

Milling Quality and White Salt Noodle Color of Chinese Winter Wheat Cultivars

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ABSTRACT

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Improvement of milling quality is an important aspect in wheat breeding programs. However, the milling quality of Chinese wheats remains largely unexplored. Fifty-seven Chinese winter wheat cultivars from four regions were used to investigate the variation of milling quality parameters and to determine the associations between milling quality traits and color of noodle sheet. Substantial variation was presented for all measured parameters in this germplasm pool. Complete soft, hard, and medium-hard types were observed. Soft wheat and hard wheat show significant differences in flour ash content, flour bran area, and flour color grade. No simple trait can be used to select for flour milling quality. High flour ash content and bran speck area contributed negatively to brightness of dry flour. Correlation coefficients (r) between L^* value of

dry flour and flour ash content and bran speck area were -0.47 and -0.65 for hard cultivars, and -0.51 and -0.72 for soft cultivars, respectively. Flour color grade (FCG) was significantly and positively associated with bran speck area; $r = 0.56$ and 0.73 for hard and soft wheats, respectively. There was a high correlation between FCG and L^* value of flour water slurry ($r = -0.95$). Strong associations were also established between milling quality index (MQI) and FCG, L^* value of dry flour, flour-water slurry, and white salted noodle sheet for both hard and soft wheats. In conclusion, substantial progress could be achieved in improvement of milling quality in Chinese winter wheats through genetic selection, and FCG and MQI could be two important parameters for evaluation of milling quality in breeding programs.

Milling quality, including flour yield, ash content, bran speck, and flour color, is largely related to grain morphology characteristics if milling is done under similar conditions. It has a strong effect on the quality of wheat-based end products such as bread (Finney et al 1987), cake and cookies (Gaines 1985; Finney et al 1987; Kaldy and Rubenthaler 1987; Steve et al 1995), oriental noodles (Toyokawa et al 1989; Konik et al 1992), and Chinese steamed bread (He et al 2003). Therefore, it is an important characteristic used for quality selection in wheat breeding programs (Marshall et al 1986; Wrigley and Morris 1995).

Variation in milling parameters such as test weight, thousand kernel weight, flour yield, and ash content for hard winter wheat (Kim et al 1995) and variation in flour yield (Steve et al 1995) and ash content (Gaines 1985) in soft wheat have been reported. The mineral elements (ash) and protein concentrations in the bran were much higher than those in the flour (Peterson et al 1983). The bran speck counts among hard red winter samples had a wide range of variation (Kim and Flores 1999) and it is higher in the straight-run flour than in the more pure endosperm flour from the reduction roll. Bran content in the form of specks is the major factor causing differences in flour color grade (FCG) (Barnes 1986). Oliver et al (1992) reported the L^* , a^* , and b^* values of dry flour in Australian wheat. The prediction of flour refinement by the measurement of pericarp fluorescence was studied by Symons and Dexter (1992).

Several morphological characters play an important role in the determination of flour yield. Grain size and shape and thickness of the bran coat influence the proportion of endosperm in the kernel. Grain hardness and cell wall thickness affect ease of separation of the endosperm from the nonendosperm components and influence flour yield (Baker and Golumbic 1970; Marshall et al 1986). A significant correlation has been found between flour yield and kernel size (Shuey and Gilles 1969; Dattaraj et al 1975;

Marshall et al 1986; Li and Posner 1987; Flores 1989; Zhou et al 2003) but it was not confirmed by Steve et al (1995). In general, hard wheat cultivars have superior milling qualities such as high flour yield and sieving efficiency (Bass 1990; Pomeranz and Williams 1990; Zhou et al 2003). However, milling yield of soft wheat was not significantly correlated with grain hardness (Gaines 1985). In general, milling yield was significantly correlated with test weight (Shuey 1960; Dattaraj et al 1975; Zhou et al 2003) and thousand kernel weight (Dattaraj et al 1975; Flores 1989) but this was not confirmed by Steve et al (1995).

Significant relationships among flour ash, bran speck, flour yield, flour and noodle color have been observed. Shellenberger (1965) showed a positive relationship between flour ash content and flour yield, and the coefficient of determination (r^2) between ash content and bran speck count was 0.91. The number and size of bran specks influence the flour ash content (Kim and Flores 1999). High flour ash content and bran specks were associated with darker flour color when measured as three tristimulus values (L^* , a^* , and b^*) and Kent Jones color grade (Takashi and Mitsuo 1962; Shuey and Skarsaune 1973; Oliver et al 1992; Kim and Flores 1999; Zhou et al 2003). Flour protein content also had a negative effect on flour color (Barnes 1986; Baik et al 1995; Ge et al 2003). In addition to these, the enzyme polyphenol oxidase (PPO) activity (Hatcher and Kruger 1993; Kruger et al 1994; Baik et al 1995; Ge et al 2003) and yellow pigment content also had a negative influence on flour and noodle color (Takashi and Mitsuo 1962; Alvarez et al 1998; Parker 1998; He et al 2004).

China is the world's largest wheat producer and consumer, and the so-called winter wheat sown in autumn provides $\approx 90\%$ of the national wheat production. Quality improvement is still in its infancy stage in China because it was only initiated in the late 1980s. Efforts in quality improvement have focused on protein content, gluten quality, and starch parameters. Characterization of milling quality in Chinese winter wheats still remains largely unexplored. Genetic improvement of milling quality for Chinese wheats is of crucial importance because the major wheat products such as steamed bread and noodles require bright white color, and commercial flour extraction rate is relatively high in China (He et al 2003; Liu et al 2003; Zhou et al 2003). Therefore, the objectives of this study were to investigate the variation of milling quality parameters and to estimate the association among these traits and color of noodle sheet to develop a strategy for improvement in milling performance of Chinese wheat.

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MATERIALS AND METHODS

Materials

Fifty-seven winter wheat cultivars and advanced lines as presented in Table I, including 16 from Northern China Plain winter wheat region, 23 from Yellow and Huai River Valleys winter wheat region, 15 from Middle and Low Yangtze Valley winter wheat region, and three from Southwestern winter wheat region, were grown in the 1999-2000 cropping season at the Cotton Research Institute of the Chinese Academy of Agricultural Sciences in Anyang, located in the Yellow and Huai Valleys, Henan province. These cultivars were widely planted by farmers and provided >60% of the sowing acreage in the winter wheat regions. Henan is the largest wheat-producing province in China and various types of wheat from the above four regions can be grown normally in Anyang. Tested cultivars were grown in a randomized block design and samples from three replicates were blended to maintain manageable numbers for analysis. Test plots were managed according to local practices. Harvested grain samples were cleaned before milling. Broken, shriveled, and foreign grains were removed by hand. Falling Number testing indicated that all samples were free of sprouting damage. Testing of milling and all quality parameters was performed by BRI Australia, Ltd. (Sydney, Australia).

Grain Characteristics

Test weight (TW) was determined for each sample as bulk density (kg/hL). Kernels of each sample were counted with a seed counter (Numigral Grain Counter, Tripette & Fenaud, Paris, France) and thousand kernel weight (TKW) was measured using an electronic balance. To determine particle size index (PSI), wheat kernels were ground on a laboratory mill (Mo359, Laboratory Construction) at 11–13% moisture according to Approved Method 55-30 (AACC International 2000) then sieved through a 15N screen (Simon Laboratory sifter). Sieving data was converted to a relative hardness scale. Kernel hardness also was determined using the Single Kernel Characteristic System (SKCS 4100, Perten Instruments).

Milling and Flour Characteristics

The straight-run flour yield was determined by a laboratory experimental mill (MLU 202, Buhler Bros. Ltd., Uzwil, Switzerland), this included addition of flour removed from the bran and pollard using two passes through a Buhler bran finisher to produce flour equivalent to the typical commercially produced flours as described by Osborne (1998). The wheat was tempered overnight to 14.5, 15.5, and 16.5% moisture for soft, medium, and hard wheat depending on PSI results and kernel moisture determined by SKCS, respectively. Flour protein content (14% mb) was determined by NIR analysis (InfraAnalyser 260, Bran+Luebbe GmbH, Germany). Flour ash was determined by Approved Method 08-01 (AACC International 2000).

Measurement of Flour Color

The color of dry flour was measured with a chromameter (CR 110, Minolta) using the CIE (1976) L^* , a^* , b^* color space equipped with a D65 illuminant on dry flour loaded in a Dickey-john near-infrared reflectance cell. L^* is a measure of the brightness from black (0) to white (100), a^* is a function of the green to red difference, and b^* is a function of the blue to yellow difference. The flour color grade (FCG) measurements were made in a color grader (Series IV, Henry Tinsley & Co., England) by using 30 g of flour plus 50 mL of distilled water, mixing for 45 sec, and reading after an additional 45 sec in a test cell. Color space measurements (L^* , a^* , b^*) of the same slurries were made with the Minolta instruments using a Dickey-john near-infrared reflectance cell. Flour bran specks were measured using the method described for dry flour (Branscan 2000, Parascan, UK) with Branscan computer software to assess flour images and count the bran specks and their proportion of the surveyed area.

To assess the relationship between brightness of flour and flour-water slurry and noodle sheets, and flour yield and bran speck, a milling quality index (MQI) has been applied (Southan et al 2000). The index was computed as: Milling quality index (MQI) = Bran speck number/Flour extraction rate \times 100.

TABLE I
Name and Origin of Cultivars and Advanced Lines Used in This Study

No.	Name	Origin ^a	No.	Name	Origin ^a
1	Zhongyou 9507	Zone I	30	Fengyou 5	Zone II
2	Jingdong 8	Zone I	31	Huaimai 14	Zone II
3	Jing411	Zone I	32	Huaimai 16	Zone II
4	Zhongyou 16	Zone I	33	Huaimai 18	Zone II
5	CH153	Zone I	34	Huaimai 894	Zone II
6	CH161	Zone I	35	Xuzhou 25	Zone II
7	Yuandong 6	Zone I	36	Xuzhou 727	Zone II
8	Yuandong H89	Zone I	37	Xuzhou 826	Zone II
9	Yuandong 853	Zone I	38	Xuzhou 858	Zone II
10	Jinnong 61	Zone I	39	9436	Zone II
11	Jinnong 207	Zone I	40	Yangmai 5	Zone III
12	Jinnong 214	Zone I	41	Yangmai 9	Zone III
13	Jinnong 215	Zone I	42	Yangmai 10	Zone III
14	Jinnong 216	Zone I	43	Yangmai 158	Zone III
15	Jinnong 217	Zone I	44	Ningmai 8	Zone III
16	Jinnong 218	Zone I	45	Ningmai 9	Zone III
17	Jinmai 50	Zone II	46	Ning 9247	Zone III
18	Linhan 6114	Zone II	47	Ning 9415	Zone III
19	Zhongliang 8837	Zone II	48	Annong 8415	Zone III
20	Shaanyou 225	Zone II	49	Wanmai 18	Zone III
21	Jinan 17	Zone II	50	Wanmai 33	Zone III
22	Shandong 924402	Zone II	51	Wanmai 38	Zone III
23	Shandong 955159	Zone II	52	Sumai 6	Zone III
24	Shandong 935031	Zone II	53	Emai 12	Zone III
25	Yannong 18	Zone II	54	Pin 555	Zone III
26	Yan Hangtian 2	Zone II	55	Mianyang 26	Zone IV
27	Yumai 2	Zone II	56	Yun 97154	Zone IV
28	Yumai 18	Zone II	57	Yun 97169	Zone IV
29	Yumai 47	Zone II			

^a Zone I, North China Plain winter wheat region; Zone II, Yellow and Huai Valleys facultative wheat region; Zone III, Mid and Lower Yangtze Valleys autumn-sown spring wheat region; Zone IV, Southwestern autumn-sown spring wheat region.

Measurement of White Salt Noodle Sheet Color

White salted noodle (WSN) dough was prepared by mixing 150 g of flour on 13.5% moisture basis with enough water to achieve 34% water absorption and 2% (w/w) salt in a mixer (N50, Hobart, North York, Canada) for 1 min using a slow mixing speed (speed position 1 of the mixer), followed by mixing at high speed (speed 2) for 1 min, and then at slow speed for 3 min. The dough crumbs were aggregated by hand kneading; then the final stiff dough obtained was passed through the sheeting rolls of a laboratory noodle machine (Otake, Tokyo, Japan), and sheeted four times using a 3.0-mm roll gap setting. The sheeted dough was rested in a plastic bag for 30 min at $21 \pm 1.5^\circ\text{C}$, and then successively sheeted using 2.2-mm, and 1.4-mm roll gap settings (final thickness of the sheeted dough was adjusted to 1.5 ± 0.05 mm at the final setting). The final dough sheet was cut to produce a noodle sheet 15 cm long. The noodle sheet was measured with a chromameter (CR 310, Minolta) using the CIE (1976) L^* , a^* , b^* color space equipped with a D65 illuminant on a Royal Australian Cereal Institute (RACI) standard backing tile; three measurements were made on each side of the noodle sheet. Noodle sheets were stored in sealed plastic bags at 28°C for 24 hr, and measurements were made at 0.5 and 24 hr.

Statistical Analyses

Mean and standard deviation, and simple correlation coefficients were computed. LSD multiple comparison was used to examine the mean difference for hard, medium, and soft genotypes. All computation was completed using SAS software (SAS Institute, Cary, NC) at CIMMYT-China.

RESULTS AND DISCUSSION

Variation for Milling Quality Traits

Mean and standard deviation of milling quality parameters and noodle sheet color of tested cultivars are presented in Table II. Chinese winter wheat is a mixed population in terms of grain hardness: soft (21 genotypes), hard (15 genotypes), and medium (21 genotypes) types were presented as indicated in Fig. 1. Although breeders and farmers generally have a preference for hard grain, soft and medium types will also be acceptable if the agronomic performance of a cultivar is outstanding. Significant differences were observed between hard and soft endosperm wheats in flour

ash, flour bran area, flour bran number, L^* and b^* of flour, and flour color grade, although the difference in flour yield is not significant at the 5% probability level.

Using the bran finisher to increase flour yield resulted in high extraction rates ranging from 79.0% for hard and soft wheats to 80% for medium wheat, accompanied by high ash content (0.66, 0.64, and 0.61% for hard, medium, and soft wheat, respectively). Use of the bran finisher allowed evaluation of the wheats to a more extreme level than is usually achieved in test milling. It must be determined whether this approach improves discrimination between samples or is more commercially relevant in a Chinese context.

White flour color is desirable for traditional Chinese products such as steamed bread and noodles. The minimum requirements of Chinese white noodles are 80.00 for L^*b^* and -1.30 for a^* based on unpublished data from our laboratory. Five cultivars (Emai 12, Xuzhou 727, Mianyang 26, Yumai 18, and Ningmai 8) show the best dry flour color and all of them have soft kernel. Except for a slightly high b^* value, which could be caused by the wide spread of 1B/1R translocation in Chinese wheat (unpublished

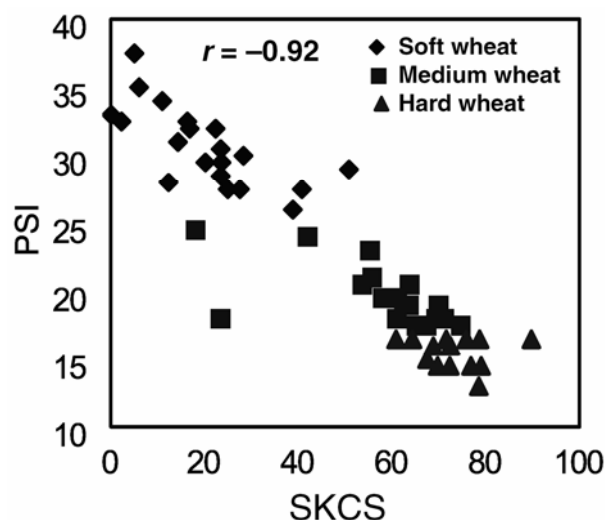


Fig. 1. Relationship between particle size index (PSI) and single kernel characteristic system (SKCS) grain hardness.

TABLE II
Mean Values and Standard Deviations of Milling Quality Parameters and White Noodle Color^a

Parameter	Grain Hardness		
	Hard (n = 15)	Medium (n = 21)	Soft (n = 21)
Test weight, kg/hL	79.8a (2.15)	80.8a (1.59)	80.0a (2.00)
1,000 kernel weight, g	43.0b (3.83)	46.8a (4.55)	44.9ab (5.85)
Hardness, PSI	15.5c (1.11)	19.7b (2.40)	30.7a (2.85)
Hardness, SKCS	73.2a (7.00)	57.5b (15.76)	20.3c (12.76)
Flour yield, %	79.0a (1.74)	80.0a (1.21)	79.0a (1.48)
Flour ash, %	0.66a (0.05)	0.64a (0.05)	0.61b (0.04)
Flour bran area	24.1b (0.07)	26.1ab (0.12)	34.7a (0.18)
Flour bran number	3.07b (1.07)	3.55b (2.08)	5.50a (3.04)
Flour protein, % (14% mb)	10.8b (1.02)	11.9a (0.91)	10.5b (1.06)
Flour color			
L^* _{flour}	91.26b (0.54)	91.24b (0.47)	92.03a (0.37)
a^* _{flour}	-0.21a (0.33)	-0.35a (0.30)	-0.29a (0.33)
b^* _{flour}	9.76a (1.56)	10.32a (1.55)	8.36b (1.19)
L^* _{slurry}	78.95a (0.61)	78.90ab (0.44)	78.58b (0.47)
a^* _{slurry}	-0.63a (0.35)	-0.66a (0.30)	-0.55a (0.40)
b^* _{slurry}	11.31a (1.80)	11.81a (1.46)	11.77a (1.43)
Flour color grade (FCG)	1.80b (0.87)	2.13ab (0.73)	2.54a (0.77)
Noodle sheet color			
L^*	78.37a (1.14)	77.75a (0.88)	78.16a (1.12)
a^*	2.56a (0.46)	2.65a (0.49)	2.57a (0.64)
b^*	24.56b (3.33)	26.64a (2.96)	24.80ab (2.81)

^a Values followed by the same letter are not significantly different ($P < 0.05$). Values in parentheses are standard deviations.

data from our laboratory), L^* and a^* values of Chinese winter wheat flour were similar to those of Australian wheat flour (Oliver et al 1992; Symons and Dexter 1992). Three hard wheat cultivars (Jinnan 17, Shaanyou 225, and Zhongyou 16) with high protein content and excellent breadmaking quality had the highest L^* - b^* value of flour-water slurry and could be used as parents in the crossing program to improve the flour color of Chinese wheat. The color of dry flour was significantly brighter than the color of the flour-water slurry. This was largely due to bran contamination darkening when wet, and endosperm greyness in flour-water pastes influencing flour slurry color (Barnes 1986). The reflection of light from the flour particles could be another reason.

A high proportion of variation for grain morphological characters, flour yield, ash content, and flour color in the tested cultivars was basically determined by genotype because all cultivars used in this experiment were sown in the same environment. The broad variation observed for these grain traits could result from the fact that wheat breeding programs in China have primarily focused on improving yield in response to the high demand for wheat by a large population during the last 50 years. No selection was made for quality parameters, particularly for milling quality traits. No testing for milling quality parameters is required before a cultivar is released, even at present. Therefore, the broad variation for milling quality parameters in Chinese germplasm is not unexpected, and substantial progress could be achieved in improving milling quality of Chinese wheat through genetic selection.

Relationship Among Milling Quality Traits

Correlation analysis indicated a very close association between PSI and SKCS hardness measurements (Fig. 1). This indicates that only one of these two methods is required. The SKCS is recommended as it provides additional measurements during the same testing. A very close relationship was also established between flour bran area and bran speck number ($r = 0.99$), suggesting that a single value of bran scan area is sufficient to describe bran contamination.

Further correlation analysis was performed separately between grain and flour measurements for soft cultivars (SKCS < 42) and for hard cultivars (SKCS > 42) as presented in Tables III and IV. As shown in Table III, test weight was significantly associated with TKW ($r = 0.47$), flour ash content ($r = -0.63$), flour protein content for hard cultivars ($r = 0.37$), and bran area for soft

cultivars ($r = -0.45$). This indicates that large size and non-shriveled kernels could contribute positively to reduction of ash content and bran area, which are desirable parameters for milling quality. SKCS hardness was negatively associated with TKW for hard and soft cultivars, where $r = -0.62$ and -0.54 , respectively. However, further study is needed to investigate the association between SKCS hardness and TKW. SKCS hardness was also negatively associated with flour yield and protein content for hard cultivars, where $r = -0.36$ and -0.50 , respectively. This shows, to some extent, that small kernels exhibit high grain hardness and decreased protein content and milling extraction rate. However, SKCS hardness was not significantly associated with flour yield for soft cultivars. This is in agreement with Gaines (1985). Several researchers have also reported significant correlations between flour yield and test weight (Shuey 1960; Dattaraj et al 1975; Zhou et al 2003), TKW (Dattaraj et al 1975; Flores 1989), and grain hardness (Bass 1990; Pomeranz and Williams 1990; Zhou et al 2003). Shellenberger (1965) and Kim et al (1995) reported a positive relationship between flour yield and flour ash content, but this was not confirmed in the present study.

Flour bran area was significantly correlated with flour yield and flour ash content for soft cultivars, where $r = 0.60$ and 0.46 , respectively, but not for hard cultivars. These results suggest that no simple trait can be used to select for flour milling performance.

Relationship Between Flour Color and Milling Quality Parameters

No significant relationship was observed between flour color grade (FCG) and dry flour color parameters including L^* , a^* , and b^* values (detailed data not presented). However, as indicated in Fig. 2, FCG was highly and significantly correlated with L^* value ($r = -0.95$), but not with a^* and b^* values of flour-water paste. This clearly indicated that FCG could be used as an indicator for L^* value of flour-water slurry.

As presented in Table IV, L^* value of dry flour was significantly correlated with flour yield ($r = -0.50$) for soft cultivars and was negatively correlated with flour ash and bran area ($r = -0.47$ and -0.65 for hard wheat, $r = -0.51$ and -0.72 for soft wheat, respectively). This suggests that high extraction rate leads to high ash and bran content, which subsequently contributes negatively to brightness of dry flour color.

TABLE III
Correlation Coefficients Among Kernel Characteristics, Flour Yield, Ash Content, Bran Area, and Flour Protein^{a-c}

	TW	TKW	SKCS	FY	FA	BA
TKW	0.47** (0.00)					
SKCS hardness	-0.28 (0.24)	-0.62** (-0.54*)				
Flour yield (FY)	0.23 (-0.28)	0.32 (-0.11)	-0.36* (0.03)			
Flour ash (FA)	-0.63** (-0.22)	-0.27 (-0.42)	0.23 (0.18)	-0.16 (0.04)		
Bran area (BA)	-0.34 (-0.45*)	0.11 (-0.39)	0.06 (0.17)	0.22 (0.60**)	0.28 (0.46*)	
Flour protein	0.37* (0.38)	0.42* (0.03)	-0.50** (0.45*)	0.27 (0.03)	-0.20 (-0.17)	-0.10 (-0.15)

^a Correlation coefficients for hard cultivars and soft cultivars (in parentheses), respectively.

^b TW, test weight; TKW, 1,000 kernel weight; SKCS, hardness from Single Kernel Characteristic System.

^c * and ** indicate significance at 5% and 1% probability levels, respectively.

TABLE IV
Correlation Coefficients Between Flour Color Parameters and Milling Quality Traits

Trait	L^*_{flour}	a^*_{flour}	b^*_{flour}	L^*_{slurry}	a^*_{slurry}	b^*_{slurry}	FCG
TW	0.33 (0.33)	-0.49** (-0.09)	0.40* (0.07)	0.20 (0.52*)	-0.16 (-0.02)	0.25 (-0.03)	-0.19 (-0.38)
TKW	-0.32 (0.37)	-0.17* (-0.56**)	0.35 (0.35)	-0.25 (0.07)	-0.01 (-0.55**)	0.26(0.44*)	0.30 (-0.07)
Flour yield	-0.24 (-0.50*)	-0.25 (0.29)	0.42 (-0.06)	-0.47** (-0.37)	-0.21(0.21)	0.42*(-0.11)	0.43* (0.36)
Flour ash	-0.47** (-0.51*)	0.10 (0.50*)	0.05 (-0.43)	-0.33 (-0.29)	-0.11(0.43)	0.11(-0.36)	0.22 (0.31)
Bran area	-0.65** (-0.72**)	0.39* (0.50*)	-0.13 (-0.20)	-0.47** (-0.75**)	0.31(0.51*)	-0.05(-0.21)	0.56** (0.73**)

^a Correlation coefficients for hard cultivars and soft cultivars (in parentheses), respectively.

^b TW, test weight, TKW, 1,000 kernel weight, FCG, flour color grade.

^c * and ** indicate significance at 5% and 1% probability levels, respectively.

The associations between a^* value of flour and test weight, TKW, flour ash, and bran area indicate that flour mineral content, bran specks, and contamination affect flour redness. However, test weight for hard cultivars had little effect on yellowness of flour ($r = 0.40$) in comparison with SKCS hardness, flour yield, protein content, ash content, and bran area. Therefore, dry flour color was mostly influenced by kernel size; flour extraction rate, flour ash, and bran contamination were mostly determined by wheat grain characteristics as well as milling process.

The color of flour-water slurry for hard cultivars was associated with flour yield and bran area; the correlation coefficients of flour yield with L^* and b^* values were -0.47 and 0.42 , respectively, and the correlation coefficient between L^* values with bran area was -0.47 . However, for soft cultivars, the color of flour-water slurry was largely determined by test weight, TKW, and bran area because significant correlations were observed between L^* values

with test weight ($r = 0.52$) and bran area ($r = -0.75$); a^* value with TKW ($r = -0.55$) and bran area ($r = 0.51$); b^* value with TKW ($r = 0.44$). FCG is highly significantly associated with bran area, with $r = 0.56$ and 0.73 for hard and soft cultivars, respectively. Significant association for hard cultivars between FCG and flour yield was also observed. This suggests that brightness of flour-water slurry and FCG could be important parameters in milling quality improvement for Chinese winter wheat as they are considered important in the prediction of flour performance in end products such as steamed bread and noodles. The present results are in agreement with previous reports (Barnes 1986; Oliver et al 1992; Kim and Flores 1999).

Relationship Between MQI and Flour Color Parameters and White Salted Noodle Color

Several analytical techniques such as measuring flour yield, flour ash content, flour color, color grade, and bran contamination are used by cereal chemists to assess flour quality, particularly for milling quality and flour performance in end product color. However, in the present study, hard and soft wheat differed in relationships among flour yield, flour ash content, flour color, color grade, and bran content. This makes it more difficult to determine the flour quality from these measurements. Therefore, a milling quality index (MQI) was used in this study to assess the relationship among flour yield, bran content, flour color, and white salted noodle color.

As presented in Table V and Fig. 3, MQI had a stronger association with flour color grade (FCG), L^* value of dry flour and flour-water slurry, and L^* and a^* values of white salted noodle sheets for hard and soft cultivars, respectively. For example, for soft wheat, the correlation coefficients were $r = 0.72$ between MQI and FCG, and $r = -0.72$ for L^* value of dry flour, $r = -0.74$ for L^* value of flour-water slurry, and $r = -0.67$ for L^* value of white salted noodle sheets. This indicates that high MQI will contribute negatively to brightness of flour and white salted noodles and be a very useful predictor for flour brightness and white salted noodle color from Chinese winter wheats.

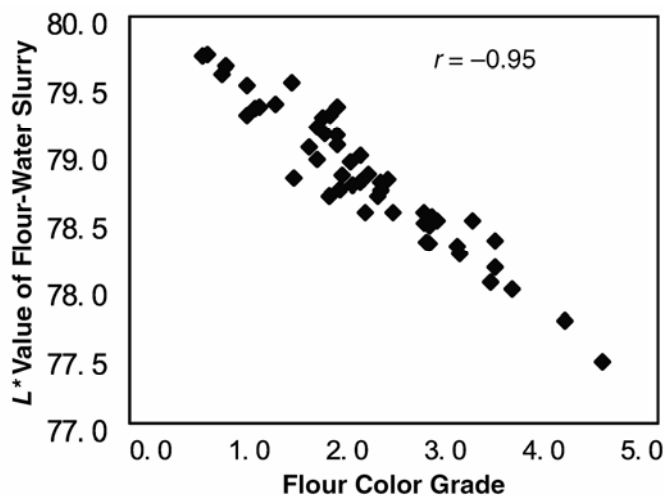


Fig. 2. Relationship between flour color grade and L^* value of flour-water slurry.

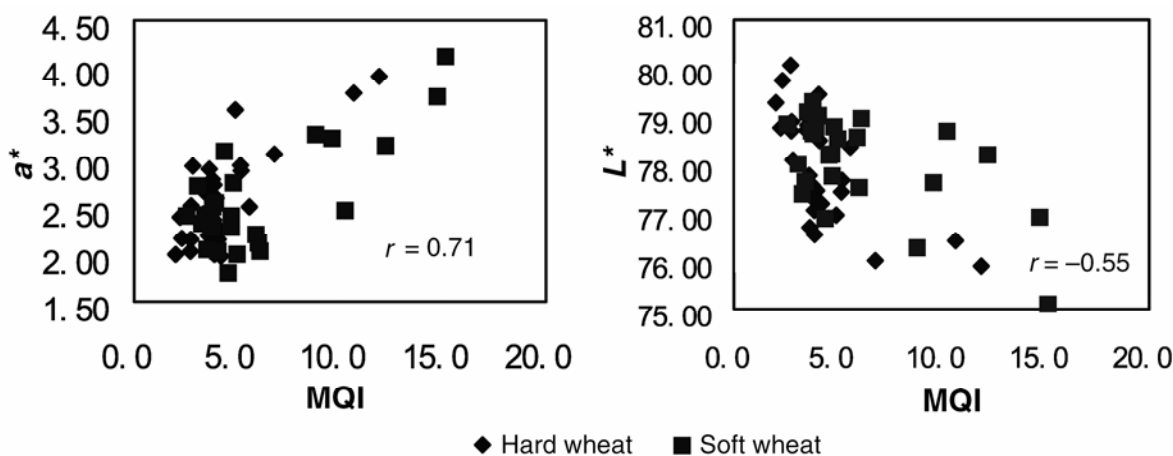


Fig. 3. Relationship between milling quality index (MQI) and a^* and L^* value of white salted noodle sheet.

TABLE V
Correlation Coefficients Between Milling Quality Index (MQI) and Flour Colour Parameters and White Salted Noodle (WSN) Color^a

Type	Flour		Flour			Slurry			WSN Sheet		
	Flour Ash	Color Grade	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*
Hard	0.32	0.53**	-0.60**	0.38*	-0.16	-0.44*	0.30	-0.07	-0.60**	0.69**	-0.28
Soft	0.44*	0.72**	-0.72**	0.51*	-0.20	-0.74**	0.51*	-0.20	-0.67**	0.79**	-0.38

^a * and ** indicate significance at 5% and 1% probability levels, respectively.

CONCLUSIONS

Chinese winter wheat cultivars are a mixed population in terms of grain hardness. They produced acceptable flour yield when using a bran finisher, accompanied by high ash contents and high levels of bran specks. Soft and hard wheat show significant differences in flour ash content, flour bran area, and flour color grade. No simple trait can be used to select for flour milling quality. High flour ash and bran content negatively affected brightness of dry flour. High flour color grade, high bran speck counts and contamination negatively affected brightness of flour-water slurry. A very close association between FCG and L^* value of flour-water slurry was observed. Strong associations were also established between MQI and FCG, L^* value of dry flour, flour-water slurry, and white salted noodle sheet for both hard and soft wheats. It is concluded that substantial progress could be achieved in improvement of milling quality in Chinese winter wheats through genetic selection. FCG and MQI could be two important parameters for evaluation of milling quality in breeding programs.

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