

Genotypic and Environmental Effects on Color and Discoloration Potential of Barley in Food Products

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ABSTRACT

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Twelve genotypes of barley, including hulled and hullless proanthocyanidin-containing and hulled proanthocyanidin-free types, were grown in five environments (location-year combination) to determine the relative contribution of genotype and environment on quality traits associated with discoloration potential of barley. Barley grains were abraded and milled into flour. Protein, ash, total polyphenol content, and polyphenol oxidase (PPO) activity were determined. Brightness (L^*) of abraded kernels, cooked kernels, gels, and dough sheets were determined and used as indicators of discoloration potential. Genetic factors were more important in determining total polyphenol content, PPO activity, and brightness of dough sheets and as important as environmental factors for

protein and ash content. Across environments, L^* of dough sheets was consistently higher in proanthocyanidin-free barley (73–76) than in proanthocyanidin-containing barley (59–70). Total polyphenol content of abraded grains was highest in barley grown in a dry area at 0.18%, lower in high rainfall areas at 0.13%, and lowest in irrigated areas at 0.12%. Genotype (G) by environment (E) interactions were significant for all traits, except for brightness of cooked kernels. However, the effects of the $G \times E$ interactions were generally small compared with either the genetic or the environmental effect alone and primarily due to changes in magnitude rather than in rank. Stability analyses confirmed the nature of the $G \times E$ interactions.

Food uses of barley are currently limited. Nevertheless, barley has good potential as food and as a functional food ingredient. Barley and barley-based food products are a source of total dietary fiber and soluble fiber (β -glucans) as well as tocopherol and tocotrienols with potential for health benefits (Newman et al 1989).

Consumer preferences are affected by the appearance of products; thus, color and discoloration of food products are important quality attributes in production and marketing (Pomeranz and Meloan 1994). Chemical composition of barley, including total polyphenol content, PPO activity, and protein content are related to the discoloration of barley-based food products (Lagasse et al 2000; Zheng et al 2000; Quinde et al 2004).

Genetic and environmental factors influence the chemical composition of barley. For protein, environmental factors may have a larger effect than genetic factors (Torp et al 1981; Molina-Cano et al 2001). Significant differences in protein content were detected among locations (Kenn et al 1993), while crop years showed no significant effect (Fastnaught et al 1996). A small but significant genotype-by-environment interaction effect on protein content was also indicated by Molina-Cano et al (2001). Kleese et al (1968) and Dick et al (1985) reported significant varietal differences in accumulation of grain minerals. Varietal differences in phenolic content in barley and consistency in the ranking of cultivars among locations were reported by Bendelow and LaBerge (1979). Barley PPO activity is influenced by genetic factors as well as by environmental factors (Jerumanis et al 1976). These changes in chemical composition could, in turn, affect the color and discoloration of barley-based food products. However, the relative magnitude of genetic, environmental, and $G \times E$ effects on parameters associated with color and discoloration of barley is unclear. Fastnaught et al (1996) demonstrated that locations and crop year had an effect on the color of whole seeds of various types of barley. Another study also reported differences in discoloration of raw and cooked abraded kernels due to location (Fastnaught et al 2002). Significant differences in discoloration potential among classes and genotypes of barley were reported by Quinde et al (2004). Our objectives were to determine relative contri-

bution of genotype (G), environment (E), and $G \times E$ interaction on total polyphenol content, PPO activity, and discoloration potential of barley.

MATERIALS AND METHODS

Materials

Twelve genotypes of barley were evaluated including eight hulled and four hullless types. Hulled barleys included proanthocyanidin-containing (Harrington, Farmington, Baronesse, and Steptoe) and proanthocyanidin-free types (Radiant, 98NZ015, Caminant, and CA803803). Hullless barleys included regular starch (Bear and CDC McGwire) and waxy types (CDC Candle and SH97110). Hullless barleys were all proanthocyanidin-containing. The 12 barley genotypes were grown in 2001 and 2002. The locations included Pullman (high rainfall), Royal Slope (irrigated), and Ritzville (low rainfall), in the state of Washington, in two replicate plots. The 2001 Ritzville trial was lost due to severe drought conditions. Average temperature (April–August) and total precipitation (September–August) for Pullman were 15.1°C and 416 mm in 2001; 14.5°C and 485 mm in 2002. Average temperature (April–August) and total precipitation (September–August) for Royal Slope were 17.4°C and 191 mm in 2001; 17.5°C and 188 mm in 2002. Average temperature (April–August) and total precipitation (September–August) for Ritzville were 15.5°C and 149 mm in 2001; 15.6°C and 248 mm in 2002. Barley grains were abraded using a tangential abrasive dehulling device (TADD, Venables Machine Works, Ltd., Saskatoon, Canada) to remove 15 and 30% of the kernels by weight for hullless and hulled barley, respectively. Abraded barleys were ground with a cyclone sample mill (Udy Corp., Fort Collins, CO) fitted with a 0.5-mm opening before chemical analysis and color measurements. Abraded barley kernels and their flours were stored at 4°C until analyzed.

Chemical Analysis

Moisture content of barley flour was determined according to Approved Method 44-15A (AACC International 2000). Protein ($N \times 6.25$) was determined using a nitrogen analyzer (Leco Corporation, St. Joseph, MI), according to AACC Approved Method 46-30. Ash content was determined according to AACC Approved Method 08-01. All analyses were performed in duplicate and mean results of all analyses were reported on a moisture-free basis. Total polyphenol content and PPO activity were determined spectrophotometrically according to the procedure described in detail by Quinde et al (2004).

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Color Measurements

As indicators of discoloration potential of barley when processed into food products, brightness (L^*) was measured in abraded kernels, cooked kernels, gels, and dough sheets. Brightness was determined using a spectrophotometer (CM-2002, Minolta Camera Co., Chuo-Ku, Osaka, Japan) and expressed as CIE-Lab L^* . The higher the L^* , the brighter the barley or barley product. Brightness of abraded kernels was determined using a glass cup (4 cm height \times 4.5 cm diameter) filled level to the top with abraded kernels and covered with plastic wrap. Color was measured through the plastic wrap on duplicate samples. Cooked barley was prepared according to Klamczynski et al (1998). After cooking, the kernels were removed, cooled for 30 min at $20 \pm 2^\circ\text{C}$, and transferred into a petri dish (clear polystyrene, 35×10 mm), then covered with a lid and inverted. Color of the cooked kernels was immediately measured through the inverted petri dish. Gels were prepared with barley flour (10 g, 14% mb) dispersed in water (90 mL). The slurry was heated and boiled for 5 min. After cooking, the hot paste was poured into a petri dish (clear polystyrene, 35×10 mm), cooled for 30 min at $20 \pm 2^\circ\text{C}$, covered with a lid, and inverted. Color of the resulting gel was immediately measured through the inverted petri dish. Dough sheets were prepared by mixing flour (10 g, 14% mb) with water (6.4 mL) in a 10-g mixograph (National Mfg., Lincoln, NE) for 1 min and sheeting on a cookie sheet to a thickness of 5 mm using a rolling pin. Dough sheets were placed in plastic bags and kept at $20 \pm 2^\circ\text{C}$ and the brightness was measured 24 hr after preparation.

Statistical Analysis

Statistical analysis of data was performed using SAS procedures and programs (SAS Institute, Cary, NC). Analysis of variance (ANOVA) was calculated considering each location-year as a

separate environment. Both genotypes and environments were considered as fixed effects. Relative influences of genotype and environment on discoloration of barley were determined using the ratios of variance components according to Peterson et al (1986). Genotype and environment means were compared using least significant differences (LSD) at $\alpha = 0.05$. Pearson's correlation coefficients between traits were also calculated. The regressions of each genotype response to an environmental index and the squared deviations from this regression were used for determining stability (Eberhart and Russell 1966). The environmental index was estimated as the mean of all genotypes at a specific environment minus the grand mean. The b -values, the slopes of the regressions, were tested for differences from $b = 1$ using t -tests. A genotype was considered responsive to change in environments if $b > 1$, stable if $b = 1$, or nonresponsive if $b < 1$. A second stability parameter calculated was deviations from regression (s^2_d). This second stability parameter indicates the variation due to the response of the cultivar to varying environmental indexes. Differences in b -values among genotypes and significance of deviations from regression were tested using an approximate F -test. A genotype with $b = 1$ and $s^2_d = 0$, stable across environment, indicates a genotype that does relatively the same over a wide range of environments. A genotype with $b < 1$ and $s^2_d = 0$, consistent across environments, indicates a genotype with low variance for a specific trait when measured across environments (Peterson et al 1992).

RESULTS AND DISCUSSION

Analysis of Trait Values

Both genotype and environment contributed to significant variation for protein, ash, total polyphenol content, PPO activity, and brightness of abraded and cooked kernels, gels, and dough sheets.

TABLE I
Mean Squares for the ANOVA of Chemical Composition and Discoloration Potential of Abraded Barley^a

Source of Variation	df	Chemical Composition				Brightness (L^*)			
		Protein	Ash	Total Polyphenol Content	PPO Activity	Abraded Kernels	Cooked Abraded Kernels	Gel	Dough
Genotype (G)	11	16.2***	0.20***	0.049***	28,592***	17.8***	9.2***	18.3***	336.9***
Environment (E)	4	40.9***	0.39***	0.016***	2,823***	72.6***	44.8***	1.4***	69.6***
G \times E	44	0.7**	0.01***	0.001***	339***	1.9***	0.9	1.0***	2.5***

^a ** and *** = $P < 0.01$ and 0.001 , respectively.

TABLE II
Genotypes Means Across Environments for Chemical Composition and Discoloration Potential of Abraded Barley

Class and Genotype	Chemical Composition				Brightness (L^*)			
	Protein (%)	Ash (%)	Total Polyphenol Content (%)	PPO (units/g)	Abraded Kernels	Cooked Abraded Kernels	Gel	Dough
Hulled								
Proanthocyanidin-containing								
Harrington	11.4	0.92	0.15	58.7	72.9	58.3	54.7	69.1
Farmington	11.5	0.92	0.14	98.2	71.0	57.7	53.8	67.9
Baronesse	11.2	0.96	0.17	59.1	71.8	58.8	55.5	68.7
Steptoe	10.9	1.00	0.18	59.9	72.3	58.8	55.7	69.5
Proanthocyanidin-free								
Radiant	10.6	1.02	0.04	126.6	74.0	59.3	57.9	76.3
98NZ015	11.5	1.00	0.06	174.7	71.5	59.4	56.9	74.2
Caminant	11.5	0.98	0.05	197.2	71.6	59.1	57.7	75.7
CA803803	11.2	0.91	0.05	176.8	72.4	58.6	57.2	73.3
Hullless								
Regular								
Bear	13.7	1.25	0.20	77.3	69.7	57.5	55.1	63.4
CDC McGwire	13.4	1.19	0.21	56.2	69.1	56.5	55.8	63.9
Waxy								
CDC Candle	13.8	1.27	0.21	70.9	72.0	58.5	55.1	60.1
SH97110	14.0	1.23	0.20	60.4	70.6	56.8	54.1	59.3
LSD ^a	0.5	0.03	0.01	4.6	0.6	0.7	0.4	0.7

^a Least significant difference ($P < 0.05$). Differences between two means exceeding this value are significant.

G × E interactions were also significant for all parameters, except for cooked kernels (Table I). Analysis of profile plots for all parameters with significant G × E interactions indicated that total polyphenol content, PPO activity, and brightness of dough sheets had noncrossover interactions. While brightness of abraded kernels and gels had crossover interactions, G × E interactions for protein and ash were noncrossover, but inconsistencies for some genotypes were observed. A noncrossover interaction indicated that the rank of the means for genotypes was unchanged although the magnitude of the differences between genotypes changed among environments.

Barley cultivar means across environments are summarized in Table II. Protein content ranged from 10.6% (Radiant) to 14.0% (SH97110) and ash content from 0.91% (CA803803) to 1.27% (CDC Candle). The hulless types had significantly higher protein and ash contents than the hulled types. Total polyphenol content of the hulless types were similar to each other (0.20–0.21%), but greater than hulled proanthocyanidin-containing (0.14–0.18%) and hulled proanthocyanidin-free types (0.04–0.06%). PPO activity was highest in the hulled proanthocyanidin-free types (126.6–197.2 units/g). However, Quinde et al (2004) reported that hulled proanthocyanidin-free types were not always high in PPO activity. CDC Candle, Bear, and Farmington had moderately low PPO activities (70.9–98.2 units/g). Genotypes with a relatively low PPO activity that were similar to each other were CDC McGwire, Harrington, Baronesse, Steptoe, and SH97110 (56.2–60.4 units/g).

Radiant had the brightest abraded kernels, while Bear and CDC McGwire had the darkest. Brightness (L^*) of cooked kernels ranged from 56.5 (CDC McGwire) to 59.4 (98NZ015). Differences among barley classes were not evident for these two kernel traits. Radiant and Caminant gels had highest brightness, and SH97110 and Farmington gels had the lowest. In general, proanthocyanidin-free types had significantly higher L^* of gels (56.9–57.9) than hulled and hulless proanthocyanidin-containing types (53.8–55.8). The L^* of dough sheets was highest in hulled proanthocyanidin-free types (73.3–76.3), lower in hulled proanthocyanidin-containing types (67.9–69.5), and lowest in hulless barley (59.3–63.9). Proanthocyanidin-free types were definitely brighter than the other barley classes for these two processed barley traits. Environment means across genotypes are shown in Table III.

Significant differences due to environment were observed for all parameters. Barley grown at Ritzville 2002 (low rainfall site) exhibited higher protein content and total polyphenol content and lower PPO activity compared with barley grown at Pullman (high rainfall site) and Royal Slope (irrigated site) in 2001 and 2002. Barleys grown at Royal Slope had lower total polyphenol content and higher ash content compared with those grown at Pullman both years. All barleys grown at Ritzville at 2002 had the lowest brightness of abraded and cooked kernels and dough sheets. Brightness of gels and doughs from barleys grown at Royal Slope was higher compared with that of those grown at Pullman and Ritzville.

Ratios of Genetic to Environmental Variance Components

The ratios of genetic to environmental (G/E) variances showed that genetic factors had a larger influence than environmental factors on total polyphenol content, PPO activity, and brightness of gels and dough sheets (Table IV). G/E variance ratios <1.0 indicated a larger influence of environment on the variability of brightness of abraded kernels and cooked kernels. G/E variance ratios were similar in magnitude and nearly evenly balanced for protein and ash content. The ratio of environmental variance to genotype-by-environment interaction [$E/(G \times E)$] indicated larger effects of environmental factors compared with G × E effects on the variability of all parameters, except for brightness of gels. Overall, these results indicate that genetic factors were more important than environmental factors or G × E interactions in determining total polyphenol content, PPO activity, and brightness of gel and dough, and were as important as environment factors for protein and ash content. For brightness of abraded and cooked kernels, environmental factors were more important than genotype or G × E interaction. The importance of the environment in the brightness of abraded and cooked kernels was probably due to the effect of environment on kernel plumpness. Grains with high plumpness (grains >2.80 for two-row or 2.78 mm for six-row barley) also showed high brightness of abraded and cooked kernels. As previously indicated by Quinde et al (2004), the measurement of brightness of abraded and cooked kernels is the result of not only the color of the kernels, but also the uneven surface of the grains, which in turn affects the accuracy and reliability of the

TABLE III
Environmental Means Across Genotypes for Chemical Composition and Discoloration Potential of Abraded Barley

Environment	Chemical Composition				Brightness (L^*)			
	Protein (%)	Ash (%)	Total Polyphenol Content (%)	PPO (units/g)	Abraded Kernels	Cooked Abraded Kernels	Gel	Dough
High rainfall site								
Pullman 2001	11.7	0.91	0.13	102.8	72.5	60.1	55.6	68.2
Pullman 2002	11.7	0.94	0.13	107.6	72.0	58.1	55.6	67.9
Irrigated site								
Royal Slope 2001	11.8	1.07	0.12	100.6	72.5	58.8	56.2	69.3
Royal Slope 2002	10.8	1.21	0.12	112.1	72.4	58.0	55.9	70.8
Low rainfall site								
Ritzville 2002	14.3	1.13	0.18	83.6	68.5	56.4	55.6	66.2
LSD ^a	0.3	0.02	0.01	3.0	0.4	0.5	0.2	0.5

^a Least significant difference ($P < 0.05$). Differences between two means exceeding this value are significant.

TABLE IV
Ratios^a of Variances Estimated for Genotype (G) and Environment (E) Main Effects and Their Interactions for Chemical Composition and Discoloration Potential of Abraded Barley

	Chemical Composition				Brightness (L^*)			
	Protein	Ash	Total Polyphenol Content	PPO Activity	Abraded Kernels	Cooked Abraded Kernels	Gel	Dough
G/E	0.9	1.2	7.2	24.5	0.6	0.5	36.6	11.7
$E/(G \times E)$	32.7	18.8	10.6	3.0	18.1	57.8	0.5	12.1

^a Ratios of genetic to environmental variance components (G/E) and environmental variance to genotype-by-environment interaction components [$E/(G \times E)$].

TABLE V
Pearson Correlation Coefficients (*r*) Between Chemical Composition and Brightness of Gel and Dough of Abraded Barley

	Brightness (<i>L</i> *)	
	Gel	Dough
Overall (<i>n</i> = 60)		
Total polyphenols	-0.696****	-0.874***
Polyphenol oxidase activity	0.626***	0.729***
Protein	-0.339**	-0.765***
Ash	-0.128	-0.496***
Proanthocyanidin-containing (<i>n</i> = 40)		
Total polyphenols	0.029	-0.640***
Polyphenol oxidase activity	-0.412**	0.063
Protein	-0.154	-0.837***
Ash	0.297	-0.514**
Proanthocyanidin-free (<i>n</i> = 20)		
Total polyphenols	-0.255	-0.734**
Polyphenol oxidase activity	-0.323	0.283
Protein	0.042	-0.888***
Ash	-0.290	-0.071

^a *, **, *** = Significant at $P < 0.05$, $P < 0.01$, $P < 0.001$, respectively.

determination. Thereby, brightness of gels and dough sheets can be considered better indicators of discoloration potential of barley than brightness of abraded and cooked kernels.

Correlations Between Chemical Composition and Discoloration Potential of Barley

Highly significant overall negative correlations ($n = 60$) between brightness of gels and dough sheets and total polyphenol content were observed (Table V). The significant differences in total polyphenol content between proanthocyanidin-free and proanthocyanidin-containing types contributed to the overall correlation between brightness and total polyphenol content (Quinde et al 2004). Within hulled proanthocyanidin-free ($n = 20$) or proanthocyanidin-containing ($n = 40$) types, brightness of dough sheets exhibited negative correlations with total polyphenol content, while the correlation between total polyphenol content and brightness of gels was not significant. PPO activity showed an overall positive relationship with brightness of gels or dough sheets. However, this positive correlation was probably because of the higher PPO activities in proanthocyanidin-free types compared with those of proanthocyanidin-containing types (Table II). Within proanthocyanidin-containing ($n = 40$) type, there was a significant negative relationship between PPO activity and brightness of gels. There was, however, no relationship between PPO activity and brightness of gels or doughs for the proanthocyanidin-free types.

Brightness of gels and dough sheets had a significant overall negative correlation ($n = 60$) with protein content. Within proanthocyanidin-containing ($n = 40$) and proanthocyanidin-free ($n = 20$) types, higher protein content resulted in lower brightness of dough sheets. Baik et al (1995) suggested that protein content may be correlated to an unknown component that affects hardness or the rate of water absorption during dough processing, thereby affecting the discoloration of wheat dough for Asian noodles. Among all types ($n = 60$) and specifically within all proanthocyanidin-containing ($n = 40$) type, brightness of dough sheets had a significant negative correlation with ash content, although the r values were relatively low. Protein and metal ions can react with phenolic compounds or their oxidized products, resulting in colored complexes (Blouin et al 1982; Friedman 1996; McDonald et al 1996). These reactions could also be contributing to the intensity of the discoloration potential of barley.

Stability Tests

$G \times E$ interactions were further evaluated using regression analysis and deviations from regression for chemical composition and brightness of gels and dough sheets (Tables VI and VII). Significant differences in genotype response to environment were

observed in the linear regression coefficients (b -values) for total polyphenol content, PPO activity, and brightness of gels. Genotypes responsive to the environment ($b > 1$) for several parameters were also identified: 98NZ015 for protein content, Caminant and CA803803 for PPO activity, and Farmington and Steptoe for brightness of gels. CA803803 and Caminant contributed more to the $G \times E$ interaction for PPO activity, but this was due to a change in magnitude and not changes in rank. Genotypes nonresponsive to the environment ($b < 1$) were Steptoe, Bear, and CDC McGwire for protein content, Harrington and all four proanthocyanidin-free types for total polyphenol content, Harrington and Steptoe for PPO activity, and CDC Candle for brightness of dough sheets. A nonresponsive genotype exhibits low variance for a quality parameter across environments. For each parameter, genotypes with nonsignificant deviations from regression could be classified as being stable for that particular parameter. Exceptions included Steptoe for total polyphenol content, Baronesse for PPO activity, and Radiant and SH97110 for gel brightness. Nonsignificant deviations from regression also indicated that the linear model accounted for much of the variation in genotype response across environments (Peterson et al 1992). Stability of quality parameters across environments is important to breeders and food processors to ensure cultivar and product consistency (Budak et al 2003). These results indicate that for quality parameters related to the discoloration of barley-based food products such as total polyphenol content, PPO activity, and brightness of dough sheets, it is possible to predict cultivar performance in a single environment.

CONCLUSIONS

For all parameters related to discoloration potential of barley evaluated in this study, the $G \times E$ interactions were significant, except for brightness of cooked kernels. For most parameters, the $G \times E$ interactions were caused by change in magnitude rather than in changes in rank, except for brightness of abraded kernels and gels. Although significant, $G \times E$ interactions were small in magnitude compared with genotype or environment effects. Genetic factors contributed more to the variability of total polyphenol content, PPO activity, and brightness of dough sheets than environment. Variation attributed to environment was similar to genetic variation for protein content and ash content, but larger for brightness of abraded and cooked kernels. In addition, total polyphenol content was lowest in barleys grown in irrigated areas, higher in relatively high rainfall areas, and highest in a dry area. Genotype stability across environments for protein, ash, total polyphenol content, PPO activity, and brightness of dough sheets

TABLE VI
Coefficients (*b*) of Regression for Each Genotype Response to an Environmental Index and Deviations from Regression (s^2_d) for Chemical Composition

Genotype	Chemical Composition ^{a,b}							
	Protein		Ash		Total Polyphenols		PPO Activity	
	<i>b</i>	s^2_d	<i>b</i>	s^2_d	<i>b</i>	s^2_d	<i>b</i>	s^2_d
Harrington	0.97	-0.60	0.77	-0.009	0.82*	-0.0005	0.12*	-162.2
Farmington	1.33	-0.49	1.06	-0.007	1.12	-0.0004	0.83	154.1
Baronesse	1.05	-0.66	0.72	-0.006	1.48	-0.0003	0.13	362.2*
Steptoe	0.73*	-0.99	0.58	-0.008	1.51	0.0011*	0.09*	-157.4
Radiant	1.01	-0.54	0.59	-0.007	0.24*	-0.0004	2.12	176.8
98NZ015	1.46*	-0.80	1.07	-0.006	0.61*	-0.0005	1.51	-34.5
Caminant	1.30	-0.87	1.20	-0.003	0.53*	-0.0005	1.82*	-111.9
CA803803	1.17	-0.91	0.81	-0.009	0.33*	-0.0004	3.14*	47.6
Bear	0.81*	-1.01	1.29	-0.006	1.58	-0.0003	0.63	-112.5
CDC McGwire	0.55*	-0.79	1.37	-0.007	1.23	-0.0002	0.57	-142.8
CDC Candle	0.73	-0.79	1.24	-0.007	1.30	-0.0002	0.63	-142.8
SH97110	0.88	-0.52	1.30	-0.007	1.24	-0.0004	0.42	-77.5

^a * = Significantly different from 1.0 for *b* and significantly different from 0.0 for s^2_d at $\alpha = 0.05$.

^b *b*-Values significantly different among genotypes based on an approximate *F*-test

TABLE VII
Coefficients (*b*) of Regression for Each Genotype Response to an Environmental Index and Deviations from Regression (s^2_d) for Brightness of Gel and Dough of Abraded Barley

Genotype	Brightness (L^*) ^{a,b}			
	Gel		Dough	
	<i>b</i>	s^2_d	<i>b</i>	s^2_d
Harrington	2.55	0.11	0.95	-1.94
Farmington	4.46*	-0.30	1.11	-1.15
Baronesse	-2.10	0.30	1.37	-1.40
Steptoe	4.69*	-0.30	1.27	0.39
Radiant	-1.75	0.90*	1.10	-1.77
98NZ015	-0.56	0.28	1.38	0.77
Caminant	1.58	-0.21	1.34	-0.94
CA803803	0.37	-0.11	1.01	-0.33
Bear	1.12	-0.31	0.84	-1.95
CDC McGwire	1.74	0.20	0.55	0.32
CDC Candle	0.33	0.20	0.32*	0.32
SH97110	-0.43	0.64*	0.76	-1.17

^a * = Significantly different from 1.0 for *b* and significantly different from 0.0 for s^2_d at $\alpha = 0.05$.

^b *b*-Values significantly different among genotypes based on an approximate *F*-test

suggests that data from one environment may be effectively used to rank genotypes and to predict relative performance of their discoloration potentials.

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