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Research Article

Effects of yellow rust on yield of race-specific and slow rusting resistant wheat genotypes

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Abstract: Rust diseases continue to cause significant losses to wheat production around the world. Among them, yellow rust caused by *Puccinia striiformis* f. sp. *tritici* is an important disease that threatens wheat production in most cool environments. Host resistance, especially race- nonspecific resistance, is the most economical way to manage wheat stripe rust disease. In this study, the effectiveness of different types of resistance was compared in field plots at Ardabil Agricultural Research Station (Iran) during 2011-2013. Yield and yield components along with 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 for 16 wheat cultivars/lines. In all, five wheat cultivars with race-specific resistance, 10 cultivars with different levels of slow rusting resistance and one susceptible cultivar were included in two treatments; with and without fungicide protection under high disease pressure. Results of combined variance analysis showed significant differences between cultivars/lines, also cultivar/line × year at 1% probability level. Wheat cultivars with slow rusting resistance displayed a range of responses indicating phenotypic diversity. Mean thousand kernels weight (TKW) losses of susceptible, race-specific and slow rusting genotypes were 41, 4.4 and 7.6%, respectively. Mean yield losses of susceptible, race-specific and slow rusting genotypes were 65.6, 7.3 and 15.9%, respectively. In this study cultivars having slow rusting resistance with low values of epidemiological parameters were identified. Also genotypes with low yield component losses, despite moderate disease levels, were characterized. Such genotypes can be used in breeding programs to get improved varieties with high levels of resistance and negligible yield losses. Kernels per spike (KPS) data of two experiments were not enough for comparing losses and need supplementary experiments.

Keywords: wheat, slow rusting resistance, yellow rust, yield components losses

Introduction

Plant diseases are among the major factors affecting the yield of wheat crops. The rust diseases of wheat have historically been one of principal biotic production constraints both in Asia and the rest of the world. There are more than 3000 rust species in the world (Laudon, 1973), three of which are pathogenic on wheat: *Pucciniaa graminis* f. sp. *tritici* (causal agent of stem rust), *P. striiformis* f. sp. *tritici* (causal agent of stripe rust) and *P. triticina* (causal agent of leaf rust). Stripe rust is principally an important disease of wheat during winter or early spring also at higher elevations (Roelfs *et al*., 1992). In most wheat producing areas, yield

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losses caused by stripe rust range from 10-70% (Chen, 2005).

Stripe (yellow) rust of wheat, caused by *P. striiformis* Westend f. sp. *tritici* Eriks. & Henn., prevails in cooler climates and cooler years in all continents except Antarctica (Chen, 2005). Stripe rust was 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 in most of the wheat-growing areas of Iran have caused over 30% crop loss and estimated grain losses were 1.5 million tons and 1.0 million ton in 1993 and 1995, 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 susceptible cultivars (Afzal *et al*., 2007) are grown.

Control of stripe rust by chemical products is available with new and more effective fungicides such as 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 friendly 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 deployed in breeding programs (de Vallavieille-Pope *et al*., 2012). Majority of these designated *Yr*-genes are race-specific with major effect 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, genes *Yr2, Yr3, Yr4, Yr6, Yr7, Yr9* and *YrA* are commonly present in bread wheat cultivars developed by CIMMYT. However, none of these genes is globally effective (Broers *et al*., 1996; Sharma-Poudyal *et al*., 2013). An alternative for breeders is quantitative resistance. Two types of resistance have been identified in several cereal-rust pathosystems; hypersensitive or qualitative (race-specific) and quantitative (race-nonspecific) resistance. Deployment of race-specific resistance gene is capable of providing highly effective protection against the disease (Shah *et al*., 2010). This type of resistance, however, is dependent on specific recognition event between the host (R gene products) and the pathogen (Avirulence gene products) that follows the gene- for- gene interactions, as described by Flor (1956), it lacks durability (Boyd, 2005). Conversely, race-nonspecific resistance is mainly polygenic, this type of resistance has often been described as slow rusting or partial resistance (Parlevliet, 1979) and is known to be long-lasting and more durable (Herrera-Fossel *et al*., 2006).

Nowadays utilization of resistant cultivars in combating yellow rust of cereals, especially durable resistance, is emphasized. However, information on the effect of different types of resistance in protecting yield losses in Iranian wheat cultivars/lines is scarce. Thus, the relationship between disease and yield components needs to be studied. This study was conducted with the objectives to (1) determine and compare the effectiveness of race-specific, slow rusting resistance and susceptibility in reducing yield losses and yield components' losses under high pressure of yellow rust (2) assess the relationship between epidemiological parameters and yield losses and yield components' losses.

Materials and Methods

Sixteen wheat genotypes used in this study are listed in Table 1. Among 16 genotype, five cultivars/lines were resistant, Morocco as susceptible and 10 cultivars having different levels of slow rusting resistance were considered (*data not published*). This experiment was conducted in Ardabil Agricultural Research Station during 2011-2013 growing seasons. Seeds of each entry was planted in strips of small adjacent plots consisted of 6 rows, with a row length of 3 meter separated by 25 cm. Plots were spaced at 140cm. Experimental design was randomized complete block design with three replications. A susceptible spreader (Morocco) row was sowed around borders of experiment and 10 entry intervals.

The entire trial was subdivided into two experiments. In experiment 1, the yellow rust epidemic was initiated by inoculating plants of all cultivars with mixture of spores and talcum powder (in 1: 20 proportions). Natural infection symptoms at testing site develop usually after anthesis, therefore one time artificial inoculation was carried out at growth stage GS 39 with common race/races of Ardabil, having virulent genes against resistance genes *Yr2, Yr6, Yr7, Yr9, Yr21, Yr22, Yr23, Yr24, Yr25, Yr26, Yr27, Yr31, YrA,* and *YrSU*. In experiment 2, wheat plots were sprayed with fungicide, Tilt (Propiconazole), to maintain wheat plants disease-free for comparison of wheat yield components in diseased and disease-free experimental units. The fungicide was applied four times with an interval of 10 days, starting from 4th of May 2012 and 2013.

Disease severity was recorded three times. Recording began when Morocco reached 40% severity according to the modified Cobb,s scale (Peterson et al., 1948) and plant reaction was assessed based on Roelfs *et al.* (1992). Coefficient of infection (CI) was calculated by multiplying of disease severity (DS) and constant values of infection type (IT). The constant values for infection types were used based on; R = 0.2, MR = 0.4, M = 0.6, MS = 0.8, MSS = 0.9, S = 1 (Stubbs *et al.*, 1986). Estimation of area under disease progress curve (AUDPC) and relative area under disease progress curve (rAUDPC) was performed as follows (Milus and Line 1986):

$$\boldsymbol{AUDPC} = \frac{N_1(X_1+X_2)}{2} + \frac{N_2(X_2+X_3)}{2}$$

Where X_1, X_2, X_3 are the rust intensities recorded on the first, second and third recording dates. N_1 is interval day between X_1, X_2 and N_2 is interval day between X_2, X_3.

$$\boldsymbol{rAUDPC} = \frac{line\ AUDPC}{susceptible\ AUDPC} \times 100$$

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

$$r = \frac{1}{t_2 - t_1}\left(ln\frac{x_2}{1-x_2} - ln\frac{x_1}{1-x_1}\right)$$

Where t_1 and t_2 are dates at which disease severity was measured, and x_1 and x_2 are the amounts of disease recorded on these dates.

Spikes from 10 randomly selected plants were threshed manually to calculate number of kernels per spike (KPS) and average was calculated per each entry. Randomly selected 250 kernels from each entry were counted and weighed with an electronic balance to calculate thousands kernel weight (TKW) (Afzal *et al.*, 2008; Herrera-Foessel *et al.*, 2006)).

Statistical analysis of yield components' data and slow rusting parameters including final rust severity (FRS), infection rate (*r*), coefficient of infection (CI) and rAUDPC was carried out by MSTAT-c software. Finally cultivars were grouped based on Duncan,s Multiple Range Test. In addition, clustering of wheat cultivars was done using SPSS software (Version 18).

Results and Discussion

Data analysis and mean comparison indicated that, different groups of cultivars were significantly different based on slow rusting parameters (Tables 2, 3). Variance analysis (Table 2) showed that cultivars/lines had significant difference in terms of four slow rusting resistance parameters (FRS, *r*, CI and rAUDPC), also yield losses and TKW losses.

Despite inoculation, infections were affected by the annual weather. Mean rust severity during 2011-2012 was 21.87% (data not published) which was followed by 2012-2013 (35.5%). The line × year interaction which was detected in the analysis of variance may be partly artificial as a consequence of non-additivity of the environmental effect on the expression of quantitative resistance and the non-additivity of scales used (Broers *et al.,* 1996). In other words, environmental factors (especially temperature) can affect expression of some resistance genes including *Yr18, Yr29, Yr30, Yr36, Yrns-B1, YrA1-YrA8* (Chen, 2005) that are expressed at high temperature. The environmental factors, temperature and humidity, also can affect yellow rust development and their value was different during the two years. Despite the observed interactions, which were small compared to the lines effect, it can be concluded that quantitative resistance behaves in a stable manner. Based on the higher disease levels in 2013 and the fact that lines-year interactions are small, selection for quantitative resistance is expected to be more effective

Analysis of data and comparison of mean values also revealed that disease significantly affected yield and yield component (TKW) of all categories of resistance in cultivars (Table 4) that are described in the following sections.

Group with race-specific resistance

This group included five cultivars/lines. The cultivars/Lines Pishgham, Mihan, Goscogene, C-87-11 and C-87-12 with race-specific resistance to yellow rust (Table 1) showed the least values of different slow rusting parameters (Table 3). Based on the results of Safavi *et al*. (2013), these cultivars/ lines may probably carry a single or combination of resistance genes *Yr1,Yr2+,Yr3V, Yr3a, Yr4a, Yr4, Yr5, Yr7+, Yr10, Yr15,Yr16, YrCV, YrSD, YrND* or unknown genes that are effective to race population of yellow rust in Ardabil. The group with race-specific resistance to yellow rust was subdivided to two groups. In the first subgroup the cultivars Pishgham and Mihan were included, because they had no infection to leaf rust in this study (Table 1). The second subgroup included the cultivar/lines Goscogene, C-87-11 and C-87-12 that showed infection to leaf rust. The yield components' losses were the least in the first subgroup in comparison with second subgroup and other groups having slow rusting resistance and susceptible reaction to yellow rust (Table 4). Mean losses of yield and TKW for first subgroup, were 7.3 and 4.4%, respectively. Hailu and Fininsa (2009) and other researchers (Ahmad *et al*., 2010; Herrera-Fossel *et al*., 2006) also concluded that resistant cultivars have the least yield or yield components' reduction.

Although resistant cultivars (in first subgroup) have no postulation, however, they show losses under disease pressure. Because, the plants respond to inoculation with energy-demanding physiological processes, probably defense reactions, using stored host energy that otherwise would go to growth and seed production. In addition, a reduction in photosynthetic leaf area due to hypersensitive flecking also can cause yield reductions (Herrera-Fossel *et al*., 2006). The use of broad-spectrum systemic fungicide treatments with triazols (to which group propiconazole belongs) have been shown to have a beneficial effect on the plants by delaying senescence, thereby prolonging the duration of green leaf area and increasing yield (Bertelsen *et al*., 2001). The cultivar/lines Goscogene, C-87-11 and C-87-12 having susceptible reaction to leaf rust (Table 1) at adult plant stage, show more reductions in yield and TKW (Table 4). Their susceptibility to leaf rust (in non-protected plots) that develops after termination of recording data on infection with yellow rust might be the reason for more reductions compared to Pishgham and Mihan that had no infection to leaf rust in this study (Table 1).

According to results of other researchers (Ali *et al*., 2007; Johnson, 1988) and in terms of reaction at seedling (Table 1) and adult plant stages (Table 3), cultivars/lines Pishgham, Mihan, Coscogene, C-87-11 and C-87-12 may probably carry major gene or combination of major gene-based resistance, effective against all virulences used. 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 pathogens (Wan and Chen, 2012). According to the results of other researchers (Dadrezaei *et al.*, 2013; Chen, 2005), the cultivars/lines Pishgam, Mihan, Goscogene, C-87-11 and C-87-12 may also contain race-nonspecific resistance genes against yellow rust that are masked by effective race-specific resistance genes.

With regard to potential change in virulence of rust fungi by different events including mutation, migration in long-distances and selection pressure of cultivar genotypes on pathogen genotypes (Hovmoller *et al*., 2011; Ben Yehuda *et al*., 2004), researchers should deploy race-nonspecific or combination of race-nonspecific and race-specific resistance sources or gene pools instead of using only race-specific.

Table 1 Pedigree of studied wheat genotypes and their reactions to yellow rust (at seedling stage) and leaf rust (at adult plant stage) during 2012-2013 in Ardabil.

Genotypes	Seedling reaction[1]	Pedigree	Reaction to Leaf rust (2012)[2]
Pishgham	2	Bkt/90-Zhong87	-
Mihan	1	Bkt/90-Zhong 87	-
C-87-11	2	Basswood/Mv17	100S
C-87-12	3	Basswood/Mv17	100S
Goscogene	3	TJB-900-8/Marengo	80S
Zareh	7-Jun	130L1.11//F35.70/Mo73/4/Ymh/Tob//Mcd/3/Lira	-
Bezostaya	7	-	-
Morvarid	4	Milan/Sha 7	-
Sisons	7	ENA(JENA)/(HYBRIDE-NATUREL)HN-35	100S
Gonbad	1	ATRAK/WANG-SHUI-BAI	-
Chamran	7-Jun	ATILA 50Y	-
Rasad	7	Fenkang 15	-
Azar2	7	Kvz/ym71//3/Maya"s"//Bb/Inia/4/Sefid	-
Sabalan	7	908/FnA12// 21-32-438	-
Sardari	7	-	-
Morocco	9	-	-

[1] Seedling reactions to yellow rust under field conditions in Ardabil during 2012-2013 (data not published).
[2] Signs (-) indicates cultivars/ lines having no infection to leaf rust because of early maturity in Ardabil during 2011-2012.

Table 2 Combined analysis of variance for different parameters of slow rusting, kernel weight and yield in protected and non-protected plots.

Source of variation	df	Mean square							
		Non-protected plots						Protected plots	
		Infection rate	rAUDPC	FRS	CI	TKW	Yield	TKW	Yield
Years (Y)	1	0.015*	710.13 ns	4482.66**	3288.87**	1630.2**	1.397**	1562.11**	2.780*
Rep / Y	4	0.001	110.30	87.10	33.35	15.82	0.046	2.52	0.155
Genotype (G)	15	0.035**	4426.30**	4630.17**	4904.98**	271.64**	2.060**	124.27**	1.510**
Y× G	15	0.002*	112.81**	290.62**	217.84**	24.85**	0.111**	7.81**	0.121**
Error	60	0.001	26.98	21.73	9.71	3.37	0.009	1.44	0.015
%C.V.		40.330	20.15	16.26	12.67	3.92	3.930	2.36	4.140

*, **: Significant at 5and 1% levels of probability, respectively- ^{ns}: non-significant, rAUDPC: relative area under disease progress curve, FRS: final rust severity, CI: coefficient of infection, TKW: Thousands kernel weight.

Table 3 Adult plant infection type and data of slow rusting parameters to *Puccinia striiformis* f. sp. *tritici* in non-protected plots for 16 wheat cultivars/lines.

Genotypes	Infection type[1]	Mean of slow rusting parameters in non-protected plots[2]			
		FRS	CI	rAUDPC	Infection rate
Pishgham	R	2.5 h	0.8 i	2.7 h	0.008 cd
Mihan	R	1.0 h	0.2 i	1.3 h	0 d
C-87-11	R	2.5 h	0.5 i	2.9 h	0.009 cd
C-87-12	R	1.7 h	0.3 i	1.7 h	0.011 cd
Goscogene	R	1.0h	0.2 i	1.3 h	0 d
Zareh	MR	19.2 g	7.7 h	15.5 fg	0.07 b
Bezostaya	MS	15.2 g	12.1 h	13.7 g	0.051 bc
Morvarid	MS	26.7 ef	16.7 fg	21.83 ef	0.068 b
Sisons	MSS	20.2 fg	17.5 ef	15.2 fg	0.068 b
Gonbad	MR	20.7 fg	8.3 h	17.3 efg	0.073 b
Chamran	MS	31.8 e	22.0 e	24.9 e	0.082 b
Rasad	MSS	44.0 d	42.8 d	39.3 d	0.087 b
Azar2	MSS	55.8 c	51.9 c	48.2 c	0.091 b
Sabalan	MSS	55.8 c	51.9 c	49.2 c	0.097 b
Sardari	S	63.3 b	63.3 b	57.8 b	0.11 b
Morocco	S	99.3 a	96.3 a	100 a	0.32 a

[1]Infection types based on Roelfs et al. (1992); R = resistant without sporulation; 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. rAUDPC: relative area under disease progress curve, FRS: final rust severity, CI: coefficient of infection. [2]Means followed by the same letters in each column are not significantly different (Duncan's Multiple Range Test at 5% level).

Table 4 Mean comparison of losses for yield and thousand kernels weight (TKW) in non-protected and protected plots for 16 wheat genotypes with different resistance types to *Puccinia striiformis* f. sp. *tritici*

Genotypes	Infection type[1]	Mean losses of TKW and Yield due to yellow rust (2012-2013)[2]					
		TKW (g)			Yield (Kg)		
		Protected	Non protected	Loss (%)	Protected	Non protected	Loss (%)
Pishgham	R	50.23 e	48.47 cde	3.5	3.05 b	2.83 c	7.2
Mihan	R	50.42 e	47.71 de	5.4	3.53 a	3.27 a	7.4
Mean	-	-	-	**4.4**	-	-	**7.3**
C-87-11	R	51.14 e	46.67 ef	8.7	3.51 a	3 b	14.5
C-87-12	R	53.05 d	49.57 abcd	6.6	3.5 a	3.15ab	10.0
Goscogene	R	53.46 cd	51.67 a	3.3	3.07 b	2.84 c	7.5
Mean	-	-	-	**6.2**	-	-	**10.7**
Zareh	MR	49.46 ef	46.65 ef	5.7	2.76 c	2.5 d	9.4
Bezostaya	MS	55.12 bc	51.32 a	6.9	2.55 d	2.24 e	12.2
Morvarid	MS	47.01 g	44.66 f	5.0	2.28 e	2.02 f	11.4
Sisons	MSS	42.89 h	39.92 g	6.9	3.58 a	3.09 b	13.7
Gonbad	MR	49.98 ef	46.72 ef	6.5	2.92 bc	2.52 d	13.7
Mean				**6.2**			**12**
Chamran	MS	48.14 fg	45.05 f	6.4	2.37 de	2.03 f	14.3
Mean	-	-	-	**6.4**	-	-	**14.3**
Rasad	MSS	55.53 b	50.16 abc	9.7	2.2 e	1.85 g	16
Azar2	MSS	55.83 ab	50.93 ab	8.8	2.52 d	1.96 fg	22.2
Sabalan	MSS	54. 35 bcd	48.83 bcde	10.1	2.50 d	2 fg	20.0
Sardari	S	57.57 a	51.5 a	10.5	2.53 d	1.85 g	26.9
Mean	-	-	-	**9.8**	-	-	**21.3**
Morocco	S	41.46 h	24.55 h	**40.8**	3.58 a	1.23 h	**65.6**

[1]Infection types based on Roelfs et al.(1992); R = resistant without sporulation; 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. [2]Means followed by the same letters in each column are not significantly different (Duncan's Multiple Range Test at 5% level).

Group with slow rusting resistance

Based on the statistical analysis, susceptibility levels of different wheat genotypes showed significant differences (Table 3). Data analysis indicated that genotypes were grouped to three categories based on slow rusting parameters. The effect of the three groups on yield and yield component (TKW) was significantly different (Tables 2, 4).

Group1: This group consisted of cultivars Zareh, Bezostaya, Morvarid, Sisons and Gonbad (Table 3). According to Pathan and Park (2006) cultivars/lines with CI values of 0-20 are regarded as possessing high levels of slow rusting. This group had rAUDPC values up to 21.8% of Morocco as susceptible check. Based on the rAUDPC values, wheat cultivars/lines were categorized into two distinct groups according to Ali *et al.* (2007). The first group included genotypes exhibiting rAUDPC values up to 30% of check, while cultivars showing rAUDPC values up to 70% of check were placed in another group. Values of other slow rusting parameters were at low level compared to another groups (groups 2 and 3). Mean yield losses and TKW losses in this group were 12 and 6.2%, respectively (Table 4). The results of this study agreewith Hailu and Fininsa (2009) and other researchers (Ahmad *et al.,* 2010; Herrera-Fossel *et al*., 2006; Safavi *et al*., 2012b). They also concluded that moderately resistantcultivar/cultivars of wheat or barley had low reduction in yield components against yellow rust.

The cultivars which had MS or MR infection type may be carrying durable resistance genes (Brown *et al*., 2001; Singh *et al*., 2005). Consequently cultivars with low levels of CI and other slow rusting parameters most probably will have durable resistance genes, such as high temperature adult plant (HTAP) and slow rusting, and their resistance can last for a long time. Because this kind of resistance is controlled by more than one gene, in other words is oligogenic or polygenic (Dehghani and Moghaddam, 2004). Seedlings of cultivars with only HTAP resistance are susceptible to all races of yellow rust at both low and high temperatures. Adult-plants of HTAP resistant cultivars are susceptible at low temperatures, but resistant at high temperatures (Chen 2007).

Bezostaya and Zareh are included in slow rusting ***group 1***, they have HTAP or slow rusting resistance gene *Yr18* which is a kind of durable resistance (Line, 2002; Singh *et al*., 2005; Dadrezaei *et al*., 2013). Thus, in breeding programs we can use these cultivars in combination with cultivars having desirable characteristics and other durable resistance genes. Seedlings of cultivars with only HTAP resistance are susceptible to all races of yellow rust at both low and high temperatures. Adult-plants of HTAP resistant cultivars are susceptible at low temperatures, but resistant at high temperatures (Chen, 2007). The races with a narrow spectrum of virulence may have advantages in aggressiveness over those with a wide spectrum of virulence on susceptible cultivars or cultivars with a moderate level of race-nonspecific HTAP resistance, such as the most widely grown cv. Baronesse and Luke in USA (Chen, 2007).

Group 2: The cultivar Chamran having CI values of 21-40 and FRS values of 31-50% (Table 3), was marked as having moderate level of slow rusting. 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 carries 2-3 slow rusting genes (for yellow and leaf rust) due to the presence of Attila in its pedigree (Singh *et al*., 2005). The cultivars/lines with different levels of partial resistance are advocated to be more durable (Singh *et al*. 2004). Besides, cultivars/lines with acceptable degree of slow rusting restrict evolution of new virulent races of the pathogen. In the group 2, rate of infection (*r*) and also rAUDPC were more than ***group 1*** but less than ***group 3***. Mean losses of yield and TKW were 14.3 and 6.4%, respectively (Table 4).

Group 3: Compared with the other two groups, had high level of epidemiological parameters and was marked as having low level of slow rusting. The cultivars Rasad, Azar 2, Sabalan and Sardari are included in this group (Table 3). Mean losses of yield and TKW were 21.3 and 9.8%, respectively (Table 4). Similarly, Hailu and Fininsa (2009) and other researchers (Ahmad *et al.,* 2010; Herrera-Fossel *et al*., 2006) also concluded that cultivars showing high level of severity and moderately susceptible to susceptible reaction incur greater losses than other slow rusting groups. The cultivar Sardari having FRS and rAUDPC less than 70%, is included in this group. However, this cultivar had the susceptible infection type and the highest reductions for yield and TKW compared with the other cultivars of group3 (Table 4). The cultivar Rasad with moderately susceptible to susceptible reaction had low reductions of yield and TKW. This may be due to some tolerance capacity of this cultivar, which must be confirmed in detailed studies and could be exploited for further breeding. Such results were observed in works of Ali *et al*., (2009b) and Afzal *et al*., (2008) for cultivars Sariab-92 and Inquilab-91, respectively.

The cultivars included in group3, showed low values of slow rusting parameters under field conditions in Ardabil during 2011-2013. However, their reactions may be different under high disease pressure because they possess very low level slow rusting resistance.

Susceptible group: Based on high values of slow rusting parameters and according to study of Ali *et al*., (2009a) and Pathan and Park (2006), cultivar Morocco was included in this group. Mean losses of yield and TKW for susceptible group were 65.6 and 41%, respectively (Table 4).

Salman *et al*., (2006) reported that yield losses increase proportionately with the increase in disease severity. According to their investigations, susceptible cultivars exhibited maximum losses (52-57%) against the leaf rust. Some other researchers also reached the same conclusion that slow ruster cultivars usually suffer less yield losses compared to fast rusters like Morocco etc, in which losses were as high as 52-57% (Afzal *et al*., 2008, Ahmad *et al.,* 2010). Keeping in view the above results, it is evident that there is a dire need to avoid fast ruster and susceptible cultivars. Besides, plant breeding departments should be encouraged and accounted for continuously monitoring rust situation through plant pathologists and produce resistant cultivars thereby ensuring sustainable production.

Diversity among the tested cultivars/lines

Cluster analysis based on the slow rusting parameters, yield losses and yield components is shown in Fig. 1. Morocco was separated with maximum distance from all the other cultivars/lines, while those other cultivars/ lines were grouped into three clusters. The first cluster consisted of five cultivars/ lines having race–specific resistance, the second of five cultivars, including the well–documented partially resistant cultivars Bezostaya, Zareh and Chamran clustered with Morvarid, Gonbad and Sisons, and the third cluster consisted of four dryland cultivars. Considerable diversity was observed for levels of slow rusting resistance (partial resistance) among the studied cultivars/lines.

Association between slow rusting parameters and yield components' losses

In this investigation, the relationship between different parameters was studied. Positive correlation of final rust severity was found with coefficient of infection (CI), rAUDPC and infection rate with a strong r^- value that was 98%, 99% and 91%, respectively (Table 5). The highest correlation coefficient (*r*) was achieved between final rust severity, rAUDPC and CI (r = 0.99) and the lowest r^- value was between CI and infection rate (r = 0.89). This strong positive correlation agreed with the results of other researchers on cereal-rust pathosystems (Shah *et al*., 2010; Sandoval-Islas *et al*., 2007; Safavi *et al*., 2012a). Previously Sandoval-Islas *et al.,* (2007) found good correlation of rAUDPC with quantitative resistance components, i.e. latent period and infection frequency. Field selection of slow rusting trait preferably by low rAUDPC and terminal ratings along with CI, is feasible in situations, where greenhouse facilities are inadequate (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. Cultivars identified with slow rusting characteristics should be improved /developed further by accumulating 4-5 minor genes to achieve near-immunity prior to deployment as a control measure for management of yellow rust disease (Singh *et al*., 2011).

Positive correlation also was observed between yield percentage, yield component (TKW) losses and slow rusting parameters (Table 5). The highest correlation coefficient was between infection rate and yield losses (r = 0.95) and the lowest correlation was between FRS rate and TKW losses (r = 0.78). The correlation coefficient between yield components losses was also significant. This well-positive correlation between slow rusting parameters and yield components' losses was in agreement with the results of Hailu and Fininsa (2009) and other researchers (Ahmad *et al*., 2010; Herrera-Fossel *et al*., 2006; Afzal *et al*., 2008). Ochoa and Parlevliet (2007) also found high correlation coefficient between rAUDPC and yield losses.

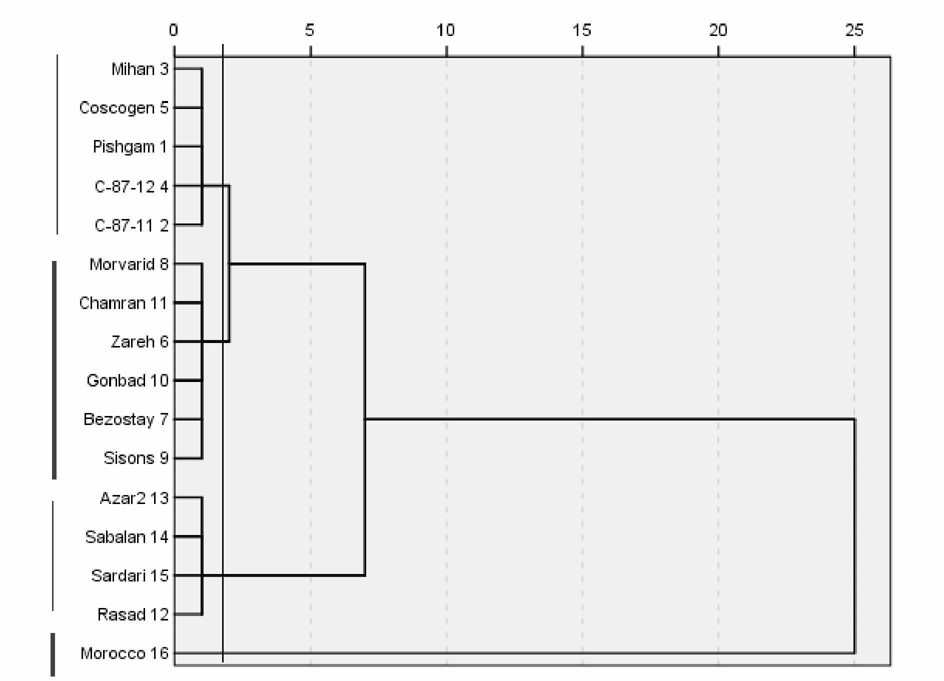

Figure 1 Denderogram of cluster analysis of 16 wheat genotypes based on slow rusting parameters, yield losses and thousand kernels weight losses.

Table 5 Linear correlation coefficients between slow rusting parameters and yield components losses for yellow rust across 16 cultivars/lines during 20112-2013 in Ardabil.

Parameters	Parameters				
	r	FRS	CI	Yield (%loss)	TKW (%loss)
FRS	0.91**	-			
CI	0.89**	0.98**	-		
Yield (%loss)	0.95**	0.87**	0.88**	-	
TKW (%loss)	0.92**	0.78**	0.79**	0.97**	-
rAUDPC	0.93**	0.99**	0.99**	0.91**	0.83**

FRS: final rust severity, rAUDPC: relative area under disease progress curve, *r:* apparent infection rate, CI: coefficients of infection, TKW: thousands kernels weigh. ** Significant at $P < 0.01$.

Conclusion

The results of current study indicated that the cultivars/lines had diversity regarding resistance reaction, ranging from complete resistance to susceptible cultivars. Most of the evaluated cultivars exhibited moderate (MR/MS) or moderately susceptible to susceptible (MSS) reactions under high disease pressure shown by susceptible check. Slow-rusting cultivars Zareh, Bezostaya, Morvarid, Sisons and Gonbad, with low values of different parameters as well as genotypes (Chamran and Rasad) with low yield component losses despite moderate disease levels supposedly have genes for varying degrees of slow rusting and HTAP can be used for future manipulation in wheat improvement.

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References

Afzal, S. N., Haque, M. I., Ahmedani, M. S., Bashir, S. and Rattu, A. R. 2007 Assessment of yield losses caused by *Puccinia striiformis* triggering stripe rust in the most common wheat varieties. Pakistan Journal of Botany, 39: 2127-2134.

Afzal, S. N., Haque, M. I., Ahmedani, M. S., Rauf, A., Muhammad, M., Firdous, S. S., Rattu, A, R. and Ahmad, I. 2008. Impact of stripe rust on kernel weight of wheat varieties sown in rainfed areas of Pakistan. Pakistan Journal of Botany, 40: 923-929

Ahmad, S., Afzal, M., Noorka, I.R., Iqbal, Z., Akhtar, N., Iftkhar, Y., Kamran, M. 2010. Prediction of yield losses in wheat (*Triticum aestivum* L.) caused by yellow rust in relation to epidemiological factors in Faisalabad. Pakistan Journal of Botany, 42: 401-407.

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

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

Ali, S., Shah, S. J. A., Raman, H., Saqib, M. S., Ibrahim, M. and Sajjad, M. 2009b. Variability in wheat yield under yellow rust pressure in Pakistan. Turkish Journal of Agriculture and Forestry, 33: 537-546.

Ben Yehuda, P., Eilam, T., Manisterski, J., Shimoni, A. and Akster, Y. 2004. Leaf rust on *Aegilops speltoides* caused by a new forma specialis of *Puccinia triticina*. Phytopathology, 94: 94-101.

Bertelsen. J. R., de Neergaard, E. and Smedegaard-Ptersen, V. 2001. Fungicide effects of azoxystrobin and poxiconazole on phylosphere fungi, senescence and yield of winter wheat. Plant Pathology, 50:190-205.

Boyd, L. A. 2005. Centenary review: can Robigus defeat an old enemy? -Yellow rust of wheat. The Journal of Agricultural sciences, 143: 233-243.

Broers, L. H. M., Cuesta-Subias, X. and Lopez-Atilano, R. M. 1996. Field assessment of quantitative resistance to yellow rust in ten spring bread wheat cultivars. Euphytica, 90: 9-16.

Brown, W. M. J., Hill, J. P. and Velasco, V. R. 2001. Barley yellow rust in North America. Annual Review of Phytopathology, 39: 367-384.

Chen, X. M. 2005. Epidemiology and control of stripe rust (*Puccinia striiformis* f. sp. *tritici*) on wheat. Canadian Journal of Plant Pathology, 27: 314-337.

Chen, X. M. 2007. Challenges and solutions for stripe rust control in the United States. Australian Journal of Agricultural Research, 58: 648-655.

Dadrezaei, S. T., Nazari, K., Afshari, F. and Mohamadi-Goltapeh, E. 2013. Phenotypic and molecular characterization of wheat leaf rust resistance gene *Lr34* in Iranian wheat cultivars and advanced lines. American Journal of Plant Sciences, 4: 1821-1833.

de Vallavieille-Pope, C., Ali, S., Leconte, M., Enjalbert, J., Delos, M. and Rouzet, J. 2012. Virulence dynamics and regional structuring of *Puccinia striformis* f. sp. *tritici* in France between 1984 and 2009. Plant Disease, 96: 131-140.

Dehghani, H. and Moghaddam, M. 2004. Genetic analysis of latent period of stripe rust in wheat seedlings. Journal of Phytopathology, 122: 325-330.

Flor, H. H. 1956. The complementary genetic systems in flax and flax rust. Advanced Genetics 8: 29-54.

Hailu, D. and Fininsa, C. 2009. Relationship between stripe rust (*Puccinia striiformis*) and common wheat (*Triticum aestivum*) yield loss in highlands of Bale, southeastern Ethiopia. Archives of Phytopathology and Plant Protection, 42: 508-523.

Herrera-Foessel, S. A., R. P. Singh, J. Huerta-Espino, J. Crossa, J. Yuen, and A. Djurel. 2006. Effect of leaf rust on grain yield and yield trait of durum wheats with race-specific and slow-rusting resistance to leaf rust. Plant Disease, 90: 1065-1072.

Hovmøller, M. S., Sørense, C. K., Walter, S., and Justesen, A. F. 2011. Diversity of *Puccinia striiformis* on Cereals and Grasses. Annual Review of Phytopathology, 49: 197-217.

Johnson, R. 1988. Durable resistance to yellow (stripe) rust in wheat and its implications in plant breeding. In: Simmonds, N. W., Rajaram, S. (Eds), Breeding strategies for resistance to the rusts of wheat. Mexico: CIMMYT. pp. 63-75.

Kilpatrick, R. A. 1975. New cultivars and longevity of rust resistance, 1971-1975.U.S Agricultural Research Services, North-East Reg. ARS-NE, NE-64.

Laudon, G. F. 1973. Uredinals. In: Anisworth, G. C., Sparrow, F. K. and Sussman, A. S. (Eds.), The Fungi. Vol. IVB. New York: Academic press. pp. 247-279.

Line, R. F. 2002. Stripe rust of wheat and barley in North America: A retrospective historical review. Annual Review of Phytopathology, 40: 75-118.

Line, R. F. and Chen, X. M. 1995. Success in breeding for and managing durable resistance to wheat rusts. Plant Disease, 79: 1254-1255.

Milus, E. A. and Line, R. F. 1986. Gene action for inheritance of durable, high–temperature, adult plant resistances to stripe rust in wheat. Phytopathology, 76: 435-441.

Morgounov, A., Yessimbekova, M., Rsaliev, S., Baboev, S., Mumindjanov, H. and Djunusova, M. 2004. High-yielding winter wheat varieties resistant to yellow and leaf rust in Central and Asia. Proceedings of the 11th International Cereal Rusts and Powdery Mildew Conference. 22-27 August 2004, John Innes Centre, Norwich, UK. European and Mediterranean Cereal Rust Foundation, Wageningen, Netherlands. Cereal Rusts and Powdery Mildew Bulletin, A2. 52.

Ochoa, J. and Parlevliet, J. E. 2007. Effect of partial resistance to barley leaf rust, *Puccinia hordei,* on the yield three barley cultivars. Euphytica, 153: 309-312.

Parlevliet, J. E. 1979. Components of resistance that reduce the rate of epidemic development. Annual Review of Phytopathology 17: 203-222

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

Peterson, R. F., Campbell, A. B. and Hannah, A. E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems of cereals. Canadian Journal of Research, Section C, 26: 496-500.

Roelfs, A. P., Singh, R. P. and Saari, E. E. 1992. Rust diseases of wheat: Concepts and Methods of Diseases Management. Mexico, D. F.CIMMYT, 81.pp.

Safavi, S. A. and Afshari, F. 2012a. Identification of resistance to *Puccinia striiformis* f. sp. *tritici* in some elite wheat lines. Journal of Crop Protection, 1, 293-302.

Safavi, S. A., Afshari, F. and Yazdansepas, A. 2013. Effective and ineffective resistance genes to wheat yellow rust during six years monitoring in Ardabil. Archives of Phytopathology and Plant Protection, 46: 774-780.

Safavi, S. A., Babai-Ahari, A., Afshari, F. and Arzanlou, M. 2012b. Effect of yellow rust on yield components of barley cultivars with race-specific and slow rusting resistance to yellow rust. Archives of Phytopathology and Plant Protection, 45: 1488-1498.

Salman, A., Khan, M. A. and Hussain, M. 2006. Prediction of yield losses in wheat varieties/lines due to leaf rust in Faisalabad. Pakistan Journal of Phytopathology, 18: 178-182.

Sandoval-Islas, J. S., Broers, L. H. M., Mora-Aguilera, G., Parlevliet, J. E., Osada, K. S. and Vivar, H. E. 2007. Quatitative resistance and its components in 16 barley cultivars to yellow rust, *Puccinia striiformis* f. sp. *hordei*. Euphytica, 153: 295-308.

Shah, S. J. A, Muhmmad, M. and Hussain, S. 2010. Phenotypic and molecular characterization of wheat for slow rusting resistance against *Puccinia striiformi*s Westend. f. sp. *tritici.* Journal of Phytopathology, 158: 393-402.

Sharma-Poudyal, D., Chen, X. M., Wan, A. M., Zhan, G. M., Kang, Z. S., Cao, S. Q., Jin, S. L., Morgounov, A., Akin, B., Mert, Z., Shah, S. J. A., Bux, H., Ashraf, M., Sharma, R. C., Madariaga, R., Puri, K. D., Wellings, C., Xi K. Q., Wanyera, R., Manninger, K., Ganzález, M. I., Koyda, M., Sanin, S. and Patzek, L. J. 2013. Virulence characterization of international collections of the wheat stripe rust pathogen, *Puccinia striiformis* f. sp.*tritici*. Plant Disease, 97: 379-386.

Singh, D., Park, R. F. and McIntosh, R. A. 2007. Characterization of wheat leaf rust resistance gene *Lr34* in Australian wheats using components of resistance and the molecular marker csLV34. Australian Journal of Agricultural Research, 58: 1106-1114.

Singh, R. P., Huerta-Espino, J. and William, H. M. 2005. Genetics and breeding for durable resistance to leaf and stripe rusts in wheat. Turkish Journal of Agriculture and Forestry, 29: 121-127.

Singh, R. P., Huerta-Espino, J., Bhavani, S., Herrera-Foessel S. A., Singh D., Singh, P. K., Velu, G., Mason, R. E., Jin, Y., Njau, P. and Crossa, J. 2011. Race non-specific resistance to rust diseases in CIMMYT spring wheats. Euphytica 179:175-186.

Singh, R. P., William, H. M., Huerta-Espino, J. and Rosewame, G. 2004. Wheat rust in Asia: Meeting the Challenges with Old and New Technologies. New Directions for a Diverse Planet. Proceeding of the 4th International Crop Science Congress, 26 Sep-1 Oct 2004, Brisbane, Australia. P. 1-13.

Stubbs, R. W., Prescott, J. M., Saari, E. E. and Dubin, H. J. 1986. Cereal Disease Methodology Manual. CIMMYT: Mexico, D. F. 46 pp.

Torabi, M., Madoukhi, V., Nazari, K., Afshari, F., Forootan, A.R., Ramai, M. A., Golzar, H. and Kashani, A. S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. Cereal Rusts and Powdery Mildews Bulletin, 23: 9-12.

Van der Plank, J. E. 1968. Disease Resistance in Plants. Academic Press, New York.

Wan, A. M. and Chen, X. M. 2012. Virulence, frequency, and distribution of races of *Puccinia striiformi*s f. sp. *tritici* and *Puccinia striiformis* f. sp. *hordei* identified in the United States in 2008 and 2009. Plant Disease, 96: 67-74.

اثر زنگ زرد بر عملکرد ژنوتیپ‌های گندم دارای مقاومت اختصاصی نژاد و مقاومت تدریجی نسبت به زنگ زرد

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چکیده: زنگ‌ها موجب خسارت‌های شدیدی در تولید گندم می‌شوند. در بین زنگ‌ها، زنگ زرد با عامل *Puccinia striiformis* f. sp. *tritici* بیماری مهمی است که تولید گندم را در مناطق خنک تهدید می‌کند. مقاومت میزبانی به‌ویژه مقاومت غیراختصاصی– نژاد (race-nonspecific)، اقتصادی‌ترین روش مدیریت زنگ زرد است. در این پژوهش کارائی تیپ‌های مختلف مقاومت در مزرعه آزمایشی ایستگاه تحقیقات کشاورزی اردبیل طی سال زراعی ۹۲-۱۳۹۰ مقایسه شد. عملکرد و اجزاء عملکرد به‌همراه مؤلفه‌های مقاومت تدریجی (Slow rusting) شامل شدت نهائی بیماری (FRS)، نرخ آلودگی ظاهری (*r*)، مقدار نسبی سطح زیر منحنی پیشرفت بیماری (rAUDPC) و ضریب آلودگی (CI) برای ۱۶ رقم و لاین گندم ارزیابی شدند. به‌طور کلی، پنج رقم با مقاومت اختصاصی- نژاد، ۱۰ رقم با مقاومت تدریجی و یک رقم حساس در این پژوهش در دو تیمار با سمپاشی قارچکش و بدون سمپاشی با قارچکش بررسی شدند. نتایج حاصل از تجزیه واریانس مرکب بیانگر تفاوت معنی‌دار بین ارقام و اثر متقابل رقم × سال در سطح احتمال ۱٪ بود. ارقام گندم با مقاومت تدریجی ازنظر شدت بیماری واکنش‌های متفاوتی نشان دادند. میانگین کاهش وزن هزار دانه (TKW) برای ژنوتیپ‌های حساس، با مقاومت اختصاصی نژاد و دارای مقاومت تدریجی به‌ترتیب ۴۱، ۴/۴ و ۷/۶ درصد بود و میانگین کاهش عملکرد برای ژنوتیپ‌های حساس، با مقاومت اختصاصی نژاد، و دارای مقاومت تدریجی به‌ترتیب ۶۵/۶، ۷/۳ و ۱۵/۹درصد بود. ارقام دارای مقاومت تدریجی با مقادیر پایین مؤلفه‌های اپیدمیولوژیکی و نیز ژنوتیپ‌هایی با مقادیر پایین کاهش اجزاء عملکرد، علی‌رغم مقادیر متوسط بیماری شناسایی شدند. چنین ژنوتیپ‌هایی می‌توانند در برنامه‌های به‌نژادی گندم با ژنوتیپ‌های دارای سطح بالای مقاومت و مقادیر جزئی کاهش عملکرد استفاده شوند. در این پژوهش، داده‌های مربوط به تعداد دانه در سنبله (KPS) برای مقایسه درصد کاهش‌ها در دو آزمایش شاهد (با سمپاشی) و بدون سمپاشی کافی نبودند و نیاز به آزمایشات تکمیلی دارند.

واژگان کلیدی: گندم، مقاومت تدریجی، زنگ زرد، عملکرد، اجزاء عملکرد