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Variation and trends in dough rheological properties and flour quality in 330 Chinese wheat varieties

Xiushi Yang[a,1], Li Wu[a,b,1], Zhihua Zhu[a], Guixing Ren[a], Sancai Liu[a,*]

[a]Institute of Crop Science, Chinese Academy of Agricultural Sciences, Beijing 100081, China
[b]Faculty of Biotechnology Industry, Chengdu University, Chengdu 610106, China

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ABSTRACT

The objective of this study was to investigate variation and trends in dough rheological properties and flour quality traits in 330 Chinese wheat varieties. The dough rheological properties of development time (DT), stability time (ST), and farinograph quality number (FQN) were evaluated, as well as the flour quality traits of protein (PC), wet gluten content (WGC), and sedimentation value (SV). The coefficients of variation of DT (40.5%), ST (58.1%), and FQN (42.4%) were higher than those of PC (9.1%), WGC (10.1%), and SV (15.3%). Normal distributions were observed for the flour quality indices but not for the rheological parameters. SV was strongly correlated with the three rheological parameters and accordingly might be used as a primary indicator for dough rheological property evaluation. Our results showed that there has been marked improvement in dough rheological properties for Chinese wheat varieties released since 1986, while flour quality has remained stable.

1. Introduction

Wheat, one of the principal cereal crops in China, is used in a variety of products including noodles, steamed breads, dumplings, pancakes, breads, and biscuits. With an increasing concern for nutrition and taste of wheat products, there has been an increased demand for high-quality wheat varieties in the food industry and corresponding interest in wheat quality improvement. Quality improvement of wheat involves grain or flour quality, dough rheological properties, and end-use product quality. In the past several decades, dough rheological properties have increased in importance in wheat breeding [1], perhaps because they provide more direct information than grain or flour traits. Additionally, in wheat breeding programs, end-use quality of many breeding materials can't be directly determined, owing to limited seed quantities, and

* Corresponding author. Tel.: +86 10 62131376.
E-mail address: liusancai@caas.cn (S. Liu).
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is often predicted by evaluation of dough rheological properties [2-5].

In recent years, wheat quality research has focused partly on correlations among flour and dough properties and end-use quality. Large variation in dough rheological properties among some wheat cultivars in China has been found in different end-use products, such as Chinese steamed bread, dry white Chinese noodles, pan bread, and fresh white noodles [6–8]. However, these studies do not represent a full evaluation of wheat quality among the numerous cultivars released in the long period from 1949 to 2010.

The trend of genetic improvement in wheat quality is also very important for wheat breeding. Breeding strategy may be guided by evaluation of genetic gain or loss of wheat quality. Fufa et al. [9] found that there had been a decrease in flour protein content but an increase in end-use quality in 30 hard red winter wheat cultivars released from 1874 to 2000 in Nebraska. Underdahl et al. [10] reported that protein content, flour-extraction yield, and dough character score of spring wheat cultivars released in 1968 did not vary significantly from cultivars released after 1968, although crumb color showed an increase overtime.

As a secondary center of diversity for wheat, China possesses abundant wheat genetic resources. Since the 1980s, studies of species diversity, genetic diversity, agronomic characters, and nutritional quality of wheat cultivars have been reported [11,12]. However, variation in flour and dough properties of different wheat varieties has remained poorly studied. The objective of this study was to evaluate variation and quality improvement trends in dough rheological properties and flour quality of wheat varieties released since 1949 in China.

2. Materials and methods

2.1. Wheat samples

A total of 330 wheat varieties with diverse origins, including leading commercial cultivars and elite advanced lines released since 1949, were provided by Prof. Lihui Li from the Resources Research Center of the Chinese Academy of Agricultural Sciences (CAAS), Beijing. The tested cultivars were sown in the 2010–2011 crop season at the wheat breeding station of the Institute of Crop Science, CAAS. The cultivars were divided into four different groups according to the release periods, as follows: period I, 1949–1976; II, 1977–1985; III, 1986–2000; and IV, after 2000. Each grain sample was tempered to a constant moisture content (14.5%) for 12 h and then milled in a Brabender Junior Laboratory mill (Brabender OHG, Duisberg, Germany).

2.2. Flour quality

Flour protein content (PC) was determined by near infrared reflectance spectroscopy following AACC method 39-11 [13]. Wet gluten content (WGC) was determined according to ISO standard 5531 [14] by a Glutomatic 2100 apparatus (Perten Instruments AB, Huddinge, Sweden). Sedimentation value (SV) was determined according to AACC method 44-15A [15]. These tests were performed in duplicate.

2.3. Dough rheological properties

Dough rheological properties were evaluated according to AACC method 54-21 [16]. Development time (DT), stability time (ST), and farinograph quality number (FQN) at 500 FU dough consistency were determined with a farinograph (Brabender GmbH & Co. KG, Duisburg, Germany) using 50 g flour samples. DT is defined as the time between the start of measurement (addition of water) and the point of the torque curve just before weakening begins, while ST is defined as the time between the first and second intersection points of the upper trace of the torque curve with the line of consistency, and FQN as the length from the water point to a point 30 FU below the center line of greatest consistency along the time axis [17]. FQN, which is strongly correlated with DT, can be easily and rapidly tested and has been accepted as a new index for rheological property measurement of dough with the farinograph [18].

2.4. Statistical analysis

Data analysis was performed by SPSS for Windows, version 13.0. Distributions of dough rheological properties and flour quality were tested by the Kolmogorov–Smirnov (K–S) normality test. The Kruskal–Wallis (K–W) test for non-parametric data was used to determine the significance of differences among mean values. Pearson's correlation analysis was used to assess the relationship among the six quality traits. Fisher's least significant difference (LSD) was calculated at significance levels of $P < 0.05$ and $P < 0.01$.

3. Results

3.1. General characteristics

As shown in Table 1, the mean values of DT, ST, and FQN were 2.7 min, 4.6 min, and 54.8 mm, respectively, and the mean values of PC, SV, and WGC were 13.2%, 30.3 mL, and 31.7%, respectively. As reflected by standard deviation (*SD*) and coefficient of variation (*CV*) values, there were wide variations in the six quality traits among the wheat cultivars. In terms of CV value, the highest was ST (58.1%), followed by FQN (42.4%), DT (40.5%), SV (15.3%), WGC (10.1%), and PC (9.1%). This order indicated that the CV values of dough rheological properties were larger than those of flour qualities.

3.2. Distributions of flour quality and dough rheological properties

As shown in Fig. 1, a normal distribution was found for PC, WGC, and SV of the wheat cultivars. However, DT, ST, and FQN were not normally distributed but showed marked left shifts. *Z*-statistics and significance levels based on the K–S normality test are listed in Table 2. The *Z*-statistics of PC, SV, and WGC were below the critical value ($Z_{0.05} = 1.63$), and their asymptomatic significance was larger than 0.05, indicating their normal distribution. However, the *Z*-statistics of DT, ST, and FQN were greater than the critical value, and their asymptomatic significances were ≤0.05, indicating that the rheological properties were non-normally distributed.

3.3. Correlation between rheological properties and flour quality parameters

As shown in Table 3, PC was significantly ($P < 0.05$) positively correlated with DT. SV showed significant positive correlations with the three rheological properties (DT, ST, and FQN), with Pearson's correlation coefficients 0.45, 0.54, and 0.52, respectively. WGC was significantly negatively correlated with ST ($P < 0.01$) and FQN ($P < 0.05$).

3.4. Trends of dough rheological properties and flour quality

The dough rheological properties and flour quality of wheat cultivars released in different periods were evaluated to identify trends of genetic improvement. As shown in Fig. 2, DT of cultivars released in period IV was 3.3 min, which was 17.9% higher than that of cultivars released in period I. Similarly, ST and FQN of cultivars released in period IV were 71.1% and 44.3% higher than those of cultivars released in period I. DT, ST, and FQN increased with time, showing that breeders have made marked improvements in dough rheological properties of wheat in China. However, PC, SV, and WGC did not show a consistent increase or decrease during different breeding periods (Fig. 3). The highest PC was observed in period II, whereas the highest SV was found in period IV.

Because the dough rheological properties were non-normally distributed, the K–W test for non-parametric data was used to determine the significance of differences among the mean values (Table 2). The results showed that the flour quality characteristics could be divided into two categories on the basis of their significance levels (asymptotic significance < 0.05). The significance levels of DT, ST, and FQN were all below 0.05 (0.001, 0, and 0, respectively), indicating that the average values of these parameters differed significantly among wheat varieties released in different periods. The significance levels of PC, SV, and WGC were greater than 0.05 (1.000, 0.963, and 0.405, respectively), suggesting that there was no significant difference in wheat flour quality among varieties released in different periods.

Table 1 – Means and variations of dough rheological properties and flour quality parameters of wheat cultivars in China.

	DT (min)	ST (min)	FQN (mm)	PC (%)	SV (mL)	WGC (%)
Mean	2.7	4.6	54.8	13.24	30.3	31.7
SD	1.094	2.674	23.255	1.200	4.629	3.200
Minimum	0.9	1.0	18	10.52	17.9	24.0
Maximum	6.7	19.5	200	16.32	45.2	40.5
CV (%)	40.5	58.1	42.4	9.1	15.3	10.1

DT: development time; ST: stability time; FQN: farinograph quality number; PC: protein content; SV: sedimentation value; WGC: wet gluten content.

Table 4 shows comparisons of dough rheological properties among varieties released in different breeding periods. It is readily seen that DT, ST, and FQN did not increase significantly ($P > 0.05$) in period II but improved significantly ($P < 0.01$) in period IV, as compared with period I. DT and FQN were significantly higher in period III than in either period I ($P < 0.05$) or II ($P < 0.01$). ST and FQN differed significantly between period II and period IV. Although the average values of rheological properties increased from period III to period IV, no significant differences among them were found. All of these results suggest that the rheological properties of Chinese wheat genetic resources have greatly improved since 1949, but that the rate of improvement is slowing.

4. Discussion

The mean value of PC in our research was 13.2%, lower than that of bread wheat in the worldwide collection (14.5%) [19] and of North Dakota wheat in the U.S. (14.7%) [10], but higher than that of European wheat (10.3%) and American winter wheat (12.7%) [9,20]. In this study, the mean value of DT was 2.7 min, which is less than the average mixing time (defined as the midline peak time) of American hard red spring wheat (3.1 min) [10] and American hard red winter wheat (3.7 min) [9], but similar to the average mixing time of the world's wheat core collection (2.8 min) [19]. The mean value of SV in our study (30.3 mL) was consistent with that of the hard red winter wheat cultivars in Nebraska (30.69 mL) [9]. It could be concluded that the wheat quality of China was at a middle level in the worldwide ranking. Zhu et al. [21] reported that PC of Chinese wheat (12.9%) was slightly higher than that of Australian wheat (12.5%), but that STs were 2.32 min for China and 3.50 min for Australia.

The CV values of DT and PC obtained in this study (40.5% and 9.1%) were higher than those of the American hard red winter wheat (14.8% and 5.7%) [9], but lower than those of the worldwide core collection (42.2% and 11.0%) [19]. The larger CV values from the world wheat core collection maybe attributed to the diversity of sources and cultivars, especially landraces. Thus, it is essential to extend the gene bank of wheat breeding by characterizing the genetic diversity of Chinese wheat landraces.

The data of dough properties were analyzed by assuming both normal distribution and non-normal distribution. When a normal distribution was assumed, significant differences were found for DT, ST, and FQN. However, no significant difference was found for ST by assuming a non-normal distribution (statistical analyses are not shown). This result indicated that the choice of statistical method was very important for obtaining an objective result.

The distribution of dough rheological properties has rarely been studied. We analyzed the data of 26 hard red winter wheat cultivars in America reported by Martinant et al. [22], and found a normal distribution of mixing time. However, in the present study, all three rheological properties were non-normally distributed. This finding maybe due to the wide end-use diversity of the 330 wheat cultivars including as bread, noodles, biscuits, etc. The agricultural standard of China has prescribed different quality indices for different

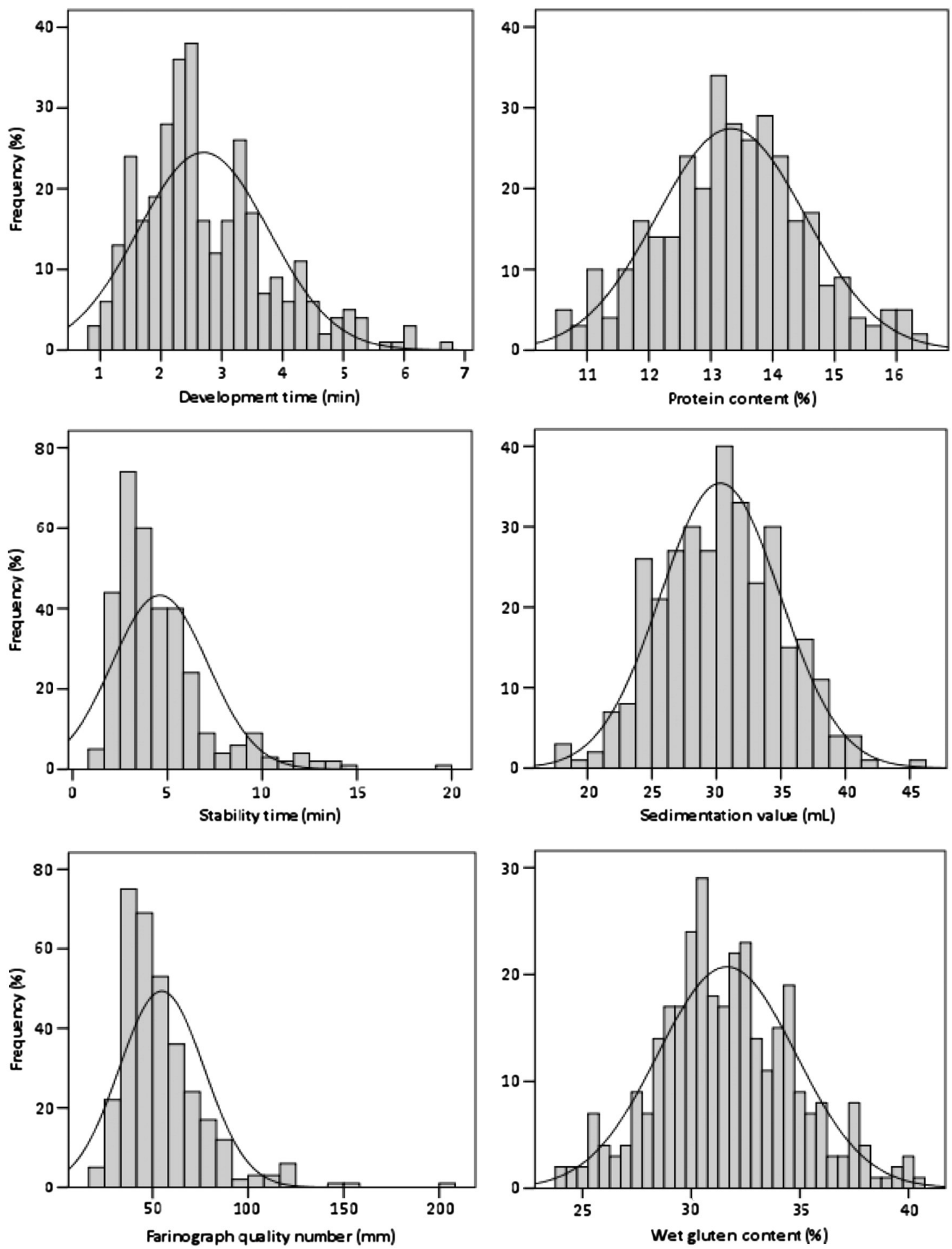

Fig. 1 – Distribution of dough rheological properties and flour quality parameters of wheat cultivars in China.

end-use products. For example, ST values for biscuits, noodles, and bread are required to be greater than 2.5, 4.0, and 10.0 min, respectively [23].

We found a weak positive correlation between DT and PC. However, Martinant et al. [22] and Bordeset al. [19] reported that middle peak time (similar to DT) was significantly negatively correlated with PC. We also found that SV was positively correlated with DT, ST, and FQN, indicating that SV could be an effective index for assessing the dough rheological properties.

The trend of DT in this study was consistent with the results of some other studies. Evaluation of 45 hard red spring wheat cultivars released from 1911 to 1990 in the USA showed that mixing time increased significantly over time [24]. Another study showed that there was a highly significant increase in mixing time for 30 hard red winter wheat varieties

Table 2 – Result of Kolmogorov–Smirnov and Kruskal–Wallis tests of dough rheological properties and flour quality parameters of wheat cultivars in China.

	DT	ST	FQN	PC	SV	WGC
Kolmogorov–Smirnov Z	1.963	2.638	2.048	0.340	0.502	0.891
Asymptomatic significance	0.001	0	0	1.000	0.963	0.405

DT: development time; ST: stability; FQN: farinograph quality number; PC: protein content; SV: sedimentation value; WGC: wet gluten content.

Table 3 – Pearson correlation coefficients between dough rheological properties and flour quality traits.

	PC	SV	WGC
DT	0.16^{*}	0.45^{**}	−0.04
ST	0.08	0.54^{**}	-0.23^{**}
FQN	0.07	0.52^{**}	-0.17^{*}

DT: development time; ST: stability time; FQN: farinograph quality number; PC: protein content.
*, **: correlation is significant at the 0.05 and 0.01 levels, respectively.

released from 1874 to 2000 (from 3.00 min to 4.03 min) [9]. In contrast, Underdahl et al. [10] reported that DT showed no significant differences over time for major hard spring cultivars released in North Dakota since 1968.

According to He et al. [1], quality improvement of wheat in China began in the middle and late 1980s. During the middle and late 1990s, the high-quality wheat breeding and processing industry experienced rapid development. In the present study, compared to period I, DT, and FQN increased significantly in period III, while all three rheological parameters improved significantly in period IV. These improvements maybe closely associated with the demand for high quality wheat in Chinese research and production. From the perspective of breeding and genetic resource utilization, they may also be associated with the importation of international elite wheat germplasm with superior rheological properties.

Flour quality traits (PC, SV, and WGC) have remained almost stable in Chinese wheat since 1976 (Table 4), and PC has remained steady over the last 40 years. This result was consistent with those of Underdahl et al. [10], but differed from the results of Souza et al. [24] and Fufa et al. [9]. Our study revealed that protein content could be maintained with improvement in rheological quality in wheat breeding programs. These results also suggested that it is easier to improve dough rheological properties than flour quality traits.

5. Conclusions

There was wide variation in dough rheological properties and flour quality traits among 330 Chinese wheat varieties released since 1949. Normal distributions were observed for flour quality parameters but non-normal distributions for dough rheological properties. Sedimentation value was strongly correlated with the three rheological parameters, indicating that it could be used as a primary indicator for dough rheological property evaluation. The dough rheological properties of wheat genetic resources in China have greatly improved from 1986, although the rate of improvement is

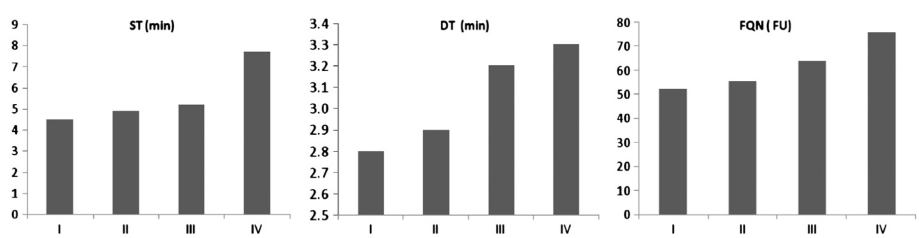

Fig. 2 – Mean values of rheological properties of wheat cultivars released in different periods. DT: development time; ST: stability time; FQN: farinograph quality number; I: cultivars released during 1949–1976; II: during 1977–1985; III: during 1986–2000; IV: after 2000.

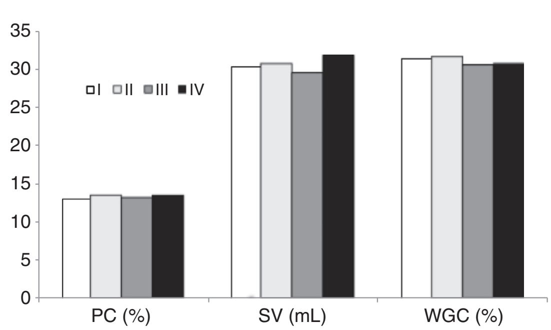

Fig. 3 – Mean values of flour quality in wheat cultivars released in different periods. PC: protein content; SV: sedimentation value; WGC: wet gluten content; I: cultivars released during 1949–1976; II: during 1977–1985; III: during 1986–2000; IV: after 2000.

Table 4 – Comparisons of dough properties from cultivars released in different periods.

Comparison	Development time	Stability time	Farinograph quality number
I and II	0.202	0.638	0.527
I and III	0.027*	0.125	0.003**
I and IV	0.009**	0.005**	0.003**
II and III	0**	0.116	0.003**
II and IV	0.676	0.003**	0.005**
III and IV	0.336	0.072	0.189

I: cultivars released during 1949–1976; II: during 1977–1985; III: during 1986–2000; IV: after 2000.
*, **: significant at 0.05 and 0.01 levels, respectively.

slowing. However, flour quality, in the form of protein content, has not markedly improved. Future studies should be focused on these issues to meet the increasing demand for wheat quality.

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