Selection and Evaluation of Three Spring Wheats with Slow-Rusting Resistance to *Puccinia graminis* f. sp. *tritici*

B. K. SALLY, Research Associate, and E. L. SHARP, Professor, Department of Plant Pathology, Montana State University, Bozeman MT 59717

ABSTRACT

Sally, B. K., and Sharp, E. L. 1988. Selection and evaluation of three spring wheats with slow-rusting resistance to *Puccinia graminis* f. sp. *tritici*. Plant Disease 72:413-415.

Spring wheat plants having susceptible reactions and comparatively low severities when infected with stem rust race 15-TNM were selected from F_3 and F_4 segregating populations in the field. Succeeding selections in the field were made on the basis of agronomic type and low severity using the slow-rusting cultivar Thatcher as a standard for comparison. Resulting selections were evaluated for latent period in the greenhouse. Three lines were selected having latent periods longer than or similar to that of Thatcher. Under field conditions and with different inoculum levels, the three slow-rusting selections maintained their receptivity and slow-rusting characteristics as measured by areas under the disease progress curve. Differences among the entries were greater under heavy inoculum load, with two selected slow-rusting lines being definitely superior to Thatcher. Significant reductions in thousand kernel weight (TKW) were sustained by both the slow-rusting control and selected lines when subjected to a heavy inoculum load, whereas the fast-rusting control sustained TKW reductions at all inoculum levels.

Eastern Montana may receive airborne urediospores of *Puccinia graminis* Pers. f. sp. *tritici* Eriks. & E. Henn. from the southern United States. Economic losses averaging $7.5 million for each of the years 1962 through 1965 (1) due to wheat stem rust provided an impetus for selecting stem rust resistance in wheats developed or recommended for use in Montana. Race-specific rust resistance has been predominantly emphasized. Because of the possible short duration of this type of resistance, efforts were made to identify a more general and durable resistance. Slow-rusting resistance has been observed and demonstrated in various host-pathogen systems (18). Some cultivars have maintained their slow-rusting character since their inception (17,18). Recent studies have shown that the slow-rusting trait is heritable and can be generally effective in reducing losses (3,9,14,16).

This paper reports on the selection and evaluation of spring wheat lines with slow-rusting characteristics.

MATERIALS AND METHODS

The hard red spring wheat (*Triticum aestivum* L.) cultivars or lines used in these studies, either as individuals or in crosses, were: Federation (CI 4734), Thatcher (CI 10003), Zambezi (PI 314920), Olaf (CI 15930), Norana (CI 15927), Lee (CI 12488), McMurachy (CI 11876), Kenya 58 (CI 12471), and CI 15838.

Material was derived from single crosses, and initial selection for slow rusting was carried out under field conditions in the F_3 and F_4 generations. Seed of selected F_3 and F_4 plants were space-planted in the stem rust nursery using Thatcher and Federation as slow- and fast-rusting controls (2,17,19). The plants were infected with stem rust race 15-TNM from surrounding inoculated plots. Readings were done at weekly intervals to compare the rust severity of single plants with that of Thatcher. Plants having undesirable agronomic characters, resistant infection type, or susceptible rust reaction were eliminated. Single plants having severities consistently lower or equal to that of Thatcher were harvested, and thousand kernel weights (TKWs) were determined for each selection. Progenies from the higher kernel weight selections were evaluated in the greenhouse for the latent period, defined as time from inoculation until sporulation of all infection sites.

Following preliminary field and greenhouse tests of initial field selections, three lines from two crosses were saved: two lines developed from Zambezi × Olaf (Sel.A, Sel.B) and one line from CI 15838 × Norana (Sel.C). All three lines were selected on the basis of different TKWs and slower rust development. The pedigree background of the cultivar Olaf includes reported slow-rusting cultivars Lee (CI 12471), Thatcher, and McMurachy. The background of Norana includes Thatcher and Kenya 58 (19,20).

In further field tests, the three slow-rusting selections (F_6, F_7) plus Thatcher and Federation were planted in 1.8 × 3.3 m four-row plots, each replicated three times. Plots were arranged in separate but adjacent control and inoculated treatments, where each was a randomized complete block design. TKW data were subjected to analysis of variance and means were separated using Duncan's multiple range test at $P = 0.05$. Inoculated and control treatments were separated by a range of a resistant spring wheat cultivar. Stem rust buildup within control plots was reduced by spraying with triadimefon (Bayleton) at 50 g a.i./ha (13). Spraying was done every 10 days beginning when rust infection was first observed within the plots. Because seed supply was limited, the first of the 3 yr of testing involved two-row plots bordered on each side by one row of Thatcher.

Inoculum in the form of a talc/urediospore mixture was applied to spreader rows surrounding experimental plots at a rate of 1 g of spores per 30 m of spreader row. Immediately before inoculation, the soil between the spreader rows was watered. After inoculation, the spreader plants were covered overnight with clear 4-mil polyethylene sheets. Plants were at the tillering growth stage (Feekes 2–3) (6) when inoculations were made. In addition to application of spores by dusting, 10 plant tillers at 3-m intervals within the spreader rows were hypodermically inoculated. Another source of inoculum was from nearby winter wheat plots infected with stem rust race 15-TNM. When necessary to ensure adequate infection, the plants were also inoculated directly with a talc/urediospore mixture at the same rate used for the spreader rows. The first year, infection was adequate and no additional inoculum was applied. The second year, infection was light and additional inoculum was applied directly to the plots at the booting stage (Feekes 10). The third year, additional inoculum was applied directly to the plots at the late tillering stage (Feekes 5) and irrigation was used.

Increase of rust was measured from the two center rows of the four-row plots by estimating the rust severity (Fig. 1), according to the modified Cobb scale (10). Initial severity ratings were made when severity was approximately 10% on the cultivar Federation. Four severity assessments were made at weekly intervals on inoculated and control treatments. Rust severities were used to

Journal Series Paper 1936.

Accepted for publication 8 December 1987 (submitted for electronic processing).

determine the area under the disease progress curves (AUDPC) for each cultivar and line (4). TKW and grain yield for each test entry were determined.

Receptivity was determined for the lines and cultivars the first year (1982) of field testing (14). Pustules arising from the primary infection on leaf sheath areas were counted. Counts were made on three groups of culms, each consisting of 20 culms, for all inoculated plot replications. A pustule count was made later on leaf sheaths not developed at the time of the primary infections. Counts were made at the heading growth stage (Feekes 10.2–10.5).

Since some slow-rusting components on plants at early growth stages do not correlate well with results on plants at later growth stages in the field, latent period measurements in the greenhouse were done at the four- to five-leaf stage (5,7,8,11,15,17). The plants, trimmed to three main tillers, were inoculated uniformly within a settling tower using 40 mg of urediospores. After a 24-hr dew period at 21 C, the plants were returned to the greenhouse bench. After 7 days of incubation at 21–26 C with supplemental illumination, the flag leaves were examined to identify areas with infection sites for future pustule counts. Leaf areas having 15–30 well-spaced infections were marked with a pen. If the flag leaf was not usable, the penultimate leaf was used. The number of sites within the delimited areas was recorded for each plant, and observations were made each succeeding day on the number of pustules that developed. Pustule counts were continued until all sites had developed pustules. Occasionally, sites remained undeveloped and eventually became necrotic. Thatcher and Federation, slow- and fast-rusting cultivars, respectively, were used as the reference standards.

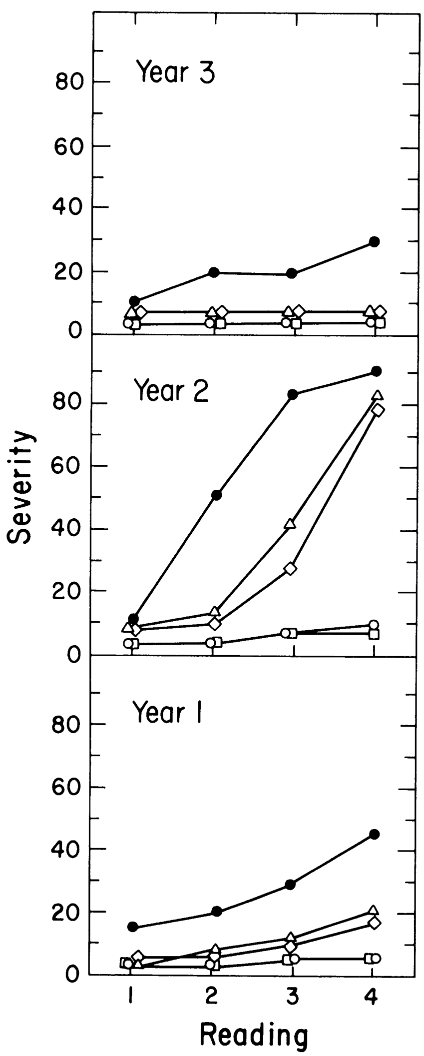

Fig. 1. Disease progress for stem rust on five wheat cultivars in three different years. Readings at 1-wk intervals. ● = Federation, ◇ = Thatcher, o = Sel.A, □ = Sel.B, Δ = Sel.C.

RESULTS

Three lines from 25 different crosses were selected for slow rusting combined with desirable agronomic traits in the F_4 and F_5 generations. For all cultivars and lines, the AUDPCs, latent period measurements, and kernel weight reductions showed similar ranking regardless of inoculum potential and weather conditions. During the first year of field trials, grain yield of Federation, the susceptible check, was significantly reduced by 31%. Nonsignificant reductions of 8.5, 6.0, 5.0, and 5.0% occurred for Sel.C, Thatcher, Sel.A, and Sel.B, respectively. Excessive infection in the control plots during the second year reduced the yield differences between the inoculated and control plots. Significant yield reductions occurred in all entries except Sel.A and Sel.B, however. Grain yields of Federation, Sel.C, and Thatcher were reduced 96, 66, and 32%, respectively. The first-year measurement of receptivity also indicated the relative slow-rusting abilities of these lines (Table 1). The heavy stem rust infection in year 2 served to emphasize the differences in AUDPCs between cultivars and lines, with Sel.A and Sel.B being definitely superior to the known slow-rusting Thatcher. AUDPCs of Sel.A and Sel.B ranged from 19 to 79 and 19 to 61, respectively, for the 3-yr evaluation, whereas the corresponding values for the Thatcher slow-rusting control ranged from 105 to 595. The two selections from Zambezi × Olaf (Sel.A and Sel.B) showed the longest latent periods, lowest receptivity, and smallest AUDPC values. Although pustule size and spore production were not assessed, the slow-rusting check and slow-rusting selections appeared to have somewhat smaller and less erumpent pustules than the susceptible control. Furthermore, fewer pustules developed on the slow-rusting types with controlled inoculations in the greenhouse.

The selection from CI 15838 × Norana (Sel.C) had a latent period slightly less than that of Thatcher but percentage of infection sites with pustules was similar to that of Federation at the eighth day of incubation. The latent period of Sel.C was midway between that of Federation and that of Thatcher (Table 2). In field tests, Sel.C rusted in a fashion more similar to that of Thatcher than to that of Federation, as indicated by AUDPC values and pustules per sheath (Table 1).

During the first test year, only Federation had significant reductions in yield and TKW. Sel.C had a significant reduction in yield. The heavy infection during the second test year resulted in significant kernel weight reductions of all cultivars and lines. Severities on Thatcher and Sel.C increased at a rate similar to that of Federation after an initial delay early in the epidemic. Sel.A and Sel.B retained low severities of less than 10%. In plots protected by the application of triadimefon, maximum severity on Federation was 10% in the 2 yr of light to moderate infection but 70% in the year of heavy infection. Concomitantly, severities on Thatcher and Sel.C in the control plots reached 20%, while Sel.A and Sel.B were rated at 5% or less.

The third test year was characterized

Table 1. Kernel weight reduction, associated areas under disease progress curve (AUDPC), and receptivity of spring wheat cultivars and lines infected with *Puccinia graminis* f. sp. *tritici*

	Reduction in TKW (%)[a]			AUDPC[b]			Receptivity[c]	
Cultivar or line	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	First count	Second count
Federation	30.7*	...[d]	53.9*	578	1,260	420	134.9	213.9
Thatcher	0	38.8*	5.5	179	595	105	7.2	44.7
Sel.A	0	18.7*	+4.3	19	79	49	0.7	1.6
Sel.B	2.0	18.8*	+1.2	19	61	49	0.8	2.0
Sel.C	4.9	63.3*	9.0	184	665	105	4.8	80.6

[a] TKW = thousand kernel weight. Reduction expressed as percentage of control plots treated with triadimefon (Bayleton). * = Significantly different according to Duncan's multiple range test at $P = 0.05$; + = nonsignificant increase.
[b] Average AUDPC for three replications; infection light to moderate in years 1 and 3 and heavy in year 2.
[c] Average pustule count made during year 1 on 20 culms in each of three replications at heading stage; second count made 10 days after first count on fresh tissue.
[d] Heavy infection in control plots reduced kernel weight to that of inoculated plots.

Table 2. Latent periods in the greenhouse for spring wheats infected with *Puccinia graminis* f. sp. *tritici*

Cultivar or line	Percentage of infection sites developing pustules at four- to five-leaf stage						
	Days after inoculation						
	8	9	10	11	12	13	14
Federation	84	100	...	...	...	...	...
Thatcher	13	54	96	100	...	...	...
Sel.A	0	5	...	20	22	35	87
Sel.B	<1	9	...	60	67	94	...
Sel.C	83	91	100	...	...	...	...

by infection earlier in the growth stage of the test plots (Feekes 6–7), followed by reduced infection and a concomitant static severity. The direct manual application of inoculum to the plots and weekly irrigations were inadequate to overcome the inhibiting effects of unfavorable conditions. Severity levels remained nearly static on the slow-rusting plants until the soft-dough stage (Feekes 11.2), when increased plant canopy and additional rainfall provided conditions more favorable for rust infection. Severity on Federation, however, increased earlier and more rapidly. There was no significant reduction in TKW of the slow-rusting lines and Thatcher, but the TKW of Federation was reduced significantly. Inoculated Federation matured 10 days earlier than its fungicide-protected control. Although severity reached 30–40% on Thatcher and Sel.C at the last observation, kernel development had reached the hard-dough stage and rust infection had little influence on TKW.

DISCUSSION

In the preliminary studies, plants were identified in F_3 and F_4 segregating populations of spring wheat that had obvious genes for specific resistance as well as plants with varying degrees of susceptibility. Within the susceptible segregates, there were definite differences in rate of rusting, and lines were selected for further study. Investigations have shown that specific resistance factors may be overcome by virulent races, but a backgound resistance or slow rusting may still be expressed (8,16).

A slow-rusting standard for comparison and an adequate inoculum load are important factors in selecting for the slow-rusting traits. Differences in dilatory response between plants are less discernible during light infection, but this may be overcome to some extent by inclusion of a slow-rusting standard. Under such conditions, however, selections rusting slower than the standard are less likely obtained.

The resistance of slow-rusting lines Sel.A and Sel.B became particularly evident in periods of heavy infection. The pustules were always more evident on tissue near the base of the plants and were extremely sparse on the upper portions. Observations were similar on Thatcher and Sel.C but not of the same magnitude. Other workers have noted that the rate of disease increase on slow-rusting plants may parallel that of fast-rusting types in cases of heavy infection (8,14). This disease increase occurred with Thatcher and Sel.C but not with Sel.A and Sel.B, regardless of the year and severity of the epidemic. With heavy infection, the TKWs of Sel.A and Sel.B were significantly reduced, but the reduction was only one-half the magnitude for Thatcher. We assume that the massive number of infections, although not being expressed visually, caused enough stress on the plants to significantly affect kernel weight. The moderately slow rusting traits of Thatcher and Sel.C provided adequate protection during times of light to moderate infection.

The three slow-rusting selections were similar to but slightly higher than Thatcher in test weight, flour yield, and protein level (C. F. McGuire, *personal communication*). Their rate of maturation was the same as that of Thatcher and they were 7 cm shorter.

It was possible to select slow-rusting types from segregating F_3 and F_4 spring wheat populations showing a specific type of resistance to stem rust. Cultivars with slow-rusting resistance should offer a more durable resistance in acceptable agronomic types and maintain yield stability. Race 15-TNM, used in this investigation, has been the most prevalent race in recent years (12), including the epidemic year of 1986. The selections reported here should also be evaluated with other races to determine if nonspecificity is maintained. An additional 14 lines (F_6, F_7) have been developed for the slow-rusting characteristic, and further selections from early generation breeding lines and international rust nurseries are being evaluated using the field methods of this study.

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