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Geographical distribution of *Puccinia triticina* physiologic races in Egypt during 2012-2014 growing seasons

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Wheat leaf rust caused by *Puccinia triticina* Eriks. is a common disease in Egypt and worldwide. Survey of wheat leaf rust samples and identification of physiological races using twenty single *Lr* genes are very important in describing virulence pattern variation, geographical distribution of leaf rust pathotypes and how its change in response to host selection. Variability in population of the causal organism is annually determined using samples collected from wheat growing areas in Egypt for three growing seasons that is, 2011/2012, 2012/2013 and 2013/2014. The results obtained showed a significant variability in pathotypes which are different from season to season. In the course of this study a total of 50, 65 and 33 leaf rust samples were collected in 2011/2012, 2012/2013 and 2013/2014, respectively from different wheat growing areas in eight governorates of Egypt that is, Beheira, Dakahlia, Gharbiya, Minufiya, Sharqiya, Domiatta, Qalyubiya and BaniSweif. A total of 118, 166 and 61 physiologic races were identified in 2011/2012, 2012/2013 and 2013/2014, respectively. The most frequent races included STTST and TKTTT (each with 2.54%) in 2011/2012; PKTST (6.63%), TTTTT (7.83%) and TTTST (10.24%) in 2012/2013 as well as FKTTT (4.92%) and PTTTT (11.47%) in 2013/2014. Race groups PT--- and TK--- were common at eight locations during the three growing seasons. Cluster analysis based on percentage frequency of virulence of *P. triticina* race groups in different location showed that in 2011/2012 and 2012/2013 growing seasons two main clusters were formed. While, in 2013/2014 growing season the cluster analysis was divided into six main clusters. Lines with *Lr* 1, *Lr* 2c, *Lr* 3, *Lr* 16, *Lr* 24 and *Lr* 26 were susceptible against most race groups, while, the leaf rust monogenic lines *Lr* 2a and *Lr* 9 showed different reactions against the tested race groups.

Key words: Wheat, *Puccinia triticina*, race analysis, geographical distribution, cluster analysis.

INTRODUCTION

Leaf rust of wheat caused by *Puccinia triticina* Eriks. (syn. *Puccinia recondita* Roberge ex Desmaz. f. sp. *tritici* E. Henn.) is found wherever wheat is grown (Samborski, 1985). In Egypt, leaf rust is the most common and important wheat diseases. It causes sever losses in grain yield which reached 23% on some varieties depending on

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environmental conditions, level of resistance, dominant physiologic races and the stage of crop development when intial infection occurs (Nazim et al., 1983). Each 1% increase in leaf rust severity decreases yield weight by 40.07 kg/ha and 1000 kernel weight 0.13 g (Leonard et al., 2005). Using resistant genotypes are the most economic and effective method to control plant diseases in general and particularly obligate parasite including leaf rust of wheat (Elyasi-Gomari and Lesovaya, 2009).

The causal orgainsm of leaf rust, is highly variable, consisting of different physiological races or virulence phenotypes (Long et al., 1992; Kolmer and Liu, 1997). Effective of leaf rust resistance of wheat cultivars in a region is dependent on the virulence of the regional populations of *P. triticina*. The development of resistant varieties, requires a knowledge about the virulence diversity, race distribution in particular region, and which resistance genes are effective against these races. In addition, virulence surveys are important for studying the evolution of new races and forecasting the virulence shifts in a physiologic races population (Admassu et al., 2009).

Rust disease surveys are conducted in many wheat growing areas of the world to studying the evolution of new races and forecasting or detect virulence phenotypes that may have been introduced to a region. In breeding for rust resistance, the survey provide essential information not only to determine the direction of the breeding program, but also to detect new virulent pathogen phenotypes that threat the currently grown wheat cultivars. Moreover, survey plays an effective role in determining the geographical sources of disease pathotypes and providing information about the effectiveness of currently used resistance genes (McIntosh et al., 1995; Park, 2008). The main objectives of this study were to study the geographical distribution of *P. triticina* in eight Egyptian governorates during three successive growing seasons (2012 - 2014) to assist in the development of wheat cultivars with high levels of leaf rust resistance. In addition to characterize the virulence phenotypes of *P. triticina* collected in Egypt over the three growing seasons.

MATERIALS AND METHODS

Samples of wheat leaf rust urediniospores were collected during 2011/2012, 2012/2013 and 2013/2014 growing seasons from some commericial fields and wheat rust trap nurseries grown in eight governorates of Egypt that is,Beheira, Dakahliya, Gharbiya, Minufiya, Sharqiya, Domiatta, Qalubiya and Bani Sweif (Table 2). Samples were kept at room temperature (18 to 24°C) overnight in order to dry the moisture content associated with samples. Samples were kept in glassine envelopes (8 x 15 cm) and stored in the refrigerator at 2 to 5°C until using in isolation.

Isolation, purification and spore multiplication

The susceptible cultivar Morocco was planted as ten seeds per 10 cm diameter plastic pots in the greenhouse of Wheat Diseases Research Department, Plant Research Pathology Institute, ARC, Egypt. When first leaf fully expanded in seven days old seedlings, it rubbed gently between moist fingers with tap water then infected samples were scraped using sterile spatula and transferred to these seedlings and sprayed gently again with water in order to form a film of free water which is essential to initiate spore germination and establishment of infection. Finally, the inoculated seedlings were incubated in moist chambers for 24 h at 18 to 20°C and 100% RH then moved onto the benches in a greenhouse and kept for 14 days at approximately 20 ± 2°C. After pustules rupture, three single pustules were isolated separately from each specimen for multiplication on the highly susceptible variety Morocco to obtain enough urediniospores for identification as described by Stakman et al. (1962).

Race identification

The North American race nomenclature system used to design the leaf rust races in a letter code was adopted by Long and Kolmer (1989) and McVey et al. (2004) including five sets with 20 differential monogenic lines each with single gene for leaf rust resistance (Table 1). These lines were grown in 6 cm square plastic pots each with seeds of four lines, planted in the corners of each pot in clockwise order. After seven-days growing seedlings were inoculated with the previously isolated single pustule isolates of *P. triticina,* by shaking. The inoculated seedlings were incubated in the humid chamber overnight (100% RH), as described above. The inoculated seedlings were transferred also, onto the greenhouse benches. Infection type data for all monogenic lines were assessed 14 days after inoculation using standard disease scoring scale 0-4 (Stakman et al., 1962). Entries which showed low infection types (LITs) (scores = 0, 0, 1, and 2) were considered host resistant and a virulent isolate, while those with scores = 3 and 4 were susceptible (high infection types, HITs) and virulent isolate. Each single isolate was assigned five letter virulence phenotype description based on high or low infection type to the differentials lines (Stakman et al., 1962; Long and Kolmer, 1989 and McIntosh et al., 1995).

Virulence frequency

Percentage of virulence frequency was calculated as a number of virulent isolates to the total number of the tested isolates.

$$\text{Virulence frequency (\%)} = \frac{\text{No. of virulent isolates}}{\text{Total number of isolates}} \text{X } 100$$

Cluster analysis

A similarity matrix of virulence phenotypes based on the simple matching coefficient was used to construct a dendogram using the unweighted pair group method with arithmetic means clustering method in numerical taxonomy system (NTSYS-pc version 2.1) according to Rohlf, (2000).

RESULTS

During the three successive growing seasons that is, 2011/2012, 2012/2013 and 2013/2014, the highest number of collected samples was calculated during 2011/2012 growing season followed by 2012/2013 and

Table 1. Five letter codes of *P. triticina* (Pt)based on high (H) and low (L) infection types (ITs) on twenty differential wheat monogenic lines (five sets of four each).

Pt-code[a]		Infection type[b] on wheat lines with indicated *Lr* gene			
	Host set 1:	**1**	**2a**	**2c**	**3a**
	Host set 2:	**9**	**16**	**24**	**26**
	Host set 3:	**3ka**	**11**	**17**	**30**
	Host set 4:	**10**	**18**	**21**	**2b**
	Host set 5:	**14b**	**15**	**36**	**42**
B		L	L	L	L
C		L	L	L	H
D		L	L	H	L
F		L	L	H	H
G		L	H	L	L
H		L	H	L	H
J		L	H	H	L
K		L	H	H	H
L		H	L	L	L
M		H	L	L	H
N		H	L	H	L
P		H	L	H	H
Q		H	H	L	L
R		H	H	L	H
S		H	H	H	L
T		H	H	H	H

[a]The race code consists of the letter designation for the pattern of ITs for the *Puccinia triticina* isolate on differential set 1 followed by set 2, then set 3, set 4 and set 5. For example, race MGBLQ is virulent on the *Lr* 1 and *Lr* 3a differntials in set 1, *Lr* 16 in set 2, none in set 3, *Lr* 10 in set 4 and *Lr* 14b and *Lr* 15 in set 5. [b]L = low infection type (avirulent isolate); H = high infection type (virulent isolate).

2013/2014. Moreover, the highest number of isolates was during season 2012/2013 followed by seasons 2011/2012 and 2013/2014. Therefore, the highest total of collected leaf rust samples and isolates were in Sharqiya (36 and 91, respectively) followed by Beheira (33 and 73, respectively), while Domiatta (3 and 6, respectively) was the lowest one (Table 2).

Race identification

A total of 234 physiologic races were identified during the three growing seasons 2011/2012 to 2013/2014 from 345 isolates based on infection types on the 20 differential monogenic lines (Table 3). No of the identified physiologic races were found in the three seasons. Moreover, in 2011/2012, the most common races were STTST (2.54%) and TKTTT (2.54%). While in 2012/2013, races PKTST (6.63%), TTTTT (7.83%) and TTTST (10.24%) showed high frequencies. On the other hand, in 2013/2014 the most dominant and common races were FKTTT (4.92%) and PTTTT (11.47%). Most identified races during the three growing seasons were rare and represented by a single isolate. A total of 100 and 49 races in 2011/2012 and 2013/2014, respectively represented by a singleisolate comprising 89.28 and 96.07%, respectively of the total races. While, in 2012/2013 a total of 67 races appeared and showed single isolate and comprised 81.70% of the total races.

Geographical distribution

Data in Table4 showed that, the most common race groups were PT--- and TK---, which were found at all eight governorates during the three growing seasons. Also, race group PT--- was the most frequent in Minufiya (29.63%) in 2013/2014 and Beheira governorates (9.09, 6.06 and 24.14%) at 2011/2012, 2012/2013 and 2013/2014, respectively. Race groups LB---, FK--- and LS--- were the lowest geographic distribution during the three growing seasons; race group LB--- was found in one location that is, Sharqiya (7.84%), FK--- found in two locations that is, Minufiya (11.11%) and BaniSweif (5.26%) and LS--- found also in two locations that is, Beheira (72.27%) and Minufiya (14.29%).

Similarity of identified race groups in different locations

To display the relationships between leaf rust populations

Table 2. Number of samples and isolates of wheat leaf rust obtained from different growing areas in Egypt during 2011/2012, 2012/2013 and 2013/2014 growing seasons.

Governorate	Season / number of samples and isolates per location						Total	
	2011/2012		2012/2013		2013/2014			
	No. of samples	No. of isolates	No. of samples	No. of isolates	No. of samples	No. of isolates	No. of samples	No. of isolates
Beheira	5	11	10	33	18	29	33	73
Dakahlia	7	13	11	27	1	1	19	41
Gharbiya	4	10	16	40	-	-	20	50
Minufiya	3	7	1	2	12	27	16	36
Sharqiya	19	51	17	40	-	-	36	91
Domiatta	-	-	2	3	1	3	3	6
Qalubiya	3	4	1	2	1	1	5	7
BaniSweif	9	22	7	19	-	-	16	41
Total	**50**	**118**	**65**	**166**	**33**	**61**	**148**	**345**

in different geographic wheat locations and similarity based on percentage frequency of virulence race groups in eight locations were illustrated in Figure 1. As indicated in cluster analysis of similarities, the studied locations in 2011/2012 growing season formed two main clusters. The first divided into two additional sub-clusters. The first included three locations that is, Dakahlia, Gharbiya and Qalyubia. Meanwhile, the second included only one location that is Sharqiya. On the other hand, the second cluster included two sub-clusters; the first included Minufiya, BaniSweif and Beheira and the second included only Domiatta (Figure 1A).

In 2012/2013 growing season, the similarity of the studied locations divided into two main groups. The first group included seven locations from a total of eight locations. This cluster divided into two sub-clusters; the first included Beheira, BaniSweif, Minufiya, Qalyubia, Gharbiya and Sharqiya and the second contained only Dakahlia. Moreover, the second group cluster included only Domiatta (Figure 1B).

In 2013/2014 growing season, dendrogram of similarity showed differences in race groups frequency. The cluster analysis in this growing season divided into six clusters; the first included Beheira, Qalyubia and Minufiya, second included Bani Swear. The third included Sharqiya. The fourth included Domiatta. The fifth included Dakahlia and the sixth included Gharbiya (Figure 1C).

Virulence frequencies:

Tests for virulence of identified race groups indicated that the leaf rust resistance genes *Lr* 1, *Lr* 2c,*Lr* 3,*Lr* 16,*Lr* 24 and *Lr* 26 were susceptible against most race groups tested during the studied three seasons of study (Table 5). While, the leaf rust monogenic lines *Lr* 2a and *Lr* 9 showed different reactions against the tested race groups. They proved to be active against some identified race groups and inactive against others. On the other hand, race group TT--- was the most virulent pathotype to eight leaf rust monogenic lines that is, *Lr* 1, *Lr* 2a,*Lr* 2c,*Lr* 3,*Lr* 9,*Lr* 16,*Lr* 24 and *Lr* 26 followed by race groups ST--- and PT--. While, race group BB--- was the least virulent one (avirulent to all tested leaf rust monogenic lines) followed by race group LB--- which was virulent to *Lr* 1 only.

DISCUSSION

On the basis of the present investigations results obtained during the three growing seasons that is, 2011/2012, 2012/2013 and 2013/2014 revealed that, a total of 234 physiologic races of *P. triticina* were identified among 345 collected isolates. Also, survey of the virulence pathotypes in some governorates in Egypt during three growing seasons showed that pathotypes STTST and TKTTT were the most common in 2011/2012. In 2012/2013, pathotypes PKTST, TTTTT and TTTST were the most common. While, in 2013/2014the most dominant and common races

Table 3. Number of isolates and frequencies of *P. triticina* collected from wheat genotypes cultivated in various wheat growing areas in Egypt in 2011/2012 to 2013/2014.

Race*	No. of isolates and frequency (%)			Race*	No. of isolates & frequency (%)		
	2011/2012	2012/2013	2013/2014		2011/2012	2012/2013	2013/2014
BBBBL	(1)* 0.85**	-	-	LKTNT	(1) 0.85	-	-
BBBBM	(1) 0.85	-	-	LMSDB	-	-	(1) 1.64
BBBBT	(1) 0.85	-	-	LRQST	(1) 0.85	-	-
BBBGT	(1) 0.85	-	-	LSPJT	(1) 0.85	-	-
BBPBS	(1) 0.85	-	-	LSTJT	(1) 0.85	-	-
BBCHS	-	-	(1) 1.64	LSTTR	(1) 0.85	-	-
BBQMK	(1) 0.85	-	-	LSTTT	(1) 0.85	-	-
BCCMS	-	-	(1) 1.64	LTKSK	-	(1) 0.60	-
BCNGB	-	-	(1) 1.64	LTTJT	(1) 0.85	-	-
BCTQP	(1) 0.85	-	-	LTTST	(1) 0.85	(1) 0.60	-
BGQPT	-	-	(1) 1.64	LTTTG	-	(1) 0.60	-
BJBGK	-	-	(1) 1.64	MHCQQ	-	-	(1) 1.64
BJTJG	-	-	(1) 1.64	MHQTT	(1) 0.85	-	-
BKTBT	(1) 0.85	-	-	MKTQG	-	(1) 0.60	-
BLBGP	(1) 0.85	-	-	MRTJT	(1) 0.85	-	-
BQTSQ	(1) 0.85	-	-	MRTQT	(1) 0.85	-	-
BRSQT	(1) 0.85	-	-	MTJTF	(1) 0.85	-	-
BTTTL	(1) 0.85	-	-	MTTJT	(1) 0.85	-	-
CHNST	(1) 0.85	-	-	MTTQT	(1) 0.85	-	-
CJNBD	-	-	(1) 1.64	MTTTT	(1) 0.85	-	(1) 1.64
CTBLT	(1) 0.85	-	-	NBKQR	(1) 0.85	-	
DGCBF	(1) 0.85	-	-	NCCDQ	-	-	(1) 1.64
DKFGP	(1) 0.85	-	-	NHTNT	-	(1) 0.60	-
DJGNT	-	(1) 0.60	-	NKKPQ	-	-	(1) 1.64
DTTST	(1) 0.85	-	-	NKKST	(1) 0.85	-	-
FGTTT	(1) 0.85	-	-	NKTNT	(1) 0.85	-	-
FKTSB	-	(1) 0.60	-	NKSRT	-	(1) 0.60	-
FKTTT	-	-	(3) 4.92	NKSST	-	(1) 0.60	-
FRQTT	-	-	(1) 1.64	NKTNT	-	(1) 0.60	-
FSTJT	(1) 0.85	-	-	NKTQT	(1) 0.85	-	-
FTRTT	-	-	(1) 1.64	NKTSS	-	(1) 0.60	-
FTTNT	-	-	(1) 1.64	NKTST	-	(3) 1.81	-
JFKTS	-	-	(1) 1.64	NKTTT	-	(3) 1.81	-
JTTQT	(1) 0.85	-	-	NQQKS	-	(1) 0.60	-
KGGBR	(1) 0.85	-	-	NSHLQ	-	-	(1) 1.64
KJPST	(1) 0.85	-	-	NSPDT	(1) 0.85	-	-
KSTJT	(1) 0.85	-	-	NSPST	(1) 0.85	-	-
KTTHP	(1) 0.85	-	-	NSRSC	-	(1) 0.60	-
LBGQT	(1) 0.85	-	-	NSSTT	-	-	(1) 1.64
LBMJR	(1) 0.85	-	-	NSTJT	(1) 0.85	-	-
LBTJS	(1) 0.85	-	-	NSTSP	-	(1) 0.60	-
LBTSR	(1) 0.85	-	-	NTNSR	(1) 0.85	-	-
LCJKB	-	-	(1) 1.64	NTPSJ	(1) 0.85	-	-
LDFNM	-	(1) 0.60	-	NTSST	-	-	(1) 1.64
LFGKQ	-	-	(1) 1.64	NTTBT	(1) 0.85		-
LFHKG	-	-	(1) 1.64	NTTSS	-	(1) 0.60	-
LFTNQ	-	-	(1) 1.64	NTTTS	-	-	(1) 1.64
LKSGQ	(1) 0.85	-	-	NTTTT	-	-	(1) 1.64
PBBFB	-	-	(1) 1.64	PTTSQ	-	-	(1) 1.64

Table 3. Contd.

PDTLP	-	(1) 0.60	-	PTTST	-	(1) 0.60	-
PDTNP	-	(2) 1.20	-	PTTTL	-	-	(1) 1.64
PDTSP	-	(1) 0.60	-	PTTTQ	-	-	(2) 3.28
PFPLG	(1) 0.85	-	-	PTTTR	-	-	(1) 1.64
PGGSG	-	-	(1) 1.64	PTTTS	-	-	(2) 3.28
PGRNP	-	(1) 0.60	-	PTTTT	-	(3) 1.81	(7) 11.47
PHRKT	(1) 0.85	-	-	QBLBN	-	-	(1) 1.64
PJJJT	(1) 0.85	-	-	QCPQT	(1) 0.85	-	-
PJJSP	-	(1) 0.60	-	QHJHJ	-	-	(1) 1.64
PJPHT	(1) 0.85	-	-	QSTST	(1) 0.85	-	-
PJTLS	-	(1) 0.60	-	RJCRQ	-	-	(1) 1.64
PJTNP	-	(1) 0.60	-	RKTQT	(1) 0.85	-	-
PJTPP	-	(1) 0.60	-	RTTTR	-	(1) 0.60	-
PJTSN	-	(1) 0.60	-	SCLKB	-	-	(1) 1.64
PJTSP	-	(3) 1.81	-	SGPGP	(1) 0.85	-	-
PJTST	-	(1) 0.60	-	SJJJS	(1) 0.85	-	-
PJTTC	-	(1) 0.60	-	SKKJP	(1) 0.85	-	-
PJTTP	-	(2) 1.20	-	SKPJT	(1) 0.85	-	-
PJTTS	(1) 0.85	-	-	SKPST	(1) 0.85	-	-
PJTTT	-	(1) 0.60	(1) 1.64	SKTST	-	(1) 0.60	-
PKNPT	-	(1) 0.60	-	SKPSS	-	-	(1) 1.64
PKSST	-	(1) 0.60	-	SKTTT	-	(2) 1.20	-
PKSTT	-	(1) 0.60	-	SQPTT	(1) 0.85	-	-
PKTNP	-	(2) 1.20	-	SRTTT	-	(1) 0.60	-
PKTNT	-	(1) 0.60	-	SSPJT	(1) 0.85	-	-
PKTSP	-	(1) 0.60	-	SSPST	(1) 0.85	-	-
PKTSQ	-	(1) 0.60	-	SSTST	(1) 0.85	-	-
PKTSS	-	(1) 0.60	-	SSTTT	(1) 0.85	-	-
PKTST	-	(11) 6.63	-	STKQT	(1) 0.85	-	-
PKTTT	-	(5) 3.01	(1) 1.64	STKST	(1) 0.85	-	-
PMLJN	(1) 0.85	-	-	STPST	(1) 0.85	-	-
PRPKT	(1) 0.85	-	-	STRST	(1) 0.85	-	-
PRSTS	-	-	(1) 1.64	STTJT	(1) 0.85	-	-
PRTSM	(1) 0.85	-	-	STTQT	(1) 0.85	(1) 0.60	-
PSPJT	(1) 0.85	-	-	STTSP	(1) 0.85	-	-
PSPSS	(1) 0.85	-	-	STTST	(3) 2.54	(4) 2.41	-
PSTJT	(1) 0.85	-	-	STTTT	(2) 1.69	(1) 0.60	-
PSTQT	(1) 0.85	-	-	STTTT	-	-	(1) 1.64
PSTST	-	(1) 0.60	-	TFQST	-	(1) 0.60	-
PSTTT	-	-	(1) 1.64	THRST	(1) 0.85	-	-
PTBJT	(1) 0.85	-	-	TJTLF	-	(1) 0.60	-
PTKQT	(1) 0.85	-	-	TJTNK	-	(1) 0.60	-
PTPQT	(1) 0.85	-	-	TJTNM	-	(1) 0.60	-
PTPSR	(1) 0.85	-	-	TJTNP	-	(1) 0.60	-
PTPSR	(1) 0.85	-	-	TJTQP	-	(1) 0.60	-
PTQTT	-	-	(1) 1.64	TJTST	-	(3) 1.81	-
PTTPR	-	-	(1) 1.64	TKJST	-	(1) 0.60	-
PTTPT	-	(1) 0.60	-	TKPST	(2) 1.69	-	-
PTTRT	(1) 0.85	-	-	TKPTT	-	-	(1) 1.64
PTTSP	-	(1) 0.60	-	TKSQT	-	(1) 0.60	-
TKSTT	-	(1) 0.60	-	TTJLF	-	-	(1) 1.64
TKTHT	(1) 0.85	-	-	TTKST	-	(1) 0.60	-

Table 3. Contd.

TKTLF	-	(1) 0.60	-	TTPJR	(1) 0.85	-	-
TKTNT	-	(2) 1.20	-	TTPQT	(1) 0.85	-	-
TKTQF	-	(1) 0.60	-	TTPST	(1) 0.85	-	-
TKTST	-	(11) 6.63	-	TTQTL	(1) 0.85	-	-
TKTTS	-	(1) 0.60	-	TTRTT	-	-	(1) 1.64
TKTTT	(3) 2.54	(10) 6.02	-	TTSST		(3) 1.81	-
TPFQT	(1) 0.85	-	-	TTSTT	-	-	(1) 1.64
TQTTT	(1) 0.85		-	TTTBR	(1) 0.85	-	-
TRPTP	(1) 0.85	-	-	TTTLT	(1) 0.85	-	-
TSKST	(1) 0.85	-	-	TTTNT	-	(1) 0.60	-
TSTJT	(1) 0.85	-	-	TTTSC	-	(1) 0.60	-
TSTSF	-	(1) 0.60	-	TTTSK	-	(1) 0.60	-
TSTSR	(1) 0.85	-	-	TTTST	(1) 0.85	(17) 10.24	-
TSTST	-	(4) 2.41	-	TTTTK	-	(1) 0.60	-
TSTTK	-	(1) 0.60	-	TTTTR	-	-	(1) 1.64
TSTTT	-	(1) 0.60	-	TTTTT	(1) 0.85	(13) 7.83	-
No. of isolates					**118**	**166**	**61**

*Total No. of identified races during the three growing seasons = 234.

were FKTTT and PTTTT.

Similar results were obtained by Kolmer (1999) who reported that races MCRK, MBRJ, MBRK and TLGF were the most common phenotypes in 1997. While, in 1996 MBRJ was the most common phenotype. Moreover, Negm et al. (2013) found that the two races PTTT and TTTT were the most common in the two growing seasons 2009/2010 and 2010/2011. These two races were comprised 12.21 and 15.84%, respectively in 2009/2010 and 10.90 and 12.80%, respectively in 2010/2011. Moreover, McVey et al. (2004) found that race MCDLQ was the most common race in Egypt, also races MCDLL and TCDML were found in Israel. While, races BBBLL, MBBLL and MBDLQ were found in Turkey as well as in Egypt but the frequencies of these races in Egypt never exceeded 1.2%. Also, race MBBLL was found in Sudan in 1998. In the present study, a total of 112, 82 and 51 pathotypes were appeared in Egypt during 2011/2012, 2012/2013 and 2013/2014 growing seasons, respectively. This is likely due to the differences in number of sampling between the three seasons. In 2011/2012 growing season, the collected samples were fifty, in 2012/2013, sixty five and thirty three in 2013/2014. It is likely a greater number of identified races will be detected in 2013/2014 if the collected samples had been obtained from a larger number of sites. McCallum et al. (2011) found that the most common races in Canada during 2008 growing season were TDBJ (23.6%), TDBG (23.1%) and MLDS (18.9%). Moreover, Hanzalova and Bartos (2014) found that the leaf rust races 14, 77, 61, 53 and 2 were dominated in Czechoslovakia/Czech Republic in the years 1966-2001. Finally, Anjum et al. (2014) identified the two leaf rust races 12-9 (93R37-1) and 77-11 (125R28) in India during 2009 growing season.

Frequencies of race groups based on IT's of the first two sets of leaf rust North American race nomenclature system (Long and Kolmer, 1989) of wheat leaf rust differential monogenic lines were compared in eight governorates in Egypt. Race groups PT--- and TK--- were the most dominant race groups, which were found at all eight governorates during the studied three growing seasons. In contrast, race group LB--- was found at only Sharqiya governorate, followed by race group FK--- found in also two locations that is, Minufiya and BaniSweif and race group LS--- found in two locations that is ,Beheira and Minufiya. Regardless of the presence of leaf rust races during the three seasons, which they appeared in some governorates and disappeared in others were mainly due to variations over locations and weather conditions. Moreover, as the prevalence of races in a specific season and region depends on the type of wheat cultivars grown and to some extent on the predominant environmental conditions, especially temperature (Roelfs et al., 1992). Also, due to the long-distance dispersal of leaf rust races (intercontinental migration) (Burdon and Silk, 1997; Kolmer, 2005; Hanzalova and Bartos, 2014). This process led to the shifts in the genetic structure of the recipient pathogen population, especially when such pathogen cannot survive the summer in the country (Saari, 1976; Burdon and Silk, 1997). Nazim et al.(2003, 2010) suggested that wheat leaf rust urediniospores cannot survive the summer in Egypt because the summer temperatures are very high and cannot permit such spores to survive.

Similar results were obtained by McVeyet al. (2004)

Table 4. Number of isolates and percentage frequency of the identified races of *P. triticina* collected from different wheat genotypes cultivated in various wheat growing areas in Egypt during 2011/2012, 2012/2013 and 2013/2014 growing seasons.

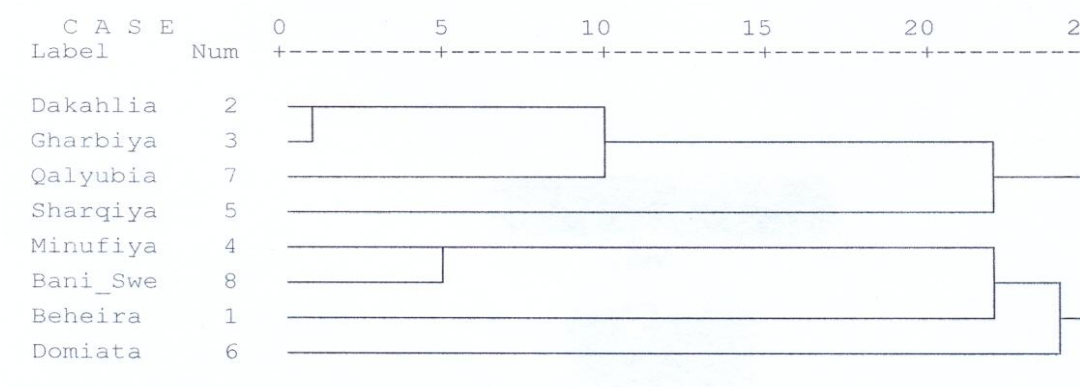
Race group	Location / Season / Number of isolates and frequency (%) of race group																							
	Beheira			Dakahlia			Gharbiya			Minufiya			Sharqiya			Domiatta			Qalubiya			BaniSweif		
	2011/2012	2012/2013	2013/2014	2011/2012	2012/2013	2013/2014	2011/2012	2012/2013	2013/2014	2011/2012	2012/2013	2013/2014	2011/2012	2012/2013	2013/2014	2011/2012	2012/2013	2013/2014	2011/2012	2012/2013	2013/2014	2011/2012	2012/2013	2013/2014
BB---	-	-	1 (3.45)	-	-	-	1(10.00)	-	-	-	-	-	4 (7.84)	-	-	-	-	-	1(25.00)	-	-	-	-	-
FK---	-	-	-	-	-	-	-	-	-	-	-	3(11.11)	-	-	-	-	-	-	-	-		-	1(5.26)	-
LB---	-	-	-	-	-	-	-	-	-	-	-	-	4 (7.84)	-	-	-	-	-	-	-	-	-	-	-
LS---	3(72.27)	-	-	-	-	-	-	-	-	1(14.29)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NK---	-	2 (6.06)	-	-	4(14.81)	-	-	-	-	-	1(50.00)	1 (3.70)	3 (5.88)	-	-	-	1(33.33)	-	-	-	-	-	2(10.53)	-
NT---	1 (9.09)	1 (3.03)	-	-	-	-	-	-	-	-	-	3(11.11)	1 (1.96)	-	-	-	-	-	-	-	-	1(4.55)	-	-
PJ---	-	3 (9.09)	-	-	5(18.52)		-	2 (5.00)	-	-	-	1 (3.70)	3 (5.88)	-	-	-	-	-	-	-	-	-	3(15.79)	-
PK---	-	7(21.21)	1 (3.45)	-	3(11.11)	-	-	9(22.50)	-	-	-	-	-	2 (5.00)	-	-	-	-	-	-	-	-	4(21.05)	-
PT---	1 (9.09)	2 (6.06)	7 (24.14)	1 (7.69)	-	-	-	3 (7.50)	-	-	-	8(29.63)	2 (3.92)	-	-	-	1(33.33)	-	-	-	1(100.00)	2(9.09)	-	-
ST---	-	-	1 (3.45)	1 (7.69)	-	-	3(30.00)	5(12.50)	-	-	-	-	3 (5.88)	1 (2.50)	-	-	-	-	-	-	-	5	-	-
TJ---	-	1 (3.03)	-	-	4(14.81)	-	-	-	-	-	-	-	-	2 (5.00)	-	-	-	-	-	-	-	-	1 (5.26)	-
TK---	-	1 (3.03)	-	1 (7.69)	1 (3.70)	-	3(30.00)	8(20.00)	-	-	-	1 (3.70)	-	16(40.00)	-	-	1(33.33)	-	1(25.00)	-	-	1(4.55)	2(10.53)	-
TS---	1 (9.09)	-	-	-	2 (7.41)	-	-	3 (7.50)	-	1(14.29)	-	-	1 (1.96)	2 (5.00)	-	-	-	-	-	-	-	-	-	-
TT---	-	9(27.27)	3 (10.34)	-	2 (7.41)	-	-	8(20.00)	-	3(42.86)	1 (50.00)	1 (3.70)	2 (3.92)	13(32.50)	-	-	-	-	-	1(50.00)	-	3(13.64)	4(21.05)	-
Others	5(45.45)	7(21.21)	16(55.17)	10(76.92)	6(22.22)	1(100.00)	3(30.00)	2 (5.00)	-	2(28.57)	-	9(33.33)	28(54.90)	4 (10.00)	-	-	-	3(100.00)	2(50.00)	1(50.00)	-	10(45.45)	2(10.53)	-
Total No. of isolates	**11**	**33**	**29**	**13**	**27**	**1**	**10**	**40**	**0**	**7**	**2**	**27**	**51**	**40**	**0**	**0**	**3**	**3**	**4**	**2**	**1**	**22**	**19**	**0**

Others = less than 3 races in all locations and seasons.

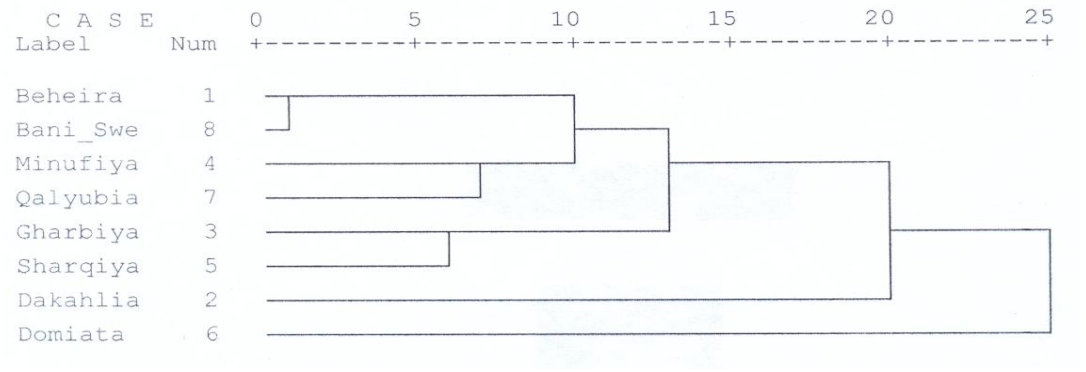
they suggested that the common races in Egypt also found in Romania and Israel indicated that windborne urediniospores of *P. triticina* frequently move between Egypt and Israel and some inoculum may come to Egypt from Eastern Europe. On the other hand, the contribution of races from either Sudan or Turkey to the population of *P. triticina*in Egypt in 1998 to 2000 is very small. Negm et al. (2013) found that race groups TT-- and PT-- were common in ten governorates of Egypt that is, Domiatta, El-Beheira, El-Dakhlia, El-Nubaria, El-Sharkia, El-Suez, Kafr El-Sheikh, BaniSweif, El-Qalubia and Sohag. Also, Soliman et al. (2012) found that race groups BB-- and PK-- were the most common race groups in five governorates of Egypt that is, Dakhlia, Kafr El-Shekh, Beheira, Sharqia and Sohag.

Similarity between leaf rust populations in different locations under study showed that in 2013/2014 growing season there are great differences between race groups frequency so the dendrogram of the tested race groups was divided into six clusters. This probably caused by the low number of collected field samples in this growing season.These results are in agreement with Negm et al. (2013) found that in 2009/2010 growing season dendrogram of similarities based on frequency of virulence of race groups divided into two clusters; the first included ten locations that is Gharbiya, Minufiya, Sohag, Nubariya, Sharqiya, Suez, Domiatta, Beheira, Dakahlia and Kafer El-Sheikh. Meanwhile, the second cluster included the two locations BaniSweif and Qalyubia. On the other hand, in 2010/11 growing season the tested locations clustered divided into two main clusters. The firs cluster included BaniSweif, Sohag, Nubariya, Gharbiya, Minufiya, Qalyubia, Sharqiya, Kafer El-Sheikh, Domiatta, Beheira and Dakahlia. While, the second main cluster included Suez only.

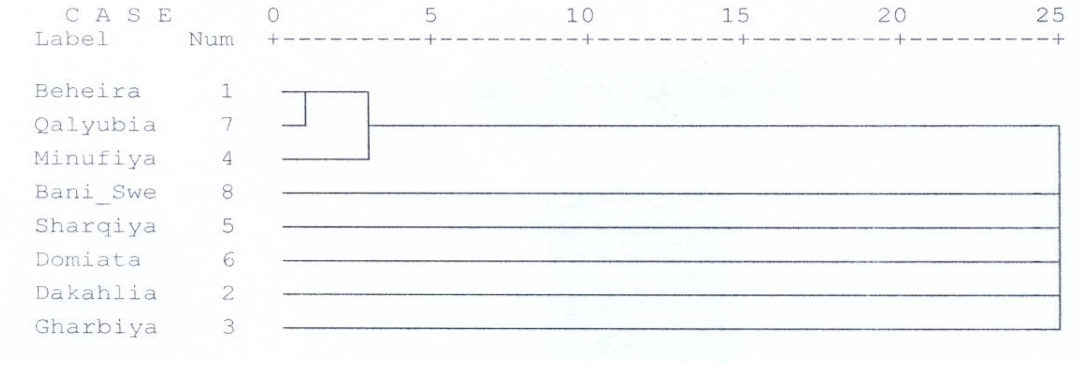
Virulence against leaf rust resistance genes showed that *Lr* 1, *Lr* 2c, *Lr* 3,*Lr* 16, *Lr* 24 and *Lr* 26 genes were susceptible, while, *Lr* 2a and *Lr* 9 showed different reactions against the tested race



(A)



(B)



(C)

Figure 1. Dendrograms of similarity based on percentage race group frequency for collections of *P. triticina* isolates from eight locations in (A) 2011/2012, (B) 2012/2013 and (C) 2013/2014 growing seasons.

groups depending on the aggressiveness of the tested race groups. Similar results were reported by Niazmand et al. (2010) who found that no virulence were detected on *Lr* 9, *Lr* 19, *Lr* 25 and *Lr* 28 resistance genes in Iran during 2007-2008 growing season. Moreover, McCallum et al. (2011) found that the frequency of virulence to both *Lr* 9 and *Lr* 17 increased in the growing season 2008 compared with the growing season 2007, whereas it decreased for *Lr* 24 and *Lr* 2a. Moreover, Soliman et al. (2012) found that *Lr*s 1, 2c, 9, 16, 24 and 26 were

Table 5. Virulence formula, number of isolates and frequency (%) of race groups of *P. triticina* collected from wheat in Egypt during 2011/2012, 2012/2013 and 2013/2014 growing seasons.

S/N	Race	Virulence formula (ineffective genes)	No. of isolates and frequency (%)					
			2011/2012		2012/2013		2013/2014	
			No. of isolates	Frequency (%)	No. of isolates	Frequency (%)	No. of isolates	Frequency (%)
1	BB---	-	6	5.09	-	-	1	1.64
2	FK---	*Lr* 2c, 3, 16, 24, 26	-	-	1	0.60	3	4.92
3	LB---	*Lr* 1	4	3.39	-	-	-	-
4	LS---	*Lr* 1, 9, 16, 24	4	3.39	-	-	-	-
5	NK---	*Lr* 1, 2c, 16, 24, 26	3	2.54	10	6.02	1	1.63
6	NT---	*Lr* 1, 2c, 9, 16, 24, 26	3	2.54	1	0.60	3	4.92
7	PJ---	*Lr* 1, 2c, 3, 16, 24	3	2.54	13	7.83	1	1.64
8	PK---	*Lr* 1, 2c, 3, 16, 24, 26	-	-	25	15.06	1	1.64
9	PT---	*Lr* 1, 2c, 3, 9, 16, 24, 26	6	5.09	6	3.61	16	26.23
10	ST---	*Lr* 1, 2a, 2c, 9, 16, 24, 26	12	10.17	6	3.61	1	1.64
11	TJ---	*Lr* 1, 2a, 2c, 3, 16, 24	-	-	8	4.82	-	-
12	TK---	*Lr* 1, 2a, 2c, 3, 16, 24, 26	6	5.08	29	17.47	1	1.64
13	TS---	*Lr* 1, 2a, 2c, 3, 9, 16, 24	3	2.54	7	4.22	-	-
14	TT---	*Lr* 1, 2a, 2c, 3, 9, 16, 24, 26	8	6.78	38	22.89	4	6.56
Others (less than 3 isolates)			60	50.85	22	13.25	29	47.54
Total No. of isolates			**118**	**100**	**166**	**100**	**61**	**100**

susceptible to most tested race groups. Also, Negm et al. (2013) found that *Lr* 3, *Lr* 16,*Lr* 24 and *Lr* 26 were ineffective against most race groups tested during 2009/2010 and 2010/2011 growing seasons. While, *Lr* 1,*Lr* 2a,*Lr* 2c and *Lr* 9 showed different infection types (IT) against the tested race groups.

Conclusion

Survey of wheat leaf rust pathotypes using leaf rust North American differential lines is very important in describing virulence variation, geographical distribution of virulence pathotypes and how leaf rust pathotypes change in response to host selection. This activity should be execute in all wheat growing seasons using rust survey and planting of wheat rust trap nurseries at all Egyptian governorates including rust hot spot locations. This will ultimately provide timely warning to wheat breeders about the change in virulence of *P. triticina* pathotypes. Thus, it will be very important to avoid future leaf rust epidemics and reduced annual losses of the commercial wheat cultivars grown in Egypt.

Conflict of Interests

The authors have not declared any conflict of interests.

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