Effects of Protein Content and Composition on White Noodle Making Quality: Color[1]

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ABSTRACT

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Wheat cultivars, representing three winter and three spring wheats were grown in western Canada with six levels of nitrogen fertilizer and flours were prepared from them with an extraction rate of 65%. Using a chromameter, flour color and the color of uncooked white noodle sheets made from these flours with different resting times were assessed. The cooked noodle sheet color was also assessed. While protein content initially declined with added nitrogen and increased with further nitrogen addition, brightness (L^*) of flour decreased and redness (a^*) and yellowness (b^*) increased. Positive correlation coefficients of flour brightness with particle size index (PSI) were also observed. Flour redness (a^*) and yellowness (b^*) were also affected by flour moisture content, whereas L^* values were not significantly correlated with moisture contents. For the uncooked white noodle sheet, as protein content increased brightness decreased but there was an increase in a^* and b^* values. Thus, the L^* value for noodle sheets was negatively correlated with the a^* and b^* values. The percentages of monomeric protein and soluble glutenin in flour were equal to or better than protein content in relation to most noodle sheet color characters. Uncooked noodle sheet brightness decreased, while redness and yellowness increased with rest time. In general, uncooked white noodle sheets prepared from different wheat flours can be ranked in terms of brightness and yellowness within each level of nitrogen fertilization.

About 40% of wheat products in Asian countries are consumed in the form of noodles (Crosbie 1991). Noodle appearance is a key quality determinant of white salted noodles prepared from wheat flour, followed by cooked noodle texture. The most extensively studied white salted noodle type is Japanese udon, but Chinese and Korean white noodles have also received some consideration (Hou 2001). Although all types of white noodles are made using only flour, water, and salt, the traditional and regional preferences for each vary markedly in texture but only slightly in appearance.

All types of noodles require good brightness, and for Asian consumers the best noodle color is a bright creamy white with the absence of any discoloration. Noodle color and discoloration can depend on several factors such as intrinsic flour color (Miskelly 1984), ash content (Crosbie et al 1990), flour extraction rate (Yasunaga and Uemura 1962; Hatcher and Symons 2000), flour particle size (Hatcher et al 2001), sprout damage (Kruger et al 1995), protein content (Miskelly 1984), and enzyme activity (Hatcher and Kruger 1996).

The flour for Japanese white noodles is predominantly made from relatively soft wheat of low to medium protein levels (8–10%), low flour ash content (0.36–0.40%), low levels of damaged starch, and a good color grade (Nagao et al 1977; Crosbie et al 1990), giving a bright, creamy appearance to the noodles. The lower content of damaged starch suggests that wheat hardness and granularity of the flour may be important. Entire starch granules reflect more light, and this reflectance decreases with increasing starch damage in the milling process. Therefore, flour color $L^* > 90$ measured with a Minolta chromameter is often required (Hou 2001). Because flour extraction rate and flour color are closely related to ash content, the latter is widely used as a key element in development of specifications for noodle flours. However, color appeared to be influenced more by protein than by ash content because color had a better correlation with both protein content in flour (Miskelly 1984) and white noodles (Jun et al 1998).

In an evaluation of the quality of Japanese noodles made from different wheat cultivars, Moss (1971) found that brightness was inversely proportional to flour protein content. Low protein resulted in a less tough and lighter colored dough for noodle formation (Oh et al 1985). Toyokawa et al (1989) carried out a fractionation and reconstitution interchange of gluten, primary starch, tailing starch, and water solubles to investigate the role of each in Japanese noodle quality. They found that the gluten fraction of the flour mainly affected white noodle color.

In addition to the effects of protein content on flour and end-product color, protein content also affects the water activity of a dough, which in turn influences the discoloration of noodle dough (Baik et al 1995). Discoloration was associated with the degree of darkening developed by gluten washed from the samples after drying under standard conditions (Moss 1971). Within cultivars, discoloration of noodles was affected more by protein than by enzymes such as polyphenol oxidase (Baik et al 1995). Across cultivars that varied widely in protein content, discoloration was affected more by cultivar-governed enzymes than by protein levels.

Our objective was to evaluate the effects of protein content and quality on flour and noodle color by using samples with wide variation in protein content obtained from wheat cultivars grown with different levels of nitrogen fertilization. In addition, the differences of noodle sheet color between tested samples and a commercial udon sample were investigated.

MATERIALS AND METHODS

Samples

Flours with 65% extraction rate were Buhler-milled from three spring and three winter wheat cultivars grown at six fertilizer levels (0, 40, 80, 120, 160, and 240 kg of nitrogen/ha) applied as ammonium nitrate (34-0-0) at Sasktoon, SK, Canada, for each of two years (1994 and 1995) (Tables I and II). The cultivars were chosen to represent quality types and protein content ranging from low protein soft white winter wheat (SWW) and Canada Western Soft White Spring (CWSWS) to Canada Western Red Winter (CWRW), and finally to high protein Canada Hard Red Spring (CWRS) wheat. The spring wheat cultivars were AC Reed (CWSWS), Katepwa (CWRS), and Roblin (CWRS), while the winter wheat cultivars were S86-375 (SWW), Norstar (CWRW), and Winalta (CWRW). Fowler (1998) described their growth conditions, nitrogen fertilization rates, yields, and resulting protein content. Seventy-two flour samples obtained following the above trials were stored in sealed plastic bags at –5°C until used.

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Commercial Japanese white noodle flour (udon) milled from Australian Standard White Noodle wheat with an extraction rate of ≈50–60% was provided by Nippon Flour Mills, Japan, and this flour was used for comparison.

Moisture, protein content, and particle size index (PSI) were previously determined (Fowler et al 1998). Protein fractions were determined by turbidity measurement as described by Wang and Kovacs (2002a). Quality parameters including protein content, protein fraction content, and PSI are presented in Tables I and II.

Flour Color Assessment

Flour color was measured in triplicate using a chromameter (model CR210, Minolta, Osaka, Japan) with the granular materials attachment, and brightness (L^*), redness (a^*), and yellowness (b^*) values were taken.

Noodle Sheet Preparation

The noodle sheet (40 g of flour) was prepared using the procedure described by Wang and Kovacs (2002b) on a bench-top machine (Kovacs et al 2003). Constant water absorption (32% based on flour with 14% mc) was used for noodle sheetmaking. The final noodle sheet was placed in a plastic bag closed with a rubber band and held at room temperature (23–25°C) for color measurement.

Noodle Sheet Color Measurement

L^*, a^*, and b^* values of noodle sheets were measured using the chromameter at 0, 2, and 24 hr after dough sheets were made. Color measurements were made in three locations on a dough sheet. After the 24-hr measurement, the noodle sheet was cooked in 500 mL of distilled water to the optimum cooking time as determined with noodles (Wang 2003). The cooked noodle sheets were placed in 300 mL of distilled water (room temperature) for 5 min and then drained. Excess water on the surface of the noodle sheet was gently wiped off with filter paper. Cooked noodle sheet color was measured using the Minolta chromameter in three locations across the cooked dough sheet.

Statistical Analysis

Data were statistically analyzed using SAS software (v. 8.2, SAS Institute, Cary, NC) for computing Fisher's least significant difference (LSD) of multiple comparisons, Pearson's correlation coefficients, multivariate analysis of variance (MANOVA), and multiple stepwise regressions.

RESULTS AND DISCUSSION

Effects of Flour Protein Content and Characteristics on Flour Color

As with all food products, the quality of the starting material (flour) dictates the performance of the final end product (noodles). Flour color is regarded as one of the most important factors in assessing the value of flour for Japanese udon noodles (Miskelly 1984).

The flour color characteristics obtained are shown in Table III. Almost all L^* values were >90, which indicated the flour extraction rate used in this study satisfied the Japanese requirements for noodle production (Hou 2001). However, test L^* values <90 were

TABLE I
Protein Parameters and PSI for 1994 Test Samples[a]

Cultivar and Class	N Rate	Pro	MPF	SGF	IGF	PSI
Katepwa CWRS	0	10.6	5.29	1.34	3.16	60.6
	40	9.9	4.94	1.24	2.86	58.4
	80	10.4	5.45	1.29	2.88	58.9
	120	11.9	6.62	1.50	3.27	59.1
	160	12.5	6.96	1.52	3.23	59.1
	240	12.7	7.14	1.63	3.25	58.1
Roblin CWRS	0	11.0	5.33	1.33	3.27	65.8
	40	10.1	4.70	1.25	3.15	64.9
	80	11.1	5.56	1.53	3.37	63.6
	120	12.5	6.47	1.70	3.55	62.3
	160	13.3	6.87	1.87	3.78	63.4
	240	13.6	7.00	1.96	3.77	61.2
AC Reed CWSWS	0	7.3	4.01	1.02	1.76	75.2
	40	7.1	3.88	1.02	1.58	74.5
	80	7.7	4.29	1.18	1.63	74.4
	120	8.5	4.94	1.33	1.78	72.0
	160	8.9	5.09	1.49	1.84	75.5
	240	9.1	5.22	1.50	1.84	73.7
Norstar CWRW	0	10.1	5.48	1.01	2.83	67.2
	40	8.5	4.44	0.76	2.63	69.0
	80	8.6	4.54	0.85	2.60	66.5
	120	9.9	5.33	1.18	2.87	67.5
	160	10.7	5.54	1.40	3.06	65.2
	240	11.7	6.10	1.61	3.28	68.0
S86-375 SWW	0	7.9	4.85	0.54	2.10	77.8
	40	7.5	4.26	0.61	2.08	77.6
	80	7.7	4.26	0.70	2.16	76.5
	120	8.4	4.69	0.91	2.17	76.2
	160	9.1	5.09	1.07	2.15	75.4
	240	9.8	5.28	1.27	2.38	75.9
Winalta CWRW	0	10.4	5.28	0.95	3.20	68.6
	40	9.1	4.57	0.86	3.01	67.6
	80	9.2	4.56	0.94	3.14	66.1
	120	10.6	5.03	1.36	3.36	66.4
	160	11.3	5.50	1.41	3.61	66.0
	240	11.9	5.62	1.62	3.72	67.3

[a] Pro, protein content; MPF and MPP, % of monomeric protein in flour and protein, respectively; SGF and SGP, % of soluble glutenin in flour and protein, respectively; IGF and IGP, % of insoluble glutenin in flour and protein, respectively; PSI, particle size index; SWW, Soft White Winter Wheat; CWSWS, Canada Western Soft White Spring; CWRW, Canada Western Red Winter; CWRS, Canada Western Red Spring.

observed in three Katepwa and four Roblin samples from 1995 spring wheat. Generally, for most cultivars, flour color *L** value decreased, while *a** and *b** values increased with increasing levels of nitrogen fertilization up to the highest level used (240 kg/ha). Some exceptions were also observed; for example, the *L** value of 1994 spring wheat Katepwa tested with 240 kg/ha was the highest among the six levels of nitrogen fertilization used.

For comparison, the commercial udon flour color values are also presented in Table III. Most flours had *L** and *b** values similar to those of udon flour, but udon flour had a lower *a** value. This difference may have been due to the use of different flour extraction rates or may have developed in response to other factors instead of protein content. Udon flour was prepared using a 50–60% extraction rate according to the information from the miller, which was less than the 65% extraction rate used for domestic samples. When all color characters were considered and compared by MANOVA, the color of all Canadian flour samples was significantly different from that of the udon flour (results not shown).

Results in Table IV report the pertinent features of the correlation matrix linking flour quality parameters with flour color measurements. Protein content showed a significant negative correlation with flour brightness (*L**) and positive correlations with redness (*a**) and yellowness (*b**). Flour color grade is strongly associated with protein content (Bushuk et al 1969; Miskelly 1984); and high protein content is often associated with increased redness (Barnes 1989).

On the other hand, PSI showed a significant positive correlation with flour brightness and negative correlations with redness and yellowness, supporting results obtained by Symons and Dexter (1991). PSI showed better correlations with brightness and yellowness than shown by protein (Table IV). This indicated that granularity influenced flour color; flour with finer particle size was brighter and less yellow.

Although moisture was not significantly correlated with flour brightness, it was significantly correlated with flour redness and yellowness (Table IV). This agreed with results of Symons and Dexter (1991), who found that *a** and *b** values were sensitive to moisture.

Among the flour color characteristics, brightness was inversely related to yellowness and redness, while no significant correlation between yellowness and redness was observed (Table IV).

Predictive equations for color parameters incorporating protein content, PSI, and moisture content were obtained from stepwise multiple linear regressions (Table V). Flour PSI and moisture content accounted for 50% of the variation in flour *L** values, while flour PSI and protein content accounted for 74% of the variation in flour *b** values. However, only 37% of the variation in flour *a** values was accounted for by flour moisture and protein content. The value of the equations for color prediction rests in their ability to quantify the importance of a particular parameter in determining overall color. This procedure yields data which could not be obtained by simply making color measurements.

Effects of Protein Content on Noodle Sheet Color

It has been observed in previous studies that the brightness of noodle sheets is strongly affected by water absorption, and flours with higher protein content had lower optimum absorption (Hatcher

TABLE II
Protein Parameters and PSI for 1995 Test Samples[a]

Cultivar and Class	N Rate	Pro	MPF	SGF	IGF	PSI
Katepwa CWRS	0	10.2	5.30	1.12	2.99	61.8
	40	9.8	5.22	1.04	2.78	58.4
	80	10.4	5.65	1.11	2.84	58.9
	120	11.7	6.67	1.19	3.12	56.3
	160	12.7	7.32	1.32	3.30	54.5
	240	13.5	7.73	1.40	3.49	56.2
Roblin CWRS	0	10.2	5.18	1.13	3.11	66.3
	40	10.2	5.10	1.16	2.97	61.3
	80	11.7	6.02	1.36	3.30	63.2
	120	12.3	6.69	1.37	3.40	61.0
	160	13.3	7.04	1.50	3.63	59.1
	240	14.3	7.68	1.60	3.84	61.8
AC Reed CWSWS	0	7.2	4.09	1.16	1.56	73.7
	40	7.0	3.85	1.08	1.48	72.2
	80	7.8	4.38	1.37	1.63	69.3
	120	8.6	5.04	1.42	1.70	69.2
	160	8.6	5.06	1.43	1.64	68.5
	240	9.5	5.60	1.69	1.78	68.9
Norstar CWRW	0	9.0	4.82	0.75	2.66	67.9
	40	6.9	3.46	0.57	2.20	71.7
	80	7.5	3.78	0.71	2.29	67.9
	120	8.8	4.51	0.89	2.63	65.4
	160	9.9	5.26	1.06	2.96	64.8
	240	10.7	5.67	1.13	3.08	63.0
S86-375 SWW	0	8.2	4.96	0.59	2.07	79.2
	40	6.6	3.55	0.57	1.86	79.3
	80	7.1	3.77	0.71	1.96	78.8
	120	7.6	4.19	0.79	1.99	78.8
	160	8.3	4.68	0.93	2.07	76.3
	240	9.2	5.15	1.09	2.29	76.5
Winalta CWRW	0	9.3	5.12	0.70	2.85	69.4
	40	7.8	4.16	0.62	2.52	71.3
	80	8.4	4.31	0.80	2.59	68.9
	120	9.9	5.19	1.05	2.94	64.4
	160	10.4	5.49	1.13	3.10	63.7
	240	11.0	5.94	1.20	3.22	64.9

[a] Pro, protein content; MPF and MPP, % of monomeric protein in flour and protein, respectively; SGF and SGP, % of soluble glutenin in flour and protein, respectively; IGF and IGP, % of insoluble glutenin in flour and protein, respectively; PSI, particle size index; SWW, Soft White Winter Wheat; CWSWS, Canada Western Soft White Spring; CWRW, Canada Western Red Winter; CWRS, Canada Western Red Spring.

et al 1999; Morris et al 2000). To avoid the difficulty of optimum absorption measurement, noodle sheets in the present study were all processed to give the same water absorption (32%). Noodle sheets made from all of the flours had no difficulty in passing through the sheeting rolls of the bench-top laboratory noodle machine with the absorbed moisture. The color of raw noodle sheets was measured at 0, 2, and 24 hr, and after being cooked.

The multiple comparisons using Fisher's least significant difference test for raw white noodle sheet color (after a 2-hr rest) of samples from the different wheat cultivars is shown in Table VI. The effect of rest time on noodle sheet color for two cultivars is shown in Fig. 1. For all cultivars, raw noodle sheet brightness decreased, and redness and yellowness increased with an increase in flour protein content resulting from nitrogen fertilization. Generally, in spring wheats, the brightness of noodles measured at 2 hr from samples with the 40 kg/ha N treatment was the highest within a cultivar. The L^* value of noodle sheets from samples with 0 kg/ha N treatment was significantly lower than that of noodle sheets from samples of the 40 kg/ha N treatment. Above the three lower levels of nitrogen fertilization (0, 40, and 80 kg/ha), the L^* value of noodle sheets decreased with the higher nitrogen levels. In contrast, the lowest a^* and b^* values were observed in noodle sheets from samples grown with the 40 kg/ha N treatment. It was assumed that the brightest color of noodle sheets from samples with the 40 kg/ha N treatment was due to the lowest protein content (Tables I and II) (Fowler 1998).

For winter wheat, the brightness, redness, and yellowness of noodle sheets was related to the protein content of flours. However, protein content of winter wheat corresponded to nitrogen fertilization in a different quantitative way from spring wheat (Fowler 1998). In the winter wheat, although the lowest protein content of samples was observed at the 40 kg/ha N treatment, protein content in samples of the 0 kg/ha N treatment was higher than that of 40 and 80 kg/ha N treatment samples, and was similar to 120 kg/ha N treatment samples (Fowler 1998). Therefore, noodle sheets from samples with the 40 kg/ha N treatment had the highest brightness and the lowest redness and yellowness. Noodles from samples grown with the 0 kg/ha N treatment were less bright than noodles from samples with 80 kg/ha N treatment, and had similar brightness to noodles from samples with 120 kg/ha N treatment (Fig. 1 and Table VI).

The changes in raw noodle sheet color (L^*, a^*, and b^* values over time) are also shown in Fig. 1 for typical spring and winter wheat cultivars. Raw noodle sheet brightness (L^*) decreased with time but increased after cooking. On the other hand, yellowness (b^*) increased faster in the first 2 hr and then increased slightly up to 24 hr. This result was similar to the observation by other researchers on alkaline noodles (Kruger et al 1994). Redness (a^*) increased with rest time, and obvious increases occurred between determinations at 2 and 24 hr. A marked decrease of a^* and b^* values was observed after cooking. Similar results were observed for all tested cultivars (results for other cultivars not shown).

TABLE III
Multiple Comparison of Flour Color[a]

Cultivar and Class	N Rate	1994 L^*	1994 a^*	1994 b^*	1995 L^*	1995 a^*	1995 b^*
Katepwa CWRS	0	90.43b[b]	–1.60d	8.40d	91.36a	–1.64d	8.50e
	40	90.36c	–1.61d	8.55b	91.21b	–1.65d	8.50e
	80	90.36c	–1.56c	8.68a	90.06c	–1.53c	8.66a
	120	90.32d	–1.49b	8.46c	89.93d	–1.41b	8.53d
	160	90.13e	–1.41a	8.40d	89.47f	–1.28a	8.61b
	240	90.54a	–1.42a	8.37e	89.88e	–1.27a	8.57c
Roblin CWRS	0	91.14c	–1.50c	7.63a	89.78c	–1.48c	7.52a
	40	91.02d	–1.48c	7.53b	89.66d	–1.45c	7.42b
	80	91.70b	–1.35b	7.49d	90.33b	–1.33b	7.38d
	120	90.81e	1.33b	7.51c	89.45e	–1.31b	7.40c
	160	92.17a	–1.28a	7.55b	90.79a	–1.26a	7.43b
	240	90.68f	–1.27a	7.55b	89.32f	–1.25a	7.43b
AC Reed CWSWS	0	92.02a	–1.84d	6.44e	91.89a	–1.75c	6.48b
	40	91.86b	–1.85d	6.60c	91.85ab	–1.76c	6.61a
	80	91.83c	–1.80c	6.67a	91.49d	–1.72c	6.48b
	120	91.82c	–1.70b	6.63b	91.55c	–1.61b	6.49b
	160	91.66d	–1.67a	6.44e	91.59c	–1.58b	6.38c
	240	91.63e	–1.65a	6.57d	91.84b	–1.47a	6.19d
Norstar CWRW	0	91.37d	–1.52b	7.38f	91.15f	–1.61c	7.46e
	40	91.53b	–1.86e	8.01a	92.09a	–1.79f	7.52b
	80	91.59a	–1.82d	7.91b	91.79b	–1.74e	7.51b
	120	91.16e	–1.65c	7.85c	91.65c	–1.67d	7.58a
	160	91.40c	–1.63c	7.80d	91.56d	–1.51b	7.30d
	240	91.04f	–1.46a	7.59e	91.39e	–1.35a	6.97e
S86-375 SWW	0	91.95d	–1.60a	6.04f	92.04f	–1.59b	6.15a
	40	92.18b	–1.74d	6.47c	92.93a	–1.55a	6.07c
	80	92.31a	–1.77d	6.25e	92.72b	–1.71d	5.84e
	120	92.12c	–1.75d	6.63b	92.64c	–1.69cd	5.96d
	160	91.70f	–1.69c	6.82a	92.48d	–1.66c	6.15a
	240	91.88e	–1.65b	6.32d	92.40e	–1.59b	6.10b
Winalta CWRW	0	91.16d	–1.51a	7.28f	91.63b	–1.59d	7.03d
	40	91.37b	–1.66c	7.44e	91.69a	–1.63e	7.00e
	80	91.28c	–1.65c	7.46d	91.67a	–1.60d	7.11c
	120	91.09e	–1.66c	8.00a	91.42d	–1.52c	7.16b
	160	92.30a	–1.59b	7.68b	91.42d	–1.47b	7.19a
	240	90.95f	–1.52a	7.62c	91.56c	–1.38a	6.99e
Udon		92.46	–2.03	7.30			

[a] Flour color measured in triplicate for brightness (L^*), redness (a^*), and yellowness (b^*) values. Other abbreviations as defined in Table I.
[b] Mean values in the same column within a cultivar and heading followed by the same letter are not statistically different ($P > 0.05$) by Fisher's least significant difference (LSD) of multiple comparison test.

For comparison, the color of a noodle sheet prepared from udon flour is also presented in Table VI and Fig. 1. Noodles from udon flour had unique characteristics with high brightness and yellowness and low redness compared with noodles from the Canadian spring and winter wheat flours. At 0 hr of rest time, noodle sheet color from some test samples was very close to that of the udon flour noodle; for example, brightness of the noodle sheet from Norstar with 40 kg/ha N treatment (Fig. 1D). However, after 2 hr of rest, no noodle sheet possessed color characters similar to those of the udon noodle sheet. The changes in noodle sheet color (*L**, *a**, and *b** values over time) for the udon sample were small compared with other noodle sheets, which indicated that the color stability of the udon noodle sheet was superior to noodle sheets from other flours. Surprisingly, the udon noodle sheet retained very good yellowness (high *b**) after cooking (Fig. 1). When all color characteristics were considered and compared by MANOVA, noodle sheets from all flour samples were significantly different from that from udon flour (results not shown) for color at 2 and 24 hr and after being cooked. Based on noodle color, there was no flour in the test samples that satisfied the requirements for udon noodle production, although some flours had protein content equal to or lower than udon flour (8.70%), such as AC Reed at 40 kg/ha N treatment (1994) with 7.1% protein. This indicated that in addition to protein content, there could be other factors which contribute to udon flour color.

Relationship Between Flour Color and Noodle Color

A correlation matrix linking flour color with noodle sheet color values is shown in Table VII. The flour *L** values were significantly correlated with the brightness of noodle sheets assessed at 2 and 24 hr, and after being cooked, but not at 0 hr. They were also negatively related to *a** and *b** values of noodle sheets rested

TABLE IV
Simple Correlation Coefficients of Flour Color with Flour Protein Content, Moisture, and Particle Size Index[a,b]

	*L**	*a**	*b**
*L**	1.00		
*a**	–0.34**	1.00	
*b**	–0.60**	ns	1.00
Protein content	–0.62**	0.56**	0.61**
Particle size index	0.70**	–0.46**	–0.86**
Moisture	ns	0.42**	0.42**

[a] Flour color measured in triplicate for brightness (*L**), redness (*a**), and yellowness (*b**) values.
[b] ** indicates $P < 0.01$; ns, not significant ($n = 72$).

TABLE V
Predicting Flour Color Using Stepwise Multiple Linear Regression of Protein Content, Particle Size Index(PSI), and Moisture Content[a,b]

	Selected Parameters	R^2
*L**	PSI/moisture	0.518**
*a**	Moisture/protein content	0.375**
*b**	PSI/protein content	0.749**

[a] Flour color measured in triplicate for brightness (*L**), redness (*a**), and yellowness (*b**) values.
[b] ** indicates $P < 0.01$ ($n = 72$).

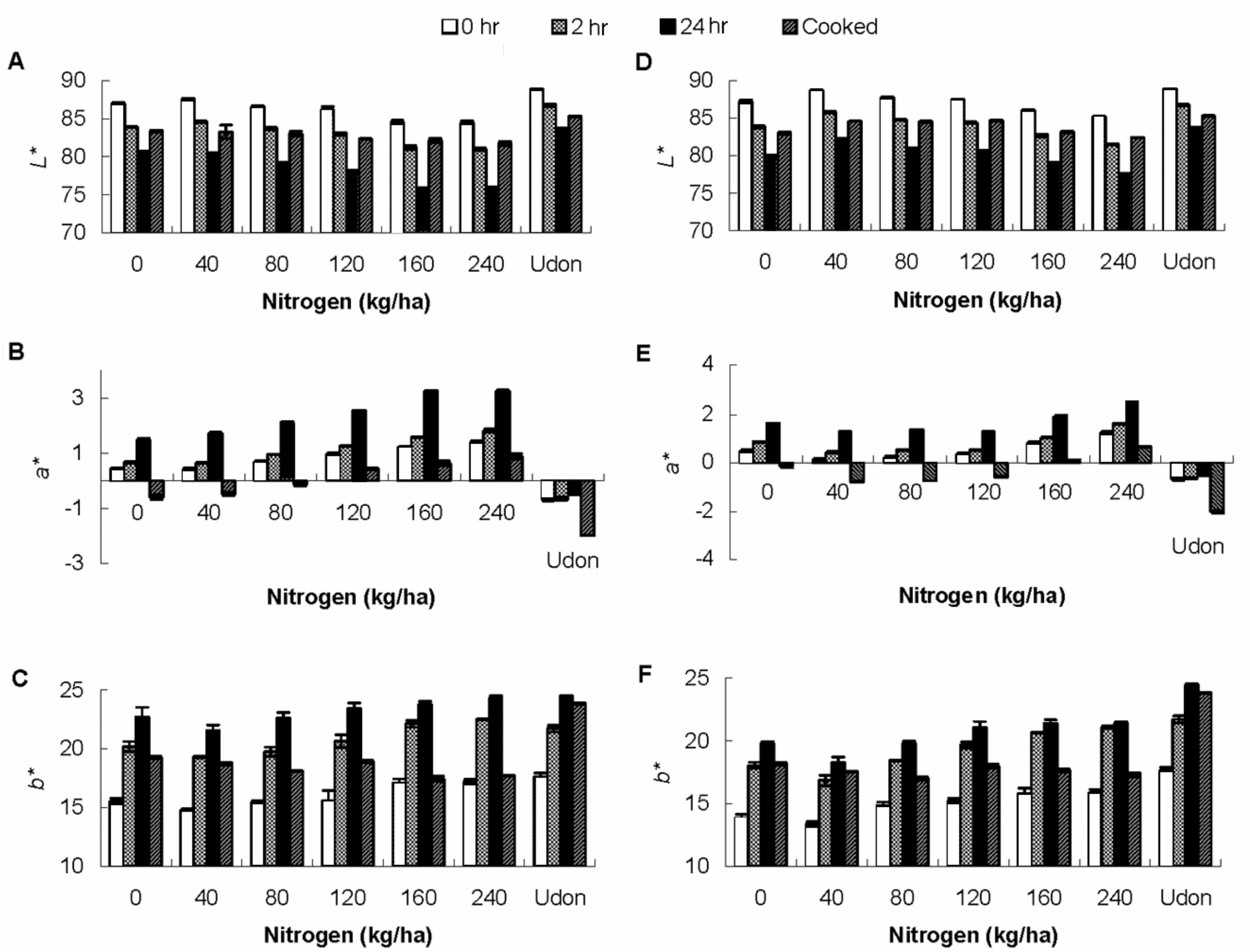

Fig. 1. Color changes over time in noodles from 1995 spring wheat Katepwa (**A,B,C**) and 1995 winter wheat Norstar (**D,E,F**) flours; brightness (*L**), redness (*a**) and yellowness (*b**). Error bars indicate standard deviations ($n = 3$).

TABLE VI
Multiple Comparison of Noodle Sheet Color Measured at 2 hr for Brightness (L^*), Redness (a^*), and Yellowness (b^*)

		1994			1995		
Cultivar and Class	**N Rate**	***L******	***a******	***b******	***L******	***a******	***b******
Katepwa CWRS	0	83.93b	1.02c	19.52c	83.93b	0.68e	20.17cb
	40	84.27a	0.81d	20.02cb	84.57a	0.67e	19.30d
	80	83.91b	1.00c	20.54b	83.72b	0.98d	19.74cd
	120	83.28c	1.07b	21.63a	82.98c	1.26c	20.63b
	160	82.70d	1.30a	22.00a	81.21d	1.60b	22.14a
	240	82.88d	1.29a	21.52a	80.97d	1.83a	22.50a
Roblin CWRS	0	83.08b	1.09c	20.30cd	82.49b	0.53e	17.60d
	40	84.04a	0.93d	19.68d	82.84a	0.36f	17.78d
	80	82.46c	1.43b	20.62c	80.51b	0.88d	18.97c
	120	82.46c	1.37b	18.12b	80.33c	1.07c	18.98c
	160	81.90d	1.66a	21.68ab	79.52c	1.31b	19.78b
	240	81.37e	1.67a	22.69a	78.10d	1.85a	20.45a
AC Reed CWSWS	0	84.69a	0.47d	16.65e	83.54b	0.84e	18.01e
	40	84.28b	0.55c	17.44d	84.28a	0.76f	17.32d
	80	84.64a	0.44d	17.83d	83.42b	1.04d	17.71cd
	120	82.92c	0.90a	19.86c	82.03d	1.46b	18.86b
	160	82.70d	0.77b	20.40b	82.58c	1.21c	19.73a
	240	82.28e	0.78b	21.52a	80.88e	1.74a	19.95a
Norstar CWRW	0	82.29c	1.03c	22.40cd	83.81d	0.85c	18.05e
	40	84.28a	0.28e	21.48e	85.79a	0.44e	16.86f
	80	83.32b	0.64d	21.89de	84.78b	0.51d	18.46d
	120	81.80e	1.26b	22.45c	84.37c	0.52d	19.67c
	160	81.97d	1.02c	23.19b	82.70e	1.04b	20.66b
	240	80.74f	1.60a	24.25a	81.48f	1.60a	21.09a
S86-375 SWW	0	84.46b	0.56c	14.52e	82.36d	0.74c	17.51c
	40	85.16a	0.34e	16.85d	85.18a	0.48f	14.84e
	80	84.62b	0.28f	18.19c	84.27b	0.55e	16.40d
	120	83.34c	0.41d	21.09b	83.33c	0.67d	17.68c
	160	81.92d	1.01b	22.05a	81.86e	0.96b	19.58b
	240	80.64e	1.20a	22.03a	80.67f	1.26a	20.48a
Winalta CWRW	0	82.85c	1.26b	19.47c	83.12d	0.79c	18.91b
	40	84.70a	0.74d	18.32d	84.96a	0.77c	16.23d
	80	83.87b	0.89c	19.17c	84.46b	0.72d	17.70c
	120	82.24d	1.22b	22.74a	83.62c	0.86b	18.96b
	160	82.07d	1.39a	21.99b	82.92d	0.88b	20.04a
	240	81.44e	1.43a	22.58a	81.96e	1.25a	20.01a
Udon		86.71	–0.65	21.72			

[a] Flour color measured in triplicate. Other abbreviations as defined in Table I.
[b] Mean values in the same column within a cultivar and heading followed by the same letter are not statistically different ($P > 0.05$) by Fisher's least significant difference (LSD) of multiple comparison test.

for 2 hr. Positive correlations between a^* values of flour and a^* values of noodle sheets were observed, except for noodle sheets rested for 24 hr. Correlations of flour b^* values with noodle sheet a^* and b^* values were significant for assessments at 0 and 2 hr, but not with L^* values of the noodle sheets. However, the correlation coefficients of flour color with noodle color were quite small ($r < 0.50$), except flour b^* with noodle sheet b^* at 24 hr. The small correlation coefficients indicated that flour color could not be used as a good predictor for noodle sheet color.

The correlation coefficients among noodle sheet color parameters are also shown in Table VII. The brightness of the noodle sheets was negatively correlated with their yellowness and redness, except for cooked noodle sheet yellowness, which was not significant. Specifically, cooked noodle sheet brightness was negatively correlated with redness. Compared with the results from flour color, noodle sheet redness was more negatively correlated with brightness at 2 hr of rest ($r = –0.76$, $P < 0.01$) and was higher than that of flours ($r = –0.34$, $P < 0.01$) (Table IV). In addition, strong correlations between noodle sheet yellowness and redness were observed at 0 and 2 hr, but the correlations decreased as rest time increased and yielded no significant correlation for cooked noodle sheets.

Relationship Between Protein Parameters and Noodle Color

Table VIII shows correlation coefficients of noodle sheet color with protein content and protein fractions expressed as the percentage of protein fraction in flour (absolute content of protein fraction) and in protein (relative content of protein fraction). Protein content was a good predictor for noodle sheet brightness, redness, and yellowness, except for the yellowness of cooked noodle sheets. Furthermore, protein content was superior to flour color in predicting noodle sheet color, as stronger relationships were observed between protein content and noodle sheet color parameters than those between flour color and noodle sheet color (Tables VII and VIII). Similar to protein content, the absolute contents of three protein fractions were significantly correlated with most color parameters of noodle sheets at 0, 2, and 24 hr, except the relationship between insoluble glutenin content and noodle sheet redness at 24 hr. The absolute contents of soluble glutenin and monomeric protein were equal to or better than protein content in predicting noodle sheet color at 0, 2, and 24 hr. In contrast, the correlation coefficients between relative contents of protein fraction and color parameters were low compared with their absolute content. In addition, PSI was significantly correlated with noodle sheet color parameters at 2 hr but was not as good a parameter as it was in predicting flour color.

Table IX shows stepwise multiple linear regression results between noodle sheet color parameters and protein parameters (including protein content, protein fraction, and particle size index). The selected parameters accounted for >55% of the variations in noodle L^* and a^* values measured at 0, 2, 24 hr, and after cooking. Furthermore, the regression ($R^2 \geq 0.70$) of L^* and a^*

TABLE VII
Simple Correlation Coefficients Among Flour and Noodle Sheet Color Parameters[a,b]

	Flour			0 hr			2 hr			24 hr			Cooked	
Color	***L****	***a****	***b****	***L****	***a****	***b****	***L****	***a****	***b****	***L****	***a****	***b****	***L****	***a****
0 hr														
*L**	ns	–0.29*	ns	1.00										
*a**	ns	0.41**	0.31**	–0.63**	1.00									
*b**	ns	ns	0.24*	–0.61**	0.62**	1.00								
2 hr														
*L**	0.31**	–0.37**	ns	0.92**	–0.64**	–0.51**	1.00							
*a**	–0.27*	0.43**	0.26*	–0.71**	0.95**	0.54**	–0.76**	1.00						
*b**	–0.27*	ns	0.50**	–0.59**	0.67**	0.89**	–0.58**	0.61**	1.00					
24 hr														
*L**	0.34**	–0.32**	ns	0.88**	–0.63**	–0.48**	0.94**	–0.78**	–0.53**	1.00				
*a**	ns	ns	ns	–0.67**	0.66**	0.47**	–0.62**	0.77**	0.39**	–0.77**	1.00			
*b**	–0.42**	ns	0.71**	–0.41**	0.68**	0.75**	–0.44**	0.60**	0.90**	–0.42**	0.29*	1.00		
Cooked														
*L**	0.31**	ns	ns	0.56**	–0.24*	ns	0.71**	–0.41**	ns	0.74**	–0.35**	ns	1.00	
*a**	ns	0.40**	ns	–0.71**	0.77**	0.36**	–0.77**	0.86**	0.37**	–0.81**	0.76**	0.29*	–0.66**	1.00
*b**	ns	–0.25*	0.37**	ns	ns	0.50**	ns	ns	0.51**	ns	ns	0.58**	ns	ns

[a] Flour color measured in triplicate for brightness (*L**), redness (*a**), and yellowness (*b**) values.
[b] *,** indicate $P < 0.05$ and 0.01, respectively; ns, not significant ($n = 72$).

TABLE VIII
Simple Correlation Coefficients Between Noodle Sheet Color Values and Protein Content, Fractions, and PSI[a,b]

	0 hr			2 hr			24 hr			Cooked		
	L*	***a****	***b****	***L****	***a****	***b****	***L****	***a****	***b****	***L****	***a****	***b****
Pro	–0.59**	0.71**	0.42**	–0.69**	0.76**	0.64**	–0.64**	0.38**	0.74**	–0.44**	0.62**	ns
MPF	–0.66**	0.72**	0.43**	–0.73**	0.77**	0.60**	–0.71**	0.49**	0.66**	–0.47**	0.69**	ns
SGF	–0.66**	0.67**	0.56**	–0.64**	0.75**	0.62**	–0.70**	0.71**	0.63**	–0.32**	0.62**	ns
IGF	–0.31**	0.54**	0.24*	–0.45**	0.54**	0.52**	–0.34**	ns	0.70**	–0.30*	0.36**	ns
MPP	ns	ns	ns	ns	ns	ns	ns	0.37**	–0.34**	ns	ns	–0.33**
SGP	–0.40**	0.26*	0.40**	–0.28*	0.35**	0.27*	–0.42**	0.70**	0.19	ns	0.31**	ns
IGP	0.32**	ns	ns	ns	ns	ns	0.34**	–0.64**	0.24*	ns	–0.26*	0.31**
PSI	ns	–0.47**	ns	0.28*	–0.50**	–0.46**	0.30*	ns	–0.68**	ns	ns	ns

[a] Pro, protein content; MPF and MPP, % of monomeric protein in flour and protein, respectively; SGF and SGP, % of soluble glutenin in flour and protein, respectively; IGF and IGP, % of insoluble glutenin in flour and protein, respectively; PSI, particle size index.
[b] *,** indicate $P < 0.05$ and 0.01, respectively; ns, not significant ($n = 72$).

TABLE IX
Predicting Noodle Sheet Color Using Stepwise Multiple Linear Regressions of Protein Content and Composition

		Selected Parameters	R^2
0 hr	*L**	MPF/MPF/PSI	0.636**[a]
	*a**	MPF/SGF	0.569**
	*b**	SGF	0.317**
2 hr	*L**	PSI/SGF/SGP/Pro/IGF/IGP	0.785**
	*a**	MPF/SGF	0.673**
	*b**	Pro/SGP	0.453**
24 hr	*L**	MPF/SGP/PSI	0.695**
	*a**	IGP/MPF/SGP	0.737**
	*b**	Pro/MPP/SGP/IGP/MPF	0.643**
Cooked	*L**	MPF/PSI/Pro/MPP/MPF/SGF/SGP	0.569**
	*a**	MPF/PSI/SGF	0.681**
	*b**	MPP	0.107**

[a] ** indicates $P < 0.01$ ($n = 72$). Abbreviations as defined in Table I.

indicated a good fit to the data and suggested that noodle *L** and *a** values after 24 hr of rest can be accurately predicted by the selected parameters. However, <50% of the variation in noodle *b** values was contributed by the selected parameters (except for *b** values measured at 24 hr). Notably, the selected parameters only accounted for 11% of the variation in cooked noodle *b** values.

CONCLUSIONS

Protein, particle size, and moisture of flour influenced flour color, and particle size was equal to or better than protein and moisture content in prediction of flour color (*L** and *b**). Flour color characteristics were weakly correlated with noodle sheet color, but protein content was more strongly correlated with noodle color. Protein fractions, expressed as absolute and relative contents, were significantly correlated with most noodle color characters, and the absolute contents of monomeric protein and soluble glutenin were equal to or better than protein content for predicting most noodle sheet color characters.

There was a noticeable decrease in noodle sheet brightness and an increase in yellowness and redness when noodle sheets were rested. Cooking allowed recovery of some brightness and redness in the noodle sheets but there was a loss of some yellowness. The correlation coefficients of protein and protein fractions with cooked noodle sheet color decreased in most situations.

Substantial differences in flour and noodle color were found between test samples and commercial udon flour. Although protein contents of some test samples were lower than that of udon flour, no flour among the test samples possessed the noodle sheet color characteristics of udon flour. This showed that udon flour had considerably different intrinsic color, which was influenced by properties beyond protein content.

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