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Research Paper

Evaluation of wheat genotypes to rust diseases (*Puccinia* spp.) under agroclimatic conditions of Egypt and China

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Abstract. Wheat cultivars vary in their responses to rust diseases during growing seasons due to the climatic conditions, the quantity of pathogen source, and time of infection. Forty-seven wheat genotypes planted in Egypt and Yunnan, China during 2015/2016, 2016/2017, 2017/2018 growing seasons and evaluated at field level to determine their effectiveness to stripe, leaf, and stem rust diseases under natural conditions. Results showed that 26, 29 and 34 genotypes in Egypt, while 17, 21, and 16 genotypes in Yunnan were resistant to stripe rust during 2016, 2017 and 2018 seasons, respectively. Also, eight, nine, and ten genotypes in Egypt were resistant to leaf rust during 2016, 2017, and 2018 seasons, respectively. In Yunnan, there was no infection occurred in 2016 to leaf rust while 43 and 44 wheat lines were resistant to leaf rust in 2017 and 2018 seasons, respectively. In Egypt, 37, 40, and 29 lines were resistant to stem rust in 2016, 2017, and 2018 seasons, respectively. While in Yunnan, there was no infection recorded for stem rust during all three growing seasons. Results exhibited that the resistance genes *Yr5, Yr15, Yr17, YrTr1, Yr (7, 25)* were resistant to stripe rust, and *Lr19* was resistant to leaf rust during all growing seasons in both locations, while the resistance genes *Sr24, Sr36, Sr38* were resistant to stem rust in Egypt during all years of the study, for that, these genes can be used safely in the breeding program for releasing new commercial cultivars under agroclimatic conditions of Egypt and Yunnan, China.

Keywords: Wheat, rust, resistance genes, Egypt, China.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an essential source of carbohydrates, multiple nutrients, and dietary fibre (Shewry and Hey, 2015). In 2018/2019, the whole world wheat production was 730.55 million metric tons, while China and Egypt produced 131.43 and 8.45 million metric tons, contributed 17.99 and 1.16% to world production, respectively (USDA, 2019). Therefore, the safety of wheat production in China and Egypt play a crucial role in world food safety. Wheat rusts, however, including stripe rust (*Puccinia striiformis* f. sp. *tritici)*, leaf rust (*Puccinia triticina*), and stem rust (*Puccinia graminis* f. sp. *tritici*), cause severe yield losses worldwide, threating safety of wheat production (Wellings, 2011).

Wheat rusts breakout frequently in both of China and Egypt. The estimated yield losses by stripe rust are at least 5.5 million tons per year at a global level (Beddow *et al*., 2015). In China, stripe rust has been considered the most severe disease of grain since the first major

Table 1. Temperature datasets of experimental sites during 2016, 2017, and 2018 wheat growing seasons.

Months	Gharbiya-Air temp. °C						Kunming-Air temp. °C					
	2015/2016		2016/2017		2017/2018		2015/2016		2016/2017		2017/2018	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
November	12	26	14	28	16	24	6	11	4	22	3	23
December	10	21	11	23	10	20	-1	18	3	19	1	20
January	8	20	10	21	9	15	-1	18	2	8	0	19
February	9	22	10	24	12	20	1	18	4	8	-2	23
March	10	25	11	26	15	25	5	25	5	25	6	24
April	13	30	12	32	17	28	9	24	9	17	7	28

epidemic in 1950 (Kang *et al*., 2010). It led to a significant yield loss and affected more than 67,000 square kilometers of cropland between 2000 and 2016 due to the massive extension of the epidemic (Shi *et al*., 2018). In Egypt, Gebrel *et al*. (2018) reported disease severity of stripe rust reached to 30% in some bread wheat cultivars during 2017/2018 growing season and found that rust diseases have a strong negative correlation with grain yield. Losses in grain production in susceptible varieties may be reaching to 100% if an infection has occurred very early by stripe rust (Afzal *et al.*, 2007).

Leaf rust can cause more than 40% production losses when the disease is severe on susceptible cultivars (Khan *et al*., 2013). In China, more than 15 million hectares of wheat are affected annually. Regular wheat leaf rust epidemics occur in the southwest and northwest, the middle and lower Yangtze River Valley and the southern Huang-Huai-Hai region of China (Huerta-Espino *et al*., 2011). Significant yield losses were documented in Gansu, Shanxi, Henan, and Anhui provinces of China in 2012 (Li *et al*., 2014; Zhou *et al*.,2013). In Egypt, leaf rust is the most common and one of important wheat diseases. It caused severe losses in grain yield reaches more than 23%, and in epidemic years, they may reach up to 50% (Kassem *et al.*, 2011; Draz *et al*. 2015).

In China, stem rust has controlled since the 1970s. While, with the emergence of aggressive race Ug99, which breakdown the resistance gene *Sr31* became a new threat to wheat production in China, as 60% of wheat cultivars in China contain *Sr31* (Li *et al*., 2016). Kokhmetova *et al*. (2011) found stem rust have impacts on the entire wheat crop, causing losses in grain yield up to100%. Hasan *et al*. (2016) noted that stem rust disease caused injuries in grain yield in some wheat cultivars in Egypt, and disease severity reaches up to more than 60%.

Egypt located in north-eastern Africa, which has water boundaries over the Mediterranean Sea and the Red Sea, considered a part of the Middle East, the origin of common wheat, also the most likely source of newly spreading, optimum-temperature-adapted strains (Ali *et al.*, 2014). While Yunnan, located in south-western China, borders on Myanmar westward, close to the Himalayan, the source of wheat yellow rust disease. Previous research indicated that the Himalayan and neighbouring regions such as Pakistan, Nepal, as well as China, are the centre of origin for wheat stripe rust pathogen (Ali *et al*., 2014). Thus, Yunnan is a vital ring for the migration chain of wheat stripe rust pathogen in the world. Therefore, monitor the effectiveness of resistance genes to wheat rust in these hotspots will provide useful information for breeding and rational use of resistant genes. The objective of this study was to determine the effectiveness of various resistance genes to the stripe, leaf and stem rust diseases at field level under natural conditions in Gharbiya, Egypt and Kunming, Yunnan, China during three growing seasons (2015 to 2018) to assist in the development of wheat cultivars with high level resistance.

MATERIALS AND METHODS

Experimental site

This experiment conducted at two locations: 1) Gharbiya, Egypt with the geographical position N 23° 33' Latitude, E 89° 44' Longitude, 2) Kunming, China with 2140 m Altitude, N 25° 07'11'' Latitude, and E 102° 51'12'' Longitude. Both of the two locations have similar latitude, most of the area located on the North of the Tropic of Cancer, N 23.5° Latitude. The monthly temperature datasets of the experimental sites listed in Table 1, which was an essential resource for monitoring and understanding climate variability and climate change and its impacts on the occurrence of rust diseases.

Experimental material and design

Forty-seven wheat rust resistance genes derived from CIMMYT used in this work (Table 2). Field assays conducted in a randomized complete block design (RCBD) with four replicates for each genotype during 2015/2016, 2016/2017, and 2017/2018 wheat growing seasons. Each genotype was grown in two lines of 3 meter long with 30 centimeters apart and spaced at 20

Table 2. List of wheat genotypes evaluated for wheat rusts in Egypt and China during 2016, 2017, and 2018 growing seasons.

No.	Genotypes	Property	Resistance Gene
1.	Avocet S*6/*Yr1*	Spring	*Yr1*
2.	Avocet S*6/*Yr5*	Spring	*Yr5*
3.	Avocet S*6/*Yr6*	Spring	*Yr6*
4.	Avocet S*6/*Yr7*	Spring	*Yr7*
5.	Avocet S*6/*Yr8*	Spring	*Yr8*
6.	Avocet S*6/*Yr9*	Spring	*Yr9*
7.	Avocet S*6/*Yr10*	Spring	*Yr10*
8.	Avocet S*6/*Yr15*	Spring	*Yr15*
9.	Avocet S*6/*Yr17*	Spring	*Yr17*
10.	Avocet S*6/*Yr27*	Spring	*Yr27*
11.	Avocet-*YRA**3/3/ALTAR 84/AE.SQ//OPATA	Spring	*Yr28*
12.	Avocet-*YRA**3/PASTOR	Spring	*Yr31*
13.	Avocet S*6/*Yr32*	Spring	*Yr32*
14.	Avocet R	Spring	*YrA*
15.	Avocet S*6/*YrSP*	Spring	*YrSP*
16.	AvS*YrTres1*	Spring	*YrTr1*
17.	T.spelta album	Winter	*Yr5*
18.	Hybrid 46	Winter	*Yr(4,H46,3b,4b,+)*
19.	Reichersberg 42	Winter	*Yr(7, 25)*
20.	Heines Peko	Winter	*Yr(2,6)*
21.	Nord Desprez	Winter	*Yr(3,+)*
22.	Compare	Winter	*Yr(8,19)*
23.	Carsten V	Winter	*Yr32*
24.	Spaldings Prolific	Winter	*YrSpP*
25.	Heines VII	Winter	*Yr(2,+)*
26.	Kalyansona	Spring	*Yr(2, 29)*
27.	Virmorin 23	Winter	*Yr(3,V23,+)*
28.	Hugenoot	Winter	*Yr25*
29.	Jupateco R	Spring	*Yr18*
30.	Transfer/6*TC	Spring	*Lr9*
31.	TC*6/Exchange	Spring	*Lr16*
32.	TC*7/Tr	Spring	*Lr19*
33.	TC*6/Agent	Spring	*Lr24*
34.	TC*6/ST-1.25	Spring	*Lr26*
35.	I*Sr5*-Ra	Spring	*Sr5*
36.	I*Sr6*-Ra	Spring	*Sr6*
37.	Verstein Sr9e	Spring	*Sr9e*
38.	I*Sr11* Ra	Spring	*Sr11*
39.	CnS_T_mono_deri	Spring	*Sr21*
40.	Lc*Sr24*Ag	Spring	*Sr24*
41.	Eagle *Sr26* McIntosh	Spring	*Sr26*
42.	Bt*Sr30* Wst	Spring	*Sr30*
43.	*Sr31* (Benno)/6*LMPG-6 DK42	Spring	*Sr31*
44.	W2691SrTt-1	Spring	*Sr36*
45.	Trident *Sr38*	Spring	*Sr38*
46.	Avocet S	Spring	*None*
47.	Little Club	Spring	*None*

Table 3. Adapted scale for rust infection type in wheat.

Response value	Description	Infection type
0	No visible symptoms	Immune (0)
0.2	Uredia minute, supported by distinct necrotic area	Resistant (R)
0.4	Uredia small to medium, in green islands surrounded by chlorotic tissue	Moderately resistant (MR)
0.8	Uredia medium in size, no necrotic but chlorotic areas may be present	Moderately susceptible (MS)
1	Uredia large, no necrosis but chlorosis may be evident	Susceptible (S)

centimeters apart between the rows. Regular agricultural practices were carried out, and susceptible cultivar as Morocco was grown as spreader rows to spread rust inoculums under natural infection conditions.

Disease assessment

When rust symptoms were fully developed, nearly at the early dough stage (Large, 1954), the rust reaction data of adult plant scored as plant response and rust severity. Plant response expressed in five infection types (ITs), according to (Johnston and Browder, 1966). When the spreader plants were 50% infected, the rust data were scored four times for disease severity as percentage coverage of leaves with rust pustules using Cobb's scale modified by Peterson *et al.* (1948) at weekly intervals (Table 3). Partial resistance (slow rusting) behaviour assessed through host response and epidemiological parameters estimates as the average coefficient of infection (ACI). ACI calculated according to (Saari and Wilcoxson, 1974; Pathan and Park, 2006).

ACI = *Values of rust severity* × *Response value*

RESULTS

Forty-seven wheat rust resistance genes derived from CIMMYT cultivated and evaluated to determine their effectiveness to rust diseases at field level between two locations Gharbiya, Egypt and Kunming, China during 2015/2016, 2016/2017, and 2017/2018 wheat growing seasons. Results showed that 9 genotypes, *i.e. AvS/Yr5, Yr15, Yr17, YrTr1, T.sp/Yr5, Yr(7,25), Lr9, Lr16, Sr6,* and 8 genotypes, *i.e. YrTr1, T.sp/Yr5, Yr (7, 25), Yr(2,6), Yr(2,+), Lr19, Sr5, Sr24,* while 28 genotypes, *i.e. Yr1, AvS/Yr5, Yr8, Yr10, Yr15, Yr27, YrSP, YrTr1, T.sp/Yr5, Yr(4,H46,3b,4b,+), Yr(7, 25), Yr(2,6), Yr(3,+), Yr(8,19), Yr32, YrSpP, Yr(2,+), Yr2, Yr (3,V23,+), Yr25, Yr18, Avocet S*, *Lr9, Lr16, Lr26, Sr24, Sr36, Sr38* were gave the highest values of disease resistance 100% efficiency to stripe, leaf and stem rust diseases, respectively during the three successive growing seasons.

Evaluation of wheat genotypes under agro-climatic conditions of Egypt

Evaluation of wheat lines to stripe rust disease

During wheat growing season 2015/2016, results showed that the stripe rust severity for the examined lines varied from 0 to 40% with different ITs under field conditions. Out of 47 tested genotypes, 26 genotypes showed desirable resistance to stripe rust disease, rust severities ranged from 0 to 0.2%. On the other hand, 21 genotypes showed different ITs (MR, MS and S) with varying levels of disease severity ranged from 3% to 40% (Table 4). In season 2016/2017, results revealed that the number of resistant genotypes was 29, which gave immune reaction 0. While 18 genotypes showed different ITs (MS and S) with different disease severity ranged from 3 to 50% (Table 4). In season 2017/2018, results revealed that the number of resistant genotypes increased to 34, which gave immune reaction 0. While 13 genotypes showed different ITs (MS and S) with different disease severity ranged from 3% to 40% (Table 4).

Evaluation of wheat lines to leaf rust disease

In season 2015/2016, results showed that leaf rust severity of the examined lines varied from 0 to 80% with different ITs under field conditions. Out of 47 tested genotypes, eight genotypes showed desirable resistance to leaf rust (Table 5). In season 2016/2017, results revealed that the number of resistant genotypes was nine, which gave immune reaction ranged from 0 to 0.2%. On the other hand, 38 genotypes showed different ITs (MS and S) with different disease severity ranged from 3% to 80% (Table 5). In season 2017/2018, results revealed that the number of resistant genotypes increased to ten, which gave immune reaction 0. While 37 genotypes showed different ITs (MS and S) with different disease severity ranged from 3 to 80% (Table 5).

Evaluation of wheat lines to stem rust disease

From season 2015/2016, results revealed that the

Table 4. An average coefficient of infection (ACI) and rust severity (RS) of the evaluated wheat lines to stripe rust under natural conditions of Egypt and China during 2016, 2017, and 2018 growing seasons.

No.	Resistance gene /genotype	Stripe Rust											
		2016				2017				2018			
		Egypt		China		Egypt		China		Egypt		China	
		RS	ACI	RS	ACI	RS	ACI	RS	ACI	RS	ACI	RS	ACI
1	*Yr1*	0	0	100S	100	0	0	60S	60	0	0	0	0
2	*AvS/Yr5*	0	0	0	0	0	0	0	0	0	0	0	0
3	*Yr6*	30S	30	100S	100	20S	20	60S	60	10S	10	30S	30
4	*Yr7*	30MS	24	100S	100	20S	20	60S	60	20S	20	0	0
5	*Yr8*	0	0	80S	80	0	0	60S	60	0	0	90S	90
6	*Yr9*	10S	10	90S	90	10S	10	80S	80	0	0	30S	30
7	*Yr10*	0	0	0	0	0	0	0	0	0	0	5MS	4
8	*Yr15*	0	0	0	0	0	0	0	0	0	0	0	0
9	*Yr17*	0	0	0	0	0	0	0	0	0	0	0	0
10	*Yr27*	30S	30	60MR	24	20S	20	0	0	20S	20	0	0
11	*Yr28*	20S	20	0	0	10S	10	0	0	10S	10	0	0
12	*Yr31*	TRS	3	10S	10	10S	10	50S	50	10S	10	40S	40
13	*AvS/Yr32*	0	0	60MR	24	0	0	0	0	0	0	50S	50
14	*YrA*	30S	30	80S	80	30S	30	40S	40	20S	20	70S	70
15	*YrSP*	0	0	100S	100	0	0	20S	20	0	0	30MR	12
16	*YrTr1*	0	0	0	0	0	0	0	0	0	0	0	0
17	*T.sp/Yr5*	0	0	0	0	0	0	0	0	0	0	0	0
18	*Yr(4,H46,3b,4b,+)*	0	0	0	0	0	0	0	0	0	0	40S	40
19	*Yr(7, 25)*	0	0	0	0	0	0	0	0	0	0	0	0
20	*Yr(2,6)*	0	0	90S	90	0	0	40S	40	0	0	20S	20
21	*Yr(3,+)*	0	0	100S	100	0	0	20S	20	0	0	20S	20
22	*Yr(8,19)*	0	0	100S	100	0	0	10S	10	0	0	40S	40
23	*CaV /Yr32*	0	0	80S	80	0	0	30S	20	0	0	10S	10
24	*YrSpP*	0	0	60MR	24	0	0	0	0	0	0	40S	40
25	*Yr(2, +)*	0	0	70MR	28	0	0	50S	50	0	0	20S	20
26	*Yr(2, 29)*	TRMR	1.2	100S	100	0	0	30S	40	0	0	0	0
27	*Yr (3,V23,+)*	0	0	80S	80	0	0	40S	40	0	0	80S	80
28	*Yr25*	70S	70	70S	70	50S	50	20S	20	40S	40	5MS	4
29	*Yr18*	0	0	0	0	10MS	8	0	0	TRS	3	0	0
30	*Lr9*	0	0	0	0	0	0	0	0	0	0	0	0
31	*Lr16*	0	0	0	0	0	0	0	0	0	0	0	0

Table 4. Contd

32	*Lr19*	30S	30	70MR	28	20S	20	0	0	10MS	8	20MS	16
33	*Lr24*	10S	10	0	0	5S	5	0	0	0	0	20S	20
34	*Lr26*	0	0	20MR	8	0	0	0	0	0	0	20MS	16
35	*Sr5*	TRMR	1.2	10MS	8	0	0	0	0	0	0	30S	30
36	*Sr6*	0	0	0	0	0	0	0March in Kunming.igated on 6th	0	0	0	0	0
37	*Sr9e*	20S	20	60MS	48	TRS	3	30S	30	10S	10	30S	30
38	*Sr11*	5S	5	0	0	TRS	3	20S	20	0	0	0	0
39	*Sr21*	TRS	3	0	0	TRS	3	0	0	0	0	10S	10
40	*Sr24*	30S	30	5MS	4	10S	10	30S	30	20S	20	70S	70
41	*Sr26*	0	0	10MS	8	0	0	5R	1	0	0	20S	20
42	*Sr30*	10MR	4	90S	90	0	0	20S	20	0	0	40S	40
43	*Sr31*	10S	10	60MS	48	10S	10	20S	30	0	0	40S	40
44	*Sr36*	0	0	20S	20	0	0	40S	40	0	0	40S	40
45	*Sr38*	TRR	0.6	0	0	0	0	20S	20	0	0	10MS	8
46	*Avocet S*	40S	40	100S	100	20S	20	50S	50	20S	20	60S	60
47	Little Club	20S	20	20S	20	10S	10	60S	60	10S	10	40S	40

Note: 0-100 = values of rust severity; R–resistant; MR–moderately resistant; MS – moderately susceptible; S – susceptible; TR- Trace = 3.

number of resistant genotypes was 37, which gave resistant reaction ranged from 0 to 0.2%. On the other hand, ten genotypes, which gave resistant response ranged from 2.4 to 40% (Table 6). In season 2016/2017, results revealed that stem rust severity was low. In this regard, the highest number of resistant genotypes observed during this season (40 genotypes) showed immune reaction ranged from 0 to 0.2%, whereas seven genotypes which gave values ranged from 2.4 to 24% (Table 6). In season 2017/2018, results revealed that the number of resistant genotypes was 29, which gave resistant reaction ranged from 0 to 0.2%. While, 18 genotypes showed different ITs (MR, MS, and S) with different disease severity ranged from 1.2 to 50% (Table 6).

Evaluation of wheat genotypes under agroclimatic conditions of China

Evaluation of wheat lines to stripe rust disease

During wheat growing season 2015/2016, results showed that stripe rust severity of the examined lines varied from 0 to 100% with different ITs under field conditions. Out of 47 tested genotypes, 17 genotypes showed desirable/acceptable resistance to stripe rust, which gave resistant reaction 0. On the other hand, 30 genotypes showed different ITs (MR, MS, and S) with different disease severity ranged from 4 to 100% (Table 4). In season 2016/2017, data in Table (4) revealed that the number of resistant genotypes was increased to 21, whereas rust severities ranged from 0 to 0.2%. While 26 genotypes showed differently IT (S) with different disease severity ranged from 10 to 80%. In season 2017/2018, data in Table 4 revealed that the number of resistant genotypes was 16, which gave immune reaction 0. While 31 genotypes showed different ITs (MR, MS, and S) with different disease severity ranged from 4 to 90%.

Evaluation of wheat lines to leaf rust disease

In season 2015/2016, results showed that leaf rust severity for the examined lines was 0 under field conditions. All 47 tested genotypes showed desirable/acceptable resistance to leaf rust (Table 5). In season 2016/2017, data in Table (5) revealed

Table 5. An average coefficient of infection (ACI) and rust severity (RS) of the evaluated wheat lines to leaf rust under natural conditions of Egypt and China during 2016, 2017 and 2018 growing seasons.

No.	**Resistance gene /genotype**	**Leaf Rust**											
		2016				**2017**				**2018**			
		Egypt		**China**		**Egypt**		**China**		**Egypt**		**China**	
		RS	**ACI**	**RS**	**ACI**	**RS**	**ACI**	**RS**	**ACI**	**RS**	**ACI**	**RS**	**ACI**
1	*Yr1*	10S	10	0	0	10MS	8	0	0	5MS	4	0	0
2	*AvS/Yr5*	40MS	32	0	0	20MS	16	0	0	60MS	48	0	0
3	*Yr6*	40S	40	0	0	30S	30	0	0	50S	50	0	0
4	*Yr7*	50S	50	0	0	60S	60	0	0	60S	60	0	0
5	*Yr8*	40S	40	0	0	60S	60	0	0	60S	60	0	0
6	*Yr9*	70S	70	0	0	20S	20	0	0	50S	50	0	0
7	*Yr10*	TRMR	1.2	0	0	20MRMS	6.4	0	0	5MRMS	1.6	0	0
8	*Yr15*	20S	20	0	0	10S	10	0	0	5S	5	0	0
9	*Yr17*	60S	60	0	0	40S	40	0	0	40S	40	0	0
10	*Yr27*	10S	10	0	0	20S	20	0	0	40S	40	0	0
11	*Yr28*	70MS	56	0	0	30MS	24	0	0	5MS	40	0	0
12	*Yr31*	50MS	40	0	0	20MS	16	0	0	30MS	24	0	0
13	*AvS/Yr32*	70S	70	0	0	30S	30	0	0	50S	50	0	0
14	*YrA*	50S	50	0	0	20S	20	0	0	40S	40	0	0
15	*YrSP*	50S	50	0	0	30S	30	0	0	40S	40	0	0
16	*YrTr1*	0	0	0	0	0	0	0	0	0	0	0	0
17	*T.sp/Yr5*	0	0	0	0	0	0	0	0	0	0	0	0
18	*Yr(4,H46,3b,4b,+)*	5MS	4	0	0	TRMS	2.4	0	0	TRMS	2.4	0	0
19	*Yr(7, 25)*	0	0	0	0	0	0	0	0	0	0	0	0
20	*Yr(2,6)*	0	0	0		0	0	0	0	0	0	0	0
21	*Yr(3,+)*	10S	10	0	0	TRS	3	5MS	4	5s	5	0	0
22	*Yr(8,19)*	10MS	8	0	0	TRMS	2.4	5MR	2	0	0	0	0
23	*CaV /Yr32*	60S	60	0	0	40S	40	0	0	40S	40	0	0
24	*YrSpP*	5MS	4	0	0	TRMS	2.4	0	0	TRS	3	0	0
25	*Yr(2, +)*	0	0	0	0	0	0	0	0	0	0	0	0
26	*Yr(2, 29)*	TRMS	2.4	0	0	10MS	8	0	0	30MS	24	0	0
27	*Yr (3,V23,+)*	TRMR	1.2	0	0	0	0	IMS	0.8	0	0	0	0
28	*Yr25*	TRMS	2.4	0	0	TRMS	2.4	0	0	5MS	4	0	0
29	*Yr18*	40S	40	0	0	40MS	40	0	0	50S	50	0	0
30	*Lr9*	80S	80	0	0	TRMS	2.4	0	0	30MS	24	0	0
31	*Lr16*	80s	80	0	0	40MS	32	0	0	50MS	40	0	0
32	*Lr19*	0	0	0	0	0	0	0	0	0	0	0	0
33	*Lr24*	80S	0	0	0	80S	80	0	0	70S	70	0	0
34	*Lr26*	30S	0	0	0	10S	10	0	0	20S	20	5MS	4
35	*Sr5*	0	0	0	0	0	0	0	0	0	0	0	0
36	*Sr6*	TRMR	1.2	0	0	10R	2	0	0	10MR	4	0	0
37	*Sr9e*	40S	40	0	0	20S	20	0	0	30S	30	0	0
38	*Sr11*	5S	5	0	0	TRMS	2.4	0	0	5MS	4	0	0
39	*Sr21*	5S	5	0	0	TRMS	2.4	0	0	20S	20	0	0
40	*Sr24*	0	0	0	0	0	0	0	0	0	0	0	0
41	*Sr26*	5S	5	0	0	TRMS	2.4	0	0	TRMS	2.4	0	0
42	*Sr30*	10S	10	0	0	20S	20	0	0	30S	30	0	0
43	*Sr31*	20S	8	0	0	40S	40	0	0	30S	30	0	0
44	*Sr36*	5S	5	0	0	10S	10	0	0	40S	40	0	0
45	*Sr38*	60MS	48	0	0	5S	50	0	0	20S	20	0	0
46	*Avocet S*	60S	60	0	0	30S	30	0	0	50S	50	60S	60
47	Little Club	80S	80	0	0	70S	70	0	0	80S	80	60S	60

Note: 0-80 = values of rust severity; R – resistant; MR – moderately resistant; MS – moderately susceptible; S – susceptible; TR- Trace = 3.

that the number of resistant genotypes was 43, which gave immune reaction 0. On the other hand, four genotypes showed different ITs (MR, MS, and S) with different disease severity ranged from 0.8 to 10%. In season 2017/2018, data in Table 5 revealed that the number of resistant genotypes increased to 44, which gave immune reaction 0. While three genotypes showed different ITs (MS and S) with different disease severity.

Evaluation of wheat lines to stem rust disease

From all three growing seasons 2016, 2017, and 2018 noticed that there were no stem rust infections recorded in Yunnan province Table 6.

DISCUSSION

Wheat rust rated the most severe disease that effect on yield production and grain quality worldwide (Wellings, 2011). Using resistant wheat lines or resistance genes will protect wheat production from disease infection and consequently yield losses. In this study, 47 wheat genotypes evaluated to rust diseases, stripe, leaf, and stem rust. The tested genotypes cultivated in different hotspot of wheat rust in two countries Egypt and China during 2015/2016, 2016/2017, and 2017/2018 wheat growing seasons. Resistance to wheat rust is one of the main objectives for breeding program both in Egypt and China. The results indicated that nine resistant genes showed high resistant to stripe rust in both countries during all growing seasons, *i.e. Yr5, Yr15, Yr17, YrTr1, Yr(7,25), Lr9, Lr16, Sr6,* however, 38 wheat genotypes varied in their response to stripe rust. In Yunnan 2016, no virulences were found for *Yr5*, *Yr10*, *Yr15*, while the virulence frequencies to *Yr24*, *Yr8* ranged from 0.74% to 11.76% by greenhouse virulence identification (Li *et al*., 2016). It seemed some genes such as *Yr8, Yr10, Yr32, Yr24* became susceptible to some extent either in the field or in greenhouse monitoring (Li *et al*., 2018), which needs to be paid more attention in wheat production. Resistance genes such as *Yr5* and *Yr15* are previously known to show a high level of resistance to stripe rust in China, Iran, Turkey, North America, and Africa (Zeybeck and Fahri, 2004; Chen, 2005; Afshari, 2008). The obtained results indicated the excellent performance of *Yr5, Yr15*, since it couldn't be attacked all over the growing seasons (100%) efficacy to stripe rust, thus it can be used more widely in both of China and Egypt.

During the three successive seasons, eight genotypes, *YrTr1, T.sp*/*Yr5, Yr(7,25), Yr(2,6), Yr(2,+), Lr19, Sr5, Sr24* showed the high level resistance to leaf rust which correspondingly with low severity (0) in both countries. Recent research indicated that all 30 tested winter cultivars from China didn't carry *Lr19* gene (Yan *et al*., 2017). Therefore, it is necessary to introduce these genes into Chinese wheat cultivars considering its excellent resistance performance to a leaf or stripe rust in the field. In Egypt, El-Orabey *et al*. (2015) found wheat resistance genes *Lr1, Lr2c, Lr3, Lr16, Lr24*, *Lr26* were susceptible to leaf rust, while, *Lr2a* and *Lr9* showed different reactions. Also, Negm *et al.* (2013) found that *Lr3, Lr16, Lr24,* and *Lr26* were ineffective against leaf rust during 2009/2010 and 2010/2011 growing seasons, while, *Lr1, Lr2a, Lr2c* and *Lr9* showed different infection types. Draz *et al*., (2015) found that 13 *Lr* genes (*Lr9, Lr10, Lr11, Lr16, Lr18, Lr19, Lr26, Lr27, Lr29, Lr30, Lr34, Lr42*, and *Lr46*) exhibited seedling resistance to leaf rust disease while, nine *Lr* genes (*Lr19, Lr20, Lr21, Lr24, Lr29, Lr30, Lr32, Lr34* and *Lr44*) showed adult plant resistance during 2010/2011 and 2011/2012 growing seasons. Moreover, Niazmand *et al*. (2010) found that no virulence detected on *Lr9*, *Lr19, Lr25* and *Lr28* resistance genes to leaf rust in Iran during 2007/2008 growing season. Our research supplemented additional information regarding leaf resistance genes, also confirmed that *Lr19* still effective in both Egypt and China at present.

In Egypt, during all growing seasons, the high resistant genotypes to stem rust were, *Yr1,Yr5, Yr8, Yr10, Yr15, Yr27, YrSP, YrTr1,Yr(4,H46,3b,4b,+), Yr(7,25), Yr(2,6), Yr(3,+), Yr(8,19), CaV/Yr32, YrSpP, Yr(2,+), Yr(2,29) Yr (3,V23,+), Yr25, Yr18, AvocetS, Lr9, Lr16, Lr26, Sr24, Sr36, Sr38*, these genotypes can be used as a potential source for breeding program in Egypt, while the other tested wheat genotypes were varied in their response to stem rust and showed different ITs (MR, MS, and S) with different disease severity. While in China, all tested genotypes including highly susceptible cultivar Little Club, showed immune to stem rust, this means either the climate was not suitable or the stem pathogen source was not enough for stem rust occurrence in recent years. Thus, we can not draw a conclusion if these genotypes were effective or not by the results of this study. McIntosh *et al*. (2017) reported 82 *Sr* genes by now. Jin *et al*. (2008) found that resistance genes *Sr5, Sr6, Sr7b, Sr8a, Sr8b, Sr9b, Sr9e, Sr9g, Sr11, Sr15, Sr17, Sr30, Sr31*, *Sr38* ineffective to stem rust race (Ug99). Mirza *et al*. (2010) reported that the virulence to resistance genes *Sr13, SrTmp, Sr1A.1R*, in Africa, the Middle East, and Asia decreases the focus in the usage of these lines in breeding programs. Wheat line *Sr25* was given a high level resistance only when the adult plant *Sr2* also exist, e.g., in recently released Ug99-resistant cultivars Misr 1 in Egypt and Muquawin 09 in Afghanistan (Jain *et al*. 2009). The economic importance of finding and searching for resistance genes to stem rust from old and new cultivars of wheat as a valuable tool has indicated by the Global Rust Initiative (2005).

CONCLUSIONS

Using resistant varieties or resistance genes is the most economical, effective practice, environmentally safe, and

Table 6. An average coefficient of infection (ACI) and rust severity (RS) of the evaluated wheat lines to stem rust under natural conditions of Egypt and China during 2016, 2017, and 2018 growing seasons.

No.	Resistance gene /genotype	Stem Rust											
		2016				2017				2018			
		Egypt		China		Egypt		China		Egypt		China	
		RS	ACI	RS	ACI	RS	ACI	RS	ACI	RS	ACI	RS	ACI
1	*Yr1*	0	0	0	0	0	0	0	0	0	0	0	0
2	*AvS/Yr5*	0	0	0	0	0	0	0	0	0	0	0	0
3	*Yr6*	0	0	0	0	0	0	0	0	TRMR	1.2	0	0
4	*Yr7*	0	0	0	0	0	0	0	0	5MR	2	0	0
5	*Yr8*	0	0	0	0	0	0	0	0	0	0	0	0
6	*Yr9*	TRMS	2.4	0	0	0	0	0	0	5MS	4	0	0
7	*Yr10*	0	0	0	0	0	0	0	0	0	0	0	0
8	*Yr15*	0	0	0	0	0	0	0	0	0	0	0	0
9	*Yr17*	0	0	0	0	0	0	0	0	5MR	2	0	0
10	*Yr27*	0	0	0	0	0	0	0	0	0	0	0	0
11	*Yr28*	0	0	0	0	0	0	0	0	TRMR	1.2	0	0
12	*Yr31*	0	0	0	0	0	0	0	0	TRMR	1.2	0	0
13	*AvS/Yr32*	0	0	0	0	0	0	0	0	TRMR	1.2	0	0
14	*YrA*	0	0	0	0	0	0	0	0	5MR	2	0	0
15	*YrSP*	0	0	0	0	0	0	0	0	0	0	0	0
16	*YrTr1*	0	0	0	0	0	0	0	0	0	0	0	0
17	*T.sp/Yr5*	0	0	0	0	0	0	0	0	0	0	0	0
18	*Yr(4,H46,3b,4b,+)*	0	0	0	0	0	0	0	0	0	0	0	0
19	*Yr(7, 25)*	0	0	0	0	0	0	0	0	0	0	0	0
20	*Yr(2,6)*	0	0	0	0	0	0	0	0	0	0	0	0
21	*Yr(3,+)*	0	0	0	0	0	0	0	0	0	0	0	0
22	*Yr(8,19)*	0	0	0	0	0	0	0	0	0	0	0	0
23	*CaV /Yr32*	0	0	0	0	0	0	0	0	0	0	0	0
24	*YrSpP*	0	0	0	0	0	0	0	0	0	0	0	0
25	*Yr(2, +)*	0	0	0	0	0	0	0	0	0	0	0	0
26	*Yr(2, 29)*	0	0	0	0	0	0	0	0	0	0	0	0
27	*Yr (3,V23,+)*	0	0	0	0	0	0	0	0	0	0	0	0
28	*Yr25*	0	0	0	0	0	0	0	0	0	0	0	0
29	*Yr18*	0	0	0	0	0	0	0	0	0	0	0	0
30	*Lr9*	0	0	0	0	0	0	0	0	0	0	0	0
31	*Lr16*	0	0	0	0	0	0	0	0	0	0	0	0
32	*Lr19*	0	0	0	0	0	0	0	0	TRMS	2.4	0	0
33	*Lr24*	0	0	0	0	0	0	0	0	TRMS	2.4	0	0
34	*Lr26*	0	0	0	0	0	0	0	0	0	0	0	0
35	*Sr5*	20S	20	0	0	5S	5	0	0	10S	10	0	0
36	*Sr6*	20S	20	0	0	10S	10	0	0	20S	20	0	0
37	*Sr9e*	30MS	24	0	0	TRMS	2.4	0	0	10S	10	0	0
38	*Sr11*	TRMS	2.4	0	0	0	0	0	0	10MS	8	0	0
39	*Sr21*	40S	40	0	0	TRMS	2.4	0	0	10S	10	0	0
40	*Sr24*	0	0	0	0	0	0	0	0	0	0	0	0
41	*Sr26*	10R	2	0	0	TRR	0.6	0	0	10R	2	0	0
42	*Sr30*	40S	40	0	0	30MS	24	0	0	10S	10	0	0
43	*Sr31*	10MS	8	0	0	0	0	0	0	0	0	0	0
44	*Sr36*	0	0	0	0	0	0	0	0	0	0	0	0
45	*Sr38*	0	0	0	0	0	0	0	0	0	0	0	0
46	*Avocet S*	0	0	0	0	0	0	0	0	0	0	0	0
47	Little Club	40s	40	0	0	20S	20	0	0	50S	50	0	0

Note: 0-50= values of rust severity; R–resistant; MR–moderately resistant; MS – moderately susceptible; S – susceptible; TR- Trace = 3.

sustainable disease management strategy, especially for developing countries. Results showed that nine and eight wheat genotypes gave the highest values of disease resistance to stripe rust and leaf rust in Egypt and China, respectively. While 28 genotypes showed highly resistant to stem rust in Egypt, this will provide valuable information for using these resistance genes in wheat breeding program for releasing new resistant cultivars to rust diseases under agroclimatic conditions of Egypt and Yunnan, China.

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