Performance of industrial dough mixers and its effects on noodle quality

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Abstract: The effects of different types of industrialized dough mixing units on the characteristics of noodle dough and noodle quality were investigated. The study involved four mixing units, including two horizontal mixers with double shafts and two continuous high-speed mixers. Of the four mixing modes, mixing mode I, which used a horizontal pin-mixer with a constant mixing speed, provided the worst performance. This finding was indicated by worse mixing uniformity and noodle quality, larger-sized dough crumbs, lower hardness and chewiness of cooked noodles, and lower sensory scores of both color and elasticity. Mixing mode II, which used a horizontal mixer with angled, large surface-area blades and adjustable-speed mixing, gave the best performance. The flour hydration was observed to be even, and smaller even-sized dough crumbs were formed. During boiling of the dried noodles, there was lower water uptake, less cooking loss, and the cooked noodles showed better stickiness scores with higher hardness and chewiness of TPA compared to the other mixing modes. Mixing mode III involved a vertical continuous high-speed mixer with a speed of 970 r/min and had better mixing uniformity compared to mixing mode IV, which involved a horizontal high-speed mixer and a higher mixing speed of 1440 r/min. No single mixer performed best over all three flours. Therefore, the final choice of mixing modes should be based on the major flour type used by the noodle manufacturer.

Keywords: industrial dough mixers, mixing speed, mixing performance, noodle quality
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1 Introduction

Noodles are a traditional staple food that enjoyed by great popularity in China, composing approximately 40% of the country's wheat consumption[1]. Favored types include dry noodles, fresh noodles, frozen noodles and instant noodles[2,3]. Mixing is a key step in noodle processing and strongly influences the performance in subsequent steps, particularly in the quality of the noodles. The primary aim in dough mixing was to distribute the ingredients rapidly and uniformly and hydrate the flour particles. Unlike traditional bread dough with a 50% to 60% moisture content, the noodle dough is much drier (30%-35% moisture) and in the form of a crumb with discontinuous gluten formation. Gluten formation is enhanced and more continuous after the next stage, which is called compounding, where two dough sheets feed into a single pair of rolls to form a single noodle sheet.

Currently, there are many types of dough mixing equipment used in the noodle manufacturing industry, including vertical, horizontal, one-shaft, double-shaft,

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continuous high-speed and vacuum mixing types. These types vary with respect to construction, capacity and mode of operation, leading to different mixing effects. However, there was no study on the efficiency and mixing effects of different industrial dough mixers, and many enterprises lack data support related to the choice of mixing equipment, which would restrict the rapid development of the noodle industry.

In traditional noodle production, batch-type dough mixers were commonly used, which allow good control on water addition and mixing time. However, more recently, horizontal mixers with double shafts, both constant and adjustable speeds, have become popular. Horizontal mixers also vary with respect to mixing blade type – either pins or angled, large surface area blades. It is generally considered that the special configuration of the large surface area blades causes the flour to move both vertically and horizontally in opposite directions at the same time, which is reported to ensure the uniformity and efficiency of mixing[4]. This conclusion, however, is currently lack of the support of experimental data. In relation to constant and variable mixing speed, some researchers used a combination of moderately high-speed and low-speed for dough mixing, persuaded that the mixing effect was superior to that of constant-speed mixing[5-7]. Vertical and horizontal high speed mixers which can mix the flour and water uniform in seconds, have recently been introduced into the industrial process of noodle dough mixing[4]. The mixing water is sprayed into flying fine flour particles in a mixer rotating at a speed of 800-1 400 r/min. The high speed mixer creates a large surface area for both water and flour, enabling flour particles to hydrate sufficiently, uniformly and rapidly. Additionally, this type of high-speed mixer can facilitate continuous production. In this study, a lower speed horizontal mixer with homogenizing and conveying functions was utilized after a high-speed mixer to develop a gluten structure prior to resting[8]. The wheat flour conveying modes of the continuous high-speed mixer include vertical and horizontal conveying. Continuous mixers are now widespread used in the industry due to better production efficiency and lower labor costs.

In this study, three types of wheat flour with differing levels of quality were used as test materials; two horizontal mixers with double shafts (one with pins and constant speed, and the other with large surface area blades and adjustable speed) and two continuous high-speed mixers (vertical and horizontal types) were used for dough mixing. The quality traits of dough crumbs, sheet and noodles produced by different mixing modes were analyzed and compared to help noodle manufacturers select mixing equipment, optimize processes and improve product quality, as well as to provide important references for the design of dough mixing equipment. In addition, mixing experiments were conducted in a commercial-scale production line with a daily output of approximately 45 t of dough, so this research is especially useful for industrial production.

2 Materials and methods

2.1 Experimental materials

Three types of commercial wheat flours were obtained from Hebei Jinshahe Flour Manufacturing Co., Ltd. (Xingtai, China). The wheat materials were commercial mixtures of hard red winter wheat grown in the Hebei Province, China. The granularity fineness degree of the flour was determined by AACCI Method 55-60.01 using a screen with mesh size of 137 μm[9]. Protein content was determined with AACCI Method 39-11.01[9]. Wet gluten and the gluten index were determined by the Glutomatic system according to AACCI Method 38-12.02[9]. Extensograph tests and water absorption of the flour were determined following AACCI Method 54-10.01 and 54-21.02[9]. Pasting properties of the flours were measured using a Brabender Micro Visco-Amylograph according to AACCI Method 76-21.01[9].

2.2 Mixing experiments

Mixing mode I: A Model 550 horizontal mixer with double shafts (Henan Dongfang Noodle Machine Group Co., Ltd., Zhengzhou, Henan Province, China), pin-shaped blades and constant-speed mixing was used. At each time, 225 kg of wheat flour, 67.5 kg of water and 2.25 kg of NaCl were added. The dough was mixed for 13 min at constant speed (80 r/min).

Mixing mode II: A Model 765 horizontal mixer with double shafts (Henan Dongfang Noodle Machine Group Co., Ltd., Zhengzhou, Henan Province, China) with large surface area blades and adjustable-speed mixing was adopted. At each time, 325 kg of wheat flour, 97.5 kg of water and 3.25 kg of NaCl were added. The dough was mixed for 13 min totally: first at low speed (70 r/min) for 2 min, then at high speed (105 r/min) for 2 min, and finally at low speed (70 r/min) for 9 min.

Mixing mode III: A vertical continuous high-speed mixer (Henan Dongfang Noodle Machine Group Co., Ltd., Zhengzhou, Henan Province, China) with vertical material conveying at a velocity of 970 r/min was used. Wheat flour and water were added into the mixer proportionally, with a feeding rate of wheat flour of 24 kg/min. A double-shaft horizontal mixer was used for subsequent homogenization and mixing with a mixing speed of 90 r/min and the mixing and conveying time of 9 min.

Mixing mode IV: A horizontal continuous high-speed mixer (Henan Dongfang Noodle Machine Group Co., Ltd., Zhengzhou, Henan Province, China) with horizontal material conveying at a velocity of 1 440 r/min was used. The flour feeding rate was 24 kg/min. The method of subsequent homogenization and mixing was the same as mixing mode III.

The moisture and NaCl contents of all the resulted dough crumbs were 32% and 0.76%, respectively. Mixing experiments were carried out in triplicate under each treatment.

2.3 Noodle preparation

After mixing, the dough crumbs were rested in a PE plastic bag for 30 min at room temperature and were passed through the rolls of a laboratory noodle machine (JMTD-168/140, Beijing Dongfang Fude Technology Development Company, China) at a 3.0 mm gap. The dough sheet was folded and put through the sheeting roll two more times. The dough sheet was rested in a plastic bag for another 30 min and then sheeted four times at progressively reduced roll gaps setting of 2.4, 1.8, 1.4 and 1.0 mm. Finally, the dough sheet was cut into 2 mm wide noodles. The noodle strips were placed into a constant temperature and humidity chamber with temperature of 40°C and relative humidity of 75% for 10 h, then taken out and cooled at room temperature for 10 h. The dried noodles were placed into PE plastic bags for later use.

2.4 Determination of quality characteristics of dough crumbs

Moisture was determined according to AACCI Method 44-19.01[9]. Moisture uniformity was determined by Chinese Ministry of Commerce Standard Method SB/T 10071-1992[10]. After dough mixing, the machine was stopped and the cover was opened, and five samples of dough crumbs were taken. The five sampling points included four corners and one center point (for continuous high-speed mixer, continuously sample five times, with 2 min intervals between each sampling). The moisture uniformity was expressed as the coefficient of variation (CV) of the moisture above five dough samples.

Particle size distribution of crumbs was determined according to the method of Liu et al.[11]. The sampling method was same as above method. 300-400 g of dough crumbs were sieved in sequence through standard sieve with mesh diameters of 4000 μm (5 mesh), 2360 μm (8 mesh), 1180 μm (14 mesh), 500 μm (35 mesh), and 250 μm (60 mesh), respectively. The percentage of particles with different sizes to the total mass of dough crumb particles was calculated.

2.5 Color and color uniformity of dough sheet

Color was measured by a chromameter (CR-400, Konica Minolta Camera, Japan) with the CIE L^*, a^*, b^* color space equipped with a C illuminant.

Color uniformity was determined as follows: the color at 10 different parts of the dough sheet was measured using the CR-400 chromameter and the color uniformity was expressed as the standard deviation (SD) of the above ten results.

2.6 Cooking properties of noodles

The optimal cooking time was determined according to AACCI Method 66-50.01[9]. The cooked noodle strands were squeezed between two transparent glass plates when the white core disappeared. Sampling was taken after 2 min cooking and then sampling was carried out once every 30 s.

The water uptake and cooking loss were determined as previously described by Lu et al. with some modification[12]. A 10 g sample of dried noodle was placed into 500 mL of boiling distilled water until the optimal cooking time, then drained for 5 min and weighed. Water uptake was calculated as the weight increase of noodles and expressed as a percentage of the weight of uncooked noodles. The noodle soup was evaporated on the induction cooker until nearly dry, and then placed the stainless steel pot into an air oven at 105°C until dryness. The residue was weighed and reported as a percentage of the starting material weight (calculated by dry basis).

2.7 Texture profile analysis test

Textural properties of cooked noodles were measured by compression (texture profile analysis, TPA) using a TA-XT2i Texture Analyzer (Stable Micro Systems, London, England) under optimal test conditions. Dried noodles were first cut into 20 cm-long strands and then cooked to the optimal cooking time. The cooked noodles were drained, rinsed for 30 s with distilled water (20°C), and shaken to release any free water. Five strands of cooked noodles were placed in parallel without space between each other on the flat testing plate, with three parallel tests for each sample. Instrument settings were in compression mode with use of an A/LKB-F probe, trigger type, auto-10 g; pretest speed, 2.0 mm/s; posttest speed, 2.0 mm/s; test speed, 0.8 mm/s; strain, 70%; interval between two compressions, 10 s. From the force-distance curves generated, three texture parameters were obtained: hardness (g), cohesiveness (ratio) and chewiness (ratio).

2.8 Sensory evaluation of cooked noodles

The cooked noodles were taken out and rinsed for 30 s with cold water, and then evaluated by six trained evaluators according to the Chinese Ministry of Commerce Standard Method SB/T 10137-1993[13] as reported by Liu et al.[14], with some modification. The maximum score of 15 is given for a bright white uniform color, 10 for visual surface smoothness, 20 for medium firmness, 20 for elasticity, 20 for no stickiness, 10 for smoothness in the mouth and 5 for a fragrant wheat smell. The control sample used in the present study was a representative cultivar Xiaoyan 6, because Xiaoyan 6 showed a relatively good noodle quality score in a preliminary sensory test. The control noodles were given scores for each of the characters, except for firmness assessed, that were 75% of the full score. Firmness of Xiaoyan 6 was 100% of the full score, with medium firmness.

2.9 Statistical analysis

The data obtained in this study were expressed as the mean value of at least three replicated determination results. One-way analysis of variance was used to analyze the data and significant differences among the obtained mean values were compared by the LSD test using SPSS ver. 16.0 for Windows. Differences were considered significant at $p<0.05$.

3 Results

3.1 Quality characteristics of wheat flours

The quality characteristics of three wheat flour samples were shown in Table 1. Gaojin flour and Fuqiang flour were significantly different from Shangbai flour for all quality parameters. Significant differences were observed between Gaojin flour and Fuqiang flour for all quality characteristics ($p<0.05$) except for granularity and maximum tensile resistance. The results indicated that Gaojin flour showed a larger particle size, lower protein and wet gluten contents and water absorption, and stronger gluten and dough strength compared to Shangbai flour.

Table 1 Quality traits of three wheat flour samples

Flours	Granularity /%	Protein content/%	Wet gluten content/%	Gluten index/%	Water absorption /mL·100 g^{-1}	Max. resistance /BU	Extensibility /mm	Peak viscosity /BU
Gaojin	24.8±0.7a	11.86±0.16c	30.6±0.5c	63±6a	60.1±0.4c	308±19a	125±5c	165.7±4.1a
Fuqiang	23.2±1.0a	12.70±0.18b	32.9±0.6b	58±6b	60.7±0.5b	298±11a	135±9b	157.4±5.1b
Shangbai	17.6±0.5b	14.72±0.30a	36.7±0.8a	48±5c	61.8±0.7a	239±17b	166±7a	143.3±4.8c

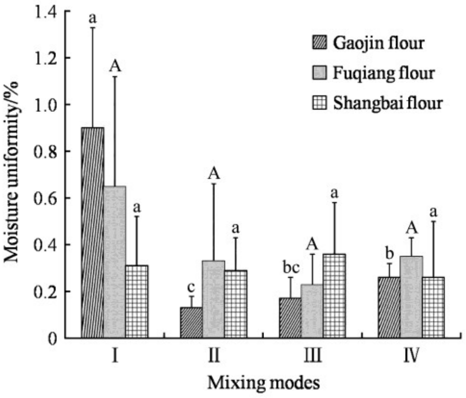
Note: Different letters within columns are significantly different at $p<0.05$ level.

3.2 Mixing performance of different types of dough mixers

During noodle processing, dough mixing is used to achieve a relatively homogeneous crumbly mixture with uniform water distribution, uniform medium size particles and appropriately formed gluten[4,8]. Thus, the moisture uniformity and particle size distribution of dough crumbs, the color, and the color uniformity of the dough sheet can be used to indicate the efficiency of the dough-mixing step.

3.2.1 Moisture uniformity

As shown in Figure 1, when using Gaojin flour as the material, the moisture uniformity of dough crumbs obtained by mixing mode I was significantly worse than that of the other three mixing modes ($p<0.05$), while there was no significant difference between the moisture uniformity of dough crumbs obtained by the other four mixing modes for Fuqiang and Shangbai flours.



Note: Different superscript letters within the same flour indicate significant difference at $p<0.05$ level. The same below.

Figure 1 Moisture uniformity of dough crumbs obtained from four mixing modes

3.2.2 Crumbs size distribution

As shown in Table 2, there were significant differences between the crumb size distributions of noodle dough obtained by different mixing modes. The crumb size of dough obtained by mixing mode II was relatively smaller, while the proportion of small-sized (particle size less than 1 180 μm) dough crumbs obtained by mixing mode II was significantly higher than that of the other three mixing modes ($p<0.05$); the size of the main group of crumbs was in the range of 500-1180 μm, 35% or so of the total particles. The crumb size of dough obtained by mixing mode I was relatively larger, and the size of the main group of crumbs was more than 4000 μm, up to 55% of the total quantity. The crumb size of dough obtained by two continuous high-speed dough mixers was between that of the two horizontal mixers with double shafts, while the proportion of large-sized (particle size more than 4000 μm) dough crumbs was significantly higher than that of mixing mode II, yet significantly lower than that of mixing mode I ($p<0.05$). When using Shangbai flour as material, the crumb size of dough obtained by mixing mode IV was relatively larger than that of mixing mode III.

Table 2 Comparison of crumbs size distribution of noodle dough among four mixing modes

Mixing modes		Crumbs size distribution of noodle dough/%				
		⩽500 μm	>500-1180 μm	>1180-2360 μm	>2360-4000 μm	>4000 μm
Gaojin flour	I	3.0±1.4b	17.5±3.9c	10.6±0.9c	10.8±0.4c	58.2±6.4a
	II	12.7±3.0a	35.2±1.7a	14.3±0.9b	11.3±0.6bc	29.6±3.1c
	III	4.3±0.8b	28.3±2.7b	16.3±0.3a	13.2±0.8a	39.0±3.6b
	IV	5.4±1.8b	25.1±3.2b	13.7±0.4b	12.0±0.5ab	41.4±4.2b
Fuqiang flour	I	2.4±1.0bc	18.4±2.9c	11.6±0.4c	11.4±0.9b	56.2±4.0a
	II	13.0±1.4a	35.2±0.9a	14.1±0.5b	10.8±0.7b	26.9±1.3c
	III	1.7±0.3c	21.0±1.7bc	15.7±0.3a	14.2±0.8a	47.5±2.4b
	IV	3.8±0.7b	23.7±2.2b	13.6±0.8b	13.3±0.5a	45.6±3.8b
Shangbai flour	I	0.1±0.1d	4.9±2.6c	6.8±2.3c	8.9±2.0b	79.2±6.9a
	II	11.7±0.8a	34.7±2.2a	14.2±1.0ab	11.1±0.7a	28.4±3.1c
	III	6.4±0.8b	33.6±2.4a	16.0±0.5a	12.4±0.5a	31.6±2.6c
	IV	2.8±1.2c	19.3±3.8b	13.7±1.6b	13.6±2.4a	50.7±6.2b

Note: Different letters within columns are significantly different at $p<0.05$ level. The same below.

3.2.3 Color and color uniformity of dough sheet

The thickness of this initial dough sheet was 2.58-2.66 mm for Gaojin flour, 2.59-2.74 mm for Fuqiang flour, and 2.66-2.75 mm for Shangbai flour, respectively. The color of raw dough sheet was measured at infinite optical thickness (by stacking several sheets), which eliminates interference from the background and effects of variation in sheet thickness[15]. As shown in Table 3, different mixing modes had significant influence on the color of the dough sheet (CIE L^*, a^*, b^*). The color of dough sheet obtained by mixing mode I had significantly lower L^* and higher b^*, which had higher a^* in mode II and higher L^* and lower b^* in mode IV. Regarding the color of dough sheet, higher L^* and lower a^* and b^* were desirable for consumers in China based on a preliminary market survey on supply and demand. Above all, the color of dough sheet obtained by mixing mode I was the worst, with low brightness and high yellowness, showed a dark yellow color, while the mode IV was preferable with higher brightness and lower yellowness, close to a creamy white color, which would meet the requirements and preferences of Chinese consumers[16].

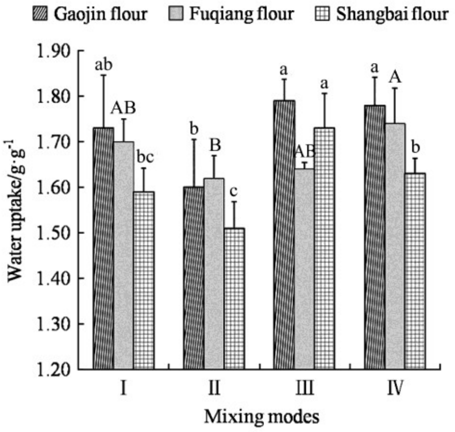
Table 3 Comparison of noodle dough sheet quality among four mixing modes

Mixing modes		Color			Color uniformity /%		
		*L**	*a**	*b**	*L**	*a**	*b**
Gaojin flour	Ⅰ	85.11±0.72c	−0.92±0.10c	17.92±1.13a	0.48±0.10a	0.09±0.01a	1.01±0.14a
	Ⅱ	86.10±0.93b	−0.74±0.10a	17.11±0.68b	0.30±0.02b	0.05±0.03b	0.48±0.09b
	Ⅲ	85.95±0.34b	−0.87±0.07b	17.55±0.65ab	0.30±0.10b	0.06±0.01b	0.66±0.09b
	Ⅳ	87.35±0.52a	−0.76±0.08a	15.52±1.04c	0.38±0.07ab	0.06±0.01b	0.92±0.38ab
Fuqiang flour	Ⅰ	84.27±0.68b	−0.38±0.07b	17.45±0.94a	0.62±0.12a	0.06±0.01a	0.91±0.28ab
	Ⅱ	85.00±0.42a	−0.25±0.07a	17.13±0.76ab	0.38±0.07b	0.06±0.02a	0.77±0.15ab
	Ⅲ	83.31±0.60c	−0.25±0.06a	17.55±0.83a	0.45±0.05ab	0.05±0.01a	0.68±0.09b
	Ⅳ	85.09±0.65a	−0.26±0.06a	16.54±1.17b	0.57±0.22ab	0.06±0.00a	1.05±0.22a
Shangbai flour	Ⅰ	79.65±0.83b	0.44±0.16a	19.54±0.91a	0.74±0.34a	0.13±0.06a	0.90±0.16a
	Ⅱ	81.67±0.84a	0.52±0.08a	17.24±0.98b	0.54±0.13a	0.07±0.01b	0.78±0.21a
	Ⅲ	82.01±0.64a	0.30±0.07b	17.09±0.94b	0.55±0.19a	0.04±0.02b	0.82±0.24a
	Ⅳ	81.69±1.07a	0.32±0.09b	17.14±1.16b	0.74±0.07a	0.07±0.02ab	0.96±0.11a

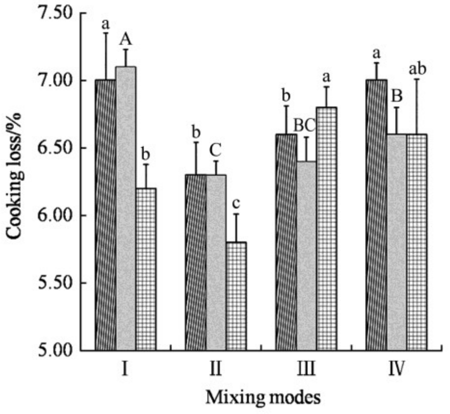
Different mixing modes also had a significant influence on the color uniformity of the dough sheet (Table 3). When using mixing mode I, the color (L^*, a^*, b^*) uniformity of the dough sheet of Gaojin flour was significantly worse than others, and the color L^* uniformity of the dough sheet of Fuqiang flour and the color a^* uniformity of the dough sheet of Shangbai flour was both worse, which indicated that the colors uniformity of the dough sheet obtained by mixing mode I was worse. The results also showed that the color of the dough sheet obtained by mixing mode II and III was relatively more uniform.

3.3 Effects of different types of mixers on physico-chemical properties of noodles

As shown in Figure 2, different mixing modes had a significant influence on the cooking loss and water uptake during cooking. The cooking loss and water uptake of the dried noodles obtained by mixing mode II were significantly lower ($p<0.05$) than the other three modes. When using Gaojin and Fuqiang flours as the material, cooking loss of the dried noodles obtained by mixing mode I was significantly higher than that of modes II and III ($p<0.05$); when using Shangbai flour as the material, mixing mode I had significantly higher cooking loss of dried noodles than mixing mode II ($p<0.05$), yet significantly lower than mixing mode III ($p<0.05$), with no significant differences compared to mixing mode IV.



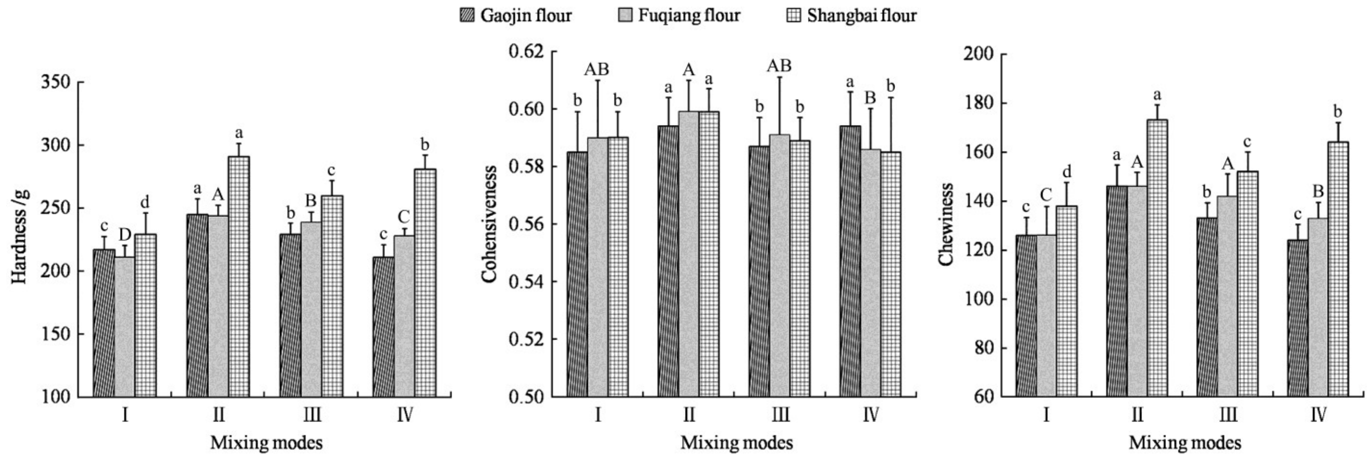
a. Water uptake during cooking



b. Cooking loss

Figure 2 Cooking properties of dried noodles made by mixing modes I-IV

As shown in Figure 3, different mixing modes had significant effects on the TPA parameters of cooked noodles. The hardness, cohesiveness and chewiness of the noodles obtained by mixing mode II were significantly higher than those of the other three mixing modes ($p<0.05$), indicating the cooked noodles had a firm and chewy texture; the hardness, cohesiveness and chewiness of the noodles obtained by mixing mode I were significantly lower. There was no significant difference in the cohesiveness of the noodles obtained between two continuous high-speed mixers except for Gaojin flour (modes III and IV); cohesiveness of Gaojin noodles using mode III was significantly less than mode IV ($p<0.05$). The differences in hardness and chewiness between the noodles obtained by the two continuous mixers varied with wheat flours of different quality. For Gaojin and Fuqiang flours, mixing mode III had significantly higher hardness and chewiness of cooked noodles than mixing mode IV ($p<0.05$); as for Shangbai flour, the hardness and chewiness of the noodles obtained by mixing mode III were significantly lower than those of mixing mode IV ($p<0.05$).



a. Hardness b. Cohesiveness c. Chewiness

Figure 3 Texture parametersof the cooked noodles made by mixing modes I-IV

3.4 Effects of different types of mixers on noodle sensory qualities

As shown in Table 4, different mixing modes had no significant effects on the sensory scores of firmness, smoothness and flavor of the cooked noodles, but did have an influence on the evaluation scores of other sensory elements and total noodle score. As for the noodles made by Gaojin flour, there were no significant differences between the color scores for different mixing modes. For the noodles made by Fuqiang and Shangbai flours, however, the color score for mixing mode I was relatively lower, this was due to lower brightness and whiteness and worse color uniformity, which was consistent with instrumental data.

Table 4 Comparison of cooked noodle sensory qualities among different mixing modes

Mixing modes		Color	Appearance	Firmness	Elasticity	Stickiness	Smoothness	Flavor	Total score
Gaojin flour	Ⅰ	14.4±0a	8.0±0a	16.8±3.2a	12.3±1.2b	18.4±0.8ab	7.5±0.5a	3.9±0.3a	82.0±5.0a
	Ⅱ	13.0±1.3a	8.0±0a	19.2±0.8a	14.7±0.9a	19.7±0.5a	7.9±0.2a	3.8±0a	86.3±0.5a
	Ⅲ	13.2±1.0a	8.0±0a	18.7±1.2a	13.6±1.6ab	17.9±1.9ab	7.7±0.6a	3.8±0.4a	82.9±3.8a
	Ⅳ	13.4±0.9a	7.6±0.4b	16.8±0a	14.4±0.8a	17.1±1.7b	7.2±0.7a	4.1±0.2a	80.6±2.3a
Fuqiang flour	Ⅰ	9.4±2.1b	8.0±0.4a	18.9±0.9a	13.1±1.2b	18.1±0.5b	7.3±1.2a	4.2±0.2a	79.1±1.0b
	Ⅱ	13.2±1.8a	8.0±0.4a	19.2±0.8a	14.9±1.2a	19.5±0.5a	7.1±0.2a	3.9±0.3a	85.8±0.8a
	Ⅲ	10.8±2.1ab	8.1±0.2a	19.5±0.9a	15.2±0.8a	17.6±0b	7.7±0.6a	3.9±0.1a	82.8±1.9a
	Ⅳ	11.4±1.0ab	8.0±0.4a	20.0±0a	14.9±0.5a	18.9±0.9ab	8.0±0.7a	4.0±0.2a	85.3±3.0a
Shangbai flour	Ⅰ	5.5±1.1b	8.3±0.2a	18.9±1.9a	14.1±1.2b	19.2±0a	7.7±0.6a	4.1±0.1a	78.9±1.9a
	Ⅱ	6.6±0.6ab	7.9±0.2a	17.6±0.8a	15.2±0ab	19.2±0.8a	6.8±0a	4.0±0.2a	76.0±1.5a
	Ⅲ	8.4±2.1a	8.0±0a	18.1±1.2a	15.2±0ab	17.6±2.1a	7.1±0.2a	4.1±0.3a	78.5±2.5a
	Ⅳ	6.0±1.8ab	7.2±0.4b	18.7±0.5a	16.3±1.2a	18.1±1.2a	7.3±0.2a	3.7±0.2a	76.8±3.7a

When using Gaojin and Shangbai flours as material, the appearance for mixing mode IV was significantly lower than that of the other three mixing modes ($p<0.05$). As for the three wheat flours, the elasticity score of noodles made by mixing mode I was significantly lower ($p<0.05$), but no significant differences were observed in noodle elasticity among the other three mixing modes. For Gaojin and Fuqiang flours, the stickiness score of noodles made by mixing mode II was the highest of the four mixing modes. When respectively using Gaojin and Shangbai flours as material, different mixing modes had no significant influence on the total score, but when using Fuqiang flour, the total score of noodles made by mixing mode I was significantly lower than those of the other three mixing modes ($p<0.05$).

4 Discussion and conclusions

In this study, the operating time of the mixers was determined according to the inherent characteristic of the mixers and actual production times, which were 13 min for the two types of horizontal mixers with double shafts and 9 min for the two types of continuous high-speed mixers. Thus the continuous high-speed mixers had the advantage of being rapid, continuous and timesaving.

The dough crumbs using mode I were significantly larger and the dough sheet had worse color uniformity than those of the other three mixing modes. Additionally, the cooked noodles had lower hardness, worse chewiness and lower sensory scores for color and elasticity, indicating that the uniformity of dough mixing was worse and the formation of gluten structure was incomplete. Although the flour was mixed at a constant speed, the worse mixing might be due to the action of the mixing pins, which only allowed the flour to move in a circle with poor axial movement ability. It was observed that the mixing speed was too low to break the large-sized dough lumps which were wet on the outside and dry inside and retarded hydration of the protein and later formation of gluten. When using mixing mode II, the flour hydration was even and sufficient, and the gluten network was well-developed during mixing and sheeting. This dough had smaller-sized dough crumbs, lower cooking loss and water uptake of dried noodles, higher hardness and chewiness of cooked noodles, and higher noodle stickiness scores for both Gaojin flour and Fuqiang flour. This is due to a reasonable mixing blade configuration and suitable mixing speed. Mixing by the angled, large surface area blades made the dough crumbs move longitudinally and axially in the mixer. Meanwhile, the flour was mixed at an adjustable speed (high-speed and low-speed alternating method). The low-speed mixing during the initial period ensured the addition of water, the high-speed mixing of the middle period ensured the better mixing evenness and allowed sufficient contact between water and flour, and the low-speed mixing of the last period promoted penetration of water and proper formation of the gluten matrix, while avoiding damage to the gluten structure.

In the two types of continuous high-speed mixers, the flour was rapidly combined with water but little gluten was formed during this process. The subsequent homogenization process, that is, mixing and conveying, allowed for some gluten development. However, the mixing speed was higher and the dough was axially conveyed in a single direction and lacked slow mixing and ripening, thus the gluten formation was less than with mixing mode II.

There were significant differences between the uniformity of dough mixing by the two types of continuous high-speed mixers. The dough crumbs of Shangbai flour obtained by mixing mode IV had a higher proportion of large-sized crumbs with a particle size more than 4000 μm, while the moisture uniformity of the dough crumbs of Gaojin flour and the color b^* uniformity of the dough sheet of Fuqiang flour were both significantly worse than with mode III. Overall, the uniformity and stability of mixing mode IV were relatively worse than those of the mixing mode III, which was possibly caused by different material conveying modes. The material conveying direction for the vertical continuous mixer was vertical, with horizontally rotating blades, while the material conveying direction for the horizontal continuous mixer was horizontal with vertically rotating blades. As for vertical conveying, the acting forces, including the frictional force between the materials, were smaller because of their own gravity and the horizontally rotating blades could disperse the falling materials easily. As for horizontal material conveying, the impact force and frictional force between the materials were larger, thus the materials were more likely to bond with each other. However, the impact and friction force between the materials equated to kneading action, so mixing mode IV induced better gluten and dough development than mixing mode III.

The flours with different qualities ideally required different continuous mixing modes. Mixing mode III should be used for Gaojin flour, leading to noodles with significantly higher hardness and chewiness of TPA, sensory scores of appearance, and lower cooking loss; mixing mode IV should be used for Shangbai flour, leading to noodles with denser texture, relatively higher hardness and chewiness of TPA, elasticity score, and relatively lower cooking loss. The differences in the quantity and quality of gluten protein and flour particle size lead to the differences in hydration speed and degree of flour and water mixing. Fu[4] and Hou et al.[8] proposed that flour with a high protein content hydrates relatively faster and larger particle size flour required a longer time for water to be incorporated. Gaojin flour showed significantly lower protein content, wet gluten content and dough water absorption, and higher granularity, gluten index and maximum tensile resistance compared to Shangbai flour. The results also suggested that Gaojin flour had a slower hydration speed. Therefore, surface checking and texture embrittlement could occur more easily after drying for noodles made of Gaojin flour. Meanwhile, compared with mixing mode III, the moisture distribution of fresh wet noodles of mixing mode IV was uneven; this can also result in noodle surface checking and embrittlement after drying. Hence, for Gaojin flour, dried noodles made by mixing mode IV showed higher cooking loss and lower hardness and chewiness than that of mixing mode III. As for Shangbai flour with a relatively smaller particle size and higher protein and gluten contents, noodle quality could be better maintained during drying. Mixing mode IV induced better gluten development than mixing mode III, therefore mixing mode IV should be used for Shangbai flour.

No single mixer performed optimally over all three flours. Ideally, the final choice of mixing mode should be based on the major flour type used by the noodle manufacturer. The noodle manufacturer should also consider applying tighter specifications on the quality of flour supplied by the flourmill.

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