ORIGINAL PAPER

# The Impact of Wheat Yellow Rust on Quantitative and Qualitative Grain Yield Losses under Egyptian Field Conditions.

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## ABSTRACT

The purpose of the present study is to determine the effect of wheat yellow rust caused by *Puccinia striiformis* f. sp. *tritici* on quantitative and qualitative grain yield losses, in addition to predict them through regression model for each tested wheat variety, *i.e.,* Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and check variety Morocco in 2020 and 2021seasons at Bahteem Agricultural Research Station, Agricultural Research Center, Egypt. The disease parameters *i.e.,* final rust severity (FRS %), rate of yellow rust increase (r-value) and area under disease progression curve (AUDPC) in the first season were higher than the second season. Gemmeiza-11 and Sids-12 varieties recorded the highest values of these parameters during the two seasons compared to the check variety Morocco. Corresponding data ranged from 63.33 to 83.33% for FRS (%) 0.043 to 0.063 for r-value and 783.33 to 1350.0 for AUDPC. Shandweel-1 and Sids-1 varieties recorded the moderately values of these parameters but Sakha-94 recorded the lowest values of the same parameters. The actual losses (%) values, ranged from 1.31 to 36.44% for 1000 kernel weight/gm and grain yield/plot (kg), were lower than the total losses (%) which ranged from 1.38 to 42.94%, respectively, for each of wheat varieties in the two seasons under study. The highly susceptible wheat varieties, Sids-12 and Gemmeiza-11 exhibited the highest values of actual losses (%) and total losses (%) up to 42.94%, while the moderately susceptible varieties, Shandweel-1 and Sids-1 were less, being 21.05% compared to the check variety Morocco. In addition, Sakha-94 variety showed less than 3.37%. The regression analysis showed that a positive strong correlation between FRS and total losses (%) of 1000 kernel weight/gm and grain yield/plot (kg), during the two growing seasons. The qualitative properties of wheat varieties revealed that the reduction rates for carbohydrate mg/g, total protein mg/g, crude fiber, dry gluten and wet gluten were higher in the susceptible wheat varieties, Shandweel-1, Gemmeiza-11, Sids-12 and Morocco (check), where the corresponding values ranged from 3.80 to 33.07%, while Sakha-94 and Sids-1 showed the lowest reduction from 1.30 to 9.6%, in the tested chemical properties. So, through this study, it can expect the yield loss by linking disease parameters, yield components and chemical properties. Principal component analysis showed that the most important components were FRS (%) and AUDPC, as they contributed 88.607% of the total cumulative variance and a prediction equation may link all the components together.

**Keywords:** Wheat, *Triticum aestivum*, yellow rust, *Puccinia striiformis*, yield losses, disease parameters, grain quality, correlation coefficient.

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## INTRODUCTION

Wheat (*Triticum aestivum L.*) is the most commonly cultivated grain crop in the world. In Egypt, it is considered the most important grain and the third largest crop in the cultivated area. In Egypt, wheat production was about 8.9 million tons in 2020, an increase of 1.48% over the previous year 2019 (Statista, 2020). The annual wheat consumption is about 19 million tons, the local production is about 8.9 million tons, and the local annual output and consumption gap is about 10.1 million tons. There are two ways to increase local wheat production to close this gap, the first method is to increase the yield per unit area through vertical expansion through new varieties with high yields and resistance to biotic and abiotic stresses. The second way is horizontal expansion that is, increasing the wheat planting area. Serious losses have been reported due to infection by various wheat diseases, including yellow rust (Kissana *et al*., 2003). Yellow rust caused by *Puccinia striiformis* f. sp. *tritici* is also one of the devastating diseases of wheat in the world (Eriksson 1894) and continues to cause serious damage around the world (Chen *et al.,*

2013). The disease can affect 80% of Turkey's wheat acreage, especially in cool and humid areas (Karakas *et al.,* 2009). Of the various abiotic factors, temperature and humidity are the main determinants of the spread of yellow rust, which are used to develop predictive models of disease. Predictive models have also been developed to predict wheat yellow rust (Line 2002). Stripe rust occurs often in the Mediterranean, Northern Europe, the Middle East, Australia, the Western United States and East Africa, as it was more dangerous in cool areas, especially in humid conditions (Danial 1994 and Mamluk *et al.,* 1996). While recent outbreaks of disease in equatorial nations have shown new levels of adaptation of pathogens to different temperature ranges (Khanfri *et al.,* 2018). Also, Khan and Mumtaz (2004) reported epidemics of yellow rust in Pak 81 and Pirsabak 85 in 1995 and Inquilab 91 in Pakistan in 2003. This may be due to favorable climatic conditions and the cultivation of mega genotypes. Yellow rust is more public in the highlands, tropical regions of the Himalayan hills of North Africa, Mexico, India and Pakistan (McIntosh 1980). Yellow rust attacks most of Egypt's commercial wheat varieties causing serious infections and thereby high losses especially in Northern provinces and can therefore cause significant losses (Abu El-Naga *et al.*, 2001 and Omara *et al.,* 2016). It can cause a 100% drop in yield, but often in the range of 10-70% (Chen 2005). Yellow rust infection deprives the host plant of nutrients and sugar and the infected tissue on the leaf surface narrows the photosynthetic range of the plant, causing excessive water loss. It effects on yield through reducing the area of green leaves, thereby affecting the sugar supply of developing seeds. The most important leaves for sugar production for developing grains are the flag leaf and the second leaf. The flag leaf infection is expected to cause significant yield losses, with flag leaves accounting for more than 70% of grain filling (Marsalis and Goldberg 2006), which makes the plant unable to develop its life span and thus affects the yield by affecting the filling of the grains, the degree and quality of the grains, as well as the flour yield and its durability (Brien *et al.,* 1990). As a result, losses can reach in total from 10-90% in wheat varieties (Sharma *et al.*, 2016). The best approach to avoiding the yield loss associated with this disease is durable resistant program in commercially used varieties that have otherwise excellent agricultural traits and qualities but are prone to yellow rust. So, Chen *et al.* (2013) explained the advantages of durable resistance in overcoming wheat rust disease in terms of being more effective, reliable and environmentally friendly and developing new genotypes with resistance genes. It is considered the most effective tool for addressing challenges. Thus, the main objective of the study was to evaluate the effect of yellow rust on quantitative and qualitative traits of some wheat varieties through the three disease parameters, the two yield components and some chemical properties of wheat grains.

## MATERIALS AND METHODS

The impact of wheat yellow rust on disease parameters and yield components of some varieties, *i.e.*, Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and check variety; Morocco (Table, 1) was studied at Bahteem Agricultural Research Station, Agricultural Research Center, during 2020 and 2021 growing seasons. In addition, qualitative characters were estimated in Regional Center for Food and Feed, Agricultural Research Center and in Analysis and Measurement Lab., Central Laboratory of Biotechnology, Plant Pathology Research Institute, ARC, Giza, Egypt.

**Table (1): Pedigree and year of release of six wheat varieties.**

| Wheat variety | Pedigree | Release year |
|---|---|---|
| Shandweel-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 |
| Sids-1 | HdHD2172 / Pavon"S" // 1158.57/Maya74"S"SD46-4SD-2SD-1SD-0SD | 1996 |
| Sids-12 | BUC // 7C / ALD /5/ MAYA74 /ON //1160-147/3/BB/GLL/4/ CHAT"S"/6/ MAYA/VUL-4SD-1SD-1SD-0SD. | 2007 |
| Sakha-94 | OPATA / RAYON // KAUZCMBW90Y3180-0TOPM-3Y-010M-010M-010Y-10M-015Y-0Y-0AP-0S | 2004 |
| Morocco | highly susceptible check variety | - |

**Experimental design:**

Experimental design was split-plot with three replicates, during 2020 and 2021 growing seasons. The main treatments of plots were represented by wheat varieties, while subplots were infected and protected plants.

The plot size was $6 \times 7$ m $= 42$ m$^2$, and 20 rows for each plot with a length of 7 m and 30 cm spacing. The tested varieties were planted 15 days after the normal sowing date (early December) to expose the plant to an environment suitable for rust development and the disease epidemiology. All plants were surrounded by a highly yellow rust susceptible spreader (*Triticum spelta saharinsis*). In addition, the plants under study were artificially inoculated with a mixture of yellow rust races at booting stage, whereas the other treatments were protected by the effective fungicide Telt EC 25% (propiconazole) at the rate of 25cm/100 L. In the early stages of the dough crop stand/vitality was maintained according to normal agricultural practices, including recommended fertilizer application rates and watering schedules.

**Disease assessment:**

From the onset of the disease to the early stages of the dough (Large, 1954), the type of rust was determined according to Roelfs *et al.* (1992). It was determined as the percentage of leaves covered with rust pustules according to the method described by Peterson *et al.* (1948). The final rust severity (%) was recorded as outlined by Das *et al.* (1993). Infection type, constant values were used based on: R= 0.2, MR= 0.4, MRMS= 0.6, MS= 0.8 and S= 1.0. Rate of increase in yellow rust (r-value) was estimated using the following equation by Van Der Plank (1963):

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

**Where:**

$t_2 - t_1$ = the interval in days between these dates.

$X_1$ = the proportion of the susceptible infected tissue (disease severity) at date $t_1$.

$X_2$ = the proportion of the susceptible infected tissue (disease severity) at date $t_2$.

Area under disease progress curve (AUDPC), was estimated by Pandey *et al.* (1989).

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

**Where:**

$D$ = days between reads.

$Y_1$ = first disease recording.

$Y_k$ = last disease recording.

**Quantitative estimation of yield components:**

Yield of each 42 m$^2$ variety was weighted on a conventional scale. Effect of yellow rust on yield components, *i.e.,* 1000 kernel weight (g) and grain yield/plot (kg) was determined by comparing the yields of infected and protected varieties.

**The total loss (%):**

The total losses were estimated using the formula described by Colpauzos *et al.,* 1976.

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

**Where:**

**Yd** = yield of diseased plants.

**Yh** = yield of healthy plants.

**The Actual loss (%):**

Actual losses were estimated according to coefficient of determination ($R^2$) which obtained from statistical analysis of the data between final rust severity (%) and yield components under study of infected plants.

$$\text{Where, the actual losses (\%) =}$$
$$\text{Total losses (\%)} \times R^2$$

**Estimation of qualitative characters:**

Chemical properties (carbohydrate mg/g, total protein mg/g, crude fiber, dry gluten and wet gluten) of grains in six bread wheat varieties were determined in protected and infected plants. The qualitative characters of the grains (Dry and wet gluten) were conducted in Regional Center for Food and Feed, ARC, Egypt, by Anonymous (2000) method. While, carbohydrate was determined by Masuko (2005), total protein and crude fiber were estimated according to Anonymous (2005) in Analysis and Measurement Lab., Central Laboratory of Biotechnology, Plant Pathology Research Institute, ARC, Giza, Egypt.

**Statistical analysis:**

Combined analysis of the data was achieved with the software package MSTAT-C, then LSD was used to compare means between different treatments. Principal component analysis and the correlation coefficient were used to determine the relationship between final rust severity (%) and yield components using SPSS 22.

# RESULTS

To determine the quantitative and qualitative effects of yellow rust on wheat, disease parameters, yield components and chemical properties were estimated during 2020 and 2021-growing seasons.

**Effect of yellow rust on the three disease parameters of some wheat varieties:**

Five Egyptian wheat varieties *i.e.,* Shandweel-1, Gemmeiza-11, Sids-1, Sids-12 and

Sakha-94, in addition to the highly susceptible wheat variety, Morocco were evaluated against yellow rust depending on the three disease parameters, *i.e.,* FRS (%), r-value and AUDPC in 2020 and 2021 seasons.

Data presented in Table (2) reveal that disease parameters; FRS (%), r-value and AUDPC values in the second season (2021) were lower than in the first season (2020), the most of wheat varieties which show high final disease severity % exhibited maximum values of AUDPC. In the first season, final rust severity (%) was the highest in the susceptible wheat varieties; Gemmeiza-11 (83.33%) and Sids-12 (80.00%) compared to check variety; Morocco (76.66%), also Shandweel-1 and Sids-1 varieties (moderately level of susceptibility) exhibited FRS (%) 50.00 and 46.66%, respectively, while Sakha-94 recorded 13.33% of FRS (%). In the second season, the final rust severity (%) was less on the susceptible wheat varieties Gemmeiza-11, Sids-12 and Morocco (check), being 73.33, 63.33 and 73.33%, respectively followed by Shandweel-1(30.00%) and Sids-1(16.66%). While Sakha-94 showed the lowest value of FRS (0.80%).

In the first season, r-value was the highest in wheat varieties; Gemmeiza-11, Sids-12 and Morocco, which ranged from 0.043 to 0.063. On the other hand, Shandweel-1, Sids-1 and Sakha-94, the values ranged from 0.027 to 0.038 (Table 2). While, in the second season, r-value ranged from 0.008 to 0.046 in all the tested wheat varieties (Table 2). Also, AUDPC values were more than 600 in Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, and Morocco varieties (738.33, 1333.33, 708.33, 1270.00 and 1350.00), respectively, in the first season but in the second season the two varieties, Gemmeiza-11 and Sids-12 with Morocco (check) exhibited AUDPC values more than 600, ranged from 783.33 to 1100.00 and were considered highly susceptible varieties during the two seasons. While, Sakha-94 showed the lowest values in AUDPC, being170.66 and 4.00 in the two seasons, respectively (Table 2).

**Table (2): Effect of yellow rust on disease parameters of some wheat varieties under field conditions during 2020 and 2021 growing seasons.**

| NO. | Variety | Disease parameters | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| | | [1]FRS % | | [2]r-value | | [3]AUDPC | |
| | | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| 1 | Shandweel-1 | 50.00 | 30.00 | 0.038 | 0.034 | 738.33 | 513.33 |
| 2 | Gemmeiza-11 | 83.33 | 73.33 | 0.063 | 0.046 | 1333.33 | 1100.0 |
| 3 | Sids-1 | 46.66 | 16.66 | 0.036 | 0.023 | 708.33 | 220.00 |
| 4 | Sids-12 | 80.00 | 63.33 | 0.052 | 0.043 | 1270.00 | 783.33 |
| 5 | Sakha-94 | 13.33 | 0.80 | 0.027 | 0.008 | 170.66 | 4.00 |
| 6 | Morocco | 76.66 | 73.33 | 0.043 | 0.043 | 1350.00 | 1008.33 |
| | Mean | 58.33 | 0.043 | 0.033 | 0.032 | 928.33 | 604.83 |

LSD$_{0.05}$ for:

| | | | |
| --- | --- | --- | --- |
| Varieties (V) | 9.23 | 0.011 | 18.21 |
| Seasons (S) | 6.34 | 0.003 | 20.35 |
| V×S | 4.21 | 0.005 | 14.23 |

([1]FRS), Final rust severity %; ([2]r-value), Rate of disease increase; ([3]AUDPC), Area under disease progress curve

**Figure (1): Effect of yellow rust on wheat grains of some varieties.**

**Quantitative estimation of yield parameters:**

Yield parameters: 1000 kernel weight (gm) and yield/plot (kg), as well as total and actual losses (%) were estimated during the two seasons under study.

**Thousand kernel weight:**

Data presented in Table (3) reveal that 1000 kernel weight/gm of the protected varieties was higher than infected ones during 2020 and 2021 seasons. In the first season (2020), 1000 kernel weight/gm in Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 varieties recorded (41.58 and 50.84gm), (39.28 and 56.82gm), (43.32 and 51.89gm), (38.67 and 54.67gm) and (51.21 and 53.00gm) compared to check variety, Morocco (32.50 and 46.71gm) for infected and protected

varieties, respectively (Table 3 and Fig. 1). In the second season (2021), 1000 kernel weight/gm in Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and Morocco varieties was (45.60 and 51.34gm), (45.77 and 56.78gm), (46.69 and 51.89gm), (47.25 and 53.76gm), (55.55 and 56.33gm) and (38.73 and 48.71gm) for infected and protected varieties, respectively (Table 3).

**Total losses (%):**

Total losses (%) of 1000 kernel weight showed differences among the wheat varieties according to the variety's response to disease. The estimated total loss (%) of 1000 kernel weight was more in Gemmeiza-11, Sids-12 and Morocco varieties which exhibited the highest values of FRS (%), r-value and AUDPC than

Shandweel-1, Sids-1 and Sakha-94 varieties during the two seasons under study (Table 3). In the first season, the highest total loss (%) was recorded with Gemmeiza-11, Sids-12 and Morocco varieties, being 30.86, 29.26 and 30.42%, respectively, followed by Shandweel-1 and Sids-1, being 18.21 and 16.52%. While, Sakha-94 variety was the lowest one (3.73%). In the second season, the estimated total losses (%) in Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and Morocco varieties were 11.18, 19.39, 10.02, 12.10, 1.38 and 20.48%, respectively (Table 3).

**Actual loss (%):**

In order to estimate the actual loss, it is necessary to calculate the coefficient of determination. In the first season, the coefficient of determination ($R^2$) value was high in all tested

wheat varieties, Shandweel-1, Gemmeiza-11, Sids-12, Sakha-94 and Morocco except Sids-1. The corresponding values were 0.863, 0.983, 0.997, 0.934, 0.870 and 0.610, respectively. According to $R^2$, the actual losses (%) values were, 15.71, 30.33, 10.07, 29.17, 3.14 and 26.46% for Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and Morocco, respectively (Table 3 and Fig. 2).

In the second season, $R^2$ value was high in each of Shandweel-1, Sids-1, Sids-12, Sakha-94 and Morocco varieties that ranged from 0.799 to 0.990 except for Gemmeiza-11 (0.588). The actual loss (%) recorded 11.06, 11.40, 8.47, 11.94, 1.31 and 16.36% in Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and Morocco (check) varieties, respectively (Table 3 and Fig. 3).

**Table (3): Effect of yellow rust on 1000 kernel weight of some wheat varieties at adult stage in 2020 and 2021 seasons.**

| Wheat variety | 1000 kernel weight (gm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | | | | | 2021 | | | | |
| | Infected | Protected | Total losses (%) | [1]Actual losses (%) | [2]$R^2$ | Infected | Protected | Total losses (%) | [1]Actual losses (%) | [2]$R^2$ |
| Shandweel-1 | 41.58 | 50.84 | 18.21 | 15.71 | 0.863 | 45.60 | 51.34 | 11.18 | 11.06 | 0.990 |
| Gemmeiza-11 | 39.28 | 56.82 | 30.86 | 30.33 | 0.983 | 45.77 | 56.78 | 19.39 | 11.40 | 0.588 |
| Sids-1 | 43.32 | 51.89 | 16.52 | 10.07 | 0.610 | 46.69 | 51.89 | 10.02 | 8.47 | 0.846 |
| Sids-12 | 38.67 | 54.67 | 29.26 | 29.17 | 0.997 | 47.25 | 53.76 | 12.10 | 11.94 | 0.987 |
| Sakha-94 | 51.21 | 53.00 | 3.37 | 3.14 | 0.934 | 55.55 | 56.33 | 1.38 | 1.31 | 0.955 |
| Morocco | 32.50 | 46.71 | 30.42 | 26.46 | 0.870 | 38.73 | 48.71 | 20.48 | 16.36 | 0.799 |
| Mean | 41.09 | 52.32 | 21.44 | 19.14 | 0.874 | 46.59 | 53.13 | 12.42 | 10.72 | 0.860 |
| LSD$_{0.05}$ for: | | | | | | | | | | |
| Varieties (V) | 1.23 | | | | | 1.11 | | | | |
| Treatments (T) | 2.34 | | | | | 3.34 | | | | |
| V×T | 1.54 | | | | | 1.32 | | | | |

[1]Actual losses were estimated according to $R^2$; [2]($R^2$) Coefficient of determination
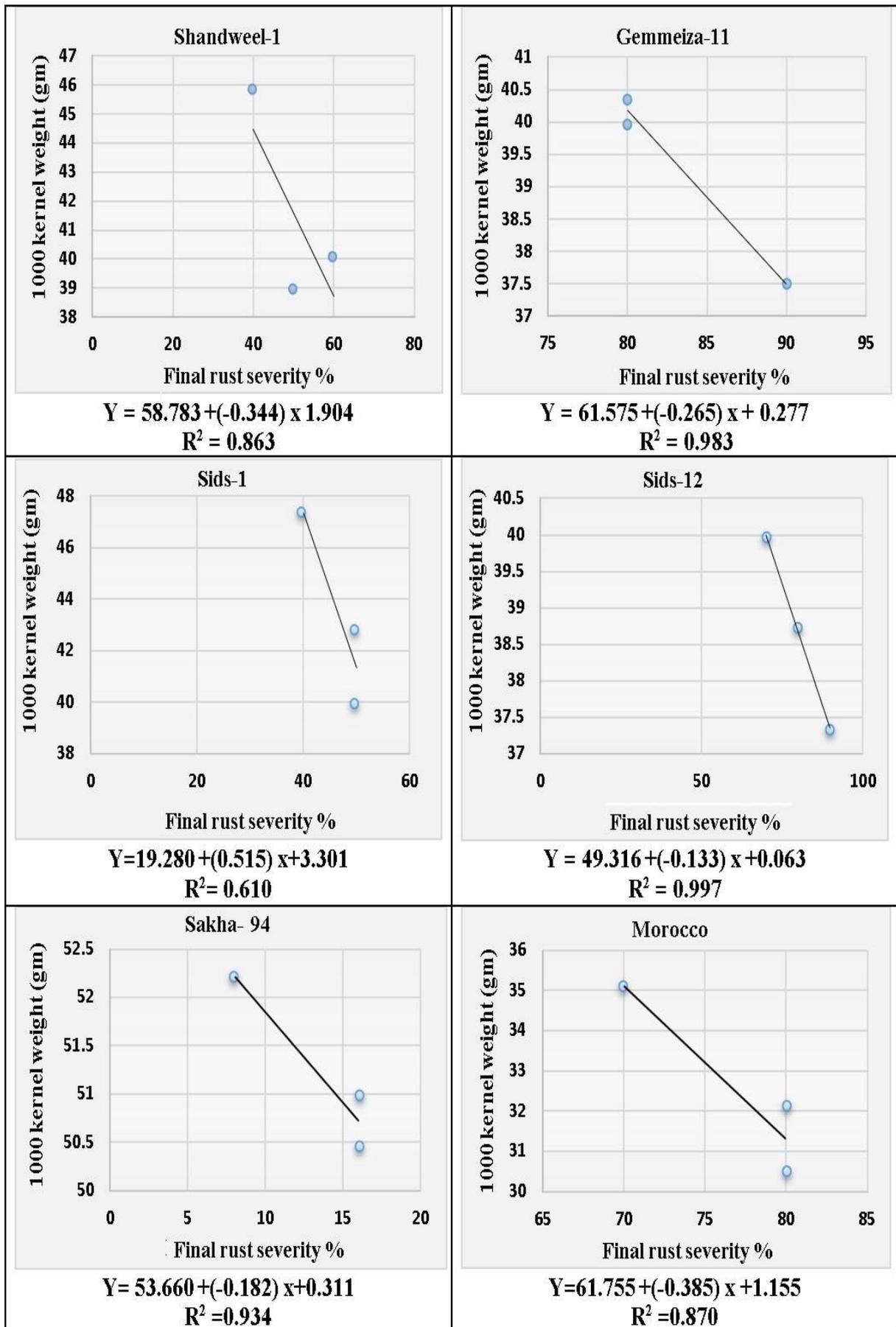
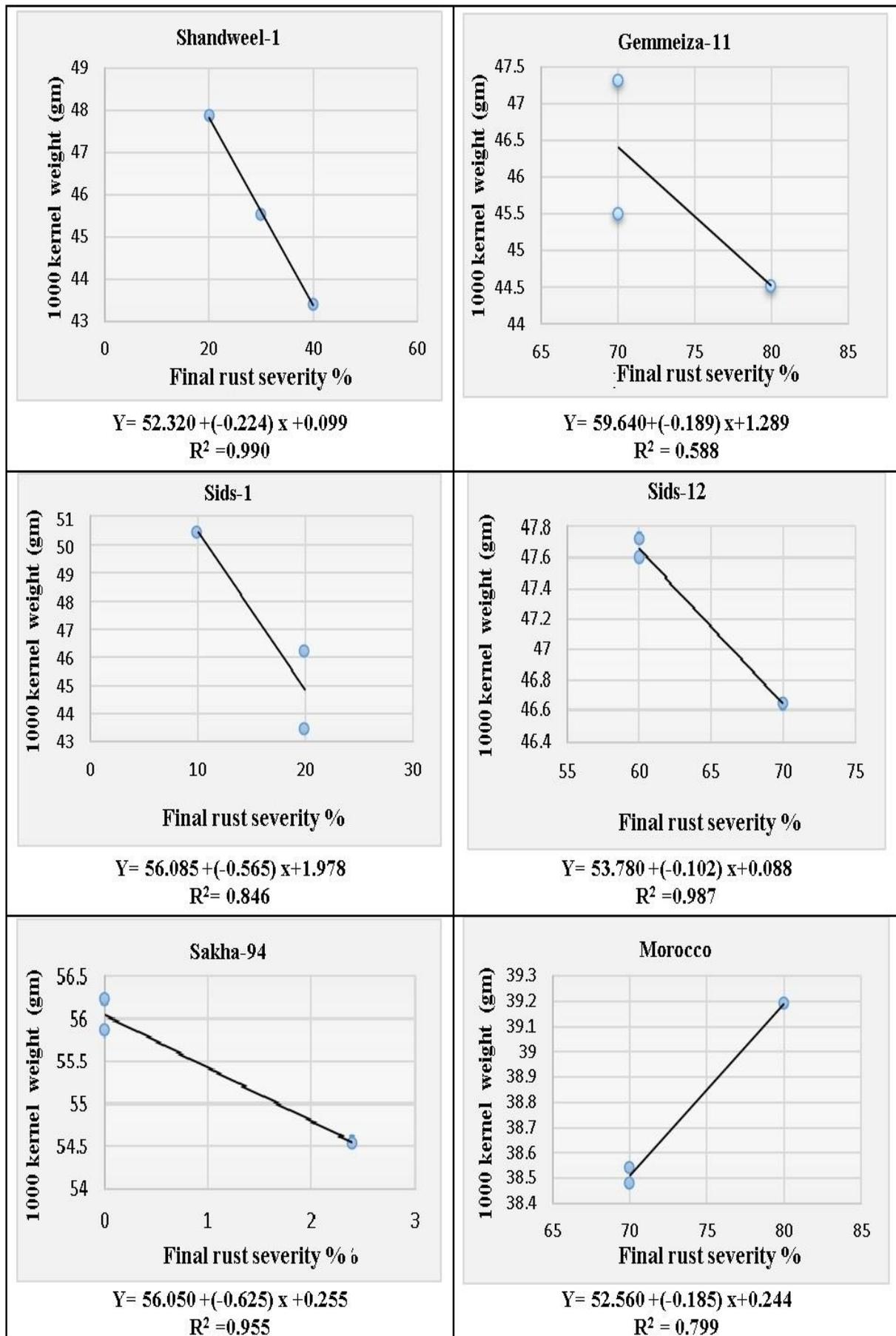**Figure (2): Association between FRS (%) and 1000 kernel weight (gm) of six wheat varieties during 2020 season.**

**Figure (3): Association between FRS (%) and 1000 kernel weight (gm) of six wheat varieties during 2021 season.**

**Grain yield:**

Data presented in Table (4) show that grain yield/plot (kg) of the protected varieties was higher than that of infected ones during the two seasons under study. In the first season, the grain yield per plot/kg, of Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and Morocco varieties was (21.79 and 27.60 kg),(15.39 and 26.52 kg),(21.76 and 27.02 kg), (18.28 and 28.93 kg),(24.38 and 25.73 kg) and (13.70 and 24.01 kg) for infected and protected varieties, respectively. In the second season, the grain yield/ plot (kg) of Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and Morocco varieties was (24.16 and 29.30 kg), (17.17 and 26.08 kg), (23.50 and 28.02 kg), (21.50 and 28.43 kg), (24.40 and 25.23 kg) and (15.89 and 25.01 kg) for infected and protected varieties, respectively (Table 4).

**Total losses (%):**

In 2020, Gemmeiza-11, Sids-12 and Morocco varieties recorded the highest values of total losses (%) in grain yield/plot, being 41.96, 36.81 and 42.94%, respectively. Shandweel-1 (21.05%) and Sids-1 (19.46%) varieties recorded the second rank of the total loss (%). On the other hand, Sakha-94 variety showed the lowest total loss (5.24%) (Table 4). While, in 2021, the estimated total losses (%) in grain yield/plot were higher in Gemmeiza-11(34.16), Sids-12 (24.37) and Morocco (36.46%) varieties, respectively followed by Shandweel-1 (17.54) and Sids-1 (16.13%). On the other hand, Sakha-94 variety (3.28%) recorded the lowest value of total losses % in grain yield per plot (Table 4).

**Actual loss (%):**

The coefficient of determination ($R^2$) value was positive strong in the two varieties, Shandweel-1(0.967) and Sids-12 (0.999) and ranged from 0.385 to 0.550 in the rest of varieties. According to $R^2$, the actual losses (%) recorded 20.35, 16.15, 9.84, 36.44, 2.55 and 23.61% for all tested wheat varieties; Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and Morocco varieties, respectively in the first season (Table 4 and Fig. 4). While, in the second season, $R^2$ value was high in all tested wheat varieties and ranged from 0.649 to 0.987. Therefore, the actual losses (%) were 17.31, 26.16, 14.54, 15.81, 2.87 and 35.98% for Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and Morocco varieties, respectively (Table 4 and Fig.5).

**Table (4): Effect of yellow rust on grain yield / plot (Kg) of some wheat varieties at adult stage in 2020 and 2021 seasons.**

| Wheat variety | Grain yield / plot (Kg.) | | | | | | | | | |
| | 2020 | | | | | 2021 | | | | |
| | Infected | Protected | Total losses (%) | [1]Actual losses (%) | $R^2$[2] | Infected | Protected | Total losses (%) | [1]Actual losses (%) | $R^2$[2] |
|---|---|---|---|---|---|---|---|---|---|---|
| Shandweel-1 | 21.79 | 27.60 | 21.05 | 20.35 | 0.967 | 24.16 | 29.30 | 17.54 | 17.31 | 0.987 |
| Gemmeiza-11 | 15.39 | 26.52 | 41.96 | 16.15 | 0.385 | 17.17 | 26.08 | 34.16 | 26.16 | 0.766 |
| Sids-1 | 21.76 | 27.02 | 19.46 | 9.84 | 0.506 | 23.50 | 28.02 | 16.13 | 14.54 | 0.902 |
| Sids-12 | 18.28 | 28.93 | 36.81 | 36.44 | 0.999 | 21.50 | 28.43 | 24.37 | 15.81 | 0.649 |
| Sakha-94 | 24.38 | 25.73 | 5.24 | 2.55 | 0.487 | 24.40 | 25.23 | 3.28 | 2.87 | 0.877 |
| Morocco | 13.70 | 24.01 | 42.94 | 23.61 | 0.550 | 15.89 | 25.01 | 36.46 | 35.98 | 0.987 |
| Mean | 19.21 | 26.63 | 27.91 | 18.15 | 0.649 | 21.10 | 27.02 | 21.99 | 19.25 | 0.861 |
| LSD$_{0.05}$ for: | | | | | | | | | | |
| Varieties (V) | 2.12 | | | | | 2.31 | | | | |
| Treatments(T) | 3.12 | | | | | 2.12 | | | | |
| V×T | 1.76 | | | | | 1.57 | | | | |

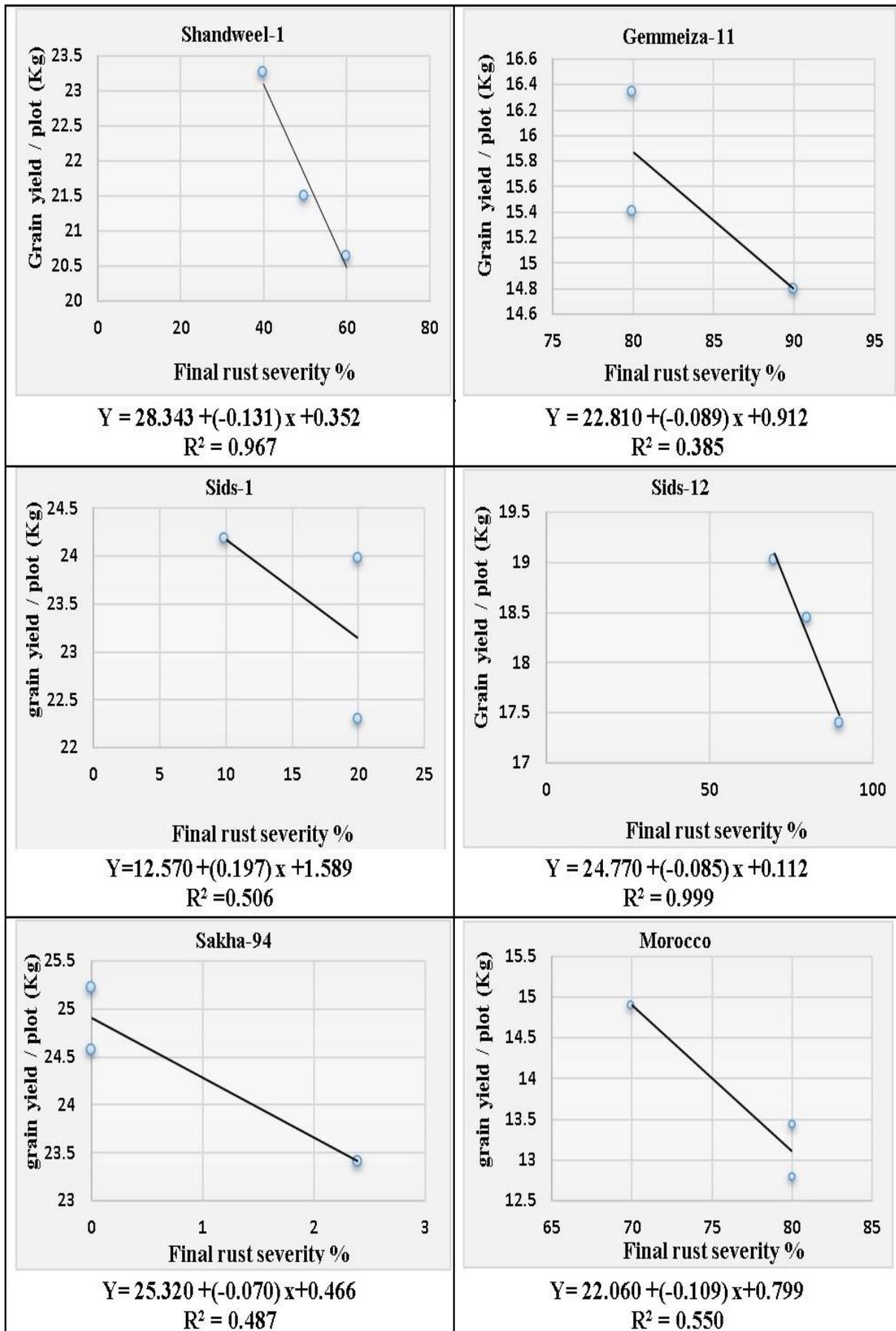[1]Actual losses were estimated according to $R^2$; [2]($R^2$) Coefficient of determination

**Figure (4): Association between FRS (%) and grain yield/plot (kg) for six wheat varieties during 2020 season.**
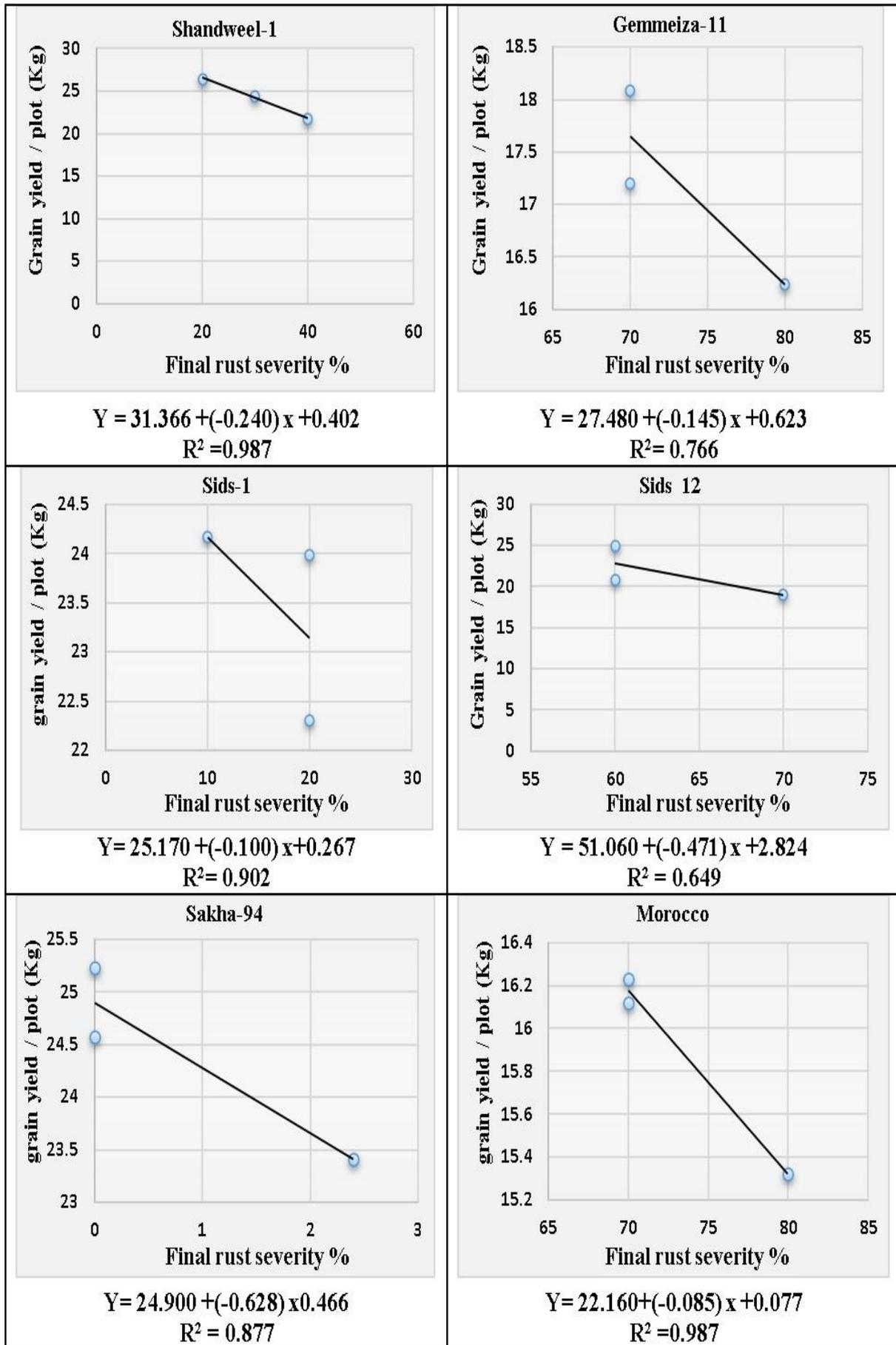
**Shandweel-1**

$Y = 31.366 + (-0.240) x + 0.402$
$R^2 = 0.987$

**Gemmeiza-11**

$Y = 27.480 + (-0.145) x + 0.623$
$R^2 = 0.766$

**Sids-1**

$Y = 25.170 + (-0.100) x + 0.267$
$R^2 = 0.902$

**Sids 12**

$Y = 51.060 + (-0.471) x + 2.824$
$R^2 = 0.649$

**Sakha-94**

$Y = 24.900 + (-0.628) x 0.466$
$R^2 = 0.877$

**Morocco**

$Y = 22.160 + (-0.085) x + 0.077$
$R^2 = 0.987$

**Figure (5): Association between FRS (%) and grain yield/plot (kg) for six wheat varieties during 2021 season.**

## Chemical properties of grains of some wheat varieties:

Data presented in Table (5) determine some chemical properties (carbohydrate mg/g, total protein mg/g, crude fiber%, dry gluten% and wet gluten%) of grains in six wheat varieties. The tested chemical properties of the protected varieties were always higher than those in infected ones. The values of carbohydrate in Shandweel-1, Gemmeiza-11, Sids-1, Sids-12, Sakha-94 and Morocco varieties were (13.01 and 15.91 mg/g), (22.61 and 28.20 mg/g), (30.55 and 31.77 mg/g), (30.69 and 38.11 mg/g), (36.12 and 36.95 mg/g), (23.27 and 29.24 mg/g) for infected and protected varieties, respectively. The values of protein were (6.01 and 8.66 mg/g), (6.89 and 10.31 mg/g), (4.84 and 5.05 mg/g), (9.43 and 12.19 mg/g), (10.17 and 10.89 mg/g), (9.31 and 11.93 mg/g) in the same varieties for infected and protected varieties, respectively. The crude fiber values (%) of the same six varieties were (73.67

and 84.34 %), (78.94 and 82.06 %), (61.82 and 65.18 %), (56.9 and 61.52 %), (82.92 and 84.02 %) and (57.72 and 86.24 %) for infected and protected varieties, respectively. In addition to, wet gluten values ranged from 20.3 to 26.0% in the infected varieties and from 23.7 to 30.3% in the protected varieties. While, dry gluten values ranged from 5.8 to 8.6% in the infected varieties and from 6.2 to 8.9% in the protected varieties Accordingly, all reduction rates for infected varieties were higher than those for protected varieties. The highest reduction (%) was observed in susceptible wheat varieties, Shandweel-1, Gemmeiza-11, Sids-12 and Morocco and ranged from 15.29 to 33.17%. While, Sakha-94 and Sids-1 varieties recorded the lowest values of disease parameters and also recorded the lowest reductions (%), from 1.30 to 9.6%, in the all tested chemical properties (Table 5 and Fig. 6).
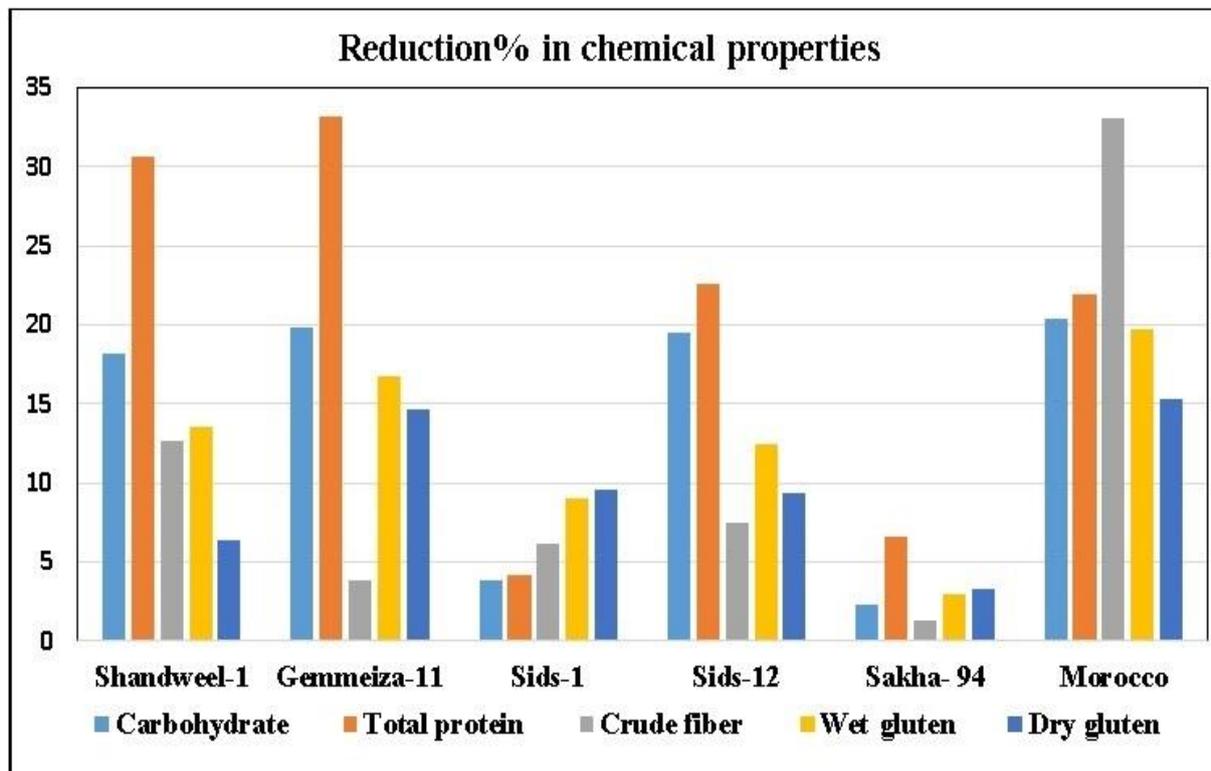


**Figure (6): Reduction (%) of some chemical properties (carbohydrate mg/g, total protein mg/g, crude fiber %, dry gluten %, and wet gluten %) in grains of six wheat varieties.**

## Principal component analysis:

Principal component analysis (PCA) of 12 components, *i.e.,* FRS (%), AUDPC, r-value, total and actual losses of 1000 kernel weight (gm) and yield/plot (kg), carbohydrate mg/g, total protein mg/g, crude fiber, dry gluten, and wet gluten showed that the best components were

PCA1 (FRS%) and PCA2 (AUDPC). Where, the PCA1 and PCA2 achieved more than one and together contributed 88.607% (Table 6 and Fig. 7A). The PCA1 contributed 78.932% and the PCA2 contributed 9.674%. While, the rest of the components had a similar effect (Table 6 and Fig. 7B).
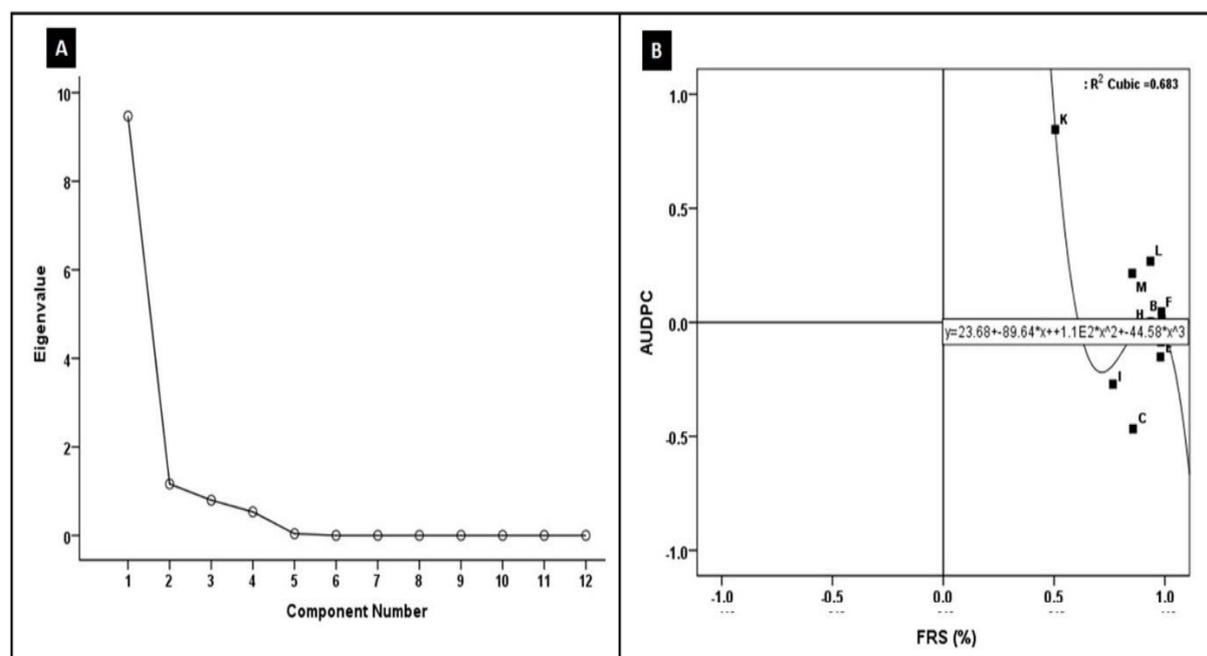
**Table (5): Effect of yellow rust on some chemical properties of grains of some wheat varieties grown under field conditions.**

| No. | Wheat varieties | Treatments | Carbohydrate (mg/g) | *Redu. % | Total protein (mg/g) | Redu. % | Crude fiber % | Redu. % | Wet gluten % | Redu. % | Dry gluten % | Redu. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Shandweel-1 | Infected | 13.01 | 18.22 | 6.01 | 30.60 | 73.67 | 12.65 | 20.5 | 13.5 | 5.8 | 6.4 |
| | | Protected | 15.91 | | 8.66 | | 84.34 | | 23.7 | | 6.2 | |
| 2 | Gemmeiza-11 | Infected | 22.61 | 19.82 | 6.89 | 33.17 | 78.94 | 3.80 | 25.4 | 16.7 | 7.5 | 14.7 |
| | | Protected | 28.20 | | 10.31 | | 82.06 | | 30.3 | | 8.8 | |
| 3 | Sids-1 | Infected | 30.55 | 3.84 | 4.84 | 4.15 | 61.82 | 6.13 | 25.1 | 9.0 | 7.5 | 9.6 |
| | | Protected | 31.77 | | 5.05 | | 65.18 | | 27.6 | | 8.3 | |
| 4 | Sids-12 | Infected | 30.69 | 19.46 | 9.43 | 22.64 | 56.9 | 7.50 | 25.2 | 12.5 | 7.7 | 9.4 |
| | | Protected | 38.11 | | 12.19 | | 61.52 | | 28.8 | | 8.5 | |
| 5 | Sakha-94 | Infected | 36.12 | 2.24 | 10.17 | 6.61 | 82.92 | 1.30 | 26.0 | 2.9 | 8.6 | 3.3 |
| | | Protected | 36.95 | | 10.89 | | 84.02 | | 26.8 | | 8.9 | |
| 6 | Morocco | Infected | 23.27 | 20.41 | 9.31 | 21.96 | 57.72 | 33.07 | 20.3 | 19.7 | 7.2 | 15.29 |
| | | protected | 29.24 | | 11. 93 | | 86.24 | | 25.3 | | 8.5 | |
| L.S.D 1% | | | 2.03 | | 2.11 | | 3.22 | | 1.86 | | 1.03 | |
| L.S.D 5% | | | 1.45 | | 1.48 | | 2.29 | | 1.77 | | 1.02 | |

*Redu. % = Reduction %

**Table (6): Principal component analysis (PCA) of disease parameters, yield components and chemical properties.**

| Component | | Total | % Of Variance | Cumulative % | Total | PCA1 | PCA2 |
|---|---|---|---|---|---|---|---|
| Disease parameters | FRS (%) | 9.472 | 78.932 | 78.932 | 9.472 | 78.932 | 9.674 |
| | AUDPC | 1.161 | 9.674 | 88.607 | 1.161 | | |
| | r-value | 0.796 | 6.630 | 95.237 | | | |
| 1000 kernel weight | Total loss (%) | 0.532 | 4.433 | 99.670 | | | |
| | Actual losses (%) | 0.040 | 0.330 | 100.000 | | | |
| Yield/plot | Total loss (%) | 2.795E-16 | 2.329E-15 | 100.000 | | | |
| | Actual losses (%) | 7.362E-17 | 6.135E-16 | 100.000 | | | |
| Chemical properties | carbohydrate mg/g | -5.884E-18 | -4.903E-17 | 100.000 | | | |
| | total protein mg/g | -5.172E-17 | -4.310E-16 | 100.000 | | | |
| | crude fiber | -1.616E-16 | -1.347E-15 | 100.000 | | | |
| | dry gluten | -2.419E-16 | -2.016E-15 | 100.000 | | | |
| | wet gluten | -3.689E-16 | -3.074E-15 | 100.000 | | | |



**Fig. (7): Scree plot (A) and component plot (B) of 12 components for principal component analysis.**

Details: 1,A= FRS (%), 2,B= AUDPC, 3,C= r-value, 4-7/D-G= total and actual losses of 1000 kernel weight (gm) and yield/plot (kg), 8,H= carbohydrate mg/g, 9,I= total protein mg/g, 10,K= crude fiber, 11,L= dry gluten, and 12,M= wet gluten.

## DISCUSSION

Wheat rusts are listed as the most serious diseases affecting global yield and grain quality (Wellings 2011). Yellow rust is a devastating disease that causes crop losses in most varieties growing in worldwide and in Egypt (Abu EL-Naga *et al.,* 2001; Yahyaoui and Rajaram 2012, Chen *et al.,* 2014 and Omara *et al*., 2016). Therefore, the use of resistant varieties contributes and even helps to avoid disease,

maintain wheat productivity and reduces losses resulting from disease to a minimum.

For this reason, some varieties, Shandweel-1, Gemmeiza-11, Sids-1, Sids-12 and Sakha-94 which are acceptable to farmers have been studied and the losses resulting from them have been known, by studying disease parameters and yield components and linking them to technological qualities. Through this study, it is clear that, the tested wheat varieties had a different levels of disease parameters; FRS (%), r-value and AUDPC, yield components; 1000 kernel weight/gm, yield per plot/kg and chemical properties.

The disease parameter, AUDPC is an important indicator of disease progression over the lifespan of the host (Van der Plank 1963), while the infection rate of the tested varieties (r-value) has a large variation, partly because the incidence rate is a regression coefficient and the error variation is large, compared to FRS and AUDPC, the disease increase rate in this study seems to produce an unreliable estimate of slow rusting resistance (Negm 2004; Ali *et al.*, 2008; Safavi *et al.*, 2010; Jindal *et al.*, 2012; Ashmmawy *et.al.*, 2013; Boulot and Aly, 2014; Soliman *et al.*, 2016 and Mabrouk *et al.*, 2019 & 2021).

Field observations showed that the evaluation of yellow rust in 2020 was higher in severity than in the 2021 growing season. Gemmeiza-11 and Sids-12 varieties recorded the highest values of FRS (%) ranged from 63.33 to 83.33%, r-value ranged from 0.043 to 0.063 and AUDPC values ranged from 783.33 to 1333.33 compared to the highly susceptible check variety, Morocco, followed by Sids-1 and Shandweel-1 which recorded moderate values of the three disease parameters (FRS%, r-value and AUDPC) and considered moderately susceptible varieties. On the other hand, Sakha 94 recorded the lowest values of FRS (%), r-value and AUDPC. Where, the values were less than or equal to 13.33%, 0.027, 170.66, respectively and had high level of resistance in the two growing seasons. The difference in the genetic background of resistance reflects the difference between the type of infection and the disease. This is due to the appearance of new virulent race in pathogen populations therefore, the type of infection of some varieties may change over time (Omara *et al.*, 2021). Some varieties can maintain resistance for many years but become susceptible after a period of time (Al-Maaroof, 1997).

Biotic stress affects wheat plants (*Triticum aestivum* L.) and therefore grain yield is inversely proportional to the degree of rust infection.

Assessing the damage caused by disease is a requirement for developing disease control strategies, especially through disease-resistant breeding programs (Simmmonds 1988). The resistance of any variety to yellow rust can be described as its ability to reduce the amount of grain loss due to infection. So, it can conclude that the yield of protected varieties was higher than infected ones, the grain wilting caused by nutrients mainly produced in the flag leaves is used by the fungus instead of being transported to the grain (Johnston 1931; Buchenau 1975; Seck *et al.*, 1988 and Subba Rao *et al.*, 1989). According to the relationship between disease parameters and yield components, 1000 kernel weight and yield per plot, a positive significant strong correlation between FRS (%) and total losses (%) ranged from 0.934 to 0.998 was determined in the two seasons under study. This indicated that the highly susceptible wheat varieties exhibited the highest values of FRS (%), r-value and AUDPC and the highest losses of yield components.

Yield loss depends on many factors, such as the susceptibility of the variety, the time of infection, the speed of disease development, the disease period, crop growth period and environmental conditions (Pretorius 2004 and Chen 2005). If the infection occurs in the early stage of growth, the loss of grain yield for susceptible varieties is major, because the crop maintains acceptable environments for a longer period of time (Afzal *et al.*, 2007). Because the yield loss may be caused by other factors, in addition to the effect of the disease, therefore, it was necessary to calculate the coefficient of determination ($R^2$) to help in calculating the actual loss (%). Therefore, actual loss (%) was estimated according to coefficient of determination ($R^2$) values to obtain the loss due to yellow rust infection only with eliminating the other effective factors (Soliman *et.al.*, 2016; Omara *et al.*, 2018; Al-Maaroof and Nori, 2019 and Khushboo *et al.*, 2021). Accordingly, Gemmeiza-11 and Sids-12 varieties recorded the highest reduction in 1000 kernel weight and yield/plot of the total loss (%) and the actual loss (%) that ranged from 11.40 to 41.96%, respectively, compared to the highly susceptible check variety, Morocco. On the other hand, Sakha 94 recorded the lowest values in the total loss and the actual loss (%) ranged from 1.31 to 5.24% for 1000 kernel weight (TKW) and yield per plot in each growing season. This result was confirmed by those obtained by several investigators (Afzal *et al.*, 2007; Ahmad *et al.*, 2010; Yahyaoui and Rajaram, 2012; Ashmmawy

*et al*., 2013; Aktas and Zencirci 2016; Wendale *et al*., 2016; Soliman *et al*., 2016; Omara *et al*., 2016; Draz *et al*., 2018 and Al-Maaroof and Nori 2019).

As a result of the yield loss, it was necessary to study the effect of the disease on the grain quality and it was necessary to know whether there was an effect or not. Some scientists, such as Johnston 1931; Buchenau 1975; Seck *et al.,* 1988; Subba-Rao *et al.,* 1989; Marsalis &Goldberg 2006 and Khushboo *et al.,* 2021 explained that the yield loss is usually caused by the reduction in the number and size of grains, reduced dry matter, poor root growth and reduced grain quality, environmental conditions and infection stage, because rust fungi affect yield by reducing the area of green leaves, thereby affecting the sugar supply of developing seeds. The flag leaf and the second leaf contribute significantly to sugar production for developing grains. The wilt of the grain caused by the nutrients produced mainly in the flag leaves is used by fungi instead of being transported to the grain. The flag leaf infection is expected to cause significant yield losses, with flag leaves accounting for more than 70% of grain filling. On the other hand, the other leaves are resposible only for 25%.

The results showed the effect of yellow rust on amount of carbohydrate, protein content, crude fiber, wet gluten and dry gluten. The effect was increased in the highly susceptible wheat varieties, Gemmeiza-11 and Sids-12, which lowers protein in grains due to suppression of protein synthesis enzymes, especially nitrate reductase and increases activity of lytic enzyme at the seed formation stage infected tissue (Al-Maaroof & Nori 2019). Ames (2003) and Edward *et al.* (2003) mentioned that protein and gluten contents are commonly used to measure wheat flour quality and increased the protein content of grains is closely associated with an increase in gluten starch. The protein and gluten lead to better value of flour and play an important role in the final product flour. But total amount of rusted protein grain tissue sometimes increases by 20-50% with new weight based on much of the total protein, the fungus body development, especially sporulation and after that, the total protein decreases, but indication for accelerated RNA metabolism suggesting that synthesis of some host proteins can be fortified by infectious diseases, especially before sporulation (Mobarak *et al*., 2010; Ali *et al*., 2016 and Al-Maaroof & Nori 2019). Thus, it is clear that there is a relationship between disease parameters, yield

components and grain quality and the loss can be predicted through the prediction equation.

By studying principal component analysis, it became clear that the most influential components were FRS (%) and AUDPC, as they contributed 88.607% of the total cumulative variance and a prediction equation reached that links all the components together. The study also showed the lack of importance of some of the components under study, which advises researchers in the future not to rely on them in the study.

## CONCLUSIONS

There was positive correlation between disease parameters, yield components and grain quality. For example, the highly susceptible wheat varieties, Gemmeiza-11 and Sids-12 recorded the highest values of FRS (%), AUDPC and the highest values of actual loss (%) of 1000 kernel weight/gm and grain yield/plot (kg). The total loss (%) values were more than the actual loss (%) during the two growing seasons. Therefore, it is necessary to rely on the actual loss in the case of estimating the loss. Qualitative properties were the highest in susceptible wheat varieties, Gemmeiza-11 and Sids-12. Sakha-94 was the best variety in all the tested parameters. It is possible to predict the loss through regression model and the importance of only two components under study are FRS (%) and AUDPC.

## CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

## REFERENCES

Abu El-Naga, S.A.; Khalifa, M.M.; Sherif, S.; Youssef, W.A.; El-Daoudi, Y.H. and Shafik, I. 2001. Virulence of wheat stripe rust pathotypes identified in Egypt during 1999/2000 and sources of resistance. First Regional Yellow Rust Conference for Central & West Asia and North Africa 8-14 May, SPH, Karj, Iran.

Afzal, S.N.; Haque, M.I.; Ahmadani, M.S.; Bashir, S. and Rehman, A. 2007. Assessment of yield losses caused by *Puccinia striiformis* triggering stripe rust in the most common wheat varieties. Pak. J. Bot., 39: 2127-2134.

Ahmad, S.; Afzal, M.; Noorka, I.R.; Iqbal, Z.; Akhtar, N.; Iftkhar, 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(1): 401-407.

Aktas, H. and Zencirci, N. 2016. Stripe rust partial resistance increases spring bread wheat yield in south-eastern Anatolia, Turkey. J. Phytopathol., 164: 1085–1096.

Ali, R.G; Omara, R.I and Ali, Z.A. 2016. Effect of leaf rust infection on yield and technical properties in grain of some Egyptian wheat cultivars, Menoufia J. Plant Prot., 1(8): 19-35.

Ali, S.; Shah, S.J.A. and Maqbool, K. 2008. Field-based assessment of partial resistance to yellow rust in wheat germplasm. J. Agric. Rural. Dev., 6: 99-106.

Al-Maaroof, E.M. 1997. The Role of Variety Mixtures in Disease Control of Wheat Rusts caused by *Puccinia recondita* and *P. striiformis* in Iraq. Ph.D. Thesis, Univ. Agric., Baghdad. 132 Pp.

Al-Maaroof, E.M. and Nori, A.M. 2019. Effect of yellow rust disease on quantitative and qualitative traits of some wheat genotypes under rain-fed conditions. J. Appl. Biol. Sci., 13(2): 75-83.

Ames, N.P.; Clarke, J.M.; Dexter, J.E.; Woods, S.M.; Selles, F. and Marchylo, B. 2003. Effect of nitrogen fertilizer on protein quality and gluten strength parameter in durum wheat varieties (*Triticum turgidum* L.) of the variable gluten strength. Cereal Chem., 80(2): 203-211.

Anonymous, 2000. American Association of Cereal Chemists Approved Methods of the AACC, 10th ed. Methods 08-01, 44-16, 46-30, 56-10, 56-11, and 56-61A. The Association: St. Paul, MN, USA.

Anonymous, 2005. Official Methods of Analysis of the Association of Official Analytical Chemists AOAC. Arlington, Virginia, USA.

Ashmmawy, M.; El-Orabey, W.; Nazim, M. and Shahin, A. 2013. Effect of stem rust infection on grain yield and yield components of some wheat cultivars in Egypt. Int. J. Phytopathol., 2(3):171-178.

Boulot, O.A. and Aly, A.A. 2014. Partial resistance of wheat (*Triticum aestivum*) to leaf rust (*Puccinia triticina*) in Egypt. Egypt. J. Agric. Res., 92(3): 835-850.

Brien, L.; Brown, J.S.; Panozzo, J.F. and Archer, M.J.1990. The effect of stripe rust on the quality of Australian wheat varieties. Aust. J. Agric. Res. 41(8): 27-33.

Buchenau, G.G. 1975. Relationship between yield loss and area under the wheat stem rust and leaf rust progress curves. Phytopathology, 65:1311-1318.

Chen, W.; Welling, 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.

Chen, X. 2005. Epidemiology and control of stripe rust (*Puccinia striiformis* f. sp. *tritici*) on wheat. Can. J. Plant Pathol., 27(3): 314-337.

Chen, X.; Coram, T.; Huang, X.; Wang, M. and Dolezal, A. 2013. Understanding molecular mechanisms of durable and non-durable resistance to stripe rust in wheat using a transcriptomics approach. Curr. Genomics, 14: 111-126.

Colpauzos, 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).

Danial, D.L. 1994. Aspects of Durable Resistance in Wheat to Yellow Rust. Ph.D. Thesis, Wageningen Agric. Univ., 143 pp.

Das, M.K.; Rajaram, S.; Ktonstad, W.K.; Mundt, C.C. and Singh, R.P. 1993. Association and genetics of three components of slow rusting in leaf rust of wheat. Euphytica, 68: 99-109.

Draz, I.S.; Esmail, S.M.; Abou-Zeid, M. and Hafez, Y. 2018. Changeability in stripe rust infection and grain yield of wheat associated to climatic conditions. Env. Biodiv. Soil Security, (2): 143-153.

Edwards, N.M.; Mulvaney, S.J.; Scanlon, M.G. and Dexter, J.E. 2003. A role of gluten and its components in determining *durum semolina* dough viscoelastic properties. Cereal Chem., 80(6): 755-763.

Eriksson, J. 1894. Uber die Spezialisierung des Parasitismusbei den Getreiderostpilzen. Ber. Dtsch. Bot. Ges., 12: 292-331.

Jindal, M.M.; Sharma, I. and Bains, N.S. 2012. Losses due to stripe rust caused by *Puccinia striiformis* in different varieties of wheat. J. Wheat Res., 4: 33-36.

Johnston, C.O. 1931. Effect of leaf rust infection on yield of certain varieties of wheat. J. Am. Soc. Agron., 23: 1-12.

Karakas, O.; Hasancebi, S.; Ertugrul, F.; Akan, K.; Mert, Z.; Cetin, L.; Bolat, N. and Uncuoglu, A.A. 2009. Est-Based multiplex gene expression in yellow rust infected wheat using genome lab Gexp genetic analysis system. Proceed of 12th International Cereal Rust and Powdery Mildews in Antalya, Turkey in (13-16) October 2009, 46 pp.

Khan, M.A. and Mumtaz, H. 2004. Combining yellow rust resistance with high yield in grain wheat. Pp. 28, In: Abstracts. Second Regional

Yellow Rust Conference for Central & West Asia and North Africa, 22-26 March 2004, Islamabad, Pakistan.

Khanfri, S.; Boulif, M. and Lahlali, R. 2018. Yellow Rust (_Puccinia striiformis_): a Serious threat to wheat production worldwide. Not. Sci. Biol., 10(3): 410-423.

Khushboo, S.S.; Gupta, F.; Pandit, D.; Abrol, S.; Choskit, D.; Farooq, S. and Hussain, R. 2021. Epidemiology of stripe rust of wheat: A Review Int. J. Curr. Microbiol. App. Sci., 10(1): 1158-1172.

Kissana, S.N.; Mujahid, Y.M. and Mustafa, Z.S. 2003. Wheat production and productivity 2002-2003. A technical report to apprise the issues and future strategies. National Agricultural Research Center, Pakistan Agricultural Research Council, Islamabad, 19 pp.

Large, E.C. 1954. Growth stages in cereals. Illustration of the feekes scale. Plant Pathol., 3(4): 128-129.

Line, R.F. 2002. Stripe rust of wheat and barley in North America: a retrospective historical review. Annu. Rev. Phytopathol., 40: 75-118.

Mabrouk, O.I.; EL-Hawary, M.N. and Gad, Kh. I. 2021. Disease incidence and genetic analysis of adult plant resistance to leaf rust in some Egyptian wheat cultivars. Egypt. J. Phytopathol., 49(2): 54-67.

Mabrouk, O.I.; El-Orabey, W.M. and Esmail, S.M. 2019. Evaluation of wheat cultivars for slow rusting resistance to leaf and stem rust diseases in Egypt. Egypt. J. Phytopathol., 47(2): 1-19.

Mamluk, O.F; El Naimi, M. and Hakim, M.S. 1996. Host preference in _Puccinia striiformis_ f. sp. _tritici_. In: Proc. Eur. Mediterr. Cereal Rusts Powdery Mildews Conf. 9th, 86-88 Pp.

Marsalis, M.A. and Goldberg, N.P. 2006. Leaf, stem and stripe rust diseases of wheat. New Mexico State University, Guide A-415, 1-8.

Masuko, T.; Minami, A.; Iwasaki, N.; Majita, I.; Nishimura, S.I. and Lee, Y.C. 2005. Carbohydrate analysis by a phenol-sulfuric acid method in microplate format. Anal. Biochem., 339(1): 69-72.

McIntosh, R.A. 1980. Chromosome location and linkage studies involving the wheat stem rust resistance gene _Sr14_. Cereal Res. Commun., 8: 315-320.

Mobarak, E.A.; Omara, R.I. and Najeeb M.A. 2010. Effect of susceptible of some Egyptian wheat cultivars to stripe rust infection on physical, chemical and technological properties, J. Food Dairy Sci., Mansoura Univ., 1(6): 375-385.

Negm, S.S. 2004. Partial Resistance to Leaf Rust in some Egyptian Wheat Varieties. Ph.D. Thesis, Fac. Agric., Menoufia Univ., 180 Pp.

Omara, R.I.; Abu Aly, A.A.M. and Abou-Zeid, M.A. 2018. Characterization of partial resistance to stripe rust (_Puccinia striiformis_ f.sp. _tritici_) in some Egyptian wheat cultivars J. Plant Prot. and Path., Mansoura Univ., 9(2): 111-119.

Omara, R.I.; El-Naggar, D.R.; Abd El-Malik, N.I. and Ketta, H.A. 2016. Losses assessment in some Egyptian wheat cultivars caused by stripe rust pathogen (_Puccinia striiformis_). Egypt J. Phytopathol., 44(1):199-203.

Omara, R.I.; Nehela, Y.; Mabrouk, O.I. and Elsharkawy, M.M. 2021. The emergence of new aggressive leaf rust races with the potential to supplant the resistance of wheat cultivars. Biology, 10(925): 1-25.

Pandey, H.N.; Menon, T.C.M. and Rao, M.V. 1989. A simple formula for calculating area under disease progress curve. Rachis, 8(2): 38-39.

Peterson, R.F.; Campbell, A.B. and Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Can. J. Res., 60: 496-500.

Pretorius, Z.A. 2004. The impact of wheat stripe rust in South Africa. In Proceedings of the 11th International Cereal Rusts and Powdery Mildews Conference. 22–27 August 2004, John Innes Centre, Norwich, UK. European and Mediterranean Cereal Rust Foundation, Wageningen, Netherlands. Cereal Rusts and Powdery Mildews Bulletin, Abstr., A1.29.

Roelfs, A.P.; Singh, R.P. and Saari, E.E. 1992. Rust Diseases of Wheat: Concepts and Methods of Disease Management. CIMMYT, Mexico, D.F., 81 pp.

Safavi, S.A.; Ahari, A.B.; Afshari, F. and Arzanlou, M. 2010. Slow rusting resistance in 19 promising wheat lines to yellow rust in Ardabil, Iran. Pak. J. Biol. Sci., 13: 240-244.

Seck, M.; Roelfs, A.P. and Teng, P.S. 1988. Effect of leaf rust (_Puccinia recondite tritici_) on yield of four isogenic lines. Crop Prot., 7: 39-42.

Sharma, R.C.; Kumarse, N.; Amir, A.; Zafar, Z. and Anwar, U.J. 2016. Reduction of winter wheat yield losses caused by stripe rust through fungicide management. J. Phytopathol., 164(9): 671-677.

Simmonds N.W. 1988. Synthesis: The strategy of rust resistance breeding. In CIMMYT (ed.), Breeding Strategies for Resistance to the Rusts of Wheat (pp. 119-136). Mexico, D.F.: CIMMYT.

Soliman, N.E.; Negm, S.S.; Abd El-backi, A.M. and Mabrouk, O.I. 2016. Quantitative relationship between leaf rust and wheat grain yield in some Egyptian wheat cultivars. Int. J. Sci. Eng. Res., 7(7): 1223-1232.

Statista. 2020. Wheat production in Egypt 2010-2020 Published by Saifaddin Galal, Sep 28, 2020. https://www.statista.com/chartoftheday.

Subba-Rao, K.V.; Yang, X.B.; Berggren, G.T. and Snow, J.P. 1989. A multiple regression model to estimate the contributions of leaves and the effects of leaf rust on yield of winter wheat. Phytopathology, 79(11): 1233- 1238.

Van der Plank, T.E. 1963. Plant Diseases: Epidemics and Control. Academic Press. New York, 349 Pp.

Wellings, C.R. 2011. Global status of stripe rust: a review of historical and current threats. Euphytica, 179: 129-141.

Wendale, L.; Ayalew, H.; Woldeab, G. and Mulugeta, G. 2016. Yellow rust (*Puccinia striiformis*) epidemics and yield loss assessment on wheat and triticale crops in Amhara region, Ethiopia. African J. Crop Sci., 4(2): 280-285.

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, 175 Pp