

Environmental Influences on Flour Quality for Sheeted Noodles in Idaho 377s Hard White Wheat¹

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ABSTRACT

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Production of common wheat (*Triticum aestivum* L.) in the Pacific Northwest of the United States specifically for Asian noodle products is a relatively new goal for grain producers. We surveyed commercial fields of the hard white spring wheat cultivar Idaho 377s in two years to determine the variables contributing to Asian noodle quality and to validate previous observations made with small-plot research. Fields were surveyed in 1998 and 1999 in two areas of the Snake River Plain of southeastern Idaho separated by ≈100 km, with both irrigated fields and rain-fed fields sampled in both zones. Samples were evaluated for grain characteristics then milled and evaluated for flour quality, alkaline noodle color, and color and texture of nonalkaline Chinese (salted, neutral pH) noodles. Grain from rain-fed fields produced brighter and more yellow alkaline noodles than grain from irrigated fields. Grain produced in rain-fed fields

also had lower peak flour pasting viscosity than grain produced in irrigated fields. Flour ash was lowest in grain from rain-fed fields located in a higher elevation district (Upper Valley) and greatest in grain from irrigated fields located in a lower elevation district (Lower Valley). Noodle hardness and chewiness were greater in Chinese noodles made from grain produced in the Upper Valley than grain from the Lower Valley. Chinese noodle color had significant interaction with the location and irrigation management used for producing the grain. However, Chinese noodle brightness was consistently negatively correlated with flour protein concentration. The color and texture of noodles produced from flours milled from on-farm commercial production was consistent with previous experiment station small-plot research.

In North America, hard endosperm, common wheat (*Triticum aestivum* L.) is used primarily for leavened food products, with bread the most widely consumed of the food products. Export of hard common wheat outside of North America to East Asia has raised the need for grain that also can be used for sheeted noodles such as Hokkien, Bamee, and Ramen style noodles.

Flour quality requirements for Asian noodles vary depending on the specific style of noodle. Characteristics of cultivars that generally improve Asian noodle quality include bright flour color, low flour ash content, and low polyphenyl oxidase activity (Baik et al 1995). Depending on the type of noodle, cultivars may require reduced amylose content due to mutations to the granule bound starch synthase (GBSS) genes (Miura and Tani 1994). Similarly, the protein content required for a noodle will vary with the style of noodle. Increasing the protein concentration and gluten strength results in increasing the hardness of a noodle, improving the sensory texture of many classes of Asian noodle (Crosbie et al 1999; Park et al 2003). However, elevated grain protein often discolors noodles. Therefore, protein quality is important to produce the greatest gluten strength with the least amount of protein required to produce the specific chewiness or bite characteristic of the noodle style (Lang et al 1998; Souza et al 2004).

Based on the results of laboratory quality evaluations and international collaborative panels coordinated by the U.S. Wheat Associates, in 1996 the University of Idaho released the hard white spring wheat cultivar Idaho 377s for use in Asian noodle products. The cultivar is a reduced-amylose type with good noodle color stability and moderate grain protein concentration (Souza et al 1997). At peak production, Idaho 377s was produced in four western states and North Dakota.

Genotype is but one component of the factors that determine grain quality. Like bread quality, Asian noodle quality is affected by crop management. Both bread and Asian noodle quality are sen-

sitive to flour protein content. Nitrogen fertilization often influences the protein content of grain and the flour derived from the grain (Dubetz et al 1979; Gauer et al 1992), although the influence of added nitrogen varies depending on the environment (Souza et al 2004).

In previous research, we found that moisture stress affected noodle color by elevating protein content and by increasing the yellowness of noodles produced from moisture-stressed grain (Guttieri et al 2001; Souza et al 2004). In irrigated production systems, inadequate watering late in the season elevated flour ash and caused darkening of alkaline noodles (Guttieri et al 2005). From previous work in an arid grain production region, moisture stress or its minimization through irrigation is one of the primary limitations to grain yield and a significant modifier of grain quality (Guttieri et al 2001, 2005; Souza et al 2004). In addition to relatively well-defined parameters such as moisture and fertilization, a range of nonspecific or difficult to quantify parameters also influence the quality of wheat for both noodles and bread (Habernicht et al 2002; Souza et al 2004).

Previous small-plot research suggests that both genotype and environment contribute to noodle quality (Lang et al 1998; Habernicht et al 2002; Souza et al 2004). However, the genotype-by-environment interaction, while occasionally significant, is less important than the main effects of genotype and environment for most noodle quality measurements (Souza et al 2004). The greater importance of genotype and environment effects relative to the genotype-by-environment interaction suggests that a good quality noodle wheat could be used to evaluate the commercial production factors that contribute to superior noodle quality. The purpose of this research was to sample Idaho 377s produced in the commercial grain fields of southeastern Idaho and evaluate the noodle quality of harvested grain, relating the findings to previous small-plot research conducted in these environments (Lang et al 1998; Guttieri et al 2001, 2005; Habernicht et al 2002; Souza et al 2004).

MATERIALS AND METHODS

Grain Production

A total of 26 fields in 1998 and 23 fields in 1999 of Idaho 377s in southeastern Idaho were monitored from planting to harvest. Grain was sampled from three sites within each field at harvest. Sites within a field were at least 100 m apart and 100 m from the

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edge of a field and selected in a line at an angle of $\approx 45^\circ$ to the edge of a field or the lines of the sprinkler pipes. In irrigated fields, the sites were positioned approximately halfway between sprinkler pipe lines. The exact position of the site was selected at random within the general guidelines outlined above but positioned to avoid obvious defects in the field (rock outcroppings or gopher colonies). In 1998, all sampling sites were 1 m² in area, while in 1999, sampling sites in irrigated fields were 1 m² in area and sampling sites in rain-fed fields were 4 m² in area to ensure sufficient grain for a full milling and noodle evaluation from each of the three sites within a field.

The location and description of the fields is summarized in Table I and Fig. 1. Fields were classified based on water management and production region. Fields were classified as having rain-fed water management if the fields received no supplemental irrigation during the production year. Fields were classified as irrigated if the fields received at least one supplemental irrigation during the growing season, although all irrigated fields received at least three supplemental irrigations during the growing season. Fields in the lower elevation district (Lower Valley) were in Bingham, Power, and Oneida counties. Fields in the high elevation district (Upper Valley) were in Bonneville, Jefferson, and Madison counties (Fig. 1). The Upper Valley fields were, on average, ≈ 300 m higher in elevation than the Lower Valley fields.

Grain was harvested by hand from the sample areas, threshed using a stationary thresher, and cleaned using a fanning mill to remove chaff and foreign material. Samples were measured for test weight and evaluated using the Single Kernel Characterization System (SKCS 4100, Perten Instruments North America, Inc., Springfield, IL). When <500 g of grain was harvested from sites within a rain-fed field, grain from all three sites were composited into a single sample for subsequent milling and noodle analysis. In all other cases, grain samples from each of the three sites within a field were evaluated separately and treated as subsamples of the main field plot.

Milling and Flour Analysis

Total grain protein of samples was determined using a near-infrared analyzer (Approved Method 39-10A, AACC International 2000), calibrated by automated combustion analysis of total nitrogen content (model NFP-428, Leco Corp., St. Joseph, MO), and corrected to 12% moisture. Samples were tempered (Approved Method 26-10) and milled with a Brabender Quadramat Senior mill (Approved Method 26-21A). Flour protein concentration was determined by the same protocol as whole grain protein. Using a chromameter (CR-310, Minolta, Ramsey, NJ), flour color was measured against the Commission Internationale de l'Eclairage (CIE) $L^*a^*b^*$ color scale. Brightness was measured by the L^* axis and yellow-blue colors by the b^* axis.

Noodle Analysis

Nonalkaline Chinese (salted, neutral pH) noodles were prepared using a method similar to Kruger et al (1992) with the modifications described in Habernicht et al (2002). Flour (100 g) was premixed at low speed on a pup-loaf mixer (National Manufacturing, Lincoln, NE) for 1 min with 29.2 mL of a NaCl solution (4.29%, w/v) over 30 sec. Mixing continued at medium speed for 5 min. Dough rested in a plastic bag for 30 min before sheeting with a noodle machine (Ohtake Manufacturing, Tokyo, Japan). Dough was folded and sheeted six times using a gap of 5 mm at 30°C. The dough rested 30 min before reduction sheeting using five reductions to a thickness of 1.2 mm. Dough sheets were stored in plastic bags at room temperature during evaluations. Noodle color was evaluated at 0 and 24 hr after sheeting using the chromameter. The Chinese salted (nonalkaline) noodles were boiled and evaluated for texture profile after cooking as previously described (Lang et al 1998; Habernicht et al 2002). Texture characteristics (hardness and chewiness) at 0 and 5 min after cooking were measured on five strands of rinsed noodles using a texture analyzer (TA-XT2, Texture Technologies, Scarsdale, NY) with a 6-mm, flat, lexan probe.

TABLE I
General Description of Fields and Management Input for Fields
of Idaho 377s (1998 and 1999)^a

Water Source	District	Number of Fields		Seeding Date (day of year)		Seeding Rate (kg/ha)		Preplant Nitrogen (kg/ha)		Preplant Phosphorous (kg/ha)	
		1998	1999	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Lower	18	12	112	3	85	2	93	4	28	4
	Upper	8	11	122	4	88	3	110	5	24	5
Irrigated		16	15	108	3	101	2	131	4	32	4
Rain-fed		10	8	126	4	73	3	72	5	20	5
Irrigated	Lower	12	8	97	4	101	3	141	5	42	5
Irrigated	Upper	4	7	118	4	100	4	120	6	22	6
Rain-fed	Lower	4	4	126	5	69	4	45	7	15	6
Rain-fed	Upper	6	4	126	5	76	5	99	8	26	7

^a SE, standard error of the mean.

TABLE I (continued)
General Description of Fields and Management Input for Fields
of Idaho 377s (1998 and 1999)^a

Water Source	District	Top-Dress Nitrogen (kg/ha)		Heading Date (day of year)		Field Maturity (day of year)		Grain Yield (kg/ha)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Lower	12	4	187	1	220	6	4,841	215
	Upper	6	4	195	1	229	6	4,641	255
Irrigated		17	3	186	1	223	6	6,544	209
Rain-fed		2	5	196	1	226	6	2,937	260
Irrigated	Lower	21	4	180	1	217	6	7,461	246
Irrigated	Upper	13	5	192	2	229	6	5,627	328
Rain-fed	Lower	4	6	194	2	223	6	2,220	344
Rain-fed	Upper	0	7	198	2	229	6	3,655	383

^a SE, standard error of the mean.

Alkaline noodles were prepared as described in Guttieri et al (2001) by mixing 50 g of flour to a crumbly consistency with 9 mL of alkaline salt solution (0.25%, w/v, Na₂CO₃, 1% NaCl) on a 35-g National pin mixer for 45 sec. Dough was scraped down from the pins and bowl sides and mixed for another 45 sec. Dough was collected and sheeted through a hand-crank pasta maker (Atlas/Marcato, Wilton Industries, Woodridge, IL) at the widest (zero) setting for the first pass. The dough piece was folded twice and repeatedly passed through the sheeter to a sheet thickness of ≈1.5 mm. The dough sheet was cut into three strips, stacked on a white tile, and measured for color at 0 and 24 hr after sheeting, as described for the nonalkaline Chinese noodles. Noodles were stored at room temperature in sealed plastic bags between color measurements.

Rapid Visco-Analysis of Flour Pasting

The flour pasting viscosity of each flour sample was determined using the Rapid Visco Analyser (Newport Scientific, Melbourne, Australia) to analyze 3 g of flour mixed with 25 mL of water. Pasting curves were determined using heating and mixing profiles from Guttieri et al (2001): flour suspension cycle of 10 sec with a rotor speed of 960 rpm, followed by a pregelatinization step for 2 min at 60°C, 160 rpm rotor speed (rotor speed held constant for all subsequent steps), a gelatinization step ramping the temperature to 93.5°C over 6 min, held at 93.5°C for 4 min, then cooled to 50°C over 4 min, and finally held at 50°C for 4 min. Peak flour pasting viscosity during the heating step was recorded in centipoise (cP = kg m⁻²s⁻²) as were final viscosities during the 50°C holding cycle.

Statistical Analysis

Analysis of variance (ANOVA) was performed for all measured quality traits. In ANOVA, years were treated as random effects. In our survey of fields, we classified fields into two districts: the Lower Valley, representing the Lower Snake River Plain (Bingham, Oneida, and Power counties), and the Upper Valley, representing the Upper Snake River Plain (Bonneville, Fremont, Jefferson, and Madison counties). District was treated as a fixed effect in ANOVA. Water management (irrigated or rain-fed) also was treated as a fixed effect. The experimental unit for the research was the grower fields, which were treated as random effects within the treatment combinations of year, district, and management. Within each field, the three sample sites were treated as subsamples of the field experimental unit. A mixed effect ANOVA model was used to partition sources of variation (Steele and Torrie 1980). The mixed models were calculated using the Statistical Analysis System software (v. 8.1, SAS Institute, Cary, NC).

RESULTS

We sought to evaluate the effect of large and obvious grain production factors on salted oriental noodles, both alkaline and nonalkaline Chinese-style noodles, to interpret environmental variation that grain producers and grain purchasers observe. In southeastern Idaho, two obvious production factors are field elevation and the use of irrigation. The Upper Valley district was seeded 10 days later than the Lower Valley district, a difference reflected throughout the growing season as measured by heading and maturity date (Table I). Timing of N top-dressing was an important management difference we observed between the two districts.

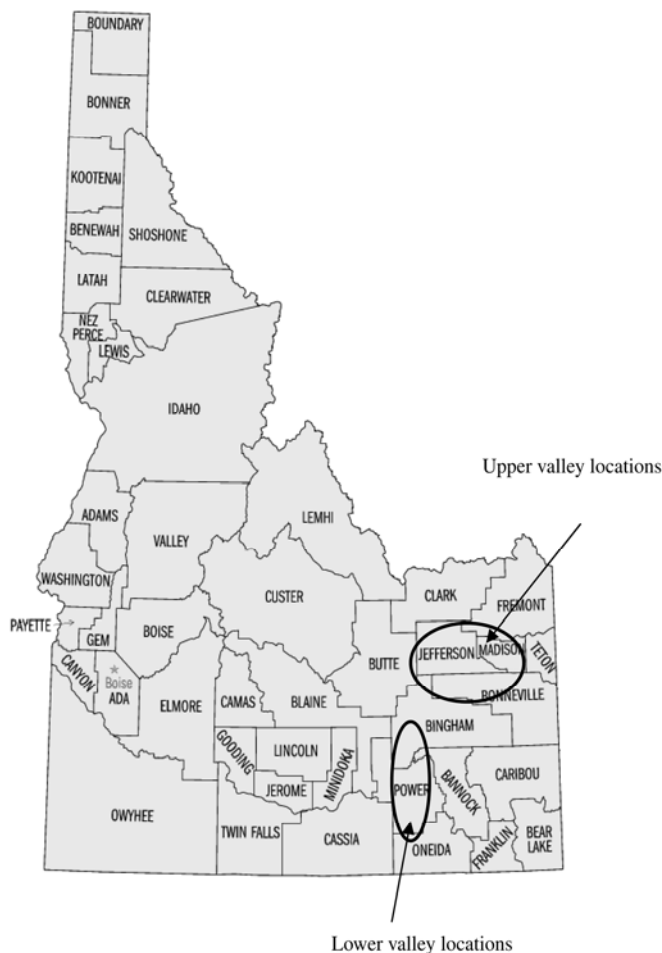


Fig. 1. Idaho county map showing counties included in upper and lower valley test sites evaluated in 1998 and 1999.

TABLE II
Analysis of Variance for Measured Variables in Survey of Idaho 377s
in Fields in Southeastern Idaho (1998 and 1999)^a

Traits ^b	Source of Variation		
	Elevation (E)	Irrigation (I)	E × I
Grain traits			
Test weight	0.1	0.3	1.4
Grain protein	1.6	0.9	2.8
NIR hardness	4.5*	1.7	0.6
Kernel weight	0.4	15.1	6.3
Flour traits			
Flour ash	11.5**	5.6*	2.1
Flour yield	0.7	0.1	0.2
Flour protein	1.6	0.3	3.5
Flour L*	0.2	0.0	2.4
Flour b*	2.2	0.5	7.9**
RVA peak viscosity	0.8	10.3**	0.1
RVA final viscosity	0.5	7.1*	1.0
Alkaline noodle color			
L* (0 hr)	1.9	2.0	1.5
b* (0 hr)	0.8	3.7	0.6
L* (24 hr)	2.2	5.2*	1.3
b* (24 hr)	26.3***	7.6**	0.2
Change in L* in 24 hr	0.5	13.0***	4.3*
Chinese noodle color			
L* (0 hr)	0.0	0.6	6.5*
b* (0 hr)	1.8	0.3	4.9*
L* (24 hr)	0.3	0.7	7.7**
b* (24 hr)	1.7	0.5	8.2**
Change in L* in 24 hr	0.7	0.8	7.8**
Chinese noodle cooking and texture			
Cooking yield	1.1	0.4	0.4
Hardness (0 hr)	9.7**	2.3	2.3
Chewiness (0 hr)	17.4***	1.6	4.6*
Hardness (24 hr)	7.0*	2.1	2.0
Chewiness (24 hr)	6.5*	2.8	5.0*

^a *, **, ***, significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.

^b L* and b*, respectively, measure brightness and blue-yellow pigmentation from the Commission Internationale de l'Eclairage (CIE) L*a*b* color scale.

The Lower Valley district had a greater percentage of N applied postplanting (11% of applied N) than did the Upper Valley district (5% of applied N). Use of phosphorous fertilizer was consistent across both districts.

Flour yield, protein, and color effects were similar for the two districts (Table II). The two districts were significantly different from each other for grain hardness, flour ash, alkaline noodle color (b^* yellowness), noodle hardness, and noodle chewiness. The grain harvested from the Lower Valley district was significantly harder than that from the Upper Valley district, as measured by NIR hardness, but not SKCS hardness (Table III, SKCS hardness data not shown). Alkaline noodles from the Upper Valley district were more yellow (greater b^* values) than those from wheat of the lower district, when compared 24 hr after sheeting. In contrast, the two districts produced nonalkaline Chinese noodles that were similar in color. Yet the hardness and chewiness of the noodles differed between districts; noodles of the Upper Valley district had more desirable texture derived from harder bite as measured by the TA-XT2 analysis (Table IV). We observed no differences among the treatments for cooking yield of nonalkaline Chinese noodles.

The second production factor affecting the hard white crop was supplementation of precipitation with irrigation during the growing season. Irrigated fields typically were in drier zones of the two districts and the soil tended to dry out earlier in the spring. Irrigated fields were seeded 18 days earlier in the spring than rain-fed fields (Table I). Despite the earlier seeding date, irrigated fields matured at nearly the same time as rain-fed fields. Irrigated fields were more productive than rain-fed fields, with irrigated fields producing more than twice the grain yield of the rain-fed fields. To achieve this greater productivity, irrigated fields were seeded at greater seeding rates than rain-fed fields and had greater amounts of applied nitrogen and phosphorous fertilizers.

The irrigated fields produced flour with greater ash content, greater RVA peak viscosity, and greater RVA final viscosity than

the rain-fed fields (Table III). In this study, we did not find a significant difference between the irrigated and rain-fed fields for test weight, grain protein, kernel hardness, kernel weight, flour yield, flour protein, or flour color. The alkaline noodles produced from grain of irrigated fields and rain-fed fields were similar in color at the time of sheeting (0 hr). However, 24 hr after sheeting, the alkaline noodles from irrigated fields became darker (smaller L^* values) and less yellow (smaller b^* values) than the noodles from rain-fed fields (Table IV). Chinese noodles from grain produced on irrigated and rain-fed fields were similar in color.

In our field surveys, we found a significant interaction between district and water management for all measured traits of Chinese noodle color. An example of this interaction occurred with initial L^* values (0 hr). Irrigation in the Lower Valley district increased the brightness of the Chinese noodles relative to that of the rain-fed fields. In contrast, irrigation in the Upper Valley district produced darker Chinese noodles than the rain-fed fields (Table IV). For this data set, we observed a decline of 0.06 in L^* in initial Chinese noodle brightness for each increase of 1 g/kg of grain protein ($R^2 = 71\%$). Alkaline noodle brightness only declined 0.02 L^* for each increase of 1 g/kg of grain protein ($R^2 = 29\%$). Similarly, the change in Chinese noodle brightness over 24 hr was greater with increasing grain protein ($R^2 = 54\%$), while the two factors were completely uncorrelated in alkaline noodles ($R^2 = 1\%$). In these fields, grain protein content was not strongly correlated with either of the major management factors recorded. Flour protein seems to be the overriding factor determining Chinese noodle brightness, rather than location or water management as we observed for alkaline noodles.

Chinese noodle texture also was difficult to predict from management factors. Chinese noodle hardness was significantly affected by district, while chewiness reflected significant interactions between district and water management factors (Table V). In this study, as in previous research, grain protein content was significantly corre-

TABLE III
Characteristics of Grain and Flour of Idaho 377s Produced in Southeast Idaho Farms (1998 and 1999)^{a,b}

Water Source	District	NIR Hardness (0–100)		Flour Ash (g/kg)		Flour Color b^{*a}		RVA Peak Viscosity (cP)		RVA Final Viscosity (cP)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Irrigated	Lower	61	2	4.24	0.27	9.39	0.07	3,066	56	2,862	118
	Upper	58	2	3.90	0.27	9.54	0.08	3,004	63	2,794	124
Rain-fed	Lower	60	2	4.18	0.27	9.50	0.06	3,147	55	2,949	117
	Upper	58	2	3.95	0.27	9.43	0.08	2,923	64	2,706	125
Irrigated	Lower	62	2	4.42	0.27	9.57	0.07	3,164	61	2,937	123
	Upper	58	2	3.94	0.28	9.43	0.10	3,129	77	2,962	138
Rain-fed	Lower	59	2	4.05	0.28	9.21	0.11	2,967	80	2,787	140
	Upper	57	2	3.86	0.29	9.65	0.13	2,879	88	2,625	148

^a b , Blue-yellow pigmentation from the Commission Internationale de l'Eclairage (CIE) $L^*a^*b^*$ color scale.

^b SE, standard error of the mean.

TABLE IV
Noodle Color of Flour from Grain of Idaho 377s Grown in Southeastern Idaho Farms (1998 and 1999)^{a,b}

Water Source	District	Alkali Noodle Color						Chinese Noodle Color									
		L^* (24 hr)		b^* (24 hr)		Change in L^* (24 hr)		L^* (0 hr)		b^* (0 hr)		Change in L^* (24 hr)					
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE		
Irrigated	Lower	79.6	1.3	23.4	0.3	7.2	1.4	87.5	0.3	14.1	0.3	80.3	0.5	20.4	0.49	7.22	0.25
	Upper	80.2	1.3	25.7	0.4	6.9	1.4	87.5	0.3	14.7	0.3	79.9	0.6	21.4	0.59	7.55	0.31
Rain-fed	Lower	79.4	1.3	23.9	0.3	7.7	1.4	87.7	0.2	14.3	0.2	80.4	0.5	20.6	0.46	7.21	0.24
	Upper	80.4	1.3	25.2	0.4	6.4	1.4	87.4	0.3	14.5	0.3	79.8	0.6	21.2	0.61	7.56	0.32
Irrigated	Lower	78.9	1.3	22.8	0.4	8.2	1.4	88.2	0.3	13.5	0.3	81.7	0.6	19.1	0.54	6.49	0.28
	Upper	80.0	1.3	25.1	0.5	7.2	1.4	87.1	0.4	15.0	0.4	79.2	0.7	21.8	0.73	7.93	0.38
Rain-fed	Lower	80.3	1.3	24.0	0.5	6.1	1.4	86.9	0.4	14.7	0.4	78.9	0.8	22.2	0.81	7.96	0.42
	Upper	80.5	1.4	26.3	0.5	6.6	1.4	87.8	0.5	14.3	0.5	80.7	0.9	20.6	0.92	7.17	0.48

^a L^* and b^* , respectively, measure brightness and blue-yellow pigmentation from the Commission Internationale de l'Eclairage (CIE) $L^*a^*b^*$ color scale.

^b SE, standard error of the mean.

lated to noodle hardness ($r = 0.52, P < 0.01$). Flour ash was negatively correlated with initial and 24-hr b^* values of alkaline and Chinese noodles ($r = -0.36$ to $-0.54; P < 0.05$). Flour ash concentration also was correlated to reduction in alkaline noodle brightness over a 24-hr period ($r = 0.74, P < 0.01$). The opposite was true for the change in Chinese noodle brightness; higher ash flours had less change over 24 hr ($r = -0.32, P < 0.05$).

Relationships between noodle color characteristics for alkaline noodles and Chinese noodles were dependent on the trait. In this data set, initial L^* values of alkaline noodles were correlated with initial L^* values of Chinese noodles sheeted from Idaho 377s samples ($r = 0.57, P < 0.01$). In contrast, the 24-hr L^* values were not correlated for alkaline and Chinese noodles made from Idaho 377s from these southeastern Idaho fields ($r = 0.07$). Initial and 24-hr b^* values for alkaline and Chinese noodles were correlated (0 hr $r = 0.46, P < 0.01$; 24 hr $r = 0.37, P < 0.01$). This suggests that factors controlling the yellowness of alkaline and Chinese noodles are similar. However, factors controlling darkening of Asian noodles in Idaho 377s are different for alkaline and Chinese noodles.

DISCUSSION

The rates of nitrogen fertilization used by the growers in this study favored low grain protein concentrations. The average grain protein for the Lower Valley district was 125 g/kg, and the average for the Upper Valley district was 132 g/kg (data not shown). In an irrigation-by-fertility experiment at Aberdeen, ID, using several cultivars, including Idaho 377s, we found the optimum total nitrogen required for optimum grain yield to be 303 kg/ha with even higher nitrogen fertilization required for 140 g/kg of grain protein (Guttieri et al 2005). In the comparable production environment of this study (Lower Valley, irrigated), grain producers applied an average 162 kg/ha. It was not possible to obtain residual nitrogen fertilization for all fields. However, the difference between observed and optimum nitrogen fertilization is 140 kg/ha, much higher than typical residual nitrogen recorded in this zone and over twice the residual nitrogen values measured in the fields where pre-fertilizer application soil tests were obtained. The less-than-optimum nitrogen fertilization for the irrigated production zones resulted in a grain protein concentration lower than that normally expected for hard red spring genotypes (140 g/kg), yet closer to the targets requested for many styles of Asian noodles (105 g/kg to 130 g/kg).

The alkaline noodles produced from flours milled from the irrigated production systems were significantly less bright than noodles sheeted from flour derived from rain-fed produced grain. Although high grain protein is correlated with darkening of Chinese noodles (Graybosch et al 2004; Souza et al 2004), clearly other environmental factors are more important for determining the brightness of the alkaline noodle than flour protein concentration. This also is consistent with the findings of Souza et al (2004), where environment was a more important determinant of

noodle brightness than nitrogen fertilizer treatment. In addition to being brighter than noodles produced from irrigated grain, the noodles from rain-fed fields were more yellow than noodles from irrigated fields (Table III). This finding is consistent with previous small-plot research where reduced moisture availability elevated the yellow pigmentation of alkaline noodles (Guttieri et al 2001, 2005; Souza et al 2004).

In this study, the color of nonalkaline Chinese noodles at 0 and 24 hr had significant interactions with district and water management of the fields. Therefore, it may be difficult to predict which fields would provide flour for making the best color of Chinese noodles. In previous studies, the location affected color of Chinese noodles, but limited location-by-genotype or location-by-management interactions were observed (Souza et al 2004). The differences in these findings may be due in part to the scale and power of testing. In this study, the range in 24-hr Chinese noodle color was 2 L^* compared with the difference among genotype mean values of 5 L^* and 4 L^* for environmental mean values based on cultivars with both poor and good noodle color in Souza et al (2004). The detection of subtle interactions among relatively minor differences in this study may be due to the large number of samples that comprise the mean values of each treatment and the effect of protein concentration on Chinese noodle brightness. Grain protein concentration in this study generally was not determined by elevation or irrigation, rather by individual field management within those treatments. This resulted in field-to-field variation in grain protein that may be difficult to predict but relatively easy to measure.

In earlier small-plot research with multiple cultivars, management effects on flour ash were difficult to predict (Souza et al 2004; Guttieri et al 2005). In this study with a single cultivar, flour ash effects were relatively simple: higher elevation fields produced flour of lower ash content than lower elevation fields; rain-fed fields produced flour of lower ash content than irrigated fields, and the two effects acted additively without interaction (Table II). Therefore, grain buyers seeking to minimize flour ash can use knowledge of the grain source and production to purchase grain with low ash content.

Flour pasting viscosity is an important measure of swelling of the flour for certain types of noodles such as Udon and Korean style noodles. In this study, the rain-fed fields produced flours with lower peak and final flour pasting viscosity than flours from irrigated fields. Using controlled irrigated experiments to simulate late-season moisture stress, Guttieri et al (2005) found that flour-pasting viscosity was elevated by late season moisture stress for all genotypes evaluated, including Idaho 377s. This suggests that artificially induced moisture stress may not mimic RVA differences between irrigated and rain-fed production systems and that direct measurements of these parameters in rain-fed fields are necessary to make accurate predictions of RVA profiles.

Previous small-plot research with multiple cultivars indicated that grain protein concentration was positively correlated with noodle

TABLE V
Chinese Noodle Texture and Cooking Characteristics of Noodles from Flour of Idaho 377s Grain Grown in Southeastern Idaho (1998 and 1999)^a

Water Source	District	Chinese Noodle Texture (g)							
		Hardness (0 min)		Chewiness (0 min)		Hardness (5 min)		Chewiness (5 min)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Lower	1,257	24	604	21	979	23	422	23
	Upper	1,376	30	691	23	1,075	28	476	25
Irrigated		1,287	23	634	20	1,001	22	432	22
Rain-fed		1,345	30	661	23	1,053	29	467	25
Irrigated	Lower	1,198	27	568	22	928	25	381	24
Irrigated	Upper	1,376	38	700	26	1,075	36	482	28
Rain-fed	Lower	1,315	40	639	27	1,031	38	463	29
Rain-fed	Upper	1,376	46	682	29	1,075	43	470	31

^a SE, standard error of the mean.

hardness, and greater noodle hardness is generally desirable for moderate- to high-protein noodles (Lang et al 1998; Graybosch et al 2004). Although Souza et al (2004) found an overall correlation between grain protein and noodle hardness, the effect was not consistent across all cultivars. For the hard wheat cultivars with normal amylose content, the positive relationship between protein concentration and noodle hardness was consistent with previous work. However, for low-amylose content cultivars Klasic, Lolo, and Idaho 377s, Souza et al (2004) found no significant correlation between protein content and noodle hardness. Within this study, our samples covered a much wider range of protein concentrations than observed in Souza et al (2004), suggesting that the correlation between protein and hardness in this partial waxy genotype is weak but still exists. Culling the samples to only those with protein concentrations that would be commercially purchased for noodle manufacture (105 g/kg to 130 g/kg), the correlation coefficient is virtually identical ($r = 0.28$) to that found within Souza et al (2004) and is not significantly different from zero ($P > 0.15$). The apparent advantage of partial waxy wheat in providing stable noodle hardness across environments and range of normal commercial protein concentrations may be worthy of additional investigation.

Finally, the consistent responses of noodle color and noodle texture between small-plot research and on-farm commercial production suggests that, with the exception of flour ash and RVA profiles, the experiment station methodologies may be used as indicators for growers seeking to improve their end-use quality and grain buyers seeking specific types of end-use quality.

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