing. I. Relationships between glutenin macropolymer content and quality parameters. *J Cereal Sci*. 23(2):103. <https://doi.org/10.1006/jcrs.1996.0010>
- Xiao, F., Zhang, X., Niu, M., Xiang, X.Q., Chang, Y.D., Zhao, Z.Z., Xiong, L.C., Zhao, S.M., Rong, J.H., Tang, C. and Wu, Y. 2021. Gluten development and water distribution in bread dough influenced by bran components and glucose oxidase. *Food Sci Technol (LWT)*. 137:110427. <https://doi.org/10.1016/j.lwt.2020.110427>
- Xing, J.J., Jiang, D.H., Guo, X.N., Yang, Z. and Zhu, K.X. 2021. Effect of dough mixing with slightly acidic electrolyzed water on the shelf-life and quality characteristics of fresh wet noodles. *Food Control*. 124:107891. <https://doi.org/10.1016/j.foodcont.2021.107891>

- Xu, M., Wu, Y., Hou, G.G. and Du, X.F. 2019. Evaluation of different tea extracts on dough, textural, and functional properties of dry Chinese white salted noodle. *Food Sci Technol (LWT)*. 101:456. <https://doi.org/10.1016/j.lwt.2018.11.066>
- Yan, Y.Q., Li, B.S. and Ruan, Z. 2012. Effects of storage methods and time on the quality of fresh cooked noodles. *Food Ferment Ind.* 38(07):132. <https://doi.org/10.13995/j.cnki.11-1802/ts.2012.07.035>
- Yan, H. and Lu, Q. 2021. Physicochemical properties of starch-wheat germ oil complex and its effects on water distribution and hardness of noodles. *Food Sci Technol (LWT)*. 135:110211. <https://doi.org/10.1016/j.lwt.2020.110211>
- Yao, Y.F., Qiu, X., Wang, L., Li, Y., Fang, M.C. and Qing, H.F. 2025. Effects of natural phenols and aldehyde on shelf life and quality of fresh wet noodles. *Food Ferment Ind.* 51(3): 182-189. <https://doi.org/10.13995/j.cnki.11-1802/ts.038969>