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Research Article

A seven-year assessment of resistance durability to yellow rust in some wheat cultivars in Ardabil province, Iran

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Abstract: Yellow (stripe) rust caused by *Puccinia striiformis* f. sp. *tritici* is an important disease that threatens wheat production where the weather conditions are congenial and susceptible cultivars are present. Host resistance is the most economical and environmentally safe control method to manage wheat yellow rust; and slow rusting resistance, a kind of quantitative resistance, has been reported to have more durability. We planned an experiment aimed to evaluate resistance durability to yellow rust in some wheat cultivars. This study was conducted in field plots under natural infection conditions against race(s) populations of stripe rust believed to have virulence against *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr10*, *Yr17*, *Yr18*, *Yr21*, *Yr22*, *Yr23*, *Yr24*, *Yr25*, *Yr26*, *Yr27*, *Yr31*, *Yr32*, *YrA* and *YrSU* resistance genes. Slow rusting parameters, including final rust severity (FRS), apparent infection rate (*r*), relative area under disease progress curve (rAUDPC), and coefficient of infection (CI) were evaluated in a set of 50 wheat genotypes along with susceptible control during a seven-year study from 2008 to 2014. Seedling reaction was also evaluated under field conditions. Based on evaluated resistance parameters, the cultivars (entries: 34, 40-50) as well as susceptible check with the highest values of FRS, CI, *r* and rAUDPC, were considered as susceptible cultivars. Eight cultivars (entries: 1-7and 9) were resistant at the seedling and adult plant stages. Thirteen cultivars (entries: 13, 15, 16, 17, 20, 21, 24, 28, 29, 32, 33, 35, 37) showed resistance reaction at the seedling, but susceptible to moderate reactions at the adult plant stage. Sixteen cultivars (entries: 8 10, 11, 12, 14, 18, 19, 22, 23, 25, 26, 27, 30, 31, 38, 39) were susceptible at the seedling stage, and had moderately resistant to moderately susceptible reactions at the adult plant stage. Accordingly, these later cultivars with low level of slow rusting parameters were supposed to have gene(s) for varying degrees of slow rusting resistance or high temperature adult plant (HTAP) resistance. The remaining cultivars may have low level of slow rusting resistance that need further study to elucidate their nature of resistance. Cluster analysis of wheat cultivars revealed four major groups/clusters, based on slow rusting resistance parameters and seedling infection types.

Keywords: Wheat cultivars, durable resistance, yellow rust, *Puccinia striiformis* f. sp. *tritici*

Introduction

The three wheat rusts, stem (or black), leaf (or brown) and stripe (or yellow) continue to cause losses, often major, in various parts of the world (Singh *et al*., 2011). Wheat yellow rust caused by *Puccinia striiformis* Westend. f. sp. *tritici*, is an important disease worldwide and causes high yield losses if it is not controlled by resistant cultivars or the application of fungicides. Stripe rust, is principally an important disease of wheat during winter or early to mid-spring or at higher elevations

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(Roelfs *et al.,* 1992). In most wheat producing areas, yield losses caused by stripe rust range from 10-70% (Chen, 2005).

Stripe rust was a dominant disease in central Asian countries in the late 1990s and early 2000s, accounting for yield losses of 20-40% in 1999 and 2000 (Morgounov *et al.,* 2004). During the last decades, several yellow rust epidemics have happened in most of wheat-growing areas of Iran of which the most sever epidemics caused over 30% crop losses on extensively grown cultivars Falat and Ghods (Torabi *et al.,* 1995). The estimated grain losses for the 1993 and 1995 epidemics were 1.5 and 1.0 million tons, respectively (Torabi *et al.,* 1995). Stripe rust can cause 100% yield loss if infection occurs very early and the disease continues to develop during the growing season provided the cultivars are susceptible and the congenial weather conditions are present (Afzal *et al.,* 2007).

Control of stripe rust by chemical products is available with new and more effective fungicides like Tilt® (propiconazole), Quadris® (azoxystrobin), Stratego™ (propiconazole + trifloxystrobin), Headline™ (strobilurin), and Quilt™ (azoxystrobin + propiconazole) (Chen, 2005). However, growing resistant cultivars is the most efficient, economical and environmentally safe approach to control the disease (Line and Chen, 1995). Approximately 53 *Yr*-genes that confer resistance to stripe rust have been identified in wheat and the relatives of which many have been deployed in breeding programs (deVallavieille-Pope *et al.*, 2012). It should be noted that the majority of these designated *Yr*-genes are race-specific and therefore become ineffective in combating current pathogen populations due to development of new races. The average lifetime of the genes conferring race-specific resistance is estimated to be five years on global basis (Kilpatrick, 1975). For example, the genes *Yr2, Yr3, Yr4, Yr6, Yr7, Yr9* and *YrA*are commonly present in bread wheat cultivars developed by CIMMYT (Badebo *et al.*, 1990; Bux *et al.,* 2011). However, none of these genes are globally effective (Broers *et al.,* 1996; Sharma-Poudyal *et al.,* 2013). An alternative procedure for wheat breeders is the use of quantitative resistance. Two types of quantitative resistance, including high temperature adult-plant (HTAP) resistance and slow rusting resistance have been intensively investigated (Line, 2002). In many cereal-rust pathosystems, the quantitative aspects of the resistance in many wheat cultivars have been described and estimated by means of disease severity at a certain crop development stage, the area under disease progress curve (AUDPC) or by means of apparent infection rate '*r*' and average coefficient of infection (ACI) values for adult plant resistance (Broers *et al.*, 1996; Pathan and Park, 2006). Many researchers reported that slow rusting parameters can be used for selecting and grouping of different cultivars/lines based on their resistance reaction (Ali *et al.,* 2008; Safavi *et al.,* 2010, 2013b; Hei *et al.,* 2015; Saleem *et al.,* 2015; Singh *et al.,* 2017).

Regarding occurrence of new races with wide virulence spectrum, the use of durable resistance in wheat should be emphasized more and considered as the best method to protect the crop from the losses of yellow rust and to increase the yield. This study was designed to evaluate slow rusting parameters and seedling reaction to wheat yellow rust under field conditions in order to determine the resistance durability in wheat cultivars from 2008 to 2014.

Materials and Methods

The entire trial was subdivided into two experiments. A seedling test was conducted under field conditions during the spring of 2010 (from 21st of March to 23rd of May). Another study was focused on evaluating slow rusting resistance parameters in a number of wheat cultivars from 2008 to 2014, in Ardabil province of Iran.

Seedling test

Fifty wheat cultivars (Table 1) and a susceptible cultivar (Morocco) obtained from

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Cereal Department of Seed and Plant Improvement Institute (SPII), Karaj, Iran, were used in the current study. The resistance response of the seedlings was evaluated under field conditions by planting seeds of each entry 5-7 cm apart on two one meter rows with 30 cm distance. Plots were spaced at 65 cm. The responses of the seedlings were recorded three times with 7-10 days intervals using 0-9 scale of infection types (ITs) (Line and Qayoum, 1992) as follow: no symptoms (IT 0), necrotic or chlorotic flecks (IT1), necrotic or chlorotic blotches without sporulation (IT 2), necrotic or chlorotic blotches with only a trace to slight sporulation (IT 3 to 4), moderate to abundant sporulation with or without necrosis or chlorosis (IT 5, 6, 7, 8, or 9). Infection types 0-5 (mostly 0-3) were considered as resistant and 6-9 (mostly 7-8) as susceptible reactions for wheat cultivars.

Field tests

This experiment was conducted under natural infection conditions of race (s) populations of stripe rust believed to have virulence on *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr10*, *Yr17*, *Yr18*, *Yr21*, *Yr22*, *Yr23*, *Yr24*, *Yr25*, *Yr26*, *YrA*, *YrSU*, *Yr27*, *Yr31* and *Yr32* resistance genes (Safavi *et al.*, 2013a). About 50 seeds of each of the entries were planted 5-7 cm apart on two one- meter rows with 30 cm distance. Plots were spaced at 65 cm. The responses were recorded three times at 7-10 days intervals based on the modified Cobb,s scale (Peterson et al., 1948) Disease severity was evaluated when it was reached to 50% on the flag leaf of susceptible check Morocco using Roelfs *et al*. (1992) method. The Coefficient of infections (CIs) was calculated by multiplying disease severity (DS) and constant values of the infection types. The constant values for infection types were used based on Stubbs *et al*. (1986) where resistant (R) = 0.2, moderately resistant (MR) = 0.4, moderate (M) = 0.6, moderately susceptible (MS) = 0.8, moderately susceptible to susceptible (MSS) = 0.9 and susceptible (S) = 1.0.

Estimation of area under disease progress curve (AUDPC) and relative area under disease progress curve (rAUDPC) were performed as described by Milus and Line (1986).

Also the infection rate (*r*) was estimated in terms of disease severity recorded on wheat cultivars/lines at different times (Van der Plank, 1968). The infection rate (*r*) per unit (*t*) was calculated as follows:

$$r = 1/t_2\text{-}t_1[(\ln(x_2/1\text{-}x_2)) - (\ln(x_1/1\text{-}x_1))]$$

Where t1 and t2 are dates at which disease severity measurements were made, and x1 and x2 are the amounts of disease severity that were recorded at t1 and t2 dates. The mean values of final rust severity (FRS), infection rate (r), coefficient of infection (CI) and rAUDPC were computed by Excel software. Finally, comparison of the cultivars was used for grouping them based on the method of Ali *et al*. (2007) and Patahn and Park (2006). Cluster analysis and generating denderogram for the grouping of wheat genotypes were carried out by SPSS software (Version 18).

Results and Discussion

Seedling and adult plant infection type

According to the infection types observed at seedling and adult plant stages (Table 2), cultivars were categorized into four groups as follow: The first group included eight cultivars (entries: 1, 2, 3, 4, 5, 6, 7, 9), that were resistant to stripe rust both at the seedling and post seedling adult plant stages. This group most probably carried major gene(s) that were effective against all the pathotypes present. However, the cultivars with race-specific resistance often become susceptible within a few years after their release because of the rapid evolution of new virulent races of the rust pathogens (Wan and Chen, 2012). The cultivars included in the first group may also contain race-nonspecific resistance genes that their effects were masked by effective race-specific resistance genes (Dadrezaei *et al.*, 2013; Chen, 2005).

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Table 1 Pedigrees of the wheat genotypes, their growth habit and origin.

No.	Cultivars/ lines	Pedigree	Origin[1]	Growth habit[2]
1	Gaspard	Arminda/FD-71036	France	W
2	Pishgam	Bkt/90-Zhong87	China	F
3	MV17	Slaviya/3/Krasnodari 1/ Bezostaya//3Zg.4431	Martovasar	W
4	Gascogen	TJB-900-8/Marengo	France	W
5	Urom	Alvand//NS732/Her	-	F
6	Mihan	Bkt/90-Zhong 87	China	W
7	Parsi	Dove"s"/Buc"s"//2*Darab	CIMMYT	S
8	Dena	TARRO-3	-	S
9	Aflak	HD160/5/Tob/ Cno / 23854 /3/ Nai60// Tit/ Son64 /4/ LR/ Son 64	-	S
10	Zareh	130L1.11//F35.70/Mo73/4/Ymh/Tob//Mcd/3/Lira	CIMMYT	W
11	Yavarous	YAVAROOS 79	-	S
12	Sison	ENA(JENA)/(HYBRIDE-NATUREL)HN-35	-	W
13	Nicknejad	F13471/CROW"S"	CIMMYT-ICARDA	S
14	Sivand	Kauz "s" / Azadi	CIMMYT	S
15	Morvarid	Milan/Sha 7 or MILAN/SHANGHAI-7	CIMMYT	S
16	Arya	Stork	-	S
17	Gonbad	ATRAK/WANG-SHUI-BAI or ATRAK/WANG-SHUI-BAI	-	S
18	Behrang	D-79-15 (ZHUNG ZOU/2*GREEN-3)	-	S
19	Karkheh	Shwa/Mald//Aaz	-	S
20	Darya	Sha4/Chil	-	S
21	Pishtaz	ALVAND//ALDAN"S"/IAS58,40-72-48	Iran	S
22	Darab 2	MAYA "S"//NAC	CIMMYT	S
23	Arta	Seri 82 derivative	CIMMYT	S
24	Bahar	Bloyka ICW84-0008-O13AP-300L-3AP-3000L-0AP	ICARDA	W
25	Sepahan	Azd/5/L2453/1347/4/KaI//Bb/KaI/3/Au//Y50E/KaI*3	-	S
26	Chamran	ATILA 50Y	CIMMYT	S
27	Marvdasht	HD2172/Bloudan//Azd	Iran	S
28	Shirodi	ATILA 4Y	CIMMYT	S
29	Dez	KAUZ*2/OPATA//KAUZ	-	S
30	Tajan	BOW"S"/NKT"S"	CIMMYT	S
31	Alvand	1-27-6275- X CF 1770	Iran	F
32	Shiraz	GV/D630//ALD"S"/3/AZD	Iran	S
33	Navid	Kirkpinar79	-	F
34	Hamon	CROSS OF FALAT(KVZ/BUHO//KAL/BB)	-	S
35	S-78-11	Bow"S"/CM 34798/3/Snb/Pewee"S"/Snb/Mus	-	S
36	Toos	SPN//MOD//CAMA/3/NZR	USA	F
37	Argh	1-66-22/INIA-66	-	S
38	Zarin	PK 14841	Iran	F
39	Atrak	JUP/BJY "S"// URES	CIMMYT	S
40	Moghan3	Luan/3/V763.23/V879.C8//Pvn/4/Picus/5/Opata	CIMMYT	S
41	Azar#2	Kvz/ym71//3/Maya"s"//Bb/Inia/4/Sefid	Iran	W
42	Akbari	1-63-31/3/12300/TOB//CNO67/SX	-	S
43	Sistan	Bank"s"/Vee"s"	-	S
44	Kavir	Stm/3/Kal//V534/Jit716 or SHORTIM/3/KALYANSONA//V-534/JIT-716	Iran	S
45	Falat	KVZ/BUHO//KAL/88	CIMMYT	S
46	Mahdavi	TI/PCH/5/MT48/3/WTE*3/NAR59/TOTA63/4/MUS	Iran	S
47	Alemoot	KVZ/T171/3/MAYA"S"//BB/INIA/4/KARAJ2/5/ANZA/3/PI/NAR//HYS	Iran	W
48	Shahriar	Kvz/Ti71/3/Maya s"//Bb/Inia/4/Karaj2/5/Anza/3/Pi/Nar//Hys	Iran	W
49	Bam	Vee"s"/Nac//1-66-22 0r VEERY/NACOZARI-76//1-66-22	CIMMYT	S
50	Sardari	-	Iran	W
51	Morocco	-	-	

[1]: The origin was not known.

[2]: S; spring, W; Winter, F; Facultative.

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Table 2 Adult plant infection type, seedling reaction, and mean values for coefficient of infection, final rust severity, infection rate and rAUDPC in 51 wheat cultivars/lines to yellow rust in Ardabil from 2008 to 2014.

No.	Cultivars/lines	Seedling reaction[1]	Infection type[2]	Mean values of different parameters[3]			
				FRS	CI	rAUDPC	*r*
1	Gaspard	0	0/R	1	0.4	3.7	0
2	Pishgham	0	0/R	2	0.4	3.7	0
3	MV17	0	R	2	0.4	3.7	0
4	Gascogen	0	R	2	0.4	3.7	0
5	Urom	0	R	6	0.8	3.7	0
6	Mihan	0	R	2	0.4	3.7	0.03
7	Parsi	2	RMR	6	1.3	8.0	0.06
8	Dena	7	MR	7	2.8	4.4	0.08
9	Aflak	0	RMR	6	2.5	10.2	0.065
10	Zareh	6	MR	15	7.1	24.0	0.04
11	Yavarous	7	MR	17	7.9	5.9	0.06
12	Sissons	7	MR	19	10.7	12.6	0.09
13	Nicknejad	3	M	13	6.3	21.5	0.08
14	Sivand	7	M	23	10.9	23.7	0.09
15	Morvarid	0	M	27	16.6	24.5	0.07
16	Arya	5	MR	27	15.3	10.2	0.09
17	Gonbad	5	MR	31	16.9	21.5	0.07
18	Behrang	7	MS	30	18.7	31.0	0.09
19	Karkheh	8	MS	29	17.9	24.6	0.09
20	Darya	0	MS	30	20.0	23.0	0.08
21	Pishtaz	5	MSS	33	20.9	32.0	0.09
22	Darab 2	8	M	36	19.7	35.9	0.11
23	Arta	7	MS	39	30.3	44.3	0.10
24	Bahar	3	M	38	19.1	39.2	0.11
25	Sepahan	7	M	41	20.4	40.9	0.08
26	Chamran	7	M	46	28.3	26.7	0.07
27	Marvdasht	8	M	39	23.9	33.0	0.08
28	Shirodi	3	M	46	32.4	26.1	0.07
29	Dez	5	MSS	41	32.3	52.3	0.085
30	Tajan	6	MS	57	46.0	57.1	0.12
31	Alvand	7	MS	54	41.7	46.0	0.09
32	Shiraz	5	MS	59	42.0	58.4	0.13
33	Navid	0	MS	57	48.7	37.5	0.095
34	Hamon	8	S	64	61.4	75.2	0.15
35	S-78-11	0	MSS	57	50.6	62.9	0.14
36	Toos	8	MSS	67	63.4	64.5	0.13
37	Argh	0	MSS	68	62.6	60.5	0.13
38	Zarin	7	MS	60	50.4	46.4	0.11
39	Atrak	6	MS	61	49.4	57.7	0.12
40	Moghan3	7	S	67	62.1	77.7	0.15
41	Azar2	7	MSS	70	64.3	66.1	0.14
42	Akbari	7	S	71	67.9	82.0	0.18
43	Sistan	7	S	74	71.4	74.6	0.15
44	Kavir	7	S	76	72.1	66.2	0.14
45	Falat	7	MSS	77	65.4	52.1	0.11
46	Mahdavi	7	MSS	77	71.9	77.9	0.17
47	Alemoot	7	MSS	76	70.7	57.7	0.11
48	Shahriar	7	S	86	83.6	95.9	0.22
49	Bam	7	S	84	77.1	91.3	0.2
50	Sardari	7	S	81	81.4	76.6	0.16
	Morocco	8	S	99	98.6	100.0	0.38

1: Seedling infection type based on Line and Qayoum (1992) during the spring of 2010.
2: Adult plant infection types based on Roelfs*et al.* (1992); 0 = Immune, R = Resistant without sporulation, RMR = Resistant to moderately resistant, MR = moderately resistant; small pustules surrounded by necrotic areas, MS = moderately susceptible; medium-sized pustules, no necrosis, but some chlorosis possible, MSS = moderately susceptible to susceptible; medium to large sized pustules without chlorosis or necrosis, S = susceptible; large pustules, no necrosis or chlorosis.
3: Mean values for different slow rusting parameters, which was calculated for CI and FRS during 2008-2014, and for rAUDPC and *r* in 2011 and 2014.

With regard to the high changing potential of rusts fungi by different events such as mutation, asexual recombination, migration in long-distances and selection pressure of host

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(wheat) genotypes on pathogen genotypes (Hovmoller *et al.*, 2011; Ben Yehuda *et al.*, 2004), researchers should deploy race-nonspecific or combination of race-nonspecific with race-specific resistance genes.

The second group included 16 cultivars (entries: 8, 10, 11, 12, 14, 18, 19, 22, 23, 25, 26, 27, 30, 31, 38, 39) which were susceptible to stripe rust at the seedling stage but moderately resistant to intermediate (MR or M) or moderately susceptible (MS) at the adult plant stage. These cultivars which had low values of slow rusting parameters at the adult plant stage may have different levels of durable resistance (Singh *et al.*, 2005). This kind of resistance, in some cultivars, can be kept for a long time, even if pathogen changes its genotypes. Durable resistance, such as slow rusting and HTAP, is controlled by more than one gene (Dehghani and Moghaddam, 2004).

The third group included 14 cultivars (entries: 34, 36, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51) that were susceptible to stripe rust both at the seedling (IT 7-8) and adult plant (IT MSS or S) stages. This group lacked adult plant and effective race-specific resistance gene(s) to the race(s) populations of Ardabil.

In the fourth group, 13 cultivars (entries: 13, 15, 16, 17, 20, 21, 24, 28, 29, 32, 33, 35, 37) were resistant at the seedling stage (0-5), but MR/M to MSS/S at the adult plant stage. Some of these cultivars may lack adult plant resistance genes. The cultivars that showed resistance reaction at seedling, but moderate or susceptible reaction at adult plant stages, have probably been affected by some pathotype(s) that were not present at the time of seedling test evaluation or alternatively the pathotypes frequencies were so low that did not infect the mentioned cultivars (Dadrezaei*et al.*, 2013).

Slow rusting of wheat genotypes

The data obtained from disease severity and host reaction was combined to calculate coefficient of infection (CI). According to Ali *et al*. (2007), cultivars with CI values of 0-20, 21-40, 41-60 were regarded as possessing high, moderate and low levels of adult plant resistance, respectively. Twenty cultivars (entries: 1-20) were grouped in the first category. Nine cultivars (entries: 21, 22, 23, 24, 25, 26, 27, 28, and 29) were shown to have a moderate level of slow rusting resistance. Seven cultivars (entries: 30, 31, 32, 33, 35, 38 and 39) were identified to have a low level of slow rusting resistance, and 15 cultivars (entries: 34, 36, 37, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51) exhibited a CI value greater than 60, were grouped as susceptible ones.

Table 2 clearly shows that disease pressure was considerably high as indicated by the CI related to susceptible check during 2008 to 2014. Maximum CIs recorded among tested cultivars were between 66-85% of the CI of the susceptible check for nine entries including 42, 43, 44, 45, 46, 47, 48, 49, 50; while the CIs for the remaining 41 cultivars were recorded up to 64% of the CI of Morocco. Based on the results, common stripe rust pathotypes of Ardabil were considered virulent on most of the evaluated cultivars/lines (Table 2). The cultivars Gaspard, Pishgham, MV17, Gascogen, Urom, Mihan and Parsi (with resistance reaction at both the seedling and adult plant stages) may probably carry major genes or combination of major gene-based resistance, effective against all virulences used (Ali *et al.*, 2007; Johnson, 1988). However, the cultivars/lines with race-specific resistance to the wheat rusts diseases often become susceptible within a few years after their commercial release, because of the rapid evolution of new virulent races of the wheat rust pathogens (Wan and Chen, 2012). According to the results of other researchers (Dadrezaei *et al.*, 2013; Chen, 2005), the cultivars Gaspard, Pishgham, MV17, Gascogen, Urom, Mihan and Parsi may also contain race-nonspecific resistance genes against yellow rust that are masked by effective race-specific resistance genes.

The presence of some genes conferring slow rusting phenotypes can be predicted by pedigree analysis of each cultivar. Considering this method, it would be suggested that Chamran, and Shirodi cultivars carry 2-3 slow rusting resistance genes to the stripe rust pathotypes of Ardabil due to the presence of Attila in their pedigree (Singh

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et al., 2005). It should be noted that the resistance in Chamran and Shirodi has been overcome by virulent pathotypes since the last decade in Iran. However if they carry 2-3 slow rusting resistance genes, then it can be stated that such a resistance has not been effective to protect the crop from the loss of yellow rust in many wheat growing areas of Iran. The genotypes Shahriar, Alemoot, and Bam possibly carry *Lr34* due to sharing Anza and Vee/Nac as parents in their pedigrees, respectively. Gene *Lr34* is closely linked to *Yr18* and confers slow rusting, but its resistance is not sufficient in areas where disease pressure is very high. The three mentioned cultivars Shahriar, Alemoot and Bam have shown susceptibility to yellow rust in many areas of Iran. Thus, in order to obtain cultivars with high level of durable resistance, 4-5 slow rusting genes should be combined (Singh *et al.,* 2011).

Based on the rAUDPC values, cultivars were categorized into two distinct groups according to Ali *et al.* (2007). The first group included genotypes exhibiting rAUDPC values less 30% of the check, while cultivars showing rAUDPC values 30 to 70% of the check were placed in the second group. In regard to the cultivars/lines in both groups, stripe rust was initiated and sporulated but with final chlorotic and necrotic strips (MR and/or MS infection type). Subsequently, the progress of rust development remained slower and restricted. Therefore the cultivars in group one were identified to have better partial resistance. Cultivars with the above mentioned traits are expected to possess genes that confer partial resistance (Parlevliet, 1988). Apart from those eight cultivars that showed resistance reaction at both seedling and adult plant stages, the remaining cultivars that exhibited rAUDPC values less than 30% of Morocco were shown to have better partial resistance.

The group one included cultivars with varying degrees of partial resistance that probably have more longevity to yellow rust under the conditions of Iran. Moreover, cultivars with acceptable levels of partial resistance restrict the evolution of new virulent races of the pathogen, because multiple point mutations are usually rare in nature (Ali *et al.,* 2007).

The data obtained from final rust severity recording on 50 cultivars along with susceptible check (Morocco) are shown in Table 2. High disease pressure was recorded at the testing site as mean of FRS up to 99% for Morocco, followed by Shahriar (86%), Bam (84%) and Sardari (81%) classified as susceptible cultivars based on their infection types. Similarly based on FRS the tested cultivars were grouped into three groups of high, moderate and low levels of partial resistance having 1-30%, 31-50% and 51-70% of FRS, respectively. Twenty cultivars were included in the first group, nine cultivars exhibited moderate level of partial resistance and 12 cultivars were identified to have low level of partial resistance. Similarly, Broers *et al*. (1996), Ali *et al*. (2009) and Safavi and Afshari (2012a) have carried out field assessment of partial resistance to yellow rust for ranking of wheat cultivars/lines. According to the resistance levels based on disease severity along with other slow rusting resistance (partial resistance) parameters, they found that resistance levels ranged from very low to very high among the tested genotypes.

Infection rate of all the cultivars were less than that of Morocco during the study periods. Apart from Morocco, the highest mean *r*-value of 0.22 was recorded for Shahriar followed by Bam (r = 0.2), Akbari (r = 0.18), belonging to the susceptible group based on their infection types. Similar to the findings of Ali *et al.* (2008) and Sandoval-Islas *et al.* (2007), the present study also demonstrated that infection rate seemed an unreliable estimation of partial resistance when compared with FRS, CI and rAUDPC, because it could not identify different levels of partial resistance among some of the cultivars, as when compared with other parameters. The present study identified that cultivars with better level of partial resistance (having CI = 0-20 and FRS = 0-30) had infection rates less than 0.09.

Diversity among the tested cultivars

Cluster analysis based on the slow rusting parameters is shown in Fig. 1. The Morocco cultivar along with three cultivars Shahriar, Bam and Sardari were separated with maximum

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distance from all the other cultivars which were grouped into three main clusters. The first cluster consisted of 15 cultivars that eight of them showed to have race–specific resistance. The second cluster comprised of 14 cultivars, characterized with the well–documented partially resistant cultivars Chamran, Shirodi, Morvarid, Gonbad and others. It should be noted that in the last decade, Chamran and Shirodi have shown intermediate resistance responses to the yellow rust pathotypes in Ardabil province, but they showed high susceptible responses in some areas of Iran. The third cluster consisted of 18 cultivars most of which had very low level of slow rusting resistance. Diversity among tested cultivars was considerable in the disease parameters and cluster analysis based on slow rusting parameters to stripe rust which in turn can be related to the diversity of the genetic basis of resistance among the tested cultivars. Other researchers (Ali *et al.* 2009; Safavi and Afshari, 2012a) also reported varying degrees of partial resistance to stripe rust among the commercial wheat cultivars/lines. The diversity recorded in the current work may be exploited in further breeding programs for developing improved cultivars with diversity resistance background. This will help to avoid mono-culturing in terms of resistance genes.

Association between slow rusting parameters

During this investigation, an attempt was made to elucidate the relationship between field-based partial resistance parameters and seedling infection types. Positive relation of FRS was found with coefficient of infection CI, rAUDPC, and *r* with a strong r^- value that were 98%, 94% and 84%, respectively (Table 3). The highest correlation coefficient (*r*) was between CI with FRS (r = 0.98) and the lowest r^- value was between *r* with FRS (r = 0.84). This well positive correlation agreed with the results of other researchers on cereal-rust pathosystems (Shah *et al.,* 2010; Sandoval-Islas *et al.,* 2007; Safavi and Afshari, 2012b). The correlation coefficient of seedling infection types with different slow rusting parameters was very low, but significant. This low correlation coefficient can be due to the nature of seedling and adult plant resistances or changing of race frequency during the period of the present study. Previously Sandoval-Islas and co-workers (2007) found good correlation between rAUDPC and quantitative resistance components, *i.e*. latent period and infection frequency. Ochoa and Parlevliet (2007) and Safavi (2015) also found high correlation coefficient between rAUDPC and yield losses. Field selection of partial resistance trait preferably by low rAUDPC and terminal ratings along with CI, is feasible in situations, where greenhouse facilities are adequate (Singh *et al.,* 2007). Since all disease parameters strongly and positively correlated in the present study, it can be concluded that FRS and CI are the most appropriate parameters. The cultivars that were identified to have partial resistance characteristics should be improved/developed further by accumulating 4-5 minor genes to achieve near-immunity as a control strategy in the region for controlling yellow rust problem despite its difficulties (Singh *et al.,* 2011).

Table 3 Linear correlation coefficients between slow rusting parameters and seedling infection type to yellow rust for 51 wheat cultivars in Ardabil during 2008-2014.

Parameters	*r*	FRS	CI	Seedling IT
FRS	0.84**	-		
CI	0.84**	0.98**	-	
Seedling IT	0.53**	0.53**	0.48**	-
rAUDPC	0.87**	0.94**	0.95**	0.51**

FRS: final rust severity, rAUDPC: relative area under disease progress curve, *r*: apparent infection rate, CI: coefficients of infection, IT: Infection type.
**Significant at P < 0.01 level of probability.

Conclusion

The results of current study showed that the cultivars had diversity of resistance, ranging from complete resistance to full susceptibility. Most of the evaluated cultivars exhibited low performance under high disease pressure when compared with the susceptible check. Resistance of all categories including complete resistance to partial resistance to yellow rust was observed. Some of the cultivars were susceptible at the seedling stage and had moderate (MR, M or MS) reactions at adult plant stage. Thus, these cultivars were supposed to confer genes for varying degrees of slow rusting

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resistance (partial resistance) or HTAP that can be used for future manipulation in wheat improvement programs after confirmatory studies. Nowadays marker-assisted selection is being applied to make the task easier. Some of these markers have good association with HTAP and slow rusting genes and can be used in selection and confirmation studies.

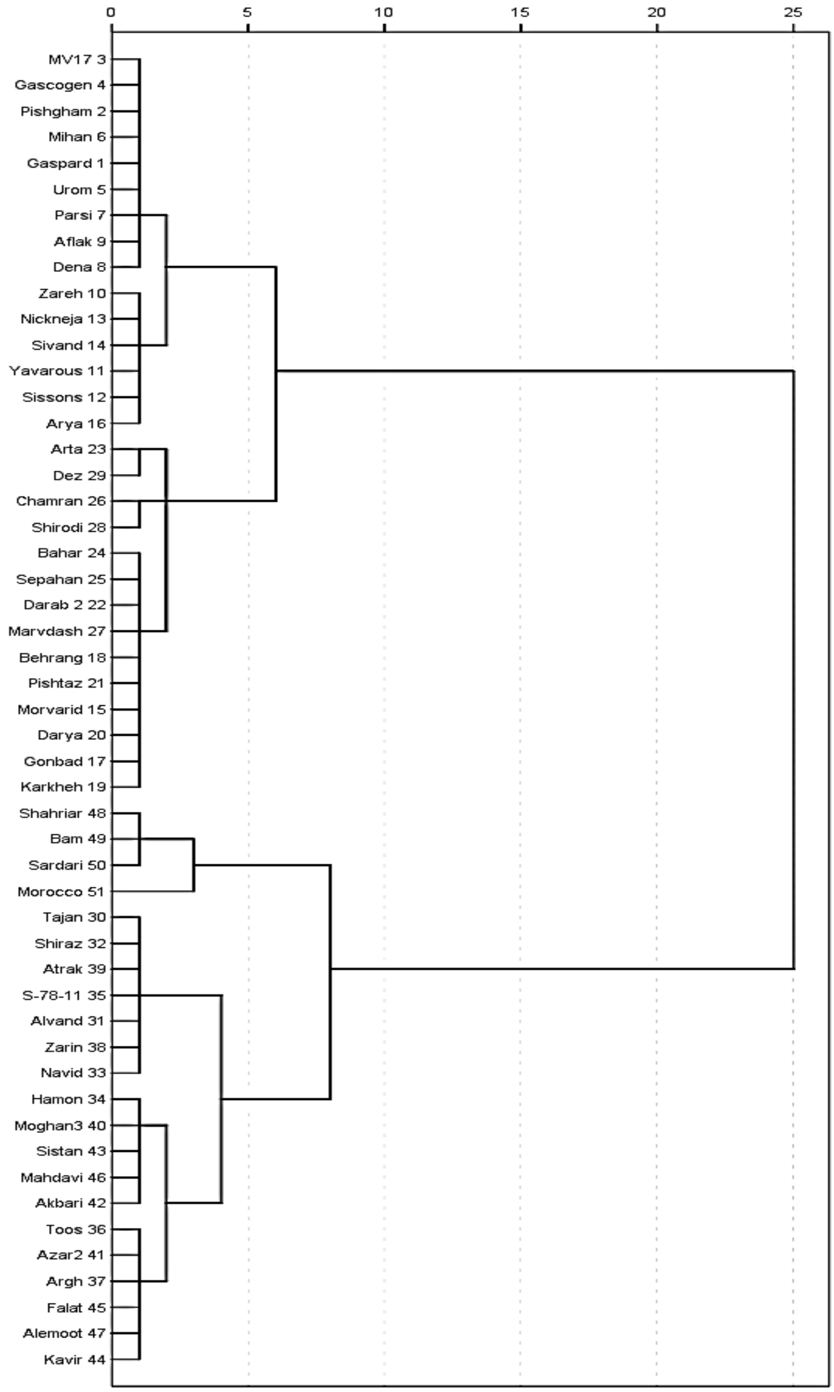

Figure 1 Denderogram of cluster analysis for 51 wheat cultivars/lines based on slow rusting parameters and seedling infection type to yellow rust.

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بررسی هفت ساله پایداری مقاومت ارقام گندم در مقابل زنگ زرد در استان اردبیل

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چکیده: زنگ زرد گندم با عامل *Puccinia striiformis* f. sp. *Tritici* یکی از بیماری‌های مهم گندم می‌باشدکه تولید گندم را در مناطقی که شرایط محیطی مساعد و ارقام حساس وجود دارند، تهدید می‌کند. مقاومت میزبانی، اقتصادی‌ترین و ایمن‌ترین روش مدیریت زنگ زرد گندم است و مقاومت تدریجی، نوعی از مقاومت کمی، از پایداری بیش‌تری برخوردار است.آزمایشی با هدف ارزیابی پایداری مقاومت در تعدادی از ارقام گندم طراحی شد. در این مطالعه، پارامترهای مقاومت تدریجی، شامل ضریب آلودگی (CI)، شدت نهائی بیماری (FRS)، مقدار نسبی سطح زیر منحنی پیشرفت بیماری (rAUDPC) و نرخ آلودگی ظاهری (r) برای ۵۰ ژنوتیپ گندم همراه با شاهد حساس طی سال‌های ۱۳۸۷ تا ۱۳۹۳ ارزیابی شد. ارزیابی تحت شرایط آلودگی طبیعی نسبت به جمعیت نژادی زنگ زرد که دارای ویرولانس روی ژن‌های مقاومت *Yr2*،*Yr6*،*Yr7*،*Yr9*،*Yr17*،*Yr22*،*Yr23*،*Yr24*،*Yr25*،*Yr26*،*Yr27*،*YrA*،*Yr21*،*Yr31*،*Yr32*و*YrSU* بود، انجام شد. واکنش گیاهچه‌ای نیز تحت شرایط مزرعه‌ای ارزیابی شد. نتایج ارزیابی‌ها برای پارامترهای مقاومت نشان داد که ارقام (شماره‌های۳۴، ۴۰ تا ۵۰)، همراه با رقم حساس بالاترین مقادیر FRS ، CI، *r* و rAUDPC را دارند و به‌عنوان ارقام حساس گروه‌بندی شدند. هشت رقم در هر دو مرحله گیاهچه‌ای و گیاه کامل مقاوم بودند. سیزده رقم در مرحله گیاهچه‌ای مقاوم ولی در مرحله گیاه کامل واکنش متوسط (MR, M, MS) یا حساس تا نیمه‌حساس (MSS) نشان دادند. شانزده رقم در مرحله گیاهچه‌ای حساس ولی در مرحله گیاه کامل واکنش متوسط (MR, M, MS) نشان دادند. بنابراین، این ارقام با داشتن مقادیر پایین پارامترهای مختلف مقاومت به احتمال زیاد دارای درجات متفاوتی از مقاومت تدریجی یا HTAP (مقاومت غیراختصاصی- نژادی یا پایدار) می‌باشند. بقیه ارقام سطح پایینی از مقاومت تدریجی داشتند و برای اثبات طبیعت مقاومت آنها نیاز به مطالعه بیش‌تری است. تجزیه خوشه‌ای هم براساس واکنش گیاهچه‌ای و گیاه کامل، ارقام مورد مطالعه را در چهار گروه مختلف قرار داد.

واژگان کلیدی: ارقام گندم، مقاومت پایدار، زنگ زرد، *Puccinia striiformis* f. sp. *Tritici*