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PARTIAL RESISTANCE TO STRIPE RUST AND ITS EFFECT ON SUSTAINABILITY OF WHEAT YIELD

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ABSTRACT:- Stripe rust (*Puccinia striiformis* Westend. f. sp. *tritici*) poses a serious threat to wheat production in cooler areas of Pakistan. The 70% area of wheat in Pakistan is prone to stripe rust disease. It can cause 10-17% yield losses if susceptible cultivars are planted under favorable conditions. Level of partial plant resistance in bread wheat and its impact on sustainable wheat production was studied at the National Agricultural Research Centre, Islamabad under natural conditions in the field. Eleven Pakistani commercial wheat cultivars/advance lines including check (Inqalab 91) were assessed for the level of partial resistance against stripe rust using Area Under the Disease Progress Curve (AUDPC), disease severity (DS) and epidemic growth rate in comparison with wheat cultivar, Inqalab 91. During 2007 cropping season, natural epidemic was developed and relative AUDPC was recorded from 0 to 100% whereas the 2008 cropping season was dry and no stripe rust appeared. Two advanced lines (NR 268 and NR 285) showed the infection type (IT) less than 7 (incompatible reaction) to the mixture of prevailing stripe rust inoculums. Very low level of DS and AUDPC were recorded in the remaining cultivars/lines indicating a high level of partial resistance to stripe rust compared to the susceptible check cultivar, Inqalab 91. Among eight cultivars/lines that showed compatible type of reaction (IT $\geq$7), one was resistant (relative AUDPC $\leq$ 20% of Inqalab 91) and six showed very high resistance levels (relative AUDPC $\leq$5%). Maximum level of resistance (relative AUDPC = 0.1%) was observed in advanced line, NR 271. The wheat cultivars/lines that showed a slow disease development (low DS and AUDPC), could be considered as partially resistant for stripe rust infection. The yield (2178 kg ha^{-1}) of susceptible check cultivar Inqalab-91 during 2007 was reduced to 45% as compared to its yield (3945 kg ha^{-1}) in epidemic free year (2008). Thus the use of these partially resistant cultivars/lines in hybridization programme or their cultivation can considerably reduce yield losses incurred by stripe rust.

Key Words: Triticum aestivum ; Puccinia striiformis; Susceptibility; Disease Severity; Hypersensitive Resistance; Non-Hypersensitive Resistance; Crop Yield; Pakistan.

INTRODUCTION

Wheat crop occupies a central position in the diverse farming system of Pakistan. It is the major food in Pakistan, contributing 60% of the daily diet of people. It is grown on about 9.05 m ha with 24.03 m t

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annual production and an average yield of 2657 kg ha^{-1} (GoP, 2010). In 1960s, a dramatic improvement in the production of cereals happened due to the use of high yielding and disease resistant cultivars in many developing countries (Witcombe, 1996). During the post green revolution period, when high yielding cultivars continued to spread over large areas (GoP, 2005), national and international research programmes have focused to release semi-dwarf wheat cultivars to prevent lodging and improve harvest index (Rajaram et al., 2002). Following this success, a few high yielding cultivars were widely adopted that led to the monoculture cropping system and narrowed the genetic basis of wheat crop (Witcombe, 1996). Despite the success stories of green revolution and subsequent advances made in genetic improvement, the wheat breeding still faces complex challenges in advancing yield potential and stability. Wheat diseases cause a significant threat to yield stability and quality in the country. Among these, the diseases caused by rust fungi are the most important which have resulted in huge economic losses in the country over the last 60 years.

Stripe rust (*Puccinia striiformis* Westend. f. sp. *tritici*) is a serious concern, to the wheat production in Pakistan as the new pathotypes are being continuously evolved. The 70% area (5.8 m ha) under wheat in Pakistan is prone to stripe rust (Singh et al., 2004a; Qamar et al., 2012). It can cause yield losses ranging from 10 to 70% (Chen, 2005) under favorable conditions in susceptible cultivars. In 1978, severe stripe rust was reported over all wheat growing areas of Pakistan (Anonymous, 2000). Controlling stripe rust with host resistance is very efficient, environment friendly and cost effective method. Breeding for resistant cultivars is historically based on hypersensitive resistance and use of this resistance in breeding programmes is attractive being easy to incorporate into improved germplasm and it provides complete protection to crop (Singh et al., 2000). This type of resistance is race-specific and is conferred by a single or a few major genes. Their utilization in high yielding cultivars leads to “boom and bust” cycles and hence the cultivars become susceptible within short time to new emerged virulent races of the pathogen.

Recently, over 70 genes for stripe rust resistance have been detected and many have been characterized and incorporated into commercial wheat cultivars (McIntosh et al., 2008). A number of these genes have been mapped (Uauy et al., 2005), majority of them are race specific and virulence in different parts of the world (Hovmøller and Justesen. 2007, Bahri et al., 2011, De Vallavieille-Pope et al., 2012). Given the ephemeral nature of the hypersensitive (race-specific) resistance, there is an increasing interest in improving the durability of this resistance by gene pyramiding or by use of multilines. Another option would be to exploit and incorporate resistance types that are durable. Non-hypersensitive also called partial resistance and usually expressed at adult plant stage (Parlevliet et al., 1980) is supposed to be more durable (Parlevliet, 1985), the most valuable alternative to hypersensitive resis-tance. Van der Plank (1963) was the first who defined it theoretically and later it was linked to stripe rust by Johnson (1988). Partial resistance decreases pandemic severity in the cultivars that show a compatible host-pathogen interaction (Parlevliet and Van Ommeren, 1975). The present study was designed to quantify the sequential progress of stripe rust and level of partial resistance in bread wheat in fields and compare its affect on cultivars in terms of yield losses.

MATERIALS AND METHOD

Two field experiments were carried out at the Wheat, Barley and Triticale Programme experimental area at the National Agricultural Research Centre (NARC), Islamabad during 2007 and 2008 cropping seasons. The study comprised eleven wheat cultivars/lines (Table 1) including the susceptible check cultivar, Inqalab 91. Three commercial wheat cultivars, GA 02, Wafaq 01, and Chakwal 97 have been recommended and released for commercial cultivation in rainfed areas whereas Inqalab 91 and Auqab 2000 were released for irrigated areas of Pakistan. The remaining six genotypes were advanced lines (NRs) that were developed/ selected by the Wheat Breeding Programme at NARC. These wheat cultivars/lines were tested against a complex stripe rust races (mixture of races), provided by Crop Diseases Research Programme (CDRP), NARC, Islamabad, for inoculation.

A randomized complete block design (RCBD) with three replications was used. Each experimental unit (sub-plot, 1m x 5 m) consisted of four 0.25m apart rows. Sub-plots were kept apart by a distance of 0.5m to avoid interplot interference. The susceptible wheat cultivar, Morocco, was planted in between each test genotype as a spreader for maximizing stripe rust development on the test wheat cultivars/lines. At tillering stage, inoculation was done by using a mixture of prevailing races of the

Table 1. Bread wheat genotypes used in the study

S. No.	Cultivars/ Lines	Year of release	Parentage
1	Inqalab 91	1991	WL 711/CROW 'S'
2	Chakwal 97	1998	BUC`S'/FCT 'S'
3	Auqab 2000	2000	CROW'S'/NAC/BOW'S'
4	Wafaq 01	2001	Opata/Rayon/Kauz
5	GA 02	2002	DWL5003/SNB/SNB
6	NR 234	-	Fret-2
7	NR 268 (NARC 09)	-	Inqalab-91/2/Tukuru
8	NR 271	-	Chen/*Aegilops squarrosa* (TAUS)//BCN/3/CMH 81.38/2*Kauz
9	NR 281	-	Fret2/Kuruku//Fret2
10	NR 285	-	Fret2/Tukuru//Fret2
11	NR 301	-	PFAU/Weaver*2/Kiritati

stripe rust fungus. All plants including spreader rows in each experimental unit were inoculated. The plants were inoculated by spraying over leaves with the urediniospores suspended in a light weight mineral oil (1.5 mg l^{-1}). Evening time was chosen for inoculations to offer optimal darkness for germination of urediniospores. Humidity was enhanced by watering the plots before inoculation.

Weather conditions during the 2008 cropping period did not support the establishment of stripe rust infection while there were optimal environmental conditions for establishment of the stripe rust colonies in 2007. Data for the stripe rust severity was initiated to record at the time when 50 pustules on upper three leaves per tiller of the susceptible cultivar, Morocco were observed. The observations were taken six times. The first reading was taken 28 days after inoculation on March 16, 2007. The five additional readings were taken on March 19, 25, 27 and 31 and April 3, 2007. Scoring for disease severity was done by counting the number of pustules on upper three leaves of ten randomly selected and tagged tillers of each genotype within each replication. The average of ten tiller counts constituted the plot record. The six disease assessments (number of pustules) were used to estimate the area under the disease progress curve (AUDPC) using the formula given by Joshi et al. (2002) and Joshi and Chand (2002).

The relative AUDPC (%) for each cultivar/line was determined, dividing the actual AUDPC of any cultivar/line by the AUDPC of Inqalab 91. Disease severity (DS) was calculated by transforming the data according to the scale suggested by Parlevliet and Van Ommeren (1984) that displays a logarithmic progression. Linear regression of transformed DS on time was used to obtain epidemic growth rate. The regression coefficients were considered as comparable to apparent or logistic growth rate described by Van der Plank (1963). A scale (Table 2) suggested by

Table 2. Scale used for estimation of stripe rust infection type (IT) in wheat

IT	Description	Interpretation
0	No visible symptoms	Resistant
1	Very small, pinpoint necrotic flecks	Resistant
2	Large necrotic flecks	Resistant
3-4	Very small pustules/stripes surrounded by necrosis	Resistant
5-6	Small and large pustules/stripes, necrotic and chlorotic flecks	Intermediate
7	Large pustules/stripes with extensive chlorosis	Susceptible
8	Large pustules/stripes with some chlorosis	Susceptible
9	Large pustules/stripes with little or no chlorosis	Susceptible

McNeal et al. (1971) was used to determine infection type (IT).

Meteorological data was provided by Water Resources Research Institute, Field Station, NARC, Islamabad (Table 3).

The statistical procedure, "analysis of variance" (Steel and Torrie, 1981) was adopted to analyze data to determine the level of significant difference among genotypes. LSD test (P = 0.05) was used to compare the genotypic means.

RESULTS AND DISCUSSION

In Islamabad, weather conditions are usually favourable during February and March for natural epidemics of wheat stripe rust. However, in 2008, the weather conditions were not conducive for rust outbreak. Relative high rainfall and humidity along with low temperatures was recorded in the growing season of 2007 as compared to 2008. In February 2007, total rainfall was 93.6 mm with average minimum and maximum temperatures of 6.6°C and 18.9°C, respectively. In March 2007, total rainfall was 179.6 mm and average minimum and maximum temperatures of 9.1°C and 22.9°C were recorded. The average minimum and maximum relative humidity in February and March 2007 was 75.1% and 81.3%, respectively. In 2008, a total rainfall of 87.4 mm and 78.4 mm was recorded in February and March, respectively. The average minimum and maximum temperatures were 4.5°C and 19.3°C in February whereas it was 11.2°C and 28.1°C in March 2008. Likewise a lower relative

Table 3. Meteorological data recorded at Water Resource Research Institute, Field station, NARC, Islamabad

Year/ month	Temperature (°C)		Total rainfall (mm)	Relative humidity (%)		Average relative humidity (%)
	Maximum*	Minimum**		Maximum*	Minimum**	
2007						
January	18.9	1.6	0.0	92.4	45.9	69.1
February	6.6	1.9	93.6	95.3	67.4	81.3
March	22.9	9.1	179.6	92.3	57.9	75.1
April	33.3	14.7	7.3	71.0	37.0	54.0
2008						
January	14.5	1.6	122.1	90.7	57.4	74.0
February	19.3	4.5	45.4	87.4	48.9	68.2
March	28.1	11.2	24.4	78.4	40.0	59.2
April	28.8	14.3	80.9	75.3	47.1	61.2

** and ** data recorded at 0800 hours and 1400 hours , respectively* humidity of 59.2% and 68.2% was recorded during February and March 2008, respectively. Thus, it is concluded that the weather data (higher rain, both the average minimum and maximum temp-eratures and relative humidity) were more favorable for stripe rust in the 2007 season as compared to the 2008 growing season. The weather conditions during 2008 did not allow the stripe rust epidemic development naturally. Therefore, stripe rust was not observed. The weather conditions in the growing season of 2007 supported natural development of stripe rust epidemics. Thus stripe rust data were recorded in 2007.

The genes responsible for non-hypersensitive/partial resistance usually slow down the rate of disease development (Parlevliet and Van Ommeren, 1975). These do not provide complete resistance to the host genotype. The relative effectiveness of partial resistance genes depends on environmental conditions (Cortazar, 1985; Qayoum and Line, 1985; Milus and Line, 1986a & b; Uauy et al., 2005; Dereje and Fininsa, 2007), genetic background of the cultivar in which they have been deployed (Rapilly, 1979), number of the resistance genes for partial resistance (Singh et al., 2000) and aggressiveness of races of stripe rust (Todorova, 2000; Milus et al., 2006 and 2009). Thus the effect of partial resistance cannot be assessed in the cultivars showing complete resistance against stripe rust. In present study, all tested cultivars/lines except NR 268 and NR 285 showed compatible type of host-pathogen relationship indicating absence of hypersensitive type of reaction (Table 5). So, these lines were not included to assess the level of partial resistance. Partial resistance could be studied only if there is a compatible host-pathogen relationship (IT $\geq$7).

Epidemic Parameters

The analysis of transformed values of disease severities (DS) demonstrated a highly significant host genotypic effect on stripe rust epidemics on all assessment dates except the first assessment date (Table 4). The highest level of disease severities (DS) was assessed on susceptible check cultivar, Inqalab 91, at all assessment dates (Table 6). On March 16, 2007, there was non-significant difference among cultivars /lines for disease severity (Table 4). On second (March 19, 2007), third (March 25, 2007), fourth (March 27, 2007), fifth (March 31,2007) and sixth (April 3, 2007) assessment dates, the test cultivars/lines did not differ significantly from each other whereas they exhibited significantly lower DS than the susceptible check cultivar, Inqalab 91 (Table 6). The maximum level of DS on 5th assessment date was observed on Inqalab 9 (513.87) followed by Chakwal 97 (101.74) whereas remaining cultivars were at par and showed very low levels of DS. On the terminal disease assessment date, the range of DS transformed values were 2.42 on NR 301 and 555.31 on check cultivar Inqalab 91. This suggests the presence of high levels of partial resistance in all tested cultivars/lines against stripe rust.

DS was plotted against number of days after sowing date to obtain disease progress curves for nine bread wheat genotypes (Figure 1). This also signifies a slow rate of disease development and a very low level of DS on the tested cultivars/lines as compared to the susceptible check cultivar, Inqalab 91, at different assessment dates.

The linear regression of transformed DS on time was used to obtain epidemic growth rate “r” for different genotypes. Analysis of variance for growth rate showed a non-significant time/genotypic interaction (Table 4) which means that the test wheat cultivars/lines did not vary in expressing their epidemic growth rate.

A highly significant effect of host cultivars/lines was observed for AUDPC (Table 4). The check cultivar, Inqalab 91, differed significantly from the test cultivars/line; however, there was non-significant difference among other cultivars/lines for AUDPC value. The values recorded for AUDPC ranged between 5.7 for NR 271 and 4696.2 for Inqalab 91 (Table 7). The relative AUDPC (%), which was calculated by dividing actual AUDPC of any cultivar/line with the AUDPC of check cultivar, Inqalab 91, ranged from 0.1% on NR 271 to 100% on Inqalab 91 (Table 7). The low AUDPC recorded in the test cultivars/line indicated a high level of partial resistance to stripe rust compared to the susceptible check, Inqalab 91. Seven test cultivars/lines showed very high partial resistance (relative AUDPC $\leq$ 5% of Inqalab 91) and one cultivar Chakwal 97 showed partial resistance (relative AUDPC $\leq$ 0% of Inqalab 91) to prevailing stripe rust races/pathotypes.

The weather data (higher rain, both the average minimum, average maximum temperatures and relative humidity) was in the range of optimum for stripe rust development, disease severity and its progress rate in the 2007 season than in 2008 (Table 3). This data suggested that wet conditions and average minimum (6°C) and maximum (23°C) temperatures are favorable for germination and development of stripe rust infection. Cortazar (1985) and Dereje and Fininsa (2007) observed a significantly higher stripe rust severity with higher amount of

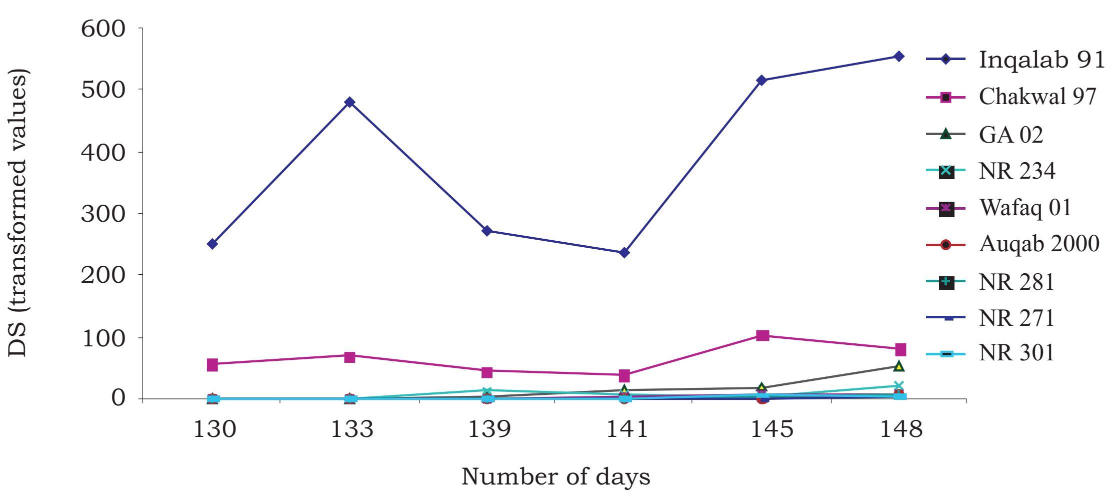

Figure 1. Disease progress curve of nine wheat genotypes obtained by plotting DS against number of days after sowing

Table 4. Mean square values for area under disease progress curve (AUDPC), diseases severity (DS), epidemic growth rate (r) on different wheat cultivars/lines in 2007

		DS in March-April 2007							
S.O.V	df	16-03-07	19-03-07	25-03-07	27-03-07	31-03-07	03-04-07	AUDPC	r
Rep	2	6906.6	11923.9	3442.8	4768.0	2485.7	1420.3	291376	74.5
Cultivar	8	20194.9	74509.9	23313.1	17808.5	85563.9	96978.3	7043901	214.4
		(0.11)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.55)
Error	16	9855.3	9934.7	2869.0	3661.0	3057.9	1963.8	367806	242.4
Total	26								

Values in the parenthesis represent probability

rainfall. Bekele et al. (2002) also reported similar findings. They have observed average minimum and maximum temperatures of 7.9°C and 21°C, respectively, with the optimum temperature of 11 °C for stripe rust disease development during growing season. According to Hogg et al. (1969) the minimum, optimum and maximum temperature for stripe rust is 0°, 11° and 23°C, respectively. Genes for non-hypertensive resistance manifested at a relatively higher temperature (Qayoum and Line, 1985; Chen and Line, 1995b; Chen, 2005, Uauy et al., 2005; Lin and Chen, 2007; Guo et al., 2008, Arron et al., 2009) during later stages of plant development, when temperatures are typically above 21°C (Chen and Line, 1995a; b). Thus unfavorable environmental conditions in growing season of 2008 hindered the germination and development of stripe rust. Therefore, no data could be recorded for disease parameters. Partial resistance can only be studied if there is compatible type of host-pathogen relationship (IT$\geq$7). In the current study, all tested cultivars/lines except two advance lines NR 268 and NR 285 showed compatible type of host-pathogen relationship indicating absence of hypersensitive type of reaction (Table 7). Transformed values of disease severities (DS) confirmed a highly significant host genotypic effect on stripe rust epidemic development. However, the cultivars/lines did not vary in expressing their epidemic growth rate (Table 4). The low levels of DS and AUDPC noticed in the test cultivars/lines indicating a high level of partial resistance to stripe rust compared to the susceptible check, Inqalab 91. The genotypes exhibiting low DS and AUDPC are characteristics of partial resistance for stripe rust disease. DS and AUDPC are usually used to assess partial/ non–hypersensitive resistance (Broers, 1989). This study supports the idea that epidemic growth rate is an unreliable parameter for assessment of resistance to stripe rust while DS and AUDPC are comparatively more reliable parameters of resistance estimators. Broers (1989) and Qamar et al. (2007) also reported non-significant effect of genotypes on epidemic growth rate for leaf and stripe rust, respectively. They preferred DS and AUDPC against epidemic growth rate for estimations of partial resistance in wheat to rust. It can thus, be deduced that partial resistant genotypes for stripe rust disease can be discriminated by low DS and AUDPC.

Previous literature also supports the significant effect of environmental conditions and genotype on the level of resistance against rust diseases (Rapilly, 1979; Kurt, 2002; Qamar et al., 2007; Hailu and Fininsa, 2007; Qamar et al., 2009; Ahmad et al., 2010a, b). Temperature sensitive and race-non-specific genes with additive effect for partial resistance in wheat against stripe rust have been studied by many researchers (Lewellen et al., 1967; Sharp and Volin, 1970; Robbelen and Sharp, 1978; Wallwork and Johnson, 1984; Singh and Rajaram, 1994; Bariana and McIntosh, 1994; Qamar et al., 2008). Several cultivars with durable resistance (Capelle-Desprez, Juliana, Carstens VI and Arminda) have been reported in Europe (Johnson, 1981; Stubbs, 1985) and the United States (Gaines and Nugaines) (Line et al., 1983). Singh et al. (2000) accumulated minor genes with additive effects for partial resistance in several wheat lines. Those lines conferred a high level of resistance almost near to immunity against leaf and stripe rust. Qamar et al. (2007) observed high level of partial resistance to stripe rust in NR 268 (NARC 09) and Wafaq 01. Qamar et al. (2012) identified stripe rust and leaf rust resistance gene complex Yr18/Lr34 in wheat cultivars GA 02 and Wafaq 01. Partial resistance has also been reported by Singh (personnel communication, 2006) to stripe rust in NR 234 (Fret-2), NR 268 (NARC 09), Wafaq 01 and Fert-2 derived lines NR 281 and NR 285. He viewed that the resistance in these genotypes against stripe rust is due to Yr18 gene and this gene in

Table 5. Mean square values for various yield, yield components and some other morphological traits

S.O.V	df	Plant height (cm)	Spike length (cm)	Spikelet spike^{-1}	Grains spike^{-1}	Weight of grains spike^{-1} (g)	1000-grain weight (g)	Grain yield (kg ha^{-1})
Rep	2	4.227	2.714	2.209	241.254	0.342	27.152	84603
Cultivar (C)	10	97.246	5.487	2.411	54.430	0.511	76.246	1245689
		(0.00)	(0.00)	(0.11)	(0.23)	(0.00)	(0.00)	(0.00)
Year (Y)	1	0.136	0.021	0.061	0.015	0.356	2.970	124976
		(0.79)	(0.85)	(0.84)	(0.98)	(0.12)	(0.25)	(0.48)
C x Y	10	0.136	0.305	0.813	16.329	0.291	5.336	513342
		(0.99)	(0.88)	(0.82)	(0.94)	(0.05)	(0.02)	(0.05)
Error	42	1.894	0.305	1.415	40.049	0.140	2.215	250814
Total	65							

Values in the parenthesis represent probability combination with some minor unknown gene confers slow rusting or partial resistance in wheat against stripe rust (Singh, 1992; McIntosh, 1992, Suenga et al., 2003). According to Singh et al. (2004b), all Tukuru derivatives also carry some unidentified QTLs that act additively. CIMMYT derived several lines from PBW-353 through back cross for Asia showed durable resistance. According to Singh (1992) and McIntosh (1992) many spring and winter wheat cultivars carrying Yr18 and many other unknown genes confer on slow rusting.

Grain Yield and its Components

As already mentioned the contrast weather conditions during the consecutive years provided a good opportunity for studying the effect of partial resistance on grain yield of wheat crop.

The effect of cultivar x year interaction showed significant effect on grain yield (Table 5). The main effect of cultivars was also highly significant on grain yield. However, the significant effect of cultivar x year interaction was recorded only with susceptible check cultivar, Inqalab 91, for grain yield though the test cultivars /lines did not show signi-ficant cultivar x year interaction. The maximum yield was produced by advanced line NR 234 over both years (Table 8). The susceptible check cultivar, Inqalab 91, ranked sixth regarding grain yield (3945 kg) in the rust free year (2008) whereas it produced the lowest grain yield (2178 kg) in epidemic year (2007). The yield of susceptible check, Inqalab 91, in epidemic year (2007) was significantly lower than its yield in rust free year (2008). Nevertheless, the ranking order of the tested cultivars/ lines for grain yield was not changed during next year (2008). This means

Table 6. Transformed value of diseases severity (DS) of stripe rust on upper three leaves on six assessment dates on various wheat cultivars/lines during March-April 2007

Cultivar	16-03-07	19-03-07	25-03-07	27-03-07	31-03-07	03-04-07
Inqalab 91	249.62	480.72 a	271.44 a	237.25 a	513.87 a	555.31 a
Chakwal 97	54.70	67.55 b	43.02 b	36.88 b	101.74 b	78.74 b
GA 02	0.75	0.83 b	3.05 b	12.43 b	18.67 bc	50.91 b
NR 234	0.28	0.41 b	10.26 b	4.27 b	1.99 c	21.07 b
Wafaq 01	0.28	0.62 b	6.11 b	3.05 b	4.58 c	6.84 b
Auqab 2000	0.00	0.00 b	0.00 b	0.00 b	0.00 c	6.73 b
NR 281	0.00	0.19 b	2.84 b	1.66 b	2.59 c	4.89 b
NR 271	0.00	0.00 b	1.04 b	0.21 b	0.00 c	2.59 b
NR 301	22.21	37.09 b	13.45 b	11.23 b	4.50 c	2.42 b

Means followed by same letter do not differ significantly at 5% level

Table 7. AUDPC, relative proportion (%) of AUDPC to check cultivar Inqalab 91, epidemic growth rate (r) and infection type (IT) on different wheat cultivars/lines in 2007

Cultivar	AUDPC	Relative AUDPC	r	IT
Inqalab 91	4696.2 a	100.0	24.277	7-9
Chakwal 97	785.9 b	16.7	-1.474	5-9
NR 301	186.0 b	4.0	-3.856	5-8
GA 02	153.0 b	3.3	8.301	6-7
NR 324	63.3 b	1.3	2.884	3-7
Wafaq 01	42.6 b	0.9	0.525	6-7
NR 281	23.4 b	0.5	0.473	5-7
Auqab 2000	8.1 b	0.2	0.687	1-7
NR 271	5.7 b	0.1	0.072	3-7
NR 268	-	-	-	0-4
NR 285	-	-	-	0-3

Means followed by same letter do not differ significantly at 5% level

that the epidemic of stripe rust did not affect grain yield on partially resistant cultivars. It caused yield losses in the susceptible check cultivar. The decrease in grain yield of susceptible check cultivar, Inqalab 91, in 2007 than pooled mean grain yield was 28.9%. Similarly the grain yield obtained in 2007 was 44.8% less than grain yield obtained in rust free year (2008) on susceptible check, Inqalab 91. It indicated that the partial (non-hypersensitivity) resistant cultivars reduced yield loss approximately up to 44.8%.

Effect of year (disease) was significant on 1000-grain weight and grain weight spike^{-1} whereas it did not affect plant height, spike length, spikelet spike^{-1} and grains spike^{-1} of susceptible check (Table 5). As the significant effect of cultivar x year interaction was observed only on Inqalab 91 for these parameters, therefore, morphological traits and yield components of only check cultivar were compared for both years to assess the effect of partial resistance in reduction of yield losses. Susceptible check cultivar, Inqalab 91, produced 35.0 g and 38.1 g 1000-grain weight during the 2007 (epidemic year) and 2008 (disease free year), respectively (Table 9). The reduction in 1000-grain weight in epidemic year was 27.2% of disease free year. Similarly, the grain weight spike^{-1} in epidemic year was less (8.25%) than the disease free year. This data also suggests that the resistant cultivars can also reduce yield losses by minimizing effect of disease on yield components like 1000-grain weight and grain weight spike^{-1}.

The ranking order in these parameters of the tested cultivars/ lines did not change in both years. The decrease in grain yield during epidemic year (2007) was only in susceptible check Inqalab 91. This means that the epidemic of stripe rust do not have much effect on grain yield of partially resistant cultivars. Thus data suggests that the resistant cultivars can also reduce yield losses by minimizing effect of disease on 1000-grain weight and grain weight spike^{-1}.

Murray et al. (1995) reported that stripe rust epidemics cause 84%, 43% and 72% reduction in grain yield, grain weight and grain number in very susceptible cultivars, respectively. Hailu (2003) and Hailu and Fininsa (2007) observed 36-71% grain yield losses in the highlands of Bale, Southeastern Ethiopia on the susceptible wheat cultivar, Wabe. In their experiments, Wabe, the resistant cultivar, and use of fungicide lessened the stripe rust epidemic development. They believed that advantage of fungicides can be enhanced by cultivating resistant cultivars. Syed et al. (2008) and Ahmad et al. (2010a, b) found a direct correlation between the disease level of stripe rust and loss of grain weight in commonly grown Pakistani wheat cultivars. They also observed variation among the cultivars for losses of grain yield due to stripe rust.

Table 8. Effect of partial resistance to stripe rust in wheat genotypes on yield

Cultivars/lines	Yield (kg ha^{-1}) 2007	2008	Pooled mean	% change in yield over 2008	% change in yield over pooled mean
NR 234	4504.3 a	4519.7 a	4512.0 a	- 0.3	- 0.2
Wafaq 01	4311.0 ab	4280.0 ab	4295.5 ab	+ 0.7	+ 0.4
NR 281	4135.3 ab	4083.7 ab	4109.5 abc	+1.3	+0.6
NR 301	4111.0 ab	4074.7 ab	4092.8 abc	+ 0.9	+ 0.4
NR 268	4084.7 ab	4153.0 ab	4118.8 abc	- 1.6	- 0.8
NR 271	3809.0 ab	3698.3 abc	3753.7 bcd	+ 3.0	+1.5
Chakwal 97	3584.3 b	3522.0 bc	3553.2 cde	+1.8	+ 0.9
NR 285	3577.7 bc	3559.0 bc	3568.3 cde	+ 0.5	+ 0.3
Auqab 2000	3564.7 bc	2968.3 cd	3266.5 de	+ 20.1	+ 9.1
GA-02	3486.7 bc	3500.0 bc	3493.3 de	- 0.4	- 0.2
Inqalab 91	2178.0 d	3945.0 ab	3061.7 e	- 44.8	- 28.9

Means followed by same letter do not differ significantly at 5% level; (+) increase in yield, (-)decrease in yield

Table 9. Effect of stripe rust on yield, yield components and some morphological parameters of susceptible cultivar, Inqalab 91, during stripe rust epidemic and rust free year

Year	Plant height (cm)	Spike length (cm)	Spikelet spike^{-1}	Grains spike^{-1}	Grain weight spike^{-1} (g)	1000- grain weight (g)	Grain yield (kg ha^{-1})
2007	94.67	12.44	19.67	51.33	2.06	35.00	2178
2008	93.50	11.79	19.74	51.66	2.82	38.13	3945
% change	+ 1.25	+ 5.54	- 0.38	- 0.63	- 27.15	- 8.22	- 44.79
P value	0.31	0.14	0.97	0.89	0.04	0.04	0.01

(+) % gain and (-) % loss over 2007

Bolat and Altay (2007) also found that a yield loss due to stripe rust varied from 12.7% to 87.0% among various wheat genotypes. It can be concluded that partial resistant genotypes for stripe rust disease can be discriminated by low DS and AUDPC. Accordingly, the use of these partial resistant cultivars/lines in the future breeding/hybridization programmes or their cultivation can considerably reduce yield losses incurred by stripe rust.

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