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Identification of resistance to *Puccinia striiformis* f. sp. *tritici* in some elite wheat lines

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Abstract: Race-specific resistance of wheat to yellow rust caused by *Puccinia striiformis* f. sp. *tritici* has been reported as short-lived. Partial resistance, a kind of quantitative resistance, has been reported to be more stable. Partial resistance in terms of slow rusting parameters including final rust severity (FRS), apparent infection rate (*r*), relative area under disease progress curve (rAUDPC), and coefficient of infection (CI) was evaluated in a set of twenty six wheat genotypes along with susceptible control during 2010-2011 cropping year. This study was conducted in field plots at Ardabil Agricultural Research Station (Iran) under natural infection conditions with twice artificial inoculation. Artificial inoculation was carried out by yellow rust inoculum having virulence against *Yr2, Yr6, Yr7, Yr9, Yr22, Yr23, Yr24, Yr25, Yr26, Yr27, YrA,* and *YrSU*. Seedling reaction was also evaluated in greenhouse by using race 66E0A+, Yr27+. Results of mean comparison for resistance parameters showed that, lines C-89-4, C-89-17 and C-89-16 along with susceptible had the highest values of FRS, CI, *r* and rAUDPC, therefore were selected as moderately susceptible or susceptible lines. The lines C-89-7, C-89-8, C-89-9, C-89-10, C-89-13, C-89-14 and C-89-20 had susceptible reactions at seedling stage and low level infection at adult plant stage. Accordingly these lines with low level of different parameters supposed to be having gene/s for varying degrees of partial resistance or high temperature adult plant resistance (HTAP) that can be used for future manipulation in wheat improvement program after confirmatory studies. The remaining lines (except for C-89-2) were immune or had low level of infection. Thus, these were selected as resistant lines. In this study correlation coefficient between different parameters of slow rusting was highly significant. Based on the results, the reaction of the studied genotypes to stripe rust varied from sensitive to immune.

Keywords: Wheat, partial resistance, durable resistance, yellow (stripe) rust, leaf tip necrosis

Introduction

Stripe (yellow) rust of wheat, caused by *Puccinia striiformis* Westend f. sp. *tritici* is an important disease of wheat worldwide (Line, 2002). This is mainly due to the pathogen's ability to mutate and multiply rapidly and its air-borne dispersal mechanism that permits it to disperse over long distances (Singh *et al.,* 2005). Stripe rust can severely damage wheat production worldwide (Roelfs *et al.,* 1992; Line, 2002) and cause yield losses from 10 to 70 % and reducing the quality of grain and

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forage (Chen, 2005). Stripe rust was the dominant wheat 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). Stripe rust epidemics in most of the wheat-growing areas of Iran 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). On susceptible cultivars, stripe rust can cause 100 % yield loss if infection occurs very early (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 friendly approach to control the disease (Line and Chen, 1995). 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 genes ensures effective protection against the disease (Shah *et al.,* 2010). This type of resistance, however, is dependent on a specific recognition event between the host (R gene products) and the pathogen (Avirulence gene products). The race-specific resistance follows the gene- for-gene interactions, as described by Flor (1956), and may, 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.,* 2007).

Several *Yr*-genes that confer resistance to stripe rust in wheat have been identified and incorporated into commercial wheat cultivars (McIntosh *et al.,* 1995). However, 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, genes *Yr2, Yr3, Yr4, Yr6, Yr7, Yr9* and *YrA* are commonly present in breed wheat cultivars developed by CIMMYT (Badebo *et al.,* 1990; Bux *et al.,* 2011). However, none of these genes is globally effective (Broers *et al.,* 1996). An alternative for breeders is quantitative resistance. Two types of quantitative resistance, *i. e*, 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 cultivar resistance 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). Shah *et al.,* (2010), Sandoval-Islas *et al.,* (2007) and Ali *et al.,* (2007) reported that slow rusting parameters can be used for grouping of different cultivars/lines based on their resistance reaction.

Therefore, the aim of this study was to evaluate partial resistance in promising wheat lines and to test the efficiency of different epidemiological parameters in selected wheat.

Materials and Methods

The entire trial was subdivided into two experiments, a seedling test that was conducted on under greenhouse conditions and a field study focused on evaluating partial resistance parameters of the wheat lines.

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Table 1 Parentage and pedigree of studied wheat lines for evaluation of partial resistance during 2010-2011 in Ardabil.

No.	Lines	Pedigree/Parents
1	C-89-1	Oroum (C-83-7)
2	C-89-2	Zareh (C-83-8)
3	C-89-3	Mihan (C-84-8)
4	C-89-4	Owl//Ombul/Alamo
5	C-89-5	Bow"s"/Crow"s"//Kie"s"/Vee"s"/3/MV17
6	C-89-6	Fdo 2062
7	C-89-7	Zarrin*2/Gaspard
8	C-89-8	Babaga
9	C-89-9	Pyn*2/Co725052/3/Kauz*2/Yaco//Kauz
10	C-89-10	Alvand*2/Gaspard
11	C-89-11	Shi#4414/Crows"s"//Gk Sagvari/Ca8055
12	C-89-12	308.02.2/Weaver//F362K2.121
13	C-89-13	Zander/3/Kauz*2/Yaco//Kauz
14	C-89-14	Gascogne/Col. no.3625//Zarrin
15	C-89-15	Fdo 4085
16	C-89-16	Fdo 1104-2
17	C-89-17	Fdo 5121
18	C-89-18	Fdo 6087
19	C-89-19	Bez/Nad//Kzm(Es85-24)/3/Ptzniska/Ut1556-170
20	C-89-20	Kleiber/2*Fl80//Donsk.Poluk./3/Ks82W409/
21	-	Marin/Humtsman/3/2*Alvd//Aldan/Ias58
22	-	Lcr/Seri/3/Mex-Dw/Baca//Vona/4/Tam200/Ji5418
23	-	Zarrin//Rsh*2/10120
24	-	Tx71C8130R/Tx81V6610/3/Rl6010/6*Inia 60//Kauz
25	-	Agri/Nac//Kauz/3/1D13.1/Mlt
26	-	Es14/Sitta//Agri/Nac
27	Bolani	-

Seedling test

Twenty-six promising lines (Table 1), having desirable agronomic characters, and a susceptible cultivar (Bolani) obtained from Cereal Department of Seed and Plant Improvement Institute, Karaj, Iran, were used in this study. The resistance response of the seedlings was evaluated in greenhouse by planting the lines in pots (5 seeds/pot) which had a mixture of soil, peat moss and sand in a 7:5:5 proportions. Ten days after sowing, inoculation with race 66E0A+, Yr27+ was conducted by spraying of plants with a mixture of spores and talcum powder (in 1:4 proportions). The pots subsequently were placed for 24 h in a dark moist chamber at 10 ºC and then transferred to a greenhouse at 15- 18 ºC and 16: 8 L: D. After 14-17 days of inoculation (Rizwan *et al.,* 2010), seedling reaction was recorded using a 0-9 scale based on McNeal *et al.,* (1971). Infection types equal to or higher than 7 were considered as susceptible, and those less than 7 were considered resistant.

Field tests

This experiment was conducted in Ardabil Agricultural Research Station (Iran) during 2010-2011cropping season. Each entry was planted in two rows of 1 meter spaced at 30cm apart. Plots were spaced at 65 cm. Experimental design was randomized complete block design with three replications. Artificial inoculation was carried out twice after the sun set with Ardabil isolate having virulence on plants with gene/s *Yr2, Yr6, Yr7, Yr9,Yr22, Yr23, Yr24, Yr25, Yr26, Yr27, YrA,* and *Yr*SU by spraying all test entries and spreader rows with mixture of spores and talcum powder (in 1: 20 proportions). Percent severity was recorded three times, starting when the susceptible check Bolani reached 50 % severity on the modified Cobb,s scale (Peterson et al., 1948) and reaction based on Roelfs *et al.,* (1992). Coefficient of infection (CI) was calculated by multiplying 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, S = 1 (Stubbs *et al.,* 1986). Leaf tip necrosis was also recorded according to described method by Navabi *et al.,* (2005) based on 0-4 scale, where 0 = lines without leaf-tip necrosis, 1 = lines with faint necrosis, 2 = lines with necrosis extending to one fourth of the individual leaves, 3 = lines with necrosis extending to less than half of the individual leaves and 4 = lines with necrosis extending

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to more than one half of the individual leaves.

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

Also the infection rate (*r*) was estimated in terms of disease severity recorded on wheat lines in 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 t_1 and t_2 are dates at which disease severity measurements were made, and x_1 and x_2 are the amounts of disease recorded on these dates. Then variance of final rust severity (FRS), rate infection (r), coefficient of infection (CI) and rAUDPC was analyzed by MSTAT-c software (Anonymous, 1991). Finally comparison of lines was used for grouping of them based on Duncan,s Multiple Range Test (Gomez and Gomez, 1984).

Results and Disussion

Seedling Test

The results of seedling assessment are listed in Table 2. Ten lines showed resistance reaction at both seedling and adult plant stages, two susceptible at seedling stage and moderately susceptible at adult plant stage. Seven lines had resistance and moderate reaction at seedling and adult plant stage, respectively. The lines C-89-7, C-89-8, C-89-9, C-89-10, C-89-13, C-89-14 and C-89-20 had the susceptible reaction at seedling tests and moderately resistant to moderate reaction at adult plant stage. These lines which had low values of slow rusting parameters at adult plant stage could have durable resistance (Singh *et al.,* 2005). This kind of resistance can be kept for a long time, even if pathogen changes its genotype. Durable resistance, such as slow rusting and HTAP, is controlled by more than one gene (Dehghani & Moghaddam, 2004).

Field assessment

The data on disease severity and host reaction was combined to calculate coefficient of infection (CI). According to Ali *et al.,* (2009a), lines with CI values of 0-20, 21-40, 41-60 were regarded as possessing high, moderate and low levels of adult plant resistance, respectively. Table 2 clearly shows that disease pressure was considerably high as indicated by CI of susceptible check. Maximum CI recorded among tested lines was 27-46.7 % of susceptible check for three entries (i.e. C-89-16, C-89-17 and C-89-4), while the remaining 23 lines were up to 15.3 % of Bolani. Based on the results, common pathotypes of Ardabil were considered avirulent on most evaluated lines (Table 2). Lines C-89-1, C-89-3, C-89-6, C-89-11, C89-15, C-89-18, and lines with No. 21, 23, 24 (with resistance reaction at both stages) have been reported elsewhere as carrying major or combination of major and minor genes (Ali *et al.,* 2007; Johnson, 1988). However, the lines/ 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).

Based on the rAUDPC values, promising lines were categorized in to two distinct groups according to Ali *et al.,* (2007). The first group included genotypes exhibiting rAUDPC values up to 30 % of check, while lines showing rAUDPC values up to 70 % of check were placed in second group. In these lines rust initiated and sporulated but with final chlorotic and necrotic strips (MR and/or MS infection types). Subsequently, the progress of rust development remained slower and restricted. Lines of group 1 were marked as having better partial resistance. Lines with such traits are expected to possess genes that confer partial resistance (Parlevliet, 1988). Apart from nine lines having resistance reaction at both stages, the remaining lines that exhibited rAUDPC values less than 30 % of Bolani were considered as having better partial resistance.

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Table 2 Adult plant infection type, seedling reaction, score of leaf tip necrosis and mean comparison for coefficient of infection, final rust severity, infection rate and rAUDPC in promising wheat lines to yellow rust, in Ardabil (2010-2011).

Lines	Seedling reaction[a]	Values of different parameters under field conditions					
		Infection type	Mean values of different slow rusting parameters[b]				Leaf tip necrosis[c]
			Final rust severity	Coefficient of infection	rAUDPC	Infection rate	
C-89-1	0	R	1 g	0.2 h	1 g	0 e	0
C-89-2	0	MR	36.7 c	14.6 de	33.2 c	0.046 cd	2 (3)[d]
C-89-3	0	R	1 g	0.2 h	1 g	0 e	1 (1)
C-89-4	8	MS	63.3 b	46.7 b	48 b	0.11 b	1 (1)
C-89-5	0	M	4 g	2.8 gh	4.1 fg	0.006 e	1 (1)
C-89-6	0	R	1 g	0.2 h	1 g	0 e	3 (2)
C-89-7	8	MR	7 fg	2.7 gh	7.5 fg	0 e	2 (2)
C-89-8	8	MR	13.7 efg	5.5 fgh	12.3 f	0.013 e	2 (2)
C-89-9	8	MR	23.3 de	9.3 defg	25 cd	0.006 e	2 (3)
C-89-10	8	M	30 cd	15.3 d	28.4 cd	0.043 d	1 (1)
C-89-11	0;	R-MR	1 g	0.3 h	1 g	0 e	1 (1)
C-89-12	2CN	MR	17 ef	6.8 efgh	13.5 ef	0.016 e	1 (1)
C-89-13	8	M	23.3 de	11.3 def	22.6 de	0.013 e	1 (1)
C-89-14	8	MR	7.3 fg	2.9 gh	6.4 fg	0.013 e	1 (1)
C-89-15	0	TMR	1 g	0.2 h	1 g	0 e	3 (2)
C-89-16	8	MS	36.7 c	27 c	26.6 cd	0.06 c	1 (1)
C-89-17	2C	M	53.3 b	28.6 c	53 b	0.043 d	3 (2)
C-89-18	0;C	R	1 g	0.2 h	1 g	0 e	2 (3)
C-89-19	0;C	MR	4 g	0.3 h	4 fg	0.006 e	2 (3)
C-89-20	7	MR	4 g	1.5 gh	4.2 fg	0 e	0
21	0;	R	1 g	0.2 h	1 g	0 e	2 (3)
22	0	TMR	1 g	0.2 h	1 g	0 e	3 (1)
23	0	R	1 g	0.2 h	1 g	0 e	2 (3)
24	0	R	1 g	0.2 h	1 g	0 e	2 (3)
25	5C	MR	30 cd	12 def	31.7 cd	0.016 e	2 (3)
26	;2CN	MR	4 g	1.6 gh	4.2 fg	0.006 e	2 (2)
Bolani	8	S	100 a	100 a	100 a	0.31 a	0

a: Infection type based on McNeal *et al.,* (1971); Letters C and N were used to indicate more than normal chlorosis and necrosis, respectively.
b: Means followed by the same letters in each column are not statistically significant at 1 % level.
c: Leaf tip necrosis based on Navabi *et al.,* (2005) d: Values in parentheses indicate frequency of observed scores in three replications.

This group comprised lines with varying degrees of partial resistance which has been advocated to be more durable (Singh, *et al.,* 2004). Moreover, lines with acceptable levels of partial resistance restrict the evolution of new virulent races of the pathogen because multiple point mutations are extremely rare in nature (Ali *et al.,* 2007).

Data on final rust severity of 26 lines along with susceptible check (Bolani) are shown in Table 2. High disease pressure was recorded at the testing site as maximum FRS up to 100 % for Bolani, followed by C-89-4 (63.3 %), C-89-17 (53.3 %) and C-89-16 (36.7 %) classified as moderate (M) to moderately susceptible (MS) based on infection type, while none of the tested lines was recorded to be immune. Similarly based on FRS the tested lines were grouped into three groups of partial resistance, *i. e.*, high, moderate, low levels of partial resistance having 1-30 %, 31-50 %, 51-70 % FRS, respectively. Twenty two lines were included in first group, three lines were marked as having moderate level of partial resistance and only one was marked as having low level partial resistance. Similarly Broers *et al.,* (1996) and Ali *et al.,* (2009a) also carried out field assessment of partial resistance to yellow rust for ranking of lines. According to the resistance level based on disease severity along with other

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partial resistance parameters, they found that resistance level ranged from very low to very high among the tested lines.

Infection rate of all lines was less than Bolani during 2010-2011. Apart from Bolani, the highest mean *r*-value of 0.11 was recorded for C-89-4 followed by C-89-16 (r = 0.06) belonging to moderately susceptible group based on infection types. Similarly, Ali *et al.,* (2008), Sandoval-Islas *et al.,* (2007), and the present study demonstrated that infection rate seemed an unreliable estimate of partial resistance when compared with FRS, CI and rAUDPC, because it did not mark some lines as having different level of partial resistance with regard to other parameters. In this study lines marked as having better level of partial resistance (in terms of other parameters), indicated infection rate less than 0.043.

The data on leaf tip necrosis (LTN) were recorded on flag leaves using a 0-4 scale (Table 2), whereas only lines having scale 2 with two- three replications were considered acceptable. Shah *et al.,* (2010) and Ali *et al.,* (2009b) also used LTN trait for grouping wheat lines. They also found different categories among tested cultivars/lines based on LTN trait. LTN, a morphological trait, shows complete linkage or pleiotropism with *Yr18* and *Lr34* genes (Singh, 1992) and could be use as a marker to identify wheat lines carrying these genes (Shah *et al.,* 2011). LTN trait can be observed at adult plant stage and its expression in the present study was considered positive for 11 lines; less frequent in nine lines, but was totally absent in lines C-89-1, C-89-20 and susceptible check. In three lines LTN scale was 3 and wasn't considered acceptable. Although phenotypes, based on LTN, have been used in this study; however, its expression can be obscured by genetic background (Singh *et al.,* 1999) and variable influences of environments (Dyck, 1991). Singh *et al.,* (1999) reported that wheat lines not exhibiting LTN in some environments may still carry *Lr34*. Furthermore, combination of optimal moisture for plant development and cool night temperatures after heading stage may be required for consistent expression of LTN (Wamishe and Milus, 2004). The lines with resistance reaction at both stages without LTN or less frequent LTN most probably carry all-stage resistance. Lines with race-specific, all-stage resistance often become susceptible soon after they are released because of the rapid evolution of new races (Line and Chen, 1995). Some lines may be carry combination of HTAP resistance with effective all-stage resistance and because HTAP resistance is often controlled by quantitative-trait loci (QTL), masked by effective all-stage resistance (Chen, 2005). This is a challenge, but use of marker-assisted selection is a promising approach to meet this.

Association between slow rusting parameters

During this investigation, an attempt was made to elucidate the relationship between field-based partial resistance parameters. Positive relation of final rust severity was found with rAUDPC, coefficient of infection (CI), and infection rate with a strong r^{-} value that was 98 %, 94 % and 87 %, respectively (Table 3). The highest correlation coefficient (r) was between rAUDPC with final rust severity (r = 0.98) and the lowest r^{-} value was between infection rate with final rust severity (r = 0.87). This well positively correlation agreed with the results of other researchers on cereal-rust pathosystems (Shah *et al.,* 2010; Sandoval-Islas *et al.,* 2007; Safavi *et al.,* 2010). Previously Sandoval-Islas *et al.,* (2007) found good correlation of rAUDPC with quantitative resistance components, *i.e.* latent period and infection frequency. Ochoa and Parlevliet (2007) 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 in 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. Lines identified with partial resistance characteristics should be improved /developed further by accumulating 4-5 minor genes to achieve near-immunity prior to deployment as a control strategy in the region for controlling yellow rust problem.

Table 3 Linear correlation coefficients between slow rusting parameters for yellow rust across 27 lines during 2010-2011 in Ardabil.

parameters	Parameters		
	CI	rAUDPC	FRS
rAUDPC	0.94**	-	-
FRS	0.94**	0.98**	-
r	0.95**	0.87**	0.87**

FRS, final rust severity; rAUDPC, relative area under disease progress curve; *r*, apparent infection rate; CI, coefficients of infection

* Significant at P = 0.01 levels of probability.

Conclusion

The results of current study showed that the lines had diversity of resistance, ranging from complete resistance to moderate susceptibility. Most of the evaluated lines exhibited good performance under high disease pressure shown by susceptible check. Resistance of all categories including complete resistance to partial resistance to yellow rust was observed. The lines C-89-7, C-89-8, C-89-9, C-89-10, C-89-13, C-89-14 and C-89-20 supposed to be having genes for varying degrees of partial resistance or HTAP can be used for future manipulation in wheat improvement program after confirmatory studies. Now day's 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.

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تعیین مقاومت به زنگ زرد در برخی از لاین‌های امیدبخش گندم

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چکیده: مقاومت ویژه-نژادی گندم نسبت به زنگ زرد (با عامل *Puccinia striiformis* f. sp. *tritici*) اغلب ناپایدار است ولی مقاومت نسبی، مقاومت پایداری گزارش شده است. مقاومت نسبی براساس پارامترهای Slow rusting شامل شدت نهائی بیماری (FRS)، نرخ آلودگی ظاهری (*r*)، مقدار نسبی سطح زیر منحنی پیشرفت بیماری (rAUDPC) و ضریب آلودگی (C) در ۲۶ ژنوتیپ گندم همراه با شاهد حساس طی سال زراعی ۹۰-۱۳۸۹ در مزرعه آزمایشی ایستگاه تحقیقات کشاورزی اردبیل ارزیابی شد. این آزمایش تحت شرایط آلودگی طبیعی با دو بار آلودگی مصنوعی انجام گردید. آلودگی مصنوعی با اسپور زنگ زرد با بیماریزائی بر روی ژن‌های مقاومت *Yr2, Yr6, Yr7, Yr9, Yr22, Yr23, Yr24, Yr25, Yr26, Yr27, YrA* و *YrSU* انجام شد. واکنش گیاهچه‌ای نیز در گلخانه با استفاده از نژاد 66E0A+,Yr27+ ارزیابی گردید. نتایج مقایسه میانگین برای پارامترهای مقاومت نشان دادند که لاین-های C-89-4, C-89-17, C-89-16 همرا با شاهد حساس بالاترین مقادیر FRS، *r*، CI، rAUDPC را دارند، بنابراین به‌عنوان لاین‌های حساس یا نیمه حساس انتخاب شدند. لاین‌های C-89-7, C-89-8, C-89-9, C-89-10, C-89-13, C-89-14 و C-89-20 در مرحله گیاهچه‌ای واکنش حساسیت و در مرحله گیاه کامل آلودگی پایینی داشتند، بنابراین این لاین‌ها با مقادیر پایین پارامترهای مختلف به احتمال زیاد دارای ژن‌هایی با درجات متفاوت از مقاومت نسبی یا HTAP هستند. بقیه لاین‌ها (به‌جز لاین C-89-2) مصون و یا آلودگی پایینی نشان دادند بنابراین به‌عنوان لاین‌های مقاوم انتخاب گردیدند. در این بررسی ضریب پیوستگی بین پارامترهای مختلف Slow rusting به‌طور معنی‌داری بالا بود. براساس نتایج این تحقیق، واکنش ژنوتیپهای گندم مورد بررسی از حساس تا مصون متغیر بود.

واژگان کلیدی: گندم، مقاومت نسبی، مقاومت پایدار، زنگ زرد، نکروز نوک برگ

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