Quality Response to the Control of Leaf Rust in Karl Hard Red Winter Wheat[1]

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ABSTRACT

Samples of Karl hard red winter wheat from Kansas fungicide trials in 1992 and 1993 were used to evaluate the impact of leaf rust on physical grain quality, milling properties, flour protein content, absorption, and peak mixing time. Leaf rust was allowed to develop naturally on control plots and was prevented from developing on plots treated with systemic fungicides. Changes in kernel characteristics and flour properties were observed for the fungicide in both years, whereas flour extraction percentage and test weight did not respond significantly (P >.05). Differences between control and fungicide-treated wheat were consistent between years, except for single kernel size standard deviation. Increases in grain and flour protein content related to fungicide were 0.7% in both studies. Using protein premiums for 1992 and 1993 marketing years, an economic comparison between fungicide and control treatments revealed that the added value of increased protein exceeded 50% of the fungicide treatment cost.

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Hard red winter wheat (*Triticum aestivum*) grown in Kansas experiences numerous disease and environmental stresses that determine yield and grain quality. Leaf rust epidemics during the 1992 and 1993 growing seasons resulted in reductions in yield potential estimated at 11.3 and 11%, respectively (Bowden and Appel 1992, 1993) and possibly led to a deterioration in milling and baking quality.

Leaf rust, incited by *Puccinia recondita* f. sp. *tritici*, occurs primarily on the adaxial leaf surface and causes premature senescence of leaf tissue. When released in 1988, Karl displayed moderate resistance to leaf rust (Bowden et al 1990) and superior milling and baking properties (Bequette et al 1991). Acres seeded to Karl increased rapidly, and by 1993, ≈23% of Kansas wheat acres were planted to this cultivar (Kansas Ag. Stat. 1993). When a cultivar occupies large acreages, the probability increases that genetic resistance to leaf rust will be defeated by a new race of the fungus (Johnson 1984). By 1991, Karl began to show some deterioration in its resistance (Bowden et al 1991), and in 1994, Karl was rated moderately susceptible (Bowden et al 1994).

While scientists have evaluated the additive and interactive effects of plant diseases on yield potential (Wiese et al 1984), the impact of disease on grain quality has been understood less clearly. Peltonen and Karjalainen (1992) concluded that the control of Septoria leaf blotch and powdery mildew (*Erysiphe graminis* f. sp. *tritici*) resulted in increased wheat grain yield and protein content because of the prolonged duration of green leaf area and the grain filling phase in spring wheat. In contrast, Gooding et al (1994) reported that crude protein concentration and Hagberg falling number were reduced significantly following *Septoria tritici* control. Despite reductions in crude protein, overall loaf quality was improved by fungicide application. O'Brien et al (1990) reported a similar trend between disease incidence and grain protein content when comparing stripe rust (*Puccinia striiformis*) resistant and susceptible cultivars, whereas Kelley (1993) found that foliar fungicide had no significant effect 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 upon growing conditions as well as wheat genotype (Peltonen 1993).

In Kansas, cash premiums for high protein and other end-use quality characteristics are seldom realized by wheat producers. However, as farmers and grain handling firms strive to increase profits, additional value may be achieved through producing, segregating, and marketing better quality wheat. Characterizing the impact that foliar diseases exert on wheat end-use quality in Kansas may reveal additional benefits to foliar fungicide beyond increased yield.

In view of this need, a study was conducted to investigate the relationship between leaf rust incidence, end-use quality, and added value of fungicide application in two field trials using Karl wheat.

MATERIALS AND METHODS

Field Treatment

Fungicide plots of the hard red winter wheat cultivar Karl were established at the South Central Kansas Experiment Field in Hutchinson, KS, on an Ost silt loam soil that had been planted to oats the previous year. Plots received a total of 106 kg/ha actual nitrogen and 45 kg/ha P_2O_5 fertilizer. Seed was drilled at 67 kg/ha into 1.5- × 7.5-m plots on October 15, 1991. The experiment was a completely randomized design with six replicates and two treatments. The first treatment was a nonsprayed control. The second treatment was sprayed on April 29, 1992 (early boot stage; Feekes growth stage 10) with 0.29 L/ha of tebuconazole (Folicur 3.6F) fungicide plus 0.0625% (v/v) X-77 spreader/sticker in 280 L/ha water. Leaf rust was the only significant foliar disease that developed in the plots. Percentage of leaf rust (James 1971) on the flag leaf was estimated on May 27 (soft dough stage; Feekes growth stage 11.2) by averaging visual estimates from four randomly chosen leaves per plot. Plots were harvested on June 30, and yields were corrected to 14% moisture.

In the second year of the study, plots were established at the Harvey County Experiment Field in Hesston, KS, on a Ladysmith silty clay loam soil that had been cropped previously to wheat. Plots received a total of 103 kg/ha actual nitrogen and 36 kg/ha P_2O_5 fertilizer. Seed was drilled at 67 kg/ha into 1.5- × 12-m plots on October 3, 1992. The experiment was a randomized complete block design with four replicates, two cultivars (Karl and Newton), and eight treatments. The only grain samples that were retained in sufficient quantity to be included in this study were the cultivar Karl and three treatments (control, disease-free, and a single fungicide treatment at Feekes growth stage 8). The disease-

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free treatment was sprayed on April 20, May 4, May 18, June 1, and June 11, 1992 with 0.29 L/ha of propiconazole (Tilt 3.6E) fungicide in 234 L/ha water. Leaf rust was the only significant foliar disease that developed on Karl. Septoria leaf blotch was present but only at low severity levels because of Karl's high level of resistance. Percentage of leaf rust on the flag leaf was estimated on June 1. Plots were harvested on June 29, and yields were corrected to 14% moisture.

Grain Evaluation

Individual kernel weight, size, and hardness were measured using the single kernel wheat characterization meter developed at the Agricultural Research Service, Grain Marketing Research Laboratory 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). The percentage (by weight) of kernels left on a U.S. standard sieve 7 after running 200 g of seed on a ro-tap shaker (Seedburo, Chicago) for 2 min was used to measure the plump kernel percentage.

Flour protein was measured using standard methodology for crude protein (AACC 1983) and was corrected to 14% flour moisture. Wheat protein evaluation was performed by grinding 20-g samples with a Udy grinder (Fort Collins, CO), measuring protein content using a Percon NIR instrument (Reno, NV), and correcting to 12% moisture. Wheat samples were tempered to 15% moisture and milled on a Brabender Quadrumat Senior Laboratory flour mill (South Hackensack, NJ). Mixograms for flour samples were performed using a 10-g bowl and mixing to optimum water absorption (Finney and Shogren 1972).

Economic Analysis

The formula for economic comparisons for mill yield was:

$$\text{Bu/cwt flour yield} = (1.667 \text{ bu/cwt/\% extraction}) \times 100$$

The average protein premium for each marketing year was used to compute the value of grain protein. The average price of one fungicide application in Kansas is ≈$17 per acre.

Statistical Analysis

Data from 1992 and 1993 were treated as separate experiments for the purpose of statistical analysis. A multivariate analysis of variance (MANOVA) was performed to address potential use of leaf rust as a predictor beyond (or in addition to) its effect as expressed through treatment. An analysis of covariance (multiple regression) was performed to determine whether the effect of leaf rust on the response variable was consistent for both treatment groups. An analysis of variance (ANOVA) of each response (including leaf rust) against treatment was performed to determine whether treatment affects responses. Least square means were computed only for the control and fungicide groups and differences taken for each year were tested for significance using *t*-tests. Error ratios were computed by dividing the 1992 mean square error (MSE) by the 1993 MSE, and the Chi-square test was performed to evaluate equality of these variances. All statistical analyses were performed using SAS (SAS 1989).

RESULTS AND DISCUSSION

Fungicide Effect

Fungicide application prevented leaf rust from developing (disease incidence <1%) on the flag leaf tissue, whereas the controls displayed infection levels of 17.5 and 21.4% in 1992 and 1993, respectively (Table I). As a consequence of the fungicide treatment's effectiveness, leaf rust infection occurred as two distinct groups (leaf rust and no leaf rust) with no overlap. This effectively confounds the leaf rust effect with the treatment effect. Consequently, leaf rust does not add anything to a model that already uses treatment. Results from MANOVA and analysis of covariance indicate that a larger experiment containing a broader inference and different levels of disease incidence is necessary to predict the effect of leaf rust on wheat quality (apart from the treatment effect).

Wheat Quality Response

Leaf rust, grain protein, flour protein, sieve size, single kernel size, and uniformity (standard deviation for kernel size), and single kernel weight all responded significantly to the fungicide treatment in 1992 and 1993 (Table II). Leaf rust causes premature senescence of the flag leaf which, in turn, reduces the grain filling period and limits translocation of nitrogen into the kernels. The quality response to fungicide treatment consistently supports this phenomenon as evidenced by larger, plumper (over 7 wire), heavier, higher protein kernels.

Flour absorption and peak mixing time were examined to evaluate the influence of disease incidence on protein quality. A number of factors determine flour absorption, including flour

TABLE I
Least Square Mean Values for Wheat Quality Characteristics for Control and Fungicide Treatments in 1992 and 1993

Response Variable	1992 Control	1992 Treatment	1993 Control	1993 Treatment
Bushel yield	65.1	67.3	49.9	62.5
Leaf rust, %	17.5	0.42	21.4	0.18
Grain protein, %	14.3	15.0	13.0	13.7
Flour protein, %	12.7	13.5	11.5	12.2
Flour absorption, %	67.4	69.0	63.2	65.0
Peak mixing time, min	6.18	6.23	5.88	5.53
Flour extraction, %	67.4	70.2	70.6	70.7
Over 7 wire	34.1	48.6	36.8	59.5
Over 9 wire	62.6	48.9	61.3	39.2
Single kernel				
Hardness	62.9	62.4	66.7	69.2
Hardness SD[a]	17.1	16.9	15.8	13.7
Size, diameter, mm	2.56	2.65	2.39	2.53
Size SD	0.45	0.47	0.46	0.39
Weight, mg	30.6	32.2	29.0	32.4
Weight SD	9.8	9.9	8.8	7.9
Test weight	58.0	58.0	60.5	60.4

[a] Standard deviation.

TABLE II
Mean Values and Least Significant Differences for Year and Fungicide Main Effects

Response Variable	1992 Difference	1993 Difference	Error Ratio	*P*-Value[a]
Bushel yield	2.18	12.58**[b]	8.67	0.009
Leaf rust, %	−17.1**	−21.2**	2.86	0.17
Grain protein, %	0.713**	0.711*	0.19	0.04
Flour protein, %	0.771**	0.709**	0.81	0.78
Flour absorption, %	1.63*	1.85	0.36	0.18
Peak mixing time, min	0.05	−0.35	1.56	0.56
Flour extraction, %	2.88	0.15	50.76	0.001
Over 7 wire	14.4**	22.8**	1.50	0.59
Over 9 wire	−13.7**	−22.1**	1.33	0.70
Single kernel				
Hardness	−0.45	2.48**	1.37	0.68
Hardness SD[c]	−0.20	−2.05**	0.83	0.81
Size, diameter, mm	0.085**	0.140	0.19	0.04
Size SD	0.020*	−0.073**	0.40	0.23
Weight, mg	1.53**	3.33	0.26	0.09
Weight SD	0.15	−0.90	0.54	0.42
Test weight	0.33	−0.150	0.21	0.05

[a] *P*-value for experimental error difference between years.
[b] * = $P \leq 0.05$, ** = $P \leq 0.01$.
[c] Standard deviation.

protein, moisture content, starch damage, cultivar, and growing environment (Hoseney 1986). Flour absorption increased in response to disease control by 1.63% in 1992 and by 1.85% in 1993. Despite a similar magnitude response to the fungicide treatment in both years, flour absorption was not significant in 1993. The explanation for this lies in the different experimental error terms (0.59 in 1992 vs. 1.21 in 1993). The flour absorption response to the fungicide treatment appears to coincide with the increase in protein content in this cultivar.

The peak mixing time required to develop doughs was similar between control and fungicide treatments for both studies. Flour with low protein (<12%) requires longer mixing, but flour protein levels above 12% do not affect mixing time (Hoseney 1986). The 0.7% difference in flour protein content between treatments (Table II) appeared to be overshadowed by the abundant protein levels.

Kernel size and weight measurements responded positively to the application of fungicide in both studies. However, responses in kernel size and weight to the fungicide treatment were not significant in 1993 (Table II), even though the magnitude of response for single kernel size and weight were greater than what had occurred in 1992. The explanation for this lies in the larger experimental error terms in 1993. The standard deviation (SD) measurements in 1993 for single kernel properties were significantly lower ($P < 0.05$) for the fungicide-treated plots except for single kernel weight SD ($P = 0.062$). In 1992, SD values for single kernel measures did not follow a consistent trend.

Flour yield and test weight were not significantly influenced by the fungicide treatment in spite of the significant increase in kernel weight, size, and plumpness (over 7 wire). Results of these two studies suggest that flour mill yield and test weight, despite their economic importance, either lack the sensitivity of these other measurements or are influenced by other qualities besides kernel size and weight (e.g., kernel density or kernel shape).

An analysis of the experimental errors for the 16 quality characteristics revealed that five responses had error ratios that indicated significantly different variances ($P < 0.05$) between years (Table II). This coincides with the fact that the two trials were designed as separate experiments and thus were not intended to be considered as replicates. Each study was analyzed separately, and no statistical comparisons between years were performed. However, the significant differences between fungicide and control treatments were in the same direction across year, except for kernel size SD. These similar trends support the need to conduct further evaluation of the influence of leaf rust on wheat quality. Future experiments should be designed to allow for a broader inference space and should include multiple years, cultivars, and locations.

TABLE III
Economic Comparison of Mill Yield for Control and Fungicide Treatments for 1992

	Control		Fungicide Treatment
Mill yield			
Wheat, bu/cwt	2.473		2.375
Price of flour, per cwt	$8.66		$8.31
Difference in raw material cost per cwt of flour		$0.35	
Mill feed			
Price of mill feed, per cwt of flour	$1.69[a]		$1.48[b]
Difference in mill feed value per cwt of flour		$0.21	
Added mill value		$0.14	

[a] 0.326 mill feed extraction.
[b] 0.298 mill feed extraction.

Economic Comparison

The economic impact of disease incidence on wheat end-use quality has not been documented in the hard red winter wheat production region of the United States. Although two locations in central Kansas constitute a small sample, these data may provide some insight into the potential value associated with disease control.

Flour yields were calculated (Table III) for controls and fungicide treatments using the flour extraction values presented in Table I. Assuming an average wheat price of $3.50/bu, the wheat cost difference (between the control and fungicide treatment) to produce one cwt of flour was $0.35 in 1992. The value of the additional mill feed by-product (based on Kansas City June-May average) for the control was $0.21, resulting in an average return of $0.14/cwt of flour (Table III). This is a savings of $1,400 per day for a flour mill with a daily production level of 10,000 cwt.

Protein premiums may represent significant value during marketing years when the supply of high protein wheat is low. During the 1992 marketing season, an average price spread of $1.00/bu occurred between hard red spring wheat with 14 and 15% protein (premiums for hard red winter wheat exceeding 14% protein are not published). During the 1993 marketing season, the average price spread for hard red winter wheats with 13.0 and 13.6% protein was $0.24/bu (Anonymous 1992, 1993, 1994). Assuming an average flour yield of 2.37 bu/cwt and a $0.24/bu premium, the added protein value of fungicide-treated wheat was ≈$0.57/cwt of flour.

The decision to apply a fungicide is based on a yield increase that would provide a significant return over investment (Bowden 1992). Producers who manage their crop to optimize yield potential (as occurred on research plots used in these studies) may derive additional revenue from quality-related premiums. Study results indicate that the protein premium associated with the fungicide treated wheat was equivalent to 57% of the fungicide cost. This calculation is based on one fungicide application ($17/acre) and an average yield of 40 bu/acre. Note that multiple fungicide treatments were applied to the research plots in 1993 to ensure that wheat remained disease-free through the entire study. Furthermore, in some marketing years, protein premiums are not as high as those that occurred during these studies.

CONCLUSION

Two fungicide trials conducted on Karl hard red winter wheat in 1992 and 1993 demonstrated that the control of disease consistently increased kernel protein content, flour protein content, plump kernel percentage, and kernel weight, uniformity, and size measurements. Each study used a "narrow inference space" that limits the authors' conclusions to those conditions represented in each study. Consistencies across the two years suggest possible repeatable trends. Verification of these trends in a larger, multiyear, multilocation study appears warranted so that conclusions can be extended across a "broad inference space."

An economic assessment of the impact of disease control on wheat end-use quality indicated that protein premiums exceeded 50% of a typical fungicide treatment cost.

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