Genetic Factors Conditioning Slow Rusting in Era Wheat

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ABSTRACT

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Slow rusting with *Puccinia graminis* f. sp. *tritici*, as indicated by the area under the disease progress curve, was found in progenies of Era/Morocco and Era/Prelude tested in the field during 1977 and 1978. Slow rusting in Era appeared to be a quantitative character because progenies from both crosses were continuously distributed from slow to fast rusting. Furthermore, progeny means equaled midparent means in three of four evaluations. The heritability estimate was 41% for Era/Morocco and 45% for Era/Prelude.

Additional key words: Triticum aestivum.

Era wheat (*Triticum aestivum* L.) has been widely grown since 1970 in the hard red spring wheat region of the United States and has been used as a parent in many wheat improvement programs. It has been resistant to stem rust when grown in international wheat nurseries and in tests with many individual races of *Puccinia graminis* f. sp. *tritici*. This resistance is believed to be due to the combined effects of genes *Sr* 5, 6, 8, 9a or 9b, 11, 12, 17 and perhaps others (*unpublished data*), but it is also possible that Era possesses genetic factors that condition slow rusting, because many of its ancestors rust slowly. Such a possibility was suggested from work with wheat by Brennan (1) and with barley by Parlevliet and Kuiper (6), who crossed resistant with highly susceptible cultivars and found slow rusting lines among the progenies.

The objective of our work was to determine the existence and inheritance of factors that condition slow rusting in Era wheat.

MATERIALS AND METHODS

Three wheat genotypes (*T. aestivum* L.) were studied: Era, CI 13986, an awned semidwarf hard red spring wheat of intermediate maturity that is resistant to prevalent races of *P. graminis* Pers. f. sp. *tritici* in North America (4); Prelude, CI 4323, an awned tall hard red spring wheat of intermediate maturity (8,13); and Morocco, an awned soft red semidwarf spring wheat. Both Prelude and Morocco are susceptible to, and rust rapidly with, prevalent races of *P. graminis* f. sp. *tritici*.

Era was crossed with Prelude and Morocco in the summer of 1975. Sufficient F_1 plants were grown in the glasshouse during the fall and winter of 1975 to provide at least 4,000 F_2 plants from each cross. The F_2 populations were grown in the field during the summer of 1976 to produce approximately 2,500 F_3 lines from Era/Prelude and 1,700 from Era/Morocco. Lines that possessed gene *Sr*6 were eliminated from the experiment, by deleting the F_3 lines that were resistant to race 15B2-TLM of *P. graminis* f. sp. *tritici*, because *Sr*6 is known to be associated with genes for slow rusting (3,10). Lines classified as susceptible to stem rust were advanced to the F_4 in duplicate by single seed descent. All seeds from each F_4 plant were harvested for evaluation as F_5 lines. There were 80 F_5 lines for each set from each cross.

One set of lines from each cross was planted at Rosemount, MN, during the summer of 1977 in a randomized complete block design with five replicates. Each replicate contained the 80 F_5 lines of each cross plus the parents (Era, Prelude, and Morocco) and slow rusting check cultivars (Thatcher and Lee). All were planted as hills on 30-cm centers with 10 seeds per hill. Fertilizer (10-20-20) was applied to the plots at the rate of 225 kg/ha. Weeds were controlled both chemically and mechanically. Leaf rust (*P. recondita* f. sp. *tritici*) was controlled with Triazbutil (Indar LC70®, Rohm and Haas Co., Philadelphia, PA 19105), applied at 556 ml/ha.

On 24 June 1977, the plants were at growth stages 5–9 of the Romig Scale (2) (from pseudostem strongly erect to ligule of the last leaf just visible). They were then inoculated with fresh urediospores of *P. graminis* f. sp. *tritici* race 15B2-TLM suspended in Soltrol 170® (Phillips 66, Bartsville, OK 74003) at the rate of 0.3 mg of urediospores in 1 ml of oil per linear meter of plot. An ultra low volume sprayer was used. Stem rust severity was estimated using a modified Cobb scale (7) on 13 July 1977 and each week thereafter for 3 wk.

The second set of F_5 lines, 78 from Era/Prelude and 74 from Era/Morocco, was evaluated for severity of stem rust at Rosemount, MN, in the summer of 1978. Experimental design and plot management practices were similar to those of 1977. In 1978, the test plot was isolated from the other spring wheat plantings by at least 1.4 km, whereas in 1977, the plot was near several other wheat stem rust nurseries. On 21 and 22 June 1978, the plants were at growth stages 5–10 on the Romig Scale (2) and were inoculated with urediospores of race 15B2-TLM as in 1977. Stem rust severity was estimated on 8 July and each week for 3 wk thereafter.

Infected wheat stems were collected at random from the field plots to identify the races of *P. graminis* f. sp. *tritici* present in the plots and at other sites on the Rosemount Experiment Station each year. Race identifications were made at the Cereal Rust Laboratory, University of Minnesota (9,12).

Stem rust severity data, from 56 lines of Era/Prelude and 65 lines of Era/Morocco in 1977 and from 78 lines of Era/Prelude and 73 lines of Era/Morocco in 1978, were used to calculate the area under the disease progress curve (AUDPC) (11). AUDPC was used to indicate the slow rusting trait of the lines and cultivars. Some lines planted in the 1977 test were eliminated from the analysis because of damage from heat, abnormal growth, and extreme lateness.

Analyses of variance were computed for each cross. A linear relationship between mean and standard deviation was noted for AUDPC, but a log transformation did not significantly reduce the linear relationship. Therefore, the analyses of variance were computed from the original data of AUDPC.

Heritability of slow rusting was calculated on a line mean basis

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where 2 yr of data were available, using the estimated genetic variances according to the formula:

$$H^2 = \hat{\sigma}^2_L / (\hat{\sigma}^2_L + \hat{\sigma}^2_{YL/r} + \hat{\sigma}^2_{E/ry})$$

in which: H^2 = estimated heritability, r = replicates, $\hat{\sigma}^2_L$ = genotypic variance among lines, y = years, $\hat{\sigma}^2_{YL}$ = interaction variance of lines × years (also contains 1/7 of the total additive genetic variance in the F_4 generation), and $\hat{\sigma}^2_E$ = error.

RESULTS

Stem rust development in 1977. Because of adverse weather and poor seed quality, replicated data were obtained on only 56 lines from Era/Prelude and 65 lines from Era/Morocco. The epidemic was caused by races 15B-TNM, 151-QFB, and 151-QSH that occurred naturally; race 15B2-TLM was not recovered from the plots. Era was resistant to all of these races and Prelude and Morocco were susceptible.

On 13 July, about 2 wk after inoculation, the severities of stem rust among lines ranged from 0 to 10% in Era/Morocco and from 0 to 5% in Era/Prelude. On 28 July, Morocco and several lines from both crosses had been killed by stem rust; rust severities ranged from 0 to 60% in surviving lines of Era/Morocco and from 0 to 20% in surviving lines of Era/Prelude. On 4 August, the last date stem rust was evaluated, the rust severities ranged from 1 to 60% in surviving lines of Era/Morocco and from 1 to 40% in surviving lines of Era/Prelude. The data on rust severities and the AUDPC values shown in Table 1 indicate that the epidemic in 1977 was not severe. Despite this, the relative AUDPC values for the parent and the check cultivars were about as expected except that the AUDPC of Lee and Prelude (Table 1) was lower than reported (12). The respective progeny and midparent means for AUDPC for Era/Prelude were 107 and 108 and for Era/Morocco, 345 and 362.

Stem rust development in 1978. Favorable distribution of rain and temperatures in the beginning of the season resulted in good plant growth and an excellent epidemic of stem rust. Races 15B-TNM and 15B2-TLM were prevalent in the plots, in addition to traces of races 15-TDM, 11-32-113RTQ, and 151-QSH. Again Era was resistant and Prelude and Morocco were susceptible to these races.

On 8 July, stem rust severities ranged from 0 to 10% among the lines in both crosses. On 23 July, they ranged from 1 to 80% among lines of Era/Morocco and from 0.5 to 80% among lines of Era/Prelude; Morocco had been killed by 23 July. On 29 July, the last date stem rust was evaluated, rust severities ranged from 5 to 90% among lines of Era/Morocco and 1 to 80% among lines of Era/Prelude. The average AUDPC values for parents and check cultivars are shown in Table 1. The respective progeny and midparent means were 680 and 690 for Era/Morocco and 780 and 443 for Era/Prelude.

Analysis of variance of AUDPC data, combined over the years, indicated a significant line by year interaction; therefore data are presented by individual years. Each year, AUDPC values for lines varied significantly in both crosses. The distribution of AUDPC by lines from both crosses in 1977 were not considered to be normal, particularly in Era/Prelude. The AUDPC of 10 lines from Era/Morocco and 37 lines from Era/Prelude were lower than or equal to that for Thatcher, a slow-rusting check.

The distribution of AUDPC values of the lines from both crosses in 1978 also was not completely normal. The AUDPC of five lines from Era/Morocco and of seven lines from Era/Prelude was less than that of Lee and Thatcher. Transgressive segregation for fast rusting may have occurred in the Era/Prelude cross (Table 2).

Heritability estimates calculated from estimated variance components over years were 41% in Era/Morocco and 45% in Era/Prelude.

DISCUSSION

The data suggest that Era possesses genes that are responsible for slow rusting with *P. graminis* f. sp. *tritici* as well as genes that condition resistance that is recognized by infection types. This supports a similar conclusion of Brennan (1), who studied wheat infected with the stem rust pathogen, and of Parlevliet and Kuiper (6), who studied barley infected with the leaf rust pathogen. Our conclusion also appears to be sound because several lines from the two crosses rusted as slowly as the slow-rusting cultivars Lee and Thatcher. The genes that conditioned slow rusting in these lines probably were derived from Era because Prelude is known to possess only one gene for resistance against stem rust (A. P. Roelfs, *personal communication*) and Morocco is not known to possess any. Both Morocco and Prelude are susceptible to the races of *P. graminis* f. sp. *tritici* that are prevalent in North America.

The frequency distributions obtained each year indicated that slow rusting in Era is a quantitative character. The progenies from both crosses were continuously distributed from slow to fast rusting and could not be separated into discrete classes, as was also observed earlier in wheat (11) and barley (5). Additive genetic effects are strongly indicated because in three of the four evaluations (the exception was 1978 Era/Prelude), progeny means equaled the midparent means.

Heritability estimates of 41% for Era/Morocco and 45% for Era/Prelude indicated that selection for slow rusting should be successful. The large interaction suggested that selection would be more successful if applied after evaluation in at least two environments. However, only one line of Era/Morocco and two of Era/Prelude categorized as fast rusting in one year were rated as slow rusting the other year. Therefore, most fast-rusting lines could be eliminated after one evaluation with little risk of losing valuable slow-rusting lines. The larger AUDPC value for Morocco compared to that for Prelude may explain why Era/Prelude produced more lines that rusted more slowly than the check cultivars, Lee and Thatcher, than did Era/Morocco.

The large estimate of interaction between genotype and environment indicates a differential performance, in terms of AUDPC, of the lines for the two years involved. This difference in performance may be attributed to several causes: 1) the two sibling genotypes constituting a "line" were not genetically identical, 2) the race composition of the inoculum for the two years may have been different, and 3) the environment was more favorable for stem rust development in 1978 than in 1977. Although the first two causes probably existed, neither is considered to be as important as the environmental difference in causing the genotype-by-year

TABLE 1. Mean area under the disease progress curve (AUDPC) and standard error of the mean of wheat cultivars infected with *Puccinia graminis* f. sp. *tritici* in 1977 and 1978

Cultivar	AUDPC[a] 1977	AUDPC[a] 1978
Era	2 ± 1	5 ± 0
Morocco	732 ± 111	1,101 ± 131
Prelude	213 ± 231	653 ± 33
Lee	69 ± 47	321 ± 49
Thatcher	111 ± 50	254 ± 26

[a] Based on five replicates per cultivar each year.

TABLE 2. Number of progenies of Era/Morocco and Era/Prelude infected with *Puccinia graminis* f. sp. *tritici* in each value for area under the disease progress curve (AUDPC) in 1977 and 1978

Cross and year	Total Lines	AUDPC value[a] 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Era/Morocco															
1977	65	10	7	12	15	8	8	5							
1978	73		2	3	8	9	12	8	7	15	5	3	1		
Era/Prelude															
1977	56	37	17	2											
1978	78	1	3	3	10	5	11	5	7	3	10	7	5	6	2

[a] AUDPC value = indicated value × 100.

interaction. Seventy-five percent of the total expected segregation had already occurred before the sister lines were developed. The races present in the field each year were avirulent on Era, the resistant parent, and virulent on the other parents and on the progenies that were tested.

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