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Yield Losses in Wheat Caused by Stripe Rust (*Puccinia striiformis*) in Egypt

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Abstract: The production loss in eight local wheat cultivars was estimated under yellow rust disease pressure at four locations of northern Egypt during 2017/2018 and 2018/19 growing seasons. Considerable disease pressure, as revealed by final rust severity (%), was observed at all locations with a maximum value (100%) in northern Egypt. The tested wheat cultivars were evaluated at the adult plant stage under field conditions using two epidemiological parameters final rust severity (FRS%) and area under disease progression curve (AUDPC). Final rust severity ranged from 5% to 100% for the tested cultivars. AUDPC ranged from 260 to 2800 at Sakha, 115 to 2800 at El- Gemmeiza, 115 to 2600 at Itay El-Baroud, and 115 to 2600 at Shebin El-Koum during the two growing seasons. The values of FRS (%) and AUDPC during the first season were less than those in the second season. Losses in grain yield per plot ranged from 2.72% to 37.72% during the first season and 6.18% to 69.33% in the second season at the Delta region. The highest grain yield losses were recorded with wheat *cvs.*; Gemmeiza 11 (64.20%), followed by Misr 1 (62.38%), as well as for Misr 2 (57.66%) and Sids 12 (50.89%). While, the lowest loss *cvs.*; was recorded in Misr 3 and Giza 171, as it was 7.65% and 9.44%, respectively. Regarding yield losses in the 1000 kernel weight, wheat *cvs.*; Misr 3 showed the lowest value of loss *i.e.* 1.71%, while Gemmeiza 11 showed the highest loss *i.e.* 39.67% during 2018/2019 growing season. A significal positive correlation was found between yield losses and each of final rust severity (%) and area under disease progression curve (AUDPC). These results would serve as a fruitful tool in the national wheat breeding program for yellow rust resistance, in Egypt.

Keywords: Wheat, Yellow Rust, (AUDPC), (FRS%), Yield Losses, Cultivars

1. Introduction

Stripe (yellow) rust, caused by *Puccinia striiformis* f. s. *tritici*, has been considered an important foliar disease of wheat (*Triticum aestivum* L.), especially in cold climatic areas. In northern Egypt, the disease became very dangerous on the majority of the currently used wheat cultivars, because of their susceptibility to the disease [17, 8]. It is usually occurs at a higher level of severity on the late sowing dates than the early ones, when the environmental conditions were suitable for rust incidence and development [32]. It has been recently became a macro cyclic rust disease, [27], causing a serious economic loss in the highly susceptible wheat cultivars, [6, 16, 18, 48]. Stripe rust was a dominant disease in Central Asian countries, since the late 1990s and early 2000s, where yield losses were reached to 20% and 40% in 1999 and 2000 [30]. Incurred great yield losses around the world [23, 24, 14, 11, 3, 4]. In Egypt, the disease severely affected grain yield production at most of the Egyptian wheat cultivars. Wherein severe epiphytotic has been recorded in the last five decades, since the 1995, causing grain yield loss between 14% and 26% in Nile Delta region, while the loss at the country level reached to 10% [17].

During the 2009 & 2010 growing seasons, a stripe rust epidemic swept through Central and West Asia. Turkey, Syria, as they were the most affected countries, and they lost half of their wheat harvest in 2010, followed by Ethiopia (45%), Uzbekistan & Morocco (35%) [46]. During the 1995/1996, growing season, a similar rust epidemic in the Cukurova region, Turkey, sharply decreased grain yield by 50% [31, 15]. Also, the occurrence stripe rust epidemics in

China, [45] Pakistan, and Iran [9], caused serious yield losses across different wheat growing seasons. In addition, Sing *et al*. [41], reported that rust diseases decreased grain yield in the susceptible wheat cultivars by more than 50%. Similarly, a negative relationship was found between yield components of wheat breeding lines and final disease severity (FDS%) of stripe rust, which suggested, in general that disease pressure significantly affects the yield of these lines [5].

Therefore, the main objectives of the present study were:- 1) To evaluate eight Egyptians wheat cultivars against stripe rust infection under field conditions. 2) To assess the grain yield losses in the tested wheat cultivars due to stripe rust infection. 3) Comparison between wheat yield losses at different locations in Egypt.

2. Materials and Methods

This experiment was carried out at four locations in Egypt, *i.e.* Sakha, El- Gemmeiza, Itay El-Baroud, and Shebin El-Kom stations, during two successive growing seasons; 2017/18 and 2018/19, using eight local wheat cultivars *i.e.* Giza 171, Giza 168, Gemmeiza 11, Sids 12, shandweel 1, Misr 1, Misr 2 and Misr 3 (Table 1). The wheat cultivars were grown in a randomized complete block design (RCB) with three replicates. The plot size was 6 x 7 m (42 m^2). The experiment was planted two weeks after the regular or recommended sowing date (the first of December), to expose the plant to a suitable environment of yellow rust incidence and development. All plots were surrounded by spreader area planted with a mixture of highly susceptible wheat genotypes to stripe rust, *i.e*. *Triticum spelta saharences* and *Morocco* for spreading primary inoculum. To maintain crop stand and plant vigor, normal agronomic practices including recommended fertilization dose and irrigation schedules were followed.

Table 1. *List of the local bread wheat cultivars that were used, pedigree and year of release.*

Genotype	Pedigree	Year of release
Giza 171	Sakha 93 / Gemmeiza 9 S.6-1GZ-4GZ-1GZ-2GZ-0S	2013
Giza 168	MIL/BUC//Seri CM93046-8M-0Y-0M-2Y-0B	1999
Sids 12	BUC//7C/ALD/5/MAYA74/ON//1160-147/3/BB/GLL/4/CHAT"S"/6/MAYA/VUL-4SD-1SD-1SD-0SD.	2007
Shandaweel 1	SITE//MO/4/NAC/TH. AC//3*PVN/3/MIRLO/BUC. CMSS93B00567S-72Y-010M-010Y-010M-0HTY-0SH	2011
Gemmeiza 11	B0W"S"/KVZ"S"//7C/SERI82/3/GIZA168/SAKHA61. GM7892-2GM-1GM-2GM-1GM-0GM.	2011
Misr 1	OASIS/SKAUZ//4*BCN/3/2*PASTOR. CMSSOYO1881T-050M-030Y-O3OM-030WGY-33M-0Y-0S.	2010
Misr 2	SKAUZ/BAV92. CMSS96M0361S-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	2018

2.1. Inoculation and Assessment of Disease

For field inoculation, the experiment was artificially inoculated at the first week of February. The spreader plants were mist with water and dusted with a mixture of urediniospores of the most prevalent and more aggressive races of yellow rust, *i.e.* 4E16, 70E20, 70E32 and 192E192 and talcum powder at a rate of 1 (spores): 20 (talcum powder) (v:v). [8]

Dusting was carried out in the early evening (at sunset) before the formation of the dew. Inoculation of all wheat plants was carried out at the booting stage, according to the method [44]. To keep protection most from stripe rust (full protection) used the Sumi-eight 5EC fungicide (1H- 1, 2, 4- Triazole-1- ethanol, beta.- [(2, 4- dichlorophenyl) methylene] -.alpha. (1,1dimethylethy l) (beta E) (35 cm3 / 100 litter water) was enforcement at 5, 10, and 25 February.

Stripe rust severity (%) and disease reaction (infection type) were scored for wheat plants each plot every ten days intervals from the first rust appearance along with the stages of plant growth using the modified Cob's scale [35]. Disease reaction was expressed in four infection types *i.e.* resistance= (R), moderately resistance = (MR), moderately susceptible = (MS) and susceptible = (S) [38]. The area under disease progress curve (AUDPC) was estimated for each cultivar under study, according to the equation adopted by [34] as follows:

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

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

Sum of the first and last disease records. = $Y_1 + Y_K$

Sum of all in-between disease records = $Y_2 + Y_3 + \ldots + Y_{k-1}$

2.2. Assessment of Yield and Its Loss

At maturity, the crop of each plot (42 m^2) was harvested and grain yield of each cultivar was weighted by conventional balance. The influence of stripe rust severities on yield was determined by comparing the yield of infected and protected plant of the tested cultivars. The yield loss (%) was estimated using the simple equation of [10] as follows:

$$Loss\% = 1\text{-}Yd/Yh \times 100.$$

Where: Yield of diseased plants = Yd.

Yield of healthy plants = Yh.

Data of thousand kernel weight (g) and grain yield per plot (kg) was calculated for each treatment according to [20]. Randomly selected thousand kernels from each cultivar were counted with a seed counter and were weighted with an electronic balance to estimate 1000-kernel weight per grain. The grain weight from the threshed spikes was measured entire harvested plots and weighed with an electronic balance to calculate grain yield per plot for each cultivar under study.

2.3. Statistical Analysis

Least significant differences (L.S.D. at 5%) were used to comparisons yield components parameters under study according to [42]. The correlation coefficient was as used to expos the relation through yield loss and each of final rust severity (%) and area under the disease progression curve.

3. Results

The current study was performed during 2017/18 and 2018/19 growing seasons to characterize adult plant resistance to stripe rust, by estimating disease severity (%) and AUDPC of the tested wheat cultivars. Also to estimate the consequent losses in thousand kernel weight and grain yield per plot expressed on eight Egyptian wheat cultivars *i.e*. Gemmeiza 11, Misr 1, Misr 2, Misr 3, Sids 12, Giza 168, Giza 171 and Shandaweel 1, under field conditions.

Analysis of variance in Table 2 showed in general that all the tested variables *i.e.* disease severity (%), AUDPC, 1000 kernel weight, and grain yield per plot were significantly differed as the sources of variation.

Table 2. *Analysis of variance for the combined data to the effects of cultivars, location and years on disease severity (%)(FRS), AUDPC, of wheat stripe rust 1000 kernel weight and plot weight under field conditions during 2017/18 and 2018/19 growing seasons.*

Source of variation (S.O.V.)	Degree of freedom (DF)	Variables							
		Final rust severity FRS (%)		AUDPC		1000 kernel weight (g)		Plot weight (kg)	
		MS	F. Value	MS	F. Value	MS	F. Value	MS	F. Value
Location (L)	3	6314.3	0.99^{NS}	2708539	0.89^{NS}	321.41	1.60^{NS}	28.87	0.99^{NS}
Season (S)	1	18118.3	5.16*	8821594	5.49^{NS}	592.35	5.87^{NS}	910.37	9.24*
S X L	3	338.0	0.03^{NS}	2993380	0.41*	199.87	0.91*	25.94	1.59*
Variety (V)	7	103546.2	8.92*	43972583	8.88*	2434.20	8.75*	4332.98	6.63*
L X V	21	4760.8	1.16^{NS}	2827896	1.47^{NS}	199.83	1.77^{NS}	75.19	1.28^{NS}
S X V	7	11574.3	8.51*	4919887	7.70*	278.65	7.42*	654.54	33.20*
L×S×C	21	4079.6	0.24^{NS}	1920844	0.26^{NS}	112.27	0.21^{NS}	58.87	0.08^{NS}
Error	382	403957.9		176175781		11800.46		16244.42	

NS = Non-significant. * Significant at $P \leq 0.05$.

Interaction between locations (L), seasons (s) and cultivars (C) (L×S×C) was found to be insignificant for the tested variables i.e. FRS%, AUDPC, 1000 kernel weight, and plot weight (Table 2).

3.1. Evaluation of the Tested Wheat Cultivars Against Stripe Rust

3.1.1. The Final Rust Severity (%) (FRS%)

Wheat plants of the tested cultivars in the full protected plots were almost free from stripe rust infection at four locations during two growing seasons of the study. The reaction of the tested wheat cultivars to stripe rust has been significantly varied, where the final rust severity (%) ranged from Tr MR to 90S during the first season and from 5MR to 100S in the second season, at the four locations (Table 3). The six wheat cultivars *i.e*. Misr 3, Giza 171, Shandweel 1, Misr 1, Misr 2 and Giza 168 showed the lowest values of FRS (%) (from 5MR to 30S) at the four locations during the first season. Meanwhile, the two *cvs*., Sids 12 and Gemmeiza 11 were highly susceptible (70 to 100%) during this growing season. Stripe rust epidemic was higher, as most of the tested wheat cultivars were severely rusted and showed the highest values of FRS (%). During this season only three wheat *cvs* Showed a relatively an adequate level of adult plant resistance to stripe rust at the four locations *i.e.* Misr 3, Giza 171 and Giza 168. However, these cvs. showed the lowest percentages of FRS (%) (ranged from 5MR to 40S), at the four locations and during this growing season (Table 3). In contrast, the other wheat cvs. of the current study i.e. Sids 12, Gemmeiza 11, Misr 1, Misr 2, and shandweel 1, were highly susceptible, as they showed the highest percentages of FRS (%), ranged between 60% and 100%. (Table 3).

Table 3. *Final stripe rust severity (%) of eight Egyptian wheat cultivars under field conditions at four locations; Sakha, El- Gemmeiza, Itay El-Baroud and Shibin El-Kom during 2017/18 and 2018/19 growing seasons.*

Cultivar	Season/ Location / FRS (%)							
	2017/18				2018/19			
	Sakha	El- Gemmeiza	Itay El-Baroud	Shibin El- Kom	Sakha	El-Gemmeiza	Itay El-Baroud	Shibin El- Kom
Giza 171	10S	20S	5S	10S	20S	20S	10S	10S
Giza 168	30S	20S	20S	20S	40S	30S	40S	30S
Sids 12	90S	90S	90S	90S	100S	100S	100S	100S
Gemmeiza 11	90S	80S	90S	90S	100S	100S	90S	100S
Misr 1	20S	20S	20S	10S	100S	90S	80S	80S
Misr 2	20S	20S	20S	20S	90S	100S	80S	80S
Misr 3	5MR	5S	TrS	5S	10MR	5S	5S	5S
Shandweel 1	20S	20S	20S	20S	60S	50S	50S	50S
LSD at 5%	10.092	10.181	9.199	8.8604	5.3306	7.4546	6.1736	6.5673

3.1.2. Area Under Disease Progress Curve (AUDPC)

At Sakha location, the highest AUDPC estimates was found in the two cvs.; Sids 12 and Gemmeiza 11, with the values of 1725 and 1710, respectively, during the first season. While, Giza 168, Misr 1, Misr 2, Shandweel 1, Giza 171 and Misr 3 showed the lowest values of AUDPC *i.e.* 310, 275, 260, 260, 210 and 55, respectively, (Table 4). In the second season, the six wheat *cvs.*; Gemmeiza 11, Sids 12, Misr 1, Misr 2, Shandweel 1, and Giza 168 showed the highest values of AUDPC, *i.e*. 2800, 2600, 2450, 2100, 1550 and 825 respectively. While Misr 3 and Giza 171 displayed the lowest estimates ranged between (55 and 310). At El- Gemmeiza location, the highest of AUDPC estimates was record in the two susceptible *cvs.*; Sids 12 and Gemmeiza 11 (from 1525 and 1160), respectively, on the first season. Meanwhile Giza 168, Misr 1, Misr 2, Shandweel 1, Giza 171 and Misr 3 showed the lowest values of AUDPC *i.e.* 276, 310, 295, 310, 310 and 105, respectively, (Table 4). In the second season, the six wheat cvs.; Gemmeiza 11, Sids 12, Misr 1, Misr 2, Shandweel 1, and Giza 168 exhibited the highest AUDPC values, *i.e.* 2600, 2400, 1900, 2800, 11060 and 510 respectively. On the other hand Misr 3 and Giza 171 displayed the lowest values ranged between (155 and 410). At Itay El- Baroud location, the highest AUDPC estimates was estimated the two cvs.; Sids 12 and Gemmeiza 11 with the values of 1925 and 1710, respectively, during the first season. In contrast Giza 168, Misr 1, Misr 2, Shandweel 1, Giza 171 and Misr 3 showed the lowest values of AUDPC *i.e.* 295, 310, 285, 260, 125 and 25, respectively, (Table 4). During the second season, the six wheat cvs.; Gemmeiza 11, Sids 12, Misr 1, Misr 2, Shandweel 1, and Giza 168 showed the highest values of AUDPC, *i.e.* 2600, 2000, 1950, 1850, 825 and 560 respectively, but Misr 3 and Giza 171 showed the lowest AUDPC values (ranged between 155 and 260). At Shibin El- kom location, the highest AUDPC estimates was calculated for the two *cvs.*; Sids 12 and Gemmeiza 11, with high values of 1900 and 1575, respectively, during the first season. Meanwhile Giza 168, Misr 1, Misr 2, Shandweel 1, Giza 171 and Misr 3 showed the lowest values of AUDPC *i.e.* 195, 295, 195, 125, 265 and 125, respectively (Table 4). In the second season, the six wheat *cvs*.; Gemmeiza 11, Sids 12, Misr 1, Misr 2, Shandweel 1, and Giza 168 showed the highest AUDPC values, *i.e.* 2600, 2400, 1650, 1950, 1200 and 500 respectively, where Misr 3 and Giza 171 exhibited the lowest AUDPC values (ranged between 115 and 152).

Table 4. *Area under disease progress curve (AUDPC) of eight wheat cultivars at four locations; Sakha, Gemmeiza, Itay El-Broad and Shibin El-Kom during 2017/18 and 2018/19 growing seasons.*

Cultivar	Season / location / AUDPC							
	2017/18				2018/19			
	Sakha	El-Gemmeiza	Itay El-Baroud	Shibin El-Kom	Sakha	El-Gemmeiza	Itay El-Baroud	Shibin El-Kom
Giza 171	210	310	50	220	265	410	260	152
Giza 168	310	276	295	195	825	510	560	500
Sids 12	1725	1525	1925	1900	2600	2400	2600	2400
Gemmeiza 11	1710	1160	1710	1575	2800	2600	2000	2600
Misr 1	275	310	310	295	2450	1900	1950	1650
Misr 2	260	295	285	195	2100	2800	1850	1950
Misr 3	55	105	25	125	260	115	115	115
Shandweel 1	260	310	125	265	1550	1060	825	1200
LSD at 5%	168.31	168.9	193.45	195.56	121.13	118.08	126.76	157.21

3.2. Impact of Yellow Rust Infection on the Two Grain Yield Components; 1000 Kernel Weight and Yield per Plot

3.2.1. Loss (%) in 1000 Kernel Weight

At Sakha location, thousand kernel weight (TWK) loss (%) was sharply decreased by 1.47% to 24.22% during the first season and 1.74% to 39.67% during the second growing season (Table 5). The highest percentages of loss (%) obtained from cultivars Sids 12 and Gemmeiza 11 (24.22% and 20.56%), in the first season. Similarity Gemmeiza 11, Misr 1, Misr 2, Sids 12, Shandweel 1 and Giza 168 showed also the highest loss (%) (39.67%, 37.85%, 35.78%, 32.58% 21.75% and 23.54% respectively, during the second season. On the other hand the lowest TWK loss% was obtained from Misr 3, Giza 171, Misr 1, Misr 2, Shandweel 1 and Giza 168 (1.47% to 8.98%) during the first season. Also, the two cvs., Giza 171 (4.96%), Misr 3 (1.71%) showed the lowest loss (%) during the second growing season. At El- Gemmeiza location, (TWK) loss (%) ranged from 2.28% to 21.45% during the first season, but it was ranged between 2.45 and 35.93% during the second growing season (Table 5). The highest percentages of loss (%) found in wheat cultivars; Gemmeiza 11, and Sids 12 (16.64% and 21.45%) in the first growing season. While, Gemmeiza 11, Misr 1, Misr 2, Sids 12 Shandweel 1 and Giza 168 showed also the highest loss (%) (35.93%, 33.12%, 33.19%, 31.86%, 22.36% and 19.87%, respectively), during the second growing season. The lowest (TWK) loss was observed in Giza 171 (2.86%) and Misr 3 (2.45%) during the two seasons under study. At Itay El-Baroud location, thousand kernel weight (TWK) loss (%) decreased by 1.16% to 21.76% during the first season and 1.73% to 34.26%, during the second growing season (Table 5). The highest percentages of loss (%) obtained from cultivars Sids 12 and Gemmeiza 11 (15.16 and 21.76), in the first season. In addition the six wheat *cvs.*; Gemmeiza 11, Misr 1, Misr 2, Sids 12, Shandweel 1 and Giza 168, showed also the highest loss (%) with (34.26%, 33.53%, 34.07%, 32.91%, 20.54% and 19.87%, respectively, during the second growing season. The lowest (TWK) loss% was obtained from

Misr 3, Giza 171, Misr 1, Misr 2, Shandweel 1 and Giza 168 (1.47 to 8.98) during the first growing season. Also, the two cvs., Giza 171 (2.58%), Misr 3 (1.73%) showed the lowest loss (%) in TWK. in the second growing season. At Shibin El-Kom location, thousand kernel weight (TWK) as four in the tested wheat cultivars was sharply decreased by 1.75% to 24.07% during the first growing season, and 1.80% to 36.10% during the second growing season (Table 5). However the highest percentages of loss (%) obtained from cultivars Sids 12 and Gemmeiza 11 was (24.07% and 16.99%), in the first season. Also, wheat *cvs.*; Gemmeiza 11, Misr 1, Misr 2, Sids 12, Shandweel 1 and Giza 168 showed the highest loss (%) with (36.10%, 33.44%, 34.13%, 32.26%, 22.56% and 19.50%, respectively, during the second growing season. On the other hand the lowest (TWK) loss (%) was obtained from Misr 3, Giza 171, Misr 1, Misr 2, Shandweel 1 and Giza 168 (1.47% to 8.98%) during the first season. Also, the two *cvs.*, Giza 171 (4.96%), Misr 3 (1.71%) showed in general low estimates of 1000 KW. loss (%) during growing season.

Table 5. *Effect of stripe rust infection on the loss of 1000 kernel weight (g) of eight wheat cultivars at four locations; Sakha, Gemmeiza, Itay El-Baroud and Shibin El-Kom during 2017/18 and 2018/19 growing seasons.*

Cultivar	Season / Location / Loss (%) of 1000 kernel weight (g)							
	2017/18				2018/19			
	Sakha	El-Gemmeiza	Itay El-Baroud	Shibin El- Kom	Sakha	El-Gemmeiza	Itay El-Baroud	Shibin El- Kom
Giza 171	3.00	3.48	1.16	2.21	4.96	4.86	2.58	5.71
Giza 168	3.21	3.87	7.04	4.54	23.54	19.73	19.87	19.5
Sids 12	24.22	21.45	21.76	24.07	32.58	31.86	32.91	32.26
Gemmeiza 11	20.56	16.64	15.16	16.99	39.67	35.93	34.26	36.10
Misr 1	8.98	8.28	12.74	4.84	37.85	33.12	33.53	33.44
Misr 2	5.18	8.34	6.99	6.20	35.78	33.19	34.07	34.13
Misr 3	1.47	2.28	1.57	1.75	1.71	2.45	1.73	1.80
Shandweel 1	5.69	8.04	5.94	4.38	21.75	22.36	20.54	22.56
LSD at 5%	0.2684	0.3808	0.2403	0.2315	0.2729	0.204841	0.213	0.245

3.2.2. Loss (%) in Grain Yield per Plot

At Sakha, the loss (%) in yield per plot ranged from 2.72% to 37.72% on the first season, while it was ranged from 9.41% to 69.33% during the second season (Table 6). The two wheat *cvs.*; Sids 12 and Gemmeiza 11 were highly affected by stripe rust infection, under field conations. Therefore, they showed the highest losses (35.40% and 37.72%) on the first season. Also, wheat *cvs*.; Gemmeiza 11, Misr 1, Misr 2 and Sids 12, were severely affected or suffered from disease infection, thus they showed the highest grain yield loss per plot 69.33%, 66.65%, 58.07% and 51.66%, respectively, followed by Giza 168 (28.63%) and Shandweel 1 (32.12%) during the second season. In contrast, the lowest yield loss% was obtained by Giza 171 (9.41%), and Misr 3 (9.92%) during the second season. At El-Gemmeiza, the loss (%) in grain yield per plot ranged from 3.02% to 40.18% during 2017/18, while it was ranged from 7.65% to 65.18% during 2018/19. An increased loss found in cultivars Sids 12 and Gemmeiza 11 (40.18% and 33.16%) during the first season. Also, a relatively high loss (%) in grain yield plot was recorded in the six wheat cvs.; Gemmeiza 11, Misr 1, Misr 2, Sids 12 Shandweel 1 and Giza 168 (65.18%, 62.60%, 58.84%, 48.21%, 27.24% and 25.38%, respectively), during the second season. The lowest loss in grain yield/plot was observed in Giza 171 (9.74%) and Misr 3 (7.65%) during the second season. At Itay El-baroud, the loss (%) in grain yield/ plot ranged from 9.07% to 64.77% (Table 6). Gemmeiza 11, Misr 1, Misr 2 and Sids 12 had the highest percentage of loss (%) in grain yield/plot (64.77%, 62.18%, 57.84% and 48.47%, respectively), followed by, Shandweel 1 and Giza 168 (26.45% and 25.27%, respectively). The lowest yield loss (%) has been recorded in Giza 171 (12.48%), Misr 3 (9.07%). At Shibin El-Kom the loss (%) in yield per plot ranged from 6.18% to 58.12% with the highest loss found in cultivars Misr 1, Gemmeiza 11, Misr 2 and Sids 12 (58.12%, 57.52%, 55.92% and 55.48%, respectively), followed by Giza 168 and Shandweel 1 (16.45% and 22.13%, respectively). The loss (%) in grain yield per plot was observed in the two wheat *cvs*.; Giza 171 (6.18%) and Misr 3 (6.98%).

Table 6. *Effect of stripe rust infection on the loss (%) of plot weight (kg) of eight wheat cultivars at four locations; Sakha, Gemmeiza, Itay El-Baroud andShibin El-Kom during 2017/18 and 2018/19 growing seasons.*

Cultivar	Season / location / Loss (%) of plot weight (kg)							
	2017/18				2018/19			
	Sakha	El- Gemmeiza	Itay El-Broad	Shibin El- Kom	Sakha	El-Gemmeiza	Itay El-Baroud	Shibin El- Kom
Giza 171	6.36	6.59	3.40	4.13	9.41	9.74	12.46	6.18
Giza 168	13.76	13.71	12.53	10.13	28.63	25.38	25.27	16.45
Sids 12	35.40	40.18	32.45	38.19	51.66	48.21	48.47	55.48
Gemmeiza 11	37.72	33.61	33.37	31.95	69.33	65.18	64.77	57.52
Misr 1	10.49	11.06	13.74	7.3	66.65	62.60	62.18	58.125
Misr 2	13.56	10.98	5.53	4.23	58.07	58.84	57.84	55.92
Misr 3	2.72	3.02	2.79	2.78	9.92	7.65	6.07	6.98
Shandweel 1	13.30	10.88	6.71	9.16	32.12	27.24	26.45	22.13
LSD at 5%	0.4387	0.5407	0.2232	0.2611	0.2236	0.2954	0.2366	0.2432

3.3. The Relationship Between FRS (%) and Loss (%) in each Thousand Kernel Weight and Plot Weight

A positive and high significant correlation coefficient (R^2) (Table 7) was found between final rust severity (%) and loss (%) in grain yield per plot i.e. (0.939) in the first season and (0.956) in the second season. Furthermore, final rust severity had a high correlation with TKW loss (%) (0.937) in the first season and (0.948) in the second season. (Table 7)

3.4. The Relationship Between AUDPC and Loss (%) in the Thousand Kernel Weight and Plot Weight

A positive and high significant relationship (Table 7) was recorded between AUDPC and grain yield/plot loss (%). Whereas, the correlation coefficient (R^2) was found to be highly significant (0.928) and (0.951), during the first and second seasons, respectively). Furthermore, AUDPC had a high relationship with a thousand kernel weight loss (|%) (0.974) in the first season, and (0.95) in the second season. In general, the loss (%) in each of the two yield components *i.e.* 1000 K.W. and grain yield per plot, was sharply increased in the highly susceptible wheat cultivars, under study having the highest percentages of final rust severity (%) and highest values of area under disease progress curve. In contrast, wheat cultivars that showed an adequate level of stripe rust resistance at four locations and during the two growing season, of the study, showed in general, the relatively low losses in each of 1000 K.W and grain yield per plot.

Table 7. *Correlation among the two disease parameters; final rust severity (%) and AUDPC and the two yield components; 1000 kernel weight (g.) and plot weight, under field conditions during the two seasons 2017/18 and 2018/19.*

Disease parameter and yield components	Disease parameter and Yield components			
	FRS (%)	AUDPC	1000 Kernel weight (g)	Plot weight (kg.)
2017/18 growing season:				
Final rust Severity	-	0.992**	0.937**	0.969**
AUDPC	-	-	0.928**	0.974**
1000 Kernel weight (g)	-	-		0.939**
2018/19 growing season				
Final rust Severity	-	0.977**	0.948**	0.981**
AUDPC		-	0.951**	0.953**
1000 Kernel weight (g)	-	-	-	0.956**

4. Discussion

Stripe rust (*Puccinia striiformis* f. sp. *tritici*), as the most destructive disease, causing severe yield losses in the majority of wheat cultivars growing in Egypt and worldwide, [12, 45]. In this study, the tested wheat cvs. had a different disease reaction and final rust severity levels against stripe rust in the infected plots at the four locations during the two growing seasons of the study; Sakha, El- Gemmeiza, Itay El-Baroud and Shibin El- Kom. While, wheat plants in the full protected plots remained almost free from stripe rust infection at the four locations. Variability among the response of the tested wheat cultivars under the high pressure of stripe rust disease may be attributed to their diverse genetic makeup and / or it's varied genetic background. At the four locations under filed conditions during the two years, Misr 3 and Giza 171 showed the lowest final rust severity (ranged from 5 to 20%), while, final rust severity (%) was high in the most susceptible wheat cultivars *i.e*. Misr 1, Misr 2, Gemmeiza 11, and Sids 12. As previously reported [8] during the 2009-2010 seasons, Misr 1, Misr 2 Gemmeiza 11, and Sids 12 were the most susceptible wheat varieties, and Giza 168 was by moderately resistant wheat variety. Moreover, severe stripe rust epidemic occurred in North Africa, West and Central Asia in 2009 and 2010 wheat growing seasons [39, 22, 29]. Similarity [21] found that FRS (%) of slow rusting wheat genotypes was higher in Batan than in field trials in Obregon Ciudad, due to a more favorable environment for disease development. Many researchers have also suggested that environmental factors play an important role in the spread and development of stripe rust infection, under field conditions [17, 11, 13, 46, 28, 6, 12, 19].

Generally, wheat cultivars with high estimates of AUDPC showed the highest values of yield loss (%) in each the two yield component under study *i.e.* 1000 kernel weight and grain yield per plot. While, wheat cultivars with the lowest values of AUDPC had the lowest loss (%) at four sites under study. Susceptible cultivars (Misr 1, Gemmeiza 11, Misr 2 and Sids 12) showed the highest values of AUDPC and yield loss (%) at four sites. Many researchers found that the wheat cultivars with lower values of AUDPC mostly showed the lowest yield loss; while, higher values of AUDPC caused higher grain yield loss [33, 26]. The results obtained from regression analysis showed a positive and statistically significant relation between AUDPC and percentages of loss (%) in grain yield per plot and TKW. Similar results were previously obtained by [2], reported that high estimates of AUDPC for yellow rust increased the yield and yield component loss (%) reflecting a positive and an highly significant relationship between yield loss and AUDPC (for yield plot, R2 = 0.78; for TKW, R2 = 0.81). Furthermore, [36] reported that the wheat genotypes with higher partial resistance (PR) prevent significant yield loss.

The susceptible wheat cultivars in the current study that showed highest AUDPC values, *i.e.* Gemmeiza 11, Misr 1, Misr 2, and Sids 12 had the highest yield loss; ranged

between 51.66% and 69.33% at the four locations. On the other hand, the partially resistant wheat genotypes *i.e*. Misr 3 and Giza 171 showed lower AUDPC values, and also showed less than 12.46% yield loss at the four sites. Wheat *cvs.*; Misr 3 and Giza 171 showed lower values of FRS (%), AUDPC and yield loss (%) in the same time they showed the lowest yield loss (%) in the two yield components of the study at the four sites. Several authors were previously evaluated synthetic wheat genotypes carries different resistance genes against biotic and abiotic stresses including rust diseases, [25, 37]. They reported that, increased AUDPC and FRS (%) cause greater yield loss (%) [1, 7, 43]. Yield loss is strongly correlated with AUDPC, which means that partial resistance (PR) prevents significant yield loss [1, 2]. In the present study, high values of AUDPC and FRS (%) cause a noticeable decrease in 1000 kernel weight (ranged between 39.67% and 31.86%) at four locations. The highest TKW loss occurred in the susceptible wheat cultivars; Gemmeiza 11, Sids 12 Misr 1, and Misr 2. It was discussed in the previous studies that stripe rust infection decreased the photosynthesis area, and consequently lowered the percentages of yield and yield components [21].

Most of the widely cultivated wheat cultivars in Egypt possess low levels of adult plant resistance (APR) to stripe rust, due to the sudden occurrence of new aggressive races of wheat stripe rust pathogen in Egypt [39]. Therefore the farmers successively control the disease primarily through fungicide applications, considering up to 42% yield increases through fungicide protection against stripe rust. The wheat farmers can greatly benefit from disease control under high disease pressure. Also, using a fungicide application could be necessary to ensuring yields are maximised come harvest [40].

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