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Evaluation of some bread wheat varieties and monogenic lines for Adult Plant Resistance to Stem Rust and detection related proteins

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ABSTRACT

Stem rust disease is one of the most feared disease of wheat (in most wheat-growing regions of the world caused by (*Puccinia graminis* f. sp. *tritici* Eriks & Henn) It has been also one of the most serious diseases in Egypt. Response of eleven Egyptian wheat varieties i.e. Shandweel 1, Giza 168, Giza 171, Gemmeiza 11, Gemmeiza 12, Sids 14, Misr 1, Misr 2, Misr 3, Sakha 95 and the highly susceptible variety Morocco were evaluated against stem rust disease. The results showed a high level of resistance of the varieties Giza 171, Misr 3, Sakha 95, Shandweel 1, Giza 168, Gemmeiza 11, Gemmeiza 12 and Sids 14. While these types had sensitive reactions Misr 1, Misr 2 and Morocco. The protein was analyzed and Ten protein bands with molecular weights ranging from 320 to 9 kDa are contained in wheat plants. Nine protein bands were appeared in all varieties. Band with molecular weight 320 kDa disappeared in Shandweel 1, Gemmeiza 12, Misr 1 and Misr 2. whereas Band with molecular weight 270 kDa appeared in Shandweel 1, Misr 1 and Misr 2. According to the disease severity results showed that Shandweel 1, Misr 1 and Misr2. were the most susceptible varieties, its mean that the protein Band with molecular weight 270 kDa was related to the resistance to the stem rust disease .

Keywords: *Puccinia graminis* f. sp. *tritici*, Wheat stem rust, Cultivars, Monogenic Lines.

INTRODUCTION

Wheat (*Triticum aestivum L.*) occupied an important position among the cereal crops in the world. In Egypt, the average cultivated area at the last ten years ranged between 2.8 and 3.6 million feddans, which produce about 9.7 million tons yearly. In 2022/23 growing season, about 3.6 million feddans were cultivated by wheat and yielded about 9.7 million tons (Fao, 2023). Rust diseases pose a significant threat to wheat crops due to their capacity to spread over long distances, evolve into new strains capable to infect resistant cultivars, and proliferate

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quickly in ideal environmental settings, resulting in substantial yield losses (El-Daoudi *et al*., 1996). Stem rust, caused by *Puccinia graminis* f. sp. tritici, is widely regarded as one of the most hazardous diseases. The susceptibility of certain varieties to the stem rust disease intensifies greatly when they are planted late in the season, due to the favorable climate conditions (Park., 2007) causing 100 percent loss, depending on the level of the wheat genotypes resistance and stage of crop development when the initial infection occurs. Under favorable circumstances, the causative agent has the potential to devastate entire seedless plants. In Egypt, the conducive environmental conditions for disease transmission are likely to result in significant reductions in wheat grain yield i.e. rusts, smuts and mildew diseases. However, using resistant varieties seemed to be important to reduce the production costs and obtain economic grain yield. The early sowing of wheat leads to low level of rust infection even with the susceptible varieties. Furthermore, certain cultivars were swiftly abandoned following their introduction due to their vulnerability to rust diseases (Boulot and Aly, 2014). For example the cv. Sakha 79 was discarded from agriculture very shortly after it release because of this reason. In Egypt, the susceptibility of wheat cultivars to rust has resulted in a significant decrease in grain yield, with losses reaching up to 32% under experimental field conditions (Shahin and El-Orabey, 2016). To combat this issue, the utilization of resistant wheat cultivars has proven to be an economically viable and highly effective method in controlling wheat rust (El-Orabey *et al*., 2019).

This study aimed to evaluate the resistance potential of several Egyptian wheat cultivars against stem rust and to investigate the efficacy of stem rust resistance genes during the adult stage.

MATERIALS AND METHODS

The present studies were carried out at the experimental farm of Faculty of Agriculture, Menofia University during three growing seasons i.e. 2018/2019, 2019/2020 and 2020/2021.

1- Wheat genotypes:

Ten Egyptian wheat varieties i.e. Shandweel 1, Giza 168, Giza 171, Gemmeiza 11, Gemmeiza 12, Sids 14, Misr 1, Misr 2, Misr 3, Sakha 95 and the highly susceptible variety Morocco were tested against stem rust disease. The pedigree and year of release for these varieties are shown in Table (1). Moreover, 46 stem rust monogenic lines were tested (Table 2).

2. Field studies:

2.a. Evaluation of some wheat varieties against stem rust disease under field conditions:

Eleven wheat varieties were assessed in field conditions at the experimental farm of the Faculty of Agriculture, Menofia University over three growing seasons: 2018/2019, 2019/2020, and 2020/2021. The seeds were sown 15 days after the usual sowing date (mid-December) to ensure the plants were exposed to optimal environmental conditions for rust incidence. The different varieties were planted in rows within plots, following all recommended cultural practices from commercial fields such as fertilization, irrigation, and other management techniques. Rust incidence data were recorded weekly, combining severity, response, and infection levels, starting from the appearance of rust and continuing throughout the growth stages. All standard commercial practices, including fertilization, irrigation, and management, were strictly adhered to during the evaluation process.

A one-meter wide spreader area surrounded all the plots, which were planted with a combination of the highly susceptible varieties Morocco and Max. Prior to the appearance of rust, the spreader plants were deliberately inoculated in the latter part of February to ensure a continuous source of leaf rust for the tested plants. Inoculation took place during the booting stage, following the protocol described by Tervet and Cassel (1951). The severity of infection and rust response data were recorded during the adult stage of the tested plants, following the guidelines provided by Peterson *et al*. (1948).

Table (1): List of the local wheat varieties that were used, pedigree and year of release.

No.	Variety	Pedigree	Year of release
1	Shandweel 1	SITE//MO/4/NAC/TH.AC//3*PVN/3/MIRLO/BUC. CMSS93B00567S-72Y-010M-010Y-010M-0HTY-0SH	2011
2	Giza 168	MIL/BUC//Seri CM93046-8M-0Y-0M-2Y-0B	1999
3	Giza 171	Sakha 93 / Gemmeiza 9 S.6-1GZ-4GZ-1GZ-2GZ-0S	2013
4	Gemmeiza 11	B0W"S"/KVZ"S"//7C/SERI82/3/GIZA168/SAKHA61. GM7892-2GM-1GM-2GM-1GM-0GM.	2011
5	Gemmeiza 12	OTUS/3/SARA/THB//VEE .CCMSS97Y00227S-5Y-010M-010Y-010M-2Y-1M-0Y-0GM	2017
6	Sids 14	SW8488*2/ KUKUNACGSS01Y00081T-099M-099Y-099M-099B-9Y-0B-0SD.	2018
7	Misr 1	OASIS/SKAUZ//4*BCN/3/2*PASTOR. CMSSOYO1881T-050M-030Y-O3OM-030WGY-33M-0Y-0S.	2010
8	Misr 2	SKAUZ/BAV92. CMSS96M0361S-1M-010SY-010M-010SY-8M-0Y-0S.	2011
9	Misr 3	ATTILA*2/ABW65*2/KACHU CMSS06Y00258 2T-099TOPM-099Y-099ZTM-099Y-099M-10WGY-0B-0EGY	2018
10	Sakha 95	PASTOR//SITE/MO/3/CHEN/AEGILOPS SQUARROSA(TAUS)//BCN /4/WBLL1CMSA01Y00158S-040P0Y-040M-030ZTM-040SY-26M-0Y-0SY-0S	2018
11	Morocco (check)	-	-

Table (2): List of wheat stem rust resistance genes, genome, sources and tester lines.

No.	Sr gene	Genome location	Source	Tester
1	*Sr* 2 Comp.	3BS	*Triticum turgidum* (Yaroslav emmer)	CnS(Hope3B)
2	*Sr* 5	6DS	Reliance	ISr5-Ra
3	*Sr* 6	2DS	Red Egyptian	ISr6Ra
4	*Sr* 7a	4BL	Kenya117A	Line G sel
5	*Sr* 7b	4BL	Marquis	ISr7b-Ra
6	*Sr* 8a	6AS	Red Egyptian	ISr8-Ra
7	*Sr* 8b	6AS	Barleta Benvenuto	Barleta Benvenuto
8	*Sr* 9a	2BL	Red Egyptian	ISr9a-Ra
9	*Sr* 9b	2BL	Kenya117A	W2691Sr9b
10	*Sr* 9d	2BL	*T. turgidum* (Yaroslav emmer)	ISr9d Ra
11	*Sr* 9e	2BL	*T. turgidum* (Vernal emmer)	Vernstein
12	*Sr* 9g	2BL	Lee	CnSSr9g
13	*Sr* 10	2B	Egypt NA95	W2691Sr10
14	*Sr* 11	6BL	Lee	ISrl1-Ra
15	*Sr* 12	3BS	*T. turgidum* (Iumillo durum)	BtSr12Tc
16	*Sr* 13	6AL	*T. turgidum* (Kaphli emmer)	W2691Srl3
17	*Sr* 14	1BL	*T. turgidum* (Kaphli emmer)	Line A sel
18	*Sr* 15	7AL	Norka	W2691Srl5
19	*Sr* 16	2BL	Thatcher	ISr16-Ra
20	*Sr* 17	7BL	*T. turgidum*? (Yaroslav emmer)	CS (Hope7B)
21	*Sr* 18	1D	Marquis	LCSr18Mq
22	*Sr* 19	2BS	Marquis	LCSr19Mq
23	*Sr* 20	2BL	Marquis	LC
24	*Sr* 21	2AL	*T. monococcum*	Einkorn
25	*Sr* 22	7AL	*T. monococcum*	SwSr22T.B.
26	*Sr* 23	2BS	Exchange	Exchange
27	*Sr* 24	3DL	*Thinopyron ponticum*	BtSr24Agt
28	*Sr* 25	7DL	*Thinopyron ponticum*	LCSr25Ars
29	*Sr* 26	6AL	*Thinopyron ponticum*	Eagle (Australian)
30	*Sr* 27	3A	*Secalis cereale* (Imperial rye)	W2691Sr27
31	*Sr* 28	2BL	Kota	W2691Sr28Kt
32	*Sr* 29	6DL	Etiole de Choisy	PusaSr29Edch
33	*Sr* 30	5DL	Webster	BtSr30Wst
34	*Sr* 31	1BL	*Secalis cereale* (Imperial rye)	Line ESr31Kvz
35	*Sr* 32	2A, 2B	*T. aestivum speltoides*	ER5155
36	*Sr* 33	1DL	*T. tauschii*	TetraCanthatch/ T. tauschii
37	*Sr* 34	2A,2B	*T. comosa*	Compare
38	*Sr* 35	3AL	*T. monococcum*	Mq(2)5xG2919
39	*Sr* 36	2BS	*T. timopheevi*	W2691SrTt-1
40	*Sr* 37	4BL	*T. timopheevi*	W2691SrTt-2
41	*Sr* 38	2AS	*T. ventricosa*	VPM1
42	*Sr* 39	2B	*T. aestivum speltoides*	RL5711
43	*Sr* 40	2BS	*T. araraticum*	RL6087
44	*Sr* Tmp	4B	Triumph 64	Triumph 64
45	*Sr* wld-1	-	Waldron	BtSrWldWld
46	*Sr* McN	-	McNair 701	McNair 701

2.b. Field inoculation:

The examined cultivars were planted in rows within plots using a complete block design with 3 replications. Surrounding the plots were spreader plants that were assigned for inoculation. The spreader plants were then inoculated according to Tervet and Cassel (1951). Furthermore, the spreader plants underwent concurrent injections with uredospores suspended in distilled sterile water containing uredinospores of various pathotypes of *Puccinia graminis* f. sp. tritici sourced from the Wheat Diseases Research Department, Plant Pathology Research Institute, ARC, Giza.

2.c. Disease assessment:

2.c.1. Rust severity:

The rust severity (%) for each genotype was calculated as adult-plant reactions from the time rust first appeared until the early dough stage (stage 30) **(Large, 1954).** The modified Cobb's scale **(Peterson *et al.*, 1948)** was utilized to record the rust severity of each genotype after the initial infection and at seven-day intervals.

Plant reaction was expressed in 5 infection types i.e. Immune = (O), Resistant = (R), Moderately resistant = (MR), Moderately susceptible = (MS) and Susceptible = (S) **(Johnston, 1961)**. The disease incidence and their development were estimated as follows:

2.c.2. Final rust severity (FRS) according to **Das *et al.* (1993)**, the disease severity (%) was documented in accordance with the highly susceptible check variety being severely affected by rust, resulting in the disease rate reaching its peak and the final level of leaf rust severity.

2.c.3. Rate of stem rust increase (r-value), The estimation of the ability of the tested genotype to impact the progression of leaf rust infection under field conditions involved determining the severity of leaf rust infection at the time of rust appearance and subsequently every seven days. This severity was calculated based on the various rust scores, and the rate of leaf rust increase (r-value) was then determined using the provided formula (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:

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.

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

3. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE):

Fractionation electrophoresis was carried out using the same parameters on a vertical slab of sodium dodecyl sulfate polyacrylamide gel (SDS-PAGE) with a concentration of 12% (w/v). The BIORAD Techware 1.5 mm equipment was utilized following the **Laemmli (1970)** method with modifications by **Studier (1973).** Protein molecular weights were determined in comparison to a broad range molecular weight protein marker from Promega com.

EXPERIMENTAL RESULTS

1. Effectiveness of stem rust resistance genes at adult-plant stage for stem rust under field conditions:

The experiment of this study were performed through three successive growing seasons i.e. 2018/2019, 2019/2020 and 2020/2021 at the farm of the Faculty of Agriculture, Menofia University, Shibin El-Kom, Egypt.

The objective of this experiment was to investigate the efficacy of adult-plant stage stem rust resistance genes under field conditions.

Data presented in Table (3) showed the response of 46 stem rust monogenic lines at adult stage. Due to their response, which could be divided into three groups.

Group I: Resistant genes during the three growing seasons: *Sr* 2 Comp. (0, Tr MR, 0), *Sr* 24 (0, 0, 0), *Sr* 25 (5 MR, 0, Tr MR), *Sr* 26 (Tr MR, 10 MR, 0), *Sr* 28 (0, 0, 0), *Sr* 31 (0, 0, 0), *Sr* 32 (Tr MR, 0,Tr MR), *Sr* 33 (0, 0, 0), *Sr* 34 (0,Tr MR, 0), *Sr* 36 (0, 0, 0), *Sr* 37 (5 R, 0,Tr MR), *Sr* 38 (0, 0, 0), *Sr* 39 (0, 0, 0) and *Sr* 40 (0, Tr MR, Tr MR).

Group II: Susceptible genes during the three growing seasons: *Sr* 7a (10 S, 5 S, 5 S), *Sr* 7b (20 S, 30 S, 50 S), *Sr* 8a (20 S, 30 S, 60 S), *Sr* 8b (5 S, 30 S, 50 S), *Sr* 9a (5 S, Tr S, 10 S), *Sr* 9b (10 S, 20 S,5 S), *Sr* 9d (5 S, 30 S, 20 S), *Sr* 9e (10 S, 5 S, 20 S), *Sr* 9g (20 S, 5 S, 30 S), *Sr* 10 (Tr S, 20 S, 10 S), *Sr* 12 (Tr S, 5 S, 10 S), *Sr* 13 (5 MS, Tr S, 10 MS), *Sr* 14 (5 S, 10 S, 30 S), *Sr* 16 (20 S, 5 S, 20 S), *Sr* 17 (10 MS, 5 S, 30 S), *Sr* 18 (Tr S, 30 S, 10 S), *Sr* 19 (20 MS, 30 MS, 30 MS), *Sr* 20 (Tr S, 30 S, 50 S), *Sr* 21 (30 S, 10 S, 40 S), *Sr* 22 (5 S, 10 S, 20 S), *Sr* 23 (5 S, 20 S, 10 S), *Sr* 27 (10 S, 5 MS, 30 MS), *Sr* 30 (5 S, 10 S, 30 S), *Sr* 35 (40 S, 5 S, 20 S), *Sr* Tmp. (30 S, 10 S, 5 S) and *Sr* McN (50 S, 70 S, 80 S).

Group III: Genes with variable reactions during the three growing seasons: *Sr* 5 (5 MR, Tr S, 5 S), *Sr* 6 (Tr MR, 10 S, 0), *Sr* 11 (10 S, Tr MR, 0), *Sr* 15 (10 MR, Tr S, Tr MR), *Sr* 29 (Tr S, 0, 5 S) and *Sr* Wld-1 (5 MR, Tr S, 10 MR).

2. Performance of 11 wheat varieties against stem rust infection under field conditions:

This work aims to study the response of 11 wheat varieties i.e. Shandweel 1, Giza 168, Giza 171, Gemmeiza 11, Gemmeiza 12, Sids 14, Misr 1, Misr 2, Misr 3, Sakha 95 and the highly susceptible variety Morocco to build up data on the regional performance and disease effects due to yellow rust. Therefore, materials were grown at Shibin El-Kom location for 3 growing seasons (2018/2019, 2019/2020 and 2020/2021).

The study focused on observing the occurrence of rust, which was measured as the severity of rust from its initial appearance until the dough stage. The researchers also analyzed the final rust severity (FRS %), the rate of disease increase (r-value), and the area under the disease progress curve (AUDPC).

Table (3): Rust severity and infection type of wheat stem rust monogenic lines at Shibin El-Kom location during three successive growing seasons (2018/2019 - 2020/2021).

Monogenic lines	Season / Rust reaction		
	2018/2019	**2019/2020**	**2020/2021**
	Resistant genes		
Sr 2 Com.	0	Tr MR	0
Sr 24	0	0	0
Sr 25	5 MR	0	Tr MR
Sr 26	Tr MR	10 MR	0
Sr 28	0	0	0
Sr 31	0	0	0
Sr 32	Tr MR	0	Tr MR
Sr 33	0	0	0
Sr 34	0	Tr MR	0
Sr 36	0	0	0
Sr 37	5 R	0	Tr MR
Sr 38	0	0	0
Sr 39	0	0	0
Sr 40	0	Tr MR	Tr MR
	Susceptible genes		
Sr 7a	10 S	5S	5 S
Sr 7b	5 S	20 S	50 S
Sr 8a	20 S	30 S	60 S
Sr 8b	5 S	30 S	50 S
Sr 9a	5 S	Tr S	10 S
Sr 9b	10 S	20 S	5 S
Sr 9d	5 S	30 S	20 S
Sr 9e	10 S	5 S	20 S
Sr 9g	20 S	5 S	30 S
Sr 10	Tr S	20 S	10 S
Sr 12	Tr S	5 S	10 S
Sr 13	5 MS	Tr S	20 MS
Sr 14	5 S	10 S	30 S
Sr 16	20 S	5 S	20 S
Sr 17	10 MS	5 S	30 S
Sr 18	Tr S	30 S	10 S
Sr 19	20 MS	30 MS	30 MS
Sr 20	Tr S	30 S	50 S
Sr 21	30 S	10 S	40 S
Sr 22	5 S	10 S	20 S
Sr 23	5 S	20 S	10 S
Sr 27	10 S	5 MS	30 MS
Sr 28	0	0	0
Sr 30	5 S	10 S	30 S
Sr 35	40 S	5 S	20 S
Sr Tmp	30 S	10 S	5 S
Sr McN	50 S	70 S	80 S
	Genes with variable reactions		
Sr 5	5 MR	Tr 5	5 S
Sr 6	Tr MR	10 S	0
Sr 11	10 S	Tr Mr	0
Sr 15	10 MR	Tr S	Tr MR
Sr 29	Tr S	0	5 S
Sr wld-1	5 MR	Tr S	10 MR

R: Resistant, MR: Moderately Resistant, MS: Moderately Susceptible, S: Susceptible, Tr: Trace (<5%).

a. Final rust severity:

The ultimate percentage of rust severity was recorded when the susceptible check variety Morocco exhibited severe rusting, leading to the disease rate reaching its maximum level.

The first growing season (2018/2019):

Data presented in Table (4) showed that at Shibin El-Kom location the wheat varieties; Giza 171, Misr 3 and Sakha 95 showed the lowest levels of final stem rust severity (FRS %) i.e. 0, 0 and 5 MR, respectively during the 2018/2019 growing season. On the other hand, the wheat varieties; Shandweel 1, Giza 168, Gemmeiza 11, Gemmeiza 12 and Sids 14 showed intermediate level of FRS (%) i.e. 5 S, 10 S, 30 S, 20 S and 10 S, respectively. While the wheat varieties; Misr 1, Misr 2 and Morocco showed the highest percentage of FRS (%) i.e. 40 S, 50 S and 80 S, respectively.

The second growing season (2019/2020):

Data presented in Table (4) showed that, the wheat varieties; Giza 171, Misr 3 and Sakha 95 showed the lowest levels of final stem rust severity (FRS %) i.e. 0, 0 and 0, respectively during 2019/2020 growing season. While, the wheat varieties; Shandweel 1, Giza 168, Gemmeiza 11, Gemmeiza 12 and Sids 14 showed intermediate level of FRS (%) i.e. 20 S, 20 S, 10 S, 5 S and 5 S, respectively. While the wheat varieties; Misr 1, Misr 2 and Morocco observed the highest percentage of FRS (%) i.e. 70 S, 80 S and 90 S, respectively.

The Third growing season (2020/2021):

Data presented in Table (4) showed that, the wheat varieties; Giza 171, Misr 3 and Sakha 95 showed the lowest levels of final stem rust severity (FRS %) i.e. 0, 0 and Tr MR, respectively during 2020/2021 growing season. On the other hand, the wheat varieties; Shandweel 1, Giza 168, Gemmeiza 11, Gemmeiza 12 and Sids 14 showed intermediate level of FRS (%) i.e. 30 S, 10 S, 5 S, 10 S and 20 S, respectively. While, the wheat varieties; Misr 1, Misr 2 and Morocco showed the highest percentage of FRS (%) i.e. 60 S, 70 S and 100 S, respectively.

Table (4): Final stem rust severity (%) of 11 wheat varieties under field conditions at Shibin El-Kom location during 2018/2019, 2019/2020 and 2020/2021 growing seasons.

No.	Varieties	Season / Final rust Severity (%) (FRS)		
		2018/2019	2019/2020	2020/2021
1	Shandweel 1	5 S	20 S	30 S
2	Giza 168	10 S	20 S	20 S
3	Giza 171	0	0	0
4	Gemmeiza 11	30 S	10 S	5 S
5	Gemmeiza 12	20 S	5 S	10 S
6	Sids 14	10 S	5 S	20 S
7	Misr 1	40 S	70 S	60 S
8	Misr 2	50 S	80 S	70 S
9	Misr 3	0	0	0
10	Sakha 95	5 MR	0	Tr MR
11	Morocco (check)	80 S	90 S	100 S

b. Rate of disease increase (r-value):

The disease rate increase (r-value) was calculated based on the data collected from consecutive rust scores (rust severity %) at specific time points from the onset of rust until the early dough stage across three consecutive growing seasons (2018/2019, 2019/2020, and 2020/2021).

The first growing season (2018/2019):

Data presented in Table (5) observed that, the wheat varieties; Giza 171 (0.000), Misr 3 (0.000), Sakha 95 (0.025), Shandweel 1 (0.025), Giza 168 (0.061), Gemmeiza 11 (0.010), Gemmeiza 12 (0.099) and Sids 14 (0.061) showed the lowest values of r-values. While, wheat varieties with high rate of disease increase (r-value) were Misr 1 (0.146), Misr 2 (0.466) and Morocco (0.771).

The second growing season (2019/2020):

Data presented in Table (5) Showed that, the wheat varieties; Giza 171 (0.000), Misr 3 (0.000), Sakha 95 (0.000), Shandweel 1 (0.099), Giza 168 (0.099), Gemmeiza 11 (0.061), Gemmeiza 12 (0.025) and Sids 14 (0.025) showed the lowest values of r-values. While, wheat varieties with high rate of disease increase (r-value) were Misr 1 (0.341), Misr 2 (0.567) and Morocco (0.843).

The third growing season (2020/2021):

Data presented in Table (5) Showed that, the wheat varieties; Giza 171 (0.000), Misr 3 (0.000), Sakha 95 (0.000), Shandweel 1 (0.099), Giza 168 (0.099), Gemmeiza 11 (0.025), Gemmeiza 12 (0.061) and Sids 14 (0.099) showed the lowest values of r-values. While, wheat varieties with high rate of disease increase (r-value) were Misr 1 (0.391), Misr 2 (0.403) and Morocco (0.889).

Table (5): Rate of disease increase (r-value) on 11 wheat varieties grown at Shibin El-Kom location during 2018/2019, 2019/2020 and 2020/2021 growing seasons.

No.	Variety	Season / Rate of disease increase (r-value)		
		2018/2019	2019/2020	2020/2021
1	Shandweel 1	0.025	0.099	0.099
2	Giza 168	0.061	0.099	0.099
3	Giza 171	0.000	0.000	0.000
4	Gemmeiza 11	0.010	0.061	0.025
5	Gemmeiza 12	0.099	0.025	0.061
6	Sids 14	0.061	0.025	0.099
7	Misr 1	0.146	0.341	0.391
8	Misr 2	0.466	0.567	0.403
9	Misr 3	0.000	0.000	0.000
10	Sakha 95	0.025	0.000	0.000
11	Morocco (check)	0.771	0.843	0.889

3. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis of wheat cultivars.

The SDS-PAGE findings outlined in Table (6) and Figure (1) indicate the presence of 10 protein bands in wheat plants, with molecular weights ranging from 320 to 9 kDa. All varieties displayed nine protein bands in common. The 320 kDa band was absent in Shandweel 1, Gemmeiza 12, Misr 1, and Misr 2. On the other hand, the 270 kDa band was observed in Shandweel 1, Misr 1, and Misr 2. Only Gemmeiza 12 lacked the 125 kDa band.

Table (6): Sodium dodecyl sulfate-polyacrylamide gel electrophoresis of wheat cultivars.

Band No	M.W Bp	Shandweel 1	Giza 168	Giza 171	Gemmeiza 11	Gemmeiza 12	Sids 14	Misr 1	Misr 2	Misr 3	Sakha 95	Morocco
1	320	0	1	1	1	0	1	0	0	1	1	1
2	270	1	0	0	0	0	0	1	1	0	0	0
3	125	1	1	1	1	0	1	1	1	1	1	1
4	86	1	1	1	1	1	1	1	1	1	1	1
5	67	1	1	1	1	1	1	1	1	1	1	1
6	43	1	1	1	1	1	1	1	1	1	1	1
7	38	1	1	1	1	1	1	1	1	1	1	1
8	26	1	1	1	1	1	1	1	1	1	1	1
9	16	1	1	1	1	1	1	1	1	1	1	1
10	9	1	1	1	1	1	1	1	1	1	1	1
Total		9	9	9	9	9	9	9	9	9	9	9

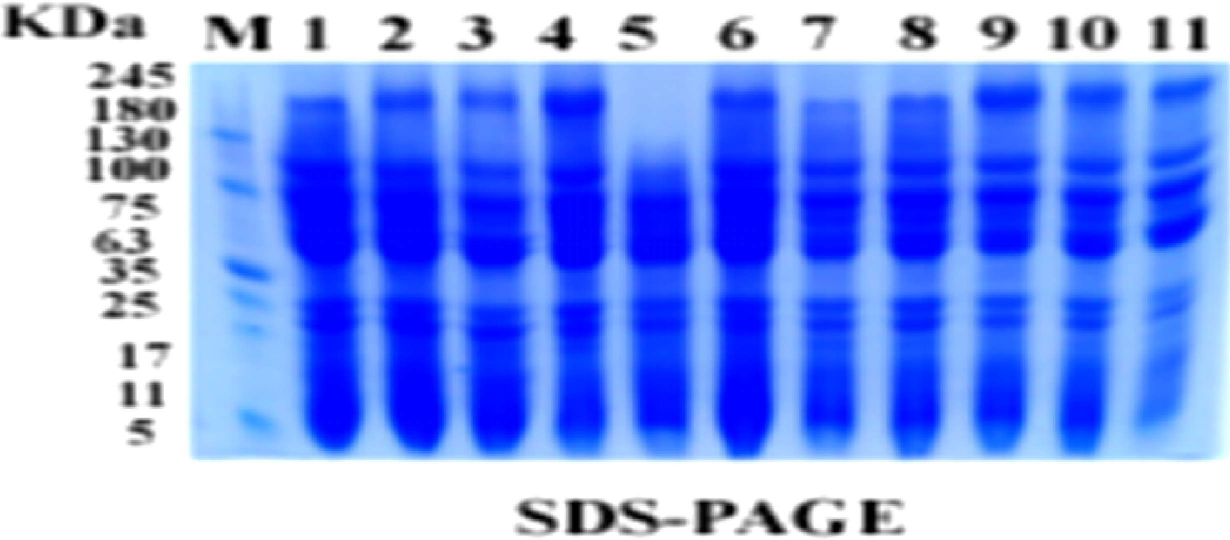

Figure 5: Sodium dodecyl sulfate-polyacrylamide gel electrophoresis of wheat cultivars.

DISCUSSION

Stem rust poses a significant threat to wheat (*Triticum aestivum L.*) crops in various wheat-growing areas worldwide, being caused by (*Puccinia graminis* f. sp. *tritici* Eriks & Henn). This disease has been particularly problematic in Egypt. A study was conducted to assess the response of eleven Egyptian wheat varieties - Shandweel 1, Giza 168, Giza 171, Gemmeiza 11, Gemmeiza 12, Sids 14, Misr 1, Misr 2, Misr 3, Sakha 95, and the highly susceptible variety Morocco - to stem rust disease.

The tested wheat varieties can be categorized into distinct groups. The initial group comprises wheat varieties that exhibited the lowest AUDPC values (less than 300). The second group consists of wheat varieties, namely Giza 171, Misr 3, Sakha 95, Shandweel 1, Giza 168, Gemmeiza 11, Gemmeiza 12, and Sids 14. These varieties can be utilized safely without any genetic enhancements to combat stem rust infection, as they demonstrated a remarkably high level of resistance. On the other hand, the second group encompasses varieties that displayed susceptible reactions, including Misr 1, Misr 2, and Morocco. The wheat varieties may vary in their capacity to impede disease progression due to the diverse response components, ultimately resulting in the manifestation of slow rusting (Ashmawy *et al*., 2013, El-Orabey *et al*., 2019, Mabrouk *et al*., 2019, Elkot *et al*., 2020 and El-Orabey *et al*., 2020). Partial resistance, as defined by Parlevliet and Kuiper in (1977) , is a form of quantitative resistance that relies on minor genes. This type of resistance is believed to be more long-lasting compared to resistance based on major race-specific genes. It has been acknowledged early on as a more stable form of resistance when compared to other types of resistance, as stated by Caldwell in (1968) . Based on the final severity of rust, the tested wheat varieties can be categorized into three primary groups. The first group consists of varieties with race-specific resistance, which includes wheat varieties that exhibited immunity, as well as varieties with infection types resistant (R) and moderately resistant (MR), such as Giza 171, Misr 3, and Sakha 95. The second group comprises genotypes with partial resistance (slow rusting resistance), which includes wheat genotypes with infection types susceptible (S) and rust severity of up to 30%, such as Shandweel 1, Giza 168, Gemmeiza 11, Gemmeiza 12, and Sids 14. The last group encompasses fast rusting varieties, which includes wheat varieties with infection types susceptible (S) and rust severity exceeding 30%, such as Misr 1, Misr 2, and Morocco. Disease severity, which indicates the extent of rust disease and damage on the infected plants, was utilized as a parameter to assess the partial resistance of the genotypes Broers *et al*., (1990); Burleigh *et al*. (1991); Kolmer (1991); Kumar and Tewori (1997); Winzeler *et al.* (2000) and Martinez *et al.* (2001). Hence, the severity of the disease appeared to be a suitable factor for assessing different types of partial resistance.

Wheat plants exhibit ten protein bands, varying in molecular weights from 320 to 9 kDa. Among these bands, nine were identified across all varieties. However, the band with a molecular weight of 320 kDa was not detected in Shandweel 1, Gemmeiza 12, Misr 1, and Misr 2. On the other hand, the band with a molecular weight of 270 kDa was observed in Shandweel 1, Misr 1, and Misr 2. Based on the severity of the disease, it can be concluded that Shandweel1, Misr1, and Misr2 are the most susceptible varieties. This suggests that the protein band with a molecular weight of 270 kDa is associated with resistance to stem rust disease. Similar findings were reported by Elwy *et al*., (2021), who observed the disappearance of the band with a molecular weight of 15 kDa in Misr 2, Sids 14, Sakha 95, and Gemmeiza 11. These cultivars were found to be highly susceptible to rust disease. It is evident that the band with a molecular weight of 15 kDa is correlated with resistance to puccinia rust. This is consistent with the findings of Rabia *et al*., (2014), who reported a significant correlation between the level of protection and the expression of PR proteins. Additionally, Ahmed (2016) reported that the severity of plant diseases can be progressively reduced by the presence of newly discovered protein bands that have a low molecular weight

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