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Research Article

Variability in wheat yield under yellow rust pressure in Pakistan

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Abstract: Wheat yield of 37 wheat varieties along with a susceptible check, Morocco, was studied under yellow rust pressure across 3 locations of North West Frontier Province (NWFP), Pakistan during 2007. Considerable high disease pressure, as revealed by yellow rust severity, was observed at all locations with the maximum (100%) at Cereal Crop Research Institute (CCRI), Nowshera. Disease severity ranged from 0% to 70% for the tested varieties while reached 100% for Morocco with S type of host response. We report the presence of sufficient variability across locations for both yield potential and yellow rust severity. Locations with maximum disease pressure had lower mean grain yield and vice versa. NIFA followed by AUP had higher mean grain yield (5533 kg ha^{-1} and 4292 kg ha^{-1}, respectively) with lower maximum disease severity values (70% and 80%, respectively). CCRI had higher disease pressure (100% severity for Morocco) with lower mean grain yield (3676 kg ha^{-1}). Bahawalpur-95, Suleman-96, Kohsar-93, Fakhre-Sarhad, Tatara, and Frontana had relatively stable severity across locations in a range of 0% to 10%. Based on overall traits, Kohsar-93, Bakhtawar-92, Saleem-2000, Fakhre-Sarhad, Tatara, and Karwan had better yield and lower yellow rust severity and is recommended for cultivation and further breeding exploitation.

Key words: *Puccinia striiformis*, wheat varieties, multi-locations, yield variability

Introduction

Yellow/stripe rust of wheat, caused by *Puccinia striiformis* Westendorf f. sp. *tritici,* is an important disease and severe infestation has been reported both in Pakistan (Saari et al. 1995; Kissana et al. 2003) and elsewhere (Zadok and Rijsdijk 1984; Singh et al. 2004). In Pakistan, almost 70% of the acreage under wheat is prone to the disease (Aquino et al. 2002). This biotroph reduces the total photosynthetic area, utilize plant's assimilates and interrupt with normal growth of host, leading to reduction in yield. The reduction in yield due to the disease may lead to severe economic losses as reported for Pakistan (Kissana et al. 2003) and elsewhere (Zadok and Rijsdijk 1984; Long 2007). Thus control of the disease is crucial for the national as well as global food security.

The development and deployment of resistant cultivars is considered to be the only economic and environment friendly disease control measure (Stubbs et al. 1986; Smale et al. 1998; Singh et al. 2004; Pathan and Park 2007). The diversity in pathogen may, however, vary considerably across regions and over years (Stubbs 1985; de Vallavieille-Pope and Line

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1990; Bayles et al. 2000; Shah et al. 2006). Similarly, a negative relationship between yields and yield components with disease severity have been reported (Allen et al. 1963; Ali et al. 2007), suggesting variability in yield potential according to yellow rust pressure. Little is known about the performance of Pakistani wheat varieties for yield related traits in special reference to yellow rust pressure and its variability across locations, which could provide an insight to the status of these varieties under diseased conditions. A regular assessment of breeding materials and approved varieties for their yield potential in reference to yellow rust pressure across locations is crucial. This could provide an evaluation of existing and old varieties, which could be utilized as resistance sources or variety-mixture for disease management. The present study was thus designed to assess the yield potential of 37 wheat varieties across 3 locations of NWFP, with special reference to yellow rust.

Materials and methods

Wheat yield potential under yellow rust pressure was assessed across 3 locations of North West Frontier Province (NWFP), Pakistan, during wheat growing season 2006-07. NWFP is situated in the north-west of Pakistan and is considered to be more prone to yellow rust epidemics due to cool climatic conditions (Akhtar et al. 2002; Chatrath et al. 2007). Thirty seven wheat varieties (Table 1), released by different agricultural research institutes of Pakistan along with Morocco, as a susceptible check, was grown across 3 locations of NWFP, Pakistan, namely Agricultural Research Farm, NWFP Agricultural University Peshawar (Coordinates: 34° 1'N, 71°28'E, Elevation: 1199 ft), Nuclear Institute for Food and Agriculture Peshawar (Coordinates: 34° 0'N, 71°42'E, Elevation: 997 ft), and Cereal Crop Research Institute Nowshera(Coordinates: 34° 1'N, 72° 2'E, Elevation: 958 ft), abbreviated in this article as AUP, NIFA, and CCRI, respectively.

Seed of each entry was planted in strips of small adjacent plots consisted of 2 rows plot^{-1}, with a row length of 1 m separated by 0.3 m. Morocco, a fully susceptible wheat variety, was sown around entries and after each 4 entries as spreader as well as to serve for assessment of rust pressure at the respective location. Remaining cultural practices were followed uniformly for all the entries as recommended at each location. Disease scoring was made at the stage immediately after heading. Estimates of severity were measured according to Modified Cobb Scale (Paterson et al., 1948), which is used to determine the percentage of possible tissue rusted and was evaluated from 1% to 100%. Yellow rust severity of Morocco and the tested varieties was used to estimate yellow rust pressure and its variability at the respective location. Data on grains spike^{-1}, 1000-grain weight (g), biological yield (kg ha^{-1}), harvest index (%), and grain yield (kg ha^{-1}) was calculated following Hassan (2004). Spikes from 10 randomly selected plants were threshed manually to calculate number of grains per spike and average was calculated for each entry. Randomly selected thousand grains from each entry were counted with a seed counter and were weighed with an electronic balance to calculate 1000-grain weight. The dry biomass of entire harvested plots was weighed with an electronic balance to calculate biological yield per plot for each entry. Similarly, grain weight from the threshed spikes was measured with an electronic balance to calculate grain yield per plot for each entry. Per plot yield for both grain and biological yield was converted into per hectare yield. Harvest index (HI) was estimated by dividing grain yield by biological yield, stated as percentage.

Statistical analysis of the data was carried out for 3 locations using analysis of variance technique (Gomez and Gomez, 1984), through computer packages R and MSTAT-C. Regression curve was estimated for disease severity with grain yield and 1000-grain weight. Similarly, box-plots were generated through Microsoft Excel 97 and statistical software R.

Results

Scrutiny of the data revealed highly significant differences for the tested varieties across locations ($P < 0.01$) for yellow rust severity, grains spike^{-1}, grain yield, biological yield, and harvest index, while significant variations ($P < 0.05$) for 1000-grain weight, as revealed by statistical analysis. Results for number of grains spike^{-1}, 1000-grain weight, biological yield, and harvest index are shown as box plots to compare the overall variability across the 3 locations.

Table 1. Wheat varieties assessed for yield potential in relation to yellow rust pressure across NWFP, during 2006-07.

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

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

Yellow rust severity (%)

The high yellow rust severity recorded for the susceptible check Morocco at the tested 3 locations represented the high disease pressure at these locations (Table 2). Among the tested locations yellow rust severity of Morocco was maximum at CCRI (100%) and minimum at NIFA (70%).

Yellow rust severity was not uniform across the 3 locations for all the varieties. The maximum disease pressure was found to be at CCRI with none of the

Table 2. Grain yield and yellow rust severity (RS) of wheat varieties tested across NWFP, during 2007.

	AUP		NIFA		CCRI		Mean	
	Grain Yield (kg ha^{-1})	RS (%)	Grain Yield (kg ha^{-1})	RS (%)	Grain Yield (kg ha^{-1})	RS (%)	Grain Yield (kg ha^{-1})	RS (%)
Shaheen-94	5183	20	5995	60	3175	70	4784	50
Bahawalpur-95	3883	10	3570	0	2842	40	3432	17
Suleman-96	3975	10	5518	0	4125	10	4539	7
Kohsar-93	4842	0	4335	0	2483	20	3887	7
Punjab-96	4375	5	3597	0	2700	30	3557	12
Nowshera-96	2167	5	5483	5	4450	40	4033	17
Chakwal-86	4667	10	3757	0	3758	5	4061	5
Kirin-95	6100	40	4755	30	3608	80	4821	50
Kohistan-97	6058	40	4863	0	3675	60	4866	33
Sind-81	4850	40	5542	15	4000	60	4797	38
Maxi-Pak	4400	60	6433	40	2875	60	4569	53
WL-711	5950	70	7217	60	2008	80	5058	70
Zargoon-79	3950	30	6992	10	4497	30	5146	23
Sarsabz	4125	10	5043	5	1500	60	3556	25
Zardana-89	3850	30	6503	0	3175	40	4509	23
Kaghan-93	1967	30	5335	0	3125	60	3476	30
Rohtas-90	1592	0	7193	5	2842	50	3876	18
Pasban-90	1417	0	4463	50	3642	30	3174	27
Pirsabak-91	2992	30	5617	60	2925	80	3844	57
Inqilab-91	2850	30	5762	70	1167	40	3259	47
Faisalabad-83	6542	60	6817	70	5583	60	6314	63
Faisalabad-85	3208	70	6040	30	3742	60	4330	57
Soughat-90	4517	60	4775	5	4392	20	4561	28
Bakhtawar-92	3800	30	4713	0	4808	10	4441	13
Blue Silver	4417	40	5793	0	4683	50	4964	30
Parwaz-94	4917	60	4800	0	2967	50	4228	37
Kohinoor-83	2750	60	4392	0	4108	40	3750	33
Shahkar-95	6150	40	5307	10	4325	20	5261	23
Watan-94	3533	30	4945	0	2925	10	3801	13
Tandojam-83	6233	70	6432	70	3425	70	5363	70
Sariab-92	6200	70	7947	60	6008	70	6718	67
Pak-81	4783	60	7145	40	4467	50	5465	50
Saleem-2000	6025	30	7223	0	4692	10	5980	13
Fakhre-Sarhad	5317	5	5640	0	4858	20	5272	8
Tatara	6633	0	6003	0	6058	20	6232	7
Frontana	3092	0	4353	0	3100	10	3515	3
Karwan	2042	10	4130	0	3433	30	3202	13
Morocco	3750	80	5833	70	3525	100	4369	83
Mean	**4292**	**33**	**5533**	**20**	**3676**	**43**	**4500**	**32**

AUP = Agricultural Research Farm, NWFP Agricultural University, Peshawar:
NIFA = Nuclear Institute for Food and Agriculture, Peshawar;
CCRI = Cereal Crop Research Institute, Pirsabak, Nowshera

variety having 0% severity, while AUP and NIFA had 5 and 18 varieties with 0% severity, respectively. The maximum severity for the tested varieties (excluding susceptible check) was 70% for Faisalabad-85 at AUP; 70% at NIFA for Inqilab-91, Faisalabad-83, and Tandojam-83; 80% at CCRI. Bahawalpur-95, Suleman-96, Kohsar-93, Fakhre-Sarhad, Tatara, and Frontana had relatively low and stable yellow rust severity across the 3 locations of 0% to 10%. The minimum yellow rust severity was 0% at all locations except at CCRI, where it was 5% for Chakwal-86. This severity of 0% was recorded for Kohsar-93, Rohtas-90, Pasban-90, Tatara, and Frontana at AUP and for Bahawalpur-95, Suleman-96, Kohsar-93, Punjab-96, Zardana-89, Kaghan-93, Bakhtawar-92, Blue Silver, Parwaz-94, Kohinoor-83, Watan-94, Salee-2000, Fakhre-Sarhad, Tatara, Frontana, and Karwan at NIFA.

Yield and yield components

Data on different parameters of yield potential are presented in Figures 1 and 2 and Table 2. The variability in number of grains spike^{-1} was minimum at AUP with a positive skewness, while almost equal at NIFA and CCRI (Figure 1). The maximum value at CCRI and AUP were 74 and 70, respectively, recorded for Tatara, while it was the maximum for Bahawalpur-95 at NIFA (72). Among the varieties, maximum mean number of grains spike^{-1} was produced by Bahawalpur-95, Chakwal-86, and Tatara (62), followed by Pak-81 (60) and Kohsar-93 (58). WL-711 produced the minimum number of grains spike^{-1} (32) followed by Tandojam-83 (35) and Faisalabad-85 (36). The minimum number of grains spike^{-1} was 22 at NIFA (recorded for Sarsabz); 24 at CCRI (for WL-711), and 28 at AUP (for Fakhre-Sarhad). Relatively higher number of grains spike^{-1} was recorded for Kaghan-93 at NIFA (69), Chakwal-96 (86), and Shahkar-95 (68).

Variability in 1000-grain weight was more prominent across locations (Figure 1). Mean 1000-grain weight had a greater range and a negative skewness at AUP with the maximum value of 64.3 g for Fakhre-Sarhad, while the minimum for Kohistan-97 (19.3 g). Similarly, the variability in 1000-grain weight was lower at CCRI with a maximum of 35.4 g (Maxi-Pak) and a minimum of 17.2 (Rohtas-90). Grain weight at NIFA, however, was superior to that of CCRI. However, the range was lower than CCRI, if the 2 maximum values are considered as outliers. The overall range was from 35.3 g (Morocco) to 56.0 g (WL-711). Varieties with more severity tended to be having lower 1000-grain weight.

Biological yield was relatively more variable across locations (Figure 2). A negative skewness was recorded for all the 3 locations with a maximum variability at NIFA. The skewness was most prominent at CCRI. The biological yield at AUP was in the range of 7500 kg ha^{-1} (Punjab-96) to 18533 kg ha^{-1} (Kirin-95, WL-711, Blue Silver, Shahkar-95, Sariab-92, Saleem-2000, and Tatara). It ranged from 6333 kg ha^{-1} (Pasban-90) to 18333 kg ha^{-1} (Faisalabad-93 and Shahkar-95) at NIFA. Similarly, at CCRI it was maximum for Tatara (18333) while minimum for Maxi-Pak, Faisalabad-93, and Watan-64 (8333 kg ha^{-1}). Among the varieties, the maximum mean biological yield was 15278 (kg ha^{-1}), which was recorded for Kirin-95, WL-711, Blue Silver, Shahkar-95, Sariab-92, Saleem-2000, and Tatara.

Variability in harvest index was maximum at NIFA with almost equal variability at AUP and CCRI, whereas 1 outlier was observed at each of these 2 locations (Figure 2). The minimum harvest index at AUP was recorded for Kaghan-93 and Pasban-90 (17), while the maximum was for Punjab-96 (59). Similarly, harvest index ranged from 23 (Chakwal-86) to 85 (Pirsabak-91) at NIFA. The minimum HI at CCRI was for Sarsabz (11%) and the maximum was 67% for Faisalabad-83.

The data on grain yield are given in Table 2 along with the data on yellow rust severity. The maximum mean grain yield was produced at NIFA (5533 kg ha^{-1}) followed by AUP (4292 kg ha^{-1}). CCRI had the minimum grain yield among the tested locations (3676 kg ha^{-1}). The mean grain yield among the varieties ranged from 3174 kg ha^{-1} to 6718 kg ha^{-1}. The maximum mean grain yield was produced by Sariab-92 (6718 kg ha^{-1}), followed by Faisalabad-83 (6314 kg ha^{-1}), and Tatara (6232 kg ha^{-1}). However, Saleem-2000 (5980 kg ha^{-1}), Pak-81 (5465 kg ha^{-1}), and Tandojam-83 (5363 kg ha^{-1}) also had relatively better grain yield. The maximum grain yield was recorded for Sariab-92 (7947 kg ha^{-1}) followed by

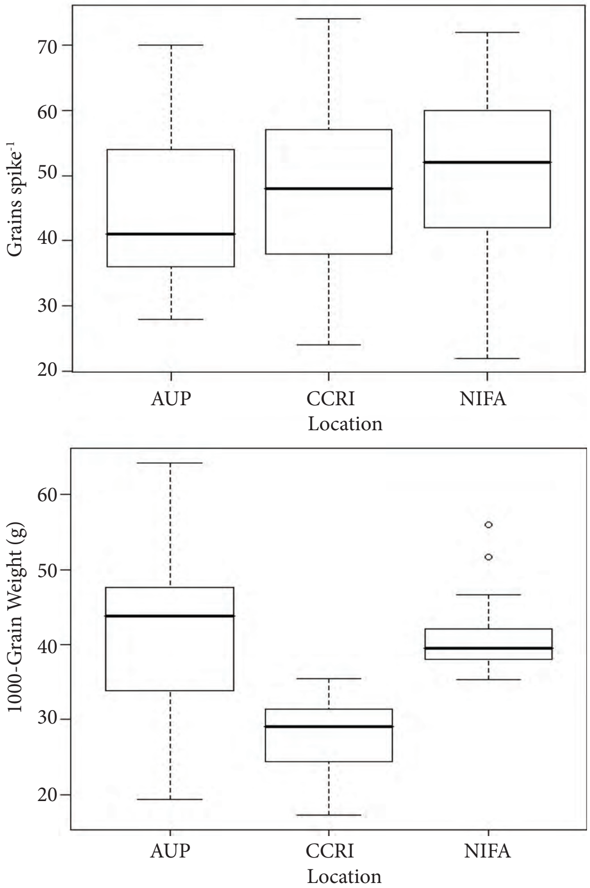

Figure 1. Box plot for grains spike^{-1} (above) and 1000-grain weight (below) of wheat varieties across 3 locations of NWFP, during 2006-07.

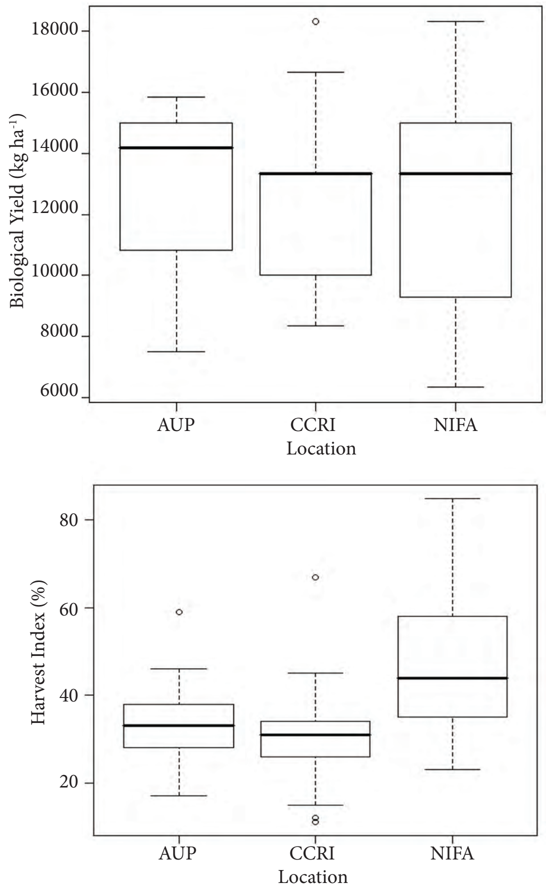

Figure 2. Box plot for biological yield (above) and harvest index (below) of wheat varieties across 3 locations of NWFP, during 2006-07.

Saleem-2000 (7223 kg ha^{-1}), WL-711 (7217 kg ha^{-1}), and Rohtas-90 (7193 kg ha^{-1}) at NIFA. Grain yield at AUP ranged from 1417 kg ha^{-1} for Pasban-90 to 6333 kg ha^{-1} for Tatara. The maximum grain yield at NIFA was 7947 kg ha^{-1} (for Sariab-92), while the minimum was 3570 kg ha^{-1} for Bahawalpur-95, which is still better than that of the other 2 locations. Grain yield of these varieties at CCRI, on the other hand, ranged from 1167 kg ha^{-1} for Inqilab-91 to 6058 kg ha^{-1} for Tatara.

Association between rust severity and yield parameters

The association of grain weight and grain yield with yellow rust severity was assessed through regression analysis only at CCRI, Nowshera, where rust severity was maximum. Sariab-92 had relatively greater severity (60) but with better grain yield and grain weight, which could be due to its tolerance behavior. Thus it was excluded from the analysis, considering it as an outlier. Similar was the case for Frontana, which was considered to be partially resistant but not adapted to our climate and had relatively poor yield potential. For the rest of varieties, a negative linear relationship was found between yield potential traits and rust severity (Figure 3). Varieties with lower yellow rust severity, like Tatara, Saleem-2000, and Fakhre-Sarhad had relatively higher grain yield and 1000-grain weight accordingly.

Discussion

Enough variability existed across the 3 locations for yellow rust severity and yield related traits.

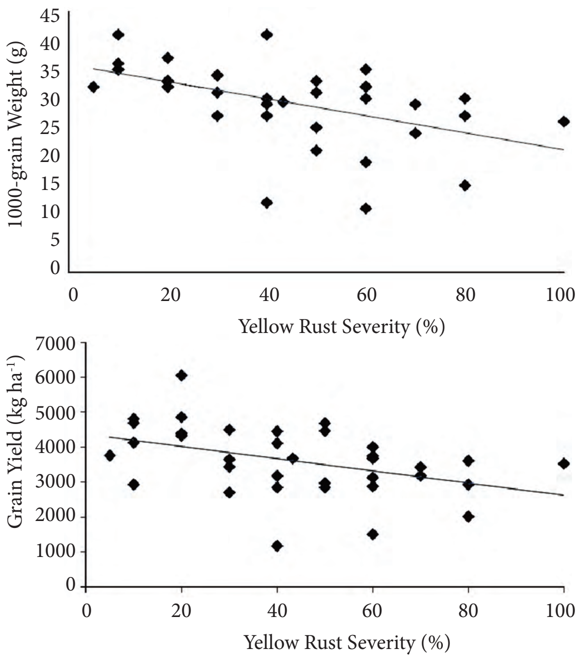

Figure 3. Association of 1000-grain weight (above) and grain yield (below) with rust severity for selected wheat varieties tested during 2006-07.

Variability among varieties may be attributed to the diverse genetic background of these varieties with different pedigrees. Variability across locations could be attributed to variations in terms of humidity and temperature in the microclimate of crop present at these locations.

Yellow rust pressure was non-uniform across the 3 locations as revealed by severity of susceptible check Morocco and other varieties. The severity of Morocco showed the presence of enough rust pressure across the 3 locations with a maximum at CCRI and a minimum at NIFA. The yellow rust pathogen is affected by different climatic conditions (Coakley 1978; de Vallavieille-Pope et al. 1995; de Vallavieille-Pope et al. 2002) along with the fact that its dispersal is considered to be favored by winds (Moschini and Pérez 1999). The 3 locations were different in terms of crop micro-climate, which could affect the development of yellow rust. The location of CCRI, Nowshera at the bank of river Kabul provides an open way to the pathogen entrance to the region along with the formation of relatively more humid micro-climate, which makes the pathogen better flourish. Similarly, the presence of a huge number of lines at the institute, including susceptible lines, may also serve in increasing disease pressure. Reduced rust pressure at NIFA may be attributed to the early sowing of the crop with the crop becoming mature earlier and thus there was a kind of escape to avoid yellow rust. Villaréal et al. (2002) also reported that natural epidemics in France occur usually in the northwest and occasionally in the south and are especially damaging when springs are cool accompanied with extended rainy seasons.

Rust severity of the tested varieties could be used to assess the resistance behavior of the plant (Ali et al. 2007). The tested varieties had highly significant differences for yellow rust severity and were grouped on the basis of their average rust severity into 3 groups. The first group (with rust severity of 0%-20%) having 14 varieties, were considered to have relatively better resistance behavior in terms of rust severity. The second group of 12 varieties (with yellow rust severity of 21%-40%), were considered to have moderately resistance behaviors in terms of yellow rust severity. The third group contained seven varieties which had their yellow rust severity values ranged from 41% to 60%, considered to be having poor resistant level. Only 4 varieties had yellow rust severity greater than 60% and were considered as susceptible. Previously, Mirza et al. (2000), Shah et al. (2003), and Ali et al. (2009) also evaluated some wheat breeding lines and introduced material for yellow rust resistance based on their rust severity and reported significant differences in their resistance levels.

Statistical analysis of the data revealed that the locations had varying effect on yield and yield components. Similarly, the tested varieties had highly significant differences for all the traits. This reveals an inconsistent behavior of the varieties across the locations.

Yield potential is generally assessed through grain yield and yield components, which themselves are complex characters and are considered to be the cumulative result of different physiologic processes. Grains per spike (Shah et al. 2007; Fonseca and Patterson 1968) and grain weight (Tammam et al. 2000) are considered to be important yield contributing traits. Similarly, biological yield is important in certain socio-economic setups, where biomass of wheat is used as a commercial product and provides appropriate revenue to the farmers (Arif et al. 2006). However, a balance should be sought between grain yield and biomass, because increased biomass could generally make the plants more susceptible to the pathogen attack. Harvest index, on the other hand, has been used by different researchers (Hassan et al. 2006; Inamullah et al. 2006) as a potential trait for determining yield potential (Calderini et al. 1995), which represents a balance in source and sink relationship and is considered to be a cumulative index resulting from overall photosynthetic and physiological phenomena. Enough variability was observed in these traits across the tested locations, representing variability in overall yield potential of these varieties in relation to yellow rust pressure.

Considerable amount of variations were prevalent across these locations and among varieties, which lead to the inconsistent behavior of the varieties across locations for various agronomic traits. The variation among the tested varieties could be attributed to their diverse genetic background. Previously, Inamullah et al. (2006) and Luthra and Singh (1974) also reported significant differences among wheat breeding lines, while studying their genetics. The inconsistent performance of these varieties across locations may be due to differences in soil fertility and air temperature at anthesis and grain-filling periods at the 2 locations (Khalil et al. 2005). The selected locations had relatively different micro-climates in terms of temperature and relative humidity, as discussed by Khalil and Jan (2003). Grain filling and grain weight have been reported to be affected by temperature and total degree days (Wiegand and Cuellar 1981), variations in these parameters could be explained by variability in these climatic factors across locations. Previously, Singh and Byerlee (1990) have also reported variability for these traits among wheat lines across locations and over years.

On overall basis, NIFA had the maximum mean grain yield and yield components with lower rust severity, followed by AUP. CCRI, Pirsabak had the minimum location mean grain yield value with the maximum rust severity. Among the tested varieties, Tatara, Fakhre-Sarhad, and Saleem-2000 were considered to be having better yield potential along with lower yellow rust severity. The lower yield of Inqilab-91 can be reflective of its disease susceptibility and hence may be a cause of its lower yield. The variety has been reported to be having Yr27 (Kisana et al. 2003), virulence to which was present at these locations during the season (Pakistan Agricultural Research Council 2007). Sariab-92, in contrast, had better yield potential but higher susceptibility to yellow rust. This may be due to some tolerance capacity of the variety, which must be confirmed in detailed studies and could be exploited for further breeding.

Different researchers have reported strong negative relationship of yield and yield components with disease severity (Allen et al. 1963; Sunderman and Wise 1964). However, most recently Ali et al. (2007) have reported a negative relationship with a weaker strength for some breeding lines with partial resistance. During the present study a negative linear relationship was estimated between yield potential traits and yellow rust severity, for only one location, CCRI, where yellow rust severity was maximum. Varieties with lower yellow rust severity, like Tatara, Saleem-2000, and Fakhre-Sarhad, had relatively higher 1000-grain yield and grain weight accordingly. However, Sariab-92 had greater severity but with better grain yield and grain weight, which could be due to its tolerance behavior. Thus it was excluded from the analysis, considering it as an outlier. On the contrary, Frontana, which is considered to be partially resistant but not adapted to our climate, had relatively lower severity but still presented a poor yield potential. However, for exact estimation of yield losses due to yellow rust infection, controlled experiments under infected and chemically controlled trials will be more appropriate.

On overall basis locations with maximum disease pressure had lower mean grain yield and vice versa. NIFA had lower disease pressure while CCRI had a higher one. Among the varieties, Bahawalpur-95, Suleman-96, Kohsar-93, Fakhre-Sarhad, Tatara, and Frontana had relatively stable yellow rust severity across locations in a range of 0% to 10%. Based on overall traits, Kohsar-93, Bakhtawar-92, Saleem-2000, Fakhre-Sarhad, Tatara, and Karwan had better yield and lower yellow rust severity and could be recommended for cultivation and further breeding exploitation.

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