PARTIAL RESISTANCE OF WHEAT *(TRITICUM AESTIVUM)* TO LEAF RUST *(PUCCINIA TRITICINA)* IN EGYPT. B. CHARACTERIZATION OF PARTIAL RESISTANCE TO LEAF RUST IN SOME EGYPTIAN WHEAT CULTIVARS.

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Abstract

Partial resistance (PR) ***(****Puccinia triticina****)*** in wheat cultivars is a form of incomplete host genetic resistance characterized by a susceptible infection type or a compatible host-pathogen interaction. Despite of this susceptible reaction, the diseased tissue remained less than that of the highly susceptible genotypes, thus the disease progress or development in PR cvs. is retarded .Although, all the tested cvs. were uniformly inoculated with the two races TKTT and PKTT, under the favourable greenhouse conditions, PR components varied significantly between PR cvs. and the highly susceptible ones. The partially resistant cvs., Giza 168, Sakha 94 Sakha 95 and sids-12, characterized by their capacity to restrict both colony and pustule sizes (mm^2), reduce a pustule eruption rate (%) and consequently prolonged latent period (LP) of both races, under study. In contrast, the highly susceptible cvs., sids-1, Gemmeiza-7 and Giza 139 (check) , showed large colony and pustule sizes, high rates of pustule eruption and shorter times (days) of LP, at seedling and adult plant stages. A close and high correlation was found between each of the four PR components in the greenhouse and FRS (%), r-value and AUDPC in the field, as indicated by the high significant correlation coefficients. Thus, these components of resistance could be considered as the promising characteristics and a best selection criterion for screening and selecting partially resistant (PR) genotypes.

key words: Latent period , Final uredinium size , Colony size , Pustule eruption , Final rust severity.

INTRODUCTION

Partial resistance (PR) to wheat leaf rust *(Puccinia triticina)* has been early detected and recognized as a good form of host genetic resistance , that hoped to be more durable , long-lasting as well as more stable over a wide range of environments and against a broad spectrum of pathogen races (Ohm & Shaner ,1976 , Broers , 1989, Denissen, 1993 & Boulot, 2007). This type of resistance is referred to an incomplete , race nonspecific (general) resistance characterized by a susceptible infection type or a compatible host-pathogen interaction . However, the diseased host tissue area as well as the rate of fungal growth and sporulation remained less than those in a very high susceptible genotype (Broers , 1989, Boulot 1997 and El-shamy & Mousa, 2004).

So far, there are no documented physiological explanations for the retardation of the disease development in PR wheat cultivars. It would appear that PR cultivars may possess some underlying factors responsible for an inhibitory effect against fungal growth , pustule formation and eruption which consequently lead to prolonged latent period (LP) of *P.triticina* (Ohm & Shaner ,1976, Shaner, 1983 , Torabi, 1992 , Denissen ,1993 , Boulot 1997 and El-shamy & Mousa, 2004).This pattern of resistance can be well explained by the combined effect of some resistance components involved in the expression of PR in wheat cultivars such as colony and pustule sizes, pustule eruption rate and latent period (LP) . The possibility of some resistance mechanisms in host plant that interfered with the growth of fungal infection structures and sporulation, had been previously reviewed by many investigators. For example , the arrest of hyphal growth and a substantial early abortion of pathogen colonies affected the success of both colonies and uredinia establishment. Thus, it was presumably responsible for the reduction of final (maximum) colony and pustule sizes , as the two main components that functioned in PR cultivars (Broers , 1989 and Jacobs & Burrlage ,1990).

On the other hand, lower rates of pustule eruption in a given time in PR cultivars led to prolong the latent period, time required for 50% of uredinia to erupt (Shaner , 1983) . Numerous studies had emphasized that latent period was an important PR component controlling the rate of leaf rust development in wheat cultivars, and was considered the major resistance component in determining PR (Shaner , 1980 , Broers , 1989 and Torabi, 1992) .

The four PR components , diminution of both colony and pustule sizes, delaying the rate of pustule development and eruption and ultimately prolonging latent period of the fungus , were estimated in the present study among the basic components that functioned in PR of the currently used wheat cultivars. Such study, would facilitate a full understanding to appreciable contribution of each resistance component studied.

Another goal of the present study is to investigate the effect of plant growth stage on the expression of the four resistance components as well as the correlation between each component and the epidemiological parameters under the field conditions as well as in the greenhouse. An ultimate goal was to identify one or more of these components as a selection criterion in the early screening for PR to leaf rust in wheat genotypes.

MATERIALS AND METHODS

The main components of PR to leaf rust races, race 1, TKTT and race 2, PKTT i.e. colony size (mm^2), pustule size (mm^2),percentage of pustule eruption and latent period in days, were measured in both seedling and adult stages of plants of the tested cultivars of wheat, under greenhouse conditions (20 ±4°C). Grains of the seven wheat cultivars ., Sids-1, Giza 168, Sakha 94, Sakha 95, Gemmneize 7, Sids-12 and Giza 139 (check), were sown in a natural soil dispensed in 10-cm and 25-cm pot diam .for seedling and adult plant tests , respectively .Seeding was made at rate of 10 grains per pot

Inoculation of wheat plants was carried out by using a mixture of the freshly collected urediniospores of each leaf rust race under study and talcum powder, at the rate of 1: 25 w/w. After inoculation, the plants were incubated in a moist chamber for 24 hrs., under approximately 100% relative humidity. Then the pots were distributed in a randomized complete block design of three replications in the greenhouse . To determine the above four components of PR, segment from the primary leaves (1-3 cm. long, cut from the middle part of inoculated leaf blades), were taken two days after inoculation and at daily intervals, till the end of sporulation. Each , Three leaf segments were taken per cultivar for a given race used (each segment represent one replicate). Leaf segments were stained, cleared and prepared for microscopic examination, by using the whole-leaf clearing and staining technique described by Warren and Brown (1962).

A. Colony and pustule area (size):

Colony diameters were measured by using an equilibrium ocular micrometer of light microscope, and its area was estimated as an ellipse, using the formula adopted by Tomerline *et al.,* (1984), as follow:

$$\text{Colony area (size)} = {}^{1}/_{4}\ (\text{length x width}) \times \pi$$

Pustule size (mm^2) was also determined by the same formula that used in estimating the colony's area.

B. Pustule eruption (%)

The number of uredinia erupted and ruptured the epidermis of leaves, number of non-erupted and total number of urediniospores per square centimeter of leaf area was daily counted for each cultivar and each race, 6 days after inoculation and until the leaves withereds. The percentage of pustule eruption was calculating according to the following equation:

$$\text{- Pustule eruption (\%)} = \frac{\text{Number of uredinia ruptured}}{\text{Total number of uredinia}} \times 100$$

C. Latent period (LP):

Latent period was determined as the time in days from that of inoculation to the day when 50% of the pustule had erupted and ruptured the epidermis of leaves .

However, latent period (LP) was accurately estimated, using the formula adopted by Das *et al.,* 1993*,* as follow:

- Latent period (days) = t_1+ ((F/2 nt_1) (t_2 - t_1)/ nt_2 – nt_1)

  Where:

  F= Final count of number of pustules.

  t_1= Day prior to 50% pustules rupture.

  t_2= Day after 50% pustules rupture.

  nt_1= Number of pustules ruptured at t_1.

  nt_2= Number of pustules ruptured at t_2.

Statistical analysis:

Statistical analysis of data was carried out for each component of partial resistance (Table, 1). Significance of difference among the studied varieties (V) , the pathogen races (R) and the interaction between varieties and races (V x R), were tested by running analysis of variance test (ANOVA) ,as adopted by Snedecor and Cochran (1967). Comparisons of means for each variable were carried out among genotypes and fungal races using L.S.D. test. Correlation coefficient was also used to detect the relationship between the four components of partial resistance in greenhouse and each of the three epidemiological parameters, FRS, AUDPC, and r-value. ANOVA and correlation analysis were performed by using MSTAT –C statistical.

RESULTS

To gain a more detailed expression on the PR variation between the tested varieties, four components involved in this type of resistance , colony size , uredinium size , pustule eruption and latent period were characterized. The four PR components were determined at both seedling and adult plant stages, against the most frequent races, TKTT and PKTT of *Puccinia triticina*, under favorable greenhouse conditions (Tables, 1,2and 3).

I-Components of partial resistance (PR):

1) Colony size (mm^2):

In general, PR cultivars have been characterized by a considerable decrease in the amount of tissues invaded by the two races under study, compared with the highly susceptible ones. However, the PR cultivars, Sids-12, Giza 168, Sakha 94 and Sakha 95 restricted the growth of the two pathogen races, once the infection is successful, resulting in smaller colony size (mm^2). The average size (mm^2) of established colonies was relatively affected by the host growth stage. Faster development of colonies was observed in the leaves of plants inoculated at heading (adult stage) resulting in larger final size of colonies. On the other hand, final size of colonies differed also with the different variety-race interactions. In general, similar trend was found in the two races under study.

On seedlings of the tested cultivars, colony developed more faster in the highly susceptible cultivars. than in partially resistant (PR) ones, Giza 168, Sakha 95, Sakha 94 and Sids -12, with both pathogen races under study. Therefore, the maximum colony size (mm^{2-}) was considerably smaller in the PR cvs., than in the highly susceptible ones. It was (0.980 mm^2 and 0.732 mm^2), (0.804mm^2 and 0.488 mm^2) and (0.801mm^2 and 0.506mm^2) in the artificially inoculated seedlings with race 1 and race 2, of the highly susceptible cultivars., Giza 139, Sids1 and Gemmeiza 7, respectively (Table,2). In contrast the final colony size (mm^2) reached only to (0.071mm^2 & 0.042mm^2), (0.122 mm^2 & 0.072 mm^2), (0.132mm^2 & 0.133mm^2) and (0.247mm^2 & 0.157mm^2), in the preinoculated seedlings, with the two pathogen races, race 1 and race 2, of the PR cultivars., Giza 168, Sakha 94, Sids-12 and Sakha 95, respectively (Table,2).

On the other hand, maximum or final size of the established colonies in the primary leaves of the adult plants of PR cultivars, was significantly smaller than those in the highly susceptible ones. Since, the colonies of race 1, reached its maximum and final size (mm^2)on the leaves of the highly susceptible cultivars., Giza 139 (1.2 mm^2), Sid-1 (0.966mm^2) and Gemmeiza-7 (0.965mm^2). Meanwhile, the established colonies of the same race (race, 1), was found to be of smaller and limited areas, as it was, 0.133mm^2, 0.241 mm^2, 0.472mm^2 and 0.507 mm^2, on the primary leaves of PR cultivars., Giza 168, Sakha 94, Sakha 95 and Sids-12, respectively (Table,3). Data obtained as a result of inoculating the other race of the study (race, 2) was in correspondence with those found in race 1, but with a much less order (Table,3).

2. Pustule size (mm^2):

On the basis of the data presented in Tables (2 and 3), it could be suggested that the final uredinium size (FUS) obviously varied between the tested varieties, reflecting the different levels of PR to wheat leaf rust. Nevertheless, the largest and highly significant difference in the FUS (mm^2) was found between the highly susceptible cultivars and PR ones, especially at adult plant stage.

Uredinia of the two wheat leaf rust races, race 1 (TKTT) and race2 (PKTT) reached its maximum size (mm^2) on the seedlings of the highly susceptible cultivars., Giza 139 (0.331 and 0.215mm^2), Sids 1 (0.278 and 0.164 mm^2) and Gemmeiza 7 (0.150 and 0.119 mm^2), inoculated with the two races, respectively (Table,2). Inversely, a considerable restriction and/ or diminution of uredinium size (mm^2) as a result of arrest and retardation of the hyphal growth was, presumably, obtained on the seedlings of the partially resistant cultivars., Giza 168 (0.037 and 0.027 mm^2), Sakha 95 (0.059 and 0.046mm^2), Sakha 94 (0.079 and 0.057 mm^2) and Sids -12 (0.099 and 0.074 mm^2), previously inoculated with the leaf rust races, 1 and 2,respectively.(Table,2).

Table 1. Analysis of variance for colony size, pustule size, pustule eruption(%) and latent period, using races TKTT and PKTT [a] of *Puccinia triticina*, on seven wheat varieties, at seedling and adult plant stages, under greenhouse conditions.

Source of variation	D.F	Variable															
		Colony size (mm^2)				Pustule size (mm^2)				Pustule eruption (%)				Latent period (days)			
		Seedling stage		Adult-plant stage		Seedling stage		Adult-plant stage		Seedling stage		Adult-plant stage		Seedling stage		Adult-plant stage	
		M.S.	F-value	M.S.	F-value	M.S.	F-value	M.S.	F-value	M.S.	F-value	M.S.	F-value	M.S.	F-value	M.S.	F-value
Replication	2	0.001	3.66^{*}	0.0001	0.1117^{NS}	0.0000	2.36^{NS}	0.0000	0.0990^{NS}	1.0123	0.873^{NS}	0.3560	0.2071^{NS}	0.0144	0.3484^{NS}	0.0527	2.13^{NS}
Varieties (V)	6	0.6532	22215.60^{**}	0.6989	1396.94^{**}	0.0504	4981.63^{**}	0.1510	666.23^{++}	1644.06	1417.80^{**}	1562.76	909.19^{**}	30.67	740.17^{**}	26.70	1079.34^{**}
Race (R)	1	0.2334	7936.44^{**}	0.3244	648.36^{**}	0.0226	2234.56^{**}	0.0993	438.03^{**}	242.27	208.93^{**}	270.68	157.48^{**}	15.61	376.55^{**}	12.26	495.57^{**}
Interaction (VX R)	6	0.0263	894.29^{**}	0.0296	59.13^{**}	0.0031	306.86^{**}	0.0154	68.12^{**}	12.06	10.40^{**}	49.60	28.86^{**}	0.72	17.43^{**}	1.39	56.33^{**}
Error	26	0.0000	-	0.0005	-	0.0000	-	0.0002	-	1.16	-	1.72	-	0.0414	-	0.0247	-

a The most frequent leaf rust races in Egypt during 2009/10 growing season.

Table 2. Leaf rust development, colony size (mm^2), pustule size (mm^2), pustule eruption (%) and latent period (days) of the two races i.e TKTT (race 1) and PKTT (race 2) of *Puccinia triticina* on seven Egyptian wheat varieties at seedling stage under greenhouse conditions.

No.	Wheat Variety	*Partial resistance* (PR) components/ *Puccinia triticina* race											
		Colony size (mm^2)			Pustule size (mm^2)			Pustule eruption (%)			Latent priod (days)[c]		
		Race 1[a]	Race 2 [b]	Mean	Race 1[a]	Race 2[b]	Mean	Race 1[a]	Race 2[b]	Mean	Race 1[a]	Race 2[b]	Mean
1	Sids -1	0.8041	0.4878	0.6460	0.2778	0.1639	0.2236	97.25	92.12	94.09	10.03	10.98	10.51
2	Sids-12	0.1324	0.1129	0.1226	0.0987	0.0739	0.0863	78.74	75.53	77.14	11.91	12.88	12.40
3	Giza 168	0.0712	0.0418	0.0595	0.0370	0.0266	0.0318	55.84	52.26	54.05	15.73	16.30	16.02
4	Sakha 94	0.1220	0.0718	0.0969	0.0788	0.0512	0.0680	67.46	65.45	66.46	14.55	14.80	14.68
5	Sakha 95	0.2471	0.1573	0.2022	0.0590	0.0456	0.0523	61.08	56.53	58.81	13.21	15.89	14.55
6	Gemmeiza-7	0.8009	0.5060	0.6535	0.1497	0.1194	0.1346	89.39	84.04	86.72	10.61	10.84	11.23
7	Giza 139 "check"	0.9812	0.7319	0.8566	0.3309	0.2150	0.2730	98.70	87.90	93.30	9.52	10.87	10.20
Mean		0.4513	0.3022	0.3768	0.1474	0.1010	0.1242	78.35	73.40	75.88	12.14	13.36	12.75
- L.S.D. of varieties 5%				0.0064			0.0038			1.28			0.24
(V) 1%				0.0087			0.0051			1.73			0.33
- L.S.D. of races 5%		0.0034			0.0020			0.68			0.13		
(R) 1%		0.0047			0.0027			0.92			0.18		
- L.S.D. of interaction 5%			0.0091			0.0053			1.81			0.34	
(R x E) 1%			0.0123			0.0072			2.44			0.46	

a: Race 1 , race TKTT and b: race 2, race PKTT, the most common races in leaf rust population in Egypt in 2009/2010 season .

c: latent period (days), as estimated by Das *et al.,* 1993.

Table 3. Leaf rust development, colony size (mm^2), pustule size (mm^2), percentage of pustule eruption and latent period (days) of *Puccinia triticina*, (Race TKTT and PKTT) on seven Egyptian wheat varieties under greenhouse conditions (at adult stage) in Giza.

No.	Wheat variety	Components of *partial resistance* (PR)/ wheat leaf rust races											
		Colony size (mm^2)			Pustule size (mm^2)			Pustule eruption (%)			Latent priod (days)[c]		
		Race 1[a]	Race 2[b]	Mean	Race 1[a]	Race 2[b]	Mean	Race 1[a]	Race 2[b]	Mean	Race 1[a]	Race 2[b]	Mean
1	Sids -1	0.9659	0.6510	0.8080	0.4707	0.2548	0.3627	94.46	84.41	89.43	10.67	11.08	10.88
2	Sids-12	0.5066	0.4240	0.4653	0.2002	0.1384	0.1703	72.25	62.81	67.53	14.87	15.17	15.02
3	Giza 168	0.1327	0.1002	0.1165	0.0939	0.0732	0.0835	52.35	50.46	51.40	17.35	17.69	17.52
4	Sakha 94	0.2411	0.1799	0.2105	0.0785	0.0593	0.0689	63.34	58.41	60.88	14.26	15.47	14.87
5	Sakha 95	0.4715	0.3878	0.4297	0.1274	0.1094	0.1184	61.19	54.47	57.80	15.05	17.14	16.09
6	Gemmeiza-7	0.9646	0.6072	0.7868	0.3334	0.2547	0.2939	92.76	84.40	88.58	11.06	15.47	11.27
7	Giza 139 (check)	1.200	0.9028	1.0514	0.6190	0.3545	0.4867	98.60	89.80	94.20	10.04	11.81	10.93
Mean		0.6405	0.4647	0.5526	0.2750	0.1778	0.2264	72.14	64.97	68.55	13.83	11.20	14.52
- L.S.D. of varieties 5%				0.0266			0.0179			1.56			0.19
(V) 1%				0.0359			0.0242			2.10			0.25
- L.S.D. of Race 5%		0.0142			0.0096			0.83			0.10		
(R) 1%		0.0192			0.0129			1.12			0.14		
- L.S.D. of interaction 5%			0.0375			0.0253			2.20			0.26	
(V x R) 1%			0.0508			0.0342			2.97			0.36	

a: Race1 , race TKTT :

b: race 2, race PKTT : The most prevalent races in *Puccinia triticina* population in Egypt during 2009/2010 season .

c: latent period (days) as estimated by Das *et al.,* 1993.

It was also found in tests with adult plants, that FUS were significantly smaller in wheats having PR to leaf rust in the field, than those rusted rapidly or showed highly susceptible reactions (Table,3). Data indicated that, uredinia of race 1 reached to its maximum size, as they were 0.619 mm^2, 0.471mm^2 and 0.333mm^2 on the adult plants of the highly susceptible., Giza 139, Sids 1 and Gemmeiza 7, respectively. Meanwhile, the uredinum size (mm^2) of the same pathogen race was significantly decreased to a limited area of 0.079mm^2, 0.094mm^2, 0.127mm^2 and 0.200 mm^2, on the primary leaves of PR cultivars., Giza 168, Sakha 95, Sakha 94 and Sids-12, respectively (Table, 3).

In the case of PR variety-race 2 combinations, limited development of uredinium occurred, resulting in relatively smaller FUS, than those obtained in PR variety-race 1 combinations. Moreover, FUS, relatively differed among the different PR cultivars , reflecting different levels of partial resistance to wheat leaf rust. The smallest uredinium size was detected in the leaves of the highly resistant, Giza 168 (0.059 mm^2), followed by the other PR cultivars., Sakha 95 (0.073mm^2), Sakha 94 (0.109mm^2) and Sids-12 (0.138mm^2), respectively. On the other hand, the average size of wheat leaf rust uredinia (race 2), was significantly larger in the highly susceptible cultivars., Giza 139 (0.355mm^2), Sids 1 and Gemmeiza 7 (each 0.255 mm^2) than in PR ones, under the same greenhouse conditions of the study. (Table, 7).

3. Pustule eruption (%):

Partially resistant varieties could be distinguished from the higly susceptible ones, by their potential ability to minimize the rate of pustule eruption in its leaves, whether in seedlings or adult plants. Although all the tested varieties were uniformly inoculated with the same pathogen race, the rate of pustule eruption was obviously higher (up to 80%) in plants of the highly susceptible cultivars., than those of the PR ones. Meanwhile, the percentage of pustule eruption significantly varied with the different variety-race combinations. Due to the significance of interaction between varieties and pathogen races (VxR), L.S.D. values were used to compare variety means within each pathogen race, under study (Tables 2 &3).

The percentage of pustule eruption of race 1, reached only to 55.84%, 61.08%, 67.46% and 78.74% on the preinoculated seedlings of the PR cultivars., Giza 168, Sakha 95, Sakha 94, and Sids-12, respectively. In contrast, highest pustule eruption (%) of 98.70%, 97.25% and 89.39% have been recorded in the seedlings of the highly susceptible cultivars., Giza 139, Sids 1 and Gemmeiza 7, inoculated with the same race (race 1), respectively (Table, 6). Similar trend was found in race 2- variety combinations, but with slightly less order.

In tests at the adult plant stage, it was also found that the eruption rate of pustules, considerably varied with the different variety-race combinations (Table,3). Whereas, in the PR variety-race 1 combinations, the percentage of pustule eruption was 52.35% (with cv., Giza 168), 61.19% (with cv., Sakha 95), 63.34 % (with cv., Sakha 94) and 72.25% (with cv., Sids-12), respectively. While, with regard to race 2-PR variety combinations, the eruption of pustules was relatively of less values, as it was 50.46%, 54.47%, 58.41% and 62.81% on the PR cultivars ., Giza 168, Sakha 95, Sakha 94 and Sids -12, respectively (Table,3). In contrast, the highly susceptible cultivars , Giza 139, Sids 1 and Gemmeiza 7, exhibited the highest and maximum percentages of pustule eruption (up to 84%), irrespective of the pathogen race used. The pustule eruption rate reached to its maximum value, as it was (98.60% and 89.80%) with Giza 139, (94.46% and 84.41%) with Sids-1, as well as (92.76% and 84.40%) with Gemmeiza 7,in the primary leaves preinoculated with race, 1 and race,2, respectively (Table,3).

4- Latent period (LP):

Latent period (LP_{50}), in terms of time in days , between infection and 50% of uredinia ruptured, has been estimated, at both seedling and adult plant stages of plants. Although, LP was potentially influenced by the host growth stage and pathogen race-variety interaction, it was found to be longer in PR cultivars than that of the highly susceptible ones. In testes at seedling stage, LP was generally longer (up to 12.80 days) in PR varieties, than that of the highly susceptible varieties. Leaves of PR wheat varieties, artificially inoculated with *P.triticina* race -1, characterized by a longer LP_{50} as it was 15.73 days (on Giza 168), 14.55 days (on Sakha 95), 13-21 days (on Sakha 94) and 12-91 days (on sids-12), respectively (Table,2). While, the highly susceptible wheat varieties, Giza 139, Sids -1 and Gemmeiza-7 showed shorter latent periods (LP_5) of this race, under the same greenhouse conditions. As it was 9.52 days, 10.03 days and 10.61 days on the above cultivars., respectively (Table,2).

In contrast LP_{50} of pathogen race (race-2) was relatively longer on all varieties, especially PR ones than that of other race under study. The LP_{50} of this particular race (race 2) ranged from. 12-88 to 16-30 days in PR wheats, while it was not exceeded up to 10.98 days, in seedlings of the highly susceptible cultivars. (Table, 2).

Results obtained from the adult plant stage tests (Table, 3) indicated that, LP_{50} significantly varied with each variety-race combination. However, with regard to variety-race 1 combinations, PR cultivars, Giza 168, Sakha 95, Sakha 94 and Sids-12 have the capacity to prolonging latent periods of this race, than did the highly susceptible ones. However, the time required for 50% of uredinia to erupt (LP_{50}) was

17.35, 15.41, 15.05 and 14.87 days on the inoculated leaves of the above PR cultivars., respectively (Table, 3). Inversely, uredinia of the same race,were found to be erupted rapidly at a faster rate, resulting a considerable short period of LP_{50}, on the inoculated leaves of the highly susceptible varieties. It was 10.04 days with Giza 139, 10.67 days with Sids-1 and 11.06 days with Gemmeiza-7 (Table,3).

Differences in LP_{50} estimates among PR cultivars and those rusted rapidly (highly susceptible) found in race 2-variety combinations, was of similar trend with those of the other tested race (race, 1), but with much more order (Table,3). Data in this table, revealed in general that latent period (LP_{50}) was considerably longer (up to 15 days), in the primary leaves of the PR cultivars, than those in the highly susceptible ones (less than 12 days). However, latent periods for PR cultivars., were approximately 3 days as long as those for the highly susceptible ones. LP_{50} of race 2, as it has been found on PR cultivars., Giza 168, Sakha 95, Sakha 94 and Sids-12 was 17.69, 17.14, 15.47 and 15.17 days, respectively. Inversely, short LP_{50} of the same pathogen race (race, 2) i.e. 11.81, 11.08, 11.47 days, was mainly recorded in the preinoculated leaves of the highly susceptible cultivars., Giza 139, Sids 1 and Gemmeiza 7, respectively (Table,3).

II- Relationship between partial resistance (PR) components in the greenhouse and the epidemiological parameters, under field conditions:

The relationship between the four PR components, as measured in the greenhouse and the three epidemiological parameters, AUDPC, FRS (%) and r-value , estimated in the field during 2009/010 and 2010/011 growing seasons, was also studied (Tables, 4 and 5). The four components of PR, colony size, pustule size, pustule eruption (%) and latent period (days), each significantly ($P<0.05$) correlated with the epidemiological parameters, under study. A close and high correlation was found between each of the four components of PR against leaf rust race-1 in the greenhouse and "AUDPC' in the field, during the two years of the study. In the first season (2009/010), the correlation coefficient data indicated that, a high positive correlation was found between AUDPC and the three PR components (Table,4) , colony size (r=0.89 & 0.88) uredinum size (r=0.99 &97) and the percentage of pustule eruption (r= 0.89 & 0.95) at seedling and adult stages, respectively. While, AUDPC was negatively correlated with latent period, as the correlation coefficient was -0.85 and -0.95 on the leaves of seedling and adult plants, respectively (Table, 4). In 2010/2011, the study on the relationship between PR components and AUDPC was repeated with the another pathogen race (race, 2) and the same wheat cultivars (Table, 5). Data obtained in this year indicated, in general, that all the components of rust resistance were closely related to AUDPC, as indicated by a significant correlation coefficient. Whereas it was 0.89 and 0.88 (for AUDPC and colony size), 0.99 and 97 (for AUDPC and US) and 0.89 and 0.95 (for AUDPC and pustule eruption) in seedlings and adult plants, respectively. On the contrary, a significant negative correlation was found (-0.85 and -0.95) for AUDPC and latent period, in seedling and adult plant stages, respectively (Table, 5).

Similarly, FRS scores from the two years were significantly correlated (P=0.01) with the four PR components of the two rust races, tested under greenhouse conditions. The correlation coefficient between FRS (%) in the field (2009/2010) and each of the PR components, CS, US, PE and LP was, 0.94, 0.98, 0.93 and -0.89 with race 1 at seedling stage, while it was 0.92, 0.96, 0.91 and -0.94 with the same pathogen race, at adult stage, respectively (Table, 4). Results of the relationship between FRS scores during the second season (2010/011) and the various PR components, confirmed the previous results obtained in the first one (2009/010). Whereas, each of PR components under study, CS, US, PE and LP were also significantly (P=0.01) correlated to FRS scores in this year.

Each of the four components of PR (CS, US, PE and LP) in the greenhouse was significantly correlated (P< 0.05) with the rate of disease increase (r-value) estimated in the field, throughout the two growing seasons of the study. High correlation coefficient of (0.94 and 0.94), (0.98 and 0.99), (0.96 and 0.92) and (-0.92 and 0.93) for r-value estimated in the first growing season and CS, US, PE and LP of race-1 at seedling and adult plant stages, respectively (Table, 4).

Similarly r-values measured in the second season (2009/010) were also significantly correlated (P=0.05) with each PR components in the greenhouse, as expressed by high correlation coefficient values. The obtained values were 0.96, 0.96, 0.95 and -0.92 at seedling stage as well as 0.96, 0.98, 0.81 and -0.91, at adult stages, for the comparisons between r-value estimates and each of CS, US, PE and LP, respectively (Table, 4).

Table 4. Correlation coefficient between three epidemiological parameters of partial resistance (PR) to wheat leaf rust, under field conditions in 2009/2010 and 2010/2011 and four components of this resistance, measured in seedling and adult plant stages against race 1 (TKTT), under greenhouse conditions.

Epidemiological parameter	Components of partial leaf rust resistance /growth stage							
	Seedling stage				Adult plant stage			
	Conlony size (mm^2)	Uredinium size (mm^2)	Pustule eruption (%)	Latent period (days)	Conlony size (mm^2)	Uredinium size (mm^2)	Pustule eruption (%)	Latent period (days)
-First season (2009/2010):								
AUDPC[a]	0.89**	0.99**	0.89*	-0.85**	0.88**	0.97**	0.95**	- 0.95**
FRS (%)[b]	0.94**	0.98**	0.93**	-0.89**	0.92**	0.96**	0.91**	- 0.94**
r-value[c]	0.94**	0.98**	0.96**	-0.92**	0.94**	0.99**	0.92**	- 0.93**
-Second season (2010/2011):								
AUDPC	0.89**	0.99**	0.89*	-0.84**	0.89**	0.98**	0.95**	- 0.94**
FRS (%)	0.95**	0.98**	-0.94**	-0.91**	0.94**	0.98**	0.91**	- 0.94**
r-value	0.96**	0.96**	-0.95**	-0.92**	0.96**	0.98**	0.87**	- 0.91**

** = significant at P<0.01 a) AUDPC: Area under disease progress curve. b)FRS (%) Final rust severity (%) .

* : Significant at P<0.05. c) r-value: Rate of disease increase.

Table 5. Correlation coefficient between three epidemiological parameters of partial leaf rust resistance (PR)expressed in wheat cvs. , under field conditions in 2009/2010 and 2010/2011 and four components of PR , under artificial infection with race2 (PKTT) of *Puccinia triticina* at seedling and adult plant stages, in the greenhouse conditions.

Epidemiological parameters	Components of partial leaf rust resistance /growth stage							
	Seedling stage				Adult plant stage			
	Conlony size (mm^2)	Uredinium size (mm^2)	Pustule eruption (%)	Latent period (days)	Conlony size (mm^2)	Uredinium size (mm^2)	Pustule eruption (%)	Latent period (days)
- 2009/010 growing season:								
AUDPC[a]	0.89**	0.97**	0.85*	- 0.85*	0.87**	0.90**	0.97**	- 0.89**
FRS (%)[b]	0.93**	0.97**	0.88**	-0.88**	0.90**	0.93**	0.94**	- 0.91**
r-value[c]	0.94**	0.98**	0.92**	- 0.93**	0.92**	0.95**	0.94**	- 0.94**
- 2010/2011 growing season:								
AUDPC	0.91**	0.98**	0.83*	-0.85*	0.89**	0.92**	0.97**	- 0.88**
FRS (%)	0.94**	0.98**	0.90**	-0.91**	0.91**	0.94**	0.93**	- 0.92**
r-value	0.97**	0.98**	0.90**	-0.92**	0.94**	0.97**	0.90**	- 0.91**

** = significant at P<0.01 a) AUDPC: Area under disease progress curve. c- r-value: Rate of disease increase.

* : Significant at P<0.05. b) FRS (%) Final rust severity (%).

In tests with the other wheat leaf rust race (race, 2), similar results were obtained (Table, 5). On the basis of the obtained data over the two years of the study, it seems reasonable to suggest that the four components of PR to leaf rust race-2 in the greenhouse, were closely related to AUDPC, FRS (%) and r-value, in the field. As indicated in the afore-mentioned results, a high positive correlation coefficient (more than 0.85) was found between CS, US and PE and each of AUDPC, FRS (%) and r-value, whether in first or in second growing seasons. Meanwhile, latent period in days was negatively correlated with the three disease parameters in the field (Table, 5).

DISCUSSION

Partial resistance (PR) to leaf rust (*P. triticina*) is a form of incomplete host genetic resistance that proved to be stable and more durable under different environmental conditions and against a wide range of pathogen races over a long period of time (Broers, 1989 , Broers & Parlevliet, 1989 ,Denissen, 1993 and Boulot, 2007).

Although this type of resistance has been early recognized, its value was not completely understood. Therefore, it has not been fully utilized and exploited in improving leaf rust resistance through the national breeding program in Egypt. To gain more detailed explanation and characterization of PR in the Egyptian wheat cultivars , the basic components of this pattern of resistance have been accurately determined and evaluated under greenhouse conditions.

It is possible to conclude that , at least, four components were involved in PR against leaf rust infection . These components were the restriction of both colony and pustule sizes, the diminution of pustule eruption rates and prolonging latency period (LP_{50}) of the two pathogen races under study. In general, significant variation was found among the PR cultivars. and the highly susceptible ones, although all of them were uniformly inoculated with the same *Puccinia triticina* races, under favorable environmental conditions in the greenhouse. However, PR character could be accurately measured and/or characterized by one or more of such components. PR as found in the tested cultivars., is well expressed as a reduced rate of pathogen race growth, once the infection is successful, resulting in a considerable reduction and/or restriction of both colony and uredinium sizes. Thus, such restricted pustules would sporulate less with lower rates of pustule eruption (%), and prolonged latent periods (days) of the two races. These components are the main elements that control the rate of wheat leaf rust development and increase. In addition, each was considered as important criterion of PR in wheat cultivars. Furthermore, PR type of resistance can be explained well by the combined or cumulative effect of the above mentioned four components .

Results previously obtained from different pathosystems ,clearly demonstrated the important role of one or more of these resistance components, as an accurate indicators, to characterize PR in the host plants. In addition, these components have been used as reliable indicators of the variation of this pattern of resistance observed in the field (Broers, 1989, Torabi, 1992 and Tiang *et al.,* 2007).

So far, there has not been documented physiological explanation for the mechanisms of PR in host plants. However, it would be supposed that, PR cultivars seemed to have some underlying factors responsible for an inhibitory effect against fungal growth, sporulation and pustule eruption rate. Also, they reduced and restricted both colony and uredinium sizes, and consequently led to a prolonging latent period of *P.triticina* in thesecultivars. (Shaner, 1983, Yang *et al.,* 1987 and Boulot, 1997).

It is reasonable to mention that PR as measured by the four components of the study, was clearly better expressed in the adult plant stage than in the seedling stage. Although, PRcultivars. could be well distinguished from the highly susceptible ones, by the significant variation of the tested components in both seedling and adult stages. This variation was substantially more pronounced in adult plants than in seedlings. This effect was predictable for such biotrophic pathogen and is in accordance with other findings, previously obtained by Tomerlin *et al.* (1984), Jacobs and Burrlage (1990), Torabi (1992) and Pariaud *et al.* (2009). They suggested that the plant growth stage substantially influenced fungal growth, sporulation and the pathogen development in the plant tissues. They also argued an explanation of this issue by an alteration in morphology and physiology of mature plant cells that may be equally responsible . They added that, cells in primary leaves have a different metabolic activity, possibly less nutrient are available for the fungus, that led to restriction in both colony and pustule sizes, and consequently lengthening latent periods. Apparent physiological disorders (localized grayish marks) and nutritional stress (light chlorosis of the leaves) in the host reduced the pathogen growth and sporulation and increased the latent period (Pariaud *et al.,*2009). On the other hand, Ohm and Shaner, 1976, suggested that the shorter latent period in seedling stage less than in adult stage, may be due to leaf senescence. Since, the leaves in seedlings begin to senescence sooner after their emergence, while in adult stage the upper leaves (flag and second ones) begin to senesce later, after flowering stage.

A close and high correlation was found between the four components of PR tested in the greenhouse and each of the three epidemiological parameters, FRS, r-value and AUDPC in the field. Correlation analysis revealed that the correlation coefficient (r) among the latent period (LP_{50}) and each of FRS (%), r-value and AUDPC were, consistently, of high significant negative estimates. Inversely, a high positive correlation was found between each of the other PR components.as in colony size, pustule size and the percentage of pustule eruption in the greenhouse and FRS (%), r-value and AUDPC, in the field. There is, so far, a lot of information in the literature about the relationship between the PR components, detected in the greenhouse and partial resistance parameters observed in the field. In some plant pathosystems, especially wheat- *Puccinia triticina* interactions, the latent period (LP) well correlated with AUDPC and other PR parameters measured in the field. LP was assumed as the most important factor in characterizing PR resistance, explaining most of the observed variation in this type of resistance, under field conditions (Broers 1989, Torabi, 1992, Das *et al.,* 1993 and El-Shamy and Mousa, 2004). In addition, the slower rates of both colony and uredinium growth led to substantial reduction in the pustule eruption rate, all considered the main components that functioned in the PR cultivars. This was indicated by the high positive correlation coefficients (P=0.01) between each of these components in the greenhouse and AUDPC in the field (Yang *et al.,* 1987, Broers, 1989, Torbai, 1992 and Tiang *et al.,* 2007). From a practical point of view, LP have been widely used to evaluate partial resistance in different plant-pathogen systems, especially wheat – *P.triticina* (Broers, 1989, Torabi, 1992 and El-Shamy and Mousa, 2004). Because it can be easily evaluated and with more accuracy than other components (Yang *et al.,* 1987), would greatly facilitate the selection and screening breeding materials. In addition, it would be very useful as a simplified alternative screening method, which can be easily implemented for the assessment of PR on a large scale, particularly for use in assessments conducted with controlled inoculations under greenhouse conditions (Tiang *et al.,* 2007). In conclusion, both AUDPC and LP would be a promising and more accurate characteristic for selecting partially resistant (PR) genotypes, and they therefore have been widely used to evaluate this type of resistance in different pathosystems.

On the basis of the obtained results, it is reasonable to conclude that rapid and considerable progress in breeding for PR, could be expected in plant breeding programs by using, one or more of the above PR components. As they are considered reliable indicators, and a good criterion for evaluating and selecting this type of resistance in any germplasm screening program.

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المقاومة الجزئية لمرض صدأ أوراق القمح "باكسينيا تريتسينا" فى مصر ب: تحديد (توصيف) مكونات المقاومه الجزئيه لمرض صدأ الاوراق "باكسينيا تريتسينا" فى بعض أصناف القمح المصريه

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تعد المقاومه الجزئيه لمرض صدأ اوراق القمح "**باكسينيا تريتسينا**" من اهم انواع المقاومه الوراثيه (العوائليه) host genetic resistance ، اذ انه على الرغم من ان اصناف القمح التى تتمتع بذلك النوع من المقاومه تظهر رد فعل توافقى مع الفطر الممرض compatible host pathogen interaction الا ان الانسجه النباتيه المصابه بالمرض تظل اقل بكثير من تلك التى تحدث داخل الانسجه النباتيه للاصناف عالية القابليه للاصابه وبالتالى فان تطور وتقدم المرض يكون بطيئا جدا بالانسجه النباتيه للاصناف التى تتمتع بهذا النوع من المقاومه كما يتميز هذا النوع من المقاومه بفاعليته العاليه ضد مجال واسع (عدد كبير) من سلالات الفطر الممرض ولفترة طويله من الزمن (عدة اعوام) وايضا بثباتها تحت مجال واسع من الظروف البيئيه المتباينه وذلك بمقارنتها بالانواع الاخرى من المقاومه النباتيه.

من اجل ذلك فقد اجريت تلك الدراسه بهدف دراسة مكونات صفة المقاومه الجزئيه فى بعض اصناف القمح المصريه تحت ظروف العدوى الصناعيه بالصوب الزجاجيه لقسم بحوث امراض القمح بالجيزه.

أوضحت نتائج هذا البحث وجود اختلافات معنوية فى مكونات المقاومة الجزئية "PR components" بين الأصناف المقاومة وتلك القابلة للإصابة على الرغم من إجراء العدوى الصناعية الموحده لكل الأصناف المختبرة على السواء بنفس سلالتى الفطر الممرض (سلالة TKTT وسلالة PKTT)، وتحت نفس الظروف الملائمة لحدوث و انتشار المرض. حيث تميزت الأصناف ذات المقاومة الجزئية وهى : جيزة ١٦٨، سخا ٩٤، سخا ٩٥، وسدس ١٢ بقدرتها على إعاقة والحد من نمو سلالتى الفطر المرض، مما أدى بدوره إلى تقليل حجم كل من المستعمرات الفطرية والبثرات الناشئة عن تلك السلالات، كذلك فقد تميزت تلك الأصناف بقدرتها على تقليل وخفض معدل انفجار الثبرات بها، وبالتالى إلى إطالة فترة الحضانة Latent period للسلالتين تحت الاختيار، وذلك بالمقارنة بالأصناف ذات القابلية العالية للإصابة وهى: سدس ١ وجميزه ٧ وجيزه ١٣٩ المستخدم كمقارنة سواء أكان ذلك فى طور البادرة أو النباتات البالغة.

وقد أوضحت النتائج أيضاً وجود علاقة وثيقة وقوية بين كل من مكونات المقاومة الجزئية الأربعة المختبره تحت ظروف الصوبة (حجم المستعمرة، حجم الثبرة، معدل انفجار الثبرات ثم فترة الحضانة)، وبين مقاييس المقاومة الجزئية بالحقل وهى الشدة النهائية للمرضى (FRS%)، معدل تزايد وانتشار المرضى (r-value) وكذلك القيم الواقعة تحت منحنى الإصابة المرضى (AUDPC)، حيث كان معامل الارتباط عال المعنوية بين كل من مكونات المقاومه الجزئيه المختبره بالصوب الزجاجيه وبين مقاييس تلك المقاومه بالحقل.

وبصفة عامة وبناءً على تلك النتائج فإنه يمكن الاعتماد على اي من مكونات المقاومة الجزئية بالصوبه كدلائل مبشرة ومستقبلية، يتم على أساسها اختيار وانتخاب الأصول الوراثية "genotypes" والتى يتوقع أن تتمتع بدرجة عالية ومقبولة من المقاومة الجزئية "Partial resistance" لمرض صدأ أوراق القمح، ويمكن الاستفادة بها فى برنامج التربية للمقاومة لذلك المرض.