

## Yield losses in wheat genotypes caused by stripe rust (*Puccinia striiformis* f. sp. *tritici*) in North Delta, Egypt

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### Abstract

Stripe (yellow) rust disease caused by *Puccinia striiformis* f. sp. *tritici*, is a catastrophic wheat disease in wheat-growing regions around the world. The objective of this study was to investigate potential sources of stripe rust resistance and the yield loss of forty local wheat varieties at four locations in Egypt (Sakha, Mutubas, Qillin and Biyala), under yellow rust disease pressure compared to 'Morroco' variety, as control. To determine slow rusting in the field, the following parameters were recorded: final rust severity (FRS%), average coefficient of infection (ACI), relative resistance index (RRI) and reduction % in the 1000 kernel weight. The severity was higher in the second season than in the first. Seven wheat genotypes ('Shaka 62', 'Shaka 9', 'Shaka 95', 'Gemmiza 7', 'Sids 14' and 'Misr 3') showed the high level of resistance, and FRS% values ranged from 0 to 20 moderately resistant (MR) during first season and achieved the least value of loss in TKW (1.28%) with 'Misr 3'. Meanwhile, four genotypes ('Sakha 93', 'Sakha 95', 'Sids 14' and 'Gim. 7') remained highly resistant during the second season and identified to have good level of slow rusting resistance, which these genotypes showed FRS% values ranged from 5R to 30 moderately resistant-moderately susceptible (MRMS), ACI values  $\leq 12$ , RRI values  $\geq 6$  and the loss % in TKW not exceed 12.54%. On the other hand, the lines; 'Shaka 69', 'Shaka 88', 'Shaka 92', 'Giza 160', 'Giza 163', 'Gem 11', 'Sids 2' and 'Sids 6' exhibited complete susceptibility at the four tested sites, recorded FRS% values  $> 50$ . Meanwhile, cv. 'Gem 11' in 2018/2019 recorded the highest level of ACI  $\geq 55$ , the lowest level of RRI  $\leq 4.05$  and the highest loss% in TKW reached 40.69%. These findings could be used in the national wheat breeding program for stripe rust resistance in Egypt.

**Keywords:** ACI; FRS; RRI; stripe rust; TKW; wheat; yield loss

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## Introduction

Wheat is the most widely crop with a serious role in food security with different biotic and abiotic stresses limit its production (Kushnirenko *et al.*, 2021). There are many abiotic and biotic factors affect the growth and yield of wheat crop (Hafez *et al.*, 2020; Alnusairi *et al.*, 2021; Abdelaal *et al.*, 2021). One of the most serious biotic stresses is stripe rust, stripe rust (also known as yellow rust) is an old disease that has emerged as a problem in some areas and develops new races that overcome resistance to wheat cultivars and/or new strains that adapt to new conditions (Omara *et al.*, 2021).

Since the infection may spread across extensive distances, it can create large-scale epidemics in a short period of time. Severe epidemics can develop immediately and entirely destroy crops when virulent races of the pathogen infect susceptible cultivars under disease-friendly climatic conditions (Chen, 2020). After the discovery of *Berberis* spp. as an alternate host and the first-ever explanation of the whole life history of this rust pathogen, it was recently thought to be a macrocyclic rust (Jin *et al.*, 2010). Barberry is as an alternate host for *P. striiformis* and is thought to have contributed to the emergence of new Pst races in several parts of the world (Zhao *et al.*, 2016). If susceptible cultivars become infected early in the crop season and develop, it has the potential to result in a complete loss of wheat output (Waqar *et al.*, 2018). However, losses have been shown to fluctuate depending on the weather, the percentage might range from 10% to 70% conditions in a given location, the emergence of new races pathogen, cultivar susceptibility, and the first infection.

In Egypt, the disease had a significant impact on grain yield production in most Egyptian wheat cultivars. Severe epiphytotic has been observed in the recent five decades, since 1995, producing grain output losses ranging from 14 to 26% in the Nile Delta region, with a 10% loss at the country level (Sajid *et al.*, 2007). The research of race dynamics in *Puccinia striiformis* populations in Europe (Hovmøller, 2001), North America (Chen and Penman, 2005), China (Wan *et al.*, 2004), and Australia (Wellings, 2007) has traditionally concentrated on virulence dynamics of national or regional importance, with little overlap of host differential lines between laboratories. Between the 1960s and 1980s, Ron W. Stubbs and colleagues in Wageningen, the Netherlands, offered yellow rust race typing to a number of countries around the world (Stubbs, 1988). Around 1990, the program was terminated, and in 2010, the collection of over 5000 spore samples preserved in liquid nitrogen was moved to Aarhus University in Denmark (Hovmøller *et al.*, 2009).

The global spread of yellow rust epidemics in recent years (Hovmøller *et al.*, 2010) as well as the spread of epidemics to new locations where the illness was previously absent or unnoticed, has reinforced the need to understand the dissemination, establishment, and evolution of yellow rust races on a global scale (Hovmøller *et al.*, 2011; Walter *et al.*, 2016). In 2011, two new races, known as the Warrior and Kranich races, were discovered on wheat and triticale in a number of European countries ([www.wheatrust.org](http://www.wheatrust.org)). Furthermore, Sing *et al.* (2004) found that rust infections reduced grain production by more than 50% in sensitive wheat varieties. During the year 2019, the intensity of stripe rust in Pakistan was estimated to have topped 30%, inflicting catastrophic damage to wheat output. During the year 2019, the intensity of stripe rust in Pakistan was estimated to have topped 30%, inflicting catastrophic damage to wheat output. It is currently, present in all wheat-growing areas from the north to the south, in both cold and hot climates (Kiani *et al.*, 2021). The present study was done to evaluate wheat breeding lines against rust disease, investigate the resistance and susceptibility of 40 Egyptian wheat varieties to stripe rust infection under field conditions, determine the grain production losses caused by stripe rust infection in the investigated varieties and compare of wheat yield losses in various regions during the two growing seasons 2017-2018 and 2018- 2019.

## Materials and Methods

### *Plant material and experimental design*

This experiment was carried out at four locations i.e., Kafr Elsheikh governorate in Egypt's North Nile Delta (Sakha, Mutubas, Biyala, Qillin) during two successive growing seasons i.e., 2017/2018 and 2018/2019, The four regions are a coastal location in the north of the country. The research regions are defined by longitudes of 30° 30' and 31° 20' east and latitudes of 31° 00' and 31° 30' north, with an elevation of 6.0 m above sea level. The yearly rainfall ranges from 100 to 150 millimeters, and the annual mean temperature is 21.5 °C. Aridisols is the dominating soil type, the dominant soil temperature regime is thermic, and the dominant soil moisture regime is torric according to USDA (2010) using 40 wheat varieties (Table 1). Three replicates were arranged in a Randomized Complete Block Design (RCBD), the plot size was 6×7 m; each plot contained 20 rows with 7 m long and 30 cm between rows. The experiment was planted 15 days after the regular sowing date (the first half of December) to expose the plants to a suitable environment of yellow rust incidence and the ability of rapid germination provided that free moisture is available in surroundings and on leaf surface along with optimum temperature range 7 to 12 °C (Waqar *et al.*, 2018). The experiment was surrounded by a spreader field planted with a variety of wheat genotypes that were extremely vulnerable to stripe rust i.e. *Triticum spelta saharences* and 'Morocco' as control variety to spread inoculums. Normal agronomic practices were applied according to the recommendations of Ministry of Agriculture, the fertilizer nitrogen at 75 kg N/fed was added in the form of urea (46% N) and phosphate 100 kg calcium superphosphate/fed (15.5 kg P<sub>2</sub>O<sub>5</sub>) during seedbed preparation (Gebrel *et al.*, 2020), and irrigation schedule was every three days intervals (Gao *et al.*, 2018).

**Table 1.** List of the used wheat genotypes

No.		Pedigree
1	'Sakha 8'	INDUS/NORTENO"S"-PK348
2	'Sakha 62'	GIZA7/BALADI42
3	'Sakha 69'	Inia/RL 4220//7 C/Yr "S" CM 15430-25-65-0S-0S
4	'Sakha 88'	KVZ//TI/3/MAYA74 "S"//BB/TNTA
5	'Sakha 92'	NAPO63/TNT1A66//WERN "S"
6	'Sakha 93'	Sakha 92/TR 810328 S 8871-1S-2S-1S-0S
7	'Sakha 94''	OPATA/RAYON//KAUZ.CMBW90Y3280-0TOPM-3Y-010M-010M- 010Y-10M-015Y-0Y-0AP-0S.
8	Sakha 95'	CMA01Y00158S-040POY-040M-030ZTM-040SY-26M-0Y-0SY-0S
9	'Giza 139'	HINDI-90/KENYA-256G.
10	'Giza 144'	REGENT/2*GIZA139
11	'Giza 150'	MIDA-CADET/2* GIZA139
12	'Giza 156'	RIO NEGRO/2?MENATANE//KENYA/3?2GIZA135/LTNE950
13	'Giza 157'	ALD"S"/HUAC"S"//CMH74A.630/SX. GM4583-5GM-1GM-0GM
14	'Giza 160'	CHENAB/GIZA155
15	'Giza 162'	Vcm//Cno67/7C/3/Kal/BbCM8399-D-4M-3Y-1 M-1Y-1 M-0Y
16	'Giza 163'	T.aestivum/Bon//Cno/7C CM33009-F-15 M-4Y-2 M-1 M-1 M-1Y-0 M
17	'Giza 164'	Kvz/Buha "s"//Kal/Bb CM33027-F-15 M-500y-0 M
18	'Giza 165'	RIO-NEGRO/2*MENAATANE//KENYA/3/*2 GIZA135LINE950
19	'Giza 167'	Au/UP301//G11/SX/Pew"S"/4/Mai"S"/May"S"//Pew"S"CM67245-C-1M-2Y-1M-7Y-1M-0Y
20	'Giza 168'	MIL/BUC//Seri CM93046-8M-0Y-0M-2Y-0B
21	'Giza 171'	S.6-1GZ-4GZ-1GZ-2GZ-0S
22	'Gem 1'	Maya74/0n//1160-147/3/Bb/1991Gall/4/chat "S" CM58924-IG OG
23	'Gem 3'	BB/7C?2//Y50/KAL?3//Sakha8/4/PRV/WW/5/BJI/ "S"//ON?3/BON

24	'Gem 5'	Vec"s"/SWM 6525 CGM.4017-1GM-6 GM-3 GM-0GM
25	'Gem 7'	GM4611-2GM-3GM-1GM-0GM.
26	'Gem 9'	GM 4583-5GM-1GM-0GM.
27	'Gem 11'	B0W"S"/KVZ"S"//7C/SERI82/3/GIZA168/SAKHA61.GGM7892- 2GM-1GM-2GM-1GM-0GM.
28	'Sids 1'	HD2172/Pavon "S"//1158.57/Maya74 "S" SD46-4Sd-2SD-1SD-0SD
29	'Sids 2'	HD2206/HORK "S"/3/NAPO63/NAPO63/INIA66//WREN "S"
30	'Sids 3'	Sakha 69/Giza155 SD723-7SD-1SD-0SD
31	'Sids 4'	Maya "s"/Mon "S"/CM H74.A592/3/Giza 157*2
32	'Sids 5'	Maya"S"/MON"S"// CMH74A.592/3/Giza158*2.
33	'Sids 6'	Maya "S"/Mon "S"//CMH174A.592/3/Sakha8*2
34	'Sids 7'	Maya "s"/Mon "S"/CM H74.A592/3/Sakha 8*2 SD10002-8SD-1SD-1SD-0SD
35	'Sids 8'	Maya "S" Mon "S"/CMH74. A592/3/Sakha 8?2SD10002-14SD-3SD-1SD-0SD
36	'Sids 14'	KAUZ"S"//TSI/SNB"S". ICW94-0375-4AP-2AP-030AP-0APS-3AP
37	'Misr 1'	OASIS/SKAUZ//4*BCN/3/2*PASTOR.CCMSOYO1881T-050M- 030Y-O3OM-030WGY-33M-0Y-0S. SKAUZ/BAV92.
38	'Misr 2'	SKAUZ/BAV92. CMSS96M0361S-1M-010SY-010M-010SY-8M- 0Y-0S.
39	'Misr 3'	ATTILA*2/ABW65*2/KACHU CMSS06Y00258 2T-099TOPM-099Y-099ZTM-099Y-099M-10WGY-0B-0EGY
40	'Shandw 1'	SITE//MO/4/NAC/TH. AC//3*PVN/3/MIRLO/BUC.

#### *Inoculation and disease assessment*

The experiment was artificially infected in the first week of February for field inoculation. The spreader plants were sprayed with water and dusted with urediniospores from the most common and vigorous yellow rust races. i.e. 4E16, 70E22, 70E32 and 192E192 (Ashmawy *et al.*, 2019) and talcum powder at a rate of 1 (spores): 20 (talcum powder) (v:v). Before the creation of dew, dusting was done in the early evening (about sunset). At the booting stage, all of the plants were inoculated according to the method of (Tervet *et al.*, 1951). To keep protected plots nearly free from stripe rust, the fungicide Sumi-eight 5EC (1H-1, 2, 4-Triazole-1-ethanol, beta.-[(2,4-di chlorophenyl) methylene]-.alpha.-(1,1dimethylethyl)-,(beta. E) (35 cm<sup>3</sup> /100 litter water) was added at 10 and 25 February. The modified Cob's scale was used to rate the intensity and reaction of striped rust in each plot at ten-day intervals from the appearance of rust to the stages of plant growth (Peterson *et al.*, 1948). Disease reaction was described in four infection types i.e., resistance = (R), moderately resistance = (MR), moderately susceptible = (MS) and susceptible = (S) (Roelfs *et al.*, 1992). By multiplying the response value by the degree of infection%, the coefficient of infection (CI) was computed. The average coefficient of infection (ACI) was calculated by adding the CI values of each item (Table 2).

**Table 2.** The observation on response of wheat stem rust

Reaction	Observation	Response value
No Disease	O	0.0
Resistant	R	0.2
Resistant to moderately resistant	R-MR	0.3
Moderately resistant	MR	0.4
Moderately resistant to moderately susceptible	MR-MS	0.6
Moderately susceptible	MS	0.8
Moderately susceptible to susceptible	MS-S	0.9
Susceptible	S	1.0

The highest ACI of a candidate line is set at 100 and all other lines are adjusted accordingly, this gives the Country Average Relative Percentage Attack (CARPA). The Relative Resistance Index (RRI) was calculated on a 0 to 9 scale, where 0 represents the most susceptible and 9 shows highly resistant variety. For leaf rust, RRI=5 or 6 indicates that the genotype is acceptable in terms of resistance, whereas RRI=7 or higher indicates that the genotype is desirable in terms of resistance. RRI=6 implies the genotype is acceptable in its resistant for stripe and stem rust, whereas RRI=7 and above implies the genotype is desired in its resistant. The following formula was used for calculation of RRI (1) (Akhtar *et al.*, 2002).

$$RRI = [(100 - CARPA) / 100] \times 9 \quad (1)$$

The desirable index and acceptable index number for stem rust are presented in Table 3 (Rehman *et al.*, 2019).

**Table 3.** The response values of wheat stem rust

Disease	Desirable index	Acceptable index
Stem rust	7 and above	6

#### *Assessment of yield loss*

At maturity, the crop of each plot (42 m<sup>2</sup>) was harvested and yield of each genotype was weighed by conventional balance. The influence of stripe rust severities on yield was determined by comparing the yield of infected and protected cultivars. Yield loss was estimated using the simple equation as follows:

$$\text{Loss \%} = 1 - Y_d / Y_h \times 100 \quad (\text{Calpouzou } \textit{et al.}, 1976) \quad (2)$$

Where: Y<sub>d</sub> = Yield of diseased plants.

Y<sub>h</sub> = Yield of healthy plants.

Data of 1000-kernel weight (g) was calculated according to Ghulam (2004). Thousand kernels randomly selected from each variety and counted with a seed counter and were weighted with an electronic balance to calculate 1000-kernel weight (g).

#### *Statistical analysis*

In this study we have three factors the first one is genotypes (40 lines), the second one is locations (4 locations) and the third one is the seasons (2 seasons). Assumption's treatments:

1-The normality of the residuals of all dependent variables is accepted by Kolmogorovby - Smirnov 's ( $p > 0.05$ ) (Barbara *et al.*, 2013). 2-Homogeneity of variances was checked by Levene's test was satisfied in all dependent variables under the three factors effect (Levene's  $p > 0.05$ ) (Brown *et al.*, 1973) The data were analysed by ANOVA, using software IBM SSSPS27, the analysis of variance (ANOVA) was used to discern differences among genotypes. Varieties and years were considered fixed while the locations were considered as random effects and the mean performance of all resistance features of the tested genotypes was compared using Fisher's protected the Least Significant Difference (LSD) at 5% (Snedecor and Cochran, 1981).

## **Results**

Analysis of variance in Table 4 showed in general that all the tested variables i.e., disease severity (%), ACI, RRI and 1000 kernel weight reduction were significantly differed as the sources of variation. Interaction between locations (L), seasons (s) and cultivars (C) (L×S×C) was found to be insignificant effect for the tested variables i.e., FRS%, ACI, RRI and 1000 kernel weight loss (Table 4).

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

During the two growing seasons of the study, wheat plants of the studied cultivars in fully protected plots were virtually completely free of stripe rust infection in four sites (Sakha, Mutubas, Qillin and Biyala). At

the four locations, the final rust severity (%) ranged from Tr R (the trace resistance) to 80S and immune with 'Misr3' during the first season, and from 5R to 100S during the second season (Table 5).

**Table 4.** Analysis of variance for the combined data to the effects of cultivars, location and years on disease severity (%) (FRS), ACI, RRI and the loss of 1000 Kernel weight (g) of wheat stripe rust under field conditions during 2017/18 and 2018/19 growing seasons

Sources of variation (S.O.V)	Degree of freedom (df)	Variables						The loss of 1000 kernel weight (g)	
		FRS%		ACI		RRI		MS	F. value
		MS	F. value	MS	F. value	MS	F. value		
Variety (V)	39	7319.3	0.96 <sup>NS</sup>	13406.158	45.357*	270.584	1.02*	708.622	7.264*
Season (S)	1	19123.3	4.17*	9821394	3.44 <sup>NS</sup>	883.204	7.31 <sup>NS</sup>	16547.172	31.606 <sup>NS</sup>
Location(L)	3	1343	0.04 <sup>NS</sup>	3630.825	12.284 <sup>NS</sup>	2994.425	0.71 <sup>NS</sup>	424.160	0.768 <sup>NS</sup>
V*S	39	104551.2	8.92*	7919889	5.40*	43973.628	11.1*	150.353	2.155*
V*L	117	5765.8	1.11 <sup>NS</sup>	4827896	1.62 <sup>NS</sup>	4920.932	2.02 <sup>NS</sup>	97.533	1.398 <sup>NS</sup>
S*L	3	12579.3	8.41*	6119877	0.32*	4920.932	9.60*	523.186	7.498*
V*S*L	116	5084.6	0.21 <sup>NS</sup>	3120854	0.22 ns	1921.889	0.24 <sup>NS</sup>	69.773	18.807 <sup>NS</sup>
Error	638	404962.9		287175781		176176.826		25500.47	

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

The striped rust outbreak was more severe since the majority of the examined wheat varieties at the four locations were extensively rusted and had the highest FRS values (%) during the two growing seasons, which the wheat cultivars i.e. ('Shaka 69', 'Shaka 88', 'Shaka 92', 'Giza 160', 'Giza 163', 'Sids 2' and 'Sids 6') showed disease severity between low resistance to highly susceptible (50 to 80%) during the first season at the all tested locations, while during the second season FRS values up to 100% with most of wheat cultivars with some exceptions, i.e. 'Sakha 8', 'Sakha 62', 'Sakha 94', 'Giza 162', 'Giza 167', 'Gema5', 'Gem 3', 'Gem. 7', 'Gem.9', 'Sids 8' and 'Misr3', which recorded the lowest ratings of FRS (%) from high to moderate level of resistance (5 to 40 S) at the four tested locations. Additionally, 7 wheat genotypes i.e., 'Shaka 62', 'Shaka 93', 'Shaka 95', 'Gemiza 7', 'Sids14' and 'Misr 3' showed the high level of resistance, which FRS values (%) (ranged from 0 to 20 MR) and showed immune variety with Misr3 during the first season. Furthermore, the disease severity in the moderate susceptible (5 MS-40 MS) was recorded with 5 genotypes i.e. ('Giza 162', 'Gem 3', 'Gem 9', 'Sids 1' and 'Sids 3'). Meanwhile, during the second season, only 4 wheat cvs demonstrated a relatively sufficient level of mature plant resistance to stripe rust at the four locations, i.e., 'Sakha 93', 'Sakha 95', 'Sids 14' and 'Gim.7', which FRS (%) values ranged from (5 R to 30 MRMS).

#### *Average coefficient of infection (ACI)*

Within the trial, excellent yellow rust (stripe rust) epidemic pressures were built at each test location. In 2017-2018 and 2018-2019, the resistance status of 40 genotypes to stem rust was determined using average coefficients of infection (ACI) and classified into resistance groups based on this disease characteristic compared to control variety (Table 6). A total of 8 out of 40 genotypes namely: 'Sakha 93', 'Sakha 94', 'Sakha 95', 'Gem 7', 'Gem 9', 'Sids 14' and 'Misr3') exhibited the highest value of resistant at the four locations during the two growing seasons of the study genotypes, which ACI values not exceeding 17.5. In contrast, 18 out of 40 genotypes were the lowest resistant at the four locations during the two growing seasons of the study genotypes. These include lines 'Sakha 69', 'Sakha 88', 'Sakha 92', 'Giza 144', 'Giza 150', 'Giza 160', 'Giza 163', 'Giza 164', 'Giza 165', 'Gem 11', 'Sids 1', 'Sids 2', 'Sids 3', 'Sids 5', 'Sids 6', 'Sids 7', 'Misr 1' and 'Misr 2' displayed an ACI values of higher than 41 reached 80.

**Table 5.** Final strip rust severity (%) of forty Egyptian wheat cultivars under field conditions at four locations; Sakha, Mutubas, Qillin and Biyala location during 2017/18 and 2018/19 growing seasons

Cultivar	FRS (%) / Location / Season							
	2017/2018				2018/2019			
	Sakha	Mutubas	Qillin	Biyala	Sakha	Mutubas	Qillin	Biyala
'Sakha 8'	20S	20S	10S	30S	30S	40S	30S	40S
'Sakha 62'	20MR	10MR	20MR	10MR	10S	50S	40S	20S
'Sakha 69'	50S	70S	70S	60S	70S	100S	90S	90S
'Sakha 88'	60S	80S	70S	70S	70S	80S	70S	100S
'Sakha 92'	50S	80S	60S	60S	80S	80S	70S	90S
'Sakha 93'	TrR	TrR	TrR	TrR	5R	TrR	5R	TrR
'Sakha 94'	20MS	20MS	10MS	10MS	5S	5S	5S	20S
'Sakha 95'	10MR	10MR	20MR	10MR	20MRMS	10MRMS	20MRMS	10MRMS
'Giza 139'	10S	5S	10S	10S	80S	80S	60S	80S
'Giza 144'	30S	20S	30S	30S	60S	80S	60S	90S
'Giza 150'	30S	20S	40S	30S	80S	100S	90S	100S
'Giza 156'	20S	10S	20S	20S	60S	70S	80S	80S
'Giza 157'	30S	30S	40S	60S	60S	40S	70S	100S
'Giza 160'	60S	80S	60S	80S	60S	80S	80S	80S
'Giza 162'	5MS	10MS	20MS	20MS	10S	10S	20S	30S
'Giza 163'	40S	60S	60S	60S	80S	100S	90S	100S
'Giza 164'	30S	40S	40S	60S	80S	100S	80S	100S
'Giza 165'	40S	40S	30S	50S	70S	100S	70S	90S
'Giza 167'	30S	30S	20S	30S	30S	30S	40S	40S
'Giza 168'	20S	40S	30S	30S	70S	80S	40S	50S
'Giza 171'	30S	20S	10S	20S	40S	30S	20S	30S
'Gem 1'	50S	40S	40S	50S	70S	40S	40S	70S
'Gem 3'	5MS	5MS	10MS	20MS	10S	20S	20S	30S
'Gem 5'	30S	40S	40S	40S	40S	50S	60S	60S
'Gem 7'	10MR	10MR	10MR	10MR	20MS	10MS	20MS	20MS
'Gem 9'	Tr S	Tr S	5 S	5S	20S	30S	20S	30S
'Gem 11'	30S	30S	40S	30S	80S	80S	90S	90S
'Sids 1'	20MS	20MS	20MS	20MS	80S	100S	80S	100S
'Sids 2'	50S	60S	60S	50S	90S	100S	80S	100S
'Sids 3'	30MS	30MS	30MS	40MS	100S	100S	70S	100S
'Sids 4'	5S	10S	20S	10S	50S	70S	70S	70S
'Sids 5'	20S	20S	30S	30S	80S	100S	90S	100S
'Sids 6'	50S	70S	70S	70S	60S	80S	90S	90S
'Sids 7'	30S	40S	40S	40S	60S	70S	80S	80S
'Sids 8'	10S	10S	20S	20S	20S	30S	40S	30S
'Sids 14'	5MR	10MR	10MR	10MR	20MRMS	30MRMS	20MRMS	30MRMS
'Misr 1'	20S	30S	40S	30S	100S	90S	100S	90S
'Misr 2'	30S	30S	20S	20S	90S	80S	800S	70S
'Misr3'	0	0	0	0	10S	5S	5S	5S
'Shandw 1'	20S	20S	20S	20S	60S	50S	50S	50S
Check	80S	90S	100S	100S	100S	100S	100S	100S
LSD 5%	9.08	9.4	9.3	8.9	7.04	6.88	6.96	7.3

Only two cultivars ('Shandw 1' and 'Giza 167') exhibited moderately resistant at the four tested locations and had ACI values not exceeding 40. Furthermore, the remaining test genotypes at four experimental locations had various ACI values between (highly to moderately resistant cultivars) and (moderately to susceptible resistant cultivars), compared to the susceptible control 'Morocco', which showed the greatest ACI values up to 95 during this study. For instance, the wheat cultivars, 'Sakha 8', 'Sakha 62', 'Giza 162', 'Giza 171', 'Gem 3' and 'Sids 8' had ACI values ranging from 7 to 35, while, the wheat genotypes, 'Giza 139', 'Giza 156', 'Giza 157', 'Giza 168', 'Gem 1', 'Gem.5' and 'Sids 4' had ACI values ranging from 27.5 to 80.

*The relative resistance index (RRI) value*

Data presented in Table (6) shows the relative resistance index (RRI) values obtained for 40 Egyptian wheat genotypes during the two seasons, in comparison of the susceptible control 'Morocco'. The highest RRI of stripe rust resistance at the four tested locations, identified in 15 elite lines: 'Sakha 8', 'Sakha 62', 'Sakha 93', 'Sakha 94', 'Sakha 95', 'Giza 162', 'Giza 167', 'Giza 171', 'Gem 3', 'Gem 7', 'Gem 9', 'Sids 8', 'Sids 14' and 'Misr3', which showed desirable/acceptable (RRI) to stripe rust with RRI value  $\geq 6$  to  $< 9$ , except Sakha 8 at Biyala location was 5.85. Generally, most of the tested genotypes depicted RRI value  $< 6$  at the four tested locations and were undesirable range with some exceptions, 'Giza 167' at (Sakha, Mutubas and Qillin locations), 'Giza 171' at (Mutubas, Qillin and Biyala locations) and 'Sids 4' at Sakha location, which recorded acceptable resistant with RRI values  $> 6$  ranging from 6.3 to 7.65.

*Loss (%) in thousand kernel weight (TKW)*

To describe and assess the capacity of 40 wheat cultivars to tolerate stripe rust infection, the effect of infection on grain production of all investigated wheat cultivars was estimated under field conditions at 4 experimental locations throughout the two growing seasons, 2017/18 and 2018/19 (Table 7).

At Sakha location, thousand kernel weight (TKW) loss decreased by 1.97 to 27.63% during the first season and 2.1 to 39.94% during the second growing season. The least reduction of TKW was recorded from lines: 'Sakha 69', 'Sakha 93', 'Sakha 95', 'Giza 156', 'Gem 7', 'Misr 1' and 'Misr3', not exceeding 5.19% during 2017/18. Additionally, during 2018/19, the least reduction was achieved with only two wheat cultivars 'Sakha 93' and 'Misr3' (3.42% and 2.1%, respectively). While, the highest percentages of loss (%) ranged between  $\geq 21.32\%$  and 39.94% obtained from cultivars: 'Giza 150', 'Gem. 11', 'Sids 5', 'Sids 6', 'Sids 7' and 'Sids 8' during both seasons, but only during the second season, the highest loss% recorded by: 'Sakha 92' (25.05%), 'Giza 165' (23.65%), 'Giza 167' (22.19%), 'Sids 1' (21.9%), 'Sids 2' (22.19%) and 'Sids 3' (28%).

At Mutubas location, TWK loss (%) ranged from 1.81% to 33.24% during the first growing season, while it was ranged between 1.34 and 39.74 % during the second experimental season. The lowest percentages of (TKW) reduction during both growing seasons depicted in two wheat cultivars: 'Sakha 94' (2.06 and 2.8 respectively) and 'Misr3' (1.81 and 134, respectively), followed by cv. 'Sakha 62' (4.37%), 'Giza 156' (3.29%), 'Gem.7' (3.6%), 'Sids 14' (3.2%) and 'Misr2' (4.93) during the first growing season.

On the other hand, the highest percentage of TKW reduction was obtained from 'Sakha 92', 'Giza 163' and 'Sids 6' (33.24, 20.87 and 29.1, respectively) in 2017/18, reached (39.74, 39.6 and 30.71%, respectively) in 2018/19, as well as only at the second growing season, 24 of the total tested cultivars namely; 'Sakha 8', 'Sakha 62', 'Sakha 69', 'Sakha 88', 'Giza 139', 'Giza 144', 'Giza 150', 'Giza 156', 'Giza 157', 'Giza 160', 'Giza 162', 'Giza 164', 'Giza 165', 'Giza 167', 'Gem 3', 'Gem. 11', 'Sids 1', 'Sids 3', 'Sids 4', 'Sids 5', 'Sids 6', 'Sids 7', 'Sids 8' and 'Misr 2', recorded the highest reduction  $> 20$  reached 39.74%.

**Table 6.** Disease response and mean comparison for Average coefficient of infection ACI, and RRI of forty Egyptian wheat cultivars under field conditions at four locations; Sakha, Mutubas, Qillin and Biyala location during 2017/18 and 2018/19 growing seasons

ACI, RRI/ Location								
Cultivar	ACI				RRI			
	Sakha	Mutubas	Qillin	Biyala	Sakha	Mutubas	Qillin	Biyala
'Sakha 8'	25	30	20	35	6.75	6.3	7.2	5.85
'Sakha 62'	9	27	24	12	8.19	6.57	6.84	7.92
'Sakha 69'	60	85	80	75	3.6	1.35	1.8	2.25
'Sakha 88'	65	80	70	85	3.15	1.8	2.7	1.35
'Sakha 92'	65	80	65	75	3.15	1.8	3.15	2.25
'Sakha 93'	0.8	0.6	0.8	0.6	8.928	8.946	8.928	8.946
'Sakha 94'	10.5	10.5	6.5	14	8.055	8.055	8.415	7.74
'Sakha 95'	8	5	10	5	8.28	8.55	8.1	8.55
'Giza 139'	45	42.5	35	45	4.95	5.175	5.85	4.95
'Giza 144'	45	50	45	60	4.95	4.5	4.95	3.6
'Giza 150'	55	60	65	65	4.05	3.6	3.15	3.15
'Giza 156'	40	40	50	50	5.4	5.4	4.5	4.5
'Giza 157'	45	35	55	80	4.95	5.85	4.05	1.8
'Giza 160'	60	80	70	80	3.6	1.8	2.7	1.8
'Giza 162'	7	9	18	23	8.37	8.19	7.38	6.93
'Giza 163'	60	80	75	80	3.6	1.8	2.25	1.8
'Giza 164'	55	70	60	80	4.05	2.7	3.6	1.8
'Giza 165'	55	70	50	70	4.05	2.7	4.5	2.7
'Giza 167'	30	30	30	35	6.3	6.3	6.3	5.85
'Giza 168'	45	60	35	40	4.95	3.6	5.85	5.4
'Giza 171'	35	25	15	25	5.85	6.75	7.65	6.75
'Gem 1'	60	40	40	60	3.6	5.4	5.4	3.6
'Gem 3'	7	12	14	23	8.37	7.92	7.74	6.93
'Gem 5'	35	45	50	45	5.85	4.95	4.5	4.95
'Gem 7'	10	6	10	8	8.1	8.46	8.1	8.28
'Gem 9'	11.5	16.5	12.5	17.5	7.965	7.515	7.875	7.425
'Gem 11'	55	55	65	60	4.05	4.05	3.15	3.6
'Sids 1'	50	60	50	60	4.5	3.6	4.5	3.6
'Sids 2'	70	80	70	75	2.7	1.8	2.7	2.25
'Sids 3'	65	62	50	66	3.15	3.42	4.5	3.06
'Sids 4'	27.5	40	45	40	6.525	5.4	4.95	5.4
'Sids 5'	50	60	60	65	4.5	3.6	3.6	3.15
'Sids 6'	55	75	80	80	4.05	2.25	1.8	1.8
'Sids 7'	45	55	60	60	4.95	4.05	3.6	3.6
'Sids 8'	15	20	30	25	7.65	7.2	6.3	6.75
'Sids 14'	7	11	8	11	8.37	8.01	8.28	8.01
'Misr 1'	60	60	70	60	3.6	3.6	2.7	3.6
'Misr 2'	60	55	50	45	3.6	4.05	4.5	4.95
'Misr 3'	5	2.5	2.5	2.5	8.55	8.77	8.77	8.77
'Shandw 1'	40	40	35	35	5.4	5.4	5.85	5.85
Check	95	95	95	100	0.9	0.45	0	0
LSD 5%	1.77	1.83	1.68	1.89	2.03	2.33	2.24	2.4

**Table 7.** Effect of stripe rust infection on the loss of 1000 kernel weight (g) of 40 wheat cultivars at four locations; four locations; Sakha, Mutubas, Qillina and Biyala location during 2017/18 and 2018/19 growing seasons

Cultivar	The loss of 1000 kernel weight (g)							
	2017/2018				2018/2019			
	Sakha	Mutubas	Qillin	Biyala	Sakha	Mutubas	Qillin	Biyala
'Sakha 8'	8.37	8.8	11.48	14.66	18.38	25.29	20.85	24.66
'Sakha 62'	7.96	4.37	5.77	6.67	16.93	29.72	14.03	16.59
'Sakha 69'	9.14 3.14	10.23	18.72	18.17	18.58 6.58	36.78	17.07	21.46
'Sakha 88'	15.17	17.81	20.26	22.8	18.9	21.29	22.48	30.02
'Sakha 92'	16.17	33.24	16.44	19.57	25.05	39.74	22.3	26.15
'Sakha 93'	3.29	3.75	3.29	4.87	3.42	7.68	4.41	4.43
'Sakha 94'	7.89	2.06	10.3	10.67	11.55	2.8	11.3	18.86
'Sakha 95'	5.19	12.54	4.35	4.19	6.02	5.03	8.64	11.1
'Giza 139'	10.76	5.52	8.26	14.39	13.7	26.89	16.4	31.01
'Giza 144'	12.8	15.01	11.52	10.76	11.6	23.36	15.02	11.6
'Giza 150'	21.32	18.91	22.54	21.31	23.06	35.91	28.631	23.06
'Giza 156'	3.29	3.29	9.73	12.69	8.95	38.91	21.54	29.05
'Giza 157'	13.62	9.83	15.39	14.76	19.05	25.54	29.6	18.33
'Giza 160'	15.89	14.92	15.49	21.72	16.56	30.64	19.25	20.49
'Giza 162'	13.42	7.453	13.13	10.26	16.09	10.25	15.14	16.95
'Giza 163'	16.72	20.87	19.72	26.13	19.97	39.6	28.72	35.76
'Giza 164'	11.64	12.48	14.55	14.28	18.58	30	24.33	11.39
'Giza 165'	18.75	11.8	18.48	21.87	23.65	32.59	22.68	20.52
'Giza 167'	15.35	9.19	15.143	18.33	22.19	29.63	26.87	24.28
'Giza 168'	9.55	15.48	16.82	19.22	19.21	18.47	19.74	22.89
'Giza 171'	12.18	9.96	11.95	16.55	13.3	15.23	15.67	18.47
'Gem 1'	15.92	18.85	18.46	13.97	19.08	17.24	18.62	23.21
'Gem 3'	9.56	15.14	15.83	20	16.48	30.07	20.73	25.21
'Gem 5'	14.61	19.06	17.48	21.37	18.63	24.67	32.91	30.64
'Gem 7'	3.81	3.6	4.78	4.57	14.97	15.74	16.04	14.88
'Gem 9'	8.81	10.5	13.85	9.35	12.17	9.62	14.11	14.34
'Gem 11'	22.51	11.89	13.51	11.28	39.94	38.98	40.69	32.25
'Sids 1'	7.99	6.92	10.2	10.5	21.9	21.47	29.95	15.89
'Sids 2'	16.55	16.7	23.44	21.37	22.19	19.89	29.57	25.1
'Sids 3'	14.59	16	15.03	19.26	28	38.45	32.37	31.92
'Sids 4'	13.25	15.37	11.32	16.7	18.13	38.62	36.36	35.3
'Sids 5'	21.8	13.43	21.75	20.92	21.29	29.75	27.56	26.25
'Sids 6'	27.63	29.1	27.94	26.33	31.01	30.71	31.79	34.68
'Sids 7'	21.85	17.77	19.76	19.37	22.42	34.58	27.41	27.85
'Sids 8'	23.93	15.69	10.31	14.77	23.24	26.27	18.69	23.28
'Sids 14'	12.38	3.02	4.11	5.19	13.76	6.62	17.67	11.95
'Misr 1'	5.03	6.74	6.034	4.28	15.45	19.96	15.49	25.79
'Misr 2'	6.49	4.93	4.33	2.52	13.09	23.25	17.3	25.02
'Misr3'	1.97	1.81	1.55	1.28	2.1	1.34	3.49	2.83
'Shandw 1'	11.7	13.57	9.24	8.95	19.17	19.83	15.58	19.83
LSD 5%	0.2356	0.2773	0.2673	0.2567	0.2345	0.2267	0.2346	0.2467

At Qillin location, TWK loss (%) was significantly decreased by 1.55% to 27.94% during the first growing season, but it was ranged between 3.49% to 36.36% during the second growing season (Table 6). During both seasons, the minimum reduction in (TWK) was registered in the wheat cultivar; Sakha 93 (3.29% and 4.41%, respectively) and Misr3 (1.55 % and 3.49%, respectively), whilst, the highest percentage drooping in test (TWK) was registered in the wheat cultivars: 'Sakha 88', 'Giza 150', 'Sids 2', 'Sids 5' and 'Sids 6' which recorded loss% between  $\geq 20.26\%$  and  $\leq 31.79$ . In particular, the wheat cultivar; 'Sakha 95', 'Gem 7', 'Sids 14'

and 'Misr 2', showed the least reduction not exceeding 4.78%, only during 2017/18, in contrast, 'Sakha 8', 'Sakha 92', 'Giza 156', 'Giza 157', 'Giza 163', 'Giza 164', 'Giza 165', 'Giza 167', 'Gem 3', 'Gem 5', 'Sids 1', 'Sids 3', 'Sids 4' and 'Sids 7' exhibited the highest loss (%) reached between  $\geq 20.73$  and  $\leq 36.36\%$ .

At Biyala location, TWK loss (%) reduced dramatically, from 1.28% to 26.33% in the first growing season, as well as, from 2.83 percent to 35.76 % in the second season. The lowest estimation of loss (%) obtained from cultivars: 'Sakha 93' (4.87%), 'Sakha 95' (4.19%), 'Gem 7' (4.57%), 'Misr 1' (4.28%), 'Misr 2' (2.52%), 'Misr3' (1.28%), in the first season. Similarity 'Sakha 93' (4.43%) and 'Misr3' (2.83%) exhibited also the lowest loss (%) during the second season. On the other hand, the highest TWK loss% was obtained from 'Sakha 88', 'Giza 150', 'Giza 160', 'Giza 163', 'Gem 3', 'Gem 5', 'Sids2', 'Sids 5', 'Sids 6' during both seasons, ranged from  $\geq 20$  to  $\leq 26.33$ , and  $\geq 20.49$  % to  $\leq 35.76\%$ . Likewise, the cvs. 'Sakha 8', 'Sakha 69', 'Sakha 92', 'Giza 139', 'Giza 156', 'Giza 167', 'Giza 168', 'Gem 1', 'Gem 11', 'Sids 3', 'Sids 4', 'Sids 7' and 'Sids 8' showed the lowest loss (%) during the second growing season, ranged between  $\geq 21.46$  and  $\leq 35.3\%$ .

## Discussion

Stripe rust (*Puccinia striiformis* f. sp. *tritici*), the most damaging disease, has caused catastrophic yield losses in the majority of wheat cultivars used in Egypt and around the world (Chen *et al.*, 2014; Martinez *et al.*, 2018; Abdelaal *et al.*, 2014). The stripe rust resistance field was defined using 40 wheat genotypes during the two growth seasons of the study in the infected plots at the four locations; Sakha, Mutubas, Qillin and Biyala. Yellow rust resistance was assessed, as well as, the interactions among them (Table 4) using four separate disease criteria: final rust severity (FRS), ACI, RRI, and loss percentage in TWK. The data was collected to determine the reaction type of the genotypes, which ranged from resistant (R) to susceptible (S). Additionally, yellow rust significantly affects yield component of all evaluated genotypes, the disease severity varied significantly, which could be attributed to variances in the amount of resistance genes present and the manner of gene activation. Wheat lines with FRS values of 1-30 %, 31-50 %, and 51-70 % were classified as having strong, moderate, and low levels of slow rusting resistance (Safavi, 2012). At the four locations under filed conditions and under a high stripe rust pandemic during the two seasons, 'Sakha 62', 'Sakha 93', 'Sakha 94', 'Sakha 95', 'Gem 7', 'Sids 14' and 'Misr3' showed the lowest final rust severity ranged from immune with cv. 'Misr3' to 20 MS during the first season, while ranged from 5R to 10S during the second season, except 'Sakha 62' recorded between high to moderate level of resistance. This resistance may be related to the existence of the effective gene Yr5 (Ashmawy and Ragab, 2016). However, final rust severity (%) was high in the most wheat cultivars particularly during the second growing season such as wheat cultivars: 'Sakha 69', 'Sakha 88', 'Sakha 92', 'Giza 139', 'Giza 144', 'Giza 150', 'Giza 156', 'Giza 157', 'Giza 160', 'Giza 163', 'Giza 164', 'Giza 165', 'Giza 168', 'Gem 11', 'Sids 1', 'Sids 2', 'Sids 3', 'Sids 5', 'Sids 6', 'Sids 7', 'Misr1' and 'Misr 2'. It means that different regions had insignificant effect on rust severity, while the different seasons had significant effect on genotypes resistance Table 4. Likewise, Shahin *et al.* (2020) reported that 'Misr3' has the lowest final rust severity, while the highest final rust severity recorded with wheat cultivars: 'Misr 1', 'Misr 2', 'Gemmeiza 11' during 2018-2019 at four tested locations: Sakha, El- Gemmeiza, Itay El- Baroud and Shubin El- Kom and 'Giza 168' was by moderately resistant wheat variety, but in our study recorded high terminal rust severity. Contrary of our study, Ashmawy and Ragab (2016) found that 'Misr 1' and 'Misr2' showed lower rust severity and 'Sakha 94', 'Sakha 93' showed higher rust severity. The discovery of new races revealed that virulence in the Pst population was changing constantly. As a result of a significant interaction between variety and the growing season, Table 4, in our investigation, it's possible that the elevated severity observed in these genotypes in the second growing season was attributable to the development of a new stripe rust race (Ashmawy and Ragab, 2016). Shahin (2020a) recorded the first report about the "Warrior" race of wheat stripe rust has been discovered for the first time in Egypt. Under strong disease pressure, lines with a low FRS may have more additive genes or genes with larger effects (Singh *et al.*, 2004). During the span of an epidemic, the FRS reflects a combination of all resistance elements. Furthermore,

in the 2009 and 2010 wheat growing seasons, major stripe rust epidemics occurred in North Africa, West and Central Asia (Hodson and Nazari, 2010). Due to a more favourable environment for disease development, FRS (percent) of slow rusting wheat genotypes was higher in Batan than in field trials in Obregon Ciudad, according to Similarity (Herrera-Foessel *et al.*, 2007). Under field conditions, several researchers have shown that environmental variables play an essential role in the transmission and development of stripe rust infection (Chen *et al.*, 2014; Omara and Abdelaal, 2019).

The infection is mostly spread through the several factors that determine the severity of the disease in the plant. Among them are the environmental factors could also play a role in the dynamics of wheat stripe rust disease the data from our previous study revealed that the rate of wheat stripe rust infection was found to have peaked between the months of January to March in Egypt, when the temperature during this period normally remains very low. Also, the diversity of the prevalent stripe rust virulent races within it is population from one year to another. Different disease reactions to stripe rust observed between the tested genotypes suggested that these wheat genotypes had diverse genetic background (Shahin *et al.*, 2018, Sahahin *et al.*, 2020a, b).

Ali *et al.* (2008) reported that genotypes with ACI values of 0-20, 21-40, and 41-60 exhibited better, moderate, and low levels of partial resistance to yellow rust, respectively. Although it is influenced by changes in the environment, partial resistance imparted by mature plant resistance. According to Aslam (1982), a scale of 0-9 was used to identify resistant wheat genotypes for rust pathogen (the Relative Resistance Index (RRI)), In Egypt, the RRI assessment is being utilized to investigate the selection of wheat genotypes resistant to rust diseases. In this study the partially resistant wheat recorded with genotypes: 'Sakha 8', 'Sakha 62', 'Sakha 93', 'Sakha 94', 'Sakha 95', 'Giza 162', 'Giza 167', 'Giza 171', 'Gem 3', 'Gem 7', 'Gem 9', 'Sids 8', 'Sids 14' and 'Misr3', showed the lowest values and slightly higher value of ACI, RRI value >6 and the lowest loss % of TKW <20% under four tested locations during the two-growing season. According to Poudyal and Chen (2010) genotypes with higher partial resistance (PR) prevent significant yield loss. Stripe rust infection can significantly diminish grain productivity on susceptible varieties (Ashmawy and Ragab, 2016). On the other hand, the susceptible tested cultivars were: 'Sakha 69', 'Sakha 88', 'Sakha 92', 'Giza 144', 'Giza 150', 'Giza 160', 'Giza 163', 'Giza 164', 'Giza 165', 'Gem 11', 'Sids 1', 'Sids 2', 'Sids 3', 'Sids 5', 'Sids 6', 'Sids 7', 'Misr 1' and 'Misr 2', which showed the lower levels of slow rusting resistance at four tested locations, which recorded the highest level of ACI >40, the lowest values of RRI <5, as well as, the highest proportion of TKW reduction >30%. Previous research has shown that stripe rust infection reduces photosynthetic area, diminishing yield and yield component percentages (Herrera-Foessel *et al.*, 2007). The reduction in TKW for 'Morocco' might be due to the effect of the disease on the size and mass of the seed. Infection on wheat stem and leaf sheaths by stem rust affects the transport of assimilates to the developing kernel and results in shrivelled kernel (Mitiku *et al.*, 2018). The studies of Patil *et al.* (2012) used the coefficient of infection to assess slow rusting resistance to stem rust and documented the presence of distinct partial resistance conferring genes in wheat lines. The genotypes with a high level of partial resistance tend to be more durable (Singh *et al.*, 2005). On the other hand, in our research the relation between independent variables; growing season and genotype was significant, it is in turn has a serious effect on pathogen-plant relation, consequently all dependent variables in this study. The significance of our findings is to provide information about the resistance of wheat stripe rust genes for wheat breeding and assess the level of slow resistance present in specific Egyptian wheat genotypes.

## Conclusions

It can be concluded that, the disease severity was decreased with seven wheat genotypes i.e., 'Shaka 62', 'Shaka 9', 'Shaka 95', 'Gemmiza 7', 'Sids 14' and 'Misr 3' which recorded the high level of resistance in the first season. However, 'Sakha 93', 'Sakha 95', 'Sids 14' and 'Gim. 7' remained highly resistant during the second season at four locations, as well as, had the lowest values of ACI ≤12, except with 'Sakha 62' at Mutubas and

Qillin and  $RRI \geq 6$  and the lower loss % in TKW regarded as good slow rusting lines. On the other hand, 'Shaka 69', 'Shaka 88', 'Shaka 92', 'Giza 160', 'Giza 163', 'Gem 11', 'Sids 2' and 'Sids 6' exhibited complete susceptibility at the four locations, and the higher level of  $ACI \geq 55$ , the lower level of  $RRI \leq 4.05$  and the highest loss% in TKW reached 40.69% were recorded with cv. 'Gem 11' in the second season. Our results could prove valuable in the national breeding program for stripe rust resistance in wheat plants.

### Authors' Contributions

Conceptualization, Y.H., Y.M., A.Sh., M.B., M.E., and Kh.A.A; methodology, Y.H., Y.M., A.Sh., M.B., M.E.; software, Y.H., Y.M., A.Sh., and Kh.A.A; validation, Y.H., Y.M., A.Sh., M.B.; investigation, Y.H., and Kh.A.A ; resources, Y.H., A.Sh., M.B., M.E.; data curation Y.H., M.B., M.E.; writing—original draft preparation, Y.H., Y.M., A.Sh., M.B., M.E., and Kh.A.A ; writing—review and editing, Y.H., A.Sh., and Kh.A.A; supervision Y.H., A.Sh., M.B.; funding acquisition, Y.H., Y.M., A.Sh., M.B., M.E., and Kh.A.A.

All authors read and approved the final manuscript.

### Ethical approval (for researches involving animals or humans)

Not applicable.

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### Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

### References

- Abdelaal Kh, Hafez Y, Badr M, Yousef W, Esmail S (2014). Biochemical, histological and molecular changes in susceptible and resistant wheat cultivars inoculated with stripe rust fungus *Puccinia striiformis* f. sp. *tritici*. Egyptian Journal of Biological Pest Control 24(2):421-429.
- Abdelaal Kh, Elafry M, Abdel-Latif, Elshamy R, Hassan M, Hafez Y (2021). Pivotal role of yeast and ascorbic acid in improvement the morpho-physiological characters of two wheat cultivars under water deficit stress in calcareous soil. Fresenius Environmental Bulletin 30(3):2554-2565.
- Akhtar M, Ahmad I, Mirza J, Rattu A, Hakro A, Jaffery A (2002). Evaluation of candidate lines against stripe and leaf rusts under national uniform wheat and barley yield trial 2000-2001. Asian Journal of Plant Sciences 1:450-453. <https://doi.org/10.3923/ajps.2002.450.453>
- Ali S, Shah S, Maqbool K (2008). Field-based assessment of partial resistance to yellow rust in wheat germplasm. Journal of Agriculture\Rural Development 6(1):99-106. <https://doi.org/10.3329/jard.v6i1.1663>

- Ali S, Shah S, Ibrahim M (2007). Assessment of wheat breeding lines for slow yellow rusting (*Puccinia striiformis* West. *tritici*). Pakistan Journal of Biological Sciences: Pakistan Journal of Biological Sciences 10(19):3440-3444. <https://doi.org/10.3923/pjbs.2007.3440.3444>
- Alnusairi GSH, Mazrou YSA, Qari SH, Elkesh AA, Soliman MH, Eweis M, ... El Nahhas N (2021). Exogenous Nitric oxide reinforces photosynthetic efficiency, osmolyte, mineral uptake, antioxidant, expression of stress-responsive genes and ameliorates the effects of salinity stress in wheat. Plants 10(8):1693. <https://doi.org/10.3390/plants10081693>
- Ashmawy M, Ragab K (2016). Grain yield losses of some wheat genotypes to stripe rust in Egypt. Menoufia Journal of Plant Protection 1(1):9-18. <https://doi.org/10.21608/mjapam.2016.176621>
- Ashmawy M, Shahin A, Esmail S, El-Naby A (2019). Virulence dynamics and diversity of *Puccinia striiformis* populations in Egypt during 2017/18 and 2018/19 growing seasons. Journal of Plant Protection and Pathology 10(12):655-666. <https://doi.org/10.21608/jppp.2019.79458>
- Aslam M (1982). Uniform procedure for development and release of improved wheat varieties. Mimeograph, PARC, Islamabad, 32.
- Barbara G, Fidell L (2013) Using: Multivariate Statistics. 7th Edition. NY, Pearson.
- Begum S, Iqbal M, Ahmed I, Fayyaz M, Shahzad A, Ali GM (2014). Allelic variation at loci controlling stripe rust resistance in spring wheat. Journal of Genetics 93:2. <https://doi.org/10.1007/s12041-014-0413-9>
- Brown MB, Forsythe A (1974). Robust tests for the equality of variances. Journal of the American Statistical Association 69:364-367. <https://doi.org/10.1080/01621459.1974.10482955>
- Chen W, Wellings C, Chen X, Kang Z, Liu T (2014). Wheat stripe (yellow) rust caused by *Puccinia striiformis* f. sp. *tritici*. Molecular Plant Pathology 15(5):433-446. <https://doi.org/10.1111/mpp.12116>
- Chen X (2020). Pathogens which threaten food security: *Puccinia striiformis*, the wheat stripe rust pathogen. Food Security 12:239-251. <https://doi.org/10.1007/s12571-020-01016-z>
- Chen X, Penman L (2005). Stripe rust epidemic and races of *Puccinia striiformis* in the United States in 2004. Phytopathology 95(6):S19-S19.
- El-Daoudi Y, Shafik I, Ghanem H, Abu El-Naga S, Mitkees R, Sherif S, Khalifa M, Bassiouni A (1996). Stripe rust occurrence in Egypt and assessment of grain yield loss in 1995. In: Proceedings, Symposium Regional sur les Maladies des Cjr Jales at des IJ gumineuses Alimentaires, pp 11-14.
- FAO (2018). Crop Prospects and Food Situation. Quarterly Global Report. Rome: Food and Agriculture Organization of the United Nations. FAOSTAT Rome, Italy.
- Gao P, Duan TY, Nan ZB, Christensen MJ, Liu QT, Meng FJ, Huang JF (2018). The influence of irrigation frequency on the occurrence of rust disease (*Melampsora apocyni*) and determination of the optimum irrigation regime in organic *Apocynum venetum* production. Agricultural Water Management 205:81-86. <https://doi.org/10.1016/j.agwat.2018.04.026>
- Gebrel EEA, Al-Farouk MO, Gad MA (2020). Study of some crop and technological characteristics of some wheat cultivars under different levels of nitrogen fertilization and their affected by rust diseases. Journal of Plant Production 11(10):1021-1030. <https://doi.org/10.21608/jpp.2020.131822>
- Ghulam H (2004). Diallel analysis of some important parameters in wheat (*Triticum aestivum* L.) under irrigated and rainfed conditions. NWFP Agricultural University.
- Hafez Y, Emeran A, Esmail S, Mazrou Y, Abdrabbo D, Abdelaal Kh (2020). Alternative treatments improve physiological characters, yield and tolerance of wheat plants under leaf rust disease stress. Fresenius Environmental Bulletin, 29(6):4738-4748.
- Herrera-Foessel S, Singh R, Huerta-Espino J, Crossa J, Djurle A, Yuen J (2007). Evaluation of slow rusting resistance components to leaf rust in CIMMYT durum wheats. Euphytica 155(3):361-369. <https://doi.org/10.1007/s10681-006-9337-7>
- Hovmoller M, Yahyaoui A, Singh R (2009). A global reference centre for wheat yellow rust: pathogen variability, evolution and dispersal pathways at regional and global levels. Borlaug Global Rust Initiative, Cd. Obregon, Sonora, Mexico; 17-20 Mar 2009. Technical Workshop BGRI-Full papers and abs. CIS-5678. CIMMYT.
- Hovmøller M (2001). Disease severity and pathotype dynamics of *Puccinia striiformis* f. sp. *tritici* in Denmark. Plant Pathology 50(2):181-189. <https://doi.org/10.1046/j.1365-3059.2001.00525.x>

- Hovmøller M, Sørensen C, Walter S, Justesen A (2011). Diversity of *Puccinia striiformis* on cereals and grasses. Annual Review of Phytopathology 49:197-217. <https://doi.org/10.1146/annurev-phyto-072910-095230>
- Hovmøller M, Walter S, Justesen A (2010). Escalating threat of wheat rusts. American Association for the Advancement of Science. Science 329(5990):369. <https://doi.org/10.1126/science.1194925>
- Johnson R (1992). Reflections of a plant pathologist on breeding for disease resistance, with emphasis on yellow rust and eyespot of wheat. Plant Pathology 41(3):239-254.
- Kiani T, Mehboob F, Hyder MZ, Zainy Z, Xu L, Huang L, Farrakh S (2021). Control of stripe rust of wheat using indigenous endophytic bacteria at seedling and adult plant stage. Scientific Reports 11(1):1-14. <https://doi.org/10.1038/s41598-021-93939-6>
- Kushnirenko IY, Shreyder E, Bondarenko NP (2021). Resistance of common spring wheat genotypes to abiotic and biotic stresses in the Southern Urals. In: Plant Genetics, Genomics, Bioinformatics, and Biotechnology 134-134.
- Line R, Qayoum A (1992). Virulence, aggressiveness, evolution, and distribution of races of *Puccinia striiformis* (the cause of stripe rust of wheat) in North America, 1968-87. Technical Bulletin-United States Department of Agriculture, 1788.
- Martinez A, Youmans J, Buck J (2012). Stripe rust (Yellow Rust) of wheat. The University of Georgia, Cooperative Extension.
- Mitiku M, Hei NB, Abera M (2018). Characterization of slow rusting resistance against stem rust (*Puccinia graminis* f. sp. *tritici*) in selected bread wheat cultivars of Ethiopia. Advances in Crop Science and Technology 6:389. <https://doi.org/10.4172/2329-8863.1000389>
- Omara RI, Nehela Y, Mabrouk OI, Elsharkawy MM (2021). The emergence of new aggressive leaf rust races with the potential to supplant the resistance of wheat cultivars. Biology 10(9):925. <https://doi.org/10.3390/biology10090925>
- Omara R, El-Kot G, Fadel F, Abdelaal Kh, Eman E (2019). Efficacy of certain bioagents on patho-physiological characters of wheat plants under wheat leaf rust stress. Physiological and Molecular Plant Pathology 106:102-108. <https://doi.org/10.1016/j.pmpb.2018.12.010>
- Patil V, Hasabnis S, Narute T, Khot G, Kumbhar C (2012). Rusting behaviour of some wheat cultivars against leaf rust under artificial epiphytotic conditions. Indian Phytopathology 58(2):221-223.
- Peterson R, Campbell A, Hannah A (1948). A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Canadian Journal of Research 26(5):496-500.
- Poudyal DS, Chen XM (2010). Models for predicting potential yield loss of wheat caused by stripe rust in the US Pacific Northwest. Phytopathology 101(5):544-554. <https://doi.org/10.1094/PHYTO-08-10-0215>
- Rehman A, Naqvi S, Umar U, Zafar M, Hussain F, Zulfiqar M, Khan A (2019). Identification of resistance sources in wheat to brown and yellow rust. Pakistan Journal of Agricultural Research 32(1):185-196.
- Roelfs A, Singh R, Saari E (1992). Rust diseases of wheat: concepts and methods of disease management. Cimmyt. Centro Internacional de Mejoramiento de Maiz y Trigo, Mexico, pp 81.
- Safavi SA (2012). Evaluation of slow rusting parameters in thirty-seven promising wheat lines to yellow rust. Technical Journal of Engineering and Applied Sciences 2:324-329.
- Shahin AA, Omar HA, El-Sayed AB (2018). Characterization of Yr18/Lr34 partial resistance gene to yellow rust in some Egyptian wheat cultivars. Egyptian Journal of Plant Protection Research 6(3):1-9.
- Shahin A (2020a). 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 53(11-12):552-569. <https://doi.org/10.1080/03235408.2020.1767330>
- Shahin A, Ashmawy M, El-Orabey W, Samar E (2020b). Yield losses in wheat caused by stripe rust (*Puccinia striiformis*) in Egypt. American Journal of Life Sciences 8(5):127-134. <https://doi.org/10.11648/j.ajls.20200805.17>
- Singh R, Huerta-Espino J, William H (2005). Genetics and breeding for durable resistance to leaf and stripe rusts in wheat. Turkish Journal of Agriculture and Forestry 29(2):121-127.
- Singh R, William H, Huerta-Espino J, Rosewarne G (2004). Wheat rust in Asia: meeting the challenges with old and new technologies. Proceedings of the 4<sup>th</sup> International Crop Science Congress, 26 Sep-1 Oct 2004, Brisbane, Australia.
- Snedecor GW, Chochran WG (1981). Statistical Methods. 6<sup>th</sup> Ed., Iowa State Univ. Press, Iowa, USA.
- Stubbs R (1988). Pathogenicity analysis of yellow (stripe) rust of wheat and its significance in a global context. Breeding Strategies for Resistance to the Rusts of Wheat 8:23-28.

- Tervet I, Rawson A, Saxon R (1951). A method for the collection of microscopic particles. *Phytopathology* 41(3):282-285.
- USDA (2010). *Keys to Soil Taxonomy*. third edition. United State Department of Agriculture: Natural Resources Conservation Service (NRCS).
- Walter S, Ali S, Kemen E, Nazari K, Bahri B, Enjalbert J, ... Jones J (2016). Molecular markers for tracking the origin and worldwide distribution of invasive strains of *Puccinia striiformis*. *Ecology and Evolution* 6(9):2790-2804. <https://doi.org/10.1002/ece3.2069>
- Waqar A, Khattak SH, Begum S, Rehman T, Shehzad A, Ajmal W, Ali GM (2018). Stripe rust: a review of the disease, Yr genes and its molecular markers. *Sarhad Journal of Agriculture* 34(1). <https://doi.org/10.17582/journal.sja/2018/34.1.188.201>
- Wan A, Zhao Z, Chen X, He Z, Jin S, Jia Q, ... Li G (2004). Wheat stripe rust epidemic and virulence of *Puccinia striiformis* f. sp. *tritici* in China in 2002. *Plant Disease* 88(8):896-904. <https://doi.org/10.1094/PDIS.2004.88.8.896>
- Wellings C (2007). *Puccinia striiformis* in Australia: a review of the incursion, evolution, and adaptation of stripe rust in the period 1979-2006. *Australian Journal of Agricultural Research* 58(6):567-575.
- Zhao J, Wang M, Chen, X, Kang Z (2016). Role of alternate hosts in epidemiology and pathogen variation of cereal rusts. *Annual Review of Phytopathology* 54:207-228. <https://doi.org/10.1146/annurev-phyto-080615-095851>



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