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Evaluation of Wheat Cultivars for Slow Rusting Resistance to Leaf and Stem Rust Diseases in Egypt

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Leaf rust (*Puccinia triticina* Eriks.) and stem rust (*Puccinia graminis* f. sp. *tritici*) have been considered to be the most common rust diseases of wheat. Twelve Egyptian wheat cultivars were evaluated for resistance at seedling stage using four slow rusting components i.e. incubation period, latent period, pustule density /cm^2 and pustule size/mm^2. Additionally, three parameters of slow rusting resistance at adult plant stage, rust reaction, infection response and rust severity (%). Rate of leaf and stem rust increase (r-value) and area under disease progress curves (AUDPC) were determined under artificial infection with the single race of the two fungi at the adult plant stage in greenhouse experiments. The five cultivars; Misr 3, Sids 12, Shandweel 1, Sakha 94 and Gemmeiza 12 showed low values of incubation period, pustule density/cm^2, pustules size/mm^2, infection response, r-value and AUDPC to wheat leaf and stem rust due to characterized as slow rusting resistance cultivars. Also, the cultivar Giza 168 showed complete resistance to leaf and stem rust, while, the two cultivars Misr 1 and Beni Sweif 5 showed slow rusting to leaf rust but characterized as highly susceptible and fast rusting cultivars to stem rust. Correlation between latent period and area AUDPC was negative and strong (r = 0.70) in leaf rust but in stem rust was (r = 0.46). Thus, the slow rusting resistant wheat cultivars can be used for developing high-yielding with more durable resistance to leaf and stem rust diseases in bread wheat.

Keywords: Wheat, *Triticum aestivum*, Leaf rust, *Puccinia triticina*, Stem rust, *Puccinia triticina*, Incubation period, Latent period, Slow rusting resistance.

Wheat (*Triticum aestivum* L.) is the main stable sources of food in most developing countries, thereby, an important source in order to maintain food security for the growing populations in these countries. Leaf rust and stem rust of wheat are amongst the most important foliar diseases of wheat. Stem rust (*Puccinia graminis* f. sp. *tritici*) and leaf rust (*Puccinia triticina*) of wheat continue to cause damage locally and globally. Stem rust occurs primarily on stem but can also be found on leaves, sheaths, glumes and owns. Wheat leaf rust is generally found on leaves. Leaf and stem rust cause significant and severe losses on susceptible wheat cultivars in Egypt and worldwide (Abdel-Hak *et al*., 1966; Ashmawy *et al*., 2014; Shahin and El-Orabey, 2016 and El-Orabey *et al*., 2017). Moreover, the detection of the wildely virulent race Ug 99 in Uganda in 1998 challenged the stem rust was a conquered disease (Singh *et al*., 2006 and 2008). Now, up to 90% of world's wheat cultivars are considered stem rust susceptible (Singh *et al.*, 2013). The high resistance to wheat rusts is primarily due to use of genetic host resistance.

Slow rusting resistance is a type of resistance that is both race-non-specific and durable (Priamvada *et al*., 2011). It is polygenic and effective against a broad range of wheat rust races (Herre-foessel *et al*., 2007). Slow rusting resistance is characterized by a slow epidemic build up despite a high infection type indicting a compatible host-pathogen relationship (Parlevliet and Van Ommeren, 1975; Priamvada *et al*., 2011 and Hei *et al*., 2014). The effectiveness of resistance in wheat cultivars to any rust disease depends on its levels, stability and durability. More attention has been drowning to alternative forms of resistance, such as, slow or non-specific resistance to be more stable and durable. Caldwell (1968) was the first who characterized the slow rusting, partial or general resistance in cereal crops. He indicated that slow rusting retarded the rate of disease development and confers a more stable form of resistance.

The disease resistance in cereals at adult plant stage can be assessed by quantitative measurements such as severity of infection, the rate increase of epidemic and area under disease progress curve (AUDPC) at adult plant stage. While at seedling stage, the components of slow-rusting resistance can be evaluated by assessing the latent period (LP), incubation period (IP), number of pustules/cm^2 and pustules size/mm^2. The slow rusting wheat cultivars had ability to retard and delay the incidence and development of leaf and stem rust diseases conditions (Nazim *et al*., 1990; Negm, 2004; Boult, 2007; Mabrouk, 2012; Boult & Ali, 2014; Fahmi *et al*., 2015; Mabrouk, 2016 and El-Orabey *et al*., 2019). Slow rusting resistance is an additional source described genes that can confer durable resistance to leaf and stem rust in bread wheat. The transfer of such resistance to commercial wheat cultivars showed contributes to long-lasting genetic control to rust diseases. Therefore, cultivation of resistant cultivars is the most effective, economic and environmentally safe control method for the farmers (Line and Chen, 1989; Chen, 2005 and El-Orabey *et al.*, 2014).

The objective of this study was to evaluate of some Egyptian wheat cultivars for resistance to leaf and stem rust using the components and parameters of slow rusting resistance at seedling and adult plant stages under greenhouse conditions.

Materials and Methods

Twelve Egyptian wheat cultivars in addition to the two highly susceptible checks varieties Morocco and *Triticum spelta saharensis* (T.s.s.) (Table 1) were evaluated for slow rusting resistance to leaf and stem rust at seedling and adult plant stages under greenhouse conditions at Wheat Diseases Res. Dept., Plant pathology Res. Inst., ARC, Giza, Egypt during 2018/19 growing season.

Twenty five wheat grains from each cultivar were grown in 25 cm diameter pot. After germination, the plants were thinned to 10 plants per pot in randomized complete block (RCB) design. Three pots (replicates) were used for each cultivar. Artificial inoculation was carried out at booting stage (70 days old), as mentioned by Large (1954). Plants were dusted with the spores of single race *i.e.*, PTTTT for leaf rust experiment and with race GFTJC for stem rust experiment, which considered more frequent and virulent according to greenhouse data analysis during this growing season which were kindly provided by Wheat Diseases Res. Dept. Plant Pathol. Res. Inst., ARC, Giza, Egypt. Spores were mixed with talcum powder at a ratio of 1: 20 (v/v) according to Tervet and Cassell (1951). After 24 h of incubation in dew chamber (100% relative humidity) the inoculated pots were transferred to greenhouse in the other greenhouse part, where the temperature was 20 ± 2°C for leaf rust greenhouse while temperature was 22 ± 2°C for stem rust with approximately 80% relative humidity in each greenhouse.

1. *Components of slow rusting resistance:*

Incubation period (IP), which is the number of days between inoculation to the commencement of the first pustule was estimated. Latent period (LP) was measured according to Parlevliet (1975) by counting the number of visible pustules on marked leaves daily until no more pustules appeared. From these data, time between inoculation and 50% of the pustule just visible was estimated. Number of pustules/cm^2 and the number of pustules per unit leaf area cm^2 on the upper side of the leaves were counted as described by Parlevliet and Kuiper (1977). Pustule size (PS) was measured using the light microscope at 10X power magnification and pustules were fixed in boiled mixture of lactophenol and ethanol solution (1:2, v/v) for three minutes. Length (L) and width (W) of 10 randomly chosen pustules per one leaf were measured following formula suggested by Broes (1989).

$$\text{Pustule size} = \frac{1}{4} \times \pi L \times W$$

Where: $\pi = 3.14$; L is the length; W is the width of each pustule.

Table (1): Name, pedigree and year of release of fourteen wheat genotypes used in this study.

Genotype	Pedigree	Year of Release
Giza 168	MAL / BUC // SERI CM93046-8M-0Y-OM-2Y-0P	1995
Giza 171	SAKHA 93 / GEMMEIZA 9S.6-1GZ-4GZ-1GZ-2GZ-0S	2013
Misr 1	OASIS/SKAUZ//4*BCN/3/2*PASTORCMSS00Y01881T-050M-030Y-030M-030WGY-33M-0Y-0S	2011
Misr 2	SKAUZ/BAV92CMSS96M03611S-1M-010SY-010M-010SY-8M-0Y-0S	2011
Misr 3	ATTILA*2/ABW65*2/KACHU CMSS06Y00258 2T-099TOPM-099Y-099ZTM-099Y-099M-10WGY-0B-0EGY	2019
Sids 12	BUC//7C/ALD/5/MAYA74/ON//1160.147/3/BB/GLL/4/CHAT"S"/6/MAYA/VUL//CMH74A.630/4*SXSD7096-4SD-1SD-1SD-0SD	2007
Sids 13	KAUZ'S" / TSI / SNP"S" ICW 94-0375-4AP-2AP-030AP-0APS-3AP-0APS-050AP-0AP-0SD	2010
Shandweel 1	SITE/ MO/4/NAC//3*PVN/3/MIRLO.	2011
Sakha 94	OPATA/RAYON//KAUZCMBW90Y3180-0TOPM-3Y-010M-010M-010Y-10M-015Y-0Y-0AP-0S	2004
Gemmeiza 11	BOW"S"/KVZ"S"//7C/SER182/3/GIZA168/SAKHA61GM5820-3GM-1GM-2GM-0GM	2011
Gemmeiza 12	OTUS/3/SARA/THB//VEECMSS97Y00227S-5Y-010M-010Y-010M-2Y-1M-0Y-0GM	2011
Beni Sweif 5	DIPPERZ/BUSHEN3.CDSS92B128-1M-0Y-3B-0Y-0SD.	2007
Morocco	Susceptible check	-
Triticum spelta saharensis (T.s.s.)	Susceptible check	-

2. *Parameters of slow rusting resistance:*

Plant response to rust infection at adult plant stage under greenhouse was termed (infection response) according to the modified Cobb's scale Peterson *et al*. (1948) and the reaction types by Roelfs *et al.* (1992) and Singh *et al*. (2013) (Table 2). The leaf and stem rust data were scored four times for disease severity% (DS %) as percentage coverage of leaves with rust pustules at weekly intervals using modified Cobb's scale (Peterson *et al.*, 1948). Adult- plant slow rusting resistance of the each of wheat genotypes was assessed through rust severity (%), infection response (IR), rate of disease increase (r-value) and area under disease progress curve (AUDPC).

The final rust severity (FRS %) was recorded as outlined by Das *et al.* (1993) as the disease severity (%), when the highly susceptible check variety was severely rusted and the disease rate reached the highest and final level of rust severity. Rate of rust increase (r-value) as a function of time was also estimated using the formula adopted by Van Der Plank (1963) to determine the ability of the tested genotype to affect the development of wheat leaf and stem rust infection. Area under disease progress curves (AUDPC) was estimated to compare different responses of the tested genotypes using the equation adopted by Pandey *et al.* (1989).

3. *Statistical analysis:*
Data were statistically analyzed, according to Duncan's multiple range test (Duncan, 1955).

Table (2): Adult plant resistance response and severity (%) for leaf and stem rust*.

Disease response	Disease severity (%)	Host response	Symptoms
R	0-5	Resistant	Resistant, no visible infection or some chlorosis or necrosis and no uredinia
R-MR	10-20	Resistant to moderately Resistant	
MR	20-30	Moderately Resistant	Moderately Resistant small uredinia present and surrounded by either chlorotic or necrotic areas
MR-MS	30-40	Moderately Resistant to Moderately Susceptible	
MS	40-50	Moderately Susceptible	Moderately susceptible, medium-sized uredinia present and possibly surrounded by chlorotic areas
MS-S	50-70	Moderately Susceptible to Susceptible	
S	70-100	Susceptible	Susceptible, large uredinia present, generally with little or no chlorosis and no necrosis

* Based on the modified Cobb's scale (Peterson *et al*., 1948) and the reaction types by Roelfs *et al*. (1992) and Singh *et al*. (2013); R = Resistant; MR = Moderately resistant; MS = Moderately susceptible; S = Susceptible.

Results

1. *Components of slow leaf rusting resistance*

Data presented in Table (3) show significant differences among the tested cultivars concerning the studied components of leaf slow rusting. Among the tested cultivars; Giza 171, Misr 1, Misr 3, Sids 13, Shandweel 1, Sakha 94 and Gemmeiza 12 exhibited the longest incubation period ranged between 12 and 15 days and the longest latent period ranged between 14 and 20 days on the basis of pustule density/ cm^2 and pustule size mm^2. These cultivars also exhibited the lowest values of the two components, pustule/cm^2 ranged from 1.00 to 8.66 and pustule size mm^2 ranged from 0.023 to 0.085 mm^2 (Table 3). Cultivars: Giza 171, Misr 1, Misr 3, Sids 13, Shandweel 1 Sakha 94 and Gemmeiza 12 could be characterized by their high levels of resistance and have slow rusting resistance to leaf rust. On contrast, cultivars; Giza 168, Misr 2 and Beni Sweif 5 were resistant where no visible infection was found and have complete resistance to wheat leaf rust. On the other hand, the Egyptian wheat cultivars Sids 12 and Gemmeiza 11 in addition to the two highly susceptible varieties Morocco and Beni Sweif 5. showed the shortest incubation and latent periods ranged from (8 to 12 days) and from (9 to 15 days), respectively, these cultivars have high values of pustule density/cm^2 ranged from 21.33 to 45.00 and pustule size/mm^2 ranged from 0.076 to 0.432 mm^2 and could be characterized as a highly susceptible or fast leaf rusting cultivars.

Table (3): Means of incubation period, latent period, pustule density/cm^2 and pustule size/mm^2 in fourteen wheat genotypes inoculated with race PTTTT of *Puccinia triticina* at seedling stage under greenhouse condition during 2018/19 growing season

No.	Genotype	Incubation period (day)	Latent period (day)	Pustule density $(cm)^2$	pustules size $(mm)^2$ Length × Width
1	Giza 171	12.33^{cd}	15.00^{c}	28.000^{b}	0.043^{d}
2	Giza 168	0.00^{h}	0.00^{g}	0.000^{d}	0.00^{g}
3	Misr 1	13.33^{bc}	20.00^{a}	5.000^{d}	0.052^{c}
4	Misr 2	0.00^{h}	0.00^{g}	0.000^{d}	0.00^{g}
5	Misr 3	13.00^{bcd}	18.00^{b}	1.000^{d}	0.023^{f}
6	Sids 12	12.00^{de}	15.00^{b}	43.333^{a}	0.076^{b}
7	Sids 13	14.00^{b}	17.00^{b}	2.000^{d}	0.056^{c}
8	Shandweel 1	15.00^{c}	17.33^{b}	3.666^{d}	0.023^{f}
9	Sakha 94	14.00^{ab}	15.00^{c}	6.000^{d}	0.052^{c}
10	Gemmeiza 11	11.00^{ef}	13.00^{d}	21.333^{bc}	0.106^{a}
11	Gemmeiza 12	12.00^{de}	14.00^{cd}	8.666^{cd}	0.085^{a}
12	Beni Sweif 5	0.00^{h}	0.00^{g}	0.000^{d}	0.00^{g}
13	Morocco	8.00^{g}	9.00^{f}	45.000^{a}	0.335^{e}
14	T.s.s.	9.00^{g}	11.00^{e}	27.333^{b}	0.432^{d}
L.S.D. at 5%		1.098	1.193	14.361	0.034

2. *Parameters of slow-leaf rusting resistance*

On the basis of rust severity (%) and infection response, the fourteen tested wheat cultivars were grouped into two groups of slow rusting resistance, the high and moderate levels of partial resistance having 1-30% and 31- 50% rust severity, respectively (Table 4). Six wheat cultivars Misr 1, Misr 3, Sids 13, Shandweel 1, Sakha 94 and Gemmeiza 12 in the first group exhibited final rust severity ranging from 1 to 20% with compatible responses (MS) and are of great importance to achieving effective breeding for durable resistance to leaf rust. The two cultivars; Misr 3 and Sids 13 displayed resistant to moderately resistant (MR) field reactions. On the other hand, cultivar Giza 171 and Gemmeiza 11were in the second group with 50% final rust severity and (MS) field response. On the other hand, the susceptible check, Morocco and T.s.s. displayed the highest disease severities of 80 and 90% with completely susceptible (S) responses, respectively. Cultivars, Giza 168, Misr 2 and Beni Sweif 5 showed immune responses.

Data in Table (4) show significant differences among the tested wheat genotypes concerning the studied parameters; r-value and AUDPC. Among the tested cultivars, Giza 171, Shandweel 1, Sakha 94 and Gemmeiza 12 showed the lowest values of r-value ranged from 0.016 to 0.038, while, the maximum mean of r-value (0.071) was observed on the fast rusting cultivars Morocco and T.s.s. The three wheat cultivars; Giza 168, Misr 1 and Beni Sweif 5 showed resistance reaction (0) and constant disease severity, which showing no increase per unit time with r-value (Table 4).

The tested wheat cultivars were categorized into two distinct groups for slow rusting resistance, based on the AUDPC values. Wheat cultivars exhibiting AUDPC values less than 300 ranged from 12.00 to 220.00 having high level of partial resistance or slow rusting resistance to leaf rust, consisted of six wheat cultivars; Misr 1, Misr 3, Sids 13, Shandweel 1 Sakha 94 and Gemmeiza 12. While, cultivars; Giza 171, Sids 12, Gemmeiza 11, Morocco and T.s.s. having AUDPC values more than 300 ranged from 330.00 to 1550.00.

A negative strong and significant correlation of latent period (LP) with area under progress curve AUDPC (r = 0.70) was observed between (LP) and AUDPC in the tested wheat cultivars against leaf rust (Tables 3 and 4).

3. *Components of slow-stem rusting resistance*

Components of wheat stem rust data indicate the presence of significant differences among the tested cultivars concerning the studied components of stem slow rusting (Table 5). Among the tested cultivars, Giza 171, Sids 12, Shandweel 1, Sakha 94, Gemmeiza 11 and Gemmeiza 12 exhibited the longest incubation period ranged between 12.00 and 21.00 days and the longest latent period ranged between 13.00 and 21.66 days. On the basis of pustule density and pustule size, these cultivars exhibited the lowest values of the two components ranged from 2.00 to 4.00 pustule/cm^2 and pustule size ranged from 2.50 to 5.26 mm^2. According to stem slow rusting components, these cultivars; Giza 171, Sids 12, Shandweel 1, Sakha 94, Gemmeiza 11 and Gemmeiza 12 could be characterized as highly levels of slow rusting resistance to stem rust. On contrast, cultivars; Giza 168 and Sids 13 were completely resistant and no visible infection or some chlorosis or necrosis and no uredinia. On the other hand, the Egyptian wheat cultivars; Misr 1, Misr 2, Misr 3 and Beni Sweif 5 in addition, to the two highly susceptible varieties Morocco and T.s.s. showed the shortest incubation and latent periods ranged from (9.00 to 10.00 days) and from (10.00 to 12.00 days), respectively. These cultivars have highly values of pustule density/cm^2 ranged from 4.33 to 17.33 and pustule size ranged from 6.66 to 14.66 mm^2, respectively.

Table (4): Adult plant reaction (rust severity (%) and infection response) (IR), Rate of disease increase (r-value) and area under disease progress curve (AUDPC) on fourteen wheat genotypes inoculated with race PTTTT of *Puccinia triticina* at adult plant stage under greenhouse condition during 2018/19 growing season.

No.	Genotype	Adult plant reaction		r-value[b]	AUDPC[c]
		Rust severity (%)	IR[a]		
1	Giza 171	50	MS	0.003[e]	603.33[c]
2	Giza 168	0.0	0	0.000[e]	0.00[k]
3	Misr 1	Tr	MS	0.053[abc]	30.00[i]
4	Misr 2	0.0	0	0.000[e]	0.00[k]
5	Misr 3	Tr	MR	0.063[ab]	18.00[j]
6	Sids 12	20	S	0.076[a]	230.00[f]
7	Sids 13	Tr	MR	0.062[ab]	12.00[j]
8	Shandweel 1	Tr	S	0.023[cde]	45.00[h]
9	Sakha 94	10	MS	0.038[bcd]	70.00[g]
10	Gemmeiza 11	50	MS	0.003 e	420.00[e]
11	Gemmeiza 12	20	S	0.016[de]	220.00[f]
12	Beni Sweif 5	0	0	0.000[e]	0.00[k]
13	Morocco	80	S	0.051[abcd]	1450.00[b]
14	T.s.s.	90	S	0.051[abcd]	1550.00[a]
L.S.D. at 5%				0.033	11.666

a = infection response; b = Rate of disease increase; c = Area under disease progress curve.

Table (5): Means of incubation period, latent period, pustule density/cm2 and pustule size/mm^2 on fourteen wheat genotypes inoculated with race GFTJC of *Puccinia graminis* f. sp. *tritici* at seedling stage under greenhouse condition during 2018/19 growing season.

No.	Genotype	Incubation period (day)	Latent period (day)	Pustule density (cm)^2	pustules size (mm)^2 Length × Width
1	Giza 171	15.00 ^{b}	15.33^b	4.00^{bcd}	5.26^{de}
2	Giza 168	0.00^e	0.00^h	0.00^e	0.00^g
3	Misr 1	10.00^d	10.66^{fg}	9.66^{ab}	10.00^b
4	Misr 2	10.00^d	11.66^{ef}	17.33^a	10.33^b
5	Misr 3	10.00^d	11.66^{ef}	8.00^{bc}	6.66^{cd}
6	Sids 12	15.00^b	16.00^b	0.66^{cd}	3.03^{ef}
7	Sids 13	0.00^e	0.00	0.00^d	0.00^g
8	Shandweel 1	21.00^a	21.66^a	3.00^{bcd}	4.73^{de}
9	Sakha 94	15.00^b	16.33^b	3.00^{bcd}	3.73^{de}
10	Gemmeiza 11	12.33^c	13.00^{cd}	3.00^{bcd}	3.66^{de}
11	Gemmeiza 12	12.00^c	14.00^c	2.00^{cd}	3.00^{ef}
12	Beni Sweif 5	10.00^d	12.00^{de}	6.00^{bcd}	8.56^{bc}
13	Morocco	9.00^d	11.00^{efg}	5.33^{bcd}	14.66^a
14	T.s.s.	9.00^d	10.00^{fg}	4.33^{bcd}	14.00^a
L.S.D. at 5%		1.257	1.271	7.97	3.287

4. *Parameters of slow-stem rusting resistance*

On the basis of stem rust severity (%) and infection response, the tested wheat cultivars were grouped into two groups of slow stem rusting resistance, the high and moderate levels of partial resistance showed 1-30 and 31- 50% rust severity , respectively (Table 6). Seven wheat cultivars; Giza 171, Misr 3, Sids 12, Shandweel 1, Sakha 94, Gemmeiza 11 and Gemmeiza 12 displayed disease severity values of up to 30%. Two cultivars; Shandweel 1 and Sids 12 had resistant to moderately resistant (MR) reactions with rust severity less than 5%. While, three wheat cultivars; Sakha 94, Gemmeiza 11 and Gemmeiza 12 showed moderately susceptible (MS) responses with stem rust severity ranged from 5 to 10%. The two cultivars; Giza 171 and Misr 3 showed susceptible (S) responses and exhibiting final stem rust severity 10%. On the other hand, cultivars; Misr 1, Misr 2, Beni Sweif 5 and the two fast rusting varieties; Morocco and T.s.s. were included in the second group and showed final stem rust severity ranged from 60 to 80 % with susceptible (S) responses, while the two cultivars; Giza168 and Sids13 remained immune responses.

Data obtained in Table (6) show significant differences among the tested wheat genotypes concerning with previous parameters of slow stem rusting. Among the tested cultivars, Giza 171, Misr3, Sids 12, Shandweel 1, Sakha 94, Gemmeiza 11 and Gemmeiza 12 showed the lowest values of r-value ranged from 0.020 to 0.038. While, the maximum mean of r-value ranged from 0.061 to 0.071, was observed on the fast rusting cultivars; Misr 1, Misr 2, Morocco and T.s.s. The two cultivars; Giza 168 and Sids 13 showed a resistance (0) and constant disease severity, thus showing no increase per unit time with r-value (Table 6).

The tested wheat cultivars were categorized into two distinct groups for slow rusting resistance, based on the AUDPC values. Wheat cultivars exhibiting AUDPC values less than 300 ranged from 30.00 to 182.00 having high level of partial resistance or slow rusting resistance to stem rust, consisted of seven wheat cultivars; Giza 171, Misr 3, Sids 12, Shandweel 1, Sakha 94, Gemmeiza 11and Gemmeiza 12. While, cultivars; Misr 1, Misr 2, Beni Sweif 5, Morocco and T.s.s. showed AUDPC values more than 300 ranged from 565.00 to 1050.00 (Table 6).

Table (6): Adult plant reaction (rust severity%, infection response (IR) rate of disease increase (r-value) and area under disease progress curve (AUDPC) on fourteen wheat genotypes inculcated with race (GFTJC) of *Puccinia graminis* f. sp. *tritici* on adult plant stage under greenhouse condition during 2018/19 growing season

No.	Genotype	Adult plant reaction		r-value	AUDPC
		Rust severity (%)	IR[b]		
1	Giza 171	10	S	0.036	154.33[de]
2	Giza 168	0	0	0.000	0.00 [f]
3	Misr 1	60	S	0.079	800.00 [b]
4	Misr 2	60	S	0.071	793.33 [b]
5	Misr 3	10	S	0.021	182.00 [d]
6	Sids 12	Tr	MR	0.020	36.00[f]
7	Sids 13	0.0	0	0.000	0.00
8	Shandweel 1	Tr	MR	0.020	30.00[f]
9	Sakha 94	5	MS	0.027	56.00[f]
10	Gemmeiza 11	10	MS	0.038	76.00[ef]
11	Gemmeiza 12	5	MS	0.027	44.00[f]
12	Beni Swear 5	60	S	0.506	565.00[c]
13	Morocco	80	S	0.061	1050.00[a]
14	T.s.s.	60	S	0.065	815.00[b]
L.S.D. at 5%				NS	83.086

The relationship between the two variables latent period (LP) and area under progress curve AUDPC in wheat cultivars tested against stem rust (Tables 5and 6) was negative and also correlation of (LP) with AUDPC (r = 0.46) was weak in these cultivars.

Data in Tables (3, 4, 5 and 6) indicate that the five cultivars; Misr 3, Sids 12, Shandweel 1, Sakha 94 and Gemmeiza 12 showed low values of incubation period, pustule density, pustules size, infection response, r-value and AUDPC to wheat leaf and stem rust characterized as slow rusting resistance cultivars. In addition, cultivar Giza 186 had complete resistance to leaf and stem rust, while the two cultivars Misr 1and Beni Sweif 5 had slow rusting to leaf rust but characterized as highly susceptible and fast rusting to stem rust. On the other hand, the cheek varieties; Morocco and T.s.s. were fast rusting to both wheat rusts.

Discussion

Slow-rusting in wheat to leaf rust defined by Broers (1989) is a form of incomplete, race non-specific resistance, characterized by a slow epidemic development and a retard of rust progress in the field although plants show a compatible, high infection type. It is often emphasized that partial resistance will be under polygenic control and therefore, assumed to be more durable compared to other forms of resistance conditioned by single major genes.

In the current study under greenhouse condition, four components i.e. incubation period (IP), latent period (LP), pustule density (cm^2) and pustules size (mm^2) were studied for both leaf and stem rust. In general, significant variation was found among the slow rusting resistance cultivars and the highly susceptible ones, although all of them were inoculated with the same *Puccinia triticina* races under favorable environmental conditions in the greenhouse. However, partial resistance character could be accurately measured and/or characterized by more of such components. Among the tested cultivars; Gemmeiza 12, Sids 13, Giza 168, Giza 171 and Sakha 94, exhibited the longest incubation period (12-14 days) and the longest (LP) (14-20 days) and have low values of pustule density and pustule size and these five cultivars could be characterized as highly level of resistance to leaf rust and considered as slow rusting cultivars. On contrast, the wheat cultivars; Sids 12 and Gemmeiza 11 in addition to the two highly susceptible varieties; Morocco and T.s.s. showed the shortest incubation and latent periods, these cultivars have highly values of pustule density and pustule size and could be characterized as a highly susceptible or fast leaf rusting cultivars (Das *et al.*, 1993; Boulot and Ali, 2014 and Mabrouk, 2016).

According to leaf rust severity (%) and infection response of the tested wheat cultivars, they were grouped into two groups of slow leaf rusting resistance, the high and moderate levels of partial resistance having 1-30 and more than 30% rust severity, respectively. Six wheat cultivars, Misr 1, Misr 3, Sids 13, Shandweel 1, Sakha 94 and Gemmeiza 12 are remained in the first group, exhibiting final rust severity ranging from 1 to 20% with compatible (MS) responses and are of great importance to achieving effective breeding for durable resistance to leaf rust (Parlevliet, 1988 and Nzuve *et al.*, 2012). Previously, Ali *et al.* (2007); Li and Liu

(2010); Tabassum (2011) and Safavi and Afshari (2013) also used the final rust severity to assess slow rusting behavior of wheat lines. Cultivars: Giza 168, Misr 2 and Beni Sweif 5 showed immune responses as a result of hypersensitive responses, resistance often breaks down due to the development of new races of the pathogen. A suitable breeding strategy like the use of inter-specific and remote crosses or even the direct transfer of these resistance reactions through backcrosses could be used to improve the adopted but highly susceptible wheat varieties (Bartos *et al.*, 2002).

Among the tested cultivars, Giza 171, Shandweel 1, Sakha 94 and Gemmeiza 12 showed the lowest values of rate of disease increase (r-value) and Area under disease progress curve (AUDPC), cultivars Giza 168, Misr 1 and Beni Sweif 5 showed a constant disease severity, thus showing no increase per unit time. More variation in infection rate among the tested cultivars than the other slow rusting parameters is partially because rate of disease increase is a regression coefficient with larger error variance. Therefore, rate of disease increase in the present study seemed to produce unreliable estimates of slow rusting resistance when compared with FRS (%) and AUDPC. Similar results were found for rusts of wheat (Rees *et al*., 1979; Broers, 1989; Ali *et al*., 2008; Safavi *et al.*, 2010). Cultivars, Giza 171, Sids 12, Gemmeiza 11, Morocco and T.s.s. showed high values of r-value and AUDPC, these cultivars could be characterized as highly level of fast rusting resistance or susceptibility to leaf rust. According to Parlevliet (1988); Brown *et al*. (2001); Negm (2004); Singh *et al*. (2005); Kaur and Bariana (2010); Boulat *et al.* (2014) and Mabrouk (2016) the wheat cultivars which had MS infection type may be carrying durable resistance genes, such as slow rusting resistance. These wheat cultivars first shown rust infection and sporulation, but the final host reaction was characterized as chlorotic and necrotic lesions. Subsequently, the disease progression remained slower and highly retarded among these cultivars. Such partially resistant lines could highly delay evolution of new virulent races of the pathogen because multiple point mutations are extremely rare in normal circumstances (Schafer and Roelfs, 1985; Ali *et al*., 2008 and Tsilo *et al.*, 2010). Likewise, despite the MS infection type exhibited on moderately slow rusting cultivars, leaf rust developed slowly as indicated by their AUDPC values. None of the tested cultivars was marked as having susceptible field response. Other researchers have also reported variations among different wheat lines for slow rusting resistance to leaf rust using AUDPC (Patil *et al*., 2005; Draz *et al*., 2015). Correlation between latent period (LP) with the area under disease progress curve (AUDPC) was strong and negative against leaf rust disease. These strong correlations are in agreement with the results of Qamar *et al*. (2007); Ali *et al*. (2008); Safavi *et al*. (2010) and Shah *et al*. (2010).

Among the tested cultivars, Giza-171, Sids-12, Shandweel 1 Sakha-94, Gemmeiza-11 and Gemmeiza-12 had the longest incubation period and latent period with low values of pustule density/ cm^2 and pustule size mm^2, these cultivars could be characterized as highly levels of slow rusting resistance to stem rust. While cultivars Giza-168 and Sids-13 were completely resistant, no visible infection or some chlorosis or necrosis and no uredia and have complete resistance to wheat stem rust. On the other hand, the Egyptian wheat cultivars Misr-1, Misr-2, Misr-3, Beni Sweif-5, Morocco and T.s.s. showed the shortest incubation and latent periods with high values of pustule density/cm^2 and pustule size mm^2 which could be characterized as a highly susceptible or fast stem rusting cultivars to stem rust. The obtained results are in agreement with those reported by Singh *et al*. (2005); Kaur and Bariana (2010) and El-Nagar *et al*. (2013).

According to the studied parameters, *i.e* stem rust severity % and infection response, the tested wheat cultivars were grouped into two groups of slow stem rusting resistance, the high and moderate levels of partial resistance having 1-30 and more than 30% rust severity. Two cultivars; Shandweel 1 and Sids12 had resistant to moderately resistant (MR) reactions, while three wheat cultivars; Sakha 94, Gemmeiza 11 and Gemmeiza 12 showed moderately susceptible (MS) responses and two cultivars; Giza 171 and Misr 3 showed susceptible (S) responses with final stem rust severity to all of cultivars mentioned before less than 20% which remained in the first group that characterized as a great importance to achieving effective breeding for slow stem rust resistance (Parlevliet, 1988 and Nzuve *et al*., 2012). The available resistance genes in these materials overcame the leaf and stem rust virulence in the field and led to statistically low disease severities despite the compatible host-pathogen reactions (Ali *et al*., 2007; Li and Liu 2010; Tabassum, 2011; Safavi and Afshari 2013 and Abou-Zeid *et al*., 2018). On the other hand, cultivars; Misr 1, Misr 2, Beni Sweif 5 and the two fast rusting varieties; Morocco and T.s.s. were included in the second group where final stem rust severity ranged from 60 to 80 % with susceptible (S) responses, while, the two cultivars; Giza 168 and Sids 13 remained immune responses. Immune response on these cultivars could be as a result of hypersensitive responses. A suitable breeding strategy like the use of inter-specific and remote crosses or even the direct transfer of these resistances through backcrosses could be used to improve the adopted but highly susceptible wheat varieties (Bartos *et al*., 2002). Area under disease progress curve (AUDPC) is a better indicator of disease expression over time (Van der Plank, 1963). Therefore, selection of cultivars having lower AUDPC values is acceptable for practical purposes. Among the tested cultivars, Giza 171, Misr 3, Sids 12, Shandweel 1, Sakha 94, Gemmeiza 11 and Gemmeiza 12, showed the lowest values of r-value and AUDPC. These cultivars could be characterized as highly level of slow rusting resistance to stem rust (Parlevliet 1988; Nazim *et al*., 1990; Brown *et al*., 2001; Singh *et al*., 2005; Kaur and Bariana 2010 and El-Nagar *et al*., 2013). While cultivars Misr 1, Misr 2, Morocco and T.s.s. had high values of r-value and AUDPC the more variation in infection rate among the tested cultivars than the other stem slow rusting parameters is partially because rate of disease increase is a regression coefficient with larger error variance. Therefore, rate of disease increases in the present study seemed to produce unreliable estimates of slow rusting resistance when compared with FRS (%) and AUDPC. Similar results were found for rusts of wheat (Rees *et al*., 1979; Broers, 1989; Ali *et al*., 2008 and Safavi *et al*., 2010).

The relationship between the two variables, latent period (LP) and area under disease progress curve (AUDPC) in the tested wheat cultivars against stem rust was negative weak, this indicates that the latent period (LP) was increasing, the area under the disease progress curve reduced a slowly compared with the same parameters in wheat leaf rust cultivars. This result may be due to the environmental conditions which were not available for development of stem rust disease and also plants were in physiological maturity stage healthy plant tissue was available for additional infections (Freedman and Mackenzie, 1992 and Maqsood *et al*., 2012).

Conclusion

Based on the present results, it is concluded that the long lasting resistance of cultivars, leaf and stem rust may be due to interactive action of the leaf rust and stem rust resistance genes carried by this cultivar. These types of gene combinations may be a good alternative for durable resistance as it behaves like horizontal resistance. Therefore, these cultivars may be useful in developing cultivars with long lasting resistance to leaf rust and stem rust diseases in Egypt.

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تقييم أصناف القمح للمقاومة بتبطيء الصدأ لمرضي صدأ الاوراق والساق فى مصر

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تعتبر أصداء القمح سواء صدأ الاوراق (*Puccinia triticina* Eriks.) أو صدأ الساق (*Puccinia graminis* f. sp. *tritici*) من اهم الامراض المدمرة لمحصول القمح. تم تقييم إثنى عشر صنف من القمح للمقاومة لصدأ الأوراق فى طور البادرة بإستخدام أربعة مكونات للصدأ البطئ وهى فترات الحضانة ، فترة الكمون ، كثافة البثرة / سم^2 ، حجم البثرة / مم^2 بالاضافة الى ثلاثة مقاييس للصدأ البطئ فى طور النبات البالغ وهى شدة الاصابة ومعدل انتشار وزيادة المرض وكذلك حساب المساحة تحت المنحنى المرضى تحت ظروف العدوى الصناعية بإستخدام سلالة واحدة من كل فطر تحت ظروف الصوبة. وقد أظهرت الأصناف الخمسة وهى مصر ٣، سدس ١٢، شندويل ١، سخا ٩٤ وجميزة ١٢ على تقليل سرعة تزايد وتطور المرض، وبالتالى اظهار مستويات منخفضة من الاصابة بكل من المرضيين (صدأ الاوراق وصدأ الساق) بالمقارنة بالاصناف الحساسة ذات القابلية العالية للاصابة وكلما كانت قيم كل من مكونات الصدأ البطيئ منخفضة فان هذه الاصناف توصف بانها تمتلك مستويات مرتفعة من المقاومة بأبطاء الصدأ وفى نفس الوقت فقد تميزت تلك الاصناف بمستويات عالية ومقبولة من المقاومة الجزئية للفطرين المسببين لكلا المرضين وقد اتضح من قدرة تلك الاصناف على اظهار قيم منخفضة من االنسبة المئوية النهائيه لشدة الاصابه تراوحت من Tr MR الى 20 S وعلى تقليل سرعة تزايد وانتشار المرض بها والتى لم تزد عن ٠٠,٧٦ وكذلك المساحة تحت منحنى المرض أقل من ٢٣٠ بالنسبة لصدأ الاوراق فى القمح اما بالنسبه لصدأ الساق فكانت قيم االنسبة المئوية النهائيه لشدة الاصابه منخفضة وتراوحت من Tr MR إلى S وعلى تقليل سرعة تزايد وانتشارالمرض وكذلك المساحة تحت المنحنى المرضى بالنسبة لصدأ الاوراق وصدأ الساق ، بينما فى المقابل لذلك يتمتع الصنف جيزة ١٦٨ بالمقاومة الكاملة لكل من صدأ الاوراق وصدأ الساق حيث لم تظهر اى اصابة بأى من المرضين واظهرت مقاومة كاملة بينما الصنفين مصر ١ وبنى سويف ٥ اظهر مستوى عاليا من ابطاء صدأ الاوراق ولكنها قابلة للاصابة بدرجة عالية لصدأ الساق: وأظهرت الدراسة ان هناك ارتباط عكسى وقوى بين فترة الكمون والمساحة تحت المنحنى المرضى $r = 0.7$ فى مرض صدأ الاوراق بينما كان الارتباط أضعف بالنسبة لمرض صدأ الساق $r = 0.46$

وبناء على النتائج المتحصل عليها فى هذا البحث فانة يمكن قياس وتشخيص صفة المقاومة بإبطاء الصدأ فى نباتات القمح وتوفير طرق البحث عن أصناف قمح تتميز بتأخير تطور الاصابة لامراض الاصداء عموما ولصدأ الاوراق وصدأ الساق فى القمح خاصة والاستفادة من هذة الأصناف من خلال برامج التربية للمقاومة لامراض الاصداء فى الاقماح المصرية.