Relationship between Partial Resistance and Inheritance of Adult Plant Resistance Gene *LR* 46 of Leaf Rust in Six Bread Wheat Varieties

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Abstract: ***Leaf rust caused by Puccinia triticina Eriks. is an important disease of wheat (Triticum aestivum L.) in Egypt and worldwide. Six Egyptian bread wheat varieties were evaluated and tested for their levels of adult plant resistance to leaf rust at Sadat City location during three successive growing seasons i.e. 2011/12, 2012/13 and 2013/14. Wheat varieties Gemmeiza 9, Giza 168 and Gemmeiza 7 showed the highest levels of partial resistance and lower values of percentage final rust severity (FRS) did not exceeded up to 30 % as well as area under disease progress curve (AUDPC) not more than 250. On the other hand, Gemmeiza 1, Sakha 93 and Sids 1 were highly susceptible or fast rusting varieties. These varieties showed the highest levels of percentage FRS and AUDPC compared with the partially resistant varieties under the same field conditions. To determine the inheritance of adult plant resistance to leaf rust, tested wheat varieties were crossed with seven adult plant leaf rust resistance monogenic lines i.e. Lr 38, Lr 42, Lr 43, Lr 44, Lr 45, Lr 46 and Lr 47. The resulted F_1 plants were selfed to produce F_2 seeds. F_2 plants were tested at adult plant stage under field conditions at Sadat City location during 2012/13 growing season. Segregations of F_2 plants at adult plant stage revealed that the wheat varieties Giza 168 and Gemmeiza 9 have the same three genes i.e. Lr 45, Lr 46 and Lr 47. While the other tested varieties Sakha 93, Gemmeiza 1, Gemmeiza 7 and Sids 1 do not carry any of the tested leaf rust resistance genes.***

Keywords: Wheat, *Puccinia triticina*, adult plant resistance, partial resistance, AUDPC.

1. Introduction

Leaf rust caused by *Puccinia triticina* Eriks. is one of the most important diseases of wheat (*Triticum aestivum* L.) in Egypt and worldwide. It causes severe losses in grain yield reaching about 23% or higher on susceptible cultivars under favorable environmental conditions for the pathogen (Nazim *et al*., 1983). Genetic resistance is the most economical and effective means of reducing yield losses to this disease (Pink, 2002). Knowledge of the identity of leaf rust resistance genes in cultivars and commonly used germplasm in breeding programs can improve efficacy of developing new resistant cultivars. Near-isogenic lines (NILs) carrying *Lr* resistance genes were developed in the spring wheat cv. Thatcher through backcrossing (Dyck & Samborski 1968 and Chelkowski *et al*., 2003).

At present, more than 80 genes and alleles of leaf rust resistance (*Lr*) genes have been identified and described. Among them 33 *Lr* genes were transferred from other species into *Triticum aestivum* L. (Herrera-Foessel *et al*., 2011; 2012; Ingala *et al*., 2012 and McIntosh *et al*., 2012). Most of these resistance genes are race-specific and therefore several of these genes are ineffective due to the emergence of new virulent races soon after their deployment (Kolmer *et al*., 2008). In contrast, slow-rusting resistance characterized by slow disease progress in the field despite a compatible host reaction (Caldwell, 1968). Although slow-rusting resistance genes have small to intermediate effects when present alone, high levels of resistance have been achieved by combining four to five genes (Singh *et al*., 2000). The leaf rust resistance gene *Lr* 46 confers slow-rusting resistance to leaf rust and stripe rust, which has also provide durable resistance in gene combination (Singh *et al*., 2005). Another gene confers slow-rusting resistance to leaf rust and stripe rust is *Lr* 34 (Dyck, 1977; 1987 and Singh, 1992a). *Lr* 34 also confers resistance to powdery mildew (*Blumeria graminis*) (Spielmeyer *et al*., 2005), stem rust (*Puccinia graminis tritici*) (Dyck, 1987) and barley yellow dwarf virus (Singh, 1993). Moreover, *Lr* 67 gene confers slow-rusting resistance for leaf rust and transferred from accession PI250413 in Pakistan (Dyck and Samborski, 1979). Furthermore, the leaf rust resistance gene *Lr* 67 showed effect to stripe rust and was associated with leaf tip necrosis in the field (Dyck and Samborski, 1979 and Dyck *et al*., 1994).

Knowledge of the identity of the leaf rust resistance genes in released cultivars and germplasm is essential for the incorporation of new effective resistance genes into breeding programs and maintenance of a diversity of resistance genes in commonly grown cultivars. The study aimed to determine the level of partial resistance to leaf rust in six bread wheat varieties under field conditions. Also, to identify seven adult plant leaf rust resistance genes in the tested varieties at adult plant stage.

2. Materials and Methods

This investigation aimed to determine partial resistance and identify adult plant resistance genes governing leaf rust resistance in six wheat varieties i.e Giza 168, Sakha 93, Gemmeiza 1, Gemmeiza 7, Gemmeiza 9 and Sids 1 under field conditions (Table 1). The selected monogenic lines were *Lr* 38, *Lr* 42, *Lr* 43, *Lr* 44, *Lr* 45, *Lr* 46, and *Lr* 47. The experiments of this study were carried out in the farm of Environmental Studies and Research Institute, University of Sadat City, Sadat City, Minufiya, Egypt.

To estimate the level of partial resistance, the above mentioned wheat varieties were cultivated in three growing seasons i.e. 2011/12, 2012/13 and 2013/14 at Sadat City location. All experiments were carried out in a randomized complete block design with three replicates. The tested wheat varieties were grown in plots; each plot contains six rows, each row was 3 m long and 30 cm apart, where the plot size was 3 m X 3 m = 9 m^2. The experimental plots were surrounded by a rust spreader belt planted with a mixture of the highly susceptible varieties to leaf rust i.e. Thatcher, Morocco and *Triticum spelta saharensis* to serve as a continuous spreader source for leaf rust urediniospores.

For identification of adult plant leaf rust resistance genes by genetic analysis, the parental varieties and the tested wheat leaf rust monogenic lines were grown in plots (9 m^2); each plot contains rows of 3 m long and 30 cm apart during 2011/12 growing season in three successive dates at 15 days intervals to overcome differences in the time of flowering. The leaf rust monogenic lines were used as male parents for crosses with each of the tested wheat cultivar to obtain F_1 seeds. The F_1 seeds were grown in the next following season (2012/13) in rows of 3 m long and 30 cm apart and spaced 30 cm in order to facilitate production of F_2 seeds. In 2013/14 growing season, parents and F_2 seeds were grown at Sadat City in plots; each plot of the parents and F_2 plants contains 9 rows of 3 m long and 30 cm between rows and seeds were 20 cm apart, therefore each row contained 15 plants and each plot contained 135 plants. Each of F_2 cross was evaluated in two plots contained 270 plants. All plots were surrounded by a spreader area in one meter width sown with a mixture of highly susceptible wheat cultivars i.e. Thatcher, Morocco and *Triticum spelta saharensis*.

3. Inoculation and disease assessment:

Spreader plants were sprayed with water and dusting with spores powder mixture of the most prevalent and aggressive leaf rust pathotypes (one volume of fresh urediniospores mixture : 20 volume of talcum powder). Dusting was carried out in the early evening (at sunset) before dew point formation. The inoculation of all plants was carried out at booting stage according to the method of Tervet and Cassell (1951). To estimate the level of partial resistance, percentage leaf rust severity was recorded for the six wheat varieties using the modified Cobb's scale described by Peterson *et al*. (1948). Then mean percentage leaf rust severity of the three replicates of all of the tested wheat varieties were calculated. Rust severity data were scored after the appearance of the first symptoms (appear of the first pustule on any of the tested wheat varieties) at seven days intervals. The percentage final rust severity (FRS) was assessed according to Das *et al*. (1993), as the disease severity (%) for each of tested variety when the highly susceptible check variety (Morocco) was severely rusted and the disease rate reached the highest level of leaf rust severity.

Area under disease progress curve (AUDPC) was also calculated for each variety as a good reliable and more accurate estimator for rust resistance under field conditions. Moreover, mean percentage of AUDPC for the three replicates of all of the tested wheat varieties were calculated. The values of AUDPC were calculated by using the following equation of Pandey *et al*. (1989).

$AUDPC = D\ [1/2\ (Y_1 + Y_k) + (Y_2 + Y_3 + \text{-----} + Y_{k-1})]$

Where: D = Days between two consecutive recording (time intervals)

$Y_1 + Y_k$ = Sum of the first and last scores.

$Y_2 + Y_3 + \text{------} + Y_{k-1}$ = Sum of all in between disease scores.

For identification of the adult plant resistance, data of leaf rust severity were recorded at the adult plant stage for each of F_2 plant at milk stage when the susceptible wheat cultivars Thatcher, Morocco and *Triticum spelta saharensis* displayed a response between 80 S to 100 S using the modified Cobb's scale of Peterson *et al*. (1948). Plant reaction was expressed in five infection types (Roelfs *et al*., 1992). The infection types were immune = (0), resistant = (R), moderately resistant = (MR), moderately susceptible = (MS) and susceptible = (S).

The F_2 plants of each cross were grouped into eight classes depending on their percentage of disease severity under field conditions. The disease severity classes were 0-10; 11-20; 21-30; 31-40; 41 50; 51-60; 61-70 and 71-80. Plants grouped in the first three classes were considered as resistant phenotype, while plants of the other classes (more than 30%) were considered as susceptible phenotype (Singh and Huerta-Espino, 1995).

For identification of the adult plant leaf rust resistance genes in each cross, goodness of fit of the observed to the expected ratio of the phenotypic classes concerning the leaf rust severity and infection types, were determined by Chi square (χ^2) analysis according to Steel and Torrie (1960).

Table 1: List of the six tested bread wheat varieties, pedigree and year of release

Variety	Pedigree	Year of release
Giza 168	MRL/BUC//Seri. CM93046-8M-0Y-0M-2Y-0B-0GZ	1999
Sakha 93	Sakha 92/TR 810328 S 8871-1S-2S-1S-0S	1999
Gemmeiza 1	Maya74/Mon//1160.147/3/Bb/199/Gall/4/chat "S" CM58924-IGM-0GM	1991
Gemmeiza 7	CMH74A.630/SX//SER182/3/AGENT. GM4611-2GM-3GM-1GM-0GM	1999
Gemmeiza 9	Ald "S"/Huac "S"//CMH74A. 630/5x CGM4583-5GM-1GM-0GM	2000
Sids 1	HD2172/Pavon "S"//1158.57/Maya74 "S" SD46-4Sd-2SD-1SD-0SD	1996

4. Results

Evaluation of the tested wheat monogenic lines against leaf rust at adult plant stage:

Data in Table (2) showed that, in 2011/12 growing season the wheat monogenic lines *Lr* 46 and *Lr* 47 were completely resistant and showed zero percent final rust severity compared with the other tested monogenic lines which showed final rust severity ranged from 5 MR to 20 MR.

In 2012/13 growing season, the leaf rust resistance genes *Lr* 42 and *Lr* 45 were immune to leaf rust infection. Meanwhile, the other tested monogenic lines showed final rust severity ranged from Tr R to 20 MR.

In 2013/14 growing season, the wheat monogenic lines *Lr* 43, *Lr* 46 and *Lr* 47 were completely resistance and showed zero rust severity. Moreover, the other tested monogenic showed final rust severity ranged from Tr MR to 20 MR.

Table 2: Final leaf rust severity of seven wheat monogenic lines at adult plant stage grown at Sadat City during three successive growing seasons (2011/12 - 2013/14).

***Lr* gene**	**Season / Final rust severity**		
	2011/12	**2012/13**	**2013/14**
Lr 38	10	5 MR	20 MR
Lr 42	10 MR	0	Tr MR
Lr 43	20 MR	10 MR	0
Lr 44	10 MR	20 MR	5 MR
Lr 45	5 MR	0	Tr MR
Lr 46	0	Tr MR	0
Lr 47	0	Tr R	0

* Final rust severity includes two components: disease severity based on modified Cobb's scale (Peterson *et al*., 1948); where Tr = less than 5 % and 5 = 5 % up to 100 = 100 % and host response based on scale described by Roelfs *et al*. (1992); where 0 = immune (no visible infection), R = resistant (flecks and small uredinia with necrosis), MR = moderately resistant (large necrotic flecks and large uredinia), MS = moderately susceptible (moderate to large uredinia with chlorosis) and S = susceptible (large uredinia).

Evaluation of the tested wheat varieties under field conditions:

1- Final rust severity (FRS %):
Data of final rust severity in Table (3) recorded during the 2011/12 and 2012/13 growing season were found to be slightly higher compared with the third growing season 2013/14. Also, data showed that final rust severity (%) of the tested wheat varieties were lower compared to the check variety Sids 1 during the three seasons at Sadat City. In 2011/12 growing season, the wheat varieties Gemmeiza 9 (10.00%), Giza 168 (16.67%) and Gemmeiza 7 (26.67%) showed the lowest values of final rust severity (did not exceed up to 30.00%) during this season. While, the wheat varieties Gemmeiza 1 (53.33%), Sakha 93 (66.67%) and Sids 1 (86.67%) showed the highest values of percentage FRS.

Data of percentage final rust severity in the second season (2012/13) showed that the wheat varieties Giza 168 and Gemmeiza 9 (each with 13.33%) and Gemmeiza 7 (26.67) showed the lowest values of percentage FRS (less than 30.00%). While the wheat varieties Gemmeiza 1 (50.00%), Sakha 93 (60.00%) and Sids 1 (80.00%) showed the highest values of percentage FRS.
In 2013/14 growing season, the wheat varieties Gemmeiza 9, Giza 168 and Gemmeiza 7 showed the lowest values of percentage FRS i.e. 6.67%, 11.67% and 23.33%, respectively. While, the wheat varieties Gemmeiza 1, Sakha 93 and Sids 1 showed the highest values of percentage FRS i.e. 46.67%, 63.33% and 73.33%, respectively.

Data of mean percentage FRS during three seasons indicated that the wheat varieties Gemmeiza 9 (10.00%), Giza 168 (13.89%) and Gemmeiza 7 (25.56%) showed the highest resistance response with the lowest mean FRS (%). While, the wheat varieties Gemmeiza 1 (50.00%), Sakha 93 (63.33%) and Sids 1 (80.00%) were susceptible and showed the highest values of mean percentage FRS.

2- Area under disease progress curve (AUDPC):
Data presented in Table (3) showed the mean area under disease progress curve (AUDPC) estimated over the three seasons, the tested wheat varieties can be classified into two main groups depending on their values of AUDPC. The first group included the wheat varieties that displayed the highest levels of adult plant resistance under field conditions through the three growing seasons of the study.

These varieties were Gemmeiza 9, Giza 168 and Gemmeiza 7 which showed the lowest values of AUDPC (less than 300) i.e. 82.06, 111.22 and 225.56, respectively. Therefore, they have been classified as slow-rusting or partially resistant varieties. The second group included the wheat varieties Gemmeiza 1 (521.11), Sakha 93 (703.89) and Sids 1 (886.67), which they showed the highest values of AUDPC to leaf rust infection. Also, they displayed the lowest levels of adult plant resistance and these varieties classified as fast-rusting varieties.

Identification of adult plant leaf rust resistance genes:

Results presented in Table (4) showed that F_2 plants of the crosses between *Lr* 38 and the wheat varieties Giza 168, Sakha 93, Gemmeiza 1, Gemmeiza 7, Gemmeiza 9 and Sids 1 segregated to (195 resistant : 63 susceptible), (180 R : 47 S), (174 R : 57 S), (166 R : 49 S), (177 R : 55 S) and (172 R : 63 S), respectively. These segregations fit the ratio (3 R : 1 S) indicated that the wheat varieties Giza 168, Sakha 93, Gemmeiza 1, Gemmeiza 7, Gemmeiza 9 and Sids 1 did not have gene Lr 38.

F_2 plants of the crosses between the leaf rust resistance gene *Lr* 42 and the tested wheat varieties Giza 168, Sakha 93, Gemmeiza 1, Gemmeiza 7, Gemmeiza 9 and Sids 1 segregated to the ratios 175 R : 47 S, 190 R : 54 S, 153 R : 54 S, 171 R : 46 S, 166 R : 54 S and 161 R : 53 S, respectively. These ratios fitting 3 R: 1 S ratio indicating that these varieties don't have gene *Lr* 42.

The F_2 plants of the crosses between *Lr* 44 and the wheat varieties Giza 168, Sakha 93, Gemmeiza 1, Gemmeiza 7, Gemmeiza 9 and Sids 1 segregated to the ratios 160 R : 52 S, 168 R : 59 S, 183 R : 65 S, 146 R : 55 S, 175 R : 48 S and 166 R : 43 S, respectively. These ratios fitting to 3 R : 1 S indicating that they don't have this gene .

All of 215 and 218 F_2 plants of the crosses between *Lr* 45 and the wheat varieties Giza 168 and Gemmeiza 9 were resistant and therefore expressed *Lr* 45 resistance but the wheat varieties Sakha 93, Gemmeiza 1, Gemmeiza 7, Gemmeiza 9 and Sids 1 segregated at 171 R : 61 S, 173 R : 47 S, 170 R : 65 S and 159 R : 49 S, respectively, fitting to 3 R : 1 S ratio and not therefore expressing this gene.

All of 233 and 231 F_2 plants of the crosses between *Lr* 46 and the wheat varieties Giza 168 and Gemmeiza 9 were resistant and therefore expressed *Lr* 46 resistance but the wheat varieties Sakha 93, Gemmeiza 1, Gemmeiza 7, Gemmeiza 9 and Sids 1 segregated to 173 R : 67 S, 154 R : 53 S, 173 R : 47 S and 178 R : 55 S, respectively, which were a good fit to the ratio of 3 R : 1 S, but still indicating that these varieties did not express *Lr* 46 gene.

Table 3: Percentage final leaf rust severity (FRS) and area under disease progress curve (AUDPC) on six bread wheat varieties under field conditions at Sadat City location during 2011/12, 2012/13 and 2013/14 growing seasons.

Variety	Growing season / Final rust severity (%) and area under disease progress curve (AUDPC)							
	Final rust severity (%)				Area under disease progress curve			
	2011/12	2012/13	2013/14	Mean FRS	2011/12	2012/13	2013/14	Mean AUDPC
Giza 168	16.67	13.33	11.67	13.89	131.83	106.17	95.67	111.22
Sakha 93	66.67	60.00	63.33	63.33	735.00	653.33	723.33	703.89
Gemmeiza 1	53.33	50.00	46.67	50.00	560.00	525.00	478.33	521.11
Gemmeiza 7	26.67	26.67	23.33	25.56	239.17	239.17	198.33	225.56
Gemmeiza 9	10.00	13.33	6.67	10.00	80.50	106.17	59.50	82.06
Sids 1 (check)	86.67	80.00	73.33	80.00	945.00	886.67	828.33	886.67
L.S.D. at 5%	**13.84**	**8.17**	**14.68**	-	**182.26**	**92.65**	**166.99**	-

All of 218 and 225 F_2 plants of the crosses between *Lr* 47 and the wheat varieties Giza 168 and Gemmeiza 9 were resistant expressed *Lr* 47 resistance but the wheat varieties Sakha 93, Gemmeiza 1, Gemmeiza 7, Gemmeiza 9 and Sids 1 segregated to 178 R : 66 S, 160 R : 52 S, 161 R : 56 S and 183 R : 49 S, respectively, fitting to the ratio 3 R : 1 S and not therefore expressing this gene.

Data in Table (5) indicated that, the wheat varieties Giza 168 and Gemmeiza 9 have the same three genes i.e. *Lr* 45, *Lr* 46 and *Lr* 47. While the other tested varieties Sakha 93, Gemmeiza 1, Gemmeiza 7 and Sids 1 do not carry any of the tested leaf rust resistance genes.

Table 4: Segregations and Chi square analysis of F_2 plants of the crosses between six bread wheat varieties and seven leaf rust monogenic lines at adult plant stage under field conditions at Sadat City location during 2013/14 growing season.

Cross	No. of F_2 plants		Expected ratio	Chi-square (χ 2)	*P.* value
	Resistant (R)	Susceptible (S)			
Giza 168 x *Lr* 38	195	63	3:1	0.047	0.829
Sakha 93 x *Lr* 38	180	47	3:1	2.233	0.135
Gemmeiza 1 x *Lr* 38	174	57	3:1	0.013	0.909
Gemmeiza 7 x *Lr* 38	166	49	3:1	0.560	0.454
Gemmeiza 9 x *Lr* 38	177	55	3:1	0.207	0.649
Sids 1 x *Lr* 38	172	63	3:1	0.410	0.522
Giza 168 x *Lr* 42	175	47	3:1	1.736	0.188
Sakha 93 x *Lr* 42	190	54	3:1	1.071	0.301
Gemmeiza 1 x *Lr* 42	153	54	3:1	0.130	0.718
Gemmeiza 7 x *Lr* 42	171	46	3:1	1.673	0.196
Gemmeiza 9 x *Lr* 42	166	54	3:1	0.024	0.876
Sids 1 x *Lr* 42	161	53	3:1	0.006	0.937
Giza 168 x *Lr* 43	168	61	3:1	0.328	0.567
Sakha 93 x *Lr* 43	170	58	3:1	0.023	0.878
Gemmeiza 1 x *Lr* 43	173	51	3:1	0.595	0.440
Gemmeiza 7 x *Lr* 43	170	45	3:1	1.899	0.168
Gemmeiza 9 x *Lr* 43	160	54	3:1	0.006	0.937
Sids 1 x *Lr* 43	179	45	3:1	2.881	0.090
Giza 168 x *Lr* 44	160	52	3:1	0.025	0.874
Sakha 93 x *Lr* 44	168	59	3:1	0.119	0.730
Gemmeiza 1 x *Lr* 44	183	65	3:1	0.194	0.660
Gemmeiza 7 x *Lr* 44	146	55	3:1	0.599	0.439
Gemmeiza 9 x *Lr* 44	175	48	3:1	1.436	0.231
Sids 1 x *Lr* 44	166	43	3:1	2.183	0.140

P. values higher than 0.05 indicate non-significant of χ^2

Table 4: Continued.

Giza 168 x *Lr* 45	215	0	No segregation	-	-
Sakha 93 x *Lr* 45	171	61	3:1	0.207	0.649
Gemmeiza 1 x *Lr* 45	173	47	3:1	1.552	0.213
Gemmeiza 7 x *Lr* 45	170	65	3:1	0.887	0.346
Gemmeiza 9 x *Lr* 45	218	0	No segregation	-	-
Sids 1 x *Lr* 45	159	49	3:1	0.231	0.631
Giza 168 x *Lr* 46	233	0	No segregation	-	-
Sakha 93 x *Lr* 46	173	67	3:1	1.089	0.297
Gemmeiza 1 x *Lr* 46	154	53	3:1	0.040	0.841
Gemmeiza 7 x *Lr* 46	173	47	3:1	1.552	0.213
Gemmeiza 9 x *Lr* 46	231	0	No segregation	-	-
Sids 1 x *Lr* 46	178	55	3:1	0.242	0.623
Giza 168 x *Lr* 47	218	0	No segregation	-	-
Sakha 93 x *Lr* 47	178	66	3:1	0.546	0.460
Gemmeiza 1 x *Lr* 47	160	52	3:1	0.025	0.874
Gemmeiza 7 x *Lr* 47	161	56	3:1	0.075	0.784
Gemmeiza 9 x *Lr* 47	225	0	No segregation	-	-
Sids 1 x *Lr* 47	183	49	3:1	1.862	0.172

P. values higher than 0.05 indicate non-significant of χ^2.

Table 5: Resistance genes for leaf rust identified in six bread wheat varieties at adult plant stage.

Variety	leaf rust resistance gene
Giza 168	*Lr* 45, *Lr* 46, *Lr* 47
Sakha 93	-
Gemmeiza 1	-
Gemmeiza 7	-
Gemmeiza 9	*Lr* 45, *Lr* 46, *Lr* 47
Sids 1	-

5. Discussion

Partial resistance has been early recognized as more stable type of resistance in contrast to other forms of resistance (Caldwell, 1968 and Van der Plank, 1975).

In this study, the components of partial resistance against leaf rust determined in six wheat varieties i.e. Giza 168, Sakha 93, Gemmeiza 1, Gemmeiza 7, Gemmeiza 9 and Sids 1 under field conditions at Sadat City location during three growing seasons i.e. 2011/12, 2012/13 and 2013/14.

According to the percentage final rust severity (FRS), the tested wheat varieties could be classified into two main groups. The first one included partially resistant varieties i.e. Gemmeiza 9, Giza 168 and Gemmeiza 7 which showed low values of percentage FRS (less than 30 %). While, the second group included the fast rusting varieties i.e. Gemmeiza 1, Sakha 93 and Sids 1 which showed the highest values of percentage FRS during the three growing seasons. Also, they displayed the lowest levels of adult plant resistance and these varieties classified as fast-rusting varieties. These results are previously supported by Bassiony (1979); Nazim *et al.* (1983); Nazim *et al.* (1990); Herrera-Fossel *et al.* (2011) and El-Orabey and Nagaty (2013)

Area under disease progressive curve (AUDPC) is a good indicator of adult plant resistance under field condition (Wang *et al*., 2005). Cultivars which had low AUDPC and terminal severity values thus may have good level of adult plant resistance (Wang *et al*., 2005). Furthermore, AUDPC in particular is the result of all factors that influence disease development such as differences in environmental conditions, varieties and population of the pathogen (Pandey *et al*., 1989; Lal Ahmed *et al*., 2004; Singh *et al*., 2005 and Boulot, 2007). According to the obtained results and depending on the values of AUDPC, the wheat varieties Gemmeiza 9, Giza 168 and Gemmeiza 7 showed the lowest values of AUDPC. Such results indicated that these varieties have good level of adult plant resistance under field conditions during the three growing seasons to leaf rust and can be used as resistance sources. Therefore, this group of varieties characterized as the partially or slow rusting resistant group. While, the three wheat varieties Gemmeiza 1, Sakha 93 and Sids 1 showed the highest AUDPC values. These varieties classified as the highly susceptible or fast rusting varieties group, as reported by Nazim *et al*. (1990); Denissen (1993); Singh *et al*. (2005) and Herrera-Fossel *et al*. (2011).

To identify the gene (s) governing adult plant resistance to leaf rust in the wheat varieties; genetic analysis was conducted. This experiment included crossing of tested six wheat varieties i.e. Giza 168, Sakha 93, Gemmeiza 1, Gemmeiza 7, Gemmeiza 9 and Sids 1 with seven monogenic lines i.e. *Lr* 38, *Lr* 42, *Lr* 43, *Lr* 44, *Lr* 45, *Lr* 46, and *Lr* 47. The F_1 plants were selfed to obtain the F_2 plants. The F_2 plants were evaluated at adult plant stages and goodness of fit of the observed to the expected ratio of the phenotypic classes concerning the leaf rust severity and infection types, were determined by Chi square analysis according to Steel and Torrie (1960).

In this study, the tested wheat varieties Giza 168 and Gemmeiza 9 have the adult plant resistance genes i.e. *Lr* 45, *Lr* 46 and *Lr* 47. While, the wheat varieties Sakha 93, Gemmeiza 1, Gemmeiza 7 and Sids 1 do not carry any of the tested wheat monogenic lines. These results in agreement with Ingal *et al*. (2012); Loladze *et al*. (2014) and Wang *et al*. (2014). Moreover, AUDPC values of the two wheat varieties Giza 168 and Gemmeiza 9 suggest that these varieties showed partial resistance to leaf rust; this mainly due to the presence of the partial leaf rust resistance gene *Lr* 46.

Obtained results has been strongly supported by Sivasamy *et al*. (2014) who found that five wheat lines carried leaf rust resistance gene *Lr* 46 and showed partial resistance to leaf rust. Meanwhile, the partial resistance in Gemmeiza 7 appeared to be based on gene (s) other than *Lr* 46. This gene (s) may be the slow rusting resistance *Lr* 34 and/or *Lr* 68. Herrera-Foessel *et al*. (2012) found that adult plant resistance to leaf rust in line the wheat cultivar Parula is governed by at least three independent slow rusting resistance genes i.e. *Lr* 34 on 7DS, *Lr* 46 on 1BL, and *Lr* 68 gene on 7BL. Khanna *et al*. (2005) found that the partial resistance in the wheat cultivar HD2009 is similar in expression to that conferred by the gene *Lr* 34, but cultivar HD2009 did not show leaf tip necrosis, a morphological marker tightly linked to the leaf rust resistance gene *Lr* 34 (Singh, 1992b).

Leaf rust resistance gene *Lr* 46 is a slow rusting resistance gene. This gene does not provide the host plant with complete immunity against leaf rust (*Puccinia triticina*) races. The effect of *Lr* 46 delayed the infection process or reduces the development of symptoms caused by leaf rust races on adult plants; reduce colony size and lower disease severity (Martinez *et al.*, 2001). *Lr* 46 was first described in 1998 by Singh *et al.* (1998) in cultivar Pavon 76, and located on chromosome 1B. Also, *Lr* 46 linked with the stripe rust resistance gene *Yr* 29. The type of resistance conferred by *Lr* 46 is similar to that of *Lr* 34, although with a smaller effect.

6. Conclusion

Our results showed the presence of different levels of resistance in the tested wheat varieties to leaf rust at adult plant stage under field conditions. None of the tested varieties were immune. The wheat varieties Giza 168 and Gemmeiza 9 showed good levels of partial resistance and this resistance mainly due to the presence of the leaf rust partial resistance gene *Lr* 46. Our results do not exclude the presence of other genes for leaf rust resistance in the tested varieties.

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