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Farmer participatory evaluation confirms higher grain yields in spring wheat using a selection index for spot blotch resistance, maturity and kernel weight

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Abstract Wheat (*Triticum aestivum* L.) cultivars for the warm regions of South Asia must produce high yields and possess resistance to spot blotch (*Cochliobolus sativus*), early maturity and high kernel weight. A study was conducted to determine the effectiveness of selecting for high grain yield based on a selection index for spot blotch resistance, maturity and kernel weight in four wheat crosses involving a susceptible cultivar and resistant genotypes. Initial selection of 40 progeny lines in each cross had been made using a selection index based on disease severity, days to heading and kernel weight as reported by Sharma and Duveiller [Crop Sci 43 (2003) 2031]. The five highest grain-yielding progeny lines from among the 40 lines in each cross, their parents and five popular commercial cultivars were evaluated in field trials at two sites in Nepal in the 2002 and 2003 wheat seasons. Multiple spot blotch assessments were made to determine the area under disease progress curve (AUDPC). Grain yield, thousand-kernel weight (TKW), days to heading and plant height were examined. The wheat genotypes in the farmer's field were also ranked on the basis of cultivar preference criteria by the local farmers. The 20 progeny lines always showed a higher (+11 to +125%) grain yield and heavier (+10 to +44%) kernels than their parents and a lower (−83 to −89%) AUDPC than the susceptible parent. The progeny lines showed 98–100% grain yield, 97–100% TKW and 66–78% AUDPC compared to the highest grain-yielding commercial cultivar. Based on the farmers' preference criteria for a desirable wheat genotype, the best progeny lines ranked from 3rd to 5th, whereas the two commercial cultivars ranked 1st (Gautam) and 2nd (BL 1473). Results indicated that selection was effective in combining adaptation genes present in a local cultivar with some level of tolerance to spot blotch and resistance genes from exotic genotypes, which translated into improved agronomic performance and disease resistance. The selection index and farmer participatory approach used in this study could serve as a guideline in breeding efforts targeted for high yielding genotypes for wheat-growing conditions in South Asia where spot blotch is a serious biotic constraint to yield.

Keywords Bipolaris sorokiniana · Cochliobolus sativus · Farmer participatory research · Foliar blight · Resistance · Spot blotch · Triticum aestivum · wheat

Abbreviations

AUDPC	Area under disease progress curve
Sel.	Selection
TKW	Thousand-kernel weight

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Introduction

Spot blotch caused by *Cochliobolus sativus* (Ito & Kurib.) Drechsler ex Dastur (anamorph *Bipolaris sorokiniana* [Sacc. in Sorok] Shoem.) is a major foliar disease of wheat (*Triticum aestivum* L.) in Nepal and other warm wheat-growing regions of South Asia for the past two decades (Saari, 1985; Dubin & van Ginkel, 1991; Duveiller & Gilchrist, 1994; Dubin & Duveiller, 2000; Duveiller, 2002), affecting the livelihood of millions of small farmers depending on wheat cultivation (Duveiller, 2004). Its importance has increased in the past decade since the release of a number of wheat cultivars in the region possessing good levels of leaf rust (*Puccinia triticina*) resistance. Hence, a large amount of wheat-breeding resources are being spent on developing high yielding wheat genotypes with spot blotch resistance for the non-traditional warm wheat-growing environments in the eastern part of the Indo-Gangetic Plains of South Asia.

Besides high grain yield, a successful commercial wheat cultivar in the Indo-Gangetic Plains must also possess heavy kernels, a crucial trait for marketing (Morris et al., 1992), early maturity to escape heat stress during grain filling (Sharma, 1992, 1994), and resistance to spot blotch, currently the most important biotic constraint (Saari, 1998). However, wheat-breeding efforts focused on combining early maturity and resistance to spot blotch faced several difficulties, probably due to the negative correlation between maturity and resistance found in several studies (Sharma et al., 1997b; Dubin et al., 1998). These earlier studies also reported a negative correlation between grain weight and resistance to spot blotch, indicating the difficulty in improving these traits simultaneously in a wheat genotype. However, Sharma and Bhatta (1999) and Joshi et al. (2002) reported that the days to heading and spot blotch resistance segregated independently in crosses involving early-maturing susceptible and late-maturing resistant genotypes. Sharma et al. (1997a) showed that kernel weight and spot blotch resistance were not correlated in some of the crosses involving a well-adapted susceptible cultivar with high grain weight and a less well-adapted resistant genotype with low grain weight. Adapted susceptible wheat cultivars in South Asia show high kernel weight primarily because of early maturity, while the less well-adapted resistant genotypes have a low kernel weight because of their late maturity, a negative characteristic in warm wheat-growing environments because the longer grain filling period is curtailed by high temperatures (Dubin et al., 1998; Sharma et al., 2004a).

Considering independent segregation of maturity and spot blotch resistance (Sharma & Bhatta, 1999; Joshi et al., 2002) and the absence of a negative correlation between grain weight and resistance (Sharma et al., 1997a), Sharma and Duveiller (2003) successfully used a selection index to simultaneously improve resistance, maturity and grain weight in the F_4 generation. These three traits determine the commercial acceptance of a wheat cultivar in the region. The selection index (S.I.) had been developed by combining area under disease progress curve (AUDPC), days to heading (DHD) and thousand kernel weight (TKW) (S.I. = AUDPC rank in ascending order + DHD rank in ascending order + TKW rank in descending order). Equal weights were given to all three traits to keep the index simple for its use in applied wheat breeding programs. After the selection index values were calculated, the 20 lowest and 20 highest scoring lines in each population had been selected for further testing. After successfully using and noting the value of the selection index in simultaneously improving disease resistance, maturity and grain weight, the next challenge was to verify its utility in selecting for higher grain yield since this complex trait depends on several additional components. From among the 40 progenies tested in the F_4, we selected the five highest grain-yielding progenies from each of the four crosses (Sharma & Duveiller, 2003). The objective of the work reported here was to test the effectiveness of selecting for grain yield in wheat compared with the parents involved in the crosses and with the leading commercial cultivars, through yield trials conducted under research station and farmers' field conditions. Also, a specific objective was to test the farmers' acceptance of the selected progeny lines in comparison with their parents and the commercial cultivars.

Materials and methods

A study was initiated in 2000 in the F_3 generation of four wheat crosses (Sonalika/Chirya 7; Sonalika/SW 89-5422; Sonalika/G162; and Sonalika/Attila). Sonalika is a widely adapted wheat cultivar in South Asia with early maturity and high kernel weight, but it is highly susceptible to spot blotch and leaf rust, and thus has been replaced by better performing

Table 1 Description of the selected progeny lines, their parents and standard checks used in the study

Cross/check	Progeny line/commercial cultivars
Sonalika/Chirya 7	Selection 1, 2, 3, 4, 5
Sonalika/SW 89-5422	Selection 6, 7, 8, 9, 10
Sonalika/G162	Selection 11, 12, 13, 14, 15
Sonalika/Attila	Selection 16, 17, 18, 19, 20
Susceptible parent	Sonalika
Resistant parents	Chirya 7, SW 89-5422, G162, Attila
Commercial cultivars	Gautam, Bhrikuti, BL 1473, Kanchan, Nepal 297

genotypes in recent years, although farmers still like its agronomic traits and kernel type. The other four genotypes are late-maturing exotic wheats with high levels of resistance to spot blotch in South Asian environments (Sharma et al., 2004b). A selection index, the details of which were published by Sharma and Duveiller (2003), was applied using foliar blight score, days to heading and kernel weight. Out of 40 progeny lines that had been selected using the index, five lines with the highest grain yields were chosen in each of the four crosses for further testing. The 20 selected lines, five parents involved in the crosses and five other commercial cultivars used in the study are listed in Table 1.

The 30 genotypes were evaluated under field conditions at two sites in Nepal: a research station at Rampur (27°40′N and 84°19′E) and a farmer's field in Janakpur (26°43′N and 85°58′E). The two sites, situated in the lowlands of Nepal at a distance of 250 km from each other, differ in environmental conditions. Relative humidity in Rampur is usually higher than in the other parts of the Nepal lowlands known as the *Tarai*. However, spot blotch has been severe on the wheat crop for the past several years at both sites. The Rampur site is located at 228 m above sea level (m asl) and is about 20 km away from the Himalayan foothills. The Janakpur site, situated at 73 m asl, is about 50 km from the foothills. Thus, when wheat is grown in the field during the winter crop season, temperatures are cooler at Rampur than at Janakpur. The soil type at Rampur is a medium textured loam, compared with the heavy clay soil at Janakpur. The two study sites are a part of the vast eastern Indo-Gangetic Plains of South Asia.

The study was conducted during the winter wheat-growing season (November–April) in 2001–2002 (2002) and 2002–2003 (2003), using a randomized complete block design with four replicates. The trials were sown on December 6, 2001 and December 2, 2002 using the standard seeding rate of 120 kg ha^{-1}. The experimental plots had been planted under rice-wheat cropping sequence for the past several years. Individual experimental plots of 4.5 m^2 were seeded as six rows, with 0.25 m row spacing. Fertilizer was mixed into the soil prior to seeding using 120, 60 and 40 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. The other trial management practices were consistent with good crop husbandry practices recommended in the region.

Days to heading was recorded when the spikes of approximately 50% of the plants in a plot were fully emerged. Spot blotch severity was visually scored three times at 10-day intervals for each plot, using the double-digit scale (00–99) developed as a modification of Saari and Prescott's severity scale to assess wheat foliar diseases (Saari & Prescott, 1975; Eyal et al., 1987). The first digit (D_1) indicates vertical disease progress on the plant; the second digit (D_2) refers to severity measured as diseased leaf area. For each score, percentage disease severity was estimated based on the following formula:

$$\%\text{severity} = \left[\left(\frac{D_1}{9}\right) \times \left(\frac{D_2}{9}\right)\right] \times 100$$

The area under disease progress curve (AUDPC) was calculated from the three disease scores as outlined by Das et al. (1992). At maturity, plant height in each plot was measured from ground level to the tip of the spikes. All plants in a plot were hand-harvested and threshed to record grain weight. One thousand kernels taken randomly from grain harvested in each plot were weighed to obtain the thousand-kernel weight (TKW).

Trials were conducted under natural disease infection during both seasons at each location. The experimental field had no stubbles from the previous wheat crop. The field remained submerged in floodwater for several weeks in August and September as is the case in most years in the lowlands of Nepal. Disease spreader rows of a mixture of foliar blight susceptible wheat genotypes were seeded at both ends of each experimental plot. The spreader rows were not inoculated because air borne conidia of *C. sativus* are present since the last week of December under the Nepal lowland condition (Duveiller et al., 2005). Disease severity exceeded 90%

in susceptible genotypes in both years at both sites and leaf rust, when it occurred, was observed very late in the season with no effect on spot blotch severity assessment or yields. Weather conditions were optimal and yield potential was normal.

A combined analysis of variance was conducted using Genstat (2002) statistical software to determine genotypic differences and genotype × environment (location and year) interactions for various traits. The selected progeny lines were compared with their parents to determine their relative improvement in disease resistance and agronomic traits. The 20 selections were also compared with the leading commercial cultivars for disease resistance and agronomic performance.

Farmers' perception of the 30 wheat genotypes planted in the farmer's field was determined by using farmers' participatory appraisal methodology (Neupane & Sharma, 1994). A group of 21 men and 14 women farmers were first asked to make a list of traits they considered important for their preference of the wheat genotypes in the plots labeled 1–30. Each plot was labeled with genotype number without any name. The farmers were asked to do a comparative ranking of the traits on a scale of 1–10, with 10 being the most important. Finally, they were asked to score the wheat genotypes for individual traits on a scale of 1–10, with 10 being the most desirable. The farmers closely observed the four replications of each genotype before assigning a value. The score given to a trait was multiplied by the score given to the individual genotype for the same trait to determine its 'test value'. The 'test values' for all traits of a genotype were added to determine the total test value that was used in the farmers' preference ranking of the genotypes.

Results

Grain yields were high at both sites in both years due to optimal weather conditions. High spot blotch severity occurred in the experimental plots both at the experimental station and in the farmer's field, as reflected by >90% disease severity in the susceptible cultivar Sonalika at both sites in both years, while no other foliar diseases were present. In particular, the level of leaf rust remained negligible throughout the growing season in both years. Typical symptoms of spot blotch were noticeable on the spreader rows and susceptible cultivars as early as the 4th week of January before the wheat reached the heading stage. Disease symptoms were uniformly visible on all plants in a plot. Isolates of representative samples confirmed a high incidence of *C. sativus* conidia, observed on most diseased leaves.

There was a significant effect of year and location on all traits studied (Table 2). Year × location interaction was significant only for grain yield. The 30 wheat genotypes differed significantly for all traits. Genotype × year and genotype × location interactions were significant for grain yield, TKW and AUDPC. The third order interaction was non-significant for all traits.

Grain yields of the 20 progeny lines were higher than that of their parents and compared well with the highest yielding commercial cultivars used as standard checks at both locations in both years (Table 3). The

Table 2 Analysis of variance for various characteristics in 30 wheat genotypes evaluated under field conditions at two locations in the 2002 and 2003 wheat-growing seasons

		Mean squares				
Source	*df*	Grain yield ($\times 10^5$)	1000-kernel weight	AUDPC	Days to heading	Plant height
Year (Yr)	1	102.4**	1,059**	1,312,542**	210.3**	1272*
Location (Loc)	1	193.2**	1,382**	2,322,715**	227.9**	1334*
Yr × Loc	1	82.0*	61	423,184	42.4	631
Replication (Yr Loc)	12	15.5	39	147,527	18.1	246
Genotype (Geno)	29	34.7**	194**	418,231**	419.5**	1610**
Geno × Yr	29	10.2**	46**	47,522**	7.2	218
Geno × Loc	29	6.6**	37**	25,148**	6.4	197
Geno × Yr × Loc	29	1.9	11	2,913	5.5	161
Error	348	1.3	7	2,570	12.2	69

*,**Significant at 0.05, and 0.01 probability levels, respectively

highest grain yields of the progeny lines at Rampur and Janakpur were 4.1 (Sel. 12) and 4.9 (Sel. 14, 15) t ha^{-1}, respectively. The corresponding highest yields of the commercial checks were 4.2 (Gautam) and 5.0 (Gautam) t ha^{-1}. Similarly, the highest yields of the progeny lines were 4.2 (Sel. 15) and 4.6 (Sel. 14, 15) t ha^{-1} in 2002 and 2003, respectively. The highest grain-yielding check (Gautam) yielded 4.3 and 5.2 t ha^{-1} in 2002 and 2003, respectively.

The TKW of the progeny lines was higher than that of their parents and compared well with the commercial cultivars (Table 3). The highest TKW of the progeny lines at Rampur and Janakpur were 48.0 (Sel. 2) and 52.2 g (Sel. 14), respectively. The corresponding highest TKW of the checks were 48.4 (Nepal 297) and 51.6 g (Gautam). Similarly, the TKW of the progeny lines were 48.3 (Sel. 14) and 51.2 g (Sel. 2) in 2002 and 2003, respectively. Cultivar Gautam had the highest TKW among the commercial cultivars in 2002 and 2003 with 49.2 and 50.5 g, respectively.

The lowest AUDPC values for the progeny lines were 137 and 99 (Sel. 7) at Rampur and Janakpur, respectively (Table 3). The corresponding lowest AUDPC for the resistant cultivars at Rampur and Janakpur were 180 and 144 (SW89-5422), respectively. The lowest AUDPC for the progeny lines in 2002 and 2003 were 132 and 105 (Sel. 7), respectively. The corresponding lowest AUDPC for the resistant parents were 176 and 149 (SW 89-5422) in 2002 and 2003, respectively.

The number of days to heading for the progeny lines varied between 69 and 75 at the two locations, which compared well with the values for the early heading parent Sonalika (70 and 73 days) (Table 3). Plant height for the progeny lines ranged from 84 to 110 cm, compared with 84–111 cm for the parents and the commercial cultivars, respectively. The rank correlation coefficients between the two sites and between the two years were significantly positive for grain yield, TKW and AUDPC (Table 3).

Grain yield, kernel characteristics, maturity and healthy leaves were the traits that farmers considered important for a wheat genotype to be adopted. They ranked progeny lines high compared with several of the commercial cultivars (Table 3). However, in this study, the two commercial cultivars Gautam and BL1473 were ranked higher than the progeny lines, suggesting that the National Wheat Research Program in Nepal has a good understanding of farmers' needs and expectations. Gautam, which was released in 2004 in Nepal, was ranked 1st by the farmers. BL 1473 was ranked 2nd, despite its yields being a little lower than those of the highest yielding progeny lines; this was because of its high biomass yield (suitable as feed) and its earliness and high TKW. Selections 12, 14 and 16 were ranked 3rd, 4th, and 5th, respectively.

The five progeny lines for each of the crosses showed higher than average grain yield and TKW and lower AUDPC than both their parents at both sites in both years (Table 4). The average grain yield and TKW of the 20 progeny lines were comparable (97–102%) with the best commercial check cultivars. The average AUDPC of the progeny lines was 66–78% of the best check (Gautam) at both sites in both years.

Discussion

The 30 wheat genotypes differed significantly for all traits examined in the study, but the presence of significant genotype × year and genotype × location interactions for grain yield and TKW (Table 2) suggested that the genotypes' relative performance for these two traits differed over years and between locations. The presence of significant positive rank correlation coefficients between the two years and the two locations (Table 3) suggested that the 30 genotypes' relative rankings did not change significantly over years and between locations.

The progeny lines in each of the four crosses had higher grain yields and TKW than that of their parents (Table 3), indicating that the parental complementary genes contributing positively to these traits recombined in the progeny and produced transgressive segregates. Three of the highest grain yielding progeny lines (Sel. 12, 14, 15) resulted from a cross involving low yielding resistant G162 and susceptible Sonalika genotypes. Such a result is not generally expected in a normal selection for yield in wheat. This can result from a combination of rare high yield genes from the parents. The susceptible cultivar Sonalika could produce high yield under timely seeded condition and in the absence of foliar diseases in the Nepal lowlands (Sharma et al., 2004b; Duveiller et al., 2005). It is also possible that there could have been an error at the time of crossing when all resistant and susceptible genotypes were planted closely in the same crossing block. There could

Table 3 Mean values for various traits of 30 wheat genotypes in a study at two locations in Nepal in 2002 and 2003

Cultivar or selection	Genotype	Grain yield (t ha^{-1})				Thousand-kernel weight (g)				AUDPC (%-day)				Days to heading		Plant height (cm)		Farmers' preference rank[‡]
		Ramp[†]	Janak	2002	2003	Ramp	Janak	2002	2003	Ram	Janak	2002	2003	Ram	Janak	Ram	Janak	
1	(Chirya 7/ Sonalika)	4.0	4.5	4.0	4.4	45.2	51.0	46.4	49.9	206	126	184	149	70	74	97	106	7
2	(Chirya 7/ Sonalika)	3.9	4.3	3.9	4.2	48.0	51.1	47.9	51.2	203	139	194	148	69	72	100	111	3
3	(Chirya 7/ Sonalika)	3.4	4.6	3.9	4.1	47.2	51.4	48.2	50.4	249	172	235	186	71	73	98	107	6
4	(Chirya 7/ Sonalika)	3.7	3.8	3.6	3.9	44.9	47.7	45.0	47.7	248	171	233	186	69	71	99	108	22
5	(Chirya 7/ Sonalika)	4.0	4.6	4.1	4.5	47.2	49.4	47.3	49.3	220	161	213	169	71	73	94	104	9
6	(SW89-5422/ Sonalika)	3.4	3.8	3.5	3.7	42.0	43.1	41.6	43.5	184	178	201	161	72	74	98	110	25
7	(SW89-5422/ Sonalika)	3.7	4.7	4.0	4.4	45.1	49.3	46.1	48.3	137	99	132	105	71	74	89	100	12
8	(SW89-5422/ Sonalika)	3.4	3.7	3.5	3.7	47.2	50.1	47.4	49.9	155	136	161	130	69	74	95	106	15
9	(SW89-5422/ Sonalika)	3.8	4.2	3.8	4.1	45.1	47.7	45.2	47.6	154	127	157	125	70	73	94	101	13
10	SW89-5422/ Sonalika)	3.6	4.0	3.7	3.9	42.7	45.7	43.1	45.3	195	156	196	155	69	72	97	105	24
11	(G162/ Sonalika)	3.5	3.7	3.5	3.7	41.7	43.3	41.4	43.7	229	199	238	190	72	74	84	89	26
12	(G162/ Sonalika)	4.1	4.4	4.0	4.4	46.1	51.8	47.8	50.2	226	178	226	178	69	71	84	96	11
13	(G162/ Sonalika)	3.4	4.3	3.7	4.0	44.7	45.5	43.7	46.5	246	153	223	176	70	74	84	91	21
14	(G162/ Sonalika)	3.8	4.9	4.1	4.6	46.9	52.2	48.3	50.7	228	183	229	182	69	72	87	94	4
15	(G162/ Sonalika)	3.9	4.9	4.2	4.6	47.6	51.3	48.2	50.7	221	165	215	172	69	72	85	91	8
16	(Attila/ Sonalika)	3.7	4.2	3.8	4.1	43.9	47.1	44.5	46.5	236	155	218	173	72	75	89	92	5

(*Continued on next page*)

Table 3 (*Continued*)

Cultivar or selection	Genotype	Grain yield (t ha^{-1})				Thousand-kernel weight (g)				AUDPC (%-day)				Days to heading		Plant height (cm)		Farmers' preference rank[‡]
		Ramp[†]	Janak	2002	2003	Ramp	Janak	2002	2003	Ram	Janak	2002	2003	Ram	Janak	Ram	Janak	
17	(Attila/ Sonalika)	3.6	4.3	3.8	4.1	43.5	47.8	44.5	46.9	218	170	216	171	68	72	83	92	20
18	(Attila/ Sonalika)	3.6	4.7	4.0	4.4	45.5	50.2	46.6	49.2	246	183	241	189	70	74	85	90	9
19	(Attila/ Sonalika)	3.8	4.4	3.9	4.2	46.0	48.1	45.8	48.3	221	159	213	167	71	75	85	92	14
20	(Attila/ Sonalika)	3.5	4.3	3.8	4.1	43.1	46.6	43.6	46.1	244	172	234	182	71	73	86	93	19
Attila		2.9	3.5	3.1	3.3	33.5	34.2	33.2	34.6	254	205	246	213	86	88	85	93	28
Chirya 7		3.3	3.6	3.4	3.5	34.6	34.9	34.1	35.4	251	157	216	191	83	87	103	108	23
G162		2.1	2.5	2.3	2.3	35.0	35.6	34.7	35.9	259	190	236	213	84	89	84	95	30
SW89-5422		3.1	3.1	3.0	3.2	32.8	36.7	33.8	35.7	180	144	176	149	83	86	97	100	29
BL1473		3.9	4.4	4.1	4.3	48.0	49.8	48.3	49.5	889	802	958	734	70	72	104	111	2
Gautam		4.2	5.0	4.4	4.8	48.0	51.6	49.2	50.5	511	437	539	409	73	77	101	109	1
Bhrikuti		3.6	4.3	3.9	4.1	42.5	44.4	42.6	44.3	598	502	627	473	76	79	89	100	16
Kanchan		2.8	3.7	3.2	3.4	43.4	44.8	43.1	45.1	999	917	1104	811	71	73	102	108	18
Nepal 297		2.4	3.2	2.8	2.8	48.4	50.8	49.0	50.3	1051	919	1123	848	71	71	100	107	17
Sonalika		1.8	2.0	1.8	2.0	39.5	42.6	39.7	42.4	1361	1234	1489	1106	70	73	102	109	27
	Mean	3.5	4.0	3.6	3.9	43.6	46.5	44.0	46.2	354	290	362	281	72	75	93	101	
	$LSD_{0.05}$	0.3	0.3	0.2	0.3	1.8	1.6	1.8	2.1	49	51	62	47	2	3	5	4	
Rank correlation (£)		0.779**		0.984**		0.908**		0.969**		0.822**		0.971**						

**Significantly different from 0 at $P = 0.01$. [†]Ramp: Rampur, Janak: Janakpur

[‡]Overall preference rank by the farmers. Sel.: Selection (details of selection given in Table 1). £ Rank correlation coefficient between two locations or two years for the same trait

Table 4 Comparison of average values of the progeny lines with their parents for grain yield, thousand-kernel weight and area under disease progress curve (AUDPC) in four wheat crosses evaluated at two locations in the 2002 and 2003 wheat-growing seasons in Nepal

Cross	Grain yield				Thousand-kernel weight				AUDPC			
	Ramp[†]	Janak	2002	2003	Ramp	Janak	2002	2003	Ramp	Janak	2002	2003
Cross: Chirya 7/Sonalika												
Average improvement in progeny over Chirya 7 (%)	11	19	18	23	32	43	37	44	−4	2	−16	−6
Average improvement in progeny over Sonalika (%)	111	125	110	118	18	18	18	17	−84	−88	−83	−87
Cross: SW89-5422/Sonalika												
Average improvement in progeny over SW89-5422 (%)	16	30	17	30	35	30	36	28	−7	−1	−11	−7
Average improvement in progeny over Sonalika (%)	99	114	96	103	13	12	12	10	−88	−89	−88	−88
Cross: G162 × Sonalika												
Average improvement in progeny over G162 (%)	61	74	94	82	28	37	32	37	−6	−2	−17	−14
Average improvement in progeny over Sonalika (%)	106	131	109	121	15	16	15	14	−83	−86	−83	−85
Cross: Attila × Sonalika												
Average improvement in progeny over Attila (%)	26	26	28	27	31	40	34	40	−3	−16	−14	−21
Average improvement in progeny over Sonalika (%)	103	127	103	119	13	13	12	12	−83	−87	−83	−86
Best value among progeny (% of best among checks)	98	100	100	98	97	100	101	102	78	70	74	66

[†]Ramp: Rampur, Janak: Janakpur

be a remote chance of seed mixture as well. The above error might occur despite all the precautions taken during crossing and handling of large number of progenies in a breeding program.

Several progeny lines showed lower disease severity than the resistant parents, indicating either that the susceptible cultivar Sonalika possessed minor resistance genes, or that the genes for wide adaptation in Sonalika transmitted some level of tolerance to the progeny. This finding supports previous results recorded by Sharma et al. (1997b) and Pandey-Chhetri (2004) who found that foliar blight susceptible local cultivars did possess some level of tolerance to *C. sativus*. Days to heading and plant height of the progeny lines were comparable with their parents, illustrating that previous selection had led to genetic improvement in these agronomic traits in the selected progenies.

Farmers ranked a number of progeny lines high according to their preference criteria, suggesting that the selection technique used in the study by Sharma and Duveiller (2003) combined with the current study identified lines with very good adoption prospects. However, red kernels and some variation in plant height appeared undesirable traits in a number of the selected lines with resistance to spot blotch. While the farmers in the region prefer amber kernels, most of the progeny lines had red kernels that came from spot blotch resistant exotic parents. A few farmers did not like the bronze color of the chaff in the selection that came from Sonalika. These findings on farmers' preferences suggest that color of the chaff and kernel should also be considered in the early segregating generation while selecting for spot blotch resistance. These two traits are successfully selected by the most wheat breeders in the region as evident in most commercial cultivars.

Considering that only a few reports (Sharma et al., 1997a; Sharma & Bhatta, 1999; Joshi et al., 2002) have suggested the possibility of improving wheat resistance to foliar blight caused by *C. sativus* at the same time as kernel weight and maturity, the present study is significant because it is the first comprehensive research effort undertaken to select for grain yield *per se* after using a simple selection index in the early generation (Sharma & Duveiller, 2003). In addition, farmers' selection criteria were applied to validate the desirability of new wheat genotypes obtained by scientists using a new empirical selection index. This applied study was conducted over two wheat seasons at two sites, including a farmer's field in the eastern Indo-Gangetic Plains of South Asia where high grain yielding and early maturing wheat cultivars more resistant to spot blotch are urgently needed. It was carried out under natural conditions in a region where foliar blight is a major constraint and where wheat, a key food crop for millions of resource poor small farmers, is grown under a rice-wheat cropping sequence (Duveiller, 2004).

This study shows successful selection of high yielding wheat genotypes that also possess resistance to foliar blight, early maturity, high kernel weight and satisfactory plant height for the non-traditional warm wheat growing regions of South Asia. The development of such cultivars with higher productivity has not been as successful as hoped in the past 15 years of breeding efforts, primarily because of the lack of a suitable selection technique that would allow the combination of the above traits in early generation (Dubin & Rajaram, 1996; van Ginkel & Rajaram, 1998).

An earlier breeding plan for spot blotch resistance by van Ginkel and Rajaram (1998) suggested that selection for spot blotch should be strict and delayed to the later generation, taking into account many minor genes with small additive effects conditioning resistance. However, the recent studies suggest that that mainly one to three dominant or recessive genes control spot blotch resistance in the warm environment of South Asia (Sharma & Bhatta, 1999; Bhushan et al., 2002; Joshi et al., 2004; Ragiba et al., 2004). Since resistance to spot blotch has a high heritability (Sharma et al., 1997b; Bhushan et al., 2002; Joshi et al., 2004) and is negatively correlated with days to heading and kernel weight, early generation relaxed selection pressure should be used to identify superior lines with a combination of the above traits (Sharma & Duveiller, 2003), followed by strict selection for high yield among the superior lines. This selection approach could serve as a guideline for targeted breeding for genotypes with high grain yield that are suitable for the warm wheat-growing conditions in the eastern Indo-Gangetic Plains of South Asia where spot blotch and high night temperatures during the grain-filling period are serious perennial threats to successful wheat production in the rice-wheat cropping system. This constraint of biotic and abiotic stresses was shown again in March 2004 when overall wheat yield performance fell below expectations in the Indian Subcontinent (Farooqi, 2004).

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