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# Characterization of Partial Resistance to Stripe Rust (*Puccinia striiformis* f.sp. *tritici*) in some Egyptian Wheat Cultivars

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## ABSTRACT

Partial resistance (PR) to stripe rust (*Puccinia striiformis* f.sp. *tritici*) in 12 Egyptian wheat cultivars was experimentally measured and characterized, using three epidemiological parameters; final rust severity (FRS %), area under disease progress curve (AUDPC) and rate of disease increase (r-value) at two locations, *i.e.* Sharkyia and Kafr El-Sheikh Governorates, during 2015/16 and 2016/17 growing seasons. All of these parameters found to be lower in the partially resistant (PR) cultivars; Sakha-94, Sakha-95, Misr-1 and Misr-2, rather than those in the highly susceptible or fast-rusting cultivars; Sids-12 and Gemmeiza-11, as well as the check variety; Morocco, during the study. Each of the four partially resistant cultivars had the potentiality to decrease the amount of stripe rust infection, also retard the disease development, during an epidemic, in both years and under the two locations. Additionally, higher amounts of both 1000 kernel weight (g) and grain yield/plot (kg) were obtained from the partially resistant cultivars. More than 90% of the differences in a disease response of the tested cultivars against stripe rust were mainly due to it's genetic structure. Where, the genetic make-up of the tested cultivars found to be relatively contributed by 97.59, 97.10 and 95.16% in 2015/16 and 97.43, 96.87 and 94.98% in 2016/17, to the expression of the aforementioned three epidemiological parameters, respectively. The expression of resistance was slightly affected by a very little change in environmental conditions between the two locations or from one year to another, as the relative contribution of the environment (locations) was very low (less than 5%). These results were ensured with the high estimates of heritability (%), during the two growing seasons of the study, which indicated that most of the phenotypic variation in these PR components were essentially due to a genetic structure (genetic make-up) of the tested cultivars. Also, the high heritability estimates of the studied parameters, clearly demonstrated that any of these parameters could be used as a good criterion for evaluating and selecting PR wheat genotypes, under field conditions. Correlation matrix gave evidence to the importance of these disease parameters, especially FRS (%), as it considered being a good and more reliable indicator for evaluation partial resistance (PR) of the tested wheat cultivars against stripe rust. Thus, partial resistance to stripe rust could be accurately measured, characterized, screened and selected equally well in different wheat genotypes under field conditions, using one or more of these convenient and more reliable epidemiological parameters; FRS%, AUDPC and r- value.

**Keywords:** wheat, stripe rust, partial resistance (PR), genetic structure, heritability, genetic advance

## INTRODUCTION

Stripe rust (*Puccinia striiformis* f.sp. *tritici*), is the most destructive rust disease in many wheat growing areas in the world, as well as in Egypt (Fu *et al*., 2008 and Abu Aly *et al*., 2017). This disease has been reported as a major threat to wheat production in more than 27 countries of the globe (Li and Zeng 2002). Wheat stripe rust has recently become a macrocyclic rust disease (Jin *et al*., 2010), resulting in a significant and serious economic loss in the highly susceptible wheat cultivars (Omara *et al*., 2016 and Abu Aly *et al*., 2017). In Egypt, wheat stripe rust considered to be a sporadic disease, as it was the cause of significant yield losses during the severe epidemics in 1967, 1986, 1995, 1997, 1999 and recently 2015, through the severe attacking of the most popular commercial wheat cultivars, nationwide (Abd El-Hak *et al*., 1972; Abu El-Naga *et al*., 1999 and Omara *et al*., 2016).

Utilization of host-genetic resistance or releasing resistant cultivars is, still, an economical, environmentally safe and the most effective method for a successful disease control via avoiding the sudden occurrence of the severe and more damaging stripe rust epidemics. However, the main obstacle in the control of wheat rusts, especially stripe rust, is the short duration and rapid loss of host-genetic resistance, due to the breaking down or a rapidly overcome of the newly deployed resistance genes, as a result of the evolution or emergence of new virulent races in a pathogen population.

Under field conditions in Egypt, some of the newly released wheat cultivars were discarded rapidly after it's wide cultivation, due to their high susceptibility to such disease, despite they were resistant at the time of release. Nevertheless, many of these cultivars served in agriculture for a long period of time (many years), showing an acceptable and high levels of rust resistance. Most of these cultivars were characterized by their ability to retard and slowdown the onset and development of disease during an epidemic in the field. Consequently, they can reduce and restrict the rate of disease progress and minimize the amount of disease in the infected tissues, irrespective of their susceptibility to stripe rust in terms of infection type. This type of resistance has been early defined by Parlevliet (1976), as a partial resistance (PR) and/or an adult plant resistance (APR), that assumed to be more stable and more durable, compared to other forms of genetic resistance (Borers and Parlevliet, 1989 and Boulot, 2007). Such resistance was also identified, from other point of view, as a polygenic resistance, race-non-specific (general) resistance (Boulot and Gad-Alla, 2007). So, it has a permanent effect against a broad spectrum of pathogen races, hence it has been little or not affected by a sudden race changing or evolving in rust pathogen populations (Miedaner and Korzun, 2012). It presumably, lasts longer and remains effective over a wide range of environmental conditions for many years. It is, therefore, considered to be more durable, than other types of resistance (Broers and Parlevliet, 1989 and Boulot, 2007).

Although PR to rust pathogens, in general, has been early known and detected in some Egyptian wheat cultivars (Boulot and Aly 2014), it's epidemiological nature and genetic behavior was not definitely understood, and it's value was not completely appreciated. Therefore, this type of resistance has been not fully exploited for improving genetic resistance of the new released wheat cultivars against stripe rust, during the national breeding program in Egypt. Hence, the evaluation and testing some Egyptian wheat cultivars against stripe rust and characterization of partial resistance (PR) expressed in these cultivars was the main objective of the present work. The second objective was to detect an epidemiological nature and genetic behavior of the three disease parameters that function in the expression of this type of resistance. The correlation matrix among each of these parameters and grain yield components was also investigated in order to clearly understand the importance of these parameters and their impact on grain yield of the tested wheat cultivars.

## MATERIALS AND METHODS

Partial resistance to stripe rust (*Puccinia striiformis* f.sp. *tritici*) was studied and characterized in 12 Egyptian bread wheat cultivars, under field conditions, during 2015/16 and 2016/17 growing seasons.

**1. Experimental site:**

The present work was carried out at the experimental farms of Sakha Agric. Res. Station (Kafr El-Sheikh) and Kafr El-Hamam Agric. Res. Station (Sharkyia), during 2015/16 and 2016/17 growing seasons.

**2. Wheat cultivars:**

Twelve wheat cultivars, *i.e.* Sids-1, Sids-12, Sids-13, Sakha-93, Sakha-94, Sakha-95, Gemmeiza-9, Gemmeiza-10, Gemmeiza-11, Misr-1, Misr-2 and Giza-168, kindly obtained from wheat Research Department, Field Crops Research Institute, ARC, Giza, Egypt. In addition to the check variety namely; Morocco.

**3. Filed experiments:**

The experiments were carried out in a randomized complete block design (RCBD), with three replicates. The grains of the tested cultivars were sown in 6 row plots; each row was 3m long and 30 cm apart, where the plot size was 3m x 3.5m (10.5 $m^2$). All plots were surrounded by rust spreader belt, planted with a mixture of the highly susceptible varieties to stripe rust, *i.e. Triticum spelta saharenses* (T.S.S) and Morocco, to serve as a predominant and continuous source for the primary inoculum. Artificial inoculation with a mixture of freshly collected urediniospores of the most prevalent stripe rust races and talcum powder in a ratio of 1: 20 (v/v) was carried out, to maintain a regular rust inoculum with spores on all spreader plants and generate stripe rust epidemic, under field conditions (Tervet and Cassel, 1951).

**Disease assessment:**

Stripe rust severity (%), was measured for the tested wheat cultivars, as a percentage of leaf area infected or rusted according to the modified Cobb's scale (Peterson *et al*., 1948). Rust severity data were recorded starting with the appearance of the first pustule on each of the tested cultivar and continued, at 7 days intervals, until the termination of the experiment. Also, final rust severity (FRS %) was assessed as a percentage of disease severity for each of the tested wheat cultivars, when the highly susceptible (check) variety was severely rusted and the disease severity reached it's maximum and final level (Das *et al*., 1993).

To estimate, more accurately, the level of PR or adult plant resistance in the tested wheat cultivars, under field conditions, area under disease progress (AUDPC) value was calculated for each cultivar, under study, using the equation of Pandey *et al*. (1989), as follows:

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

**Where:**

**D = Time intervals (days between consecutive records)**
**$Y_1 + Y_k$ = Sum of the first and the last disease scores.**
**$Y_2 + Y_3 + \ldots. + Y_{(K-1)}$ = Sum of all in between disease scores.**

Rate of stripe rust disease increase (r-value), as a function of times was also estimated, according to the formula of Van der Plank (1963), as follows:

$$\textbf{r-value} = \frac{1}{t_2 - t_1}\left(\log_e \frac{X_2}{1-X_2} - \log_e \frac{X_1}{1-X_1}\right)$$

**Where:**

**$X_1$ = the proportion of the susceptible infected tissue (disease severity) at date $t_1$.**
**$X_2$ = the proportion of the susceptible infected tissue (disease severity) at date $t_2$.**
**$t_2 - t_1$ = the interval in days between these two dates.**

**4. Genetic components:**

To estimate the percentage of heritability in it's broad sense ($h^2$) for FRS (%), AUDPC and r-value, the following formula was applied according to Miller *et al*. (1958):

$$\textbf{\% Heritability } (h^2) = \frac{\textbf{Genotypic variance } (\sigma^2 g)}{\textbf{Phenotypic variance } (\sigma^2 ph)} \times 100$$

**Where:**

**$\sigma^2 g = [(\sigma^2 e + r\sigma^2 g) - \sigma^2 e]/r$**
**$\sigma^2 ph = (\sigma^2 e + r\sigma^2 g)/r$**

Genetic advance (GA %), expected from selection, was also calculated, for each of these epidemiological parameters according to the following formula:

$$\textbf{Genetic advance (\%)} = \sqrt{\sigma 2ph}\,^2ph)k\ x$$

(Miller *et al*., 1958).

**Where**:

**k = 2.06 at 5% selection intensity.**

**5. Yield assessment:**

Grain yield, expressed as 1000 kernel weight (g) and grain yield/plot (kg), were determined for all tested cultivars in the two growing seasons and at the two locations, under study.

**6. Statistical analysis:**

The analysis of variance (ANOVA) of the data that performed with the software package SPSS18 was carried out (Table 1). The least significant difference (LSD) at 5% level of significant was used to compare treatment means. Also, correlation matrix between the three epidemiological parameters; FRS (%), AUDPC and r-value and the two yield components; 1000 kernel weight (g) and grain yield/plot (kg) has been performed with the software package SPSS18.

## RESULTS AND DISCUSSION

To gain a more detailed analysis and characterization of partial resistance (PR) to stripe rust, artificial inoculation was applied to 12 Egyptian wheat cultivars at the two hot-spot locations, during the two successive growing seasons (2015/16 and 2016/17). The interaction between genotype and environment has been often described as consistent differences among different genotypes from an environment to another. In this regard several attempts have been previously carried out to evaluate the relationship between genotype and environmental conditions (Niks *et al*., 2011).

**1. Analysis of variance for the three epidemiological parameters under study:**

To assess the level of partial resistance (PR) of the tested Egyptian wheat cultivars, combined analysis of variance of the two locations, during the two seasons; 2015/16 and 2016/17 was used. Significant difference was recorded among locations (L) and the tested wheat cultivars (C), concerning with FRS (%), AUDPC and r-value in 2015/16 and 2016/17 growing seasons (Table 1). Also, significant difference was recorded with the interaction between locations (L) and the tested wheat cultivars (C). Due to the highly significance of interaction between cultivars and locations (C x L), the L.S.D. values were used to compare the differences in FRS (%), AUDPC and r-value means of any two cultivars within each environment (location). In general, different values of these parameters were presented for each of the tested wheat cultivars, during the two locations and the two years of the study, as affected by the slight changes in environmental conditions, in each growing season (Qamar *et al*., 2007).

**Table 1. Combined analysis of variance over the two locations for FRS (%), AUDPC and r-value, of 12 Egyptian wheat cultivars, as well as check variety; Morocco evaluated for the level of partial resistance to stripe rust disease, during 2015/16 and 2016/17 growing seasons.**

| S.O.V. | DF | F prob | | | | | |
|---|---|---|---|---|---|---|---|
| | | FRS[a] (%) | | AUDPC[b] | | r-value[c] | |
| | | 2015/16 | 2016/17 | 2015/16 | 2016/17 | 2015/16 | 2016/17 |
| Replicates (R) | 2 | 0.1336 | 0.1985 | 0.9545 | 0.0830 | 0.0997 | 0.1534 |
| Cultivar (C) | 12 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 |
| Location (L) | 1 | 0.0075 | 0.0037 | 0.0066 | 0.0089 | 0.0001 | 0.0003 |
| C×L | 12 | 0.0050 | 0.0067 | 0.0033 | 0.0034 | 0.0004 | 0.0002 |
| Error | 50 | - | - | - | - | - | - |

**FRS[a] (%) = final rust severity, AUDPC[b] = area under disease progress curve, r-value[c] = rate of disease increase.**

**2. Characterization of partial resistance (PR) to stripe rust in the tested wheat cultivars:**

The level of partial resistance to stripe rust was determined for each cultivar, by estimating the three main epidemiological parameters of resistance; final rust severity (FRS%), area under disease progress curve (AUDPC) and rate of disease increase (r-value), under disease stress of the field conditions at two different hot-spot locations, during the two seasons of the study.

In general, environmental conditions observed in the second season (2016/17) were apparently more favorable for disease onset and development, compared to the first season (2015/16). Thus, the high levels of FRS (%), AUDPC and r-value were recorded in the highly susceptible wheat cultivars, during the second growing season, (Tables 2 and 3).

**Final rust severity (FRS %):**

Due to the slight changes in environmental field conditions from one year to another, stripe rust epidemic was found to be less severe in it's magnitude in the first growing season (2015/16) compared to the second growing season (2016/17).

The potentiality of the PR cultivars to decrease or restrict the amount and development of stripe rust infection, under field conditions, hence, to minimize the final level of rust severity (%) reached on each, was estimated as FRS (%) (Tables 2 and 3). In general, severe stripe rust epidemic was recorded in Sharkyia location, as well as in the second season (2016/17), rather than in Kafr El-Sheikh location and in the first season (2015/16). Due to the relatively high infection of stripe rust at Sharkyia location and during the second season, rust severity reached it's maximum levels (96.67%) in the highly susceptible (check) variety; Morocco.

The obtained data in these two Tables, also indicated that the wheat cultivars, *i.e.* Sids-12 and Gemmeiza-11, as well as the check variety; Morocco, showed the lowest levels of field resistance or APR to stripe rust infection, in comparison with the other cultivars, under study. Since, they recorded the highest percentages of FRS (%) (ranged from 70.00 to 96.67 %) at both locations, *i.e.* Sharkyia and Kafr El-Sheikh, during 2015/16 and 2016/17 growing seasons.

On the other hand, wheat cultivars; Sids-1, Sids-13, Sakha-93, Gemmeiza-9, Gemmeiza-10 and Giza-168, exhibited adequate moderate levels of APR to stripe rust infection, under the same environmental conditions of the two locations, during the two growing seasons. Meanwhile, the superiority of the four cultivars; Sakha-94, Sakha-95, Misr-1 and Misr-2, as they displayed the highest resistance response (FRS % not exceeded up to 10.00 %) and satisfactory level of adult plant resistance or partial resistance (PR), under the stress of disease in the same field conditions at the two locations, during the two seasons of the study. Consequently, it was concluded that, each of these wheat cultivars had the potentiality to decrease the amount of stripe rust infection, during an epidemic development, in both years of the study. Similar results were reported by Niks *et al*. (2011) who explained and characterized partial resistance to wheat rust, in general, by a decreased rate of an epidemic development and/or build-up in the field, despite a susceptible infection type or irrespective of a compatible host pathogen interaction. Recently, Abu Aly *et al*. (2017) emphasized that 35 lines from CIMMYT having the ability to retard and delay stripe rust development under field conditions. Thus, they characterized these promising lines, as the partial resistance advanced lines, which could be released directly for cultivation or used as the new profitable sources of stripe rust resistance during the future breeding program in the country.

**Table 2. Partial resistance to stripe rust, expressed as FRS (%), AUDPC and r-value of 12 Egyptian wheat cultivars, as well as the check variety; Morocco, under field conditions at Sharkyia and Kafr El-Sheikh, during 2015/16 growing season.**

| Wheat cultivar | Epidemiological parameters/locations | | | | | |
|---|---|---|---|---|---|---|
| | FRS[a] (%) | | AUDPC[b] | | r-value[c] | |
| | Area 1* | Area 2** | Area 1 | Area 2 | Area 1 | Area 2 |
| Sids-1 | 50.00 | 46.67 | 1025.0 | 775.0 | 0.112 | 0.098 |
| Sids-12 | 86.67 | 76.67 | 1875.0 | 1750.0 | 0.119 | 0.101 |
| Sids-13 | 46.67 | 43.33 | 525.0 | 565.0 | 0.093 | 0.085 |
| Sakha-93 | 50.33 | 43.33 | 725.0 | 525.3 | 0.098 | 0.085 |
| Sakha-94 | 8.33 | 6.67 | 155.3 | 160.0 | 0.043 | 0.033 |
| Sakha-95 | 5.00 | 4.67 | 85.0 | 91.3 | 0.049 | 0.025 |
| Gemmeiza-9 | 46.67 | 36.67 | 625.6 | 525.0 | 0.098 | 0.085 |
| Gemmeiza-10 | 23.33 | 16.67 | 325.3 | 345.0 | 0.070 | 0.072 |
| Gemmeiza-11 | 83.33 | 70.00 | 1850.0 | 1550.0 | 0.119 | 0.112 |
| Misr-1 | 3.46 | 5.33 | 90.0 | 135.0 | 0.041 | 0.034 |
| Misr-2 | 2.93 | 3.46 | 87.3 | 90.0 | 0.060 | 0.041 |
| Giza-168 | 30.00 | 23.33 | 375.3 | 365.0 | 0.070 | 0.064 |
| Morocco (check) | 90.00 | 86.67 | 1900.00 | 1800.0 | 0.146 | 0.114 |
| L.S.D.$_{0.05}$ of interaction (cultivars × locations) | 5.01 | | 18.06 | | 0.003 | |

**FRS[a] (%) = final rust severity, AUDPC[b] = area under disease progress curve, r-value[c] = rate of disease increase.**
**Area 1[*]= Sharkyia and Area 2[**] = Kafr El-Sheikh**

**Table 3. Partial resistance to stripe rust, expressed as FRS (%), AUDPC and r-value of 12 Egyptian wheat cultivars, as well as the check variety; Morocco, under field conditions at Sharkyia and Kafr El-Sheikh, during 2016/17 growing season.**

| Wheat cultivar | Epidemiological parameters/locations | | | | | |
|---|---|---|---|---|---|---|
| | FRS[a] (%) | | AUDPC[b] | | r-value[c] | |
| | Area 1* | Area 2** | Area 1 | Area 2 | Area 1 | Area 2 |
| Sids-1 | 63.33 | 50.00 | 1100.0 | 870.0 | 0.106 | 0.101 |
| Sids-12 | 90.00 | 83.33 | 1900.0 | 1775.0 | 0.146 | 0.119 |
| Sids-13 | 56.67 | 53.33 | 575.0 | 570.0 | 0.098 | 0.073 |
| Sakha-93 | 60.00 | 53.33 | 800.6 | 675.0 | 0.098 | 0.093 |
| Sakha-94 | 10.00 | 8.33 | 162.0 | 165.6 | 0.050 | 0.043 |
| Sakha-95 | 6.66 | 5.00 | 212.6 | 117.6 | 0.050 | 0.030 |
| Gemmeiza-9 | 53.33 | 43.33 | 650.0 | 575.3 | 0.098 | 0.085 |
| Gemmeiza-10 | 26.67 | 23.33 | 355.6 | 325.0 | 0.070 | 0.064 |
| Gemmeiza-11 | 86.67 | 76.67 | 1900.0 | 1625.0 | 0.144 | 0.114 |
| Misr-1 | 4.80 | 6.66 | 172.0 | 172.0 | 0.042 | 0.042 |
| Misr-2 | 4.00 | 4.00 | 90.0 | 75.0 | 0.060 | 0.041 |
| Giza-168 | 33.33 | 26.67 | 375.0 | 365.6 | 0.073 | 0.064 |
| Morocco (check) | 96.67 | 93.33 | 2000.0 | 1875.0 | 0.171 | 0.146 |
| L.S.D.$_{0.05}$ of interaction (cultivars × locations) | 4.11 | | 15.21 | | 0.004 | |

**FRS[a] (%) = final rust severity, AUDPC[b] = area under disease progress curve, r-value[c] = rate of disease increase.**
**Area 1[*]= Sharkyia and Area 2[**] = Kafr El-Sheikh**

**Area under disease progress curve (AUDPC):**

To gain a more details on the variation for PR to stripe rust infection in the tested cultivars, and so far, a more accurate characterization of this type of resistance, AUDPC was estimated for each cultivar under study (Tables 2 and 3). However, AUDPC, as a good and more reliable estimator for evaluation and characterization of PR to wheat rusts, in general, has been widely applied and previously used by many investigators (Lal Ahamed *et al*., 2004; Boulot and Aly 2014 and Abu Aly *et al*., 2017). All of them emphasized that AUDPC being a more reliable and a most convenient estimator for measuring PR, than other epidemiological parameters, because it can be represent both the amount of rust infection, and the rate in which the disease or pathogen has increased during an epidemic (Lal Ahamed *et al*., 2004 and Boulot, 2007). From other point of view, a wide application of AUDPC for estimating PR, rather than other epidemiological parameters, is also due to it's enclosure of all factors that influence or affect the disease development (Pandey *et al*., 1989; Das *et al*., 1993 and Lal Ahamed *et al*., 2004).

According to the obtained results and on the basis of AUDPC estimates, the tested cultivars could be substantially classified into two main groups. The first group included wheat cultivars with the lowest AUDPC estimates (less than 212.6), *i.e.* Sakha-94, Sakha-95, Misr-1 and Misr-2. In 2015/16, AUDPC estimates were; (155.3 and 160.0), (85.0 and 91.3), (90.0 and 135.0) and (87.3 and 90.0) for the abovementioned wheat cultivars at Sharkyia and Kafr El-Sheikh locations, respectively (Table 2). While, in 2016/17, these estimates were; (162.0 and 165.6), (212.6 and 117.6), (172.0 and 172.0) and (90.0 and 75.0) for the cultivars; Sakha-94, Sakha-

95, Misr-1 and Misr-2 in the two locations, respectively (Table 3). These cultivars were, therefore, designated or characterized as the partially resistant (PR) cvs. to stripe rust, since they displayed the highest and satisfactory levels of APR or field resistance, under the stress of stripe rust infection, through the two growing seasons and at the two locations of the study. Meanwhile, the second group, included the highly susceptible or fast-rusting cultivars; Sids-1, Sids-12, Sids-13, Sakha-93, Gemmeiza-9, Gemmeiza-10, Gemmeiza-11 and Giza-168 as well as the check variety; Morocco. As they were characterized by the lowest levels of APR to stripe rust disease. However, they comparatively showed the highest estimates of AUDPC (ranged from 325.0 to 2000.0) under the same field conditions, at the two locations and during the two growing seasons of the study (Tables 2 and 3). Accordingly, it has been, reasonably, suggested that this group of cultivars, could be classified as the fast rusting cultivars group.

It is possible to mentioned that this is the first attempt to characterize this type of resistance (partial resistance) to stripe rust expressed in Egypt on wheat cultivars, although it was previously conducted on the leaf rust by Nazim *et al*. (1983) and Boulot (2007) whom reported that some of the local wheat cultivars have an adequate level of this type of resistance to this rust pathogen, regardless of their compatible or susceptible seedling reactions in terms of infection types, and many of them served in agriculture for many years, showing high levels of PR during their vast cultivation, under the Egyptian field conditions.

**Rate of disease increase (r-value):**

Rate of disease increase (r-value), as a function of time, was also estimated, as one of the epidemiological parameters used for a quantitative determination of PR to stripe rust, under field conditions. It was possible to distinguish the partially resistant cultivars from those highly susceptible or fast-rusting ones, by their capacity to decrease or delay the rate of disease increase, either in time, in space or both, under field conditions in the two locations and the two years of the study (Tables 2 and 3). However, PR cultivars were substantially characterized by lower rates of disease increase (r-values), relative to the fast-rusting or the highly susceptible ones, when subjected to the same pathogen populations and under the same environmental field conditions of the current study. The obtained results in Tables (2 and 3) indicate, in general, that stripe rust developed more slowly and increased at the relatively lower rates (r-values) on wheat plants of the tested cultivars with the superiority of PR cultivars, during the first growing season (2015/016), compared to the second one (2016/17). Out of the tested cultivars, only four cultivars; Sakha-94, Sakha-95, Misr-1 and Misr-2 proved to possess the capacity to slowdown the disease onset and development during an epidemic development in both locations, and the two years of the study. As they displayed lower rates of disease increase (r-values did not exceeded up to 0.060). Inversely, the highly susceptible and fast-rusting cultivars; Sids-12 and Gemmeiza-11, as well as the check variety; Morocco, has been rapidly rusted with higher and faster rates of disease increase (reached to 0.171) under the same environmental conditions, during the two years of the study. However, it was previously reported that differences in r-value estimates between any two wheat cultivars tested, during an epidemic development, was mainly due to the two limiting factors. The first is the disease severity (%) in each, and the second is the spread of the fungus propagules, or the time of disease increase (Van der Plank, 1963).

**3. Relative contribution of environment (locations) and genotype (cultivars) and their interaction on epidemiological parameters of partial resistance:**

Relative contribution, expressed as the percentage of mean square of the explained model variation, was estimated for each parameter under study, *i.e.* FRS (%), AUDPC and r-value, in order to determine the effect of environment (locations) and genotype (cultivars) and their interaction in the variation of those parameters (Table 4). Based on the obtained results, it is evident that, more than 90% of the differences in stripe rust response of the tested cultivars were mainly due to the genetic make-up of the tested cultivars. Where, the genetic structure of the tested cultivars relatively contributed by 97.59, 97.10 and 95.16% (2015/16) and 97.43, 96.87 and 94.98% (2016/17), in the variations of the three rust parameters; FRS (%),

AUDPC and r-value, respectively (Table 4).

Meanwhile, relative contribution of the environment (locations) was found to be very low (less than 5%), during the two growing seasons, under study. This means that, the expression of partial resistance (PR) to stripe rust infection was slightly affected by the little changes in environmental conditions between the two locations and from growing season to another. Hence, it proved to be stable under various or different environmental conditions favorable to the pathogen infection, spread and development, during an epidemic. On the other hand, it remained effective against a broad spectrum of the prevalent pathogen races (Broers and Parlevliet, 1989, Singh *et al*., 2005 and Boulot, 2007)

**Table 4. Relative contribution (%) of environment (locations), genotype (cultivars) and their interaction on the variation of the three epidemiological parameters to partial resistance against stripe rust.**

| S.O.V. | Relative contribution (%) to a variation in: | | | | | |
|---|---|---|---|---|---|---|
| | FRS[a] (%) | | AUDPC[b] | | r-value[c] | |
| | 2015/16 | 2016/17 | 2015/16 | 2016/17 | 2015/16 | 2016/17 |
| Environment (L) | 1.64% | 1.39% | 1.87% | 2.15% | 4.19% | 4.06% |
| Cultivar (C) | 97.59% | 97.43% | 97.10% | 96.87% | 95.16% | 94.98% |
| Interaction (L×C) | 0.37% | 0.86% | 0.81% | 0.93% | 0.65% | 0.96% |

**FRS[a] (%) = final rust severity, AUDPC[b] = area under disease progress curve, r-value[c] = rate of disease increase.**

**4. Genetic nature of PR to stripe rust:**

The two genetic parameters, *i.e.* heritability (%) in it's broad sense ($h^2$) and genetic advance (%) expected from selection (GA), were computed for the three epidemiological parameters, *i.e.* FRS (%), AUDPC and r-value (Table 5). High values of broad sense heritability (up to 99%) for FRS (%), AUDPC and r-value were obtained, being 99.87, 99.53 and 95.28% in 2015/16, and 99.99, 99.79, 96.25% in 2016/17, respectively. The high heritability estimates, during the two growing seasons and both locations of the study, indicated, in general, that most of the phenotypic variations in these PR components were mainly due to the genetic effects. Also, these variations were less affected by the slight changes in environmental conditions, among the two years and from one location to another, under study. Furthermore, the high heritability (%) estimates clearly demonstrated that most of the phenotypic variations were due to genetic structure (genetic make-up) of the studied wheat genotypes. Also, the high heritability estimates of these parameters revealed, in addition, that any of these tested parameters could be widely used as a good criterion for evaluating and selecting PR genotypes, under field conditions. Moreover, the variations in the expression of these parameters were less affected by the slight changes in environmental conditions between different locations or from one season to another season (Ali *et al*., 2008; Xiaowen *et al*., 2008 and Abu Aly *et al*., 2017). Consequently, rapid and considerable progress in breeding for PR to stripe rust would be expected in current any breeding programs, using these profitable disease parameters. (Singh *et al*., 2005 and Boulot and Gad-Alla, 2007).

**Table 5. Heritability (%) in it's broad sense ($h^2$), and genetic advance (GA %) expected from selection for FRS (%), AUDPC and r-value, variables to wheat cultivars tested for their partial resistance to stripe rust.**

| Genetic parameter | Epidemiological parameters/growing seasons | | | | | |
|---|---|---|---|---|---|---|
| | FRS[a] (%) | | AUDPC[b] | | r-value[c] | |
| | 2015/16 | 2016/17 | 2015/16 | 2016/17 | 2015/16 | 2016/17 |
| Heritability in broad sense ($h^2$) | 99.87% | 99.99% | 99.53% | 99.79% | 95.28% | 96.25% |
| Genetic advance (GA) | 41.63% | 45.12% | 40.84% | 37.02% | 34.21% | 28.31% |

**FRS[a] (%) = final rust severity, AUDPC[b] = area under disease progress curve, and r-value[c] = rate of disease increase.**

From the obtained results in this part of investigation and based on the previous reports in concern with partial resistance, it can be concluded that this resistance is a quantitative, polygenic, race-non-specific type of resistance and environmentally stable, therefore it is assumed to be more durable than other forms (Boulot and Aly 2014).

**5. Impact of stripe rust infection on grain yield of the tested cultivars:**

The effect of stripe rust infection on two grain yield components; 1000 kernel weight and grain yield per plot, was determined for the tested wheat cultivars, at both the two different locations, *i.e.* Sharkyia and Kafr El-Sheikh, during 2015/16 and 2016/17 growing seasons (Tables 6 and 7).

In 2015/16, the lowest 1000 kernel weight (g) and grain yield/plot (kg) were obtained by the highly susceptible cultivars, *i.e.* Sids-12 (26.20, 29.02 g and 9.28, 11.21 kg) and Gemmeiza-11 (27.12, 29.27 g and 11.56, 13.23 kg), as well as the check variety; Morocco (23.14, 25.30 g and 8.64, 10.21 kg) at Sharkyia and Kafr El-Sheikh locations, respectively. On the other hand, grain yield of the partially resistant (PR) cultivars; Sakha-94, Sakha-95, Misr-1 and Misr-2, were less affected by stripe rust infection, wherein the highest amount of 1000 kernel weight (g) and grain yield/plot (kg) were obtained. As it was ranged from 43.02 to 48.11 g of 1000 kernel weight and from 23.75 to 27.31 kg of grain yield/plot, during the current study, at the two locations (Table 6). Also, the same trend was noticed with the results obtained in the second season (2016/17) (Table 7).

The previous studies of Sharma-Poudyal and Chen (2011), Safar (2015) and Afzal *et al*. (2007) reported that the stripe rust can cause approximately complete yield loss (100%) when severe infection occurs very early in the growth stage and the disease continues to develop under favorable environmental conditions, during the growing season. While, under Egyptian field conditions, Omara *et al*. (2016) showed that the actual percentage loss in grain yield of some highly susceptible wheat cultivars ranged between 53.7 and 55.4%.

**6. Correlation matrix between epidemiological parameters of partial resistance and yield components:**

Association between each of the three epidemiological parameters of PR to stripe rust, *i.e.* FRS (%), AUDPC, r-value, and the two yield components, *i.e.* 1000 kernel weight and grain yield/plot, was determined through correlation matrix, over the two locations and the two growing seasons of the study (Table 8 and Fig. 1). As indicated in the above Table, correlation between any two variables, was found to be highly significant. However, this correlation was positive between each pair of the disease variables (FRS (%), AUDPC and r-value). Similarly, the correlation was also positive between the two yield components, *i.e.* 1000 kernel weight and grain yield/plot. Meanwhile, the correlation was negative between any disease variables and each of the two yield components. Accordingly, final rust severity (FRS %) was the best disease variable to predict agronomic traits, due to the highest estimates between this variable and the two yield components ($r$ = -0.984 and -0.951, respectively).

The results obtained from scree plot of eigenvalue for the three epidemiological parameters; FRS (%), AUDPC and r-value and the two yield components; 1000 kernel weight and grain yield/plot, in the pooled data of 2015/16 and 2016/17 growing seasons (Fig. 2), confirmed those previously resulted from correlation analysis (Table 8 and Fig. 1). Therefore, final rust severity (FRS%) considered to be a good and more reliable indicators for the evaluation of field resistance or PR of the tested wheat cultivars against stripe rust (Omara *et al*., 2016 and Abu Aly *et al*., 2017). Similar results were previously obtained when correlation statistics were performed between different disease parameters of wheat rusts and grain yield of the studied wheat genotypes (Xiaowen *et al*., 2008 and Boulot *et al.*, 2015).

**Table 6. Effect of stripe rust infection on 1000 kernel weight (g) and grain yield/plot (kg) to 12 Egyptian wheat cultivars, as well as the check variety; Morocco at Sharkyia and Kafr El-Sheikh locations, during 2015/16 growing season.**

| Wheat cultivar | Yield components/locations | | | |
|---|---|---|---|---|
| | 1000 kernel weight (g) | | Grain yield/plot (kg) | |
| | Sharkyia | Kafr El-Sheikh | Sharkyia | Kafr El-Sheikh |
| Sids-1 | 35.24 | 37.65 | 13.13 | 15.26 |
| Sids-12 | 26.20 | 29.02 | 9.28 | 11.21 |
| Sids-13 | 36.11 | 38.23 | 15.38 | 17.03 |
| Sakha-93 | 35.88 | 37.42 | 13.97 | 15.86 |
| Sakha-94 | 43.02 | 45.17 | 23.75 | 25.04 |
| Sakha-95 | 45.01 | 46.98 | 24.26 | 26.69 |
| Gemmeiza-9 | 37.33 | 39.98 | 14.29 | 16.01 |
| Gemmeiza-10 | 40.87 | 42.47 | 17.32 | 19.54 |
| Gemmeiza-11 | 27.12 | 29.27 | 11.56 | 13.23 |
| Misr-1 | 45.21 | 47.60 | 24.16 | 26.05 |
| Misr-2 | 45.47 | 48.11 | 25.62 | 27.31 |
| Giza-168 | 39.07 | 41.50 | 16.06 | 18.62 |
| Morocco (check) | 23.14 | 25.30 | 8.64 | 10.21 |
| L.S.D.$_{0.05}$ of interaction (cultivars × locations) | 1.70 | | 1.10 | |

**Table 7. Effect of stripe rust infection on 1000 kernel weight (g) and grain yield/plot (kg) to 12 Egyptian wheat cultivars, as well as the check variety; Morocco at Sharkyia and Kafr El-Sheikh locations, during 2016/17 growing season.**

| Wheat cultivar | Yield components/locations | | | |
|---|---|---|---|---|
| | 1000 kernel weight (g) | | Grain yield/plot (kg) | |
| | Sharkyia | Kafr El-Sheikh | Sharkyia | Kafr El-Sheikh |
| Sids-1 | 32.63 | 34.30 | 12.63 | 14.34 |
| Sids-12 | 24.90 | 27.97 | 9.01 | 10.98 |
| Sids-13 | 34.97 | 37.14 | 14.08 | 16.18 |
| Sakha-93 | 33.87 | 35.87 | 13.11 | 15.25 |
| Sakha-94 | 43.01 | 45.52 | 22.04 | 24.14 |
| Sakha-95 | 43.17 | 45.87 | 23.04 | 25.21 |
| Gemmeiza-9 | 37.27 | 39.17 | 12.34 | 15.02 |
| Gemmeiza-10 | 40.67 | 42.23 | 16.19 | 18.61 |
| Gemmeiza-11 | 25.47 | 28.56 | 10.05 | 11.97 |
| Misr-1 | 44.07 | 46.50 | 23.08 | 25.43 |
| Misr-2 | 44.23 | 46.27 | 24.37 | 26.65 |
| Giza-168 | 38.57 | 41.39 | 15.11 | 17.37 |
| Morocco (check) | 21.37 | 24.08 | 8.13 | 10.45 |
| L.S.D.$_{0.05}$ of interaction (cultivars × locations) | 1.45 | | 1.52 | |

**Table 8. Pearson correlation matrix between the three epidemiological parameters and the two yield components at two locations and two growing seasons.**

| Variables | Variables | | | | |
|---|---|---|---|---|---|
| | FRS[a] (%) | AUDPC[b] | r-value[c] | 1000 kernel weight (g) | Grain yield/plot (kg) |
| FRS (%) | 1 | | | | |
| AUDPC | 0.956[d]** | 1 | | | |
| r-value | 0.955** | 0.915** | 1 | | |
| 1000 kernel weight (g) | -0.984** | -0.971** | -0.957** | 1 | |
| Grain yield/plot (kg) | -0.951** | -0.865** | -0.923** | 0.933** | 1 |

**FRS[a] (%) = final rust severity, AUDPC[b] = area under disease progress curve and r-value[c] = rate of disease increase.**
**d= Linear correlation coefficient and n=52.**

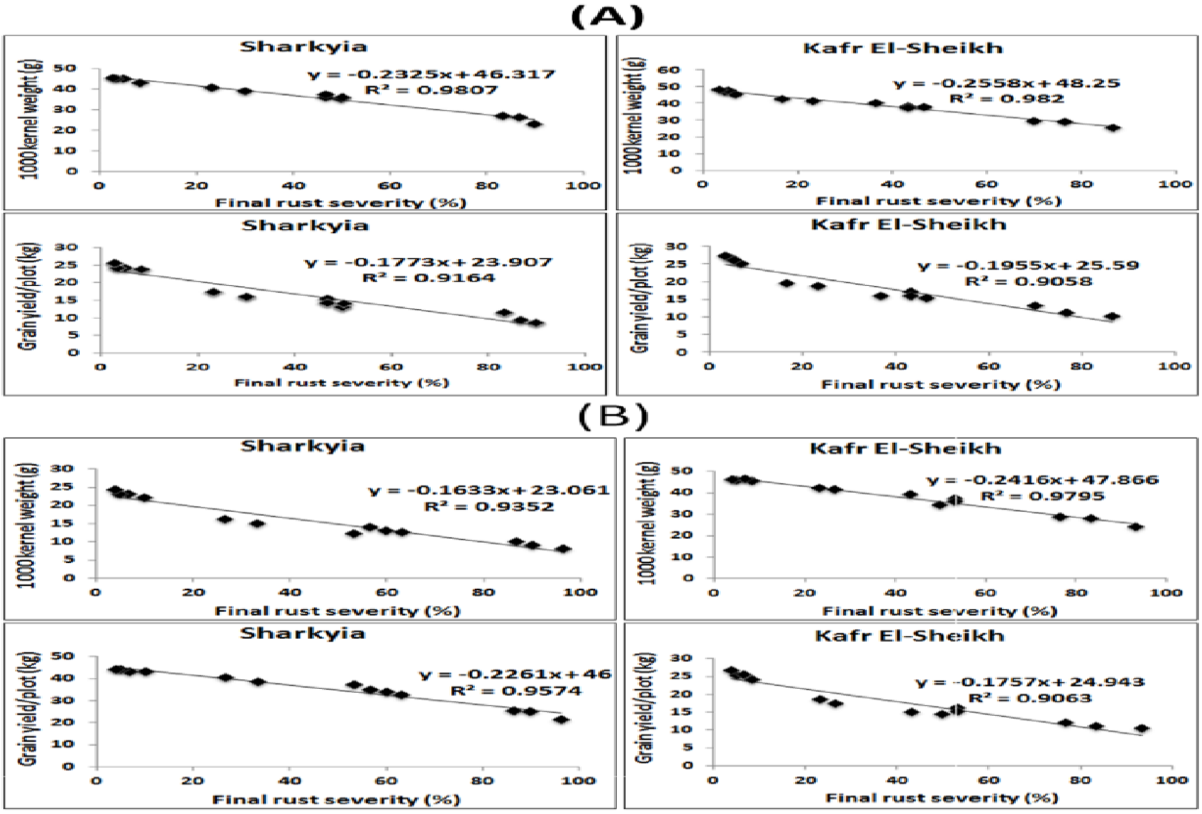


**Fig. 1. Correlation between final rust severity (FRS %) and each of the two yield components (1000 kernel weight and grain yield/plot), at Sharkyia and Kafr El-Sheikh locations, during 2015/2016 (A), and 2016/2017 (B) growing seasons.**

In general, evaluation and refine characterization of partial resistance (PR) in the currently available local wheat cultivars, to ensure the presence of acceptable levels of this type of resistance in these genotypes, would be facilitated the use of these entries in the national breeding program, that aimed to achieve more durable resistance to stripe rust.

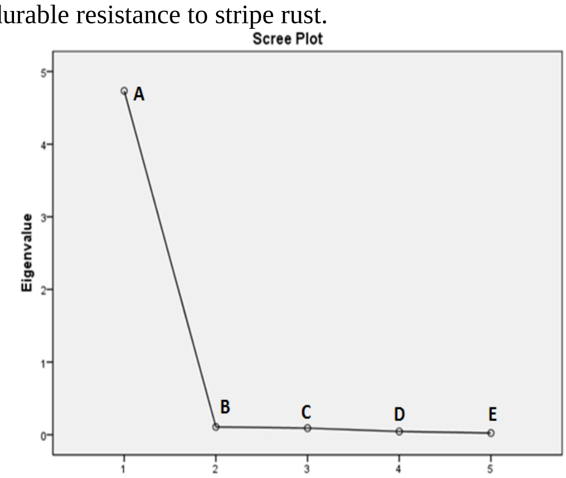


**Fig. 2. The scree plot of eigenvalue for the three epidemiological parameters; FRS (%), AUDPC and r-value and the two yield components; 1000 kernel weight (g) and grain yield/plot (kg) in the pooled data of 2015/16 and 2016/17 growing seasons and the two locations.**

**Details:- A: FRS (%), B: AUDPC, C: r-value, D: 1000 kernel weight (g) and E: grain yield/plot (kg)**

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## توصيف المقاومة الجزئية لمرض الصدأ المخطط المتسبب عن الفطر *Puccinia striiformis* f.sp. *tritici* في بعض أصناف القمح المصرية

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أجري هذا البحث بهدف دراسة وتقييم صفة المقاومة الجزئية (Partial resistance) لمرض الصدأ المخطط (الأصفر) في ١٢ صنفاً من الأقماح المصرية مقارنة بصنف موركو (الحساس أو العالي القابلية للإصابة بالمرض) وذلك بإستخدام ثلاثة مقاييس وبائية كمية للمرض وهي النسبة المئوية لشدة المرض النهائية (FRS%) والمساحة الواقعة تحت منحني الإصابة المرضي (AUDPC) و معدل تزايد المرض (r-value) بالإضافة الي تقدير إثنين من مكونات محصول الحبوب وهما: وزن الألف حبة (بالجرام) ومحصول القطعة التجريبية (بالكيلوجرام) وقد تم إجراء التجربة في محافظتي الشرقية وكفر الشيخ خلال موسمي الزراعة ٢٠١٦/٢٠١٥ و ٢٠١٧/٢٠١٦. وقد أتضح من نتائج الدراسة قدره بعض الأصناف المختبرة مثل سخا ٩٤ ، سخا ٩٥ ، مصر ١ ، مصر ٢ علي الحد من إنتشار هذا المرض وتطوره أثناء الموسم، وبالتالي إظهار مستويات منخفضة من شدة الإصابة بالمرض في نهاية الموسم بالمقارنة بالأصناف الحساسة (عالية القابلية للإصابة) مثل سدس ١٢ ، جميزة ١١ ، وأيضا الصنف المستخدم كمقارنة (موركو) وذلك تحت ظروف الحقل خلال موسمي الزراعة وفي كلا الموقعين ، مما يعكس قدره هذة الأصناف علي تقليل حجم الإصابة بمرض الصدأ الاصفر في حالة حدوثة بصورة وبائية. بالإضافة الي قدرة هذه الأصناف علي تحقيق أعلي وزن في كلٍ من الألف حبة ومحصول القطعة التجريبية. ومن ناحية أخري فقد أظهرت النتائج المتحصل عليها أن أكثر من ٩٠% من الإختلافات بين الأصناف المختبرة في رد فعلها للإصابة بالمرض ترجع اساساً إلى التركيب الوراثي أو الجيني لتلك الأصناف. حيث وجد أن التركيب الوراثي قد ساهم بنسبة ٩٧.٥٩ ، ٩٧.١٠ ، ٩٥.١٦% (موسم ٢٠١٦/٢٠١٥) و ٩٧.٤٣ ، ٩٦.٨٧ ، ٩٤.٩٨% (موسم ٢٠١٧/٢٠١٦) في التغيرات الحادثة بكل من النسبة المئوية لشدة المرض النهائية والمساحة الواقعة تحت منحني الإصابة المرضي و معدل تزايد المرض علي التوالي. وعلي النقيض من ذلك فقد إتضح أن تأثير الظروف البيئة علي تلك التغيرات كان ضعيفاً جداً حيث كان أقل من ٥%. وبالتالي فإن تأثر مستوي المقاومة الجزئية للأصناف تحت الدراسة بالتغيرات البيئية من سنة الي أخري أو من موقع الي آخر كان تأثرا طفيفياً أو ضعيفاً للغاية. وقد أيد تلك النتائج أيضا وجود قيم عالية لكفاءة أو معدل التوريث وقيم متوسطة إلي عالية لنسبة التحسن الوراثي المتوقع من إجراء عملية الإنتخاب مما يدل دلالة واضحة علي أن الإختلافات الناجمه بين الأصناف المختبرة في رد فعلها للإصابة بالمرض تعد في المقام الأول إختلافات وراثية اذ أنها ترجح أساساً إلى التركيب الوراثي لتلك الاصناف النباتية. وبتحليل مصفوفة الإرتباط بين كل من المقاييس الوبائية للمرض والصفات المحصولية للأصناف تحت الدراسة فقد أتضح أهمية تلك المقاييس وخاصة النسبة المئوية لشدة المرض النهائية (FRS%) كدلائل جيدة ومناسبة لتقييم وقياس المقاومة الجزئية لأصناف القمح تحت الدراسة. وبناءً علي النتائج المتحصل عليها خلال تلك الدراسة فأنة بالإمكان إجراء التقدير الكمي والتشخيص الدقيق لصفة المقاومة الجزئية لمرض الصدأ المخطط في نباتات القمح تحت ظروف الحقل إعتماداً علي تلك المقاييس الوبائية الهامة. حيث أنه من الممكن أن يعول عليها بدرجة كبيرة في إجراء عملية التقييم و الإنتخاب للأصول الوراثية التي يتوقع أن تحمل صفة المقاومة الجزئية لهذا المرض وبالتالي الإستفادة منها في تحسين برامج التربية لمقاومة أمراض الأصداء في القمح وخاصة الصدأ المخطط وذلك بوجة عام في مصر.