OPEN ACCESS

Int. J. Phytopathol. 09 (01) 2020. 51-70

DOI: 10.33687/phytopath.009.01.3269

Check for updates

Available Online at EScience Press

International Journal of Phytopathology

ISSN: 2312-9344 (Online), 2313-1241 (Print)

https://esciencepress.net/journals/phytopath

SCREENING OF CIMMYT WHEAT GENOTYPES AGAINST YELLOW RUST IN EGYPT

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A R T I C L E   I N F O

Article history

Received: January 07, 2020

Revised: March 11, 2020

Accepted: April 21, 2020

Keywords

Wheat

Yellow rust

Puccinia striiformis

Promising lines

A B S T R A C T

Yellow (stripe) rust caused by *Puccinia striiformis* f. sp. *tritici*, is a serious problem of wheat (*Triticum aestivum*) production in many parts of the world including Egypt. The pathogen is capable to produce new physiological races that attack resistant varieties and develop epidemic under optimal environmental conditions which results in a serious yield loss. Host resistance is the most economical way to manage wheat stripe rust. Therefore, the present study was conducted to evaluate the reaction of 53 wheat genotypes, delivered to Egypt by International Maize and Wheat Improvement Center (CIMMYT) by artificial inoculation against the major virulent races at adult plant stage at two locations; Itay El-Baroud and Sakha Agricultural Research Stations; during three growing seasons *i.e.* 2016/17, 2017/18 and 2018/19. Results of the current study showed that 34 wheat genotypes; No. 2, 3, 4, 5, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 21, 22, 24, 25, 26, 27, 28, 30, 31, 32, 33, 34, 35, 36, 40, 41, 42, 44, 45 and 48 were resistant and had the lowest values of FRS, ACI, and AUDPC. Therefore, we can select these genotypes as resistant lines in the breeding program for resistance to yellow rust. As for 1000 kernel weight, 10 wheat genotypes *i.e.* 4, 6, 11, 14, 17, 28, 33, 34, 41 and 48 showed the highest values of 1000 kernel weight and were also resistant to yellow rust. Correlation analysis of different parameters also showed a high correlation between FRS, ACI, RRI and AUDPC with 1000 kernel weight of the tested wheat genotypes. Intensive genetic and molecular studies are useful for developing high yielding and disease resistant wheat cultivars in Egypt.

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INTRODUCTION

Wheat is now the most widely cultivated cereal in the world with more than 220 million ha planted annually under wide ranges of climatic conditions and in many geographic regions (Shiferaw *et al.*, 2013). However, enhancing the production is facing many factors *i.e.* changing of climatic factors requires and biotic stresses (Singh *et al.*, 2008; Singh *et al.*, 2011) that cause significant yield loss. Among various biotic stresses, three rust diseases *i.e.* leaf, stem and stripe caused by *Puccinia triticina* Eriks., *P. graminis* Pers. f. sp. *tritici* Eriks. & E. Henn. and *P. striiformis* Westend. f. sp. *tritici*) are still the major threats to wheat production globally (McIntosh *et al.*, 1995; Murray and Brennan, 2009).

Yield losses due to stripe rust range from 10-70% (Chen, 2005; Ashmawy and Ragab, 2016), moreover, stripe rust can cause 100% yield loss if infection occurs at very early growth stage and the disease continues to develop during the growing season (Afzal *et al.*, 2007). Although the application of recommended fungicides against rust diseases can manage the disease to some extent their use adds to the production costs. Breeding for resistance remains the most effective and efficient management strategy as it does not add input costs to farmers and is environmentally safe (Yang and Daqun, 2004). To date, 80 yellow rust resistance (*Yr*s) genes have been permanently named in wheat, including the recently mapped *Yr* 79 (Feng *et al.*, 2018) and *Yr* 80 (Nsabiyera *et al.*, 2018), and 67 stripe rust resistance genes have been temporarily designated, including all-stage resistance (also termed seedling resistance) and adult-plant resistance (APR) (Wang and Chen, 2017). Although these *Yr* genes have been identified in diverse wheat accessions, the race specificity of seedling resistance genes limits their efficacy against pathotypes (Kankwatsa *et al.*, 2017). In contrast, APR is generally considered to be durable, but APR genes represent a minority of known resistance genes (Kankwatsa *et al.*, 2017; Yuan *et al.*, 2018). Therefore, enhancing the resistance of adult plants to cope with evolving races of *Pst* is the preferred strategy to breeding for resistance. The identification and knowledge of the resistance genes in commonly used parental germplasm and released cultivars is very important for utilizing the genetic resistance to manage yellow rust in full potential. The long term and economical strategy could thus be resistance breeding through the deployment of effective rust resistance genes over space and time (Zeng *et al.*, 2014). The genes expressing at adult plant stage have special significance because the cultivars having such genes have shown partial resistance that has remained effective for longer durations (Khan and Saini, 2009).

Resistant wheat germplasm to rust diseases enables the plant breeder to identify broadly adapted genotypes that offer stable performance across a wide range of sites, as well as under specific conditions such as high disease pressure (Yan and Tinker, 2005). This could aid in the development of an optimum breeding strategy for releasing varieties adapted to a target environment (Ahmad *et al.*, 1996). Consequently, the development of resistant varieties will reduce the cost of production and frequency of serious epidemics; this will enhance wheat production in Egypt and other countries.

The objectives of this study were to evaluate 53 CIMMYT wheat genotypes for yellow rust resistance at adult plant stage under artificial epiphytotic conditions and therefore, the resistance genotypes can be used for further manipulation in the wheat breeding program by incorporation into adapted cultivars to assess the variability to yellow rust resistance.

MATERIALS AND METHODS

Plant Materials

Source of wheat genotypes:

A total of 53 wheat genotypes (Table 1) in two sets were provided to Egypt by International Maize and Wheat Improvement Center (CIMMYT), Mexico, through the website (http://www.cimmyt.org/seed-request/#wheat) including the two wheat varieties; Misr 3 (Egyptian commercial cultivar) and Morocco (check highly susceptible). The two sets of germplasm evaluated included (1) Elite Spring Wheat Yield Trial (ESWYT) and (2) Stress Adaptive Trait Yield Nursery (SATYN), consisting of 100 and 30 entries, respectively. A total of 53 wheat genotypes *i.e.* 38 genotypes from (ESWYT) and 15 (SATYN) wheat germplasm that was selected from 130 tested wheat genotypes which were selected according to their response to yellow rust.

Table 1. Pedigree of wheat genotypes used in this study.

Line	Pedigree
1	ROLF07*2/3/PRINIA/PASTOR//HUITES
2	CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/FH6-1-7
3	KACHU #1/KIRITATI//KACHU
4	WBLL1*2/4/BABAX/LR42//BABAX/3/BABAX/LR42//BABAX
5	ATTILA*2/PBW65*2//MURGA
6	ROLF07*2/5/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES
7	ATTILA*2/PBW65*2//W485/HD29
8	WBLL1*2/TUKURU//FN/2*PASTOR/3/FRET2/KIRITATI
9	NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KACHU/6/KACHU
10	WAXWING/4/BL 1496/MILAN/3/CROC_1/AE.SQUARROSA (205)//KAUZ/5/FRNCLN
11	WBLL1*2/KURUKU/6/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5/2*JANZ/7/ WBLL1*2/KURUKU

Table 1 Continued…

12	UP2338*2/VIVITSI/3/FRET2/TUKURU//FRET2/4/MISR 1
13	TACUPETO F2001*2/BRAMBLING//WBLL1*2/BRAMBLING
14	CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/FH6-1-7
15	FRET2/TUKURU//FRET2/3/MUNAL #1
16	FRET2/TUKURU//FRET2/3/MUNAL #1
17	GAN/AE.SQUARROSA (408)//2*OASIS/5*BORL95/3/ TACUPETO F2001*2/BRAMBLING
18	KIRITATI//ATTILA*2/PASTOR/3/AKURI
19	KIRITATI//PRL/2*PASTOR/3/FRANCOLIN #1
20	BAJ #1/3/KIRITATI//ATTILA*2/PASTOR
21	WBLL1*2/BRAMBLING/3/KIRITATI//PBW65/2*SERI.1B
22	WBLL1*2/KURUKU//SUP152
23	WBLL4/KUKUNA//WBLL1/3/WBLL1*2/BRAMBLING
24	FRET2*2/BRAMBLING/3/FRET2/WBLL1//TACUPETO F2001/4/WBLL1*2/BRAMBLING
25	WHEAR*2/3/FRET2/WBLL1//TACUPETO F2001
26	ALTAR 84/AE.SQUARROSA (221)//3*BORL95/3/URES/JUN//KAUZ/4/WBLL1/5/KACHU/6/KIRITATI//PBW65/2*SERI.1B
27	FRANCOLIN #1*2/MUU
28	FRANCOLIN #1*2/KINGBIRD #1
29	SERI.1B*2/3/KAUZ*2/BOW//KAUZ*2/4/KINGBIRD #1
30	HUIRIVIS #1/MUU//WBLL1*2/BRAMBLING
31	CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/SARA//TSI /VEE#5/4/FRET2/5/KINDE
32	KAUZ*2/MNV//KAUZ/3/MILAN/4/BAV92/5/DANPHE #1
33	THELIN/3/BABAX/LR42//BABAX/4/BABAX/LR42//BABAX/5/BOW/NKT//CBRD/3/CBRD/6/FRET2 *2/BRAMBLING
34	WBLL1*2/KUKUNA/4/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1
35	WBLL1/KUKUNA//TACUPETO F2001/4/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1
36	WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/QUAIU
37	CHIBIA//PRLII/CM65531/3/FISCAL/4/ND643/2*WBLL1
38	DANPHE #1/3/HUW234+LR34/PRINIA//PFAU/WEAVER
39	KACHU/BECARD//WBLL1*2/BRAMBLING
40	PCAFLR/KINGBIRD #1//KIRITATI/2*TRCH
41	MUU/3/KIRITATI//ATTILA*2/PASTOR/4/MUU
42	PRINIA/PASTOR//KIRITATI/3/PRL/2*PASTOR
43	OASIS/SKAUZ//4*BCN*2/3/PASTOR/4/HEILO/5/PAURAQ
44	ND643/2*WBLL1//ATTILA*2/PBW65/3/MUNAL
45	ND643/2*WBLL1/3/KIRITATI//PRL/2*PASTOR/4/KIRITATI//PBW65/2*SERI.1B
46	ND643/2*TRCH//BECARD/3/BECARD
47	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1
48	GK ARON/AG SECO 7846//2180/4/2*MILAN/KAUZ//PRINIA /3/BAV92
49	BOW/VEE/5/ND/VG9144//KAL/BB/3/YACO/4/CHIL/6/CASKOR/3/CROC_1/AE.SQUARROSA (224)//OPATA/7/PASTOR// MILAN/KAUZ/3/BAV92
50	BOW/VEE/5/ND/VG9144//KAL/BB/3/YACO/4/CHIL/6/CASKOR/3/CROC_1/AE.SQUARROSA (224)//OPATA/7/PASTOR//MILAN/KAUZ/3/BAV92
51	D67.2/PARANA 66.270//AE.SQUARROSA (320)/3/CUNNINGHAM/4/VORB
52	D67.2/PARANA 66.270//AE.SQUARROSA (320)/3/CUNNINGHAM/4/VORB
53	H45/4/KRICHAUFF/FINSI/3/URES/PRL//BAV92
Misr 3	ATTILA*2/ABW65*2/KACHU CMSS06Y00258 2T-099TOPM-099Y-099ZTM-099Y-099M-10WGY-0B-0EGY
Morocco	-

Field testing

The experiments of this study were carried out at two locations *i.e.* Itay El-Baroud and Sakha Agricultural Research Stations during three successive growing seasons *i.e.* 2016/17, 2017/18 and 2018/19. These experiments were planted in a randomized complete block design (RCBD) with three replicates. The tested wheat genotypes were planted in rows of 3 m long. The experiments were surrounded by a spreader area planted with a mixture of highly susceptible wheat genotypes to yellow rust disease. These genotypes were *Triticum spelta sahariensis* and Morocco to spread yellow rust inoculum. For field inoculation with yellow rust, the spreader plants were sprayed with a mist of water and dusted with urediniospores of a mixture of most prevalent and aggressive pathotypes i.e. 4E16, 70E20, 70E32 and 192E192 (Ashmawy *et al.*, 2019) mixed with a talcum powder at a ratio of 1 : 20 (v/v) (spores: talcum powder). Plants were dusted in the early evening (at sunset) before dew point formation on the leaves. The inoculation of plants was carried out at the booting stage according to the method of Tervet and Cassell (1951). The urediniospores of yellow rust received from Wheat Diseases Research Department, Plant Pathology Research Institute, Agricultural Research Center, Egypt. To maintain crop vigor normal agronomic practices including recommended fertilization dose and irrigation schedules were followed.

Disease assessment

Yellow rust response of the tested wheat genotypes was characterized using the four epidemiological parameters; final rust severity (FRS %), Average coefficient of infection (ACI), relative resistance index (RRI), and area under disease progress curve (AUDPC). Yellow rust severity (%) which estimated as a percentage of leaf area covered by yellow rust (0% to 100%) (Peterson *et al.*, 1948). Final yellow rust severities were recorded for each genotype when the highly susceptible (check) variety; Morocco was severely rusted and the disease rate reached its maximum level of severity (Das *et al.*, 1993). Plant reaction (infection type) was expressed in five types (Stakman *et al.*, 1962); immune (0), resistant (R), moderately resistant (MR), moderately susceptible (MS) and susceptible (S). The coefficient of infection (CI) was calculated by multiplying rust severity with constant values of infection type (IT). The constant values for infection types were used based on; R = 0.2, MR = 0.4, MS = 0.8 and S = 1 (Stubbs *et al.*, 1986). The average coefficient of infection (ACI) was derived from the sum of CI values of each line divided by the number of locations.

After some modifications, a rating scale for disease resistance was adopted in 1982 for use with cereals (Aslam, 1982) based on the scale by Doling (1965) for selecting wheat varieties to powdery mildew. The highest ACI of a candidate line is set at 100 and all other lines are adjusted accordingly. This gives the country an average relative percentage attack (CARPA). Using 0 to 9 scale previously designated as resistance index (RI) has been re-designated as a relative resistance index (RRI). From CARPA the value of RRI is calculated on 0 to 9 scale, where 0 denote most susceptible and 9 highly resistant (Akhtar *et al.*, 2002). The relative resistance index is calculated according to the following formula:

$$RRI = \frac{(100 - CARPA)}{100} \times 9$$

The desirable index and acceptable index number for rusts are as below (Aslam, 1982).

Disease	Desirable index	Acceptable index
Stripe and stem rust	7 and above	6

The area under the disease progress curve (AUDPC) was calculated for each of the tested genotypes by using the equation of Pandey *et al.* (1989).

AUDPC = D [½ (Y1 + Yk) + Y2 + Y3 + ... + Yk-1]

Where:

D = days between two consecutive records (time intervals)

$Y_1 + Y_k$ = Sum of the first and last disease scores.

$Y_2 + Y_3 + \ldots\ldots + Y_{k-1}$ = Sum of all in between disease scores.

Yield assessment

Grain yield expressed as 1000 kernel weight (g) was determined for all of the tested wheat genotypes and calculated following Hassan (2004) in the three growing seasons at the two locations. Randomly selected thousand kernels from each genotype were counted with a seed counter and weighed with an electronic balance to calculate 1000-kernel weight.

Statistical analysis

A combined analysis of variance over the three growing seasons was also carried out (Table 2). The significance of difference among the studied genotypes was tested by the analysis of variance (ANOVA) test as outlined by Snedecor and Cochran (1967). Mean comparisons for variables were made among genotypes using least significant differences (LSD at 5%) tests.

Table 2. Analysis of variance for the effects of locations, seasons, genotypes and their interactions on average coefficient of infection (ACI), area under disease progress curve (AUDPC) and 1000 kernel weight (g) for 55 wheat genotypes grown at Itay El-Baroud and Sakha locations during 2016/17, 2017/18 and 2018/19 growing seasons.

Source of variation (S.O.V.)	Degree of freedom (DF)	Variables					
		ACI		AUDPC		1000 kernel weight (g)	
		MS	F. Value	MS	F. Value	MS	F. Value
Replication	2	1004.8	11.19*	299	2.96^{NS}	0.49	19.60^{NS}
Location (L)	1	19055.7	9.67^{NS}	2106863	4.71^{NS}	201.19	12.32^{NS}
Season (S)	2	25773.0	5.49^{NS}	3007692	3.16^{NS}	514.65	14.68*
S X L	2	3940.0	17.76*	894737	18.75*	32.67	2.66^{NS}
Genotypes (G)	54	300879.5	11.73*	36345718	12.68*	19099.83	47.75*
L X G	54	23329.6	3.90*	2808991	2.18*	772.58	2.33*
S X G	108	51289.6	4.28*	5733133	2.22*	799.98	1.21^{NS}
S X L X G	108	11976.4	3.66*	2577260	397.80*	663.79	85.30*
Error	544	16476.3		32634		39.2	

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

RESULTS

Evaluation of Wheat Genotypes Against Yellow Rust Under Field Conditions:

Final rust severity (FRS %)

Data presented in Table (3) showed that the final yellow rust severity of the tested genotypes ranged from 0-90 % at Itay El-Baroud and Sakha locations. No disease symptoms (stripe rust pustules) could be detected in wheat plants of the wheat genotypes *i.e.* 2, 4, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 22, 27, 28, 30, 31, 33, 34, 36, 40, 41, 44, 45, 48, 49 and Misr 3 showed complete resistant as they showed resistant reaction at the two locations during the 2016/17 growing season (Table 3). While during the 2017/18 growing season, the tested wheat genotypes showed FRS (%) ranged from 0-100% (Table 4). The wheat genotypes *i.e.* 4, 6, 8, 11, 12, 13, 14, 16, 17, 22, 24, 27, 28, 30, 31, 33, 34, 36, 40, 41, 44, 45, 48, 49 and Misr 3 showed resistant reaction at the two locations (Table 4). On the other hand, in 2018/19 growing season, the tested wheat genotypes showed FRS (%) ranged from 0-100% (Table 5). The wheat genotypes *i.e.* 4, 6, 8, 11, 12, 13, 14, 16, 17, 22, 27, 28, 30, 31, 33, 34, 36, 40, 41, 44, 45, 48, 50 and Misr 3 showed resistant reaction at the two locations (Table 5).

Average coefficient of infection (ACI)

ACI values ranged from 0 to 90, 0 to 95 and 0 to 100 during 2016/17, 2017/18 and 2018/19 growing seasons, respectively (Tables 3, 4 and 5). In 2016/17, 45 of the tested wheat genotypes showed low values of ACI ranged from 0 to 25. On the other hand, six wheat genotypes *i.e.* 9, 38, 50, 51, 52 and Morocco showed the highest values of ACI *i.e.* 50, 35, 40, 50, 35 and 90, respectively (Table 3). In 2017/18, 50 of the tested wheat genotypes showed low values of ACI ranged from 0 to 25. Meanwhile, the five wheat genotypes *i.e.* 38, 50, 51, 52 and Morocco displayed the highest values of ACI *i.e.* 35, 35, 55, 45 and 95, respectively (Table 4). In 2018/19, 36 of the tested wheat genotypes showed low values of ACI ranged from 0 to 27. Meanwhile, the 19 wheat genotypes *i.e.* 1 (40), 6 (35), 9 (70), 18 (50), 19 (40), 20 (50), 23 (35), 29 (35), 37 (35), 38 (50), 39 (40), 43 (35), 46 (50), 47 (35), 49 (45), 51 (60), 52 (45), 53 (40) and Morocco (100) showed the highest values of ACI (Table 5).

Relative resistance index (RRI)

All of the tested wheat genotypes showed RRI acceptable (RRI = 6) and desirable (RRI) (≥ 7) to yellow rust ranged from 9.00 to 6.50 except five wheat genotypes *i.e.* 9 (4.00), 38 (5.50), 50 (5.00), 51 (3.50), 52 (5.50) and Morocco (0.00) (Table 3) at the two locations during 2016/17 growing season. In 2017/18 growing season, all of the tested wheat genotypes showed desirable/acceptable (RRI) to yellow rust ranged from 9.00 to 6.63 except five wheat genotypes *i.e.* 38 (5.68), 50 (5.68), 51 (3.79), 52 (4.74) and Morocco (0.00) (Table 4) at the two locations. While during 2018/19 growing season, most of the tested wheat genotypes showed desirable/acceptable (RRI) to yellow rust ranged from 9.00 to 6.30 except 19 wheat genotypes *i.e.* 1 (5.40), 6 (5.85), 9 (2.70), 18 (4.50), 19 (5.40), 20 (4.50), 23 (5.85), 29 (5.85), 37 (5.85), 38 (4.50), 39 (5.40), 43 (5.85), 46 (4.50), 47 (5.85), 49 (4.95), 51 (3.60), 52 (4.95), 53 (5.40) and Morocco (0.00) (Table 5) at the two locations.

Table 3. Final rust severity (%) of 55 wheat genotypes to yellow rust along with the average coefficient of infection (ACI), country average relative percentage attack (CARPA) and relative resistance index (RRI) at Itay El-Baroud and Sakha locations during 2016/17 growing season.

Line	Location / Final rust severity (%)[a]		ACI	CARPA	RRI[b]
	Itay El-Baroud	Sakha			
1	5 S	30 S	17.50	19.44	7.25
2	5 MR	10 MR	3.00	3.33	8.70
3	Tr S	20 S	11.50	12.78	7.85
4	0	0	0.00	0.00	9.00
5	10 S	40 S	25.00	27.78	6.50
6	0	0	0.00	0.00	9.00
7	Tr S	10 S	6.50	7.22	8.35
8	0	0	0.00	0.00	9.00
9	40 S	60 S	50.00	55.56	4.00
10	0	0	0.00	0.00	9.00
11	0	0	0.00	0.00	9.00
12	0	0	0.00	0.00	9.00
13	5 MR	5 MR	2.00	2.22	8.80
14	0	0	0.00	0.00	9.00
15	0	5 MR	1.00	1.11	8.90
16	0	0	0.00	0.00	9.00
17	0	0	0.00	0.00	9.00
18	5 S	5 S	5.00	5.56	8.50
19	10 S	30 S	20.00	22.22	7.00
20	20 S	30 S	25.00	27.78	6.50
21	5 S	5 S	5.00	5.56	8.50
22	0	0	0.00	0.00	9.00
23	5 S	20 S	12.50	13.89	7.75
24	Tr S	Tr S	3.00	3.33	8.70
25	Tr S	5 S	4.00	4.44	8.60
26	Tr S	10 S	6.50	7.22	8.35
27	0	0	0.00	0.00	9.00
28	0	0	0.00	0.00	9.00
29	5 S	10 S	7.50	8.33	8.25
30	0	0	0.00	0.00	9.00
31	0	0	0.00	0.00	9.00
32	10 S	20 S	15.00	16.67	7.50
33	0	0	0.00	0.00	9.00
34	0	0	0.00	0.00	9.00
35	Tr S	10 S	6.50	7.22	8.35
36	0	0	0.00	0.00	9.00
37	5 S	10 S	7.50	8.33	8.25
38	30 S	40 S	35.00	38.89	5.50

Table 3 Continued…

39	5 S	10 S	7.50	8.33	8.25
40	0	0	0.00	0.00	9.00
41	0	0	0.00	0.00	9.00
42	10 S	20 S	15.00	16.67	7.50
43	5 S	5 S	5.00	5.56	8.50
44	0	0	0.00	0.00	9.00
45	0	0	0.00	0.00	9.00
46	20 S	20 S	20.00	22.22	7.00
47	10 S	20 S	15.00	16.67	7.50
48	0	0	0.00	0.00	9.00
49	0	0	0.00	0.00	9.00
50	30 S	50 S	40.00	44.44	5.00
51	50 S	60 S	55.00	61.11	3.50
52	20 S	50 S	35.00	38.89	5.50
53	5 S	10 S	7.50	8.33	8.25
Misr 3	0	0	0.00	0.00	9.00
Morocco	90 S	90 S	90.00	100.00	0.00
L.S.D at 5%					0.584

[a] Final rust severity includes two components: disease severity based on modified Cobb's scale (Peterson *et al.*, 1948), where Tr = less than 5% and 5 = 5% up to 100 = 100%, and host response based on scale described by Stakman *et al.* (1962), where R = resistant, MR = moderately resistant, MS = moderately susceptible and S = susceptible.
[b] RRI= Relative resistance index (above 5 is acceptable; means the variety is resistant to rusts (Aslam, 1982).

Table 4. Final rust severity (%) of 55 wheat genotypes to yellow rust along with the average coefficient of infection (ACI), country average relative percentage attack (CARPA) and relative resistance index (RRI) at Itay El-Baroud and Sakha locations during 2017/18 growing season.

Line	Location / Final rust severity (%)[a]		ACI	CARPA	RRI[b]
	Itay El-Baroud	Sakha			
1	5 S	30 S	17.50	18.42	7.34
2	Tr S	5 S	4.00	4.21	8.62
3	5 S	10 S	7.50	7.89	8.29
4	0	0	0.00	0.00	9.00
5	Tr S	10 S	6.50	6.84	8.38
6	0	0	0.00	0.00	9.00
7	10 S	20 S	15.00	15.79	7.58
8	0	0	0.00	0.00	9.00
9	10 S	30 S	20.00	21.05	7.11
10	10 S	10 S	10.00	10.53	8.05
11	0	0	0.00	0.00	9.00
12	0	0	0.00	0.00	9.00
13	Tr MR	10 MR	2.60	2.74	8.75
14	0	0	0.00	0.00	9.00
15	5 S	10 S	7.50	7.89	8.29
16	0	0	0.00	0.00	9.00
17	0	0	0.00	0.00	9.00
18	Tr S	10 S	6.50	6.84	8.38
19	5 S	20 S	12.50	13.16	7.82
20	5 S	30 S	17.50	18.42	7.34

Table 4 Continued…

21	5 S	5 S	5.00	5.26	8.53
22	0	0	0.00	0.00	9.00
23	5 S	10 S	7.50	7.89	8.29
24	0	Tr S	1.50	1.58	8.86
25	5 S	5 S	5.00	5.26	8.53
26	Tr S	20 S	11.50	12.11	7.91
27	0	0	0.00	0.00	9.00
28	0	0	0.00	0.00	9.00
29	Tr S	20 S	11.50	12.11	7.91
30	0	0	0.00	0.00	9.00
31	0	0	0.00	0.00	9.00
32	5 S	30 S	17.50	18.42	7.34
33	0	0	0.00	0.00	9.00
34	0	0	0.00	0.00	9.00
35	Tr S	20 S	11.50	12.11	7.91
36	0	0	0.00	0.00	9.00
37	Tr S	20 S	11.50	12.11	7.91
38	20 S	50 S	35.00	36.84	5.68
39	5 S	20 S	12.50	13.16	7.82
40	0	0	0.00	0.00	9.00
41	0	0	0.00	0.00	9.00
42	20 S	30 S	25.00	26.32	6.63
43	5 S	20 S	12.50	13.16	7.82
44	0	0	0.00	0.00	9.00
45	0	0	0.00	0.00	9.00
46	5 S	30 S	17.50	18.42	7.34
47	5 S	10 S	7.50	7.89	8.29
48	0	0	0.00	0.00	9.00
49	0	0	0.00	0.00	9.00
50	20 S	50 S	35.00	36.84	5.68
51	50 S	60 S	55.00	57.89	3.79
52	30 S	60 S	45.00	47.37	4.74
53	10 S	30 S	20.00	21.05	7.11
Misr 3	0	0	0.00	0.00	9.00
Morocco	90 S	100 S	95.00	100.00	0.00
L.S.D at 5%					0.535

[a] Final rust severity includes two components: disease severity based on modified Cobb׳s scale (Peterson *et al.*, 1948), where Tr = less than 5% and 5 = 5% up to 100 = 100%, and host response based on scale described by Stakman *et al.* (1962), where R = resistant, MR = moderately resistant, MS = moderately susceptible and S = susceptible.

[b] RRI= Relative resistance index (above 5 is acceptable; means the variety is resistant to rusts (Aslam, 1982).

Table 5. Final rust severity (%) of 55 wheat genotypes to yellow rust along with the average coefficient of infection (ACI), country average relative percentage attack (CARPA) and relative resistance index (RRI) at Itay El-Baroud and Sakha locations during 2018/19 growing season.

Line	Location / Final rust severity (%)[a]		ACI	CARPA	RRI[b]
	Itay El-Baroud	Sakha			
1	30 S	50 S	40.00	40.00	5.40
2	20 S	40 S	30.00	30.00	6.30
3	10 S	30 S	20.00	20.00	7.20
4	0	0	0.00	0.00	9.00
5	20 S	40 S	30.00	30.00	6.30
6	0	0	0.00	0.00	9.00
7	20 S	50 S	35.00	35.00	5.85
8	0	0	0.00	0.00	9.00
9	60 S	80 S	70.00	70.00	2.70
10	30 S	30 S	30.00	30.00	6.30
11	0	0	0.00	0.00	9.00
12	0	0	0.00	0.00	9.00
13	10 MR	5 MR	3.00	3.00	8.73
14	0	0	0.00	0.00	9.00
15	10 S	30 S	20.00	20.00	7.20
16	0	0	0.00	0.00	9.00
17	0	0	0.00	0.00	9.00
18	30 S	70 S	50.00	50.00	4.50
19	30 S	50 S	40.00	40.00	5.40
20	30 S	70 S	50.00	50.00	4.50
21	Tr S	10 S	6.50	6.50	8.42
22	0	0	0.00	0.00	9.00
23	30 S	40 S	35.00	35.00	5.85
24	5 S	30 S	17.50	17.50	7.43
25	5 S	10 S	7.50	7.50	8.33
26	10 S	20 S	15.00	15.00	7.65
27	0	0	0.00	0.00	9.00
28	0	0	0.00	0.00	9.00
29	20 S	50 S	35.00	35.00	5.85
30	0	0	0.00	0.00	9.00
31	0	0	0.00	0.00	9.00
32	10 S	50 S	30.00	30.00	6.30
33	0	0	0.00	0.00	9.00
34	0	0	0.00	0.00	9.00
35	20 S	30 S	25.00	25.00	6.75
36	0	0	0.00	0.00	9.00
37	20 S	50 S	35.00	35.00	5.85
38	30 S	70 S	50.00	50.00	4.50
39	20 S	60 S	40.00	40.00	5.40
40	0	0	0.00	0.00	9.00
41	0	0	0.00	0.00	9.00
42	5 S	50 S	27.50	27.50	6.53
43	30 S	40 S	35.00	35.00	5.85

Table 5 Continued…

44	0	0	0.00	0.00	9.00
45	0	0	0.00	0.00	9.00
46	30 S	70 S	50.00	50.00	4.50
47	30 S	40 S	35.00	35.00	5.85
48	0	0	0.00	0.00	9.00
49	20 S	70 S	45.00	45.00	4.95
50	0	0	0.00	0.00	9.00
51	40 S	80 S	60.00	60.00	3.60
52	20 S	70 S	45.00	45.00	4.95
53	20 S	60 S	40.00	40.00	5.40
Misr 3	0	5 S	2.50	2.50	8.78
Morocco	100 S	100 S	100.00	100.00	0.00
L.S.D at 5%					0.504

[a] Final rust severity includes two components: disease severity based on modified Cobb,s scale (Peterson *et al.*, 1948), where Tr = less than 5% and 5 = 5% up to 100 = 100%, and host response based on scale described by Stakman *et al.* (1962), where R = resistant, MR = moderately resistant, MS = moderately susceptible and S = susceptible.

[b] RRI= Relative resistance index (above 5 is acceptable; means the variety is resistant to rusts (Aslam, 1982).

Data in Table (6) indicated that 35 of the tested wheat genotypes *i.e.* 2, 3, 4, 5, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 21, 22, 24, 25, 26, 27, 28, 30, 31, 32, 33, 34, 35, 36, 40, 41, 42, 44, 45, 48 and Misr 3 were resistant to yellow rust and showed desirable/acceptable (RRI) at the two locations during the three growing seasons of the study.

Area under disease progress curve (AUDPC):

The AUDPC values during the 2016/17 growing season ranged from 0 to 1120.00 at the two locations. While during the 2017/18 and 2018/19 growing seasons, AUDPC values ranged from 0 to 1225.00 (Table 7). During the three growing seasons of the study at the two locations, the tested wheat genotypes divided into two groups depending on the values of AUDPC. The first group is genotypes with partial resistance which showed the lowest values of AUDPC (less than 300). This group included 49 wheat genotypes which showed AUDPC values ranged from 0 to 294. On the other hand, the second group included six wheat genotypes *i.e.* 9, 20, 38, 51, 52 and Morocco. The values of AUDPC of these genotypes were 415.00, 314.42, 417.08, 530.00, 387.50 and 1172.50, respectively (Table 7).

Table 6. Resistant wheat genotypes with desirable and acceptable relative resistance index (RRI) to yellow rust disease at Itay El-Baroud and Sakha during 2016/17, 2017/18 and 2018/19 growing seasons.

Line	Season / RRI		
	2016/17	2017/18	2018/19
2	8.70	8.62	6.30
3	7.85	8.29	7.20
4	9.00	9.00	9.00
5	6.50	8.38	6.30
6	9.00	9.00	9.00
8	9.00	9.00	9.00
10	9.00	8.05	6.30
11	9.00	9.00	9.00
12	9.00	9.00	9.00
13	8.80	8.75	8.73
14	9.00	9.00	9.00
15	8.90	8.29	7.20
16	9.00	9.00	9.00

 DOI: 10.33687/phytopath.009.01.3269

Table 6 Continued…

17	9.00	9.00	9.00
21	8.50	8.53	8.42
22	9.00	9.00	9.00
24	8.70	8.86	7.43
25	8.60	8.53	8.33
26	8.35	7.91	7.65
27	9.00	9.00	9.00
28	9.00	9.00	9.00
30	9.00	9.00	9.00
31	9.00	9.00	9.00
32	7.50	7.34	6.30
33	9.00	9.00	9.00
34	9.00	9.00	9.00
35	8.35	7.91	6.75
36	9.00	9.00	9.00
40	9.00	9.00	9.00
41	9.00	9.00	9.00
42	7.50	6.63	6.53
44	9.00	9.00	9.00
45	9.00	9.00	9.00
48	9.00	9.00	9.00
Misr 3	9.00	9.00	8.78

Table 7. Area under disease progress curve (AUDPC) of 55 wheat genotypes to yellow rust at Itay El-Baroud and Sakha locations during 2016/17 to 2018/19 growing season.

Line	Location / Season / AUDPC						Mean
	Itay El-Baroud			Sakha			
	2016/17	2017/18	2018/19	2016/17	2017/18	2018/19	
1	49.00	49.00	280.00	280.00	280.00	525.00	243.83
2	49.00	42.00	157.50	80.50	49.00	420.00	133.00
3	42.00	49.00	80.50	157.50	80.50	280.00	114.92
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	80.50	42.00	157.50	420.00	80.50	420.00	200.08
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	42.00	80.50	157.50	80.50	157.50	525.00	173.83
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	420.00	80.50	365.00	365.00	280.00	980.00	415.08
10	0.00	80.50	280.00	0.00	80.50	280.00	120.17
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	49.00	42.00	80.50	49.00	80.50	49.00	58.33
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	49.00	80.50	49.00	80.50	280.00	89.83
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	49.00	42.00	280.00	49.00	80.50	840.00	223.42
19	80.50	49.00	280.00	280.00	157.50	525.00	228.67

Table 7 Continued…

20	157.50	49.00	280.00	280.00	280.00	840.00	314.42
21	49.00	49.00	42.00	49.00	49.00	80.50	53.08
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	49.00	49.00	280.00	157.50	80.50	420.00	172.67
24	42.00	0.00	49.00	42.00	42.00	280.00	75.83
25	42.00	49.00	49.00	49.00	49.00	80.50	53.08
26	42.00	42.00	80.50	80.50	157.50	157.50	93.33
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	49.00	42.00	157.50	80.50	157.50	525.00	168.58
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	80.50	49.00	80.50	157.50	280.00	525.00	195.42
33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35	42.00	42.00	157.50	80.50	157.50	280.00	126.58
36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	49.00	42.00	157.50	80.50	157.50	525.00	168.58
38	280.00	157.50	280.00	420.00	525.00	840.00	417.08
39	49.00	49.00	157.50	80.50	157.50	365.00	143.08
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42	80.50	157.50	49.00	157.50	280.00	525.00	208.25
43	49.00	49.00	280.00	49.00	157.50	420.00	167.42
44	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	157.50	49.00	280.00	157.50	280.00	840.00	294.00
47	80.50	49.00	280.00	157.50	80.50	420.00	177.92
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	0.00	0.00	157.50	0.00	0.00	840.00	166.25
50	280.00	157.50	0.00	525.00	525.00	0.00	247.92
51	525.00	525.00	420.00	365.00	365.00	980.00	530.00
52	157.50	280.00	157.50	525.00	365.00	840.00	387.50
53	49.00	80.50	157.50	80.50	280.00	365.00	168.75
Misr 3	0.00	0.00	0.00	0.00	0.00	49.00	8.17
Morocco	1120.00	1120.00	1225.00	1120.00	1225.00	1225.00	1172.50
L.S.D at 5%	37.58497	37.51451	39.25199	37.40570	37.38796	54.42748	

Grain Yield

1000 kernel weight of the tested genotypes

The 1000 kernel weight of the tested wheat genotypes at the two locations *i.e.* Itay El-Baroud and Sakha ranged from 25.05 g to 49.02 g, 21.05 g to 49.01 g and 20.89 g to 49.31 g during 2016/17, 2017/18 and 2018/19, respectively (Table 8). During the three growing seasons of the study at the two locations, 11 wheat genotypes *i.e.* 28, 17, 6, 33, 14, Misr 3, 41, 4, 34, 48 and 11 showed the highest values of 1000 kernel weight *i.e.* 48.55 g, 48.47 g, 48.14 g, 48.14 g, 47.96 g, 47.93 g, 47.69 g, 47.60 g, 47.47 g, 47.39 g and 47.16 g, respectively. While, the four wheat genotypes *i.e.* Morocco, 2, 5 and 38 showed the lowest values of 1000 kernel weight *i.e.* 23.66 g, 34.63 g, 35.32 g and 36.41 g, respectively (Table 8).

Association between the four epidemiological parameters and 1000 kernel weight (g)

The association between each of the four epidemiological parameters *i.e.* FRS (%), ACI, AUDPC and RRI with 1000 kernel weight of the tested wheat genotypes was determined through regression analysis during 2016/17, 2017/18 and 2018/19 growing seasons at the two locations. The significant negative correlation between each of the three epidemiological parameters *i.e.* FRS (%), ACI and AUDPC with 1000 kernel weight during the three growing seasons. While, significant positive correlation between only RRI with 1000 kernel weight during the three growing seasons (Figure 1, 2, and 3). Regression analysis revealed a significant negative linear relationship between FRS (%) and 1000 kernel weight during 2016/17, 2017/18 and 2018/19 (R^2 = -0.893, -0.857 and -0.816, respectively) (Figure 1a).

Moreover, regression analysis revealed a significant negative linear relationship between ACI and 1000 kernel weight during 2016/17, 2017/18 and 2018/19 (R^2 = -0.875, -0.856 and -0.813, respectively) (Figure 1b). Also, regression analysis revealed a significant negative linear relationship between AUDPC and 1000 kernel weight during 2016/17, 2017/18 and 2018/19 (R^2 = -0.924, -0.898 and -0.912, respectively) (Figure 1c). Meanwhile, regression analysis revealed a significant positive linear relationship between RRI and 1000 kernel weight during 2016/17, 2017/18 and 2018/19 (R^2 = -0.947, -0.914 and -0.913, respectively) (Figure 1d).

Table 8. 1000 kernel weight (g) of 55 wheat genotypes grown at Itay El-Baroud and Sakha locations during 2016/17 to 2018/19 growing season.

Line	Location / Season / 1000 kernel weight (g)						Mean
	Itay El-Baroud			Sakha			
	2016/17	2017/18	2018/19	2016/17	2017/18	2018/19	
1	34.21	32.33	35.81	39.17	40.24	41.61	37.23
2	29.04	31.52	33.81	32.93	39.41	41.07	34.63
3	35.73	31.18	34.75	33.79	37.32	38.55	35.22
4	45.71	47.29	48.37	47.91	48.03	48.26	47.60
5	33.91	32.87	34.15	32.29	38.52	40.16	35.32
6	47.11	48.42	47.64	48.72	48.21	48.75	48.14
7	37.09	39.23	40.27	38.35	38.55	40.29	38.96
8	44.83	43.95	45.53	46.87	46.72	47.61	45.92
9	37.40	33.71	39.18	38.95	34.79	40.05	37.35
10	35.03	39.78	40.83	38.89	39.28	41.42	39.21
11	46.91	45.76	47.30	46.97	47.93	48.07	47.16
12	41.16	40.83	44.56	45.04	46.66	47.29	44.26
13	39.32	42.36	43.81	42.03	43.99	44.31	42.64
14	48.62	46.39	47.95	48.07	48.11	48.59	47.96
15	34.56	38.74	42.83	40.52	41.05	42.41	40.02
16	41.72	45.04	45.27	40.31	46.81	46.05	44.20
17	49.02	48.52	49.31	48.19	47.91	47.88	48.47
18	40.19	41.29	44.51	42.05	41.35	43.84	42.21
19	41.47	44.38	45.07	43.74	42.73	44.62	43.67
20	45.30	42.08	44.65	46.99	42.77	46.83	44.77
21	33.48	37.01	42.57	40.29	39.95	41.99	39.22
22	36.59	39.41	46.51	45.38	44.74	43.51	42.69
23	40.65	39.37	44.05	44.96	41.46	43.97	42.41
24	43.19	40.99	43.57	42.02	41.79	43.95	42.59
25	41.63	43.96	44.53	43.29	43.28	44.08	43.46
26	45.12	44.72	45.77	45.93	45.19	46.02	45.46
27	43.05	44.61	47.69	46.74	47.22	47.81	46.19
28	48.04	49.01	48.62	49.35	48.27	48.02	48.55

Table 8 Continued…

29	40.61	45.86	44.47	43.04	41.63	44.51	43.35
30	42.08	43.97	45.81	43.69	45.89	44.99	44.41
31	44.58	46.20	46.73	43.95	47.21	45.41	45.68
32	45.49	46.14	44.50	43.97	41.77	44.94	44.47
33	47.33	48.35	48.18	48.62	47.92	48.41	48.14
34	46.71	45.62	47.34	48.27	48.33	48.54	47.47
35	42.93	43.25	44.06	43.95	41.72	44.90	43.47
36	43.31	45.96	47.41	46.83	47.11	48.21	46.47
37	44.31	45.26	46.28	45.05	42.65	47.04	45.10
38	46.64	42.74	42,65	43.71	40.51	44.83	36.41
39	45.37	45.98	46.21	47.68	42.69	46.75	45.78
40	44.06	45.69	46.73	45.51	46.73	47.32	46.01
41	47.22	46.99	48.31	47.92	47.75	47.93	47.69
42	41.69	43.11	43.75	42.38	40.96	44.51	42.73
43	42.68	43.93	44.18	41.07	40.68	43.84	42.73
44	44.06	45.11	46.06	45.94	46.51	46.19	45.65
45	41.54	42.74	45.87	44.93	47.02	46.77	44.81
46	44.71	45.67	43.02	43.61	40.18	43.25	43.41
47	40.45	39.01	42.47	40.88	39.95	42.16	40.82
48	44.92	47.07	47.87	47.92	48.02	48.51	47.39
49	42.52	43.04	41.75	42.46	40.38	43.17	42.22
50	41.74	42.61	42.95	40.71	43.97	43.65	42.61
51	39.69	39.94	38.63	39.86	37.99	40.14	39.38
52	42.92	41.89	40.17	40.09	39.98	41.66	41.12
53	39.51	38.99	39.52	40.41	38.22	41.63	39.71
Misr 3	47.52	47.94	48.05	47.99	47.81	48.29	47.93
Morocco	25.61	22.64	26.73	25.05	21.05	20..89	23.66
L.S.D at 5%	0.89946	0.93203	0.85803	0.87513	0.89593	0.81506	

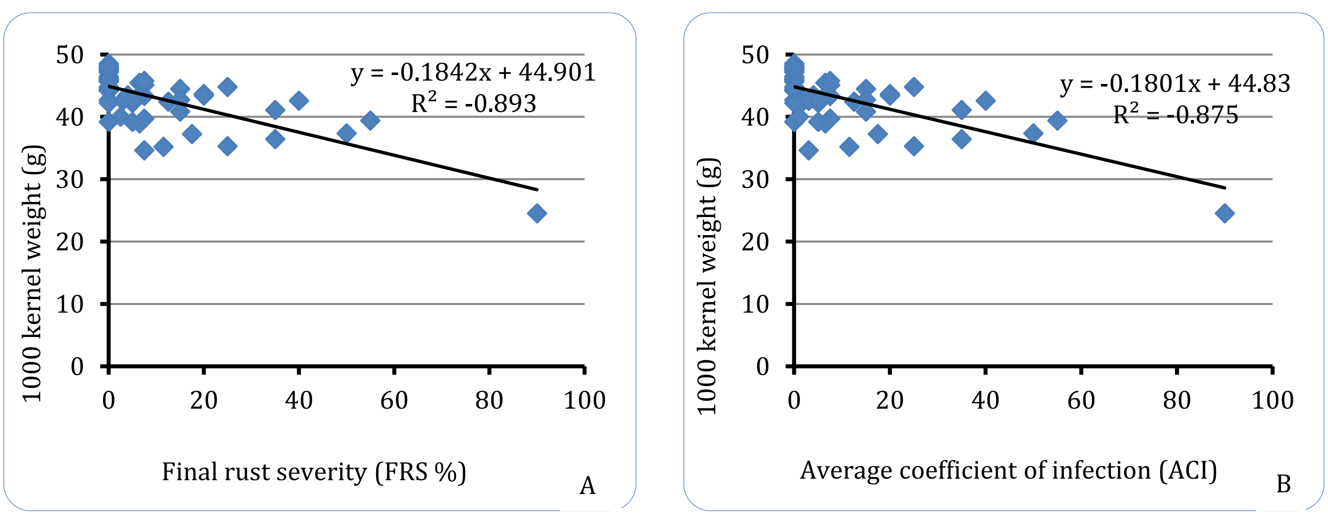

Figure 1. Correlation between each of FRS (%) (a) and ACI (b) with 1000 kernel weight (g) of 55 wheat genotypes during 2016/17 growing season.

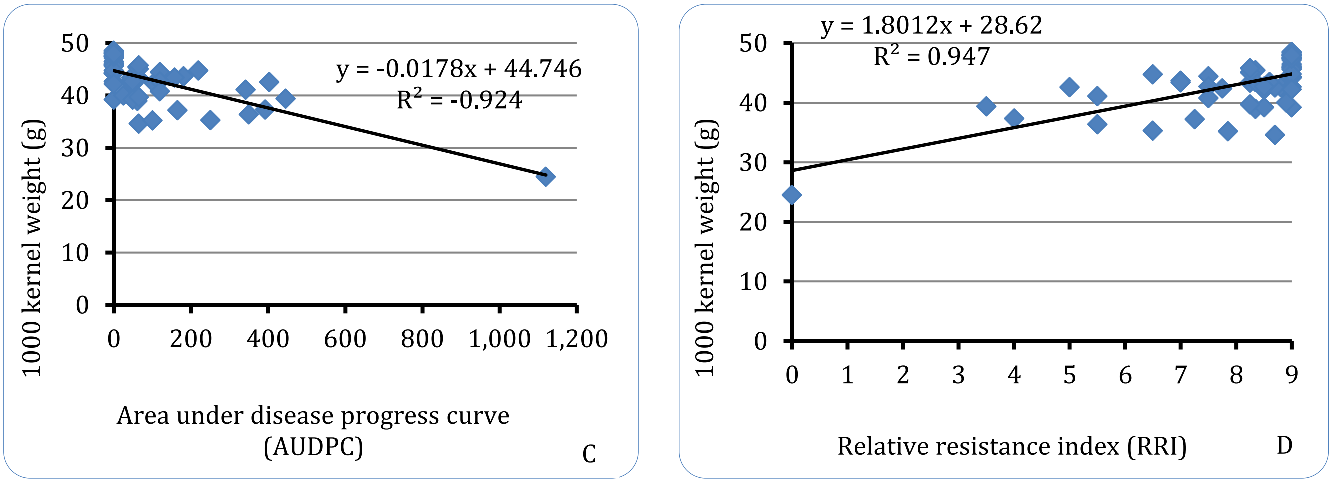

Figure 1: Correlation between each of AUDPC (c) and RRI (d) with 1000 kernel weight (g) of 55 wheat genotypes during 2016/17 growing season.

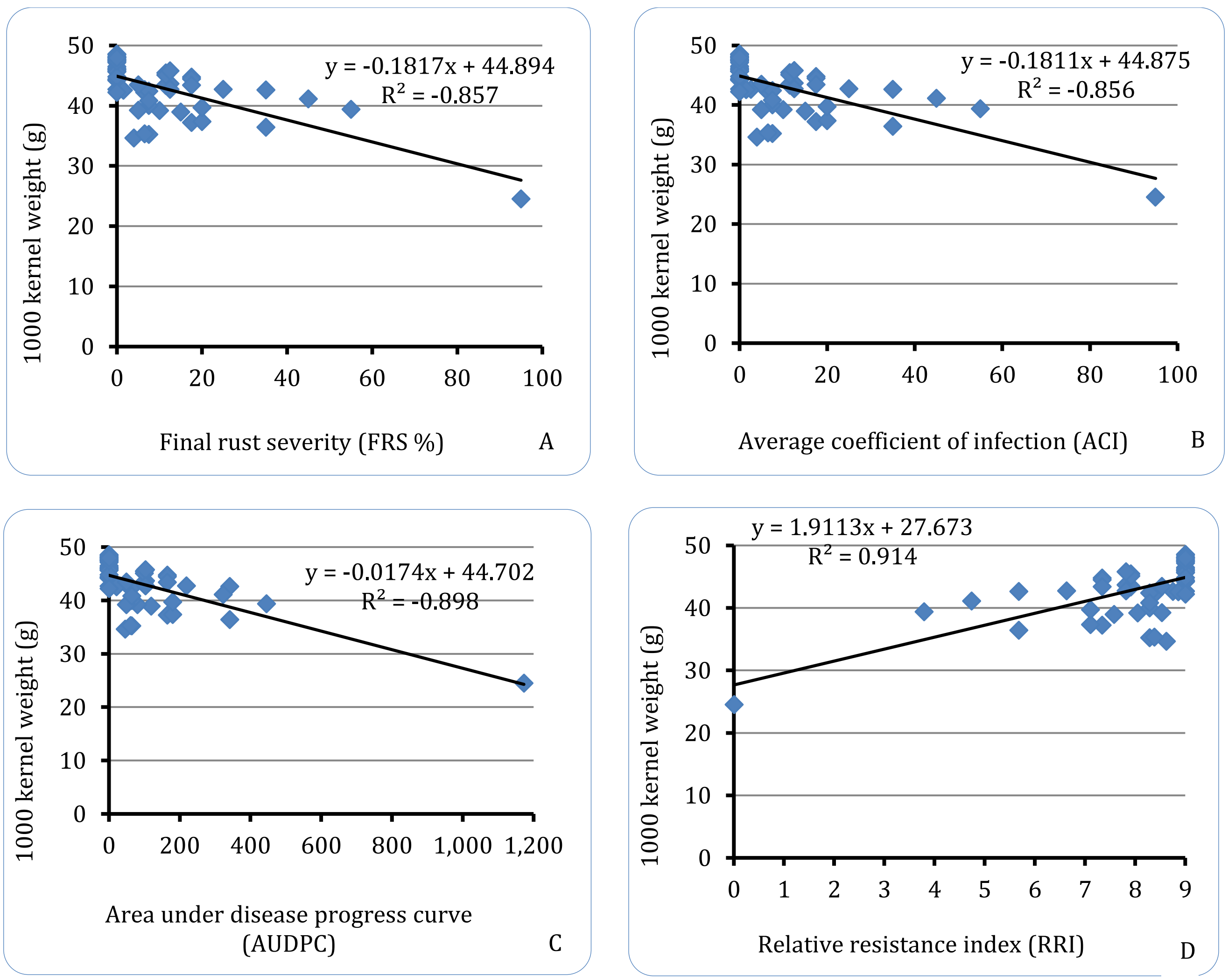

Figure 2. Correlation between each of FRS (%) (a), ACI (b), AUDPC (c) and RRI (d) with 1000 kernel weight (g) of 55 wheat genotypes during 2017/18 growing season.

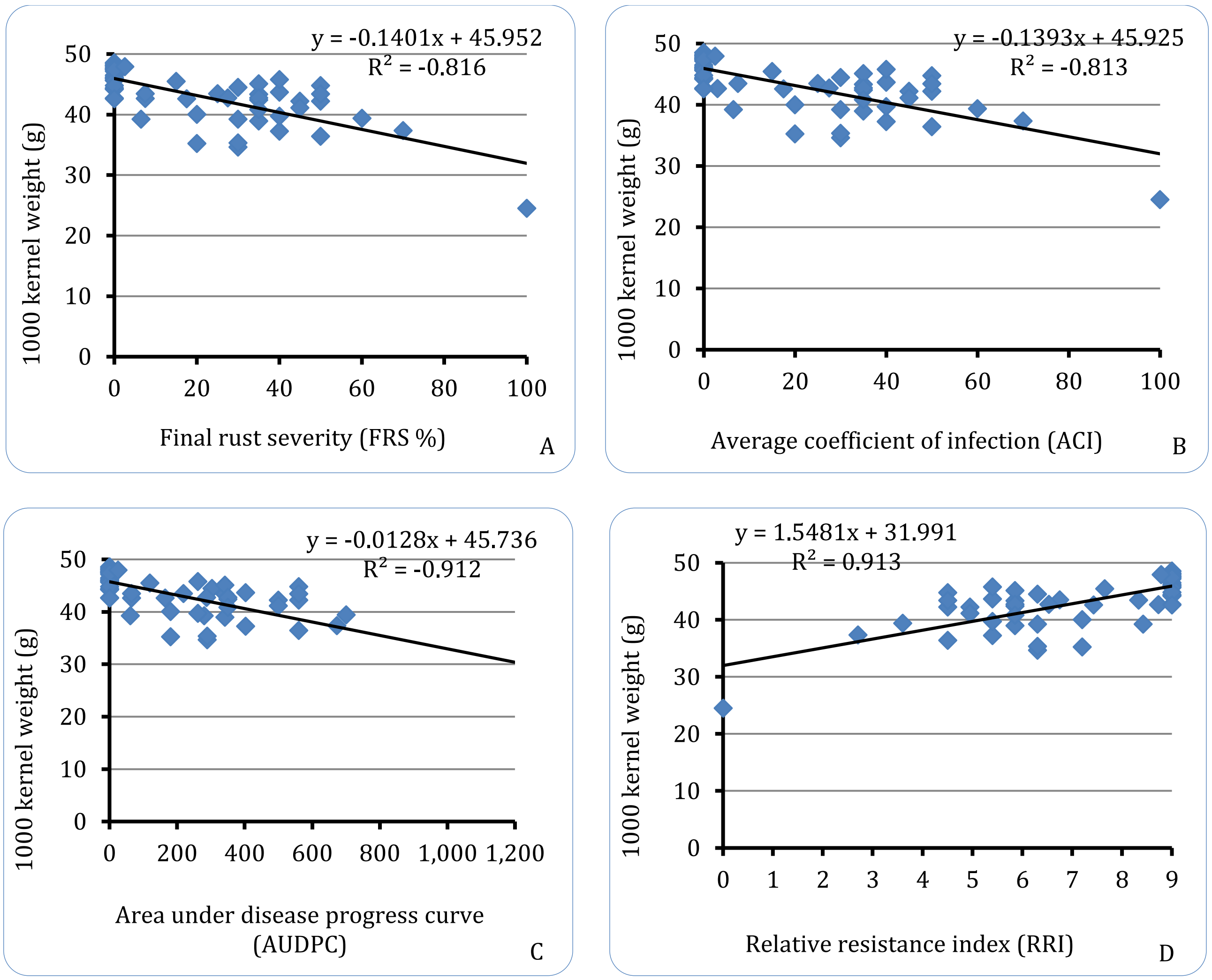

Figure 3. Correlation between each of FRS (%) (a), ACI (b), AUDPC (c) and RRI (d) with 1000 kernel weight (g) of 55 wheat genotypes during 2018/19 growing season.

DISCUSSION

It is clear that the increased number of infection cycles may lead not only to changes in the intensity and virulence of the extant rust pathotypes but also accelerated the evolution of new rust pathotypes (Chakraborty *et al.*, 2010). The rust pathogens with a high reproductive rate and the ability to spread quickly and evolve new pathotypes rapidly are a major threat to food security (Duveiller *et al.*, 2007). The emergence of the stem rust race Ug99 to which 90% of the wheat varieties grown worldwide are susceptible (Singh *et al.*, 2011) and spread of races of stripe rust virulent on varieties carrying the *Yr* 27 gene in West and Central Asia (Shiferaw *et al.*, 2013) have accelerated research investment in the identification and transfer of new sources of resistance (Singh *et al.*, 2011; Joshi *et al.*, 2010; James *et al.*, 2008). In Egypt, *Yr27* was attacked by race *Pst2, v27* (Shahin and Abou, 2015). Past experience of screening and deployment of genes (Singh *et al.*, 2011) warrants searching for additional genes, which confer race non-specific resistance to provide durable control. The horizontal resistance (Van der Plank, 1968) also known as partial resistance or slow rusting (Parlevliet, 1985) has been attributed to minor genes (Browder, 1973). The *Lr34/Yr18/Sr57/Pm38* resistance gene, provides adult-plant resistance (APR), slow rusting resistance or partial resistance (PR) to leaf rust, yellow rust, and several other diseases of wheat (Singh *et al.*, 2000; Lagudah *et al.*, 2006; Fahmi *et al.*, 2015; Shahin *et al.*, 2018; Elbasyoni *et al.*, 2019; El-Orabey *et al.*, 2019a; El-Orabey *et al.*, 2019b). Gene banks, conserving a large number of landraces, germplasm and wild relatives collected from different agro-ecological regions at different points of time provide an opportunity to bio-prospect for such genes. Genetic resources fortunately conserved in gene banks around the world carry an assortment of alleles needed for resistance/tolerance to diseases, pests and harsh environments (Hoisington *et al.*, 1999). Conservation of a resource only becomes important if the resource has or acquires recognized value.

We conducted an unprecedented experiment; the first such exercise carried out by any gene bank in the world where the entire germplasm collection of cultivated wheat was evaluated at multiple hotspots to identify potential new sources of rust diseases resistance. Such efforts can aid the ongoing efforts of wheat breeders to develop new varieties or transfer new sources of resistance to broadly-adapted high yielding wheat germplasm lines (for instance the efforts of the Borlaug Global Rust Initiative). The ambitious venture of evaluating nearly 20K wheat germplasm is significant not just by its sheer scale or that it exhibited the utility of the gene banks but it could successfully identify many sources of rusts resistance individually or in the combination that may lead to the development of multiple disease resistant cultivars in the future.

In the present study, 53 wheat genotypes from CIMMYT were evaluated to yellow rust during three growing seasons; 2016/17, 2017/18 and 2018/19 under field conditions at the two locations; Itay El-Baroud and Sakha. Four epidemiological parameters *i.e.* final rust severity (FRS %), Average coefficient of infection (ACI), relative resistance index (RRI) and area under disease progress curve (AUDPC) were used to study the effect of yellow rust diseases on these wheat genotypes.

Data of this study revealed that, 34 of the tested wheat genotypes *i.e.* 2, 3, 4, 5, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 21, 22, 24, 25, 26, 27, 28, 30, 31, 32, 33, 34, 35, 36, 40, 41, 42, 44, 45 and 48 displayed the lowest values of FRS (%) (less than 30%), lowest values of ACI and lowest values of AUDPC (less than 300). Tabassum (2011) evaluated 135 advance wheat lines against yellow rust during 2008/2009. He found that a total of 25 out of 135 lines showed the lowest values of FRS (%) (10-30%) and the lowest values of AUDPC (less than 260). Moreover, Elbasyoni *et al.* (2019) evaluated 2111 wheat genotypes for yellow rust resistance in two locations in Egypt during 2016 and 2017. They indicated that 42 landraces and 140 improved accessions were resistant to stripe rust.

Data of relative resistance index (RRI) were calculated according to the scale of 0-9 of Aslam (1982) to select resistant wheat genotypes for rust diseases, where RRI = 0 means the genotype is highly susceptible and RRI = 9 means the genotype is highly resistant. Moreover, for leaf rust, RRI = 5 or 6 means the genotype is acceptable in its resistant, while RRI = 7 and above means the genotype is desirable in its resistance. For stripe and stem rust, RRI = 6 means the genotype is acceptable in its resistance, while RRI = 7 and above means the genotype is desirable in its resistant. El-Orabey *et al.* (2014) used this scale for the first time in Egypt to evaluate some promising lines to select the resistant genotype for rust diseases and this point is the new issue in this study. Shahin and El-Orabey (2016) evaluated 90 wheat promising genotypes were evaluated for their resistance against leaf rust under field conditions during 2014/15 and 2015/16 growing seasons. They found that, thirty four candidate lines *i.e.* 3, 6, 14, 15, 16, 18, 20, 21, 22, 23, 24, 25, 28, 29, 30, 31, 32, 33, 36, 37, 38, 39, 43, 48, 50, 52, 55, 62, 77, 84, 86, 87, 89 and 90 out of ninety tested lines were found to be resistant to leaf rust disease and showed acceptable/desirable relative resistance index (RRI) during the two growing seasons.

In the present study, 11 wheat genotypes *i.e.* 28, 17, 6, 33, 14, Misr 3, 41, 4, 34, 48 and 11 showed the highest values of 1000 kernel weight and were also resistant for yellow rust. These 11 wheat genotypes should be tested for grain yield and other agronomic characters *i.e.* Days to heading and maturity, plant height (cm), biological yield (kg), straw yield and also flour extraction (%) and rheological properties to be registered as a new commercial cultivar, also, it must identify the yellow rust resistance genes present in these lines by the molecular marker to know the yellow rust resistance genes and the number of genes present in these lines.

Finally, the obtained results gave evidence to the presence of positive relation coefficient during the two seasons between ACI and the rest of the tested parameters i.e. least reading AUDPC, RRI and the 1000kernel weight, similar results run in parallel lines with the present one in Egyptian wheat varieties (Shahin, 2014). Degrees of resistance within the tested entries can be used for future manipulation in wheat improvement program in Egypt. These 11 wheat genotypes are considered new sources of resistance under the Egyptian conditions.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHORS CONTRIBUTIONS

All authors were involved in the experimental design, data collection, analysis and interpretation as well as write-up of this research.