Influence of Genotype and Environment on Kernel Discoloration of Midwestern Malting Barley

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ABSTRACT

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Thirty barley cultivars and lines grown at Crookston, Morris, Rosemount, and St. Paul, MN, during 1982 and 1983 were evaluated for black stain and carameling. Chevron was resistant to both black stain and carameling, and Karl was susceptible to both. The potential and commercial cultivars had intermediate resistance to black stain, but they were more severely black-stained than lines with a kernel discoloration resistant parent. The barleys of western origin were intermediate between the commercial cultivars and the susceptible checks. Most of the barleys were susceptible to carameling. CI 9539 and the lines with a resistant parent were as severely carameled as the potential and commercial cultivars. Effective selection for resistance to black stain could be carried out at a single location when irrigation and inoculation with *Bipolaris sorokiniana* were used. Irrigation significantly increased black stain severity, whereas inoculation increased black stain severity but not significantly ($P = 0.05$). In the nonirrigated environments, black stain was most severe when rainfall was highest. Carameling severity was not influenced by irrigation or inoculation, but under natural conditions, carameling was most severe when rainfall was highest. Differences in black stain and carameling could be detected among genotypes screened under natural conditions at two locations for 2 yr.

Kernel discoloration is a common disease of barley in the upper midwestern United States. It is important because the malting and brewing industries prefer barley free of the disease. Discolored barley is discounted in the market; severely discolored barley is not used by the malting and brewing industry and is sold as feed.

Barley kernel discoloration is associated with fungi and bacteria (4,5,13,14) and varies in severity with both cultivars and environmental conditions (7,8,11,18,19). *B. sorokiniana* has been reported to be the most important pathogen (1), but other fungi involved are *Alternaria alternata* (Fr.) Keissler, species of *Fusarium* (primarily *F. graminearum* Schwabe), and *Cladosporium herbarum* (Persoon) Link ex Fr. This last species is thought to be important only in areas where environmental conditions limit other pathogens (13). *Pseudomonas syringae* pv. *syringae* van Hall causes kernel discoloration of Klages barley grown under irrigation in the western United States but has not been reported in barley grown in the Midwest (14).

The importance of environmental conditions is suggested by the variation of kernel discoloration in barleys at different locations and in different years (3,8,19). The amount of moisture available after heading has often been associated with the disease; kernel discoloration has been most severe after abundant rain (6,7,11,18,19). Furthermore, during years of higher than average rainfall, the frequency with which fungi were isolated was increased (7,11).

The cultivars grown in the upper midwestern United States are considered moderately susceptible to kernel discoloration but may become severely diseased when conditions favor disease. Sources of resistance have been reported (2,8), and some progress has been made in incorporating resistance into barley lines that are agronomically desirable for the midwestern United States (19).

The objectives of this research were to evaluate the kernel discoloration of selected barley cultivars and lines and to determine the effect of locations, years, sprinkler irrigation, and inoculation with *B. sorokiniana* on screening for resistance to kernel discoloration.

MATERIALS AND METHODS

Thirty barley cultivars and advanced breeding lines that differed in kernel discoloration were studied. Chevron (CI 1111) and CI 9539 were included as resistant checks, whereas Cebada Capa (CI 6193), Karl (CI 15487) and CI 4974 were susceptible checks. Also studied were five cultivars commonly grown in the upper Midwest and four potential cultivars. The remaining genotypes were advanced lines from the Minnesota barley breeding program. Four of these lines had one parent from breeding programs in the western United States, where kernel discoloration is uncommon. The last 12 lines had either Chevron or CI 9539 in their pedigree and had been selected for resistance to kernel discoloration.

The experiment was conducted at the University of Minnesota agricultural experiment stations in Crookston, Morris, Rosemount, and St. Paul during 1982 and 1983. The barleys were planted at a rate of 10 g of seed per row in rows 0.3 m long spaced 30 cm apart and arranged in a randomized complete block with three replicates. At Crookston and Morris, the barleys were exposed to natural disease conditions. At Rosemount, there were two treatments: 1) natural disease conditions and 2) sprinkler irrigation for 1 hr/day on 3 days/wk, starting at anthesis. At St. Paul, there were four treatments: 1) natural disease conditions; 2) sprinkler irrigation for 2 hr on alternate mornings, starting at anthesis; 3) inoculation with *B. sorokiniana* with no irrigation; and 4) inoculation with *B. sorokiniana* on alternate evenings followed the next morning by 2 hr of overhead irrigation.

B. sorokiniana inoculum was produced on a substrate of perlite-cornmeal-potato-dextrose agar (Difco) (12). Inoculum was applied as a conidial suspension (50,000–100,000 conidia per milliliter) at 2.8 kg/cm^2 (40 psi) from a 60-L tank mounted on a garden tractor. About 0.15 L of inoculum was applied per row on alternate evenings, starting at anthesis and continuing for eight to 10 applications.

Evaluation of kernel discoloration was done on 10–15 mature heads per row. The heads were air-dried at 25–30 C for

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2–4 wk, then threshed. Severity was determined by visually examining a sample of the kernels on 15-cm-diameter white paper plates under fluorescent lights, then comparing it with a set of standards. Kernel discoloration was evaluated as black stain and carameling. Black stain is characterized by a dark brown to black discoloration on the palea and lemma of the kernel, whereas carameling is a uniform discoloration of the barley kernel that ranges from a light straw color to yellow-orange to brown.

Black stain severity was scored on a scale of 1–5, where 1 = <5% of the surface stained, limited to the base of only a few kernels; 2 = 6–15% of the surface stained, primarily on the base of the kernels; 3 = 16–30% of the surface stained, black stain not limited to the base of a few kernels; 4 = 31–50% of the surface stained and almost all kernels with some stain; and 5 = >50% of the surface was stained black, all kernels stained.

The degree of carameling was evaluated with the aid of an International Color Standard Name Chart (ICSNC) (9). The kernel samples were scored as follows: 1 = a light straw to pale orange-yellow similar to the ICSNC block 73 p.OY; 2 = intermediate orange yellow similar to ICSNC block 70 i.OY; 3 = brilliant orange yellow similar to ICSNC block 76 brill. OY; 4 = similar in color to ICSNC 66 v.OY; and 5 = similar to ICSNC blocks 68 s.OY and 71. m.OY.

Data were analyzed by analysis of variance using the SPSS statistical package. The error terms for the *F* tests in the analysis of variance were obtained from the appropriate interaction terms. Variance components attributed to genotype and genotype × environment interactions were also obtained from the analysis of variance and used to obtain the expected error variance of the genotype mean under varied allocation of years and locations (15). These error variances were then used to compute an LSD to estimate the effect of years and locations on the variations that could be detected among genotypes.

RESULTS

Black stain severity varied significantly ($P = 0.05$) among the barley genotypes (Table 1). The genotype × location and genotype × year interactions also were significant. The sources of kernel discoloration resistance, Chevron and CI 9539, had less black stain than the other barleys at all locations in both years (Table 2). The susceptible check cultivars were severely stained at all locations in both years. The black stain of the cultivar Robust was significantly ($P = 0.05$) less severe than that of Larker. The other cultivars, Bumper, Glenn, and Morex, were intermediate between Robust and Larker.

Minn 37 was most the resistant of the potential cultivars and had less black stain than Larker. The black stain of the lines with a parent of western origin was severe and resembled that of the susceptible check cultivars.

The barley lines derived from crosses involving Chevron and CI 9539 had less severe black stain than Larker and Karl, with the exception of Minn 1248, which was the most severely black-stained of this group. Minn 1248 had a mean black stain score that was similar to that of Larker. Minn 1251 and 1262 were the least severely black-stained and resembled CI 9539. Black stain of the remaining lines was intermediate in severity and appeared to form a continuous series between Minn 1248 and Minn 1262.

Black stain did not vary significantly

Table 1. Analysis of variance for black stain and carameling scores of 30 barley genotypes

		Black stain		Carameling	
Variables	**df**	**MS**	***F***	**MS**	***F***
Location	3	1.58	0.05	73.70	2.48
Year	2	16.17	0.49	28.18	0.95
Location × year	3	32.89	123.12**[a]	29.69	90.37**
Genotype	29	13.89	13.18**	8.27	7.92**
Genotype × location	87	0.43	1.62*	0.62	2.01**
Genotype × year	29	0.85	3.18**	0.72	2.17*
Genotype × location × year	87	0.27	1.23	0.33	1.36*
Error	478	0.22		0.24	

[a] * = Significant at $P = 0.05$ and ** = significant at $P = 0.01$.

Table 2. Black stain scores of barley genotypes grown at four locations in Minnesota during 1982 and 1983

	Location[a]										
	Morris[b]		Crookston[b]		Rosemount[b]		St. Paul[b]		Mean[b]		
Cultivar	**1982**	**1983**	**1982**	**1983**	**1982**	**1983**	**1982**	**1983**	**1982**	**1983**	**Mean[c]**
Resistant and parent cultivars											
Chevron	1.0	1.0	1.3	1.0	1.0	1.3	1.0	2.0	1.1	1.3	1.2
CI 9539	2.0	1.0	1.3	1.0	1.7	2.0	1.0	2.0	1.5	1.5	1.5
Susceptible check cultivars											
Cebada Capa	5.0	3.0	4.3	4.3	3.3	3.3	3.3	4.0	4.0	3.7	3.8
Karl	4.0	3.3	4.0	4.0	4.0	5.0	3.3	4.3	3.8	4.2	4.0
CI 4974	4.7	3.3	5.0	4.3	4.3	3.3	4.0	4.0	4.5*	3.7*	4.1
Commercial and potential cultivars											
Robust	3.0	2.0	2.0	3.0	2.3	2.7	2.0	3.3	2.4	2.8	2.6
Morex	3.0	2.0	3.0	2.7	2.7	3.0	2.0	3.0	2.7	2.7	2.7
Bumper	3.0	2.0	2.7	2.3	2.3	3.0	2.0	3.0	2.5	2.6	2.5
Glenn	4.0	2.3	3.0	3.0	2.7	3.3	2.0	3.7	2.9	3.1	3.0
Larker	4.0	2.3	3.0	3.0	2.7	3.3	3.0	3.3	3.2	3.0	3.1
Minn. 37	3.0	2.0	2.3	2.0	2.0	2.7	1.7	2.3	2.2	2.2	2.2
Minn. 42	3.0	2.0	2.3	2.0	2.0	2.7	1.7	2.3	2.2	2.2	2.2
Minn. 44	3.0	2.3	2.3	3.3	2.7	3.0	2.0	3.7	2.5	3.1	2.8
Barley lines with western germ plasm											
Minn. 78-2	4.0	3.3	3.3	4.3	4.3	4.0	3.0	4.0	3.7	3.9	3.8
Minn. 78-17	3.3	2.0	3.3	4.0	3.7	4.3	3.0	3.7	3.3	3.5	3.4
Minn. 78-57	3.3	2.7	3.0	3.7	3.0	3.3	2.7	3.7	3.0	3.3	3.2
Minn. 78-91	4.0	3.3	4.0	4.0	3.3	3.7	2.3	4.0	3.4	3.7	3.6
Advanced lines with a kernel discoloration-resistant parent											
Minn. 1248	3.0	2.0	2.7	3.0	2.7	3.3	1.7	4.0	2.5	3.1	2.8
Minn. 1250	2.7	2.0	2.0	2.3	2.3	3.0	2.3	2.7	2.3	2.5	2.4
Minn. 1251	2.7	2.0	1.0	1.3	2.0	2.7	1.3	2.7	1.8	2.2	2.0
Minn. 1252	2.3	2.0	2.0	2.0	2.0	2.7	1.3	3.0	1.9	2.4	2.2
Minn. 1253	2.3	2.0	2.3	2.3	2.0	2.0	1.0	2.3	1.9	2.2	2.0
Minn. 1254	3.0	2.0	1.3	2.3	2.0	3.0	1.3	2.7	1.9	2.5	2.2
Minn. 1255	3.0	2.0	1.7	2.3	1.7	2.7	1.3	2.7	1.9	2.4	2.2
Minn. 1256	2.0	2.0	2.0	2.3	1.7	3.0	1.0	2.3	1.7	2.4	2.0
Minn. 1257	3.0	2.3	2.3	2.7	2.3	3.0	1.3	3.0	2.2	2.8	2.5
Minn. 1258	2.7	2.0	2.0	2.3	1.7	2.7	1.7	3.3	2.0	2.6	2.3
Minn. 1259	3.0	2.0	1.7	2.0	2.0	2.3	1.7	2.7	2.1	2.2	2.2
Minn. 1260	2.0	2.0	2.0	2.0	1.7	2.7	1.3	2.7	1.8	2.3	2.0
Minn. 1261	2.3	1.7	2.0	2.3	2.0	3.0	1.0	2.0	1.8	2.2	2.0
Mean[d]	3.0	2.2	2.5	2.7	2.4	3.0	1.9	3.1	2.5	2.8	

[a] Mean of three replicates at each location per year.
[b] Significant genotype × location and genotype × year interactions ($P = 0.05$) LSD = 0.7.
[c] Differences among genotypes were significant ($P = 0.05$), LSD = 1.6, C.V. = 17.9.
[d] Significant location × year interactions ($P = 0.05$), LSD = 0.8.

with locations or years (Table 1); however, there was a significant location × year interaction. The interaction was most evident at Morris and St. Paul; in 1982, black stain was most severe at Morris and least severe at St. Paul, but in 1983, the opposite was true (Table 2). Black stain severity was intermediate at Crookston and Rosemount in both years.

The weather data for the four locations during 1982 and 1983 (Table 3) was collected by the University of Minnesota Agricultural Extension Service Agricultural Weather Advisory Program (16,17). There was more rain at Morris between heading and harvest in both years than at Crookston, Rosemount, or St. Paul. At all four locations, the mean temperature for July was 1–2 C warmer in 1983 than 1982. In both years, St. Paul was the warmest location and Crookston was the coolest. Morris and Rosemount were intermediate in temperature.

At Morris, Rosemount, and St. Paul, the year with the most rain or the most days with rain had the most severe black stain (Table 2); however, at Crookston, black stain was most severe in 1983. There was more rain at Crookston in 1982, but the mean temperature for July was 2.3 C cooler than in 1983.

The effects of sprinkler irrigation and inoculation with *B. sorokiniana* on the black stain resistance of the 30 barley cultivars and lines was evaluated in a separate experiment. The black stain scores of the barleys in these two experiments were similar to their scores in Table 1, so data are not shown. Data were averaged across all cultivars and lines to evaluate the effects of irrigation and inoculation on black stain (Table 4).

Black stain was more severe under sprinkler irrigation ($P = 0.05$) than when irrigation was withheld at Rosemount and St. Paul in both years (Table 4). The disease was more severe in 1983 than in 1982 at both locations, but the difference was not statistically significant. Black stain was more severe at Rosemount than at St. Paul ($P = 0.05$). There also was a significant irrigation × location × year interaction. This interaction was most evident at St. Paul; in 1982, the black stain severity increased with sprinkler irrigation, but in 1983, the severity in irrigated and nonirrigated plots was the same. A similar pattern was seen at Rosemount. This interaction was most likely due to greater rain at both locations in 1983 than in 1982. There were no genotype × environment interactions when the barleys were evaluated under irrigation.

Inoculation with *B. sorokiniana* tended to increase the severity of black stain (Table 5), but the increase was not statistically significant ($P = 0.05$). Black stain was most severe when plots were both irrigated and inoculated. There was a significant irrigation × inoculation × year interaction. In 1982, irrigation and inoculation treatments resulted in more severe black stain than occurred under natural conditions, but in 1983, the black stain severity of the barley grown under natural conditions was similar to that of the barley grown under irrigated or inoculated treatments. Again, this was probably due to the increased rain in 1983, increasing the black stain severity of the barley grown under natural conditions.

Calculation of LSDs from the variance components of the genotype and genotype × environment interactions estimate that screening for resistance to black stain at one location in 1 yr would detect differences of 0.86 among genotype means (Fig. 1). Adding a second location reduced the LSD to 0.66, a third location would detect differences of 0.56, and a fourth location reduced the LSD only slightly. Adding years to a one-location test had a similar effect. Screening for 2 yr at two locations would detect a difference at 0.5. To detect difference at 0.4, 2 yr at four locations would be needed.

Screening for black stain resistance under irrigation reduced the difference among genotypes that would be detected to 0.58 in a nursery at one location in 1 yr; adding a second location or a second year reduced difference detected by an LSD about the same, 0.43 and 0.41, respectively.

Carameling. Severity of carameling varied significantly ($P = 0.05$) among the barley cultivars and lines (Table 1). There were also significant cultivar × location, cultivar × year, and cultivar × location × year interactions.

Chevron was the least severely carameled barley (Table 5). The susceptible checks were severely carameled. The cultivars and potential cultivars were intermediate; of these cultivars, Bumper had the least severe carameling and Larker the most. The lines with a parent of western origin were similar to the susceptible checks. CI 9539 and the lines with a kernel discoloration resistance source in their backgrounds were not as severely carameled as the agricultural cultivars and were significantly less

Table 3. Rainfall and temperature at four locations in Minnesota during 1982 and 1983

Location	Year	No. days[a]	July mean temp. (C)	Rainfall		
				Total (mm)	Days with rain	Mean no. consecutive days
Morris	1982	28	22.5	110.74	16	3.2
	1983	28	23.7	109.73	6	1.5
Crookston	1982	28	20.6	83.32	10	2.0
	1983	28	22.9	46.22	6	2.0
Rosemount	1982	42	23.0	60.96	8	1.6
	1983	30	24.2	104.15	7	1.4
St. Paul	1982	37	23.3	64.77	8	1.6
	1983	31	25.0	105.39	9	2.0

[a] Number of days from which weather data were collected, 1 July to harvest (28 July to 11 August).

Table 4. Mean black stain score of 30 barley genotypes grown under different conditions of irrigation and inoculation at Rosemount and St. Paul during 1983 and 1983

Year	Rosemount[a]		St. Paul[a]				
	Nonirrigated	Irrigated[b]	Uninoculated and nonirrigated	Irrigated[b]	Inoculated[c]	Irrigated and inoculated	Year mean[d]
1982	2.4	2.9	1.9	2.5	2.6	2.7	2.4
1983	3.0	3.2	3.1	3.1	3.3	3.5	3.2
Mean	2.7	3.1	2.5	2.8	3.0	3.2	

[a] Differences attributed to location were significant ($P = 0.05$).
[b] Differences attributed to irrigation were significant ($P = 0.05$). There also was a significant irrigation × location × year interaction, LSD = 0.86 ($P = 0.05$).
[c] Differences attributed to inoculation were not significant ($P = 0.05$).
[d] Differences between years were significant at St. Paul ($P = 0.05$).

severely carameled than Larker.

The cultivar × location, cultivar × year, and cultivar × location × year interactions were due largely to an increase in carameling severity of the more resistant lines at Morris and Crookston in 1982 and at Rosemount in both 1982 and 1983.

Carameling severity did not vary significantly among the four locations or between the 2 yr (Table 1). However, there was a significant location × year interaction. This interaction was due to the difference in carameling severity at Morris and Crookston during the 2 yr of the experiment; both locations had more severe carameling in 1982 than 1983 (Table 5). Carameling severity was similar in both years at Rosemount and St. Paul. Carameling was most severe at all locations during the year with the most rain or the most days with rain between heading and harvest. However, sprinkler irrigation and inoculation with *B. sorokiniana* did not affect the severity of carameling of the barleys at Rosemount and St. Paul.

Screening for resistance to carameling in 1 yr at one location would detect an LSD of 0.75 in genotype means (Fig. 2). Adding either a second location or a second year would allow an LSD of 0.57 to be detected. To detect an LSD of 0.5, three locations in 1 yr are needed, and to detect an LSD of 0.4, screening at two locations in 2 yr would be needed.

DISCUSSION

Our work confirms earlier reports of resistance to kernel discoloration. We found the resistance to be stable across many naturally occurring environments as well as those environments created experimentally. The barleys were readily distinguished according to their black stain severity. The resistant cultivars Chevron and CI 9539 had the least black stain, followed by the lines with a resistant parent in their pedigree, and then by the potential and commercial cultivars. The barleys with western germ plasm in their pedigree had more severe black stain than the midwestern barleys, but they were not as severely black-stained as the susceptible checks. Some midwestern cultivars were moderately resistant to black stain in our tests. The origin of this resistance is not known but may have been the result of indirect selection done by midwestern barley breeders selecting lines with bright kernels. This type of selection would not occur in the west, where kernel discoloration is uncommon. Therefore, black stain was usually more severe when western germ plasm was compared with midwestern barleys.

The resistance observed in Chevron and CI 9539 was transferred to their progeny as indicated by the relatively low black stain scores of lines derived from a

Table 5. Carameling scores of barley genotypes grown at four locations in Minnesota during 1982 and 1983

	Location[a]										
	Morris[b]		Crookston[b]		Rosemount[b]		St. Paul[b]		Mean[b]		
Cultivar	1982	1983	1982	1983	1982	1983	1982	1983	1982	1983	Mean[c]
Resistant and parent cultivars											
Chevron	2.0	2.3	2.3	1.0	3.7	4.0	1.3	2.3	2.3	2.4	2.4
CI 9539	4.0	3.0	3.7	2.0	3.7	3.3	2.3	2.0	3.4	2.6	2.0
Susceptible check cultivars											
Cebada Capa	5.0	4.3	4.0	4.3	4.6	5.0	2.3	4.0	4.0	4.4	4.2
Karl	5.0	4.0	4.7	4.0	5.0	4.3	4.0	4.3	4.7	4.2	4.4
CI 4974	4.7	4.7	5.0	4.3	4.6	5.0	3.3	4.0	4.4	4.5	4.5
Commercial and potential cultivars											
Robust	3.3	3.0	4.0	2.3	4.0	3.7	3.0	2.7	3.6	2.9	3.2
Morex	3.7	2.7	4.0	2.0	4.0	4.0	2.7	2.7	3.6	2.8	3.2
Bumper	3.0	2.7	3.3	2.0	3.7	4.3	2.3	3.3	3.1	3.1	3.1
Glenn	4.0	2.7	4.0	2.3	4.0	5.0	2.6	3.3	3.7	3.3	3.5
Larker	3.7	2.7	4.3	3.0	4.0	4.6	3.0	3.3	3.8	3.4	3.6
Minn. 37	3.7	2.3	3.3	2.0	3.7	3.6	2.0	2.0	3.2	2.5	2.8
Minn. 42	3.7	3.0	4.0	3.0	3.7	3.7	2.7	3.0	3.5	3.2	3.3
Minn. 44	4.0	3.0	3.6	3.0	4.3	5.0	2.6	3.0	3.7	3.5	3.6
Barley lines with western germ plasm											
Minn. 78-2	5.0	4.0	4.3	3.7	4.7	4.7	3.0	4.0	4.3	4.1	4.2
Minn. 78-17	5.0	4.0	4.0	3.7	5.0	5.0	4.0	3.7	4.5	4.1	4.3
Minn. 78-57	4.0	3.7	4.0	3.3	4.3	5.0	3.7	4.0	4.0	4.0	4.0
Minn. 78-91	5.0	3.7	4.0	3.0	4.0	5.0	2.7	3.3	3.9	3.8	3.9
Advanced lines with a kernel discoloration-resistant parent											
Minn. 1248	3.3	2.7	4.0	2.0	4.3	4.0	2.7	2.0	3.6	2.7	3.1
Minn. 1250	4.0	3.0	4.0	2.0	3.3	3.7	2.3	2.0	3.4	2.7	3.0
Minn. 1251	3.0	2.0	3.7	1.7	4.3	4.7	1.7	2.0	3.2	2.6	2.9
Minn. 1252	3.3	2.0	3.3	2.0	4.0	4.0	1.7	2.0	3.1	2.5	2.8
Minn. 1253	3.7	2.3	3.3	2.3	3.3	3.7	1.3	2.0	2.9	2.6	2.8
Minn. 1254	3.7	2.0	3.3	1.7	3.7	5.0	1.3	2.0	3.0	2.7	2.8
Minn. 1255	3.3	2.7	3.3	1.7	4.0	4.7	1.3	2.0	3.0	2.8	2.9
Minn. 1256	3.7	2.0	3.3	2.0	3.7	3.7	1.7	2.0	3.1	2.4	2.8
Minn. 1257	3.3	2.0	3.0	2.0	3.7	4.3	1.7	2.0	2.9	2.6	2.8
Minn. 1258	3.7	3.0	3.3	2.7	4.0	4.3	2.0	3.0	3.3	3.3	3.3
Minn. 1259	4.0	2.7	4.0	2.0	4.0	4.3	2.0	2.3	3.5	2.8	3.2
Minn. 1260	3.7	2.3	4.0	2.0	3.0	2.7	2.3	1.7	3.3	2.2	2.7
Minn. 1261	3.7	2.0	3.3	2.0	3.7	4.0	2.3	2.0	3.3	2.5	2.9
Mean[d]	3.8	2.8	3.8	2.4	4.0	4.3	2.4	2.6	3.5	3.0	

[a] Mean of three replicates at each location per year.
[b] Significant genotype × location, genotype × year, and genotype × location × year interactions ($P = 0.05$); LSD = 0.9 for genotype × location and genotype × year and LSD = 0.2 for genotype × location × year.
[c] Differences among genotypes were significant ($P = 0.05$), LSD = 1.6, C.V. = 16.4.
[d] Significant location × year interaction ($P = 0.05$), LSD = 0.9.

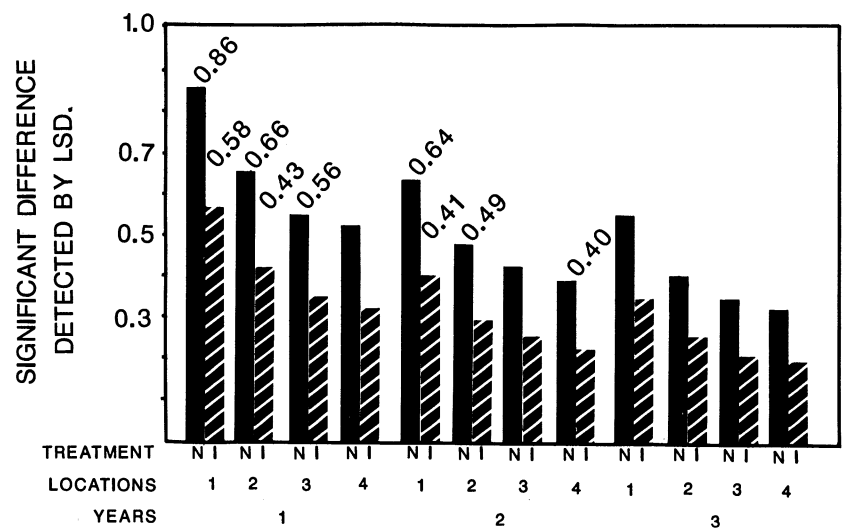

Fig. 1. Expected difference in genotype means for black stain detected by LSD under varied allocation of years and locations under irrigated (I) and nonirrigated (N) conditions.

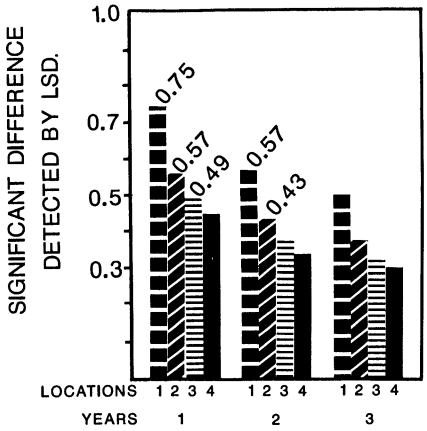

Fig 2. Expected difference in genotype means for carameling detected by LSD under varied allocation of years and locations.

resistant parent. Despite some variations in disease, Chevron, CI 9539, Minn 1251, and Minn 1262 maintained their resistance at all locations each year of the test. We conclude that it should be possible to develop cultivars with a high level of resistance that is stable in the midwestern malting barley growing area. Further evidence of this was seen in the consistently low black stain scores of M37 and Robust.

The observation that black stain severity is increased by rain is supported by the fact that sprinkler irrigation significantly increased black stain severity on barleys grown at Rosemount and St. Paul. Furthermore, irrigation had more of an effect in 1982, the year with the least rain. The increase in black stain severity with increased rain or irrigation agrees with observations reported by other workers (3,7,11,19). Treatment with irrigation also appeared to reduce the location × year interaction. We conclude that overhead sprinkler irrigation to supplement natural rainfall should be useful to produce maximum severity of black stain.

Inoculation with *B. sorokiniana* did not significantly affect the severity of black stain, though the disease was most severe in inoculated plants. A nursery inoculated with *B. sorokiniana* and irrigated to augment natural conditions appeared to be the most effective method to screen lines for resistance. When the severity of black stain was increased, lines that were resistant or intermediately resistant were more readily observed.

Screening for resistance to black stain under natural disease conditions would be effective when done at two locations in 2 yr, allowing for an LSD of 0.5 to be detected among genotype means. However, screening in 1 yr at one location with irrigation would be as effective. Furthermore, adding a second location or a second year to an irrigated nursery would allow an LSD of 0.4 to be detected. Screening under irrigation increases black stain severity, resulting in a decrease in the variance components associated with the genotype and genotype × environment interactions.

The most effective locations for screening for black stain resistance would be at Crookston, where the location × year interaction was not significant, and at St. Paul, where irrigation is available.

The causes of carameling are not known; it maybe similar to weathering (1,10). Chevron had the highest level of resistance to carameling. CI 9539 and the lines with a discoloration-resistant parent had carameling scores similar to the commercial cultivars. The barleys with parents of western origin were more severely carameled than the commercial cultivars and were similar to the susceptible checks.

At three of the four locations, it was possible to separate genotypes that carameled readily from those that did not. At Rosemount, Chevron was as severely carameled as the other barleys, indicating that, under some environmental conditions, resistance to carameling was not evident.

According to our tests, screening for resistance to carameling would be most effective at Crookston or Morris. At Rosemount, carameling was too severe and resistance was not evident; at St. Paul, it was not severe enough.

Significant genotype × environment and year × location interactions suggest that screening for carameling should be more effective if performed for more than 1 yr. Screening for 2 yr at two locations should be sufficient to distinguish among lines that differ in resistance to carameling.

Screening for resistance to kernel discoloration, both black stain and carameling, would be effective when done at St. Paul and Crookston. Screening under irrigation at St. Paul would allow for the removal of the most susceptible genotypes. The remaining genotypes would be evaluated the second year at both locations. Under this program, LSDs of 0.4 for black stain and 0.5 for carameling would be detected among genotype means.

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