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EVALUATION OF CIMMYT WHEAT LINES UNDER EGYPTIAN FIELD CONDITIONS TO IDENTIFY NEW SOURCES OF RESISTANCE TO LEAF RUST

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ABSTRACT

Leaf rust caused by *Puccinia triticina* Eriks. is a fungal disease of wheat (*Triticum aestivum* L.), which causes considerable yield loss. Host resistance is the most effective and economical method to minimize yield losses caused by leaf rust. The current research was planned to evaluate the response of 93 wheat genotypes lines selected from 716 wheat genotypes delivered to Egypt by International Maize and Wheat Improvement Center (CIMMYT). These genotypes were evaluated against leaf rust resistance under field conditions at two locations i.e. Behira governorate (Itay El-Baroud Agricultural Research Station) and Menoufia governorate during three successive growing seasons i.e. 2017/2018, 2018/2019 and 2019/2020. Results of the current study showed that 47 wheat genotypes were resistant and had the lowest values of final rust severity (FRS %), average coefficient of infection (ACI) and area under disease progress curve (AUDPC). Also, these genotypes showed desirable/acceptable relative resistance index (RRI) at the two locations during the three growing seasons of the study. Therefore, we can select these genotypes as resistant lines in the breeding program for the resistance of leaf rust.

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INTRODUCTION

Wheat leaf rust caused by *Puccinia triticina* Eriks. is the most common, widespread, and devastating disease in Egypt and worldwide. Leaf rust has the potential to cause losses up to 50% and because of its frequent and widespread occurrence, leaf rust probably results in greater total annual losses worldwide than stem and stripe rusts (Huerta-Espino *et al.*, 2011). In Egypt, grain yield loss due to artificial leaf rust has reached 32% in the susceptible wheat cultivars that are cultivated under experimental field conditions favorable to disease incidence and development (Shahin and El-Orabey, 2016; El-Orabey *et al.*, 2017).

The preferable and most economical method for controlling wheat rusts is the utilization of genetic resistance. It is the most effective, economically safe, and eco-friendly approach, as this method eliminates the need to use fungicides and reduces the cost of production. The need is to identify those cultivars with resistant sources to be suggested as the fittest for the cultivation in the diseased areas of the country keeping in view different ecological zones. The screening is considered as the best and the cheapest way to identify these cultivars of wheat which show resistance against leaf rust (Anwar *et al.*, 2019).

To contain the disease outbreak, Egyptian wheat breeders have developed several rust-resistant varieties in collaboration with pathologists and utilized advanced breeding materials. Despite the development of rust-resistant cultivars, the emergence of newer types of virulent races had led to a breakdown of resistance. Hence, the current breeding strategy warrants pyramiding disease resistance genes for all the three rusts in commercially released high yielding varieties (Tyagi *et al.*, 2014). At present, more than 80 different leaf rust resistance genes and QTL spread throughout the A, B, and D wheat genomes have been identified and cataloged (Sapkota *et al.*, 2018). Resistance imparted by many of these genes has either broken down or been lost due to emerging newer races with higher virulence and poor management of germplasm. It is, therefore, desirable that germplasm exhibiting resistance through non-specific interaction is used in breeding programs rather than germplasm exhibiting only specific interaction (McIntosh *et al.*, 1995). Hence, screening of large number of germplasm accession is essential to identify newer and diverse sources of resistance to new races/pathotypes of wheat rusts (Daetwyler *et al.*, 2014).

Screening entire cultivated wheat collections from gene banks in hotspots to identify trait-specific germplasm assumes unprecedented significance in this context. Such screening may bring to light new genes and genetic combinations in adapted genetic backgrounds for use as a source of resistance in future breeding programs. Such trials have been conducted in the past, including global initiatives screening over 200,000 wheat lines for resistance to Ug99 in Kenya (Singh *et al.*, 2002) and a national effort in the screening of wheat germplasm for stripe rust tolerance in Pakistan (Bux *et al.*, 2012). Germplasm conserved in genebanks (including crop wild relatives) is always a potential source of resistance genes that can be utilized efficiently to incorporate multiple disease resistances into popular cultivars (Jin and Singh, 2006). The objective of the present study was to identify disease-resistant wheat germplasm to leaf rust based on screening at disease hotspots and evaluate resistant germplasm against different leaf rust races under artificial epiphytotic conditions.

MATERIALS AND METHODS

Plant Materials

A total of 716 wheat genotypes in four 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 wheat variety; Morocco (check for rust resistance) as a highly susceptible. The five sets of germplasm evaluated included (1) Elite Spring Wheat Yield Trial (ESWYT), (2) Stem Rust Resistance Screening Nursery (STEMRRSN), (3) International Spring Bread Wheat Screening Nursery (IBWSN), and (4) High-Temperature Wheat Yield Trial (HTWYT) consisting of 98, 168, 329 and 121 entries, respectively. A total of 93 i.e. 26 genotypes from (ESWYT), 32 (STEMRRSN), 25 (IBWSN), and 10 (HTWYT) wheat germplasm were selected from 716 tested wheat genotypes which were selected according to their response for leaf rust resistance under field conditions. The pedigree of the tested genotypes is shown in Table (1).

Field Testing

The experiments of this study were carried out at two locations i.e. Behira governorate (Itay El-Baroud Agricultural Research Station) and Menoufia governorate (Shibin El-Kom) during 2017/2018, 2018/2019, and 2019/2020 successive growing seasons. These experiments were conducted in randomized complete block design (RCBD) with three replicates. The tested wheat genotypes were sown in rows of 3 m long. The experiments were surrounded by a spreader area planted with a mixture of highly susceptible wheat genotypes to leaf rust. These genotypes were *Triticum spelta sahariensis*, Morocco, and Thatcher to spread rust inoculum. For field inoculation with leaf rust, the spreader plants were sprayed with a mist of water and dusted with a mixture of aggressive urediniospores of the prevalent and aggressive seven pathotypes i.e. TTTJT, PTTCT, PTTGS, PTTTT, TTTBT, TTTKT, and TTTTT (El-Orabey *et al.*, 2018) 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 all plants was carried out at the booting stage according to the method of Tervet and Cassell (1951). The urediniospores of leaf rust received from Wheat Research Diseases Department, Plant Pathology Research Institute, Agricultural Research Center, Egypt. To maintain crop stand/vigor normal agronomic practices including recommended fertilization dose and irrigation schedules were followed.

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

Line	Pedigree	Line	Pedigree
1	ROLF07*2/3/PRINIA/PASTOR//HUITES	48	7846//2180/4/2*MILAN/KAUZ//PRINIA /3/BAV92
2	CNO79//PF70354/MUS/3/PASTOR/4/BAV92 *2/5/FH6-1-7	49	BOW/VEE/5/ND/VG9144//KAL/BB/3/YACO/ 4/CHIL/6/CASKOR/3/CROC_1/AE.SQUARROS A (224)//OPATA/7/PASTOR// MILAN/KAUZ/3/BAV92
3	KACHU #1/KIRITATI//KACHU	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
4	WBLL1*2/4/BABAX/LR42//BABAX/3/BABAX /LR42//BABAX	51	D67.2/PARANA 66.270//AE.SQUARROSA (320)/3/CUNNINGHAM/4/VORB
5	ATTILA*2/PBW65*2//MURGA	52	D67.2/PARANA 66.270//AE.SQUARROSA (320)/3/CUNNINGHAM/4/VORB
6	ROLF07*2/5/REH/HARE//2*BCN/3/CROC_1/ AE.SQUARROSA (213)//PGO/4/HUITES	53	H45/4/KRICHAUFF/FINSI/3/URES/PRL//BA V92
7	ATTILA*2/PBW65*2//W485/HD29	54	EGA BONNIE ROCK/4/MILAN/KAUZ//PRINIA/3/BAV92
8	WBLL1*2/TUKURU//FN/2*PASTOR/3/FRET2 /KIRITATI	55	CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5/2*JANZ/6/D67.2/ PARANA 66.270//AE.SQUARROSA (320)/3/CUNNINGHAM
9	NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PAS TOR/5/KACHU/6/KACHU	56	INQALAB 91*2/KUKUNA/4/TC14/2*HTG//DUCULA/3/ PRINIA
10	WAXWING/4/BL 1496/MILAN/3/CROC_1/AE.SQUARROSA (205)//KAUZ/5/FRNCLN	57	KANZ/5/CNO79//PF70354/MUS/3/PASTOR/ 4/BAV92/6/PRL/SARA//TSI/VEE#5
11	WBLL1*2/KURUKU/6/CNDO/R143//ENTE/M EXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5/2*JANZ/7/ WBLL1*2/KURUKU	58	BABAX/KS93U76//BABAX/3/2*SOKOLL
12	UP2338*2/VIVITSI/3/FRET2/TUKURU//FRE T2/4/MISR 1	59	ATTILA*2/PBW65*2//KACHU
13	TACUPETO F2001*2/BRAMBLING//WBLL1*2/BRAMBLI NG	60	ROLF07*2/3/PRINIA/PASTOR//HUITES
14	CNO79//PF70354/MUS/3/PASTOR/4/BAV92 *2/5/FH6-1-7	61	CNO79//PF70354/MUS/3/PASTOR/4/BAV92 *2/5/FH6-1-7
15	FRET2/TUKURU//FRET2/3/MUNAL #1	62	KACHU #1/KIRITATI//KACHU
16	FRET2/TUKURU//FRET2/3/MUNAL #1	63	PBW343*2/KUKUNA*2//FRTL/PIFED
17	GAN/AE.SQUARROSA (408)//2*OASIS/5*BORL95/3/ TACUPETO F2001*2/BRAMBLING	64	WBLL1*2/4/BABAX/LR42//BABAX/3/BABAX /LR42//BABAX
18	KIRITATI//ATTILA*2/PASTOR/3/AKURI	65	ATTILA*2/PBW65*2//MURGA
19	KIRITATI//PRL/2*PASTOR/3/FRANCOLIN #1	66	SUP152/4/BABAX/LR42//BABAX*2/3/KURU KU
20	BAJ #1/3/KIRITATI//ATTILA*2/PASTOR	67	QUAIU/5/FRET2*2/4/SNI/TRAP#1/3/KAUZ* 2/TRAP//KAUZ
21	WBLL1*2/BRAMBLING/3/KIRITATI//PBW65 /2*SERI.1B	68	TACUPETO F2001*2/BRAMBLING//WBLL1*2/BRAMBLING
22	WBLL1*2/KURUKU//SUP152	69	ROLF07*2/5/REH/HARE//2*BCN/3/CROC_1/ AE.SQUARROSA (213)//PGO/4/HUITES
23	WBLL4/KUKUNA//WBLL1/3/WBLL1*2/BRA MBLING	70	NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PAS TOR/5/KACHU/6/KACHU

Table 1: Cont…

24	FRET2*2/BRAMBLING/3/FRET2/WBLL1//TACUPETO F2001/4/WBLL1*2/BRAMBLING	71	WAXWING/4/BL 1496/MILAN/3/CROC_1/AE.SQUARROSA (205)//KAUZ/5/FRNCLN
25	WHEAR*2/3/FRET2/WBLL1//TACUPETO F2001	72	TACUPETO F2001/BRAMBLING//KACHU
26	ALTAR 84/AE.SQUARROSA (221)//3*BORL95/3/URES/JUN//KAUZ/4/WBLL1/5/KACHU/6/KIRITATI//PBW65/2*SERI.1B	73	SITE/MO//PASTOR/3/TILHI/4/WAXWING/KIRITATI
27	FRANCOLIN #1*2/MUU	74	ALTAR 84/AE.SQUARROSA (221)//3*BORL95/3/ URES/JUN//KAUZ/4/WBLL1/5/REH/HARE// 2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES
28	FRANCOLIN #1*2/KINGBIRD #1	75	ROLF07*2/3/PRINIA/PASTOR//HUITES
29	SERI.1B*2/3/KAUZ*2/BOW//KAUZ*2/4/KINGBIRD #1	76	ROLF07*2/4/CROC_1/AE.SQUARROSA (205)//BORL95/3/2*MILAN
30	HUIRIVIS #1/MUU//WBLL1*2/BRAMBLING	77	CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/HAR311
31	CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2/5/KINDE	78	CS/TH.SC//3*PVN/3/MIRLO/BUC/4/URES/JUN//KAUZ/5/HUITES/6/YANAC/7/CS/TH.SC//3*PVN/3/MIRLO/BUC/4/MILAN/5/TILHI
32	KAUZ*2/MNV//KAUZ/3/MILAN/4/BAV92/5/DANPHE #1	79	PF74354//LD/ALD/4/2*BR12*2/3/JUP//PAR214*6/FB6631/5/NL750/6/PVN/7/TOBA97/PASTOR
33	THELIN/3/BABAX/LR42//BABAX/4/BABAX/LR42//BABAX/5/BOW/NKT//CBRD/3/CBRD/6/FRET2*2/BRAMBLING	80	BAV92//IRENA/KAUZ/3/HUITES/4/2*ROLF07
34	WBLL1*2/KUKUNA/4/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1	81	FRET2/TUKURU//FRET2/3/MUNIA/CHTO//AMSEL/4/FRET2/TUKURU//FRET2
35	WBLL1/KUKUNA//TACUPETO F2001/4/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1	82	ATTILA*2/PBW65*2/4/BOW/NKT//CBRD/3/CBRD
36	WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/QUAIU	83	BAV92//IRENA/KAUZ/3/HUITES/4/FN/2*PASTOR/5/BAV92//IRENA/KAUZ/3/HUITES
37	CHIBIA//PRLII/CM65531/3/FISCAL/4/ND643/2*WBLL1	84	NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KACHU/6/KACHU
38	DANPHE #1/3/HUW234+LR34/PRINIA//PFAU/WEAVER	85	KACHU #1/6/NG8201/KAUZ/4/SHA7//PRL/VEE#6/3/FASAN/5/MILAN/KAUZ/7/KACHU
39	KACHU/BECARD//WBLL1*2/BRAMBLING	86	ATTILA*2/PBW65*2//MURGA
40	PCAFLR/KINGBIRD #1//KIRITATI/2*TRCH	87	KBIRD//WH 542/2*PASTOR/3/WBLL1*2/BRAMBLING
41	MUU/3/KIRITATI//ATTILA*2/PASTOR/4/MUU	88	KZA/5/2*WBLL1/3/STAR//KAUZ/STAR/4/BAV92/RAYON
42	PRINIA/PASTOR//KIRITATI/3/PRL/2*PASTOR	89	WBLL1*2/KURUKU/4/BABAX/LR42//BABAX*2/3/KURUKU
43	OASIS/SKAUZ//4*BCN*2/3/PASTOR/4/HEILO/5/PAURAQ	90	BAV92//IRENA/KAUZ/3/HUITES/6/ALD/CEP75630//CEP75234/PT7219/3/BUC/BJY/4/CBRD/5/TNMU/PF85487
44	ND643/2*WBLL1//ATTILA*2/PBW65/3/MUNAL	91	TACUPETO F2001/6/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5/PASTOR/7/ROLF07
45	ND643/2*WBLL1/3/KIRITATI//PRL/2*PASTOR/4/KIRITATI//PBW65/2*SERI.1B	92	BAV92//IRENA/KAUZ/3/HUITES*2/6/TURACO/5/CHIR3/4/SIREN//ALTAR 84/AE.SQUARROSA (205)/3/3*BUC
46	ND643/2*TRCH//BECARD/3/BECARD	93	FRANCOLIN #1/KIRITATI
47	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1	Morocco	-

Disease Assessment

Final leaf rust severities were recorded for each genotype using the modified Cobb's scale (Peterson *et al.*, 1948). 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.

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 (Aslam, 1982; 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
Leaf rust	7 and above	6 or 5

The area under the disease progress curve (AUDPC) was calculated by using the formula suggested by Pandey *et al.* (1989).

$$AUDPC = D \left[\frac{1}{2}(Y_1 + Y_k) + (Y_2 + Y_3 + \ldots + Y_{k-1})\right]$$

Where:

D = days between two consecutive records (time intervals)

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

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

Statistical Analysis

The mean performance of all agronomic characters of the tested genotypes was compared using the least significant difference (LSD) at 5 % (Snedecor and Cochran, 1967).

RESULTS

Evaluation of Wheat Genotypes against Leaf Rust under Field Conditions

Growing Season 2017/18

Data presented in Table (2) showed that final leaf rust severity of the tested genotypes ranged from 0-70% at Menoufia and Behira from 0-90%. All of the wheat genotypes showed resistant reaction at the two locations except 25 genotypes i.e. 3, 5, 9, 19, 20, 21, 24, 26, 38, 39, 50, 51, 53, 60, 65, 69, 72, 73, 79, 80, 85, 91, 92, 93 and Morocco (Table 2). Moreover, all of the tested wheat genotypes showed desirable/acceptable (RRI) to leaf rust ranged from 5.06 to 9.00 except the three wheat genotypes i.e. 53, 65 (each with 3.94), and Morocco (0.00) (Table 2) at the two locations during 2017/18 growing season.

Growing Season 2018/19

Data in Table (3) showed that final leaf rust severity of the tested genotypes ranged from 0-90% at Menoufia and Behira from 0-100%. All of the wheat genotypes showed resistant reaction at the two locations except 28 genotypes i.e. 2, 5, 9, 18, 19, 20, 21, 23, 24, 26, 38, 39, 51, 53, 60, 62, 65, 68, 69, 72, 73, 79, 80, 85, 91, 92, 93 and Morocco (Table 3). Moreover, all of the tested wheat genotypes showed desirable/acceptable (RRI) to leaf rust ranged from 5.21 to 9.00 except the three wheat genotypes i.e. 38 (3.32), 51 (4.74), 53 (3.79), 65 (4.74), 72 (3.32), 73 (4.74), 91 (3.32), 93 (2.37) and Morocco (0.00) (Table 3) at the two locations during 2018/19 growing season.

Growing Season 2019/20

Data in Table (4) showed that final leaf rust severity of the tested genotypes ranged from 0-60% at Menoufia and Behira from 0-70%. All of the wheat genotypes showed resistant reaction at the two locations except 23 genotypes i.e. 3, 5, 9, 18, 19, 20, 21, 23, 24, 26, 32, 37, 38, 39, 43, 47, 51, 53, 57, 60, 62, 65, 68, 69, 72, 73, 76, 79, 80, 83, 88, 91, 92, 93 and Morocco (Table 4). Moreover, all of the tested wheat genotypes showed desirable/acceptable (RRI) to leaf rust ranged from 5.54 to 9.00 except the three wheat genotypes i.e. 26, 53, 91, 92 (each with 4.85), 93 (2.77) and Morocco (0.00) (Table 4) at the two locations during 2018/19 growing season.

Data in Table (5) indicated all of the tested wheat genotypes were resistant to leaf rust and showed desirable/acceptable (RRI) at the two locations during the three growing seasons except 11 wheat genotypes i.e. 24, 51, 53, 65, 68, 72, 73, 91, 92, 93 and Morocco.

Table 2: Response of 94 wheat genotypes to leaf rust along with the average coefficient of infection (ACI), country average relative percentage attack (CARPA), and relative resistance index (RRI) at Menoufia and Behira locations during 2017/18 growing season.

Line	2017/18 Location / Final rust severity (%)[a]		ACI	CARPA	RRI[b]
	Menoufia	Behira			
1	5 MR	10 MR	3.00	3.75	8.66
2	0	0	0.00	0.00	9.00
3	0	5 S	2.50	3.13	8.72
4	10 MR	5 MR	3.00	3.75	8.66
5	10 S	20 S	15.00	18.75	7.31
6	0	0	0.00	0.00	9.00
7	0	5 MR	1.00	1.25	8.89
8	0	0	0.00	0.00	9.00
9	5 S	5 S	5.00	6.25	8.44
10	0	0	0.00	0.00	9.00
11	0	0	0.00	0.00	9.00
12	5 MR	Tr MR	1.60	2.00	8.82
13	0	5 MR	1.00	1.25	8.89
14	0	0	0.00	0.00	9.00
15	10 MR	10 MR	4.00	5.00	8.55
16	0	0	0.00	0.00	9.00
17	0	0	0.00	0.00	9.00
18	0	0	0.00	0.00	9.00
19	Tr S	10 S	6.50	8.13	8.27
20	5 S	5 S	5.00	6.25	8.44
21	5 S	40 S	22.50	28.13	6.47
22	0	0	0.00	0.00	9.00
23	5 MR	0	1.00	1.25	8.89
24	20 S	5 S	12.50	15.63	7.59
25	0	10 MR	2.00	2.50	8.78
26	30 MS	20 MS	20.00	25.00	6.75
27	0	0	0.00	0.00	9.00
28	0	0	0.00	0.00	9.00
29	5 MR	0	1.00	1.25	8.89
30	0	0	0.00	0.00	9.00
31	20 MR	20 MR	8.00	10.00	8.10
32	0	0	0.00	0.00	9.00
33	5 R	0	0.50	0.63	8.94
34	0	0	0.00	0.00	9.00
35	0	10 R	1.00	1.25	8.89
36	0	0	0.00	0.00	9.00
37	0	0	0.00	0.00	9.00
38	10 MS	50 MS	24.00	30.00	6.30
39	5 S	5 S	5.00	6.25	8.44
40	0	0	0.00	0.00	9.00
41	20 R	5 MR	3.00	3.75	8.66
42	0	0	0.00	0.00	9.00
43	5 R	20 R	2.50	3.13	8.72
44	0	0	0.00	0.00	9.00
45	0	0	0.00	0.00	9.00
46	0	0	0.00	0.00	9.00

Table 2: Cont…

47	0	0	0.00	0.00	9.00
48	0	0	0.00	0.00	9.00
49	0	0	0.00	0.00	9.00
50	Tr R	0	0.30	0.38	8.97
51	50 S	5 S	27.50	34.38	5.91
52	0	0	0.00	0.00	9.00
53	40 S	50 S	45.00	56.25	3.94
54	0	0	0.00	0.00	9.00
55	0	0	0.00	0.00	9.00
56	0	0	0.00	0.00	9.00
57	0	0	0.00	0.00	9.00
58	5 MR	0	1.00	1.25	8.89
59	0	0	0.00	0.00	9.00
60	20 S	5 S	12.50	15.63	7.59
61	0	0	0.00	0.00	9.00
62	20 MR	20 MR	8.00	10.00	8.10
63	0	10 R	1.00	1.25	8.89
64	0	0	0.00	0.00	9.00
65	70 S	20 S	45.00	56.25	3.94
66	0	10 MR	2.00	2.50	8.78
67	0	0	0.00	0.00	9.00
68	5 R	20 MR	4.50	5.63	8.49
69	30 MS	10 S	17.00	21.25	7.09
70	0	0	0.00	0.00	9.00
71	0	0	0.00	0.00	9.00
72	10 S	10 S	10.00	12.50	7.88
73	5 MS	Tr MS	3.20	4.00	8.64
74	0	0	0.00	0.00	9.00
75	0	0	0.00	0.00	9.00
76	10 R	0	1.00	1.25	8.89
77	0	0	0.00	0.00	9.00
78	0	0	0.00	0.00	9.00
79	5 MS	10 S	7.00	8.75	8.21
80	60 S	10 S	35.00	43.75	5.06
81	0	0	0.00	0.00	9.00
82	5 R	0	0.50	0.63	8.94
83	0	0	0.00	0.00	9.00
84	0	0	0.00	0.00	9.00
85	10 S	5 S	7.50	9.38	8.16
86	0	0	0.00	0.00	9.00
87	20 MR	10 MR	6.00	7.50	8.33
88	0	0	0.00	0.00	9.00
89	0	5 R	0.50	0.63	8.94
90	0	0	0.00	0.00	9.00
91	40 S	10 S	25.00	31.25	6.19
92	5 S	30 S	17.50	21.88	7.03
93	20 S	50 S	35.00	43.75	5.06
Morocco	70 S	90 S	80.00	100.00	0.00
LSD at 5%					0.761

[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 3: Response of 94 wheat genotypes to leaf rust along with the average coefficient of infection (ACI), country average relative percentage attack (CARPA), and relative resistance index (RRI) at Menoufia and Behira locations during 2018/19 growing season.

Line	2018/19 Location / Final rust severity (%)[a]		ACI	CARPA	RRI[b]
	Menoufia	Behira			
1	0	0	0.00	0.00	9.00
2	0	0	0.00	0.00	9.00
3	20 S	30 S	25.00	26.32	6.63
4	0	10 MR	2.00	2.11	8.81
5	Tr S	50 S	26.50	27.89	6.49
6	5 MR	10 MR	3.00	3.16	8.72
7	0	0	0.00	0.00	9.00
8	0	0	0.00	0.00	9.00
9	10 MS	10 MS	8.00	8.42	8.24
10	5 R	10 MR	2.50	2.63	8.76
11	0	0	0.00	0.00	9.00
12	0	0	0.00	0.00	9.00
13	20 MR	10 MR	6.00	6.32	8.43
14	10 R	20 MR	5.00	5.26	8.53
15	0	0	0.00	0.00	9.00
16	0	0	0.00	0.00	9.00
17	0	0	0.00	0.00	9.00
18	20 MR	10 MS	8.00	8.42	8.24
19	30 S	20 S	25.00	26.32	6.63
20	10 S	30 S	20.00	21.05	7.11
21	20 S	5 S	12.50	13.16	7.82
22	20 R	10 R	3.00	3.16	8.72
23	10 S	Tr S	6.50	6.84	8.38
24	50 S	40 S	45.00	47.37	4.74
25	20 MR	Tr MR	4.60	4.84	8.56
26	20 S	60 S	40.00	42.11	5.21
27	0	0	0.00	0.00	9.00
28	0	0	0.00	0.00	9.00
29	0	0	0.00	0.00	9.00
30	0	0	0.00	0.00	9.00
31	0	0	0.00	0.00	9.00
32	0	0	0.00	0.00	9.00
33	0	0	0.00	0.00	9.00
34	0	0	0.00	0.00	9.00
35	0	0	0.00	0.00	9.00
36	0	0	0.00	0.00	9.00
37	0	0	0.00	0.00	9.00
38	60 S	60 S	60.00	63.16	3.32
39	20 S	40 S	30.00	31.58	6.16
40	5 R	Tr R	0.80	0.84	8.92
41	0	0	0.00	0.00	9.00
42	5 MR	10 MR	3.00	3.16	8.72
43	0	0	0.00	0.00	9.00
44	0	0	0.00	0.00	9.00
45	0	0	0.00	0.00	9.00
46	0	0	0.00	0.00	9.00

Table 3: Cont…

47	0	0	0.00	0.00	9.00
48	0	0	0.00	0.00	9.00
49	0	0	0.00	0.00	9.00
50	20 R	10 R	3.00	3.16	8.72
51	30 S	60 S	45.00	47.37	4.74
52	0	0	0.00	0.00	9.00
53	70 S	40 S	55.00	57.89	3.79
54	0	0	0.00	0.00	9.00
55	0	0	0.00	0.00	9.00
56	0	0	0.00	0.00	9.00
57	0	0	0.00	0.00	9.00
58	0	0	0.00	0.00	9.00
59	0	0	0.00	0.00	9.00
60	10 MR	20 S	12.00	12.63	7.86
61	5S	0	2.50	2.63	8.76
62	30 MS	30 MS	24.00	25.26	6.73
63	0	0	0.00	0.00	9.00
64	0	0	0.00	0.00	9.00
65	50 S	40 S	45.00	47.37	4.74
66	0	0	0.00	0.00	9.00
67	0	0	0.00	0.00	9.00
68	20 S	70 S	45.00	47.37	4.74
69	60 S	20 S	40.00	42.11	5.21
70	10 R	30 MR	7.00	7.37	8.34
71	5 MR	10 MR	3.00	3.16	8.72
72	70 S	50 S	60.00	63.16	3.32
73	40 S	50 S	45.00	47.37	4.74
74	0	0	0.00	0.00	9.00
75	0	0	0.00	0.00	9.00
76	0	0	0.00	0.00	9.00
77	0	0	0.00	0.00	9.00
78	0	0	0.00	0.00	9.00
79	30 S	60 S	45.00	47.37	4.74
80	30 S	30 S	30.00	31.58	6.16
81	0	0	0.00	0.00	9.00
82	0	0	0.00	0.00	9.00
83	0	0	0.00	0.00	9.00
84	0	0	0.00	0.00	9.00
85	40 S	10 S	25.00	26.32	6.63
86	0	0	0.00	0.00	9.00
87	0	0	0.00	0.00	9.00
88	0	0	0.00	0.00	9.00
89	0	0	0.00	0.00	9.00
90	0	0	0.00	0.00	9.00
91	70 S	50 S	60.00	63.16	3.32
92	30 S	10 S	20.00	21.05	7.11
93	60 S	80 S	70.00	73.68	2.37
Morocco	90 S	100 S	95.00	100.00	0.00
LSD at 5%					0.965

[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: Response of 94 wheat genotypes to leaf rust along with the average coefficient of infection (ACI), country average relative percentage attack (CARPA), and relative resistance index (RRI) at Menoufia and Behira locations during 2019/20 growing season.

Line	2019/20 Location / Final rust severity (%)[a]		ACI	CARPA	RRI[b]
	Menoufia	Behira			
1	0	0	0.00	0.00	9.00
2	0	0	0.00	0.00	9.00
3	5 S	10 S	7.50	11.54	7.96
4	0	0	0.00	0.00	9.00
5	Tr S	10 S	6.50	10.00	8.10
6	0	0	0.00	0.00	9.00
7	0	0	0.00	0.00	9.00
8	0	0	0.00	0.00	9.00
9	5 MS	5 MS	4.00	6.15	8.45
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	0	0	0.00	0.00	9.00
14	0	0	0.00	0.00	9.00
15	0	0	0.00	0.00	9.00
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	7.69	8.31
19	10 S	5 S	7.50	11.54	7.96
20	5 S	10 S	7.50	11.54	7.96
21	10 S	10 S	10.00	15.38	7.62
22	0	0	0.00	0.00	9.00
23	5 S	5 S	5.00	7.69	8.31
24	20 S	10 S	15.00	23.08	6.92
25	0	0	0.00	0.00	9.00
26	10 S	50 S	30.00	46.15	4.85
27	0	0	0.00	0.00	9.00
28	0	0	0.00	0.00	9.00
29	0	0	0.00	0.00	9.00
30	0	0	0.00	0.00	9.00
31	0	0	0.00	0.00	9.00
32	Tr S	Tr S	3.00	4.62	8.58
33	0	0	0.00	0.00	9.00
34	0	0	0.00	0.00	9.00
35	0	0	0.00	0.00	9.00
36	0	0	0.00	0.00	9.00
37	Tr S	5 S	4.00	6.15	8.45
38	20 S	5 S	12.50	19.23	7.27
39	Tr S	5 S	4.00	6.15	8.45
40	0	0	0.00	0.00	9.00
41	0	0	0.00	0.00	9.00
42	0	0	0.00	0.00	9.00
43	Tr S	5 S	4.00	6.15	8.45
44	0	0	0.00	0.00	9.00
45	0	0	0.00	0.00	9.00
46	Tr S	Tr S	3.00	4.62	8.58

Table 4: Cont…

47	Tr S	Tr S	3.00	4.62	8.58
48	0	0	0.00	0.00	9.00
49	0	0	0.00	0.00	9.00
50	0	0	0.00	0.00	9.00
51	10 S	5 S	7.50	11.54	7.96
52	0	0	0.00	0.00	9.00
53	30 S	30 S	30.00	46.15	4.85
54	0	0	0.00	0.00	9.00
55	0	0	0.00	0.00	9.00
56	0	0	0.00	0.00	9.00
57	Tr S	Tr S	3.00	4.62	8.58
58	0	0	0.00	0.00	9.00
59	0	0	0.00	0.00	9.00
60	Tr S	5 S	4.00	6.15	8.45
61	5S	0	2.50	3.85	8.65
62	5 S	20 S	12.50	19.23	7.27
63	0	0	0.00	0.00	9.00
64	0	0	0.00	0.00	9.00
65	10 S	30 S	20.00	30.77	6.23
66	0	0	0.00	0.00	9.00
67	0	0	0.00	0.00	9.00
68	5 S	10 S	7.50	11.54	7.96
69	20 S	30 S	25.00	38.46	5.54
70	0	0	0.00	0.00	9.00
71	0	0	0.00	0.00	9.00
72	20 S	20 S	20.00	30.77	6.23
73	5 S	30 S	17.50	26.92	6.58
74	0	0	0.00	0.00	9.00
75	0	0	0.00	0.00	9.00
76	Tr S	Tr S	3.00	4.62	8.58
77	0	0	0.00	0.00	9.00
78	0	0	0.00	0.00	9.00
79	10 S	20 S	15.00	23.08	6.92
80	5 S	20 S	12.50	19.23	7.27
81	0	0	0.00	0.00	9.00
82	0	0	0.00	0.00	9.00
83	Tr S	Tr S	3.00	4.62	8.58
84	0	0	0.00	0.00	9.00
85	5 S	10 S	7.50	11.54	7.96
86	0	0	0.00	0.00	9.00
87	0	0	0.00	0.00	9.00
88	Tr S	5 S	4.00	6.15	8.45
89	0	0	0.00	0.00	9.00
90	0	0	0.00	0.00	9.00
91	30 S	30 S	30.00	46.15	4.85
92	20 S	40 S	30.00	46.15	4.85
93	50 S	40 S	45.00	69.23	2.77
Morocco	60 S	70 S	65.00	100.00	0.00
LSD at 5%					0.679

[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).

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Table 5: Resistant wheat genotypes with desirable and acceptable relative resistance index (RRI) to leaf rust disease at Menoufia and Behira locations during 2017/18, 2018/19, and 2019/20 growing seasons.

Line	Season / RRI		
	2017/18	2018/19	2019/20
1	8.66	9.00	9.00
2	9.00	9.00	9.00
3	8.72	6.63	7.96
4	8.66	8.81	9.00
5	7.31	6.49	8.10
6	9.00	8.72	9.00
7	8.89	9.00	9.00
8	9.00	9.00	9.00
9	8.44	8.24	8.45
10	9.00	8.76	9.00
11	9.00	9.00	9.00
12	8.82	9.00	9.00
13	8.89	8.43	9.00
14	9.00	8.53	9.00
15	8.55	9.00	9.00
16	9.00	9.00	9.00
17	9.00	9.00	9.00
18	9.00	8.24	8.31
19	8.27	6.63	7.96
20	8.44	7.11	7.96
21	6.47	7.82	7.62
22	9.00	8.72	9.00
23	8.89	8.38	8.31
25	8.78	8.56	9.00
26	6.75	5.21	4.85
27	9.00	9.00	9.00
28	9.00	9.00	9.00
29	8.89	9.00	9.00
30	9.00	9.00	9.00
31	8.10	9.00	9.00
32	9.00	9.00	8.58
33	8.94	9.00	9.00
34	9.00	9.00	9.00
35	8.89	9.00	9.00
36	9.00	9.00	9.00
37	9.00	9.00	8.45
38	6.30	3.32	7.27
39	8.44	6.16	8.45
40	9.00	8.92	9.00
41	8.66	9.00	9.00
42	9.00	8.72	9.00
43	8.72	9.00	8.45

Table 5: Cont...

44	9.00	9.00	9.00
45	9.00	9.00	9.00
46	9.00	9.00	8.58
47	9.00	9.00	8.58
48	9.00	9.00	9.00
49	9.00	9.00	9.00
50	8.97	8.72	9.00
52	9.00	9.00	9.00
54	9.00	9.00	9.00
55	9.00	9.00	9.00
56	9.00	9.00	9.00
57	9.00	9.00	8.58
58	8.89	9.00	9.00
59	9.00	9.00	9.00
60	7.59	7.86	8.45
61	9.00	8.76	8.65
62	8.10	6.73	7.27
63	8.89	9.00	9.00
64	9.00	9.00	9.00
66	8.78	9.00	9.00
67	9.00	9.00	9.00
69	7.09	5.21	5.54
70	9.00	8.34	9.00
71	9.00	8.72	9.00
74	9.00	9.00	9.00
75	9.00	9.00	9.00
76	8.89	9.00	8.58
77	9.00	9.00	9.00
78	9.00	9.00	9.00
79	8.21	4.74	6.92
80	5.06	6.16	7.27
81	9.00	9.00	9.00
82	8.94	9.00	9.00
83	9.00	9.00	8.58
84	9.00	9.00	9.00
85	8.16	6.63	7.96
86	9.00	9.00	9.00
87	8.33	9.00	9.00
88	9.00	9.00	8.45
89	8.94	9.00	9.00
90	9.00	9.00	9.00

Area under Disease Progress Curve (AUDPC)

The AUDPC values during the 2016/17 and 2017/18 growing season ranged from 0.0 to 1120.0 at the two locations. While during the 2018/19 growing seasons, AUDPC values ranged from 0.0 to 1225.0. Moreover, during the three growing seasons of the study at the two locations, AUDPC values ranged from 0.0 to 974.17 (Table 6).

Table 6: Area under disease progress curve (AUDPC) of 94 wheat genotypes to leaf rust at Menoufia and Behira locations during 2017/18, 2018/19, and 2019/20 growing seasons.

Line	Location / Season / AUDPC						Mean
	Menoufia			Behira			
	2017/18	2018/19	2019/20	2017/18	2018/19	2019/20	
1	49.0	0.0	0.0	80.5	0.0	0.0	21.58
2	0.0	0.0	0.0	0.0	0.0	0.0	0.00
3	0.0	157.5	49.0	49.0	252.0	80.5	98.00
4	80.5	0.0	0.0	49.0	80.5	0.0	35.00
5	80.5	42.0	42.0	157.5	455.0	80.5	142.92
6	0.0	49.0	0.0	0.0	80.5	0.0	21.58
7	0.0	0.0	0.0	49.0	0.0	0.0	8.17
8	0.0	0.0	0.0	0.0	0.0	0.0	0.00
9	49.0	80.5	49.0	49.0	80.5	49.0	59.50
10	0.0	5.0	0.0	0.0	80.5	0.0	14.25
11	0.0	0.0	0.0	0.0	0.0	0.0	0.00
12	49.0	0.0	0.0	42 M	0.0	0.0	8.17
13	0.0	157.5	0.0	49.0	80.5	0.0	47.83
14	0.0	80.5	0.0	0.0	157.5	0.0	39.67
15	80.5	0.0	0.0	80.5	0.0	0.0	26.83
16	0.0	0.0	0.0	0.0	0.0	0.0	0.00
17	0.0	0.0	0.0	0.0	0.0	0.0	0.00
18	0.0	157.5	49.0	0.0	80.5	49.0	56.00
19	42.0	252.0	80.5	80.5	157.5	49.0	110.25
20	49.0	80.5	49.0	49.0	252.0	80.5	93.33
21	49.0	157.5	80.5	385.0	49.0	80.5	133.58
22	0.0	157.5	0.0	0.0	80.5	0.0	39.67
23	49.0	80.5	49.0	0.0	42.0	49.0	44.92
24	157.5	455.0	157.5	49.0	385.0	80.5	214.08
25	0.0	157.5	0.0	80.5	42M	0.0	39.67
26	252.0	157.5	80.5	157.5	700.0	455.0	300.42
27	0.0	0.0	0.0	0.0	0.0	0.0	0.00
28	0.0	0.0	0.0	0.0	0.0	0.0	0.00
29	49.0	0.0	0.0	0.0	0.0	0.0	8.17
30	0.0	0.0	0.0	0.0	0.0	0.0	0.00
31	157.5	0.0	0.0	157.5	0.0	0.0	52.50
32	0.0	0.0	42.0	0.0	0.0	42.0	14.00
33	5.0	0.0	0.0	0.0	0.0	0.0	0.83
34	0.0	0.0	0.0	0.0	0.0	0.0	0.00
35	0.0	0.0	0.0	80.5	0.0	0.0	13.42
36	0.0	0.0	0.0	0.0	0.0	0.0	0.00
37	0.0	0.0	42.0	0.0	0.0	49.0	15.17
38	80.5	700.0	157.5	455.0	700.0	49.0	357.00
39	49.0	157.5	42.0	49.0	385.0	49.0	121.92
40	0.0	5.0	0.0	0.0	42.0	0.0	7.83
41	157.5	0.0	0.0	49.0	0.0	0.0	34.42
42	0.0	49.0	0.0	0.0	80.5	0.0	21.58
43	5.0	0.0	42.0	157.5	0.0	49.0	42.25
44	0.0	0.0	0.0	0.0	0.0	0.0	0.00
45	0.0	0.0	0.0	0.0	0.0	0.0	0.00

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46	0.0	0.0	42.0	0.0	0.0	42.0	14.00
47	0.0	0.0	42.0	0.0	0.0	42.0	14.00
48	0.0	0.0	0.0	0.0	0.0	0.0	0.00
49	0.0	0.0	0.0	0.0	0.0	0.0	0.00
50	42.0	157.5	0.0	0.0	80.5	0.0	46.67
51	455.0	252.0	80.5	49.0	700.0	49.0	264.25
52	0.0	0.0	0.0	0.0	0.0	0.0	0.00
53	385.0	840.0	252.0	455.0	385.0	252.0	428.17
54	0.0	0.0	0.0	0.0	0.0	0.0	0.00
55	0.0	0.0	0.0	0.0	0.0	0.0	0.00
56	0.0	0.0	0.0	0.0	0.0	0.0	0.00
57	0.0	0.0	42.0	0.0	0.0	42.0	14.00
58	49.0	0.0	0.0	0.0	0.0	0.0	8.17
59	0.0	0.0	0.0	0.0	0.0	0.0	0.00
60	157.5	80.5	42.0	49.0	157.5	49.0	89.25
61	0.0	5.0	5.0	0.0	0.0	0.0	1.67
62	157.5	252.0	49.0	157.5	252.0	157.5	170.92
63	0.0	0.0	0.0	80.5	0.0	0.0	13.42
64	0.0	0.0	0.0	0.0	0.0	0.0	0.00
65	840.0	455.0	80.5	157.5	385.0	252.0	361.67
66	0.0	0.0	0.0	80.5	0.0	0.0	13.42
67	0.0	0.0	0.0	0.0	0.0	0.0	0.00
68	5.0	157.5	49.0	157.5	840.0	80.5	214.92
69	252.0	700.0	157.5	80.5	157.5	252.0	266.58
70	0.0	80.5	0.0	0.0	252.0	0.0	55.42
71	0.0	49.0	0.0	0.0	80.5	0.0	21.58
72	80.5	840.0	157.5	80.5	455.0	157.5	295.17
73	49.0	385.0	49.0	42M	455.0	252.0	198.33
74	0.0	0.0	0.0	0.0	0.0	0.0	0.00
75	0.0	0.0	0.0	0.0	0.0	0.0	0.00
76	80.5	0.0	42.0	0.0	0.0	42.0	27.42
77	0.0	0.0	0.0	0.0	0.0	0.0	0.00
78	0.0	0.0	0.0	0.0	0.0	0.0	0.00
79	49.0	252.0	80.5	80.5	700.0	157.5	219.92
80	700.0	252.0	49.0	80.5	252.0	157.5	248.50
81	0.0	0.0	0.0	0.0	0.0	0.0	0.00
82	5.0	0.0	0.0	0.0	0.0	0.0	0.83
83	0.0	0.0	42.0	0.0	0.0	42.0	14.00
84	0.0	0.0	0.0	0.0	0.0	0.0	0.00
85	80.5	385.0	49.0	49.0	80.5	80.5	120.75
86	0.0	0.0	0.0	0.0	0.0	0.0	0.00
87	157.5	0.0	0.0	80.5	0.0	0.0	39.67
88	0.0	0.0	42.0	0.0	0.0	49.0	15.17
89	0.0	0.0	0.0	5.0	0.0	0.0	0.83
90	0.0	0.0	0.0	0.0	0.0	0.0	0.00
91	385.0	840.0	252.0	80.5	455.0	252.0	377.42
92	49.0	252.0	157.5	252.0	80.5	385.0	196.00
93	157.5	700.0	455.0	455.0	980.0	385.0	522.08
Morocco	840.0	1120.0	700.0	1120.0	1225.0	840.0	974.17
LSD at 5%	50.741	49.896	51.076	48.971	46.007	49.994	

Also, during the three growing seasons of the study at the two locations, the tested wheat genotypes were 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 47 wheat genotypes which showed AUDPC values ranged from 0 to 294. On the other hand, the second group included seven wheat genotypes *i.e.* 26 (300.42), 38 (357.00), 53 (428.17), 65 (361.67), 91 (377.42), 93 (522.08), and Morocco (974.17) (Table 6).

DISCUSSION

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). Disease resistant wheat cultivars are considered the main factor in agriculture wheat breeding programs to protect wheat plants from disease infection and consequently from yield loss. To sustain the economic viability of wheat production globally, it is necessary to protect crops from the potentially destructive impact of rusts, including leaf rust. This is the most effective method by identifying and deploying new sources of resistance that can durably mitigate the threat of a dynamic and rapidly evolving pathogen population. Moreover, the discovery of novel sources of resistance with novel genes is a constant challenge and is critical in plant breeding to combat threats to crop production caused by pests. In wheat, gene pyramiding to develop durable leaf rust-resistant cultivars is of paramount importance. Moreover, screening germplasm for resistance sources, hybridization of selected parents, selection as well as evaluation of hybrids, testing, and release of new varieties. This may require artificial epidemics created by the inoculation of pathogens onto the plant population (Alemu, 2019).

The probability of identifying resistant parents and resistant progenies is increased by the availability of a reliable screening methodology and an environment favorable for disease development. Depending on the disease and choice of the type of resistance, the methodology may require simple tests in adult plants (field tests) or even the use of resistance-linked protein and DNA markers. Inclusion of check cultivars for resistance and susceptibility is important to assess the disease pressure and degree of resistance. The choice of field sites with reliable environmental conditions is crucial for progress when selection is to be carried out in field conditions.

Among the 716 wheat genotypes collected globally from CIMMYT, 93 wheat genotypes were selected and evaluated against leaf rust at the adult plant stage under field conditions at Menoufia and Behira locations for three successive growing seasons i.e. 2017/2018, 2018/2019, and 2019/2020 growing seasons. Of the 94 wheat genotypes used in our study, 47 genotypes were found to be resistant to at both of the locations during the three successive growing seasons of the study.

Data on rust incidence were recorded as percentage final rust severity, infection type, the average coefficient of infection (ACI), and relative resistance index (RRI). 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 resistance, 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 resistance. The RRI assessment in this study is used for the second time in Egypt after El-Orabey *et al.* (2014) who used this scale for the first time in Egypt to evaluate some promising lines from CIMMYT to select the resistant genotype for rust diseases and this point is the new issue in this study.

Data of this study revealed that only 43 wheat lines showed acceptable RRI for leaf rust during the three successive growing seasons compared with Morocco (check). These wheat lines were found to be resistant to leaf rust disease and can be used in breeding programs to release commercial cultivars as safely production under Egyptian conditions. These results are in agreement with Akhtar *et al.* (2002); Rattu *et al.* (2009); Hussain *et al.* (2010a); Hussain *et al.* (2010b) and Hussain *et al.* (2013). Moreover, the results are in line with the work done by Mahmood *et al.* (2013) who reported that the rust score of Chakwal-50 varied from 5 MR/MS to 30 MS for leaf rust. Also, cv. Chakwal-50 gave RRI value of 7 to 8.6 for leaf rust. The cv. Chakwal-50 has the potential to be approved and released as a new variety. Our results conform with those of El-Orabey *et al.* (2014) who found that out of sixteen CIMMYT promising lines, seven lines, *i.e.* 1, 2, 7, 8, 10, 11, and 15 were found to be resistant to rust diseases and showed acceptable/desirable relative resistance index (RRI) during the two seasons 2012/13 and 2013/14.

The 43 tested wheat promising lines which were resistant at the two locations during the three growing seasons of the study 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 rust resistance genes present in these lines by the molecular marker to know the leaf rust resistance genes and the number of genes present in these lines.

CONCLUSION

The variability and constant evolution of wheat leaf rust populations exhort huge pressure on wheat breeders and researchers, in general, to be constantly vigilant against the emergence of new rust races. This requires timeous monitoring and collaborative surveillance of changes in the virulence patterns among rust pathogens in each country and across regions. Results of this study were promising and some immune, resistant, and moderately resistant genotypes to *Puccinia triticina* were identified and they may be used as a resistance genetic source for management of the disease in national programs. Wheat leaf rust in Egypt has caused significant crop loss and resulted in unprecedented costs in chemical control expenditure in epidemic seasons. It can be anticipated that control measures will be largely based on the development and release of resistant cultivars. Breeding for resistance will continue to be based on current awareness of variability in *Puccinia triticina*, the search for and commercial development of new and effective resistance combinations, and the resolve of the industry to adopt best management practices that minimize disease risk.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHORS CONTRIBUTIONS

Walid El-Orabey wrote the first draft of the article and finalized it with contributions by Hosam Awad, Sabry Shahin, and Yasser El-Gohary.