Quality Response of Twelve Hard Red Winter Wheat Cultivars to Foliar Disease Across Four Locations in Central Kansas[1]

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ABSTRACT

Twelve hard red winter wheat cultivars were grown at four locations in central Kansas to evaluate the role of foliar fungal diseases on wheat end-use quality in 1995. Disease was allowed to develop naturally on control plots and was controlled partially on plots treated with a systemic fungicide. After harvest, wheat samples were evaluated for the impact of the disease complex (leaf rust, tan spot, speckled leaf blotch) on physical grain quality, grain protein, milling properties, flour absorption, and peak mixing time. Data were analyzed using a mixed model to account for random (location and block) and fixed (cultivar and fungicide) effects. Location significantly influenced quality characteristics except kernel size and peak mixing time. The magnitudes of variation among random effects on all quality characteristics were larger for location than for the interactions between location × cultivar and location × fungicide. The fixed effects portion of the analysis revealed that the cultivar × fungicide treatment interaction significantly affected test weight, kernel protein, and flour absorption. Fungicide treatment resulted in significant increases in yield and kernel weight. Cultivar significantly affected all quality characteristics except kernel size and peak mixing time. Disease resistance exerted a significant influence on yield and test weight. The economic benefit associated with improved wheat quality from fungicide treatment was variety specific. Three cultivars (TAM 107, Karl 92, and Ike), which account for 50% of the 1997 planted wheat acres in Kansas, demonstrated positive improvements in test weight and protein in response to fungicide treatment.

Wheat quality can be defined in terms of physical characteristics of the kernel including size, weight, and hardness (physical), and intrinsic properties such as protein content and quality. Test weight, kernel size, and kernel weight provide a rough estimation of the potential flour yield. The intrinsic quality characteristics determine flour properties, such as absorption and mixing tolerance, and bread characteristics, including loaf volume, crumb grain, and texture.

Wheat quality is determined by genotype (cultivar), environment (climate, soil, disease), and the interaction between genotype and environment ($G \times E$). The relative magnitudes of effects of genotype, environment, and the $G \times E$ interaction on wheat-flour have been explored by Peterson et al (1992). Variances of quality characteristics associated with environmental effects were larger in magnitude than those associated with genotype effects. The $G \times E$ interaction had an effect similar to that of genetic factors on mixing tolerance and kernel hardness but a smaller effect on flour protein concentration, mixing time, and SDS sedimentation value.

Environmental stress includes climatic severity such as drought and frost damage, as well as plant diseases. Foliar fungal diseases common in hard red winter wheat produced in the south central Plains include tan spot, leaf rust, and speckled leaf blotch. In 1995, the *Septoria* leaf and glume blotch complex was the most widespread and important disease, causing an estimated statewide average yield loss of 7%. The second most important was leaf rust, which caused an average yield loss of 5%, followed by tan spot which accounted for a yield loss of ≈2% (Bowden 1995).

Tan spot is a foliar disease caused by *Pyrenophora tritici-repentis* (Died.) Drechs. (anamorph *Drechslera tritici-repentis* (Died.) Shoemaker). The disease spreads from the lower to the upper leaves under moist weather conditions and causes necrotic spots and ultimately death of the infected leaves. Leaf rust, caused by *Puccinia recondita* Roberg ex Desmaz. f.sp. tritici, occurs primarily on the adaxial leaf surface and causes premature senescence of leaf tissue. Speckled leaf blotch is caused by the pathogen *Septoria tritici* Roberge in Desmaz. Disease-induced chlorosis frequently begins at the tips of the leaves and spreads down the leaf.

Plant disease is one environmental factor that can be controlled through management by resistant cultivars and fungicide application. Herrman et al (1996) reported significant changes in kernel characteristics and flour properties of Karl wheat treated with fungicides to control leaf rust for two consecutive seasons, including a 0.7% increase in grain protein content. In contrast, Gooding et al (1994) reported that crude protein concentration and Hagberg falling number were reduced significantly after *S. tritici* control. Despite reductions in crude protein, overall loaf quality improved with fungicide application. Kelly (1993) reported that foliar fungicide displayed no significant effects on grain protein. Efforts to investigate the influence of foliar fungicide and urea nitrogen on grain protein content showed that the effect of these treatments alone or in combination depended greatly on the growing conditions and the wheat genotype (Peltonen 1993).

This study was performed to evaluate the effects of foliar disease on wheat quality across a wide range of cultivars and locations in central Kansas. Also addressed in this study was the importance of disease resistance to wheat end-use quality and the economic impact of plant disease on wheat quality.

MATERIALS AND METHODS

Four field experiments, each containing four replicates, were established during the 1994-1995 crop season near Manhattan, Hutchinson, Hesston, and Belleville, KS. Soil types were Chase silty clay loam, Ost silt loam, Ladysmith silty clay loam, and Crete silt loam, respectively. Seeding took place during September 28–30, 1995, at 67.2 kg/ha. The 12 different cultivars of hard red winter wheat selected for this study are grown in Kansas and differ considerably in their end-use (milling and baking) qualities (Bequette et al 1995) and disease resistance (Bowden and Brooks 1995) (Table I). These cultivars have been grouped under three categories by Bequette et al (1995) based on kernel characteristics and milling and baking performance. Exceptional quality wheat cultivars are characterized by large uniform kernels, high protein content, and good milling and breadbaking performance, and may bring a premium for domestic flour production. Acceptable quality cultivars exhibit acceptable milling and breadbaking attributes but are not outstanding for all properties and may have minor defects.

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Less desirable quality cultivars have one or more serious defects in milling or baking quality. Treatments were arranged in a split-plot design with cultivars as whole plots and no spraying or tebuconazole application (Folicur 3.6 F, 292 mL/ha) as subplots (1.52 × 9.14 m). Tebuconazole was applied at the boot to early heading stage in 187 L of water per hectare.

Individual kernel weight, size, and hardness were measured using the single kernel wheat characterization meter developed at the Agricultural Research Service, Grain Marketing and Production Research Center in Manhattan, KS (Martin et al 1989). Procedures for sample preparation for measuring test weight outlined by the Federal Grain Inspection Service (FGIS) were followed (FGIS 1993) and converted to kilograms per hectoliter (kg/hL) using the test weight per bushel prediction formulas for wheat (FGIS 1997). Wheat kernel protein evaluation was performed by grinding 20-g samples with a Udy grinder (Fort Collins, CO); measuring protein content using a near-infrared reflectance (NIR) instrument (Percon, Reno, NV); and correcting to 12% moisture (Approved Method 39-10, AACC 1995). Wheat samples were tempered to 15% moisture and milled on a Quadrumat Sr. laboratory flour mill (Brabender, South Hackensack, NJ). Flour moisture was evaluated using the air-oven method (Approved Method 44-15A, AACC 1995). Mixograms for flour samples were performed using a 10-g bowl and mixing to optimum water absorption (Finney and Shogren 1972) using Approved Method 54-40A (AACC 1995).

Wheat quality data were analyzed initially for all locations combined using a mixed-model analysis of variance procedure and then for each location individually using the analysis of variance procedure. All statistical analyses were performed using Proc Mixed in SAS (SAS Institute, Cary, NC). Location main effects and interactions were considered random, whereas cultivar and treatment effects and cultivar × treatment interactions were considered fixed. Likelihood ratio tests were used for all random variance components. *F*-tests were used for fixed effects, followed by least significant differences (LSD) when the *F*-test was significant. Similar analyses were performed to investigate disease-resistance effects on quality by replacing each cultivar name with its disease rating.

TABLE I
Reactions of Selected Wheat Cultivars to Important Foliar Diseases and Quality Categorization

	Disease Resistance[a]			
Cultivar	**Leaf Rust**	**Tan Spot**	**Speckled Leaf Blotch**	**Quality[b]**
Karl 92	8	3	4	E
Jagger	2	3	3	E
Ike	6	7	8	A
Arapahoe	5	8	3	A
Tomahawk	3	4	8	A
Thunderbird	7	9	6	A
Newton	9	9	9	A
Sierra	5	4	1	L
2180	5	7	5	L
TAM 200	7	6	3	L
TAM 107	9	7	6	L
2163	4	5	2	L

[a] 1–3 = Resistant; 4–6 = intermediate; 7–9 = susceptible.
[b] E = Exceptional quality, A = acceptable quality, L = less desirable quality.

RESULTS AND DISCUSSION

Random Effects Across All Locations

Results of likelihood ratio significance tests for location, location × cultivar, and location × treatment variance components are presented in Table II. Treatment and cultivar both varied across locations in their effects on yield, test weight, and kernel protein content. Additionally, cultivar effects on kernel weight, kernel weight standard deviation, and flour absorption varied across locations. All response measures except kernel size and peak mix time demonstrated some significant variability across locations.

The relative magnitudes of variation among random effects including location, location × cultivar, and location × fungicide treatment are presented in Table III as variance component estimates. Location accounted for the majority of the variability in wheat quality reported in the random effects portion of the mixed model. These results support previous research showing that location (environment) exerts a proportionally greater influence on quality variation than the cultivar *G* x *E* interaction (Peterson et al

TABLE II
Significance (λ[a] and *P* values) of Random Effects

	Location		Location × Cultivar		Location × Treatment	
Quality Variable	λ	***P***	λ	***P***	λ	***P***
Yield	11.99	<0.001	39.29	<0.001	10.27	<0.005
Test weight	22.45	<0.001	22.79	<0.001	29.00	<0.001
Kernel weight	4.45	<0.005	7.87	<0.01	0.47	>0.1
Kernel weight standard deviation	7.60	<0.01	4.56	<0.05	0.63	>0.1
Kernel size	0.00	0.99	0.00	0.99	0.00	0.99
Kernel size standard deviation	11.63	<0.001	3.19	0.99	0.00	0.99
Kernel protein	45.69	<0.001	16.43	<0.001	7.98	<0.001
Flour yield	8.12	<0.01	2.30	>0.1	0.02	>0.1
Flour absorption	15.35	<0.001	8.56	<0.01	0.07	>0.1
Peak mix time	0.73	>0.1	0.00	0.99	1.29	>0.1

[a] λ = Likelihood ratio test statistic: difference between log likelihoods obtained by analyzing the data once with and once without the effect in the model.

TABLE III
Variance Component Estimates for Location, Location × Cultivar, and Location × Treatment by Wheat Quality Characteristic

			Kernel				Flour	
Interaction	**Yield**	**Test Weight**	**Weight**	**Weight SD[a]**	**Size SD**	**Protein**	**Yield**	**Absorption**
Location	4.56**[b]	9.19**	1.37**	0.56**	0.001**	4.15**	5.86*	21.90**
Location × cultivar	0.34**	0.53**	1.11**	0.09*	0.0001	0.06**	0.08	0.77**
Location × treatment	0.03**	0.28**	0.06	0.01	0.0000	0.01**	0.02	0.06

[a] Standard deviation.
[b] *, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively.

1992). The fungicide × location interaction exerted the least amount of variability in quality response among the random effects, which indicates that fungicide may either induce little change in quality, or that quality responses to fungicide are less variable across location, or possibly both.

The test plots were located in production areas that represent ≈32% of Kansas wheat acreage (Kansas Ag. Statistics 1997). Although this experiment was designed to capture wheat quality response to fungicide treatment and cultivar selection across a wide geographical region, the variability of the treatment and cultivar effects across locations suggests that separate analyses should be performed at each location to investigate the nature of these differences.

Fixed Effects Across All Locations

The cultivar × fungicide treatment interaction had significant effects on test weight, kernel protein, and absorption (Table IV).

The cultivar main effect significantly influenced yield, test weight, single kernel weight, single kernel weight standard deviation, single kernel size standard deviation, kernel protein, flour yield, and absorption. Significant responses to the fungicide treatment were observed for yield and kernel weight, with all the treated samples recording higher values than the untreated control samples.

Yield

Although the major thrust of the study was to evaluate the effect of plant disease on quality, yield was measured. Fungicide treatment resulted in 2,655 kg/ha (39.42 bu/acre) average yield, whereas the average yield of control samples was 2,410 kg/ha (35.79 bu/acre). The difference in wheat yield response between the fungicide and control plots at individual locations varied from a high of 405 kg/ha at Hutchinson to a low of 107 kg/ha at Manhattan. The yield response to fungicide treatment at Manhattan was not significant ($P > 0.05$).

The yield response was significant ($P < 0.05$) when resistance rating was substituted for cultivar selection in the Proc Mixed model statement, indicating a significant relationship between disease resistance and yield. For example, Jagger, which was the most resistant cultivar to all three diseases observed in this study, exhibited the highest yield of 3132 kg/ha (46.5 bu/acre), whereas Newton, which was the least resistant cultivar to all three diseases, had the lowest yield of 2122 kg/ha (31.5 bu/acre) (Fig. 1). Public breeding programs in the United States work to improve yield through a variety of mechanisms including disease resistance. Study results suggest that yield is sensitive to plant disease and that the yield response to disease resistance is consistent across a broad geographic region.

Test Weight

The significant cultivar × fungicide treatment interaction for test weight resulted from differences in the magnitudes of responses to the fungicide treatment among the 12 cultivars (Fig. 2). Fungicide application tended to improve test weight. However, the magnitude of the response depended on disease resistance ($P < 0.05$). For example, the response of Newton, which was the most susceptible cultivar to all three diseases, to the fungicide treatment was far greater than that of Arapahoe, which has more resistance to all three diseases.

The variation in test weight between cultivars tended to follow a pattern consistent with the processing quality categories. For example, Karl 92, which possesses superior milling properties, displayed the highest test weight (74.4 kg/hL [57.1 lb/bu]). Cultivar 2163, which is categorized as less desirable, displayed the lowest test weight (70.9 kg/hL [54.4 lb/bu]). Test weight is important to millers because it provides a rough estimate of the flour yield.

Fungicide treatment resulted in a significant improvement in test weight at all four locations. The difference in test weight response between the fungicide and control treatments ranged from a high of 2.48 kg/hL (1.9 lb/bu) to a low of 0.33 kg/hL (0.25 lb/bu) at Hutchinson and Manhattan, respectively. This response parallels the yield response and probably is related to differences in the disease incidence between the two locations.

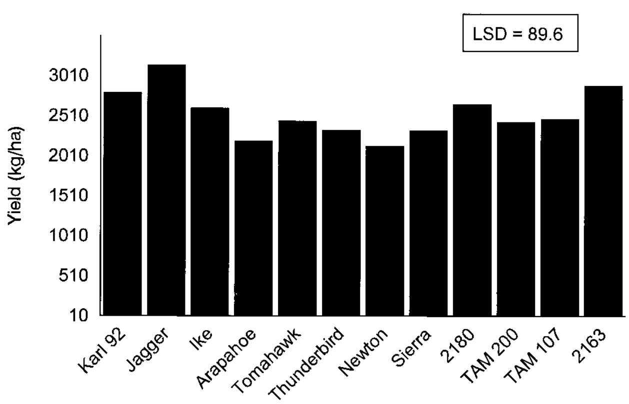

Fig. 1. Yield (kg/ha) responses of 12 hard red winter wheat cultivars across four locations in central Kansas during 1995.

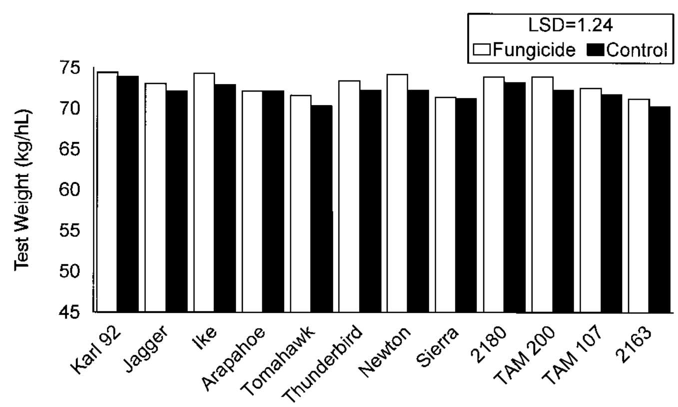

Fig. 2. Test weight (kg/hL) responses to fungicide vs. control treatment for 12 hard red winter wheat cultivars across four locations in central Kansas during 1995.

TABLE IV
***P* Values (*P* =) for Fixed Effects by Wheat Quality Characteristic**

			Kernel				Flour	
Interaction	Yield	Test Weight	Weight	Weight SD[a]	Size SD	Protein	Yield	Absorption
Cultivar	0.005	0.001	0.003	0.001	0.003	0.001	0.028	0.004
Treatment	0.050	0.149	0.026	0.205	0.750	0.578	0.833	0.763
Cutlivar × treatment	0.508	0.022	0.839	0.759	0.609	0.024	0.742	0.050

[a] Standard deviation.

Kernel (NIR) Protein

The significant cultivar × fungicide treatment interaction for protein content resulted from differences in the magnitudes of responses to fungicide treatment among the cultivars as well as differences in direction (Fig. 3). TAM 107 displayed a significant positive response (P = 0.0273) to the fungicide treatment, showing an increase of 0.33% in protein compared to the untreated control sample. Ike (P = 0.0533) and Karl 92 (P = 0.0605) also displayed positive responses to fungicide treatment with protein increases of 0.28 and 0.27%, respectively. These three cultivars comprised 50% of the planted Kansas wheat hectares in 1997 (Kansas Ag. Statistics). TAM 200 displayed a significant negative response (P = 0.0363); the untreated control sample had a 0.3% higher protein content.

In cases where the untreated control sample had a higher protein content, the fungicide could have favored carbohydrate assimilation in the grain relative to nitrogen accumulation. *Septoria tritici* has been reported to increase the nitrogen concentration in the kernel, because it is more detrimental to carbohydrate assimilation (yield) than to nitrogen assimilation (Shipton et al 1971). Speckled leaf blotch, which is caused by *S. tritici,* was one of the diseases observed in this study.

Karl 92 displayed the highest protein content (13.6%), a response typical for this cultivar. Included within Karl's lineage is Plainsman V, which possesses the genotypical characteristic of high protein (Stein et al 1992). Cultivar 2163 had the lowest protein content (12.4%). The responses for these two cultivars were consistent with quality categories assigned by Kansas State University milling scientists.

Single Kernel Properties

Kernel weight responded positively to fungicide treatment (28.0 mg) compared to the control (26.8 mg). The heavier kernels resulted from increased accumulation of photoassimilate in response to the control of foliar fungal diseases. This result is consistent with the trend reported by Thomson and Gaunt (1986), who found that speckled leaf blotch reduced yield by reducing the grain number per ear and also the grain weight. Similarly, Bockus et al (1992) reported significant increases in the amount of large seed produced after a single application of fungicide.

Cultivar also exerted a significant influence on kernel weight (Fig. 4). TAM 107 had the highest single kernel weight (30.8 mg), whereas TAM 200 had the lowest (24.4 mg) kernel weight.

No significant response in single kernel size was observed when all locations were evaluated in a single model. However, single kernel size was affected significantly by cultivar and treatment at three locations (Hesston, Belleville, and Manhattan) but not at the fourth location (Hutchinson). A rank change in the response of the 12 cultivars among the four locations is partially responsible for the lack of significance observed in the combined analysis. For instance, cultivar 2163, which ranked second at Manhattan, was ranked 11th at Belleville; Karl 92, which ranked first at Hesston, was ranked seventh at Belleville.

Single kernel weight and size standard deviation measures were affected significantly by cultivar (Figs. 5 and 6). Millers prefer large uniform kernels. TAM 107 exhibited the highest variability of the different cultivars measured by the single kernel wheat characterization meter, which is one of the reasons it is categorized as a less desirable wheat. Ike and TAM 200 possessed the

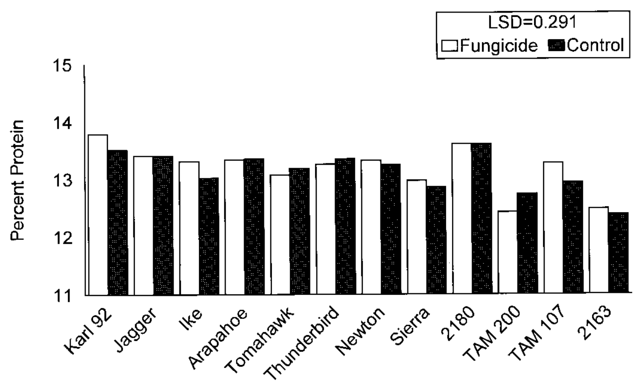

Fig. 3. Kernel protein responses to fungicide vs. control treatment for 12 hard red winter wheat cultivars across four locations in central Kansas during 1995.

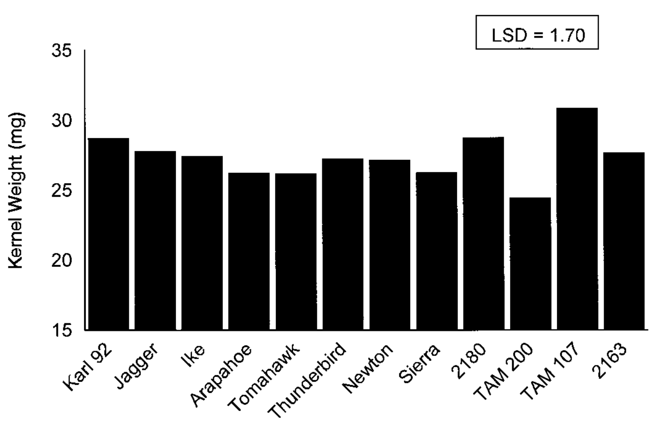

Fig. 4. Kernel weight (mg) response of 12 hard red winter wheat cultivars across four locations in central Kansas during 1995.

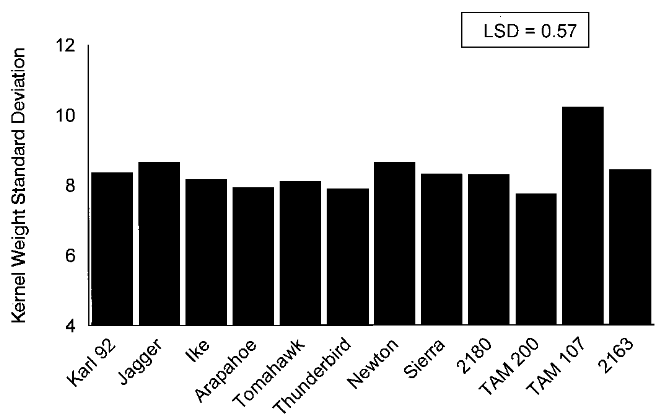

Fig. 5. Kernel weight standard deviation (mg) among 300 kernels for 12 hard red winter wheat cultivars across four locations in central Kansas during 1995.

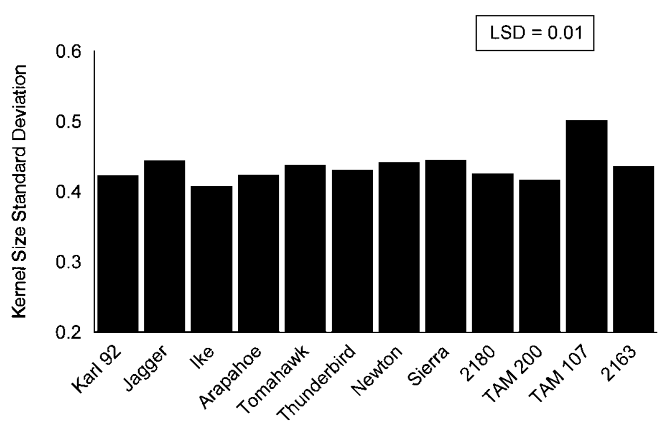

Fig. 6. Kernel size standard deviation (mm) among 300 kernels for 12 hard red winter wheat cultivars across four locations in central Kansas during 1995.

most uniform size (low standard deviation), whereas, Karl 92 and Jagger (categorized as superior quality wheat) displayed intermediate kernel size and weight uniformity when compared to the other 10 cultivars.

Flour Extraction

Flour extraction percentages were influenced significantly by cultivar. Thunderbird (65.4%) and Karl 92 (64.9%) were the cultivars with the highest flour extraction percentages, which corresponded well to the test weight results. TAM 200 had the lowest flour yield, which coincides with the low kernel weight and test weight values exhibited by this cultivar (Fig. 7).

The absence of a significant fungicide or fungicide × cultivar effect for flour extraction is difficult to explain because both test weight and single kernel weight responded positively to the fungicide treatment. Both sample size (≈1 kg) and number (384) precluded the use of larger scale laboratory or pilot milling equipment that permits role adjustment to optimize flour extraction. Were this approach feasible, we may have uncovered significant differences due to fungicide treatment that were not detected using the Brabender Quadrumat Sr. mill.

Flour Absorption and Mixing Time

The significant flour absorption effect for the cultivar × treatment interaction resulted from differences in magnitude of response to fungicide treatment among cultivars and differences in direction (Fig. 8), as was observed for kernel protein content. Ike displayed the maximum increase (1.2%) in its absorption values when treated with fungicide. The untreated control for the cultivar Tomahawk had a significantly higher absorption requirement (1.8%) when compared to the fungicide treatment.

Cultivar had a significant effect on flour absorption. The highest absorption requirement was seen for 2180 (64.9%), probably because of its high protein content, whereas TAM 200 displayed the lowest absorption requirement (61.4%), which is related to its low protein content.

Commercial bakeries operate most efficiently using flour that possess a high water absorption (63–67%), medium-long mixing peak (3.5–5.5 min), and adequate mixing tolerance (1–3 min past peak) (Herrman et al 1995).

The peak mixing time required to develop dough was not influenced significantly by cultivar or fungicide treatment across the four locations. However, peak mixing time did exhibit a significant response to cultivar at three of the four locations. The cultivars Karl 92, Tomahawk, and Arapahoe displayed the longest mix times at the three locations. Of the three, only Karl 92 is classified as strong mixing wheat by the milling and baking industry (Bequette et al 1995).

Economic Response

Producers in the hard red winter wheat production region of the United States are seldom rewarded for quality. However, in the present commodity-based marketing system, the absence of quality may be penalized through discounts. As a consequence of this marketing structure, most producers view yield response as the financial impetus to apply a foliar fungicide. Although various levels of disease incidence were present at the four locations, the improved overall yield response of 286 kg/ha (4.25 bu/acre) would cover the cost of fungicide and aerial application.

The improved test weight resulting from fungicide application led to a reduction in money lost from test weight discounts. For example, based on average 1995 discount schedules, the improved test weight for Jagger treated with fungicide resulted in a test weight discount of $0.06 per bushel compared to a discount of $0.19 per bushel for the control (a net reduction in discount of $0.13 per bushel). The improved test weight in Sierra resulting from the fungicide treatment resulted in a $0.05 reduction in the discount for low test weight compared to the control.

The protein response to fungicide application differed among cultivars, both in magnitude and direction. However, the four cultivars occupying the most acreage in Kansas all exhibited a positive protein response to the Folicur treatment. Protein premiums vary according to the supply of protein. For example, the increase in protein content from 12.9 to 13.3% for TAM 107 resulting from the fungicide application would have been worth $0.23 per bushel in 1993 and $0.03 per bushel in 1994 (Herrman et al 1995).

CONCLUSIONS

Study results indicate a consistent trend in quality response to disease incidence at the four locations. Because locations were treated as random effects, inferences about wheat quality can be extended to other locations within the same production region. Only single kernel size and peak mixing time exhibited a site-specific response that differed from trends observed across locations.

The role of disease resistance was important for yield and test weight. The absence of a significant response to disease resistance in the quality characteristics measured in this study (other than test weight) suggests that other genotypic expressions of quality overshadow the effect of disease resistance.

Karl 92 exhibited superior quality relative to other cultivars included in the study whereas 2163, TAM 107, and TAM 200 demonstrated weaknesses in kernel characteristics and processing performance. Cultivars generally conformed to their respective quality categories, with the possible exception of Jagger, which appeared to possess average quality despite its excellent rating for

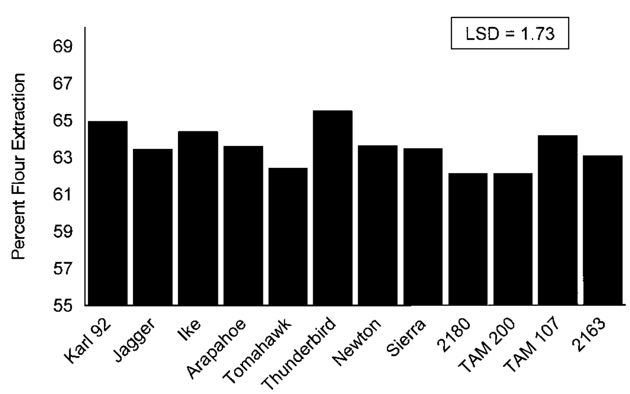

Fig. 7. Flour extraction percentage for 12 hard red winter wheat cultivars across four locations in central Kansas during 1995.

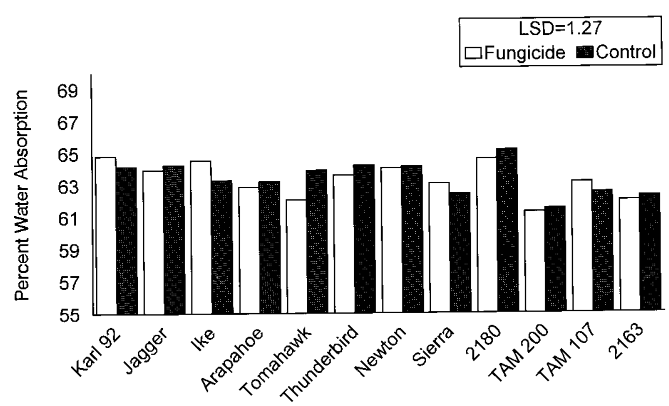

Fig. 8. Flour absorption responses to fungicide vs. control treatment for 12 hard red winter wheat cultivars across four locations in central Kansas during 1995.

disease resistance and its placement in the exceptional quality category.

Two-way interactions affecting protein content and absorption resulted from changes in the magnitude and direction of responses to fungicide treatment among cultivars. Of particular interest, however, is the response of the cultivars most prevalent in Kansas. Three cultivars that exhibited a positive protein response to fungicide application are the most prevalent varieties grown in Kansas. This suggests that applying a broad spectrum foliar fungicide to Ike, Karl 92, and TAM 107 during growing seasons with high disease pressure could improve yield, test weight, and protein content.

A dynamic relationship exists between plant diseases and their hosts. Although the role of resistance did not appear significant in this study, one can expect relationships among resistance mechanisms, fungicide, and quality responses to change over time. Therefore, a need exists to continually monitor wheat quality responses to plant diseases.

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