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Multi-location variability in Pakistan for partial resistance in wheat to *Puccinia striiformis* f. sp. *tritici*

Sajid ALI[1], S. Jawad A. SHAH[2] and Hidayatur. RAHMAN[3]

[1] UMR 1290 BIOGER-CPP, INRA-AgroParisTech, Equipe Pathologie Végétale et Epidémiologie, BP 01, 78 850 Thiverval-Grignon, France
[2] Plant Pathology Group, Crop Breeding Division, Nuclear Institute for Food and Agriculture (NIFA), Peshawar, Pakistan
[3] Department of Plant Breeding & Genetics, NWFP Agricultural University Peshawar, Pakistan

Summary. Expression of plant resistance to diseases varies according to the prevalent pathotypes and climatic conditions at different locations. This variability in partial resistance expression across locations must be known to elucidate the disease status of crop plants in field conditions. We report on the field assessment of partial resistance in wheat to yellow rust, studied at six locations in 37 wheat varieties along with the susceptible control 'Morocco' during the yellow rust season of 2007. The high disease severity of 'Morocco' revealed considerable disease pressure at all locations. The field resistance of these varieties varied across locations, with no variety being immune at all locations. Based on the average coefficients of infection, representing overall partial resistance expression, the tested varieties were grouped into high (27 varieties), moderate (9 varieties) and low levels of partial resistance (one variety). Stability in the expression of leaf tip necrosis, a marker of partial resistance to yellow rust, was recorded for the varieties Suleman-96 and Sindh-81. Kohsar-93, Bakhtawar-93, Saleem-2000, Fakhre-Sarhad, Tatara, Frontana and Karwan had an overall good level of partial field resistance across the locations. There was also considerable variation in the expression of partial resistance to yellow rust resistance across the locations.

Key words: wheat varieties, yellow rust, environments, field resistance.

Introduction

Wheat yellow stripe rust, caused by *Puccinia striiformis* Westendorf f. sp. *tritici,* is a major threat to global wheat production (Aquino *et al.,* 2002; Singh *et al.,* 2004). Utilization of genetic resistance to this disease is likely to be the most economical and environmentally friendly control measure (Stubbs *et al.,* 1986; Smale *et al.,* 1998; Singh *et al.,* 2004; Pathan and Park, 2007). Several wheat varieties have been released in Pakistan in the past based on only a few race-specific vertical resistance genes. The rust population, however, varies considerably between regions and years (de Vallavieille-Pope and Line, 1990; Hovmoller, 2001). This variation results in the breakdown of such vertical resistance due to the evolution of new virulent pathogen strains. This along with the long-distance dispersion capacity of the pathogen through winds (Moschini and Pérez, 1999) necessitates avoiding the cultivation of a single or only a few varieties with race-specific resistance genes over large areas. Deployment of varieties with partial resistance would be a better stripe rust management strategy.

Partial resistance is generally race-non specific. Race-specific resistance results in all-stage resistance with hypersensitive reactions. Partial resistance, in contrast, results in an early infection but resistance then develops at the post-seedling stage. This type of resistance could be relatively more durable (Singh and Rajaram, 1992), as some partial resistance genes have been reported to be components of durable

Corresponding author: S. Ali
Fax: +330130815306
E-mail: sajid.ali@grignon.inra.fr

resistance (such as Yr18, Spielmeyer, 2005). The development of virulence has rendered some partially resistant varieties ineffective (Park and McIntosh, 1994; Huerta-Espino and Singh, 1996), but partial resistance controlled by several additive minor genes is likely to be more durable.

Expression of resistance varies across locations according to the prevalent pathotypes and the climatic conditions. Some studies have assessed the expression of partial resistance under different temperatures in controlled conditions (Agarwal *et al.,* 2003). However, the expression of partial resistance must be studied under realistic field weather conditions with the presence of various pathotypes. Varieties with partial resistance must be identified and characterized for their field expression across locations, and their overall partial resistance levels must be determined. We assessed the field-based partial resistance of some commercially released wheat varieties across six test environments in Pakistan.

Materials and methods

Partial resistance levels in wheat varieties to yellow rust were assessed in field trials across six locations in the major wheat growing areas in the Northwest Frontier Province of Pakistan (Fig. 1), where the disease is common, during the yellow rust season of 2007. NWFP is considered to be more prone to yellow rust epidemics due to its relatively cool climate (Akhtar *et al.,* 2002). The tested germplasm included 37 wheat varieties, released by different research institutes in Pakistan; along with the variety 'Morocco' as a susceptible control (Table 1). The six locations (and their abbreviations) were:

i) Agricultural Research Station (ARS), Serai Naurang, Bannu (32°49'N, 70°46'E, elevation: 304 m);

ii) Agricultural Research Farm, NWFP Agricultural University, Peshawar (AUP) (34° 1'N, 71°28'E, elevation: 366 m);

iii) Nuclear Institute for Food and Agriculture (NIFA), Peshawar (34° 0'N, 71°42'E, elevation: 304 m);

iv) Cereal Crop Research Institute (CCRI), Pirsabak, Nowshera (34° 1'N, 72° 2', elevation: 292 m);

v) Agricultural Research Institute (ARI), Mingora, Swat (34°46'N, 72°21'E, elevation: 939 m);

vi) Hazara Agricultural Research Station (HARS), Abbotabad (34°12'N, 73°14'E, elevation: 1218 m).

Wheat varieties were grown in strips of small adjacent plots 0.6 m apart. Each plot consisted of two rows 1 m long and was separated by 0.3 m. The variety 'Morocco', which is highly susceptible to stripe rust, was sown around the test plots and after every fourth test variety plot as an inoculum spreader and also to serve as a yellow rust susceptible control. Standard crop cultural practices were used at all test locations.

For the assessment of field partial resistance natural infection was relied upon. The disease was scored during the peak of rust infection at each site, at the crop growth stage immediately after heading. Two parameters were included in, and were considered when scoring the rust, i.e. host reaction and rust severity, and they were recorded on the most heavily infected flag leaves of each variety in each entry. The nomenclature of Singh (1993) was used to score host response to infection. Estimates of disease severity were based on the modified Cobb scale (Paterson *et*

Fig. 1. Map of Northwest Frontier Province of Pakistan, showing sites selected to assess the partial resistance level of wheat varieties during 2006–2007.

Table 1. Wheat varieties assessed for resistance to yellow rust at six locations in the North West Frontier Province of Pakistan during 2006–2007.

No.	Variety	Year of release[a]	Parentage-Pedigree
1	Mexi-Pak	1965	Pj62/GB55
2	Blue Silver	1971	1153-388/AN/3/YT54/N10B//LR64 /AN//YT54/N10B/3/LR864/4/ B4946.A 4.18.2.1Y-Y53//3/Y50
3	WL 711	1978	S308/CHRIS//KAL
4	Zarghoon	1979	CC/INIA/3/TOB/CTFN//BB/4/7C
5	Pak-81	1981	-
6	Sind	1983	NORTENO/MEXIPAK
7	Faisalabad-1	1983	FURY/KAL/BB
8	Kohinoor	1983	OREF1158/FDL/MFN/2*TIBA63/3/COC
9	Faisalabad-2	1985	MAYA/MON//KVZ/TRM
10	Tandojam	1985	TZPP/PL/7C
11	Chakwal	1986	-
12	Zardana	1989	CNO S/8156 TOB 66 CNO6-PVN
13	Pirsabak	1991	-
14	Inqalab	1991	WL 711/CROW`S'
15	Pasban	1991	INIA F 66/ A.DISTCHUM//INIA66/3/GEN
16	Rohtas	1991	INIA F 66/ A.DISTCHUM//INIA66/3/GEN
17	Soghat	1991	Pavon Mutant-3
18	Sariab	1993	BB/GLL//CARP/3/PVN
19	Bahawalpur	1995	AVRORA/UP-301//GALLO/SUPER-X/3/ (SIB)PEWEE/4/ MAIPO(SIB)/(SIB)MAYA-74//PEWEE
20	Kaghan	1993	TTR/JUN
21	Watan	1994	Lu26/HD2179
22	Shaheen	1994	MLT "S"
23	Parwaz	1995	V.5648/PRL
24	Suleman	1995	F6.74/BUN//SIS/3/VEE#7
25	Punjab	1995	SA 42 *2/4CC/INIA//BB/3/ INIA/HD832
26	Kohsar	1995	PSN/BOW
27	Bakhtawar	1995	JUP/BJYG//URES
28	Shahkar	1995	WL 711//F3.71/TRM
29	Kirin	1995	
30	Nowshera	1996	
31	Tatara	1996	JUP/ALD "S" // KLT "S"/3VEE"S"
32	Kohistan	1998	V-1562//CHRC`S'/HORK/3/KUFRA-/4/CARP`S'/BJY`S'
34	Fakhre-Sarhad	1998	PFAU "S"/SERI/BOW "S"
33	Saleem	2000	
35	Karwan	-	-
36	Sarsabz	-	P1/FRND//MXP/3/P1/M20/79
37	Frontana	-	Resistant control
38	Morocco	-	Susceptible control

[a] The year of release does not always correspond exactly to the letter used in the name of the variety. This may be due to the legal registration procedure for the variety.

al. 1948), which determines the percentage of rusted tissue.

Partial resistance in the field was assessed using the coefficients of infection (CI) and the average coefficient of infection (ACI). The coefficient of infection was calculated by multiplying the severity value by 0.10, 0.25, 0.50, 0.75 or 1.00 for host response ratings of resistant (R), moderately resistant (MR), moderately resistant-moderately susceptible (M), moderately susceptible (MS) and susceptible (S), respectively, following Pathan and Park (2006). The coefficient of infection at each location was used individually to assess the partial resistance level to the yellow rust races under the field weather conditions of that location. Similarly, the overall partial resistance level was assessed through the ACI, by taking the average of the CI across all six locations. Varieties with ACIs of 0–20, 21–40 and 41–60 were taken to possess high, moderate and low levels of partial resistance, respectively. Varieties with ACI values above 60 were taken to be susceptible. Data on the expression of leaf tip necrosis (*ltn*) were recorded according to Navabi *et al*. (2005).

Data were statistically analyzed using analysis of variance (Gomez and Gomez, 1984) with the statistical software R and MS Excel. Diversity for disease resistance among the varieties was assessed through cluster analysis based on the disease parameters, using the computer software NTSYSpc.

Results

Overall disease pressure

Highly significant (P<0.01) differences for host reaction, rust severity and coefficients of infection, were observed across locations with highly significant (P<0.01) variations for these parameters among varieties. An adequate disease level was reached at all locations, as evidenced by the severity of yellow rust on 'Morocco'. A severity of 100% occurred in the variety 'Morocco' at CCRI, Pirsabak and HARS, Abbottabad, while a lower severity was recorded at ARS, Bannu where the maximum severity reached 50%. Disease severity at AUP and NIFA, Peshawar was 70% and 80%, respectively.

Among test locations, CCRI, Nowshera had the maximum disease pressure, with none of the wheat varieties rated as having 0% severity. Numbers of varieties with 0% severity at the other locations were: five at AUP, Peshawar; 18 at NIFA, Peshawar; 19 at ARI; Mingora 2 at HARS, Abbottabad and 10 at ARS, Bannu. The minimum disease severity was 0% at all locations except at CCRI, Pirsabak, where it was 5% for the variety Chakwal-86. The maximum severity for the tested varieties at the different locations (excluding the susceptible control) was 80% at AUP; 70% at NIFA, Peshawar; 80% at CCRI, Pirsabak; 60% at ARS, Bannu; 90% at HARS, Abbottabad, and 50% at ARS, Bannu.

All types of host reactions and their combinations were observed (Table 2). 'Morocco' showed a susceptible reaction at CCRI, Pirsabak, ARI, Mingora and HARS, Abbottabad, and an MSS reaction at AUP, NIFA, Peshawar and ARS, Bannu. None of the varieties displayed a uniform host reaction at all locations. Host reaction phenotypes displayed by the 37 tested varieties remained between immune and MS, except for WL-711 at CCRI, Pirsabak where it produced a susceptible host reaction. Of the varieties, five were immune at AUP, 18 at NIFA, Peshawar, 19 at ARI, Mingora, two at HARS Abbottabad and nine at ARS Bannu. Similarly, none of the varieties had an incompatible host-pathogen interaction at all locations, which made it possible to assess their partial resistance behavior. Host reaction phenotypes displayed by the varieties remained between immune and MS, except for WL-711 at CCRI, Pirsabak where the reaction was susceptible. Five varieties were immune to yellow rust at AUP, 18 at NIFA, Peshawar, 19 at ARI, Mingora, two at HARS Abbottabad and nine at ARS Bannu. No variety was immune at CCRI, Pirsabak Six varieties produced an MR reaction at AUP, Peshawar; two at NIFA, Peshawar; one at CCRI, Pirsabak; three at ARI, Mingora; one at HARS Abbottabad and two at ARS, Bannu, with one R (resistant) reaction. This suggests that CCRI, Pirsabak was the location with the greatest disease pressure and probably, diverse virulence types.

Coefficients of rust infection

Coefficients of rust infection for varieties along with the susceptible control 'Morocco' are presented in Table 3. Across locations, the greatest CI values of 'Morocco' were found at CCRI, Pirsabak and HARS, Abbottabad (100), followed by ARI, Mingora (90), while it was lowest (40) at ARS, Bannu. The CI values were converted to the ACI for assessment of partial resistance by taking an average across locations. Based on the ACI, wheat varieties were assigned to four partial resistance groups. Most varieties (27) were in the first group (ACI 0–20), and these included the locally recommended varieties like Saleem-2000 (ACI 8), Fakhre-Sarhad (ACI 2), Tatara (ACI 3) and Karwan (ACI 5) along with the partial resistance control Frontana (ACI 1). Varieties with an ACI in the range of 0–5 were considered to have vertical resistance because of their low level of disease severity, found only at one or two locations. Nine varieties were in the second group (ACI 21–40). Only WL-711 (ACI 41) was in the third category (ACI 40–60), while 'Morocco' (ACI 78) was in the highest ACI category, which lacked any partial resistance. Most varieties had lower ACI values, signifying a better partial resistance. However, individual CI values at some sites were even greater.

As regards across-location CI values, 'Morocco' had the highest CI value at all locations except ARS, Bannu, where Punjab-96 had a CI value equal to that of 'Morocco' (44). Among the tested varieties, WL-711 produced the highest CI values at NIFA, Peshawar, CCRI, Pirsabak and ARI, Mingora. Kiran-95 had the highest CI value at HARS, Abbottabad followed by Shaheen-94. Overall, WL-711 had the highest CI at most locations, with a maximum ACI of 41, among the tested varieties. The minimum and maximum CI values across locations were different for different varieties (Table 3). Based on overall CI values along with the ACI, Kohsar-93, Bakhtawar-92, Saleem-2000, Fakhre-Sarhad, Tatara, Frontana and Karwan had the lowest CI values.

Leaf tip necrosis

Leaf tip necrosis (*ltn*) is reported to be associated with the wheat gene *Yr18*. This gene confers partial resistance to stripe rust (Singh, 1992). The data on *ltn* were recorded on flag leaves using a 0–4 scale, whereas only category 2 was considered acceptable. Data on *ltn* categories are shown in Table 2. Of the locations, at HARS, Abbottabad, none of the lines had an *ltn* category greater than 1, while at ARS, Bannu and ARI, Mingora four varieties were classified as *ltn* category 2. The expression of *ltn* of category-2 was found most common at AUP and NIFA, Peshawar. The susceptible control 'Morocco' did not produce any *ltn* at any location. Among the varieties tested, Suleman-96 and Sindh-81 had relatively stable *ltn* phenotypic expression across locations (detailed data not shown). The distribution of various *ltn* categories for these varieties was almost the same at AUP and NIFA.

Diversity among the tested varieties

Cluster analysis based on the disease parameters is shown in Fig. 2. 'Morocco' was separated with maximum distance from all the other varieties, while these other varieties were grouped into four clusters. The first cluster consisted of ten varieties, the second of three, the third of five varieties, including the well-documented partially resistant variety Frontana clustered with Kohsar-93, Karwan, Tatara and Fakhre-Sarhad, and the fourth cluster consisted of 19 varieties. Considerable diversity was observed for levels of partial resistance among the introduced winter wheat breeding lines.

Discussion

The partial resistance of commercially released wheat varieties was assessed in the field by determining their average coefficient of infection as described by Pathan and Park (2006). Differences were found across locations and between varieties for host reaction, disease severity and coefficient of infection. This is evidence that these locations had different disease pressures for stripe rust and that the status of the disease was not the same at all locations. Disease pressure was assessed using disease severity for the susceptible control variety, which indicated that adequate but non-uniform disease levels occurred at all locations. Disease pressure was greatest at CCRI, Pirsabak and at HARS, Abbottabad, followed by ARS, Bannu, while disease pressure was lower at ARS, Bannu, based on the disease severity of all the varieties tested along with susceptible control 'Morocco'. Yellow rust is thought to be affected by weather conditions (Coakley, 1978; de Vallavieille-Pope *et al.,* 1995), with reduced levels of infection at locations with higher temperatures (Newton and Johnson, 1936). Variability in virulence at varying locations has also been reported across locations for yellow rust populations (Bahri, 2008). The variability in disease pressure across the locations could be explained by differences in the weather and in the agro-climatic features of these locations and variation in the yellow rust populations. The tested locations have different climatic features (Khalil and Jan, 2003). Thus the tested locations had enough disease pressure to assess the level of partial resistance in these varieties.

Table 2. Yellow rust host responses, leaf tip necrosis (*ltn*) category, and disease severity for 37 wheat varieties and the highly susceptible variety 'Morocco', evaluated across six locations in Pakistan during 2006–2007.

Disease severity	Location[a]						
	AUP	NIFA	CCRI	ARI, Mingora	HARS, Abbottabad	ARS, Bannu	Location mean
Host response							
Immune (I)	5	18	0	19	2	9	-
Resistant (R)	0	2	0	4	0	1	-
Moderately resistant (MR)	6	2	14	3	1	2	-
Moderately resistant- Moderately susceptible	14	14	19	5	28	22	-
Moderately susceptible	11	0	3	4	6	0	-
M-SS Combination	2	2	0	2	0	4	-
Susceptible (S)	0	0	2	1	1	0	-
ltn category							
Category 0	1	1	3	3	8	3	
Category 1	25	25	29	30	29	30	-
Category 2	11	11	5	4	0	4	-
Category 3	0	0	0	0	0	0	-
Rust severity							
Severity in 'Morocco'	70	80	100	90	100	50	82
Maximum severity	80	70	80	60	90	50	-
Minimum severity	0	0	5	0	0	0	-
Location mean	33	20	43	13	49	19	30
Number of varieties in each group							
0% disease severity	5	18	0	19	2	10	0
1–20% severity	9	7	11	14	5	15	13
21–40% severity	13	4	9	2	10	11	14
41–60% severity	6	5	11	2	7	1	10
61–80% severity	4	3	6	0	9	0	0

[a] ARS, Agricultural Research Station, Bannu; AUP, Agricultural Research Farm; NWFP, Agricultural University, Peshawar; NIFA, Nuclear Institute for Food and Agriculture, Peshawar; CCRI, Cereal Crop Research Institute, Pirsabak, Nowshera; ARI, Agricultural Research Institute, Mingora, Swat; HARS, Hazara Agricultural Research Station, Abbottabad.

Table 3. Coefficients of yellow rust infection of 37 wheat varieties and the highly susceptible variety Morocco, evaluated at six locations of Pakistan during 2006–2007.

Wheat variety	AUP	NIFA	CCRI	ARI, Mingora	HARS, Abbottabad	ARS, Bannu	ACI
First group (0–20)							
Frontana	0	0	5	0	0	0	1
Fakhre-Sarhad	1	0	10	0	0	0	2
Kohsar-93	0	0	5	0	5	2	2
Tatara	0	0	10	0	10	0	3
Nowshera-96	4	1	20	5	25	0	9
Bakhtawar-93	15	0	5	1	5	5	5
Karwan	3	0	15	0	15	0	5
Bahawalpur-95	8	0	30	0	3	0	7
Suleman-96	8	0	3	0	30	0	7
Chakwal-86	8	0	1	0	20	15	7
Saleem-2000	15	0	5	0	15	10	8
Parwaz-94	30	0	25	0	3	0	10
Kohinoor-83	30	0	10	0	23	0	10
Watan-94	23	0	3	0	25	15	11
Zardana-89	15	0	10	0	35	5	11
Rohtas-90	0	1	13	10	20	26	12
Pasban-90	0	25	8	0	20	20	12
Soughat-90	30	1	5	0	35	0	12
Shahkar-95	30	5	10	0	20	10	13
Kohistan-97	30	0	15	0	35	35	19
Sarsabz	3	0	15	20	35	10	14
Zargoon-79	8	5	14	8	40	15	15
Punjab-96	4	0	15	1	25	44	15
Kaghan-93	23	0	30	0	20	20	15
Sind-81	30	8	30	1	26	15	18
Faisalabad-85	40	15	30	2	20	10	20
Blue Silver	30	0	25	23	30	10	20
Second group (21–40)							
Pak-81	30	20	25	0	53	3	22
Maxi-Pak	53	20	15	5	35	10	23
Faisalabad-83	30	35	30	5	35	10	24
Kirin-95	19	15	20	15	68	16	25
Inqilab-91	15	35	10	30	40	20	25
Sariab-92	35	30	35	8	30	15	25
Pirsabak-91	8	30	60	10	45	10	27
Shaheen -94	9	31	53	2	60	10	27
Tandojam-83	35	34	35	18	39	5	28
Third group (41–60)							
WL-711	18	53	80	53	35	5	41
Susceptible (>60)							
Morocco	61	70	100	90	100	44	78

ARS, Agricultural Research Station, Bannu; AUP, Agricultural Research Farm; NWFP, Agricultural University, Peshawar; NIFA, Nuclear Institute for Food and Agriculture, Peshawar; CCRI, Cereal Crop Research Institute, Pirsabak, Nowshera; ARI, Agricultural Research Institute, Mingora, Swat; HARS, Hazara Agricultural Research Station, Abbottabad.

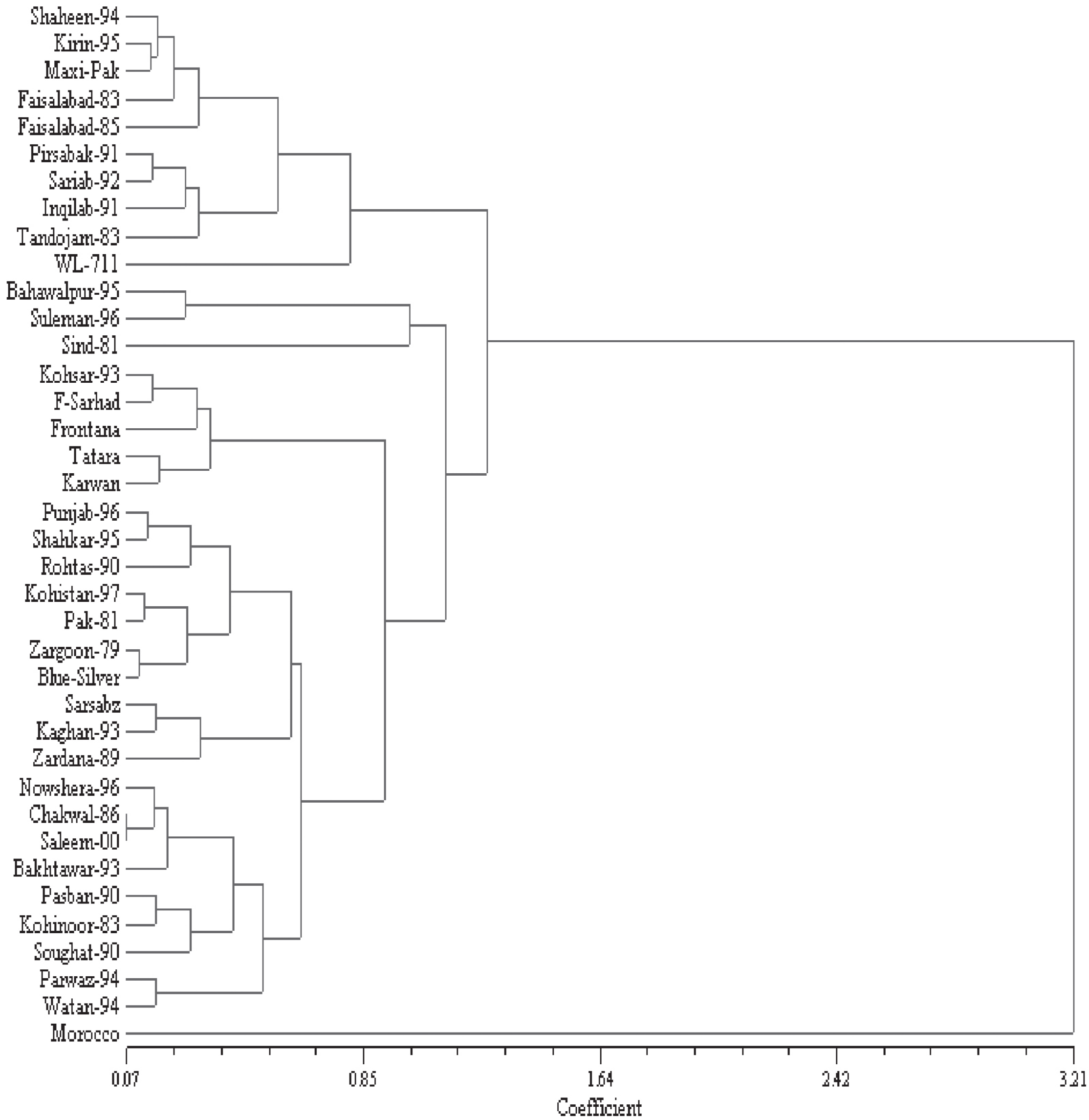

Fig. 2. Dendrogram of cluster analysis of wheat varieties based on yellow rust parameters assessed at field locations during 2006–2007.

Partial resistance

Field-based partial resistance levels of the wheat varieties were assessed through the ACI, calculated by taking the average of the CI values of each variety across all six locations. No variety was immune at all locations (ACI 0), thus enabling the partial resistance levels to be assessed. The susceptible control 'Morocco' had an ACI of 78, indicating a lack of any partial resistance. None of the 37 tested varieties were in this category. Twenty-seven of these varieties had ACI values of less than 20; these were considered to have high levels of partial resistance to stripe rust and were thus the most likely to be useful. Varieties with ACI values of 0–5 and a CI value of zero at all location except one were considered to have vertical resistance instead of partial resistance. These included only Fakhre-Sarhad and Frontana, which had CI of 10 and 5 respectively, at CCRI, Nowshera. This may be due to the presence of a low frequency of virulence to their vertical resistance at that specific location, resulting in a lower CI. Frontana is considered to contain Yr18/Lr34 genes, which confer partial resistance (Singh *et al.,* 2005). However, this variety may contain some vertical resistance genes, to which virulence did not occur at these locations except at CCRI, where it occurred with low frequency. Nine of the varieties had moderate levels of partial resistance (ACI 21–40), and these could be considered desirable varieties, if their performance is superior in other respects. Only WL-711 had an ACI of 41, with a low level of partial resistance, which was of relatively lower practical importance. Similarly, Inqilab-91, a variety previously well documented as being susceptible to stripe rust (Kisana *et al.,* 2003), also showed greater rust severity at most locations. Pedigree information for this variety revealed that it included WL-711 in its parentage. Thus these two varieties may contain *Yr27*, which was overcome by the pathogen (Kisana *et al*., 2003).

Partial resistance is expressed at the post-seedling stage of growth and is likely to be more durable than other forms of resistance (Singh and Rajaram, 1992). The development of virulence has, however, rendered some partially resistant lines ineffective (Park and McIntosh, 1994; Huerta-Espino and Singh, 1996). However, partial resistance, controlled by several additive minor genes, is generally more durable. The present study reveals the field-demonstrated partial resistance levels of these wheat varieties. Previously, Wigoire *et al.* (1999) carried out a similar study on the adult field resistance of different wheat lines. Some of these varieties are thought to have different *Yr* genes, conferring partial resistance. Of these genes, *Yr18* is common in CIMMYT lines (Singh, 1992), from which most of the varieties in Pakistan have been developed. The occurence of this gene has been confirmed through molecular markers (unpublished data, S. Jawad, A. Shah, 2008, NIFA). However, to fully elucidate the genes that control the partial resistance of these varieties, a comprehensive study would be required using molecular markers and controlled growth conditions. Several other researchers have also reported the existence of varying levels of partial resistance to stripe rust (Hovmøller, 2007), leaf rust (Winzeler *et al.,* 2000; Pathan and Park, 2006) and stem rust (Pathan and Park, 2007) in different wheat breeding lines and varieties. They further assessed the genetic factors involved in partial resistance and marked the occurrence of different genes for quantitative resistance. Similarly, Ali *et al.* (2007; 2009) identified potential sources of durable resistance to yellow rust in local and introduced wheat breeding lines. However, our study is the first attempt to elucidate the status of partial resistance levels in the varieties grown in northwest Pakistan.

Leaf tip necrosis (*ltn*) is closely associated with the genes *Yr18* and *Lr34*, which confer partial resistance to stripe rust and leaf rust, respectively (Singh, 1992; Singh *et al.,* 2007). Only *ltn* category 2 was considered desirable. Category 1, with a thin layer of necrosis, was seen in most of the varieties with this character. This was probably due to the normal physiological attributes of the varieties and to the time of data collection. Consequently, category 2 was considered the most desirable. Similarly, category 3, had necrosis covering more than half of the leaf, which is a negative attribute, since necrosis reduces the photosynthetic area of the leaf. During the present study, none of the varieties grown at HARS, Abbottabad were in category 2, while at ARS, Bannu and ARI, Mingora, four varieties were in this category. At AUP and NIFA, Peshawar, most of varieties were in this category. This may have been due to the fact that the temperature at HARS, Abbottabad was relatively low, suggesting that expression of this marker may be temperature-dependent. 'Morocco' did not produce *ltn* at any test location. Category 2 was recorded for Bahawalpur-95 at AUP, NIFA, Peshawar and CCRI, Pirsabak, while category 1 was recorded for this variety at the other locations. The varieties Suleman-69 and Sindh-81 had relatively stable expression of *ltn* across all locations except HARS, Abbottabad. The pattern of *ltn* expression was similar at AUP and NIFA, Peshawar. This could be due to similar climatic conditions of these locations, especially in terms of temperature.

Diversity among tested varieties was considerable in the disease parameters and cluster analysis based on partial resistance to stripe rust confirmed this diversity, which reflects their diversity at the genetic level. Kronstad (1996) proposed the use of wide genetic bases in cross breeding programs, in order to avoid uniformity of the resulting progenies and genetic monoculturing in any sense. Ali *et al.*

(2007) also reported varying degrees of partial resistance ("slow rusting") to stripe rust. The diversity recorded in this work may be exploited in further breeding for developing improved varieties with diverse resistance backgrounds. This will help to avoid mono-culturing in terms of resistance genes.

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Literature cited

Agarwal S., R.G. Saini and A.K. Sharma, 2003. Temperature-sensitive adult plant leaf rust resistance in bread wheat (*Triticum aestivum* L.). *Phytopathologia Mediterranea* 42, 89–92.

Akhtar M.A., I. Ahmad, J.I. Mirza, A.R. Rattu, U.H. Ehsan, A.A. Hakro and A.H. Jaffery, 2002. Evaluation of candidate lines against stripe and leaf rusts under national uniform wheat and barley yield trial 2000–2001. *Asian Journal of Plant Science* 1, 450–453.

Ali S., S.J.A. Shah and M. Ibrahim, 2007. Assessment of wheat breeding lines for slow yellow rusting (*Puccinia striiformis* West. *tritici*). *Pakistan Journal of Biological Science* 10, 3440–3444.

Ali S., S.J.A. Shah, I.H. Khalil, H. Raman, K. Maqbool and W. Ullah, 2009. Partial resistance to yellow rust in introduced winter wheat germplasm at the north of Pakistan. *Australian Journal of Crop Science* 3, 37–43.

Aquino P., F. Carrion and R. Calvo, 2002. Selected wheat statistics. In: *World Wheat Overview and Outlook 2002–2001*: *Developing No-Till Packages for Small-Scale Farmers*. (J. Ekboir, ed.). CIMMYT, Mexico DF. 52–62.

Bahri B.A. 2008. Adaptation et structuration spatiale des populations méditerranéennes de rouille jaune du blé (*Puccinia striiformis* f. sp. *tritici*). Thèse de doctorat, Université Paris-Sud 11, France.

Coakley S.M., 1978. The effect of climatic variability on stripe rust of wheat in the pacific northwest. *Phytopathology* 68, 207–212.

de Vallavieille-Pope C. and R.F. Line, 1990. Virulence of North American and European races of *Puccinia striiformis* on North American, world, and European differential wheat cultivars. *Plant Disease* 74, 739–743.

de Vallavieille-Pope C., L. Huber, M. Leconte and H. Goyeau, 1995. Comparative effects of temperature and interrupted wet periods on germination, penetration and infection of *Puccinia recondita* f. sp. *tritici* and *P. striiformis* on wheat seedlings. *Phytopathology* 85, 409–415.

Gomez K.A. and A.A. Gomez, 1984. *Statistical Procedures for Agricultural Research*. John Wiley & Sons, New York, NY, USA.

Huerta-Espino J. and R.P. Singh, 1996. Misconceptions on the durability of some adult plant resistance genes in wheat. *Proceedings of the 9th European and Mediterranean Cereal Rusts and Powdery Mildew Conference*, Lunteren The Netherlands, 109–111.

Hovmøller M.S., 2001. Disease severity and pathotype dynamics of *Puccinia striiformis* f. sp. *tritici* in Denmark. *Plant Pathology* 50, 181–189.

Hovmøller M.S., 2007. Sources of seedling and adult plant resistance to *Puccinia striiformis* f. sp. *tritici* in European wheats. *Plant Breeding* 126, 225–233.

Kisana S.N., Y.M. Mujahid and Z.S. Mustafa, 2003. *Wheat Production and Productivity 2002–2003. A Technical Report to Apprise the Issues and Future Strategies*. Published by National Agricultural Research Center, Agricultural Research Council, Islamabad, Pakistan. 19 pp.

Khalil I.A. and A. Jan, 2003. Agro-meteorology of Pakistan; Cropping Technology. National Book Foundation, Islamabad, Pakistan.

Kronstad W.E., 1996. Genetic diversity and the free exchange of germplasm in breaking yield barriers. CIMMYT, International Symposium on "Raising Yield Potential in Wheat: Breaking the Barriers", March 28–30, 1996, Obregon, Mexico.

Moschini R.C. and B.A. Pérez, 1999. Predicting wheat leaf rust severity using planting date, genetic resistance and weather variables. *Plant Disease* 83, 381–384.

Navabi A., R.P. Singh, J. Huerta-Espino, J.P. Tewari, 2005. Phenotypic association of adult-plant resistance to leaf and stripe rusts in wheat. *Canadian Journal of Plant Pathology* 27, 396–403.

Newton M. and T. Johnson, 1936. Stripe rust, *Puccinia glumarum,* in Canada. *Canadian Journal of Research* 14, 89–108.

Park R.F. and R.A. McIntosh, 1994. Adult plant resistances to *Puccinia recondita* f. sp. *tritici* in wheat. *New Zealand Journal of Crop and Horticultural Science* 22, 151–158.

Pathan A.K. and R.F. Park, 2006. Evaluation of seedling and adult plant resistance to leaf rust in European wheat cultivars. *Euphytica* 149, 327–342.

Pathan A.K. and R.F. Park, 2007. Evaluation of seedling and adult plant resistance to stem rust in European wheat cultivars. *Euphytica* 155, 87–105.

Peterson R.F., A.B. Campbell and A.E. Hannah, 1948. A diagrammatic scale for rust intensity on leaves and stems of cereals. *Canadian Journal of Research* 26, 496–500.

Singh R.P., 1992. Genetic association of leaf rust resistance gene *Lr34* with adult plant resistance to stripe rust in bread wheat. *Phytopathology* 82, 835–838.

Singh R.P., 1993. Resistance to leaf rust in 26 Mexican wheat

cultivars. *Crop Science* 33, 633–637.
Singh, R.P. and S. Rajaram, 1992. Genetics of adult plant resistance to leaf rust in 'Frontana' and three CIMMYT wheats. *Genome* 35, 24–31.
Singh R.P., H.W. William, J. Huerta-Espino and G. Rosewarne, 2004. Wheat rust in Asia: meeting the challenges with old and new technologies. "New directions for a diverse planet". *Proceedings of the 4th International Crop Science Congress,* 26 Sep–1 Oct 2004, Brisbane, Australia.
Singh R.P., J. Huerta-Espino, H.M. William, 2005. Genetics and breeding for durable resistance for leaf and stripe rust in wheat. *Turkish Journal of Agriculture and Forestry* 29, 121–127.
Singh D., R.F. Park and R.A. McIntosh, 2007. Characterization of wheat leaf rust resistance gene *Lr34* in Australian wheats using components of resistance and the linked molecular marker csLV34. *Australian Journal of Agricultural Research* 58, 1106–1114.
Smale M., R.P. Singh, K. Sayre, P. Pingali, S. Rajaram and H.J. Dubin, 1998. Estimating the economic impact of breeding nonspecific resistance to leaf rust in modern bread wheats. *Plant Disease* 82, 1055–1061.
Spielmeyer W., R.A. McIntosh, J. Kolmer and E.S. Lagudah, 2005. Powdery mildew resistance and *Lr34/Yr18* genes for durable resistance to leaf and stripe rust cosegregate at a locus on the short arm of chromosome 7D of wheat. *Theoretical and Applied genetics* 111, 731–735.
Stubbs R.W., J.M. Prescott, E.E. Saari and H.J. Dubin, 1986. *Cereal Disease Methodology Manual*. CIMMYT, Mexico D.F., Mexico, 46 pp.
Wagoire W.W., R. Ortiz, J. Hill and O. Stolen, 1999. Comparison of methods for calculating the heritability of adult field resistance to yellow rust and grain yield in spring wheat. *Theoretical and Applied Genetics* 99, 1075–1079.
Winzeler M., Á. Mesterházy, R.F. Park, P. Bartos, M. Csösz, H. Goyeau, M. Ittu, E. Jones, F. Löschenberger, K. Manninger, M. Pasquini, K. Richter, D. Rubiales, G. Schachermayr, A. Strzembicka, M. Trottet, O. Unger, G. Vida and U. Walther, 2006. Resistance of European winter wheat germplasm to leaf rust. *Agronomie* 20, 783–792.

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