Yield Loss to Spot Blotch in Spring Bread Wheat in Warm Nontraditional Wheat Production Areas

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ABSTRACT

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Twenty-five spring bread wheat (*Triticum aestivum* L.) cultivars were evaluated for 2 years at Poza Rica, Mexico, for grain yield, aboveground biomass at maturity, harvest index, yield components, and test weight under a natural epidemic of spot blotch (caused by *Cochliobolus sativus*) with and without fungicide protection. Diseased plot yields were 43.2% lower than fungicide-protected plot yields. Aboveground biomass yield at maturity and harvest index were reduced by 18 and 31.3%, respectively, on blotched plots. The average percent reduction on primary yield components due to the disease was highest for number of grains per m^2 (32.8%), followed by 1,000-grain weight (30.5%), number of grains per spike (24.6%), and number of spikes per m^2 (12%). Test weight was reduced 8.4%. Resistance to *Cochliobolus sativus* present in cultivars with resistance from *Thinopyrum curvifolium* or materials derived from Chinese germ plasm increased grain yield. This germ plasm may be a valuable source of genes for spot blotch resistance in *T. aestivum*.

Additional keyword: intergeneric hybridization

Spot blotch (leaf blotch) of wheat (*Triticum aestivum* L.) caused by *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. ex Dastur (syn.: *Bipolaris sorokiniana* (Sacc.) Shoemaker, *Helminthosporium sativum* Pammel, C. M. King & Bakke) is an important pathogen that limits production in many nontraditional hot, humid wheat-producing areas of Asia, Africa, and South America (2,4,6,8,9,12,14, 16). *Cochliobolus sativus* can attack seedlings, roots, leaves, nodes, spikes, and grains during various stages of plant development (3).

Yield loss estimates due to spot blotch on wheat vary widely. Losses of 85% were reported from Zambia (13) and 40% from field trials in the Philippines (7). In addition, yield losses with the highly susceptible cultivar Mitacore in an experiment conducted at Londrina, Brazil ranged from 79 to 87%, and the disease severely affected grain quality (5). De Milliano and Zadoks (1) found a 38% yield loss using African wheat cultivars in growth-chamber studies in the Netherlands. Because of the importance of this disease, chemical control is applied in order to obtain crop production stability in many parts of the world, and breeding resistant cultivars is a research priority. Emphasis is also being given to an integrated pest management approach utilizing resistant cultivars, healthy seed, cultural practices, and chemical sprays (5). Though breeding for resistance is a high priority, it is hampered by scarcity of adequate resistance within *T. aestivum*.

Sources of resistance to *C. sativus* in species other than *T. aestivum* (i.e., alien gene pools) are of special interest in breeding programs. The International Wheat and Maize Improvement Center (CIMMYT) has been making some effort to incorporate alien resistance genes already in a wheat background (10). Recently, some wheat lines with resistance to *C. sativus* derived from *Thinopyrum curvifolium* Lange have been obtained that also have good agronomic characteristics and yield potential (11,19,20).

The main objective of this study was to assess the effects of spot blotch under a heavy field epidemic on grain yield and other agronomic characteristics in spring wheat germ plasm possessing resistance to *C. sativus*. Advanced breeding lines derived from the CIMMYT wheat breeding program and five parental cultivars were evaluated to estimate the progress achieved in breeding for resistance to *C. sativus* using alien germ plasm.

MATERIALS AND METHODS

The 25 spring bread wheat cultivars used in the present study are listed in Table 1. Represented is germ plasm used by the CIMMYT Wheat Improvement Program to breed cultivars with resistance to spot blotch. Cultivars 1, 4, and 5 possess moderate resistance to the disease while 2 and 3 are susceptible but with a good agronomic type. These progenitors were intercrossed with the alien species *Th. curvifolium* to develop cultivars 8 to 25. Cultivars 6 and 7 possess moderate resistance to spot blotch and represent advanced materials from the conventional breeding program. In our discussion, cultivars 1, 4 ,and 5 are the resistant parents, cultivars 2 and 3 are the susceptible parents, cultivars 6 and 7 are the advanced breeding lines from the conventional breeding program, and cultivars 8 to 25 are lines with resistance derived from *Th. curvifolium*.

The 25 wheat cultivars were planted in the field at Poza Rica (20°32′N, 97°26′W, 60 m altitude), Veracruz, Mexico, where natural disease incidence was high during the 1991–92 and 1992–93 crop seasons. The experiment was a split-plot randomized complete block design with three replications. The two main plot treatments were exposed to natural infection by *C. sativus*. In one treatment, disease was allowed to develop; in the other it was suppressed by application of fungicide. During the 2 years of yield tests, each subplot (cultivar) consisted of six rows, 4 m in length, with 20 cm between rows. Both plantings were made in mid-November at a seeding rate of 100 kg per ha. Prior to seeding, fertilizer was applied at the rate of 75 kg N per ha as ammonium sulfate and 80 kg P per ha as tri-superphosphate. Thirty days after seeding, an additional 50 kg N per ha was applied to the plots. Furrow irrigation was used and continued until the latest maturing genotype reached physiological maturity (a total of four irrigations). Growth of broad-leaf weeds was restrained by use of a selective herbicide (Puma = Fenoxaprop-Ethyl = Ethyl(R)-2-[4[(6-chloro-2-benzoxazolyl) oxy]phenoxy]propanoate; 2.5 liters per ha).

Each main plot contained 25 subplots, consisting of the 25 cultivars. A row of cultivar Ciano 79, susceptible to spot blotch, was planted at both ends of these subplots and perpendicular to them, to serve as an indicator of the uniformity of disease and to promote the buildup of secondary inoculum. Beginning with the appearance of the first symptoms of infection on the susceptible indicator Ciano 79 (at about the three-leaf stage), fungicide was applied to the protected main plots. In both years, Folicur (Tebuconazole = ∝ -tertiari-

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Table 1. Germ plasm description of the 25 spring wheat genotypes used, with their respective *Cochliobolus sativus* scores when tested during the 1992–93 and 1993–94 trials at Poza Rica

Cultivar no.	Cultivar name, cross, and selection history[y]	*C. sativus* score[z]	
		A	B
1	Ald/Pvn	95	97
2	Gen	98	99
3	Glen	98	99
4	Ning4/On//Ald/Ymi4	94	98
5	Suz8	94	96
6	Fct/3/Gov/Az//Mus CM76290-32Y-04M-06Y-6B-0Y	94	96
7	Ffn/Vee # 5 CM88930-10Y-0M-0Y-2M-4Y-0B	94	96
8	Cs/A.curv.//Glen/3/Gen CIGM84.107-8B-1PR-3M-2PR-5B-0PR-0M-0Y-2Y	93	94
9	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-1B-3Y-0M-0Y-4PR-3M-3PR	93	94
10	Cs.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-2B-2Y-0M-0Y-2Y	93	93
11	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-4B-0PR-0M-0Y-1PR-3M-3PR	93	93
12	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-4B-2Y-0M-0Y-2Y	92	93
13	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-2M-0PR-0M-0Y-1Y	93	94
14	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-3M-0PR-0M-0Y-2Y	93	93
15	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-3M-2Y-0M-0Y-1PR-4M-3PR	92	93
16	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-4M-0PR-0M-0Y-2B-0PR	92	92
17	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-4M-0PR-0M-0Y-4B-0PR	92	94
18	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-5M-0PR-0M-0Y-1Y	93	94
19	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-8M-0PR-0M-0Y-3Y	93	94
20	Cs/A.curv.//Glen/3/Ald/Pvn CIGM84.295-1M-1PR-11M-2Y-0M-0Y-2PR-3M-1PR	92	93
21	Cs/A.curv.//Glen/3/Gen/4/Ning8201 CIGM87.526-6Y-1M-2PR-4M-1PR	93	94
22	Cs/A.curv.//Glen/3/Ald/Pvn/4/Suz8 CIGM87.117-2PR-4M-1PR-2M-2PR	92	92
23	Cs/A.curv.//Glen/3/Ald/Pvn/4/Ning4/On//Ald/Ymi4 CIGM87.1006-1Y-2M-1PR-2M-2PR	93	94
24	Cs/A.curv.//Glen/3/Ald/Pvn/4/Ning4/On//Ald/Ymi4 CIGM87.1006-2Y-4M-3PR-4M-1PR	92	93
25	Cs/A.curv.//Glen/3/Ald/Pvn/4/Ning4/On//Ald/Ymi4 CIGM87.1006-3Y-3M-1PR-1M-3PR	92	92

[y] Refer to Villareal and Rajaram (21) for abbreviation and selection pedigree descriptions.

[z] Used double-digit scoring of Saari and Prescott (15); A = data recorded at early milk stage; and B = data collected during soft dough stage.

Table 2. Mean grain yield and other agronomic characteristics of 25 spring wheat cultivars in the presence of spot blotch or when protected by Folicur fungicide, and the percent reduction due to spot blotch, averaged over 2 years at Poza Rica, Mexico

	Mean		
	Controlled	Diseased	Reduction (%)[z]
Grain yield (kg per ha)	1,871	1,062	43.2
Aboveground biomass (t per ha)	7.2	5.9	18.0
Harvest index (%)	25.9	17.8	31.3
Spikes per m^2	349	307	12.0
Grains per m^2	7,618	5,118	32.8
Grains per spike	21.9	16.5	24.6
1000-grain wt. (g)	28.8	20	30.5
Test weight (kg per hl)	73.5	67.3	8.4
Physiological maturity (day)	114	105	7.7
Days to anthesis	79	78	1.8
Grainfill duration (day)	40.4	32.7	19.0
Plant height (cm)	86	83	3.4
Spike length (cm)	8.1	7.6	6.2

[z] All values significant at 0.001 level of probability.

butil- ∝ -(P-chlorofenetil)-1H-1,2,4-triazole-1 ethanol; BayerAG, Germany) was applied 4 times at 2-week intervals as a foliar spray at the rate of 0.5 liters per ha in 250 liters per ha of water using a backpack sprayer.

Cochliobolus sativus infection on diseased plots was determined using a double-digit (00 to 99) scale representing the vertical disease progress (first digit) and severity estimate (second digit). The first digit gives the relative height of the disease using the 0 to 9 Saari-Prescott scale (15) as a measure. The second digit shows the disease severity as a percentage but in terms of a 0 to 9 scale. Percent severity is estimated by looking at 10 to 20 plants and deciding on an overall scale, i.e., 10% coverage = 1, 50% coverage = 5, and 90% coverage = 9. No other disease was observed within these plots during either year of study.

Seven traits were measured on each plot: (i) days to flowering, as number of days from crop emergence until 50% anthesis; (ii) plant height (cm), using three measurements in the plot from the ground to the spike apex excluding awns; (iii) spike length (cm), using three measurements from the base of the spike to the tip of the highest spikelet (awns excluded); (iv) days to physiological maturity, recorded when the green color was completely lost from 50% of the spikes in the plot; (v) grain yield (kg per ha), as grain weight from a 2.4-m^2 plot that excluded border rows and 0.5m of all rows at each plot end; (vi) test weight (kg per hl), and (vii) 1,000-grain weight (g), determined from two dried 250-grain samples from each plot.

Plot areas of 2.4 m^2 were hand-harvested 1 week after physiological maturity for each cultivar but before full maturity, in order to minimize harvest losses due to grain shattering. Plants were cut as close as possible to ground level to obtain an accurate estimation of aboveground biomass at maturity. The procedures used to obtain grain yield and its components were adapted from Villareal et al. (22) and as follows. Just after harvest, a subsample of 100 spike-bearing tillers was taken at random from the plot bundle, then weighed, placed in a cloth bag, and oven-dried at 75°C for 2 days. The plot bundle was then weighed. The subsample was used to calculate the moisture content of the plot bundle at harvest. The remaining wheat harvested from each plot was sun-dried for 10 days, threshed using a Vogel thresher; the grain was cleaned and weighed. Immediately after weighing, a grain sample of about 50 g was taken, weighed, oven-dried at 100°C for 48 h, and re-weighed to determine grain moisture content. This content was used to adjust all reported grain yields to 12% moisture. The aboveground biomass and harvest index, spikes per m^2, and grains per spikes were calculated from the data obtained as described earlier. Harvest index was defined as grain yield divided by aboveground biomass (both expressed on a dry weight basis). All variables measured for each genotype were subjected to analysis of variance using the PROC GLM procedure of Statistical Analysis Systems (17). Data for each year were analyzed separately. Where errors were homogeneous, a combined analysis of variance was done for the cultivars of the two yield trials. Mean separation was done using the least significant difference (LSD). Pearson correlation coefficients were calculated using the percent reduction means of each yield characteristic for each cultivar in all replications in the two trials.

RESULTS AND DISCUSSION

Weather data were obtained from the agrometeorological station of CIMMYT in Poza Rica, Mexico. These conditions during the 1992–93 and 1993–94 wheat seasons were favorable for the development of spot blotch. Relative humidity was between 90 and 100% for more than 95% of both growing cycles. This was due to early morning and afternoon fogs, with less than 5 h of direct sunlight during most of the two cycles. Optimum mean temperature for the development of the fungus (18 to 24°C) was also recorded during 80% of the 2 years of tests. A spot blotch score of 99 on the disease spreader susceptible cultivar Ciano 79 at the soft dough stage in both years indicated severe disease development. Summarized in Table 1 are the mean *C. sativus* scores taken from the diseased plots of the test entries during the 1992–93 and 1993–94 seasons at Poza Rica. Four applications of Folicur effectively controlled *C. sativus* in this study, as the sprayed plots had disease scores no more than 11. All components of yield and other measured yield components were significantly reduced by spot blotch (Table 2).

Overall grain yield was reduced 43.2% in the diseased plot (Table 2). Mean yield reduction due to the disease ranged from 7.1% (cultivar 25) to 83.1% for cultivar 2 (Fig. 1A). Cultivar 18 had the highest yield among the controlled plots, while cultivar 16 had the highest yield in the diseased plots. Both cultivars were derivatives of *Th. curvifolium*. Aboveground biomass yield was reduced by 18% due to *Cochliobolus* infection. The highest biomass yield reduction was 46.7% on cultivar 4 (Fig. 1B). Harvest index reduction from spot blotch ranged from 4.6% (cultivar 25) to more than 70% (cultivars 1 and 2; Fig. 1C). The yield component most affected

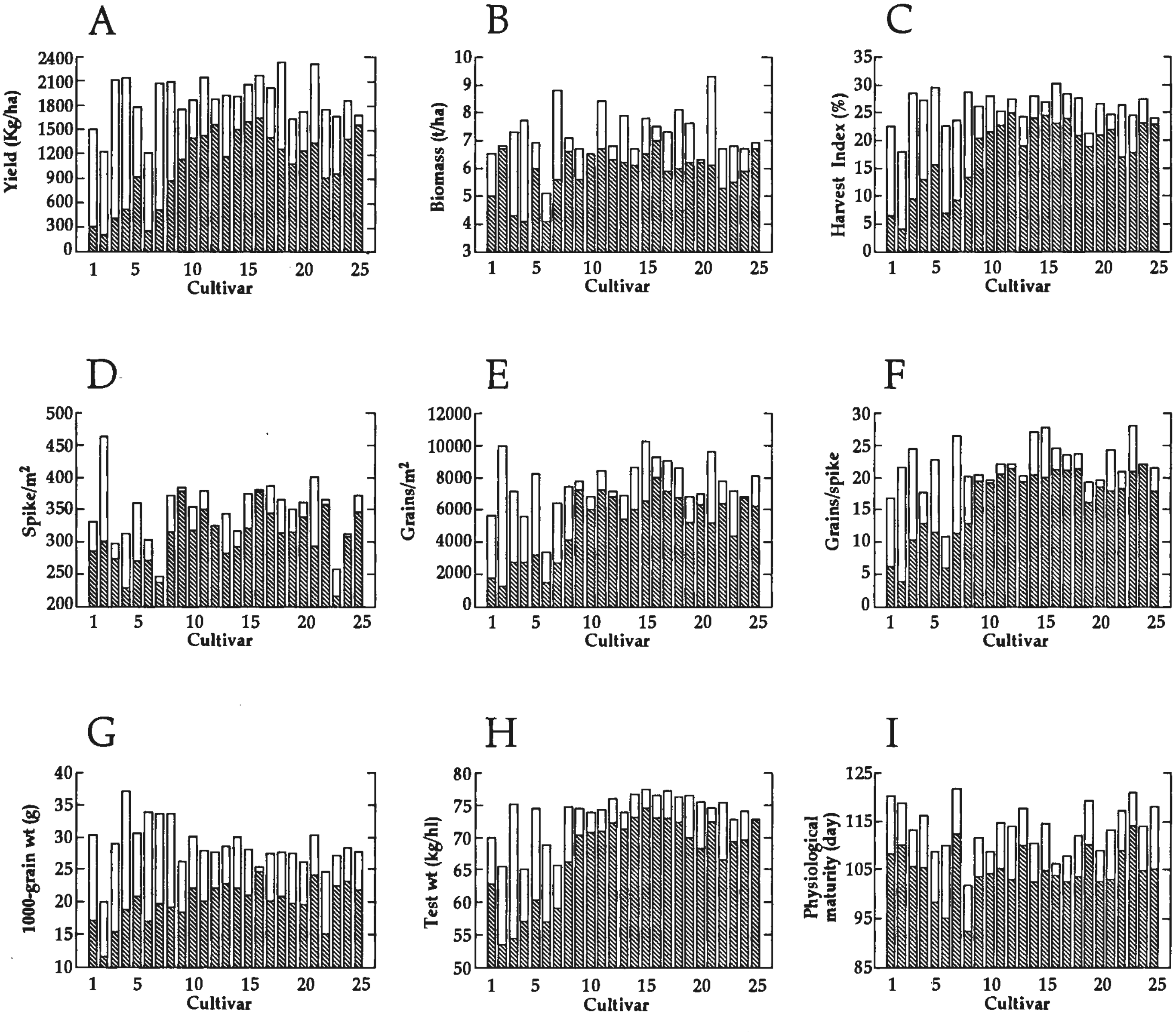

Fig. 1. (A) grain yield; (B) aboveground biomass at maturity; (C) harvest index; (D) spikes per m²; (E) grains per m²; (F) grains per spike; (G) 1,000-grain weight; (H) test weight; and (I) days to physiological maturity, of 25 wheat cultivars averaged over 2 years at Poza Rica, Mexico. Shaded bars are for plots in which spot blotch was allowed to develop. Unshaded bars are for plots in which disease was controlled by Folicur fungicide.

Table 3. Correlation coefficients between various measures of plant productivity for 25 spring wheat cultivars at Poza Rica, Mexico, during the 1992–93 and 1993–94 crop cycles[x]

	GY[y]	BIO	HI	SPM	GPM	GPS	TGW	TW
GY	1.00							
BIO	0.48*[z]	1.00						
HI	0.95**	0.23	1.00					
SPM	−0.06	0.67*	−0.24	1.00				
GPM	0.94**	0.37	0.92**	−0.08	1.00			
GPS	0.79**	0.14	0.84**	−0.26	0.82**	1.00		
TGW	0.83**	0.44*	0.79**	−0.10	0.66*	0.64*	1.00	
TW	0.77**	0.17	0.81**	−0.36	0.73**	0.69*	0.72**	1.00

[x] Data are from plots in which spot blotch was allowed to develop and from plots in which disease was controlled by Folicur fungicide.

[y] GY = grain yield; BIO = aboveground biomass at maturity; HI = harvest index; SPM = spikes per m^2; GPM = grains per m^2; GPS = grains per spike; TGW = 1,000-grain weight; and TW = test weight.

[z] *,** = significant at 0.05 and 0.01 levels of probability, respectively.

Table 4. Grain yield, aboveground biomass at maturity, harvest index, yield components, and test weight of four spring wheat cultivar groups and the percent reduction due to infection by *Cochliobolus sativus* over two crop cycles at Poza Rica, Mexico[w]

	Cultivar group[x]								
Plant characteristic	**SP**		**RP**		**ACL**		**TCD**		**LSD[y]**
C. sativus score[z]									
Early milk stage	72	a	39	b	36	b	23	c	11
Late dough stage	81	a	63	b	54	b	29	c	14
Grain yield									
Controlled	1,667	c	1,805	b	1,645	c	1,930	a	115
Diseased	310	c	584	b	389	bc	1,301	a	203
% Reduction	81.4	c	67.6	b	76.3	c	32.6	a	8.5
Aboveground biomass									
Controlled	7.0	ab	7.0	ab	6.9	b	7.3	a	0.3
Diseased	5.5	b	5.0	bc	4.8	c	6.2	a	0.5
% Reduction	21.4	b	28.6	c	30.4	c	15.1	a	5.1
Harvest index									
Controlled	23.2	b	26.4	a	23.1	b	26.4	a	2.9
Diseased	6.8	c	11.7	b	8.1	bc	21.1	a	4.7
% Reduction	70.7	c	55.7	b	64.9	c	20.1	a	7.6
Spikes per m^2									
Controlled	381.0	a	334.3	b	275.5	c	356.1	ab	42.3
Diseased	287.5	ab	262.3	b	255.0	b	321.9	a	38.8
% Reduction	24.5	b	21.5	b	7.4	a	9.6	a	4.3
Grains per m^c									
Controlled	8,570	a	6,505	b	4,892	c	8,001	a	1,006
Diseased	2,034	c	2,582	b	2,130	c	6,216	a	875
% Reduction	76.3	c	60.3	b	56.4	b	22.3	a	10.5
Grains per spike									
Controlled	23.1	a	19.1	b	18.6	b	22.7	a	2.8
Diseased	7.1	b	10.2	b	8.7	b	19.4	a	3.5
% Reduction	69.3	c	46.6	b	53.2	b	14.5	a	7.6
1,000-grain weight									
Controlled	24.5	b	32.7	a	33.8	a	28.1	b	4.2
Diseased	13.5	c	19.0	ab	18.3	b	21.1	a	2.6
% Reduction	44.9	b	41.9	b	45.8	b	24.9	a	8.3
Test weight									
Controlled	70.3	b	69.9	b	67.3	c	75.2	a	2.4
Diseased	54.0	c	60.1	b	58.0	b	70.9	a	3.3
% Reduction	23.2	c	14.0	b	13.8	b	5.7	a	4.8

[w] Data are averaged over plots in which spot blotch was allowed to develop and plots in which Folicur fungicide was applied to control spot blotch.

[x] SP = susceptible parents; RP = resistant parents; ACL = advanced lines from the conventional breeding program; and TCL = *Thinopyrum curvifolium*–derived lines where any two means on the same row having a common letter (a through c) are not significantly different at 0.05 level of probability.

[y] Least significant difference at 0.05.

[z] *Cochliobolus sativus* scores in Table 1 transformed to relative coefficient of infection according to van Beuningen and Kohli (18), where the resistant 11 and susceptible 99 double-digit scores extrapolate to 1 and 81 respectively. These were averaged according to the four cultivar groups.

by spot blotch was grains per m^2 (32.8% reduction), followed by 1,000-grain weight (30.5% reduction), grains per spike (24.6% reduction), and spikes per m^2 (12% reduction). Disease effect on these yield components for each cultivar are shown in Figure 1D to G. The effect of *C. sativus* on test weight is presented in Figure 1H. The mean percent reduction on test weight due to the disease was 8.4%. Days to physiological maturity were shortened to 7.7% on diseased plots.

When disease was controlled by fungicide application, cultivar 7 was the latest maturing entry (122 days), but cultivar 23 was latest maturing (114 days) among the diseased plots. Cultivar 8 was the earliest maturing entry with 102 and 92 days under controlled and diseased conditions respectively (Fig. 1I). Grain filling period was shortened by 19% due to spot blotch. Overall means of physiological maturity, days to anthesis, and grain filling period under controlled condition were generally longer, presumably due to the increased duration of green spike and leaf tissue from the protective effect of the fungicide. Plant height and spike length were reduced by 3.4 and 6.2%, respectively, under diseased plots. Cultivars grown with the presence of the disease were 3 cm shorter than those protected with fungicide.

Percent reduction in grain yield for the 25 test cultivars under diseased and controlled field conditions during the 1992–93 and 1993–94 crop cycles was strongly related to percent reduction in harvest index, grains per m^2, 1,000-grain weight, test weight, grains per spike, and biomass (Table 3). Changes in biomass could be attributed to changes in spikes per m^2, and 1,000-grain weight. Reduction in harvest index showed significant positive correlation with grains per m^2, grains per spike, 1,000-grain weight, and test weight. The relationship between grains per m^2 and grains per spike, 1,000-grain weight, and test weight was also significant. Percent reduction in grains per spike were related to 1,000-grain weight and test weight. Changes in 1,000-grain weight could be attributed to change in test weight.

Advances in breeding for resistance to *Cochliobolus sativus*. To assess the progress in our effort to breed for resistance to *C. sativus*, comparisons were made on disease scores, grain yield potential, and other yield characteristics of the advanced breeding lines and their resistant and susceptible progenitors. Mean disease scores of the 25 genotypes obtained at early milk and dough stages of plant growth (Table 1) were transformed to relative coefficient of infection as described by van Beuningen and Kohli (18), averaged according to the four cultivar groups and subjected to analysis of variance (Table 4). Resistance of the *Th. curvifolium* cultivars to *C. sativus* expressed at early milk stage of plant growth was superior to that of the advanced breeding lines, resistant parents, and susceptible parents. Similarly, the *Th. curvifolium* cultivars showed the highest degree of resistance at soft dough stage, followed by advanced breeding lines, resistant parents, and susceptible parents.

The combined analysis across years revealed a nonsignificant year × cultivar group interaction for grain yield and other measures of plant productivity (Table 4). *Thinopyrum curvifolium* lines had greater yield than the other cultivars under heavy disease pressure and when treated with fungicide. Percent reduction of grain yield due to spot blotch was 35, 44, and 49% lower than the resistant parents, advanced lines, and susceptible parents, respectively. When disease was controlled by fungicide application, all four cultivar groups had similar aboveground biomass yields. Under diseased conditions, however, *Th. curvifolium*-derived cultivars had the highest biomass yield followed by the susceptible parents, resistant parents, and the advanced conventional breeding lines. Moreover, the least biomass reduction due to the disease was also observed on the *Th. curvifolium* derivatives. When disease was controlled, the resistant *Th. curvifolium* lines were most productive for all yield components except 1,000-grain weight. The susceptible parents were equally productive for some yield components. Under heavy spot blotch pressure, *Th. curvifolium* derivatives generally possessed the highest yield components with the least percent reduction due to the disease. Similarly, *Th. curvifolium* derivatives had a better test weight over both test conditions resulting in minimum weight penalty due to spot blotch.

Results of the yield tests demonstrated the *Th. curvifolium* derivatives were superior to the advanced breeding lines and parental cultivars. We conclude that the *Th. curvifolium* derivatives express superior resistance to *C. sativus* under the Poza Rica conditions in Mexico. Resistance to *C. sativus* obtained from *Th. curvifolium* also exhibits an increased grain yield performance and test weight compared with our present conventional breeding materials. This germ plasm provides a valuable genetic source for enhancing spot blotch resistance in *T. aestivum*, and may lead to better plant performance and crop adaptation of wheat to warmer humid production areas of the world.

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