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FIELD RESISTANCE TO SPOT BLOTCH IS NOT ASSOCIATED WITH UNDESIRABLE PHYSIO-MORPHOLOGICAL TRAITS IN THREE SPRING WHEAT POPULATIONS

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SUMMARY

Spot blotch, caused by *Cochliobolus sativus* (Ito and Kurbayzshi) Drechsler ex Dastur is a serious constraint to production of wheat (*Triticum aestivum* L.) in tropical and sub-tropical environments. Previous efforts to develop genotypes with high levels of resistance combined with other desirable agronomic features have been unsuccessful. This failure was assumed to be largely due to the association of undesirable characters with heightened resistance but information on the existence of such associations is limited. Recently, high levels of resistance have been reported in CIMMYT synthetic wheat genotypes. Our study was done on three populations derived from the spot blotch resistant genotypes 'Milan/Shanghai #7', 'Chirya. 3' and 'NL 971' crossed with the susceptible commercial cultivar 'BL1473'. Fifteen different physio-morphological traits and areas under disease progress curves (AUDPC) were evaluated in F_2 and F_3 generations during 2005-2006 at Rampur (Chitwan, Nepal). The majority of traits showed weak negative significant or non-significant genetic and phenotypic correlation with AUDPC except Area Under SPAD (soil plant analysis development) decline curve (AUSDC) and flag leaf duration Results showed no undesirable genetic association of resistance with physio-morphological characters, and thus independent selection for individual traits is possible. In addition, AUSDC and flag leaf duration have potential application as complementary traits in selecting for high resistance.

Key words: Bipolaris sorokinina, *Cochliobolus sativus*, plant ideotype, trait association, physiological traits.

INTRODUCTION

In the last two decades spot blotch of wheat (*Triticum aestivum* L.), caused by *Cochliobolus sativus* (Ito and Kurbayzshi) Drechsler ex Dastur, also called Helminthosporium leaf blight (HLB) or foliar blight, has been an important disease in warmer wheat-growing regions, affecting livelihood of millions of small farmers (Alam *et al.*, 1994; Dubin and van Ginkel, 1991; Duveiller and Gilchrist, 1994; Duveiller *et al.*, 1998; Lapis, 1985; Sharma *et al.*, 2003). Spot blotch causes substantial yield loss (20-100%) by blighting the leaves and inducing premature senescence (Duveiller and Gilchrist, 1994; Meheta, 1998). Development of resistant wheat cultivars has been identified as the best option to help millions of subsistence farmers residing in the South Asian Gangetic plains, where the cost of fungicides is prohibitive. Currently grown cultivars in this region have low level of resistance (Sharma and Duveiller, 2006).

The best leaf blight-resistant wheats in South Asia were reported to be late and tall, two less desirable agronomic characters (Dubin *et al.*, 1998) and breeders doubted the possibility to develop early maturing resistant genotypes. During the last decade, breeders' efforts to develop genotypes with high levels of resistance and desirable agronomic traits were largely unsuccessful. Studies were made to elucidate relationships of disease severity with different agronomic features. Studies reported less spot blotch resistance in short plants with early maturity (Dubin *et al.*, 1998; Sharma *et al.*, 1997a, 1997b). Negative correlations were also observed between spot blotch resistance and different agronomic traits such as grain yield (Gilchrist and Pfeiffer, 1991; Sharma *et al.*, 1997a), thousand kernel weight (Sharma *et al.*, 1997a), biomass yield (Sharma *et al.*, 1997a), harvest index (Sharma *et al.*, 1997a) and grain fill duration (Gilchrist and Pfeiffer, 1991). However, some recent studies show no or weak association between these agronomic traits (Sharma *et al.*, 2006; Joshi *et al.*, 2002).

Recently new synthetic hexaploid wheats resistant to the disease have been identified in South Asian breeding programs (Duveiller and Sharma, 2005; Duveiller *et al.*, 2005; Siddique *et al.*, 2006). These synthetic wheats are obtained by crossing tetraploid wheat with *Aegilops tauschii* Coss. and are known for their high physiological profile, although performance during the process of introgression is largely unknown (Del Blanco *et al.*, 2000). Unfortunately, promising spot blotch resistant genotypes identified so far have some undesirable agro-

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nomic features (Sharma and Duveiller, 2007). Although the introgression of the resistance genes into local commercial cultivars is underway, consequences could be positive and negative. For instance, positive consequences could be an increase of physiological efficiency (contributing to increased abiotic stress tolerance), in addition to improved spot blotch resistance. Negative consequences could include failure to develop desirable genotypes due to undesirable associations and residual effects of "wild" genes. Therefore, the interrelationship of different physio-morphological traits and spot blotch resistance in such populations needs to be studied.

Physiological traits have caught the attention of breeders due to limitations of conventional yield-based selections, particularly for stressed environments (Reynolds *et al.*, 2001). Application of such traits in addition to conventionally measured traits such as grain yield and disease resistance might be useful to develop high performing genotypes. Thus, evaluation of such traits might help in the better understanding of physiological processes, the development of suitable selection strategies, and the identification of traits for an indirect selection process.

Association of different physio-morphological traits with spot blotch resistance is not well elucidated. Erect leaf posture was shown to reduce spot blotch incidence in wheat (Joshi and Chand, 2002). Differences among resistant and susceptible genotypes for chlorophyll decline measurements as well as flag leaf anatomy have been observed (Rosyara *et al.*, 2007). A positive correlation between the stay-green trait and HLB severity has been found (Rosyara *et al.*, 2007; Joshi *et al.*, 2007). Our study examines the genetic association of different physio-morphological traits and spot blotch resistance in populations derived from new CIMMYT resistant genotypes.

MATERIALS AND METHODS

Three resistant genotypes; 'Milan/Shanghai #7' (pedigree: VS73.600/MIRLO/3/BOW//YE/TRF/4/Shanghai #7), 'Chirya.3' (pedigree: CS/*Thcu*//Vee/3/Ald/Pvn/4/Ningmai No.4/Oleson//Ald/Yangmai No. 4), and 'NL 971' (pedigree: Mrng/Buc//Blo/Pvn/3/Pjb 81) were crossed with the susceptible genotype 'BL1473' (pedigree: Nepal 297/NL531). BL 1473 is an early-maturing, spot-blotch-susceptible commercial cultivar from Nepal (Sharma *et al.*, 2004) whereas the other three genotypes are late maturing, spot-blotch resistant CIMMYT lines (Duveiller and Sharma, 2005; Sharma and Duveiller, 2007; Sharma *et al.*, 2004, 2007). These three genotypes are known for their stable and high levels of resistance.

Crosses were made in the 2003 wheat-growing main season (November to March) at Rampur (Chitwan, Nepal, 27°40'N and 84°19'E at 228 metres above sea level). The F_1 plants were grown in an off-season, high-altitude field nursery in 2004 (June to October) at Marpha, (Nepal, 28°43'N and 83°15'E, at 2,900 meters in the Himalaya) to produce the F_2 seed. F_2 and F_3 generations were evaluated at Rampur during 2005-2006 (Table 1). Relative humidity in Rampur is usually higher than elsewhere in the lowlands of Nepal, known as the Tarai. This favors early onset of spot blotch epidemics, with the first lesions (1 to 4 mm) already visible about 4-5 weeks after sowing. During the past several years, spot blotch has been severe on wheat at this site.

Table 1. Size of F_2 and F_3 populations evaluated at Rampur, Chitwan, Nepal with objective of studying association of physio-morphological traits with spot blotch resistance during 2005-2006.

Parent/Population	F_2	F_3
BL 1473	60	60
MS 7	60	60
Chirya.3	60	60
NL 971	60	60
BL 1473 x Milan/Shanghai #7	174	216
BL 1473 x Chirya.3	211	216
BL 1473 x NL 971	206	177

The F_2 seeds were planted (seed to seed distance of 0.20 m and row to row distance of 0.25 m) in rows 4 m long. The parents of particular crosses were planted at regular intervals after every 40 progeny plants. One spike per plant was harvested from all F_2 plants. The seeds of each spike were planted in a separate of 1 m length (known as head row). The spacing between two head rows was 0.25 m. The parents of the particular populations were planted after every 20 progeny rows. Both F_2 and F_3 generations were grown in three replicated randomized complete block designs. Sonalika (most susceptible genotype for spot blotch) was grown as spreader rows around and in between the blocks to give uniform natural inoculum pressure The F_2 generation was sown on 26 November 2005, and the F_3 on 27 November 2006.

Fertilizers were applied at 120 Kg N, 60 Kg P_2O_5, and 40 Kg K_2O per hectare. Split application of nitrogen was done. Hundred kilograms of nitrogen was broadcasted as basal dose whereas the remaining 20 Kg was top-dressed at active tillering stage. Plots were weeded by hand. The trials were managed under natural disease infection; no supplementary artificial inoculation was required due to high and uniform natural inoculum pressure. The experimental field had no residue from the previous wheat crop. The field remained submerged in floodwater for several weeks in August and September in both years, which is a typical situation in the rice growing lowlands of Nepal.

Disease progress and physio-morphological traits were measured in F_2 individual plants or five randomly selected plants per F_3 head rows. Main tillers of five plants (randomly selected) were tagged and measurements were done on these. Spot blotch disease scoring was started when the flag leaf of susceptible genotypes had more than 25% diseased leaf area. Three disease readings (percentage of diseased leaf area on flag leaf) were made at 5 to 7 day intervals. The disease readings were used to calculate the Area Under Disease Progress Curve (AUDPC) using the following formula (Das *et al.*, 1992).

$$\text{AUDPC} = \sum_{i=1}^{n-1} \left[\left(\frac{X_{(i+1)} + X_i}{2}\right)\right] (T_{(i+1)} - T_i)$$

Where

X_i = Disease severity on the i^{th} date

T_i = Date on which the disease was scored

n = number of dates on which disease was recorded

A Minolta Chlorophyll Meter (Model: SPAD-502) was used for non-destructive measurement of flag leaf chlorophyll content (Rosyara *et al.*, 2007). The chlorophyll content was recorded in Minolta company-defined SPAD values. Single F_2 individual plants or the five plants (same plants used for disease and other physio-morphological measurements) in every F_3 head rows were used for the measurements. In each flag leaf, five measurements were taken at different positions (starting from tip to base) and averaged (Rosyara *et al.*, 2007). The chlorophyll content measurements were repeated three times following disease observations (within 1-2 days of these) and the readings were used to calculate the AUSDC using the following formula (Rosyara *et al.*, 2007).

$$\text{AUSDC} = \sum_{i=1}^{n-1} \left[\left(\frac{S_{(i+1)} + S_i}{2}\right)\right] (T_{(i+1)} - T_i)$$

Where

S_i = SPAD value on the i^{th} date

T_i = i^{th} day

n = number of dates of recording SPAD value

Days to flag leaf emergence were recorded when more than 90% of the plant tillers in each entry (F_2 individual plants or F_3 head rows) had a flag leaf completely emerged i.e. completely opened or unfolded. Similarly flag leaf death was scored when 90% of the tillers in each entry were completely dead. Flag leaf duration was calculated as number of days from emergence to death. Each entry was considered headed when 90% of the shoots had the entire spike emerged from the flag leaf. Days to anthesis was recorded when 90% of the shoots had the entire spike going to anthesis. Days to peduncle drying was recorded when 90% tillers had peduncles dried. Days to maturity (DM) was recorded when 90% of tillers had matured glumes (green colour completely lost).

Flag leaf angle was measured with a protractor just after ear emergence. Flag leaf length (from ligule to leaf tip) was measured after five weeks of heading. Flag leaf width was measured at tip (2 cm from top), centre (exact centre), and base (2 cm from base) and averaged. Plant height (from ground level to the tip of the spikes) was measured at physiological maturity. Peduncle length (from flag leaf ligule to spike base) and last internode length (from flag leaf ligule to penultimate leaf ligule) were measured five weeks after heading. Spike length (from spike base to tip, excluding awns) was measured at maturity. Spikes were threshed individually and grains were counted to calculate number of grains per spike. One hundred kernels were randomly selected, counted and weighed to record the hundred-kernel weight (HKW).

Frequency distribution and phenotypic correlation were calculated using the SAS (1990) software. Similarly, genetic correlation was calculated using parent and offspring covariances as outlined by Sexton (2004) using the SAS (1990) software. Transgressive segregates were defined as those progeny lines having mean disease severities greater than one standard deviation below or above individual parental means.

RESULTS

Leaf blight severity was very high during the study period, as shown by AUDPC of susceptible genotype BL 1473 (Table 2). Spot blotch was observed as early as the third week of February, after the heading stage. Disease symptoms (oval to elongated light brown to dark brown blotches) were uniformly visible on all plants. Toward maturity, disease severity on the susceptible parent reached 100% but was below 25% on the resistant parents. Isolates from representative diseased leaf samples showed conidia of *C. sativus* on the lesions. No other diseases than spot blotch were evident during the study period. Weather conditions were optimal for wheat cultivation in 2005 but rainfall was inadequate during 2006. The effect of the dry spell was minimized by increased irrigation.

In all populations, the frequency distribution of AUDPC values showed a negative skew indicating the dominance of resistance over susceptibility (Fig. 1). NL971 had slightly higher AUDPC compared to other resistant parents. Transgressive segregants were observed for AUDPC (Fig. 1). There were contrasting differences among resistant and susceptible parents for physio-morphological traits (Table 2). Means and standard deviations for physio-morphological traits are presented in Table 3.

Table 2. Mean values for physio-morphological traits and spot blotch progress of parents included in the association study done at Rampur, Chitwan, Nepal during 2005-2006.

Traits	BL 1473	Milan/Shanghai #7	Chirya.3	NL 971
Area Under Disease Progress Curve	621	120	121	338
Plant Architectural Traits				
Plant height (cm)	70	88	83	80
Peduncle length (cm)	23	16	13	12
Last internode length (cm)	43	37	32	34
Flag leaf length (cm)	16	22	23	23
Flag leaf width (mm)	14.0	15.8	16.3	15.5
Spike length (cm)	8.0	10.0	7.7	9.0
Grains per spike	38	55	41	34
Hundred Kernel Weight (gram)	3.8	4.1	4.5	4.5
Flag leaf angle (°)	113	104	60	107
Physiological Traits				
Chlorophyll content at anthesis	42	44	45	43
Area Under SPAD decline curve	441	723	724	683
Flag leaf duration (days)	39	51	52	46
Days to heading	72	82	83	82
Days to anthesis	74	84	84	83
Days to maturity	114	125	126	124
Days to peduncle dryness	116	127	128	128

Table 3. Mean values (standard deviations in parenthesis) for F_2 and F_3 populations for physio-morphological traits and spot blotch progress in the study done at Rampur, Chitwan, Nepal during 2005-2006.

Traits	BL 1473/ MS-7 (F_2)	BL 1473/ MS-7 (F_3)	BL 1473/ Chirya3 (F_2)	BL 1473/ Chirya3 (F_3)	BL 1473/ NL971 (F_2)	BL 1473/ NL971 (F_3)
Area Under Disease Progress Curve	326 (129)	267 (96)	340 (140)	283 (115)	415 (144)	385 (125)
Plant Architectural Traits						
Plant height (cm)	84 (11)	95 (11)	77(19)	88 (8)	79(15)	93 (14)
Peduncle length (cm)	20.3 (4.5)	23.9 (6.0)	17.1 (3.5)	20.2 (3.3)	17.7(6.8)	23.3 (6.3)
Flag leaf length (cm)	20.0 (3.5)	23.9 (6.0)	19.4 (3.5)	20.2 (3.3)	20.3 (3.9)	23.3 (6.3)
Flag leaf width (mm)	14.6 (2.1)	14.1 (1.3)	15.1 (2.2)	14.9 (1.3)	15.5 (2.1)	15.2 (1.5)
Spike length (cm)	11.7 (1.3)	9.7 (1.1)	10.0 (1.5)	8.4 (0.9)	10.4 (1.3)	8.0 (0.9)
Grains per spike	36.5 (8.9)	33.1 (6.1)	34.8 (6.7)	32.5 (5.7)	32.6 (6.8)	34.2 (5.6)
Hundred kernel weight (g)	3.24 (0.7)	3.37 (0.6)	3.35 (0.67)	3.54 (0.54)	3.37 (0.82)	3.77 (0.70)
Flag leaf angle (°)	114 (30)	104 (25)	108 (30)	89 (24)	108 (28)	89 (26)
Physiological Traits						
Chlorophyll content at anthesis (SPAD value)	44.2 (3.6)	39.3 (2.6)	44.2 (4.1)	40.0 (2.9)	43.2 (4.8)	39.0 (2.6)
Area Under SPAD decline curve	326 (129)	267 (96)	340 (140)	283 (115)	415 (144)	385 (125)
Flag leaf duration (days)	37.4 (4.2)	43.8 (4.2)	37.4 (4.8)	43.4 (4.6)	34.5 (4.0)	40.7 (4.5)
Days to heading	78 (4)	77 (4)	78 (3)	76 (3)	78 (4)	77 (4)
Days to anthesis	80 (4)	80 (4)	80 (3)	80 (3)	79 (4)	79 (4)
Days to maturity	120 (4)	120 (5)	119 (4)	119 (3)	118 (4)	119 (4)
Days to peduncle dryness	121 (5)	122 (6)	120 (4)	120 (4)	120 (5)	122 (5)

The majority of ‘plant architecture’-related traits showed very low (positive or negative), non-significant ($p>0.05$) genotypic and phenotypic correlation with spot blotch severity (Table 4). Peduncle length, last internode length, flag leaf angle, flag leaf width, spike length, and grain per spike showed non-significant

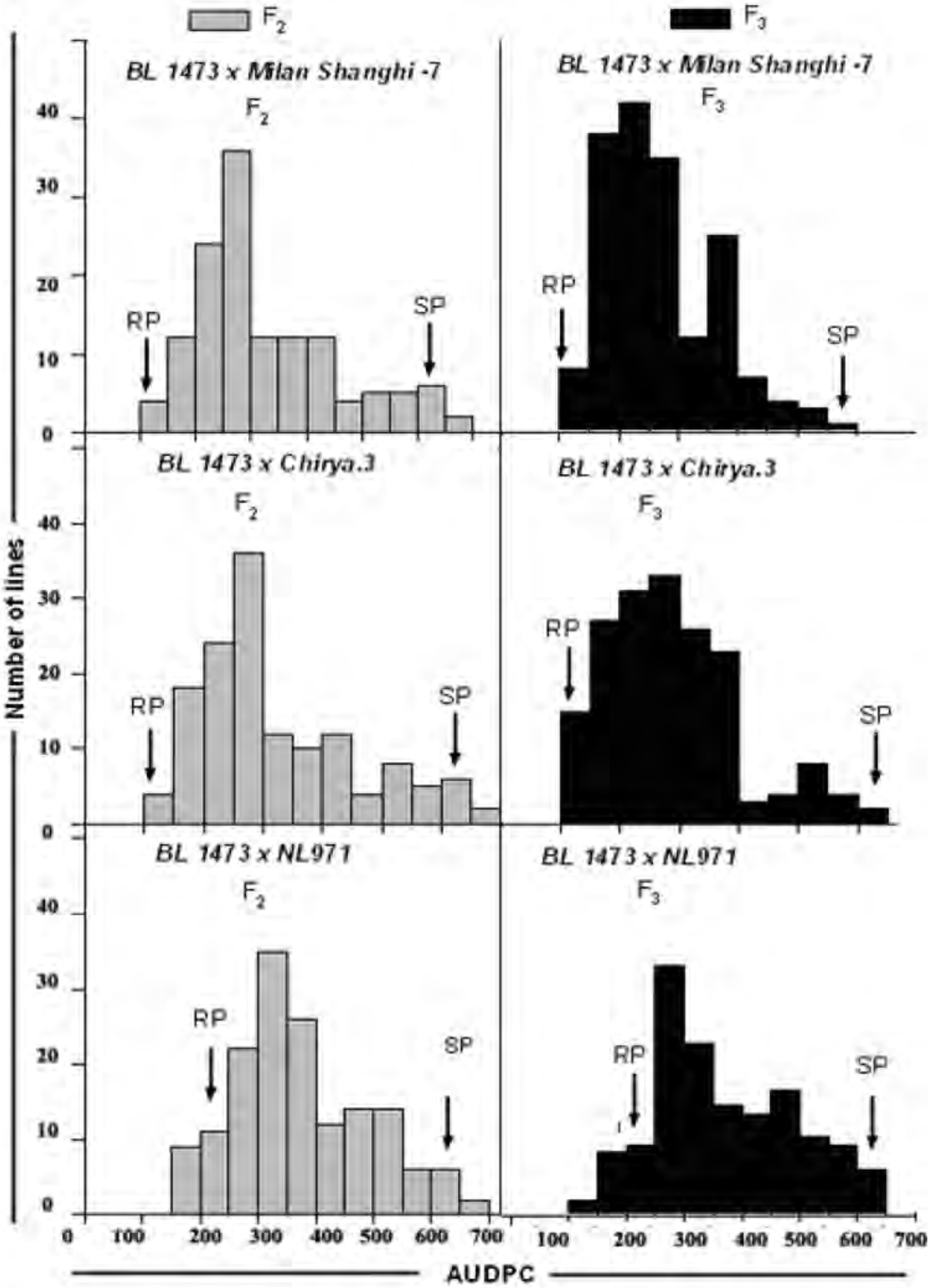

Fig. 1. Frequency distribution for Area Under Disease Progress Curve (AUDPC) in spring wheat populations evaluated at Rampur, Chitwan, Nepal during 2005-2006. Abbreviations: RP, resistant parent; SP, susceptible parent.

($p>0.05$) genetic and phenotypic correlation with AUDPC (Table 4). Phenotypic correlation between plant height and AUDPC was moderately negative and significant ($p<0.05$). The genetic correlation between these two traits was mostly non-significant ($p>0.05$).

Phenotypic and genetic correlation between chlorophyll content at anthesis and AUDPC was low and negative. In contrast, AUSDC (a measure of chlorophyll decline after anthesis) showed strong phenotypic and genetic negative correlation with AUDPC (Table 5, Fig. 2). Flag leaf duration was negatively correlated with AUDPC and showed that resistant genotypes have longer flag leaf life than susceptible genotypes (Table 5, Fig. 2). The AUDPC showed weakly significant ($p<0.05$) negative correlation with maturity-related traits including days to heading, anthesis, maturity, and peduncle dryness. Also, hundred-kernel weight showed a weak negative correlation with AUDPC (Table 4, Fig. 2). The genetic correlation between HKW and AUDPC was higher than phenotypic correlation. Transgressive segregants were observed for all traits studied and showed possibility to find desirable variants.

Table 4. Phenotypic and genetic correlation between AUDPC and plant architecture related traits in spring wheat populations evaluated Rampur, Chitwan, Nepal during 2005-2006.

Cross	Gen	PHT (cm)	PDL (cm)	LIL (cm)	FLL (cm)	FLA (°)	FLW (cm)	SPL (cm)	GPS	HKW (g)
Phenotypic correlation										
BL 1473 x MS 7	F_2	-.42[a]	ns[b]	-.22	-.35	-.34	-.38	-.33	ns	-.34
BL 1473 x MS 7	F_3	-.20	ns	ns	-.37	-.19	-.21	-.19	ns	ns
BL 1473 x Chirya 3	F_2	-.43	ns	.26	-.47	-.28	-.35	-.41	-.24	-.37
BL 1473 x Chirya.3	F_3	-.37	ns	ns	-.20	-.23	ns	ns	ns	-.32
BL 1473xNL 971	F_2	-.30	ns	-.17	-.50	ns	-.41	-.36	-.23	-.41
BL 1473xNL 971	F_3	-.29	ns	ns	-.39	-.ns	-.28	-.27	ns	-.45
Genetic correlation										
BL 1473 x MS 7	-	ns	ns	-.25	ns	-.23	-.36	-.21	ns	-.43
BL 1473 x Chirya.3	-	ns	ns	.30	-.25	-.28	-.25	-.22	ns	-.42
BL 1473xNL 971	-	-.22	ns	ns	-.23	-.22	-.23	ns	ns	-.45

Abbreviations: Gen- generations, PHT -plant height, PDL – peduncle length, LIL – last internode length, FLL – flag leaf length, FLA – flag leaf angle, FLW- flag leaf width, SPL – spike length, GPS – grains per spike, HKW – hundred kernel weight, AUDPC – area under disease progress curve, MS 7 – Milan/Shanghai # 7

[a] only significant ($p < 0.05$) have been shown.

[b] ns = $p > 0.05$

DISCUSSION

The study confirms that genotypes 'Milan/Shangahi #7', 'Chirya.3' and 'NL 971' are highly resistant to spot blotch. Previously 'Milan/Shanghai #7' and 'Chirya.3' were reported to have two non-allelic dominant resistant genes (Neupane *et al.*, 2007). Although none of these genotypes were reported as immune, they have low disease progress when compared to susceptible genotypes. These genotypes have both desirable (for example: high chlorophyll content at anthesis, high AUSDC and low AUDPC) and undesirable traits (for example: late maturity and tall plant height) for breeding purpose (Table 2).

In recent years, synthetic hexaploid wheats [derived from so-called "wide" crosses between a *Triticum turgidum* var. *durum* (Desf.) Husnot and *Triticum tauschii* (Coss.) Schmal] are identified as important resistance source to spot blotch resistance (Sharma and Duveiller, 2007; Sharma *et al.*, 2004). Such synthetic hexaploids have proven to be a useful source for resistance or tolerance to other biotic and abiotic stresses (Gorham, 1990; Limin and Fowler, 1993). Synthetic hexaploids are routinely crossed and backcrossed with common hexaploid wheat to achieve desirable agronomic traits. Wild ancestors of common wheat

Table 5. Phenotypic and genetic correlation between AUDPC and physiological traits in spring wheat populations evaluated at Rampur, Chitwan, Nepal during 2005-2006.

Trait	Gen	CCA (SPAD value)	AUSDC	FLD (days)	DH	DA	DM	DPD
Phenotypic correlation								
BL 1473 x MS 7	F_2	-.39[a]	-.61	-.45	-.27	-.30	-.41	-.37
	F_3	-.26	-.71	-.56	-.45	-.44	-.53	-.42
BL 1473 x Chirya.3	F_2	-.61	-.79	-.58	-.36	-.38	-.32	-.29
	F_3	-.19	-.71	-.54	-.25	-.25	-.26	-.27
BL 1473 x NL 971	F_2	-.57	-.68	-.47	-.36	-.35	-.40	-.34
	F_3	-.21	-.69	-.48	-.42	-.41	-.53	-.35
Genetic correlation								
BL 1473 x MS 7	-	-.19	-.72	-.65	ns[b]	-.18	-.21	-.27
BL 1473 x Chirya.3	-	-.24	-.81	-.69	ns	-.19	ns	ns
BL 1473 x NL 971	-	-.27	-.88	-.56	-.19	ns	-.31	-.24

Abbreviations: Gen, generation; CCA, chlorophyll content at anthesis; AUSDC, area under SPAD decline curve; FLD, flag leaf duration; DH, days to heading; DA, days to anthesis; DM, days to maturity; DPD, days to peduncle dryness; AUDPC, area under disease progress curve; MS 7, Milan/Shanghai # 7

[a] only significant ($p<0.05$) are shown.

[b] ns = $p>0.05$.

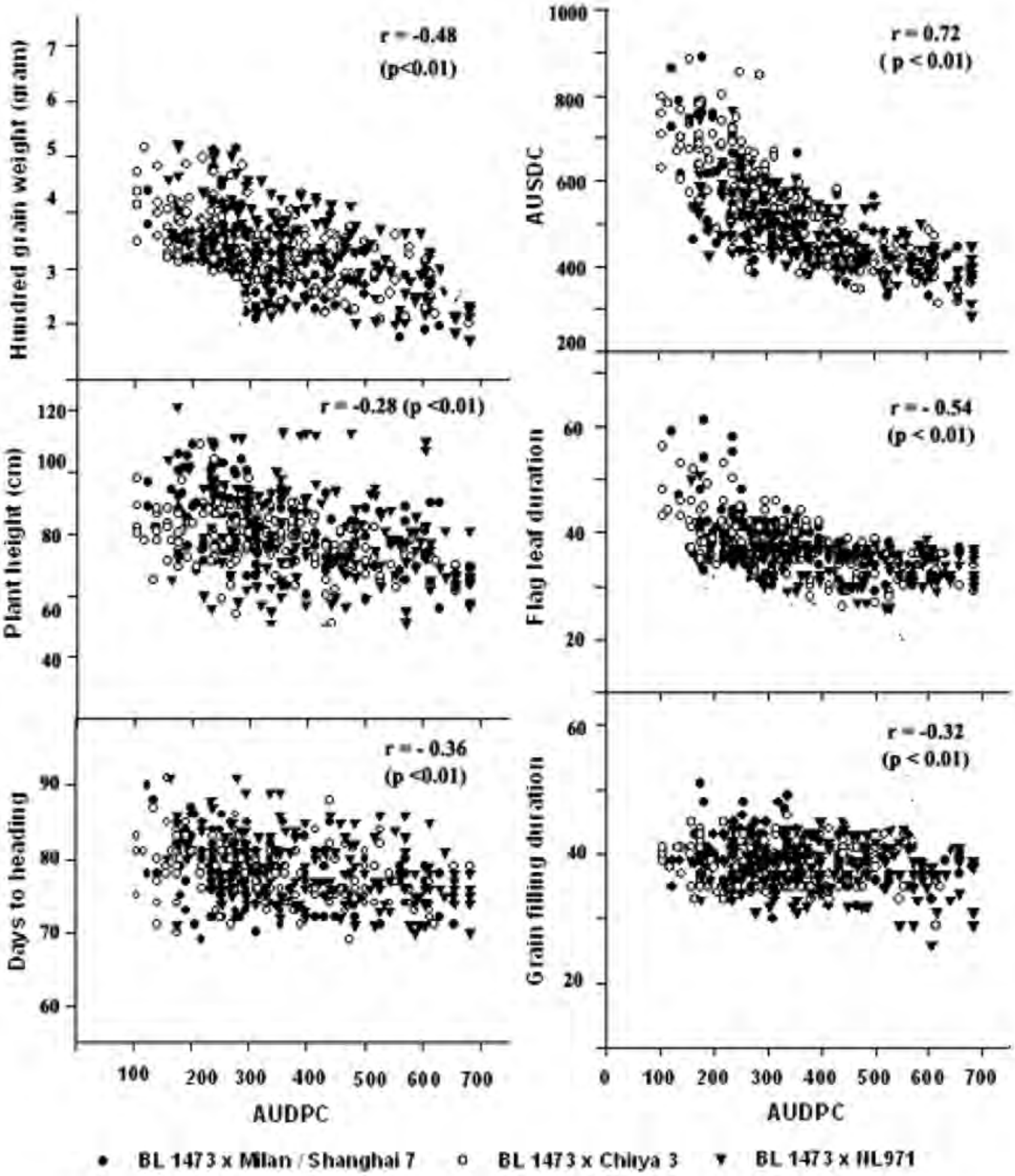

Fig. 2. Phenotypic correlation between AUDPC and physio-morphological traits in spring wheat cross populations evaluated at Rampur, Chitwan, Nepal during 2005-2006. Abbreviations: r = Pearson's linear phenotypic correlation coefficient; AUDPC= Area Under Disease Progress Curve, AUSDC = Area Under SPAD decline curve.

(*Triticum aestivum* L.) and synthetic wheats are reported to have higher photosynthetic rates compared to modern wheat cultivars (Austin *et al.*, 1989; Carver and Nevo, 1990; del Blanco *et al.*, 2000). Nevertheless, using an alien source in a breeding program can have uninvited consequences by co-transfer of undesirable traits (Knott and Dvorak, 1976). Fortunately, the resistant genotypes showed no undesirable associations with the physio-morphological traits examined.

Plant type traits showed weak correlation with leaf blight resistance in all populations and generations studied (Table 4). Among the plant type traits, plant height is one of the most important traits to wheat breeders. The results showed weak negative association between spot blotch resistance and plant height, consistent with Sharma *et al.* (2006). Studies in the past reported a negative association between these two traits (Gilchrist *et al.*, 1992; Sharma *et al.*, 1997b; Dubin *et al.*, 1998). Such differences could be due to the difference in resistance source and parents involved. This study supports the view that it is possible to develop dwarf and resistant genotypes. In contrast to Joshi and

Chand (2002), flag leaf angle measurements were weakly correlated with AUDPC in all populations studied.

Our study showed weak negative correlation between AUDPC and maturity-related traits (Sharma *et al.*, 2006; Sharma and Bhatta, 1999). Previously, a negative correlation had been observed between these two traits (Dubin *et al.*, 1998; Mahto, 2001). Such association between spot blotch severity and maturity is most likely due to high temperatures and occasional hot winds during the late grain filling period. At temperatures above 28ºC late resistant genotypes often develop severe disease symptoms (Nema and Joshi, 1973; da Luz and Bergstrom, 1986). In fact, the effect of heat stress can not be separated from spot blotch disease at this stage. In this study, both early maturing resistant genotypes and late maturing susceptible genotypes (recombinant genotypes) were observed. The results further support possibility to develop early maturing resistant genotype(s).

The phenotypic correlation between HKW and AUDPC was low to moderate, in contrast to the results of Sharma *et al.* (1997b). Moreover, the genetic correlation was higher than the phenotypic correlation for HKW. A lower correlation between HKW and AUDPC could be due to the tolerance of some genotypes. The susceptible parent, 'BL 1473' is a potential donor for such tolerance as the genotype was found tolerant to spot blotch in previous studies (Rosyara *et al.*, 2007; Sharma and Duveiller, 2007). Also, the genotype can tolerate complete removal of both flag and penultimate leaves at anthesis (Rosyara *et al.*, 2005). This indicates that there should be some type of compensatory mechanism (for example higher remobilization of stem reserves during grain filling or increased spike photosynthesis) responsible for the tolerance of this genotype. Interestingly, 'BL1473' has long and robust peduncle (Table 2). Theoretically, the most ideal plant genotypes can be developed by combining both tolerance and resistance properties together.

Post-anthesis chlorophyll decline showed high genetic correlation with spot blotch resistance. A high phenotypic correlation between these two traits was observed by Rosyara *et al.* (2007). Leaf chlorophyll content has been a trait of interest particularly in stressed environments (Yang *et al.*, 2002; Al Hakimi *et al.*, 1998). Previous studies have shown that total chlorophyll content per unit area is a good indicator of the strength of photosynthetic tissue (Nageswara Rao and Wright, 1994), high photosynthetic rate and maximum photosynthetic activity (Fischer *et al.*, 1998). Also, chlorophyll content has been correlated with heat tolerance (Yang *et al.*, 2002) and drought tolerance (Al Hakimi *et al.*, 1998).

A low rate of chlorophyll decline has been reported to be associated with tolerance to other biotic and abiotic stresses (Gorham, 1990; Limin and Fowler, 1993). Transfer of resistance will increase AUSDC values in spot blotch stressed environments. Abiotic stresses have been reported to increase spot blotch severity (Sharma and Duveiller, 2004). The senescence of flag leaves is one important consequence of spot blotch severity in susceptible genotypes (Rosyara *et al.*, 2007). For optimum grain filling, flag leaves should remain photosynthetically active until physiological maturity. Spot blotch significantly reduced flag leaf duration but not grain filling duration (Fig. 2). This indicates complete death of flag leaves before attainment of crop maturity.

The majority of traits studied showed weak genetic association with spot blotch severity, indicating absence of undesirable associations based on traits evaluated. Such weak associations could be due to one or more mechanisms that reduce genetic correlation between traits of interest (such as independent assortment, low linkage and absence of pleotropic gene action). Such independent inheritance reduces the burden to breeders by providing opportunity to combine any desired traits with spot blotch resistance. A few traits showed high positive genetic correlation with spot blotch resistance (for example, high AUSDC lines had higher disease resistance or low AUDPC). Such traits, potentially, can be used as complementary traits for development of genotypes for spot blotch stressed environments. Our results therefore apply in the development of breeding strategy for such environments.

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