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ORIGINAL PAPER

Slow-rusting Resistance to Stripe Rust Along with Grain Yield Losses in Egyptian Bread Wheat Cultivars

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ABSTRACT

The lack of durable resistance in wheat cultivars to stripe rust caused by *Puccinia striiformis* f. sp. *tritici* is the primary cause of disease epidemics causing significant yield losses. This study examined the levels of partial resistance (slow-rusting) to stripe rust in fourteen Egyptian wheat cultivars at the adult plant stage during the 2022/23 and 2023/24 growing seasons. Under greenhouse conditions, the wheat cultivars; Sakha-94, Sakha-95, Misr-3, Giza-168, Giza-171 and Gemmeiza-12 showed moderate rust severity, being moderately susceptible. These cultivars had the longest incubation and latent periods, along with the smallest stripe lengths and lowest infection frequencies (No. pustules per cm^2). Therefore, they can be classified as slow-rusting resistant cultivars. Under field conditions, slow-rusting resistance level was assessed through final rust severity (FRS %), area under disease progress curve (AUDPC) and average coefficient of infection (ACI). Cultivars, Sakha-94, Sakha-95, Misr-3, Giza-168, Giza-171 and Gemmeiza-12, were identified as potentially having partial resistance with low disease severity and lower ACI and AUDPC values during both seasons. A direct correlation was observed between disease level and yield loss in most cultivars. Susceptible cultivars experienced significant reductions in grain yield per plot and 1000-kernel weight over the two seasons. In contrast, Sakha-94, Sakha-95, Misr-3, Giza-168, Giza-171, and Gemmeiza-12 showed minimal yield losses and were identified as partially resistant to stripe rust.

Keywords: Bread wheat, Stripe rust, Partial resistance, AUDPC, Epidemiological parameters.

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INTRODUCTION

Stripe rust, caused by *Puccinia striiformis* f. sp. *tritici* (Pst) remains a significant threat to wheat production across extensive areas, causing great losses in grain yield and quality (Chen, 2005 and Mabrouk *et al.*, 2022). Stripe rust situation monitored in Egypt, new virulent races of the fungus appear due to its continuous appearance (Ashmawy *et al.*, 2012). The functional life of cultivars with single-gene resistance (race-specific resistance) is not long because of the rapid break-down of major resistance genes and difficulties in swiftly replacing susceptible wheat cultivars have prompted research into alternative forms of genetic resistance (Esmail *et al.*, 2021).

Breeding cultivars with sufficient levels of adult plant resistance remains the most effective and environmentally friendly strategy for minimizing yield losses and managing stripe rust over the long term (Zhang *et al.*, 2009). Characteristics of slow-rusting resistance in the host-pathogen system include susceptibility at the seedling stage but low severity expression at the adult plant stage, without hypersensitivity (Datta *et al.*, 2009). Slow-rusting is a form of partial or incomplete resistance that extends the latent period of fungal infection, thereby reducing disease severity (Wang *et al*., 2002). This type of resistance is generally effective against various pathotypes, maintaining disease levels below thresholds in diverse field conditions across different locations and years, thereby reducing the likelihood of new pathotype selection (Nayar *et al*., 2003).

Partial resistance has proven effective in providing durable disease control in wheat (Pandey *et al*., 1989; Boulot, 2007; Boulot and Abu-Aly, 2014). Over the past decade, breeders and pathologists have released several stripe rust-resistant wheat cultivars for commercial production in Egypt. However, these cultivars have shown susceptibility to stripe rust when grown extensively across Egypt after 4 or 5 years (Ashmawy *et al.*, 2016; Draz *et al*., 2018; Shahin *et al*., 2020). Egypt falls within the epidemiological zone of stripe rust (Saari and Prescott, 1985), where the disease has led to the elimination of many wheat cultivars such as Giza-144, Sakha-69, Giza-163, and Gemmeiza-1 (Nazim *et al.*, 1983). Despite the availability of identified resistance genes for breeding, similar challenges could arise again if lessons are not learned from past experiences. Egypt, with its extensive wheat cultivation and diverse varieties, has so far given little attention to investigating the durability of resistance to stripe rust. Therefore, the main objective of this study was to characterize slow-rusting resistance to stripe rust in fourteen Egyptian wheat cultivars, conducted under both greenhouse and field conditions.

MATERIALS AND METHODS

Plant Material

Fourteen Egyptian wheat cultivars listed in Table (1), and a susceptible check genotype “Morocco” were obtained from the Wheat Research Department, Field Crop Research Institute, Agricultural Research Center (ARC), Egypt, and used in this study.

Greenhouse Test

Under controlled conditions, the test was conducted in the greenhouse of the Wheat Disease Research Department at Sakha Agricultural Research Station, Plant Pathology Research Institute, ARC, Egypt, during the 2022/23 growing season. Four virulent *Pst* races, 32E0, 64E32, 190E0, and 230E159, were used to evaluate slow-rusting components at the adult plant stage in the wheat cultivars listed in Table (1). The highly susceptible check variety “Morocco” served as the control. Twenty-five wheat grains from each cultivar were planted in 25 cm diameter pots. After germination, the plants were thinned to 10 per pot, with three pots (replicates) used for each cultivar. Artificial inoculation was performed at the booting stage by dusting the plants with a mixture of urediniospores and talcum powder in a 1:20 (v/v) ratio, following Tervet and Cassell (1951). The inoculated plants were incubated in a dew chamber at 100% relative humidity and 10±2°C for 24 hours, then transferred to the greenhouse, where conditions were maintained at 12±2°C and 80% relative humidity. Rust scoring was performed 14 days after inoculation. Four parameters, incubation period (IP), latent period (LP), length of stripes (LS) and infection frequency (IF), were estimated according to the method described by Parlevliet (1975) and McIntosh (1992). The IP was calculated as the number of days from inoculation until the first pustule appeared. The LP was assessed by counting the daily number of uredinia on a marked leaf segment until this number plateaued, with LP defined as the time from inoculation to the appearance of 50% of the uredinia. The LS was measured from randomly selected areas on each leaf. The IF was determined by counting the number of infection lesions per unit area (cm^2) on the upper surface of the leaves.

Adult plant response was evaluated primarily based on pustule size and the presence of associated necrosis or chlorosis. Infection responses were classified into five categories *i.e*., immune (0), resistant (R), moderately resistant (MR), moderately susceptible (MS), and susceptible (S), according to Roelfs *et al.* (1992). Disease severity (DS) was assessed four times at 10-day intervals as the percentage of leaf area covered with rust pustules, using the Modified Cobb´s scale (Peterson *et al.* 1948).

Field Test

The field test was conducted at the Experimental Farm of Sakha Agric. Res. Stn, Plant Pathol. Res. Inst., ARC, Egypt, during the 2022/23 and 2023/24 growing seasons. The wheat cultivars under investigation (Table 1), along with the susceptible check variety Morocco, were planted in adjacent rows within plots measuring 3.5 × 3 meters, using a randomized complete block design with three replicates. All plots were bordered by a one-meter-wide spreader area planted with the highly susceptible check variety Morocco. Artificial inoculation was performed at the booting stage using a mixture of *Pst* races as described by Tervet and Cassell (1951). Protected plots were treated with the broad-spectrum systemic fungicide Tilt (Propiconazole 25% EC) at a concentration of 25 cm^3 per 100 liters of water. Host response and rust severity data were recorded four times at 10-day intervals. This data was used to calculate the coefficient of infection (CI) by multiplying disease severity with constant values for infection responses (Saari and Wilcoxson, 1974; Pathan and Park, 2006). The constant values for infection types were; R (0.2), MR (0.4), MR-MS (0.6), MS (0.8), and S (1.0). The area under the disease progress curve (AUDPC) was estimated using the formula outlined by Pandey *et al.* (1989) as follows:

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

Where:

D = days between reading; Y_1 = first disease recording; Y_k = last disease recording.

Grain yield expressed as 1000-kernel weight and grain yield (kg/plot) were determined for each cultivar in two growing seasons. Yield loss was estimated by an equation adopted Calpouzos *et al*. (1976) as follows:

$$\text{Yield loss \%} = 1\text{-}yd/yh \times 100$$

Where:

yd = yield of diseased plants, and yh = yield of healthy plants.

Statistical analysis

The obtained data were transformed before analysis of variance (ANOVA) using the GenStat Computer Program. To compare treatment means, the least significant difference (LSD) at a 5% level of significance was employed (Steel and Torrie, 1980).

Table 1. Pedigree/Selection history of the selected Egyptian wheat cultivars and their year of release.

Cultivar	Pedigree and selection history	Year of release
Misr-1	Oasis/Skauz//4*BCN/3/2*PASTOR.CMSSOYO1881T-050M-030Y-O3OM-030WGY-33M-0Y-0S	2011
Misr-2	Skauz/Bav92.CMSS96M0361S-1M-010SY-010M-010SY-8M-0Y-0S	2011
Misr-3	CMSS06Y00582T099TOPM-099Y-099ZTM-009Y-099M-10WGY-0B-0EGY	
Sakha-94	Opata/Rayon//Kauz CMBW9043180-OTOPM-3Y-010M-010M-010Y-10M-015Y-0Y-0AP-0S	2004
Sakha-95	CMA01Y00158S-040POY-040M-030ZTM-040SY-26M-0Y-0SY-0S	2016
Giza-168	MRL/BUC//Seri.CM93046-8M-0Y-0M-2Y-0B	1999
Giza-171	Sakha93/Gemmeiza9S.6-1GZ-4GZ-1GZ-2GZ-0S	2013
Gemmeiza-9	ALD"S"/HUAC"S"//CMH74A.630/SX. GM4583-5GM-1GM-0GM	1999
Gemmeiza-11	61Sakha/168Giza/3/82Seri/C7//KVZ “S”/BOW “S”	2011
Gemmeiza-12	OTUS/3/SARA/THB//VEECMSS97Y00227S-5Y-010M-010Y-010M-2Y-1M-0Y-0GM	2011
Sids-12	BUC//7C/ALD/5/MAYA74/ON//1160-147/3/BB/GLL/4/CHAT"S"/6/MAYA/VUL//CMH74A.630/4*SX	2007
Sids-13	KAUZ "S"//TSI/SNB"S". ICW94-0375-4AP-2AP-030AP-0APS-3AP-0APS-050AP-0AP-0SD	2010
Sids-14	SW8488*2/KUKUNA-CGSS01Y00081T-099M-099Y-099M-099B-9Y-0B-0SD	201
Shandweel-1	SITE//MO/4/NAC/TH.AC//3*PVN/3/MIRLO/BUC.CMSS93B00567S-72Y-010M-010Y-010M-0HTY	2013

RESULTS AND DISCUSSION

Slow-rusting Resistance under Control Conditions

In the greenhouse tests under controlled conditions, compatibility between the pathogen and wheat cultivars was evaluated at the adult stage using components of slow-rusting. These components included the incubation period, latent period, length of stripes, infection frequency, and rust reaction (infection type and rust severity), all of which are crucial for expressing stripe rust resistance in wheat (Broers, 1997). Data presented in Table (2) revealed significant variability among the tested cultivars in terms of rust severity. Egyptian cultivars, Shandweel-1, Gemmeiza-11, and Sids-12, along with the check genotype "Morocco," displayed the highest percentages of rust severity, classifying them as highly susceptible (fast-rusting). Conversely, cultivars such as Sakha-95, Gemmeiza-12, and Misr-3 exhibited lower rust severity and moderate susceptibility (rated 10 MS). Additionally, the cultivars Giza-168, Giza-171, and Sakha-95 demonstrated partial resistance with low rust severity (10%), identifying them as slow-rusting cultivars for stripe rust

On the other hand, the shortest incubation and latent period was observed on Shandweel-1, Sids-12 and Gemmeiza-11, as well as, the susceptible check cultivar Morocco. However, the longest incubation and latent periods were recorded in six cultivars, Sakha-94, Sakha-95, Gemmeiza-12, Misr-3, Giza-168 and Giza-171. These six cultivars exhibited the lowest values of the length of stripes (cm) and infection frequency (No. stripes/cm^2). While, the cultivars, Gemmeiza-11, Sids-12 and Morocco exhibited the higher values of both components. No spore production was observed in three cultivars *i.e.* Gemmeiza-12, Sakha-95 and Misr-3.

Slow-rusting Resistance under Field Conditions

Slow-rusting resistance to stripe rust has been initially described as a slower rate of epidemic progression and/or accumulation in the field, even when the infection type is susceptible or the host-pathogen interaction is compatible (Broers, 1997). This form of resistance has also been recognized as polygenic resistance (Boulot, 2007) or race-non-specific (general) resistance (Singh et al., 2011). As such, it provides long-lasting protection against a wide range of prevalent rust pathogen races or sudden race changes Xiaowen *et al*., 2008). This type of resistance is expected to be durable, maintaining its effectiveness across various environmental conditions for many years, making it more reliable than other forms of resistance (Broers, 1997 and Boulot, 2007). The slow-rusting resistance parameters and grain yield are effective indicators of partial resistance to stripe rust. These parameters provide a reliable measure of disease progression and are associated with slow rusting traits such as low receptivity, a longer latent period (LP), and smaller pustules (McNeil *et al*., 2008). In this study, the data on host reaction and rust severity showed considerable variation among the tested wheat cultivars under field conditions over the two seasons. Severity ranged from 10 MS to 100 S (Tables 3 and 4). Host reactions varied from low susceptibility to high susceptibility across the cultivars. Specifically, six cultivars Sakha-95, Misr-3, Gemmeiza-12, Sakha-94, Giza-171, and Giza-168, demonstrated the lowest levels of susceptibility, with stripe rust severity ranging from 10 MS to 10 S during both seasons.

Disease severity and host reaction data were combined to calculate the ACI values. Cultivars were classified into partial resistance categories based on their ACI values following the method described by Pathan and Park (2006). The cultivars with ACI values of 0-20, 21-40, 41-60 were regarded as possessing high, moderate and low levels of partial resistance, respectively. Cultivars that exhibited CI values greater than 60 were grouped as susceptible. In this study, cultivars, Sakha-94, Sakha-95, Misr-3, Gemmeiza-12, Giza-168, and Giza-171 fell into the high partial resistance category with ACI values of 0-20. In contrast, cultivars, Gemmeiza-11, Sids-12, Misr-1, Misr-2, Shandaweel-1, Gemmeiza-9, and the check genotype Morocco were classified as susceptible, with ACI values exceeding 60 (Tables 3 and 4). The AUDPC is considered a reliable indicator of adult plant resistance or partial resistance under field conditions (Broers, 1997). It reflects both the extent of rust infection and the rate of disease progression during an epidemic. The AUDPC values for the tested wheat cultivars were consistently lower than those of the susceptible check genotype Morocco during both seasons (Tables 3 and 4), aligning with disease severity data. The cultivars were classified into two main groups based on their stripe rust resistance levels and AUDPC values. Cultivars with AUDPC values below 200 were categorized as having high levels of partial resistance, including Sakha-95, Misr-3, Gemmeiza-12, Giza-171, Giza-168, and Sakha-94, all of which exhibited slow-rusting characteristics. In contrast, cultivars with the highest AUDPC values, such as Gemmeiza-11, Sids-12, Sids-13, Misr-1, Misr-2, Shandweel-1, Gemmeiza-9, and the check genotype Morocco, were classified as fast-rusting.

Grain Yield Loss and Slow Rusting Resistance

The impact of stripe rust on 1000-kernel weight (g) and grain yield (kg/plot) for the tested wheat cultivars during the two seasons was detailed in Tables (3 and 4). The highest losses in 1000-kernel weight and grain yield were observed in the susceptible check genotype Morocco, followed by Gemmeiza-11 and Sids-12, which were identified as highly susceptible (fast-rusting) cultivars based on disease parameters across both seasons. In contrast, cultivars such as Sakha-95, Sakha-94, Misr-3, Gemmeiza-12, Giza-171, and Giza-168 exhibited tolerance to stripe rust infection and experienced the least reduction in 1000-kernel weight and grain yield during the two seasons.

These data indicate an increase in the susceptibility of the cultivars to stripe rust infection and result in severe crop loss, as the cultivars Shandweel-1 and Misr-2 were exposed to greater losses (51.32%) than those that were previously recorded in other studies of Ashmawy and Ragab (2016) and Shahin et al. (2020). They reported a yield loss of up to 3.86% in both cultivars, Shandaweel-1 and Misr-2. Regarding yield losses in 1000-kernel weight, Sakha- 95 exhibited a relatively low loss of 2.53% compared to check genotype Morocco which exhibited significantly higher losses with 50.23% and 51.2% in two growing seasons, respectively.

Table 2. Components of slow-rusting resistance in fourteen Egyptian wheat cultivars at adult plants inoculated with virulent races of *Puccinia striiformis* f. sp. *tritici* under greenhouse conditions during 2022/23.

Cultivar	FRS	IP (day)	LP (day)	LS (cm)	IF (No. pustules/cm^2)
Sakha-95	10 MS	12.02	15.23	0.21	0.65
Misr-3	10 MS	11.66	14.66	0.15	0.67
Gemmeiza-12	10 MS	11.78	14.00	0.45	0.77
Giza-171	10 S	10.66	13.88	0.55	0.93
Giza-168	10 S	10.23	13.66	0.50	1.16
Sakha-94	10 S	10.25	13.45	0.68	1.60
Sids-14	20 S	10.19	13.21	0.88	1.76
Gemmeiza-11	100 S	8.00	10.00	4.99	22.26
Shandweel-1	90 S	8.75	9.09	4.23	18.66
Sids-12	100 S	8.10	8.66	4.85	25.45
Sids-13	80 S	8.50	8.66	4.96	19.23
Misr-1	90 S	8.23	11.03	4.03	22.23
Misr-2	90 S	8.24	11.03	4.05	22.66
Gemmeiza-9	60 S	8.84	10.00	3.66	18.67
Morocco (check)	100 S	7.99	8.66	4.97	24.25
$LSD_{0.05}$	-	1.154	1.073	0.329	1.19

FRS = Final rust severity, IP = incubation period, LP = latent period, LS = length of stripes, IF = infection frequency.

Among the resistance genes known for their exceptional durability against stripe rust, *Yr18* and *Yr29* confer slow-rusting resistance (McIntosh *et al*., 2003 and Risk *et al*., 2012). *Yr18*, located on wheat chromosome 7DS (Suenaga *et al*., 2003), is a non-hypersensitive gene that provides slow-rusting or partial resistance. It reduces infection frequency, extends the latent period, increases the abortion rate of infection sites, and results in smaller colonies, being most effective at the adult plant stage (Singh *et al*., 2003). Studies comparing stripe rust-protected and non-protected treatments showed that *Yr18*-based slow rusting resistance protected grain yield by 36 to 58%, depending on cultivar response and environmental conditions (Singh *et al*., 2005). *Yr29* is another widely utilized wheat locus that provides broad-spectrum resistance to stripe rust (Singh *et al*., 2011). Adult plants with *Yr29* have a longer latency period compared to those without it (Martinez *et al*., 2001). This gene increases the abortion rate of fungal colonies without causing chlorotic or necrotic effects and reduces colony size. In the current study, the wheat cultivars Sakha-95, Sakha 94, Gemmeiza-12, Giza-171, Giza-168, and Misr-3 exhibited slow-rusting resistance. These cultivars have been previously reported to possess *Yr18* and/or *Yr29*, which are associated with slow-rusting behavior (El-Orabey *et al*., 2019; Esmail *et al*., 2021 and Draz *et al*., 2024).

Table 3. Components of slow-rust resistance and yield loss of fourteen Egyptian wheat cultivars against stripe rust under field conditions during 2022/23 growing season.

Cultivar	Slow-rusting components			Yield loss (%)	
	FRS	ACI	AUDPC	1000-Kernel weight (g)	Grain yield/plot (kg)
Sakha-95	10 MS	8.00	120	2.53	1.90
Misr-3	10 MS	8.00	80	3.57	2.96
Gemmeiza-12	10 MS	8.00	80	2.82	3.78
Giza-171	10 S	10.00	260	4.18	3.90
Giza-168	10 S	10.00	260	3.39	4.49
Sakha-94	10 S	10.00	160	2.56	4.35
Sids-14	20 S	20.00	325	2.53	5.66
Gemmeiza-11	100 S	100	2350	49.45	69.47
Shandweel-1	90 S	90	1700	38.66	51.32
Sids-12	100 S	100	2400	41.43	59.25
Sids-13	80 S	80	1420	31.45	44.66
Misr-1	90 S	90	1850	37.24	57.21
Misr-2	90 S	90	1850	37.45	57.59
Gemmeiza-9	60 S	60	1250	29.29	51.06
Morocco (check)	100 S	100	2450	50.23	70.34
$LSD_{0.05}$	-	5.333	133.32	3.21	2.45

Final rust severity (FRS), Area under disease progress curve (AUDPC), Average coefficient of infection (ACI) with constant values for infection responses as R (0.2), MR (0.4), MR-MS (0.6), MS (0.8), and S (1.0).

CONCLUSION

Considerable variation of slow-rusting resistance to stripe rust was observed among Egyptian wheat cultivars under study. Cultivars with high FRS, ACI and AUDPC values caused a serious loss in grain yield (kg/plot) and 1000-kernel weight (g). However, Sakha-95, Sakha 94, Gemmeiza-12, Giza-171, Giza- 168 and Misr-3 those with slow-rusting resistance to stripe rust were found to result in a negligible yield loss. These cultivars did not restrict the infection process but slowed down the production of fresh urediniospores significantly so the disease development was very slow and appeared to have slow rusting behavior. These findings would be useful for more durable resistance to stripe rust in wheat breeding programs.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

Table 4. Components of slow-rust resistance and yield loss of fourteen Egyptian wheat cultivars against stripe rust under field conditions during 2023/24 growing season.

Cultivar	Slow-rusting components			Yield loss (%)	
	FRS	ACI	AUDPC	1000-Kernel weight (g)	Grain yield/plot (kg)
Sakha-95	5 MS	4.00	96	2.53	1.45
Misr-3	5 MS	4.00	98	3.57	2.66
Gemmeiza-12	10 MS	8.00	124	2.82	3.56
Giza-171	10 S	10.00	240	4.18	3.76
Giza-168	10 S	10.00	240	3.39	4.52
Sakha-94	10 S	10.00	160	2.56	4.35
Sids-14	20 S	20.00	302	2.53	5.45
Gemmeiza-11	100 S	100	2400	48.42	69.56
Shandweel-1	90 S	90	1750	37.9	51.43
Sids-12	100 S	100	2450	41.4	59.76
Sids-13	80 S	80	1450	31.3	44.44
Misr-1	90 S	90	1950	37.8	58.21
Misr-2	90 S	90	1875	37.9	58.59
Gemmeiza-9	60 S	60	1300	29.7	50.06
Morocco (check)	100 S	100	2500	51.2	69.34
$LSD_{0.05}$	-	5.33	133.32	2.74	3.44

Final rust severity (FRS), Area under disease progress curve (AUDPC), Average coefficient of infection (ACI) with constant values for infection responses as R (0.2), MR (0.4), MR-MS (0.6), MS (0.8), and S (1.0).

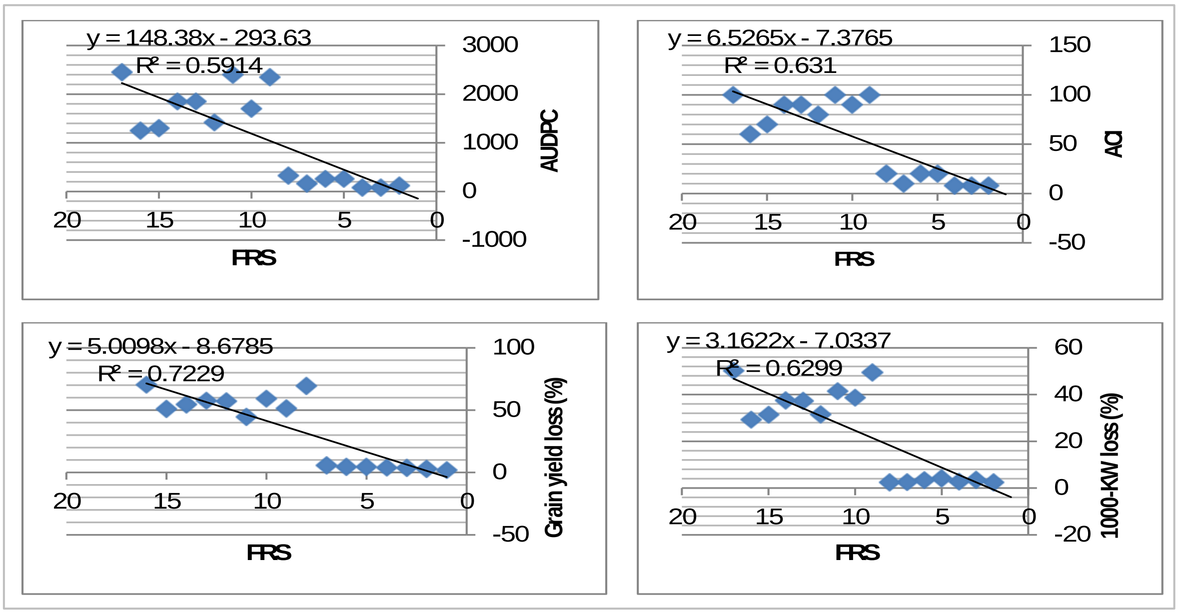

Fig. 1. The correlation between epidemiological parameters of stripe rust, including final rust severity (FRS), average coefficient of infection (ACI), area under disease progress curve (AUDPC), and losses in grain yield components such as 1000-kernel weight (KW) and grain yield per plot for Egyptian wheat cultivars during the 2022/23 season.

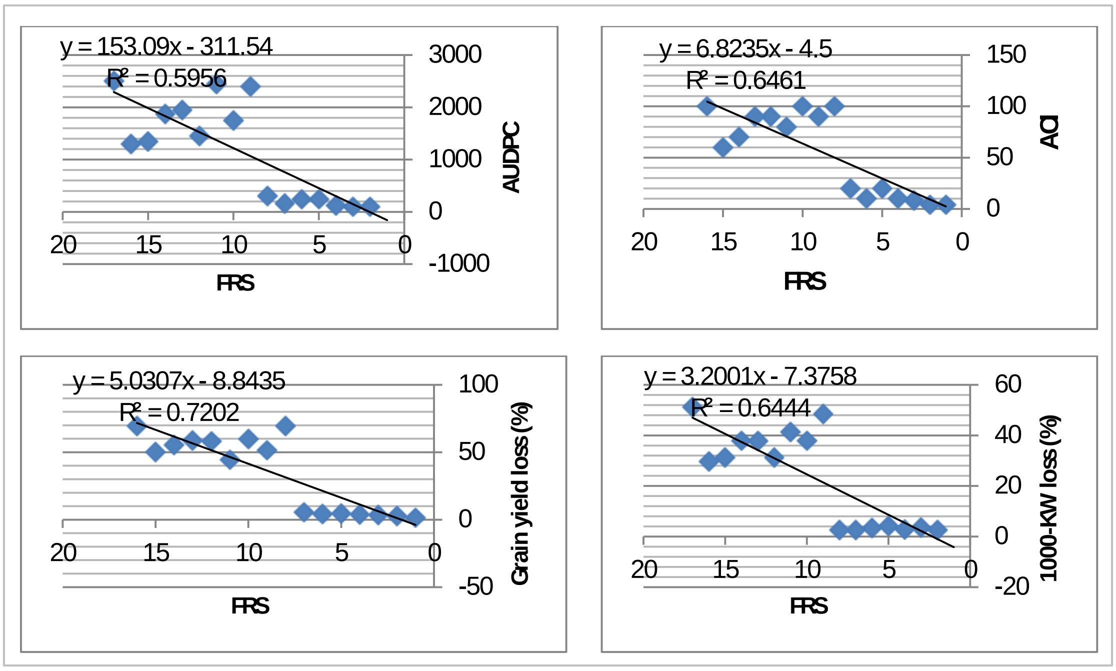

Fig. 2. The correlation between epidemiological parameters of stripe rust, including final rust severity (FRS), average coefficient of infection (ACI), area under disease progress curve (AUDPC), and losses in grain yield components such as 1000-kernel weight (KW) and grain yield per plot for Egyptian wheat cultivars during the 2023/24 season.

REFERENCES

Ashmawy, M.A., Abu Aly, A.A.M., Youseef, W.A. and Shahin A.A. (2012. Physiological race of wheat yellow rust (*Puccinia striiformis* f. sp. *tritici*) in Egypt during 1999-2011. Menoufia J. Agric. Res. 37(2):297-305.

Abu-Aly, A.A., Omara, R.I. and Abd-El-Malik, N.I. (2017). Evaluation of new sources of resistance to wheat stripe rust (*Puccinia striiformis* f. sp. *tritici*), under Egyptian field conditions. J. Plant Prot. Pathol., 8(4), 181-188.

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

Boulot, O.A. and Abu-Aly, A.A. (2014). Partial resistance of wheat (*Triticum aestivum*) to leaf rust (*Puccinia triticina*) in Egypt. A. Evaluation of seven Egyptian wheat cultivars for partial resistance against leaf rust, under field conditions. Egypt. J. Agric. Res., 92(3):835-850.

Boulot, O.A. (2007). Durable resistance for leaf rust in twelve Egyptian wheat varieties. Egypt. J. Appl. Sci., 22(7):40-60.

Boulot, O.A.; El-Naggar, Doaa R. and Abd El-Malik, N.I. (2015). Partial resistance to powdery mildew caused by *Blumeria graminis* f. sp. *tritici* and yield loss in four Egyptian wheat cultivars. Zagazig J. Agric. Res., 42(4):713-725.

Broers, L.H.M. (1997) Components of quantitative resistance to yellow rust in ten spring bread wheat cultivars and their relations with field assessments. Euphytica, 96:215-223

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

Calpouzos, J., Roelfs, A.P., Madson, M.E., Martin, F.B. and Wilcoxson, S. (1976) A new model to measure yield losses caused by stem rust in spring wheat Agric. Exp. Sta. Univ. Minnesota, Tech. Bull. 307, 1-23.

Datta, D., Nayar, S.K., Prashar, M. and Bhardwaj, S.C. (2009) Inheritance of temperature sensitive leaf rust resistance and adult plant stripe rust resistance in common wheat cultivar PBW343. Euphytica, 166:277-282.

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. Environment, Biodiversity and Soil Security, 2:143-153.

Draz, I.S., Esmail, S.M. and Komeil, D.A. (2024) Phenotypic and molecular characterization of pleiotropic resistance to rusts and powdery mildew in spring wheat. Euphytica, 220(7), 99.

El-Orabey, W.M., Hamwieh, A. and Ahmed, S.M. (2019) Molecular markers and phenotypic characterization of adult plant resistance genes *Lr34*, *Lr46*, *Lr67* and *Lr68* and their association with partial resistance to leaf rust in wheat. J. Genet. 98, 82. https://doi.org/10.1007/s12041-019-1122-1

Esmail, S.M., Draz, I.S., Ashmawy, M.A., and El-Orabey W.M. (2021) Emergence of new aggressive races of *Puccinia striiformis* f. sp. *tritici* causing yellow rust epiphytotic in Egypt. Physiol. Mol. Plant. Pathol., 114, 101612. https://doi.org/10.1016/j.pmpp.2021.101612

Mabrouk, O.I., Fahim, M.A., Abd-El Badeea, O.E., and Omara, R.I. (2022) The impact of wheat yellow rust on quantitative and qualitative grain yield losses under Egyptian field conditions. Egypt. J. Phytopathol., 50(1):1-19.

Martinez, F., Niks, R.E., Singh R.P. and Rubiales D. (2001). Characterization of *Lr46*, a gene conferring partial resistance to wheat leaf rust.

Hereditas. 135,111-114.

McIntosh, R.A. (1992) Close genetic linkage of genes conferring adult plant resistance to leaf rust and stripe rust in wheat.523-527, 41 .Plant Pathol.

McIntosh RA, Yamazaki Y, Devos KM, et al. (2003). Catalogue of gene symbols for wheat. In: Pogna NE, Romano M, Pogna A, Galterio G, editors. Proceedings of the 10th International Wheat Genetics Symposium; 2003 Sep 1-6; Istituto Sperimentale per la Cerealicoltura; Paestum, Italy.

McNeil, M.D., Kota, R., Paux, E., Dunn, D., McLean, R., Feuillet, C., Li, D., Kong, X., Lagudah, E., Zhang, J.C., Jia, J.Z., Spielmeyer, W., Bellgard, M. and Appels, R. (2008) BAC-derived markers for assaying the stem rust resistance gene, *Sr2*, in wheat breeding programs. Molecular Breeding, 221:15- 24.

Nayar, S.K., Jain, S.K., Prashar, M., Bhardwaj, S.C., Kumar, S. and Menon, M.K. (2003) Appearance of new pathotypes of *Puccinia recondite* f. sp. *tritici* virulent on *Lr9* in India. Indian Phytopathol., 196-198.

Nazim, M.S., El-Shehidi, A.A., Abdou Y.A. and El-Daoudi, Y.H. (1983) Yield losses caused by leaf rust on four wheat cultivars under epiphytotic levels. Proc. 5th Conf. Microbiol., Cairo, Egypt: 17-27.

Omara, R.I., El-Naggar, Doaa 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.

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

Parlevliet, J.E. (1975). Partial resistance of *Puccinia* ‹barley to leaf rust .I *.hordei* tivar and development Effect of cul .stage on latent periodEuphytica. 24, 293.

Pathan, A.K. and Park, R.F. (2006) Evaluation of seedling and adult plant resistance to leaf rust in European wheat cultivars. Euphytica, 149:327–342.

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.

Risk, J.M., Selter, L.L., Krattinger, S.G., Viccars, L.A., Richardson, T.M., Buesing, G., Herren, G., Lagudah, E.S. and Keller, B. (2012) Functional variability of the *Lr34* durable resistance gene in transgenic wheat. Plant Biotech. J., 10:477-487.

Saari, E.E. and Wilcoxson, R.D. (1974). Plant disease situation of high yielding durum wheat in Asia and Africa. Annu. Rev. Phytopathology, 2: 49-68.

Safavi, S.A. and Afshari, F. (2012) Identification of resistance to *Puccinia striiformis* f. sp. *tritici* in some elite wheat lines. J. Crop Prot., 1 (4):293-302.

Shahin A.A.; Ashmawy, M.A.; El-Orabey W. and Esmail, S.M. (2020) Yield losses in wheat caused by stripe rust (*Puccinia striiformis*) in Egypt. American Journal of Life Sciences, 8(5), 127-134.

Singh, R.P., William, H.M., Huerta-Espino, J. and Rosewarne, G. (2003) Wheat rust in Asia: meeting the challenges with old and new technologies. Proceedings of the 4th International Crop Science C ‹ongress Sep ‹Australia ‹Brisbane 26-1 Oct2004 .

Singh, R.P., Huerta-Espino, J. and William, H.M. (2005) Genetics and breeding for durable resistance to leaf and stripe rusts in wheat. Turkish Journal of Agriculture, 29:121-127.

Singh, R.P., Huerta-Espino, J., Bhavani, S., Herrera-Foessel, S.A., Singh, D., Singh, P.K., Velu, G.; Mason, R.E., Jin, Y., Njau, P. and Crossa, J. (2011). Race non-specific resistance to rust diseases in CIMMYT spring wheat. Euphytica, 179:175-186.

Suenaga, K., Singh, R.P., Huerta-Espino, J. and William, H.M. (2003). Microsatellite markers for genes *Lr34*/*Yr18* and other quantitative trait loci for leaf rust and stripe rust resistance in bread wheat. Phytopathology, 93:881- 890.

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

Wang, L.F., Ma, J. X., Zhou, R. H., Wang, X. M. and Jia, J. Z. (2002) Molecular tagging of the yellow rust resistance gene (*Yr10*) in common wheat, PI178383 (*Triticum aestivum* L.). Euphytica, 124:71-73.

Xiaowen, N., Xinmin, C., Xianchum, X., Zhonghu, H. and Lillemo, M. (2008). Heritability and number of genes controlling slow-mildewing resistance in Chinese wheat cultivar Lumai-21. Acta Agron. Sin., 34:1317-1322.

Zhang, P., McIntosh, R., Hoxha, S. and Dong C. (2009) Wheat stripe rust resistance genes *Yr5* and *Yr7* are allelic. Theor. Appl. Genet. 120, 25–29.