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

Atef Shahin, Mamdouh Ashmawy*, Walid El-Orabey, Samar Esmail

Wheat Diseases Research Department, Plant Pathology Research Institute, ARC, Giza, Egypt

Email address: dr.ashmawy2011@yahoo.com (M. Ashmawy)

*Corresponding author

**To cite this article:** Atef Shahin, Mamdouh Ashmawy, Walid El-Orabey, Samar Esmail. Yield Losses in Wheat Caused by Stripe Rust (*Puccinia striiformis*) in Egypt. *American Journal of Life Sciences*. Vol. 8, No. 5, 2020, pp. 127-134. doi: 10.11648/j.ajls.20200805.17

Received: May 9, 2020; Accepted: May 28, 2020; Published: September 3, 2020

**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 significant 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-Gemmeizea, 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, Gemmeizea 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 m²). 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 saharense 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.

| Genotype  | Pedigree                  | Year of release |
|-----------|---------------------------|-----------------|
| Giza 171  | Sakha 93 / Gemmeizea 9 S.6-1GZ-4GZ-1GZ-2GZ-0S | 2013            |
| Giza 168  | MIL/BUC/Seri CM93046-8M-0Y-0M-0Y-0B             | 1999            |
| Sids 12   | BUC/7C/ALD/S/MAYA74/ON/1160-1473/BB/GLL/4/CHAT*S/6/MAYAVUL-1SD-1SD-0SD | 2007            |
| Shandaweel 1 | SITE/MO/4/NAC/TW. AC/3*PVN/3/MIRLO/BUC. CMSS93B00567S-72Y-010M-010Y-010M-0HTY-0SH | 2011            |
| Gemmeizea 11 | B0W*S/KVZ*S/7C/SER152/3/GIZA168/SAKHAM16. GM7892-2GM-2GM-1GM-0GM | 2011            |
| Misr 1    | OASIS/SKAZU/4*BCN/3*PASTOR. CMSSOY01881T-050M-030Y-030OM-030WGY-33M-0Y-0S | 2010            |
| Misr 2    | SKAZU/BA/92. CMSS96M0361S-1M-010SY-010M-010SY-8M-0Y-0S | 2011            |
| Misr 3    | ATTILA*2/ABW652*KACHU CMSS06V00258 2T-099TOPM-099Y-099ZM-099Y-099M-10WGY-08-0EYG | 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 inoculation) used the Sumi-eight 5EC fungicide (1H- 1, 2, 4-Triazole-1- ethanol, buta- [(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:

\[
\text{AUDPC} = D \left[ \frac{1}{2} (Y_1 + Y_k) + (Y_2 + Y_3 + \ldots + Y_{k-1}) \right]
\]

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 m²) 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:

\[
\text{Loss} \% = 1 - \frac{Yd}{Yh} \times 100.
\]

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 | F. Value | F. Value | F. Value | F. Value |
|-----------------------------|------------------------|-----------|----------|----------|----------|----------|
| Location (L)                | 3                      | Final rust severity FRS (%) | 6314.3 | 0.99<NS> | 2708539 | 0.89<NS> |
| Season (S)                  | 1                      | F. Value | 18118.3 | 5.16*    | 8821594 | 5.49<NS> |
| S X L                       | 3                      | F. Value | 338.0   | 0.03<NS> | 2993380 | 0.41*    |
| Variety (V)                 | 7                      | F. Value | 103546.2 | 8.92*   | 43972583 | 8.88*    |
| L X V                       | 21                     | F. Value | 4760.8  | 1.16<NS> | 2827896 | 1.47<NS> |
| S X V                       | 7                      | F. Value | 11574.3 | 8.51*    | 4919887 | 7.70*    |
| L*S*C                       | 21                     | F. Value | 4079.6  | 0.24<NS> | 1920444 | 0.26<NS> |
| Error                       | 382                    | F. Value | 403957.9 | 17617578 | 11800.46 | 16244.42 |

NS = Non-significant. * Significant at P≤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, Mirs 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 |
|--------------|----------------------------|---------|---------|
|              | Saka | El-Gemmeiza | Itay El-Baroud | Shibin El-Kom | Saka | 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        | 100S         | 100S | 100S       | 100S         | 100S         |
| Gemmeiza 11  | 90S  | 80S        | 90S        | 90S          | 100S | 100S       | 90S          | 100S         |
| Misr 1       | 20S  | 20S        | 20S        | 20S          | 90S  | 100S       | 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-Baroud 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        | 300           |
| 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    | 1590       | 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 (4.96% 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...
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     | 5.18          | 7.11 |
| 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 |
| M1r 1      |                                                      | 8.98    | 8.28      | 12.74            | 4.84     | 37.85   | 33.12    | 33.53         | 33.44 |
| M1r 2      |                                                      | 5.18    | 8.34      | 6.99             | 6.20     | 35.78   | 33.19    | 34.07         | 34.13 |
| M1r 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    | 20.34         | 22.56 |
| LSD at 5%  |                                                      | 0.2684  | 0.3808    | 0.2403           | 0.2315   | 0.2729  | 0.204841 | 0.213         | 0.245  |

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 and Shibin 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-Baroud | Shibin El-Kom | Sakha   | El-Gemmeiza | Itay El-Baroud | Shibin El-Kom |
| Giza 171   |                                                  | 6.36    | 6.59      | 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     | 33.57            | 31.95    | 69.33   | 65.18    | 64.77         | 57.52 |
| M1r 1      |                                                  | 10.49   | 11.06     | 13.74            | 7.3      | 66.65   | 62.60    | 62.18         | 58.12 |
| M1r 2      |                                                  | 13.56   | 10.98     | 5.53             | 4.23     | 58.07   | 58.84    | 57.84         | 55.92 |
| M1r 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 |

3.2.2. 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 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 conditions. Therefore, they showed the highest losses (35.40% and 37.72%) on the first season. Also, wheat cvs.; Gemmeiza 11, Misr 1, Misr 2, Sids 12 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.

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.
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 |
|----------------------------------------|----------------------------------------|
| 2017/18 growing season:                |                                        |
| Final rust Severity                    | -                                      |
| AUDPC                                  | 0.992**                                |
| 1000 Kernel weight (g)                 | 0.937**                                |
| 2018/19 growing season                 |                                        |
| Final rust Severity                    | -                                      |
| AUDPC                                  | 0.977**                                |
| 1000 Kernel weight (g)                 | 0.948**                                |

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, $R^2 = 0.78$; for TKW, $R^2 = 0.81$). 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].

References

[1] Afzal, S. N.; Haque, M. I.; Ahmedani, M. S.; Bashiri, S. and Rattu, A. R. (2007). Assessment of yield losses caused by Puccinia striiformis triggering stripe rust in the most common wheat varieties. Pak J Bot 39: 2127-2134.

[2] Ahmad, S.; Afzal, M.; Noorka, I. R.; Iqbal, Z.; Akhtar, N.; Ifikhar, Y. and Kamran, M. (2010). Prediction of yield losses in wheat (Triticum aestivum L.) caused by yellow rust in relation to Epidemiological factors in Faisalabad. Pak J Bot 42: 401-407.

[3] Aktas, A.; Karaman, M.; Kendal, E.; Tekdal, S.; Erdemci, I.; Kılıc, H., (2012a). Investigation of stripe rust effect on yield and quality traits of wheat. Bursa Agriculture Fair and Congress, Publication book, p 271.

[4] Aktas, H.; Karaman, M.; Tekdal, S.; Kılıc, H. and Kendal, E. (2012b). Evaluating of yield losses caused by yellow rust pressure in some bread wheat genotypes. 13th International Cereal Rists and Powdery Mildews Conference. Beijing, China. Abstract book: Volume I., p. 16.

[5] Ali, S.; Shah, S. J. A. and Ibrahim, M. (2007). Assessment of wheat breeding lines for slow yellow rusting (Puccinia striiformis west. tritici). Pak J BiolSci 10: 3440-3444.

[6] Ashmawy, M. A. and Ragab, Kh. E. (2016). Grain yield of some wheat genotypes to stripe rust in Egypt. Menoufia J. Plant Prot., Vol. 1 August (2016): 9-18.

[7] Ashmawy, M. A.; El-Orabey, W. M.; Nazim, M. And Shahin, A. A. (2013). Effect of stem rust infection on grain yield and yield components of some wheat cultivars in Egypt. ESci J Plant Pathol 2: 171-178.

[8] Ashmawy, M. A.; A. A. Shahin; Samar M. Esmail and Hend Abd El- Naby (2019). Virulence dynamics and diversity of Puccinia striiformis populations in Egypt during 2017/18 and 2018/19 growing seasons J. of Plant Protection and Pathology, Mansoura Univ., Vol 10 (12): 655-666, 2019.

[9] Bimb, H. P. and Johnson, R. (1997). Breeding resistance to yellow rust in wheat. Wheat program special report. CIMMYT, Lisboa 27 ISSN: 0187-7787; ISBN: 968-6923-81-0. March 1997., http://libcatalog.cimmyt.org/download/cim/63731.pdf

[10] Calpouzos, L.; Roelfs, A. P.; Maolison, M. E.; Martin, F. B.; Welsh, J. R. and Wilcoxson, R. D. (1976). A new model to measure. yield losses caused by stem rust in spring wheat. Minn. Agric. Exp. Stn. Tech. Bull. 307 (123).

[11] Chen, X. M. (2005). Epidemiology and control of stripe rust [Puccinia striiformis f. sp. tritici] on wheat. Canadian Journal of Plant Pathology, 27: 31437.

[12] Chen, W.; Wellings, C.; Chen, X.; Kang, Z. and Liu, T. (2014). Wheat stripe (yellow) rust caused by Puccinia striiformis f. sp. tritici. Mol Plant Pathol. 15 (5): 433-446. doi: 10.1111/mpp.12116.

[13] Dereje, H and Fininsa, C. (2007). Epidemics of stripe rust (Puccinia striiformis) on common wheat (Triticum aestivum) in the highlands of Bale, southeastern Ethiopia. Crop Prot 26: 1209-1218.

[14] deVallavieille-Pope, C.; Ali, S.; Leconte, M.; Enjalbert, J. and Delos, M. (2012). Virulence dynamics and regional structuring of Puccinia striiformis f. sp. tritici in France between 1984 and 2009. Plant Dis 96 (1): 131-140.

[15] Dusunceli, F.; Cetin, L.; Albustan, S. and Beniwal, SPS. (1996). Occurrence and impact of wheat stripe rust (Puccinia striiformis) In Turkey in 1994/95 crop season. 9th European and Mediterranean Cereal Rusts and Powdery Mildews Conference. Netherlands., p. 309.

[16] El-Basyoni I. S.; El-Orabey, W. M.; Morsy, S.; Baenziger, P. S.; Al Ajlouni, Z. and Dowikat, I. (2019). Evaluation of a global spring wheat panel for stripe rust: Resistance loci validation and novel resources identification. PLoS ONE, 14 (11): 022755.

[17] El-Daoudi, Y. H.; Ikhsas Shafik, Ghameem, E. H.; Abu El -Naga, S. A.; Sherif, S. O.; Khalifa, M. M. O.; Mitkees, R. A. and Bassiouni, A. A. (1996). Stripe rust occurrence in Egypt and assessment of grain yield loss in 1995. Proceedings Du Symposium Regional Sur les Maladies des Cerealset des Legumineuses Alimentaries 11-14 Nov 1996, Rabat, Maroc.

[18] El-Orabey, W. M.; El-basyoni, I. S; El-Moghazy S. M. and Ashmawy, M. A. (2019). Effective and ineffective of some resistance genes to wheat leaf, stem and yellow rust diseases in Egypt. J. Plant Production, Mansoura Univ., 10 (4): 361-371.
134 Atef Shahin et al.: Yield Losses in Wheat Caused by Stripe Rust (Puccinia striiformis) in Egypt

[19] Everts, K. L.; Leath, S. and Finney, P. L. (2001). Impact of powdery mildew and leaf rust on milling and baking quality of soft red winter wheat. Plant Dis 85: 423-429.

[20] Hassan G. (2004). Diallel analysis of some important parameters in wheat (Triticum aestivum L) under irrigated and rainfed conditions. Ph. D Thesis submitted to NWFP Agricultural University Peshawar, Pakistan.

[21] Herrera-Foessel, S. A.; Singh, R. P.; Huerta-Espino, J.; Crossa, E. J.; Djurle, E. A. and Yuen, J. (2007). Evaluation of slow rusting resistance components to leaf rust in CIMMYT durum wheats. Euphytica, 155: 361-369.

[22] Hodson, D. and Nazari, K. (2010). Serious outbreaks of wheat stripe rust or yellow rust in Central and West Asia and North Africa, March/April 2010. Internet Resource: http://globalrust.org/traction/permalink/Pathogen206., May 30-31, 2010 St Petersburg, Russia.

[23] Hovmøller, M. S.; Sørensen, C. K.; Walter, S. and Justesen, A. F. (2011). Diversity of Puccinia striiformis on cereals and grasses. Annual Review of Phytopathology, 49: 197-217.

[24] Hovmøller, M. S.; Walter, S. and Justesen, A. F. (2010). Escalating threat of wheat rusts. Science, 329 (5990): 369.

[25] Hussain, M.; Khan, M. A. and Isldhad, M. (1999). Screening of wheat germplasm against leaf and stripe rust epidemics for the identification of resistant sources against these diseases. Pakistan J. Phytopathol, 11: 93-99.

[26] Irfaq, M.; Ajab, M.; Hongxiang, M. and Khattak, G. S. S. (2009). Assessment of genes controlling area under disease progress curve (AUDPC) for stripe rust (P. striiformis f. sp. tritici) in two wheat (Triticum aestivum L.) crosses. Cytol Genet, 43: 241-252.

[27] Jin, Y.; Szabo, L. J. and Carson, M. (2010). Century-old mystery of Puccinia striiformis life history solved with the identification of Berberis as an alternate host. Phytopathol, 110: 41-47.

[28] Milus, E. A.; Kristensen, K. and Hovmöller, M. S. (2009). Evidence for increased aggressiveness in a recent widespread strain of Puccinia striiformis f. sp. triticci causing stripe rust of wheat. Phytopathology, 99: 89-94.

[29] Morgounov, A.; Tufan, H. A. and Sharma, R. (2012). Global incidence of wheat rusts and powdery mildew during 1969-2010 and durability of resistance of winter wheat variety Bezostaya. Europe J Plant Pathol, 132: 323-340.

[30] Morgounov, A.; Gummadov, N.; Belen, S.; Kaya, Y.; Kesfri, M. and Mursalova, H. (2014). Association of digital photo parameters and NDVI with winter wheat grain yield in variable environments, Turk. J Agric. For, 38, 2014, 624-632.

[31] Mert, Z.; Akan, K. and Cetin, L. (2014). Current Situation of Wheat Stripe Rust in Turkey - Yr27 Virulence and Potential Effects. 2nd International Wheat Stripe Rust Symposium, 28 April-1 May., Izmir, Turkey. http://www.icarda

[32] Mundt, C. C.; Brophy, L. S. and Schmitt, M. S. (1995). Disease severity and yield of pure-line wheat cultivars and mixture in the presence of eyespot, yellow rust, and their combination. Pathology, 1995 44: 173-182.

[33] Ochoa, J. and Parlevelet, J. E. (2007). Effect of partial resistance to barley lea Puccinia hordei, on the yield three barley cultivars. Euphytica, 153: 309-312.

[34] Pandey, H. N. T. C.; Menon, M. and Rao, M. V. (1989). A simple formula for calculating area under disease progress curve. Rachis, vol. 8, no. 2: 38-39.

[35] Peterson, R. F.; Campbell, A. B. and Hannah, A. E. (1948). A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Canadian J. Res., 26: 496-500.

[36] Poudyal, D. S. and Chen, X. M. (2010). Models for predicting potential yield loss of wheat caused by stripe rust in the US. Pacific Northwest, 101: 544-554.

[37] Rizwan, S.; Ahmad, I.; Ashraf, M.; Iqbal-Mirza, J.; Mustafa-Sah, G.; Atiq-ur-Rahman, R. and Mujeeb-Kazi, A. (2007). Evaluation of synthetic hexaploid wheats (Triticum turgidum L. x Aegilops tauschii) and their durum parents for stripe rust (Puccinia striiformis westend. f. sp. tritici) resistance. Revista Mexicana de Fitzpatologia, 25: 152-160.

[38] Roelofs, A. P.; Singh, R. P. and Saari, E. E. (1992). Rust diseases of wheat: concepts and methods of disease management. March, 1992, 81 p, CIMMYT, Mexico. Internet Resource: http://www.fund.org/c��/3/8487.pdf

[39] Shahin, A. A. (2020). Occurrence of new races and virulence changes of the wheat stripe rust pathogen (Puccinia striiformis f. sp. tritici) in Egypt, Archives of Phytopathology and Plant Protection, DOI: 10.1080/03235408.2020.1767330.

[40] Shahin, A. A.; Rehab, A Dar and Hend, A Omar. (2020). Effectiveness of different fungicides formulations and certain ground spraying equipment in controlling wheat stripe rust in Egypt. Egyptian J. Plant Prot. Res. Inst., 3 (1): 11-26.

[41] Singh, R. P.; William, H. M.; Huerta-Espino, J. and Rosewarne, G. (2004). Wheat rust in Asia: meeting the challenges with old and new technologies. In: New directions for a diverse planet. Proceedings of the 4th International Crop Science Congress, Brisbane, Australia. p. 163.

[42] Snedecor, G. W. (1957). Statistical Methods, 5th eds. Iowa State College Press, Ames, Iowa, Wang.

[43] Taye, T.; Fininsa, C. and Woldeab, G. (2015). Yield variability of bread wheat under wheat stem rust pressure at be field condition of Southern Oromia. J AgricSci Food Technol 1: 11-15.

[44] Tervet, I. and Cassell R. C. (1951). The use of cyclone separation in race identification of cereal rusts. Phytopathology, 41: 282-285.

[45] Wan, A.; Zhao, Z. and Chen, X. M. (2004). Wheat stripe rust epidemic and virulence of Puccinia striiformis f. sp. tritici in China in 2002. Plant Dis., 88: 896-904.

[46] Yahyaoui, A. and Rajaram, S. (2012). Meeting the challenge of yellow rust in cereal crops. Proceedings of the 2nd, 3rd and 4th Regional conferences on yellow rust in the central and west Asia and North Africa (CWANA) Region. ICARDA, Aleppo, Syria. p. 175.

[47] Zadoks, J. C. Chang, T. T. and Konzak, C. F. (1974). A decimal code for growth stages of cereals. Weed Res, 14: 415-421.

[48] Zeng, S. M. and Luo, Y. (2008). Systems analysis of wheat stripe rust epidemics in China. Eur J. Plant Pathol., 121: 425-438.