Time-Dependent Changes in Dough Color in Hexaploid Wheat Landraces Differing in Polyphenol Oxidase Activity

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Time-dependent changes in the color of noodle sheets (using 2% NaCl or 1% alkaline salts in the formulation) made from 43 Iranian hexaploid wheat landrace accessions were measured. Pekar slick tests in water and in alkaline conditions were also carried out. A wide variation in color characteristics of the landraces was found, with L^* values of salted noodle sheets at 2 h ranging from 80.9 to 89.2 and b^* values of alkaline noodle sheets at 2 h ranging from 19.1 to 27.4, showing potential application in noodle wheat improvement programs. For initial rapid screening of samples it was observed that a single reading of the dough sheet after 2 h was adequate. The dough sheets should be kept at 5 °C during storage, to prevent microbiological activity in the dough, which would give erroneous results. The Pekar slick test results were not highly correlated to color measurements on the dough, so this test is not recommended for screening for noodle color potential in landraces.

Keywords: *Dough color; polyphenol oxidase; noodle quality; Pekar slick test; wheat; landraces*

INTRODUCTION

Color, in addition to texture and flavor, is a critical sensory attribute governing the quality of the two major classes of Asian noodles, white salted noodles (WSN) and yellow alkaline noodles (YAN). Color and discoloration of dough are affected by genotypic and environmental effects on flour quality (soundness of wheat, protein content, color of wheat pericarp, inherent pigmentation, enzymes), flour processing conditions (milling extraction rate, starch damage), formulations and methods of preparation (addition of salts/alkali), and storage time and conditions (storage under refrigeration or at room temperature). Color is most critical in raw noodles, in which time-dependent darkening due to the enzyme polyphenol oxidase (PPO) may occur (Miskelly, 1984; Kruger et al., 1992). Discoloration of boiled or steamed noodles is not a major concern because PPO is easily denatured by the heat treatment and other darkening components present in the dough are leached out during the boiling process (Kruger et al., 1992). PPO is present mainly in the bran fraction of milled wheat, and its level rises with increasing extraction rate (Hatcher and Kruger, 1993). Baik et al. (1994) found that large, fully matured wheat kernels showed higher PPO activity than small, immature kernels and attributed this difference to enzyme synthesis in the maturing wheat. Park et al. (1997) found that the growing location contributed most to flour PPO activity, followed by grain size, milling yield, and flour ash content. During storage of raw noodles, gray discoloration may occur due to oxidation of free, reduced phenolic compounds to quinones, by PPO and peroxidase (PO), which are subsequently converted to dark melanins by polymerization and interaction with protein (Fortmann and Joiner, 1971; Miskelly, 1984; Vadlamani and Seib, 1996). PPO browning can be reduced/inhibited by use of modified atmosphere packaging (Faulkner, 1989), L-ascorbic acid (Baik et al., 1995), and heat and moisture treatment of wheat flours (Vadlamani and Seib, 1996).

Chinese yellow alkaline noodles are made from flour, water, and a solution of alkaline salts known as "kansui" (typically a 9:1 mixture of sodium and potassium carbonates or sodium hydroxide in some cases) (Moss et al., 1986). The alkaline salts confer a unique flavor and texture to the noodles and are responsible for imparting the typical yellow color, by detaching the flavones from starch and allowing their natural color to manifest (Miskelly, 1984). A bright, even, light yellow appearance, free of any darkening or discoloration, represents the generally preferred color profile (Miskelly and Moss, 1985). The degree of yellowness preferred varies regionally and may be manipulated by choice of flour type, use of additives, or addition of eggs to the formulation. Sources of high natural yellowness are desirable for use in some noodle formulations in which artificial colorants are presently added to impart high levels of yellowness to the product (D. Miskelly, Goodman Fielder Mills, personal communication).

Flour samples are often screened for desirable noodle color by making a dough sheet and measuring its color change after a fixed time interval, usually 24 h (S. Huang, California Wheat Commission, Woodland, CA, personal communication). The Pekar slick test is a rapid, time-saving alternative, commonly used by millers to identify bran contamination and other discoloration in flour samples, and has been used to predict noodle dough color (Miskelly, 1984). It involves wetting the flour samples and measuring the darkening due to enzyme activity after a suitable period of time. Significant correlation has been observed between the Pekar slick test and noodle sheet color (Miskelly, 1984; Collado and Corke, 1996). These approaches do not characterize variation among genotypes in the pattern of development of color over time (Corke et al., 1997). Moreover, the diverse formulations used in different classes of

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noodles probably have different effects on noodle color. Baik et al. (1995) studied the effect of time and temperature on the discoloration of WSN, YAN, and instant noodles and found that the change in brightness was relatively greater during the first 15 h in dough sheets stored at 23 °C than those stored at 4 °C.

Little information is available on the extent of genetic variation in wild or landrace wheat for potentially desirable noodle color traits, such as lack of darkening and extremes of yellow color development. We have conducted various studies on a collection of Iranian landraces, such as for desirable starch pasting properties in relation to noodle quality (Bhattacharya and Corke, 1996; Bhattacharya et al., 1997). The objectives of the present study on Iranian hexaploid wheat landraces were to (1) examine the variation in color change over time among genotypes, using different formulations and storage temperatures, (2) assess whether the WSN and YAN dough sheet color measurements of the landraces correlate with the Pekar slick test, and (3) identify landraces with desirable color for potential use in improving cultivated wheat noodle quality.

MATERIALS AND METHODS

Wheat Samples. The samples used for the study comprised 43 Iranian hexaploid wheat landraces and 4 commercial flour samples from Hong Kong. The landraces are part of a large base collection held at the University of California, Davis, and have been subjected to a series of previous studies (Jafari-Shabestari et al., 1995; Bhattacharya and Corke, 1996; Bhattacharya et al., 1997). The genotypes used in this study are referred to by their Iranian Wheat Accession (IWA) numbers as used at the University of California, Davis. Landrace samples were grown under uniform small-plot field conditions at the University of California, Davis, Agronomy Farm, under standard agronomic conditions. The four standard brand-name flour samples were obtained from Hong Kong Flour Mills, Kowloon, Hong Kong, and are commercially used for making different end-products. They were American Roses (AR), D brand (DF), L'arc De Triomphe (LDT), and Red Bicycle (RB). All commercial samples had an extraction rate of ~70% and an ash content of ~0.40%. The landraces were stored at 4 °C until required for use, then tempered overnight to 15% moisture, and milled to 70−72% extraction rate with a Brabender Quadrumat Jr. laboratory mill (Brabender OHG, Duisberg, Germany) fitted with a sieving screen covered with 6XX silk mesh. The protein contents of the flours were determined in duplicate by Standard Method 46-11A (AACC, 1995).

Measurement of PPO Activity. Oxygen consumption was determined using a YSI Model 5300 oxygen monitor (Yellow Spring Instrument Co., Yellow Springs, OH) following the procedure of Marsh and Galliard (1986), except that the temperature was raised to 37 °C. All values were corrected for substrate autoxidation, and the results were expressed as nanomoles of O_2 consumed per minute per gram at 37 °C. All PPO results are the average of triplicate assays.

Noodle Dough Sheet Preparation. WSN and YAN dough sheets were prepared following the guidelines of Toyokawa et al. (1989) with slight modifications to suit the small sample size. Flour (25 g, (db) was mixed with 8.5 g of either 2% salt solution (w/w) or kansui solution, made from Na_2CO_3 and K_2CO_3 (9:1) adjusted to achieve a 1% concentration (w/w) in flour. The mixture was manually kneaded in a bowl to obtain a smooth, homogeneous dough ball. The dough was covered with a moist cheesecloth and rested at room temperature for 30 min. The rested dough was sheeted using a domestic-type pasta machine (Atlas Electric Model 150, Marcato Co., Italy). Four sheeting steps were used with a 50% reduction at each step, and all sheeting operations were carried out in the same direction to give more strength to the noodle structure (Hoseney, 1990). The final dough sheet (12 cm × 9 cm × 2.5 mm) was stored in a sealed plastic bag immediately after processing, at either 5 or 25 °C for 48 h.

Dough sheet color was measured with a Minolta CR-300 chromameter (Minolta Camera Co., Ltd., Tokyo, Japan). Only Hunter L^* (a measure of brightness) and b^* (a measure of yellowness) results are reported. The noodle sheet was removed from the plastic bag, and readings were taken every hour for the first 10 h and then after 24 and 48 h. Measurements were made in triplicate at three locations on the surface of the noodle sheet.

Modified Pekar Slick Test. The Pekar slick (PS) test (Miskelly, 1984) was carried out as modified by Collado et al. (1997). Flour (5.0 g, db) and distilled water (40%, w/w) were mixed in a 100 mL beaker to obtain a homogeneous moist dough of uniform color. The mixture was transferred to a transparent plastic container (4.5 cm diameter × 2 cm height), smoothed to a flat surface, covered with a transparent lid, and incubated at ambient temperature for 2 h. Color measurements (Hunter L^*, b^*) were taken using the Minolta CR-300 chromameter.

The PS test was also carried out in the presence of salt and kansui, to study the effect of formulation on color change. For the salt PS test, the sample was mixed with 2% NaCl solution instead of water, to make the final concentration to 40%, and the test was carried out as described above. For the alkaline PS test, 1% kansui (Na_2CO_3/K_2CO_3, 9:1), was used instead of water.

Statistical Analysis. Data were analyzed with SAS software version 6.12 (SAS Institute, Cary, NC). The genotype means, standard deviation of genotype means (SD), and Fisher's least significance difference (LSD) to compare means at the 5% significance level were calculated. Pearson correlation coefficients were calculated using Statistica for Windows release 4.5 (StatSoft, Inc., Tulsa, OK).

RESULTS AND DISCUSSION

Biochemical Properties and Dry Flour Color Characteristics of the Flours. The protein contents of the commercial flours (standards) AR, LDT, RB, and DF ranged from 9.5% in LDT to 14.3% in RB, with a mean of 11.6% (Table 1). The PPO activity of the standards ranged from 45 nmol of O_2 min^{-1} g^{-1} in AR to 89 nmol of O_2 min^{-1} g^{-1} in DB. Similarly, the landraces displayed a range in protein, from 10.0% in IWA 8600942 to 16.0% in 8602664. The PPO activity ranged from 48 nmol of O_2 min^{-1} g^{-1} in IWA 8602164 to 170 nmol of O_2 min^{-1} g^{-1} in IWA 8600942, with the mean being 95 nmol of O_2 min^{-1} g^{-1}.

The color of dry flour is generally influenced by the extraction rate and granularity. Flours with finer particle size have been found to have brighter and whiter appearance than those with larger particle size. The dry flour L^* value of LDT was slightly the highest among the commercial samples, and the L^* values of AR, RB, and DB were similar to one another (Table 1). Among the landraces, IWA 8600527 had the highest dry flour color value (95.8), and it was comparable to the mean of the standards (95.5), whereas IWA 8600942 had the lowest value (89.9).

Modified Pekar Slick (PS) Test. The brightness (L^* value) of the standards, in water, salt, and alkali, varied between 77.6 and 79.3, between 77.7 and 80.7, and between 78.1 and 80.0 respectively, but that of the landraces varied more widely from 70.5 to 81.6, from 71.2 to 82.0, and from 68.0 to 82.2, respectively (Table 1). IWA 8600170 was the darkest in all three conditions. The yellowness (b^* value) of the commercial samples in water, salt, and alkali ranged from 7.4 to 9.7, from 7.2 to 9.1, and from 12.3 to 13.7, respectively, whereas

Table 1. Biochemical Properties and Pekar Slick Color (in Salt, Water, and Alkali) of 4 Standard and 43 Landrace Wheat Samples

accession	PPO	protein, %	dry flour *L**	Pekar slick *L**			Pekar slick *b**			dough *L**		dough *b**	
				salt	water	kansui	salt	water	kansui	salt	kansui	salt	kansui
standards													
American Rose (AR)	45	10.1	95.3	79.0	79.3	78.1	7.2	7.4	12.3	89.5	89.4	9.5	15.1
L'arc de Triomphe (LDT)	56	9.5	96.4	80.7	79.0	79.2	7.2	8.3	12.7	88.4	87.6	9.3	15.8
Red Bicycle (RB)	71	14.3	95.2	78.6	77.6	78.6	8.1	7.8	12.4	87.6	86.7	11.1	16.0
D flour (DF)	89	12.4	95.2	77.7	77.7	80.0	9.1	9.7	13.7	86.4	86.3	11.9	16.4
mean	**65**	**11.6**	**95.5**	**79.0**	**78.4**	**78.9**	**7.9**	**8.3**	**12.8**	**86.3**	**86.0**	**11.6**	**16.5**
landraces (in order of increasing PPO)													
8602164	48	13.3	94.5	79.9	77.6	79.5	8.1	7.8	12.4	86.4	87.8	16.4	20.5
8600609	50	11.2	93.6	72.2	73.6	73.1	13.1	13.9	18.6	86.1	87.4	14.3	20.5
8602448	54	12.6	94.6	78.4	77.5	78.5	8.2	7.9	12.4	87.8	87.7	16.6	22.9
8602105	57	11.2	94.7	81.4	77.7	78.9	16.9	17.2	20.1	88.5	88.7	16.9	20.3
8602566	69	11.7	93.9	77.8	79.7	77.4	13.6	13.5	19.7	84.4	83.3	15.5	23.6
8602176	70	11.6	93.3	76.3	76.4	76.5	11.2	10.6	12.4	85.1	87.1	12.6	17.8
8600276	70	12.5	93.6	77.0	77.5	80.9	18.0	18.6	23.1	87.9	85.6	19.8	25.6
8600411	71	14.7	92.1	79.9	80.1	79.0	12.4	12.1	19.4	85.4	84.1	14.6	20.7
8600903	71	10.3	93.7	74.1	79.4	74.4	11.3	12.7	15.6	85.1	84.1	14.7	22.0
8602664	73	16.0	93.4	77.6	79.4	79.0	13.8	15.0	21.2	83.8	84.4	14.2	22.2
8600908	74	12.1	95.5	80.1	79.5	82.2	12.9	12.1	19.3	85.5	87.7	15.0	19.4
8600560	76	12.0	93.2	79.5	80.2	79.0	15.7	16.5	20.8	85.8	85.1	16.3	25.1
8602466	77	12.1	94.1	79.8	80.2	76.0	15.9	15.0	21.2	87.9	86.4	15.5	20.2
8600633	79	12.1	93.8	79.5	78.8	78.3	14.0	13.6	20.2	83.0	85.0	16.2	23.2
8602580	79	13.4	93.3	77.0	80.2	77.5	14.5	16.5	20.3	82.9	82.7	16.4	21.5
8600107	82	12.9	95.0	74.1	72.9	77.5	10.2	10.4	16.0	84.6	84.7	13.9	19.1
8600495	85	10.8	93.4	77.5	76.4	77.5	8.3	8.0	12.6	86.6	86.2	17.3	22.4
8600505	86	12.0	94.4	79.2	77.1	78.6	17.0	16.3	22.3	85.4	86.8	17.4	21.4
8600169	86	13.3	93.9	79.2	78.5	77.2	16.2	15.0	20.6	84.3	83.6	15.6	22.2
8600989	87	11.3	95.3	79.9	81.6	79.8	10.8	11.6	18.2	86.6	88.3	12.2	19.5
8602717	89	13.0	93.1	82.0	79.1	79.2	12.1	13.3	19.6	82.7	82.1	19.1	25.2
8600150	90	12.5	94.0	80.5	81.3	77.7	13.6	14.5	18.7	85.5	84.7	13.7	20.0
8600689	91	11.1	93.2	77.6	77.6	80.6	13.9	14.3	19.3	85.8	87.1	16.7	23.2
8602690	92	12.1	95.4	78.4	78.4	79.1	13.2	13.0	20.7	88.4	87.9	14.7	20.0
8600527	94	11.1	95.8	76.8	76.3	75.1	14.6	14.2	18.7	86.3	88.3	17.1	19.5
8600108	94	13.7	93.3	74.5	71.2	74.5	14.2	13.5	14.8	83.5	84.4	16.9	23.6
8600945	95	10.5	92.4	79.0	79.1	77.0	7.3	7.4	13.6	89.2	84.6	17.2	23.2
8602571	95	14.7	95.7	78.4	79.3	79.4	12.9	13.2	19.1	85.9	86.0	15.3	20.6
8600083	98	13.4	94.1	78.0	75.9	75.0	13.9	13.7	21.1	85.7	85.5	14.2	20.5
8600506	99	12.9	93.8	74.7	72.6	74.7	16.1	15.1	19.0	82.4	83.4	19.2	24.7
8600257	100	12.5	92.8	77.9	77.2	80.2	18.2	18.2	23.1	82.4	84.4	20.4	27.4
8600173	108	15.1	92.7	79.6	76.6	75.6	15.2	14.2	19.4	84.6	82.6	17.1	22.5
8600940	110	11.8	93.2	79.0	80.0	79.2	16.0	17.5	21.9	83.2	85.3	18.5	24.7
8600154	112	14.6	93.5	76.7	77.2	76.7	17.2	16.9	23.1	83.7	84.0	18.6	24.6
8600170	114	10.5	92.2	71.2	70.5	68.0	12.7	13.0	15.2	80.9	81.0	19.1	28.9
8602102	124	11.2	93.3	77.7	74.2	75.0	14.6	13.7	16.9	85.3	84.0	16.9	23.5
8600611	125	13.1	93.5	76.2	78.3	76.0	16.5	18.1	22.7	81.7	82.2	20.3	27.4
8602463	130	10.3	93.8	79.8	80.0	78.3	14.3	14.0	20.4	85.6	86.7	14.3	19.7
8600949	130	13.1	94.3	75.8	74.4	77.4	15.4	15.0	20.2	85.7	86.0	18.5	23.0
8600211	150	10.1	93.4	76.6	76.0	77.1	15.4	16.1	20.4	83.0	82.5	16.7	22.5
8600183	150	14.7	93.4	80.2	76.8	77.4	15.0	15.6	22.6	80.9	85.9	17.4	23.8
8600161	163	13.4	92.4	75.8	77.1	76.4	18.4	19.6	23.3	82.1	83.0	19.5	25.2
8600942	170	10.0	89.9	73.5	71.8	72.4	15.7	15.6	18.3	82.1	82.9	19.0	23.3
mean	**95**	**12.4**	**93.7**	**77.7**	**77.3**	**77.3**	**13.9**	**14.0**	**19.0**	**84.9**	**85.1**	**16.5**	**22.5**
LSD (0.05)	13.3	0.5	0.1	0.5	1.8	0.6	0.2	0.2	0.3	0.6	0.5	0.4	0.6

that of the landraces ranged from 7.4 to 19.6, from 7.3 to 18.4, and from 12.4 to 23.3, respectively, with IWA 8600161 showing the highest *b** in all three conditions. The ranking for brightness differed in the presence of water, salt, and kansui, implying that it would be better to carry out the PS test in the presence of salt and kansui, rather than water alone, when testing is done for the suitability of flours for making WSN and YAN, respectively. In general, the final end product for which the flour is intended should be considered carefully, and the PS test should be carried out in the presence of the necessary formulation to maximize the chance of useful results.

AR and LDT flour paste had the highest brightness in the presence of water and salt, probably due to their low protein and ash contents and inherently low PPO content. AR also had the lowest yellowness among the standards. Moss (1971) found that brightness of Japanese noodles was inversely proportional to flour protein content. Miskelly (1984) showed that flour paste brightness was inversely correlated with protein and ash content and directly proportional to starch damage, whereas flour paste yellowness was negatively correlated with protein and starch damage and positively correlated with ash content. Similar results were reported by Kruger et al. (1992) for Cantonese noodle color.

Noodle Sheet Color Change over Time. To monitor the color change in raw WSN and YAN over time, the color of noodle dough sheets containing 2% salt or

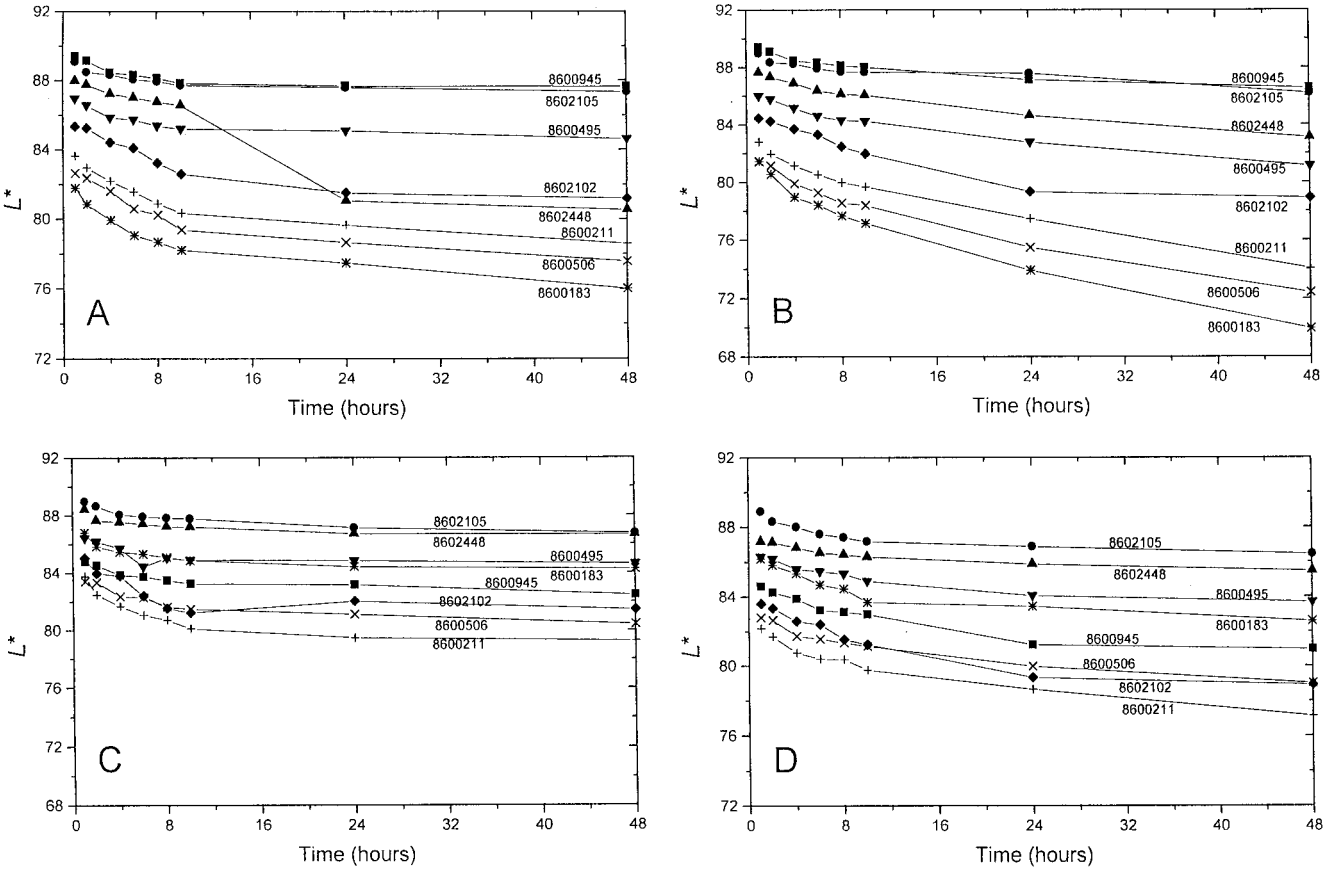

Figure 1. Changes in *L** (brightness) of noodle sheets over time: (A) 2% salt, 5 °C; (B) 2% salt, 25 °C; (C) 1% kansui, 5 °C; (D) 1% kansui, 25 °C.

1% kansui was recorded every hour for the first 10 h, followed by a reading after 24 and 48 h. The dough sheets were stored at 5 and 25 °C (ambient temperature) to test the effect of temperature on color change. Of the commercial samples, AR and LDT had the highest *L** values, followed by RB and DB (Table 1). It is apparent that low PPO activity along with low protein and ash contents gave brighter noodle color in contrast to high-protein flours. The brightness of the noodle sheets over time was more stable at 5 than 25 °C, especially in WSN. After 24 h, the *L** values of the WSN sheets dropped drastically when stored at 25 °C. Similar results were reported by Baik et al. (1995). In contrast, the brightness of the YAN sheets, although lower than that of the WSN sheets due to the presence of alkaline salts, reduced very gradually, and there was no significant difference in the *L** values of sheets kept at 5 and 25 °C, even after 48 h, implying that the alkaline salts have some inhibitory effect on the discoloration causing enzymes. Thus, different formulations seem to have different effects on dough brightness, and this was taken into account when the landrace genotypes were screened for noodle color. A large shift in the *L** values was observed in the first 2 h in the presence of both salt and alkali, after which time the values remained relatively stable. A similar trend was reported by Kruger et al. (1992) for noodle brightness. They speculated that water distribution changes altering the surface characteristics were probably responsible for the reflectance difference in the dough during the first few hours. Baik et al. (1995) also noted that discoloration changes are rapid during the first 3 h of sheeting, which was attributed to varied levels of water absorption, which in turn was a function of the protein content of the flour samples. These effects are analyzed below in more detail for the landraces.

Figure 1 shows the extent of variation over time in the *L** values observed in the landraces (only the extreme genotypes are presented in the figure). IWA 8600945 and 8602105 had the highest *L** values in the presence of salt, their values being similar to that of AR, which had the highest brightness among the commercial samples. Moreover, the brightness of these two landraces remained stable even when stored at 25 °C for 48 h, unlike the standards, which showed a dulling effect with time. This suggests that these genotypes could be exploited for improving the noodle color of existing commercial cultivars. Genotype 8602488 also showed very high *L** values in the presence of salt and kansui, but while the color remained high and stable in kansui, there was a drastic drop in brightness after 10 h in the WSN sheet (Figure 1A,B). The yellowness (*b** value) of this genotype was low in WSN sheet and bright yellow in YAN sheet. In a previous study we found that this genotype had the highest paste viscosities among the landrace collection screened (Bhattacharya et al., 1997). Its desirable starch pasting properties, coupled with its good color characteristics, indicate that this genotype also has potential application as a resource for breeding noodle wheat. Genotype 8600495 displayed a high *L** value, which remained exceptionally stable at 5 °C after 48 h in WSN sheet, but the color darkened after 10 h when stored at 25 °C. In general, the change in brightness was more gradual for all genotypes when stored at low temperature than at ambient temperature.

Table 2. Correlations among Time of Dough Color Measurement and Dough Formulation for *L (Lightness) [All Values Are Significant ($p < 0.001$, $n = 43$)]**

	dough sheet color (*L* value) in the presence of 2% salt at 5 °C						dough sheet color (*L* value) in the presence of 2% salt at 25 °C					
	1 h	2 h	4 h	6 h	10 h	24 h	1 h	2 h	4 h	6 h	10 h	24 h
						Dough Sheet Color (*L* Value) in the Presence of 2% Salt at 5 °C						
1 h	1.00						0.98	0.98	0.97	0.97	0.97	0.96
2 h	0.99	1.00					0.97	0.98	0.97	0.97	0.97	0.96
4 h	0.98	0.99	1.00				0.98	0.99	0.99	0.99	0.99	0.98
6 h	0.98	0.99	0.99	1.00			0.97	0.99	0.98	0.99	0.99	0.98
10 h	0.96	0.97	0.98	0.99	1.00		0.96	0.98	0.98	0.98	0.98	0.98
24 h	0.93	0.93	0.95	0.95	0.95	1.00	0.93	0.94	0.94	0.94	0.94	0.95
						Dough Sheet Color (*L* Value) in the Presence of 2% Kansui at 5 °C						
1 h	0.70	0.68	0.69	0.68	0.68	0.61	0.70	0.68	0.70	0.69	0.68	0.66
2 h	0.71	0.70	0.71	0.71	0.71	0.65	0.71	0.70	0.71	0.71	0.70	0.69
4 h	0.72	0.71	0.72	0.71	0.71	0.64	0.72	0.71	0.72	0.71	0.70	0.69
6 h	0.70	0.68	0.70	0.69	0.70	0.63	0.70	0.69	0.70	0.69	0.68	0.67
10 h	0.69	0.67	0.68	0.68	0.69	0.62	0.69	0.67	0.68	0.67	0.67	0.66
24 h	0.70	0.69	0.70	0.69	0.70	0.63	0.69	0.68	0.69	0.68	0.68	0.67
						Dough Sheet Color (*L* Value) in the Presence of 2% Kansui at 25 °C						
1 h	0.71	0.70	0.70	0.69	0.69	0.64	0.71	0.70	0.71	0.69	0.68	0.68
2 h	0.72	0.71	0.71	0.70	0.70	0.64	0.71	0.70	0.71	0.70	0.69	0.67
4 h	0.73	0.71	0.72	0.72	0.72	0.66	0.73	0.72	0.72	0.71	0.70	0.69
6 h	0.73	0.72	0.73	0.73	0.73	0.67	0.73	0.72	0.73	0.72	0.71	0.70
10 h	0.74	0.72	0.73	0.73	0.73	0.67	0.73	0.72	0.73	0.72	0.71	0.70
24 h	0.72	0.70	0.72	0.71	0.72	0.65	0.71	0.71	0.71	0.71	0.70	0.69

Table 3. Correlations of Dough Color Measurements (*L and *b**) for Different Dough Formulations with Flour Parameters and Pekar Slick Values[a]**

				Pekar slick (*L** value)			Pekar slick (*b** value)		
landrace dough sheet color after 2 h	protein, %	PPO	dry flour *L**	salt	water	kansui	salt	water	kansui
*L** (2% salt, 5 °C)	−0.35*	−0.56 ***	0.47**	0.34*	0.32*	0.37*	−0.38*	−0.49***	−0.29
*L** (2% salt, 25 °C)	−0.32*	−0.51***	0.42**	0.34*	0.33*	0.39*	−0.33*	−0.44**	−0.24
*L** (2% kansui, 5 °C)	−0.09	−0.45**	0.64***	0.32*	0.22	0.46**	−0.25	−0.36*	−0.17
*L** (2% kansui, 25 °C)	−0.12	−0.41**	0.64***	0.33*	0.23	0.43*	−0.26	−0.39**	−0.18
*b** (2% salt, 5 °C)	−0.11	0.45**	−0.42**	−0.18	−0.34*	−0.34*	0.47**	0.47**	0.30*
*b** (2% salt, 25 °C)	−0.02	0.45**	−0.44**	−0.16	−0.29	−0.29	0.49***	0.51***	0.34*
*b** (2% kansui, 5 °C)	0.01	0.37*	−0.52***	−0.26	−0.26	−0.26	0.37*	0.44**	0.27
*b** (2% kansui, 25 °C)	0.04	0.32*	−0.56***	−0.25	−0.28	−0.28	0.33*	0.41**	0.25
*L** value of dry flour	0.17	−0.44**	1.00	0.28	0.28	0.28	−0.17	−0.29	−0.02

[a] Significant at $p < 0.05$ (*); $p < 0.01$ (**); $p < 0.001$ (***).

The changes in the *b** values of the landrace genotypes were very different from the standards. In the presence of salt, the landraces showed no significant difference in their color change over time, at both low and room temperatures (data not shown). However, in the presence of kansui, two notable trends were observed. Most of the landraces showed a substantial increase in their *b** values in the first 2 h and remained stable thereafter, like the standards. A few genotypes, for example, IWA 8602105, increased exponentially with time during the first 24 h and then remained constant. The phenomena involved in these changes remain unclear, although it may be speculated that the reaction time between the alkaline salts and the flavone compounds present in the dough may differ among genotypes, and as the reaction proceeds, the yellowness increases. Moreover, the enzyme activity of PPO plays a major role in the increase in brightness and yellowness over time (Kruger et al., 1994).

Table 2 compares the brightness of WSN and YAN dough sheets made from the landrace genotypes. We sought to determine whether (1) the readings at different time intervals were comparable with each other and (2) the readings of WSN and YAN were comparable with one another. It was observed that the *L** values of WSN sheet stored at 5 °C correlated very highly with each other at all time intervals and also with the *L** values of WSN sheets stored at 25 °C. However, although the *L** values of YAN sheets correlated significantly with that of the WSN sheets, these values (around $r = 0.70$) are not high enough to ensure confidence in routine screening. Similar or higher correlations were observed between WSN and YAN sheet for the *b** value readings at different times and temperatures (data not shown). For example, dough sheet *b** at 2 h at 5 °C in the presence of 2% kansui was correlated ($r = 0.83$) to that at 2 h at 5 °C in the presence of 2% salt. Because the readings at each time interval were highly correlated with each other, a single reading at 2 h may be recommended for rapid screening of samples. However, for more advanced breeding lines, a second confirmatory reading after 24 h seems to be a more practical approach, as color stability for at least 24 h is a prerequisite for good-quality raw noodles. Kruger et al. (1992) also recommended measuring color more than once for raw Cantonese noodles, because the rate of color change may vary from genotype to genotype. Ross and Pudney (1994) also reiterated the importance of assessing the color of Oriental noodles after 24 h for objective testing.

Correlations among dough sheet color measurements after 2 h and the biochemical properties and Pekar slick test of the landraces were calculated (Table 3). Significant negative correlation between protein content and the *L** value of WSN sheet was seen at both tempera-

tures. There was no relationship between protein and YAN dough brightness or yellowness of WSN and YAN sheets. This is in contradiction to the findings of Miskelly (1984) and Kruger et al. (1992), who reported a high negative correlation between protein and brightness and yellowness of noodles. PPO content was highly negatively correlated with the *L** value of dry flour and WSN and YAN sheet color and positively related to the *b** value of the dough sheets. The *L** value of dry flour correlated significantly with the *L** values and negatively with the *b** values of WSN and YAN dough sheets. It also showed high negative relation to the PPO content.

The noodle dough brightness and yellowness of the commercial samples were generally highly correlated with the PS test *L** and *b** values, implying that the PS test in water is sufficient at predicting the dough color of both WSN and YAN. However, the landraces did not show similar results (Table 3). The *L** values of both WSN and YAN sheets of landraces showed low but significant correlation with salt and alkaline PS test, whereas the normal PS test (in water) showed correlation only with the WSN brightness. The *b** value of the PS test done in water correlated much more significantly with dough sheet brightness than salt or alkaline PS test. As expected, the *b** value of dough sheets did not correlate with the *L** value of the PS test, except for a low correlation between WSN sheet brightness when stored at 5 °C, and the kansui and water PS test. In contrast, the *b** values of the WSN and YAN dough sheets correlated very highly with the PS test, especially in the presence of salt and water. For reasons that are not clear, the yellowness of the alkaline PS test showed positive correlation with the *b** value of WSN dough sheet but no correlation at all with the *b** value of YAN dough sheet, unlike the high correlation seen by Miskelly (1984). Correlations were also calculated between the *b** value of alkaline PS and *b** value readings of YAN sheet recorded from 0 to 48 h, to see if the time factor played any significant role, but here again no correlation was seen (data not shown). It is speculated that the landrace genotypes may have other enzymes acting on the dough to influence the browning effect, which is not attenuated in the alkaline PS test. The results of the commercial samples are in agreement with what has been reported earlier, probably because all previous work on noodle color has essentially been done on either commercial varieties or advanced breeding lines that have been screened for other undesirable traits. The landraces, on the other hand, are unadapted lines, harboring both desirable and undesirable traits in them. Further work needs to be done on the genetic basis of noodle color in landraces before any conclusive interpretations can be made.

Conclusions. Preliminary screening of the Iranian landraces revealed a wide variation in their color characteristics and showed potential application for use of certain lines to improve color in noodle wheat improvement programs. For initial rapid screening of samples it is observed that a single reading of the dough sheet after 2 h is adequate. Separate testing of salted and alkaline noodle dough sheets is recommended during routine screening. The dough sheets should preferably be kept at 5 °C during storage. The Pekar slick test did not prove to be suitable for predicting noodle color of unimproved landrace genotypes.

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