Available Online at eSci Journals
eSci Journal of Plant Pathology
ISSN: 2305-106X (Online), 2306-1650 (Print)
http://www.escijournals.net/EJPP

GEOGRAPHICAL DISTRIBUTION OF PHYSIOLOGIC RACES OF *PUCCINIA TRITICINA* AND POSTULATION OF RESISTANCE GENES IN NEW WHEAT CULTIVARS IN EGYPT

[a]Nour E. K. Soliman, [a]Ashraf M. M. Abdelbacki, [b]Mohammad A.A. Najeeb, [a]Reda I. Omara.
Department of Plant Pathology, Faculty of Agriculture, University of Cairo, Egypt.
Department of Wheat Diseases, Plant Pathology Research Institute, Agriculture Research Center, Giza, Egypt.

A B S T R A C T

Knowledge of the geographical distribution for physiologic races of *Puccinia triticina* and identification of leaf rust resistance genes (Lr·s) in the recent Egyptian wheat cultivars are essential for maximizing resistance in future-bred cultivars. The aim of this study was to know the status of resistance in Egyptian wheat cultivars against wheat leaf rust and the most frequent race distributed**.** Infected samples were collected from five Governorates, i.e., Dakahlia, Kafr el-Sheikh, Beheira, Sharqia and Sohag comprised the wheat growing area in Egypt. These samples were isolated, purified and identified on the differential stes. Gene postulation was done using fifteen identified races on Egyptian wheat cultivars correlated with Lr genes. Thirty three races identified during three seasons 2009/2010, 2010/2011 and 2011/2012. The most frequent race was TK (10%) followed by race BB (7.58%), PK (6.55%), TT (4.82%), PT (3.79%) and MT (3.44%). Moreover, races; BB, TT and PT were present during three seasons while these races appeared in some Governorates and disappeared in other Governorates. On the other hand, the most frequently occurring gene in ten Egyptian wheat cultivars was *Lr35* (70%), followed by *Lr22* (60%), *Lr27* (40%), *Lr34* (30%), *Lr19* (30%), *Lr18* (10%), *Lr36* (10%) and *Lr46* (10%), eight out of sixteen Lr genes were not present in the tested cultivars. It is concluded that there was a good variation in Lr genes carried by wheat cultivars commercially grown in Egypt. Therefore, strategies for deploying resistance genes to prolong effective disease resistance are suggested to control wheat leaf rust disease.

Keywords: wheat, *Puccinia triticina*, physiologic races, geographical distribution, postulation, resistance genes.

INTRODUCTION

Wheat leaf rust, caused by *Puccinia triticina*, is one of the most common diseases of wheat worldwide. It probably results in higher total annual losses worldwide because of its more frequent and widespread occurrence (Huerta-Espino *et al*., 2011). In Egypt, leaf rust is the most common and important wheat disease. It caused severe losses in grain yield which reached 23% on some varieties depending on the level of rust incidence and the stage of crop development when initial infection occurs (Nazim *et al*., 1983 and Kassem *et al*., 2011).

The use of resistant cultivars is the most efficient, economical and environmentally safe method to control leaf rust disease. Although there are about 60 known genes involved in the resistance of wheat cvs. to *P. triticina*, a majority of these are not effective against current races of *P. triticina* (McIntosh *et al*., 1995 and Samsampour *et al*. 2010.). *P. triticina* has diverse virulence and is able to overcome resistance genes. The emergence of virulent pathotypes can restrict the durability and use of rust resistance genes. Accordingly, there is an ongoing need to identify, characterize and deploy new sources of resistance (Boroujeni *et al*., 2011).

For assessing the vulnerability of the crop to leaf rust, knowledge of the major resistance genes present in the predominant wheat cvs. is a prerequisite. In turn, when this information is combined with data on virulence features of the *P. triticina* population in Egypt, it is possible to make informed decisions for improving the

* Corresponding Author:
Email ID: amaeg@hotmail.com

leaf rust resistance in the Egyptian wheat cvs. The presence of race-specific resistance gene(s) in a cultivar is postulated based on the gene-for-gene relationship (Flor, 1956), provided that an array of pathogen cultures with diverse combinations of avirulence and virulence genes is used. In wheat, the presence of a specific resistance gene for *Puccinia spp*. can be ascertained by an interaction with the *Puccinia spp*. culture that lacks the corresponding gene for virulence. Leaf rust isolates that produce distinct low infection type (IT) on specific Lr genes, will also produce low ITs on cultivars that have the same resistance genes (Kolmer, 2003). A great deal of information on postulated leaf rust resistance genes has been collected from countries (including Australia, US, Canada, China, India, Pakistan and South Africa) where wheat is a major crop (Singh *et al*., 2001; Kolmer, 2003; Wamishe & Milus, 2003; Oelke & Kolmer, 2004; Pathan & Park, 2006). Little information is available on Lr genes present in Egyptian wheat cultivars. The objective of this study was to study the geographic distribution of *P. triticina* in five wheat growing Governorates in Egypt during three successive seasons (2009-2012) and postulation of resistance genes in the Egyptian wheat cvs.

Knowledge of the number and identification of the leaf rust resistance genes in these cvs. will be useful in understanding their field reaction to changing *P. triticina* populations and it can be used as parents for improving future wheat cvs.

MATERIALS AND METHODS

Samples were collected from wheat Egypt farmers and wheat Trap Rust Nurseries (EWTRN), which incorporate monogenic lines of leaf rust (*Lr's*), certain local cvs. and highly susceptible check varieties viz. " Morocco and *Triticum spleta saharences"* from five Governorates, i.e., Dakahlia (NE), Kafr el-Sheikh (N), Beheira (W), Sharqia (E) and Sohag (S). These samples were purified and multiplied by picking 3-5 pustules on the highly susceptible variety Morocco in greenhouse and laboratory of wheat Diseases Department, Plant Pathology Research Institute (PPRI), A.R.C., Giza during the period (2009-2012). The multiplied isolates were used for inoculating the differential sets.

Isolation and purification: The urediniospores of the infected specimens were transferred on the seedlings of the susceptible wheat variety Morocco. The method of inoculation was carried out as described by Stakman *et al*. (1962), in which the seedling leaves were rubbed gently between moisten fingers with tap water, sprayed in the incubation chambers with water, then inoculated by shaking or brushing rusted materials over the plant leaves and sprayed gently again with water in order to induce initial a film of free water on the plants which is essential for spore germination and the establishment of infection. The inoculated plants were then incubated in moist chambers for 24 hours to allow the rust spores to germinate and cause infection. The inoculated plants were then moved onto the benches in the greenhouse and kept under observation until the rust pustules are developed. After developing the pustules, 3-5 single pustules were isolated separately from each sample for rust reproduction on the highly susceptible wheat variety Morocco seedlings to obtain enough urediniospores for inoculation.

Race identification: The method used to identify leaf rust races was adopted by Long and Kolmer (1989) based on inoculation of isogenic lines (*Lr's*) with *P. triticina* (uredia spores) that we had modified. According to this system the plant reaction is determined on 20 lines divided into 5 groups of four lines. The first group includes iosgenic Lr-lines *1, 2a, 2c,3;* the second- *9, 16, 24, 26;* the third group- *3Ka, 11, 17 30*; the fourth- *10, 18, 21, 2b*; the fifth was the set of lines *Lr14b, Lr15, Lr35 and Lr42* (addition set for Egypt by Mc Vey *et al*., 2004). According to combination of responses of low infection type (L) and High infection type (H) plants each rust agent isolate was coded in letters. As a result each pathotype has a code including 5 letters consonants of English alphabet from B through T.

Disease assessment: The infection types for all the isogenic lines were recorded after 12 days on appearance of pustules on near-isogenic lines, the infection types for all the near-isogenic lines were recorded using standard disease scoring scale 0-4 (Stakman *et al*., 1962). The virulence patterns on differential sets were assessed on the basis of low infection types produced by each line in response to infection (infection type 0, 1 and 2 represented avirulent while 3 and 4 represent virulent) (Stakman *et al*., 1962).

Gene postulation: Ten Egyptian wheat cvs.; Sakha-94, Sakha-95, Gemmeiza-9, Gemmeiza-10, Gemmeiza-11, Sids-12, Sids-13, Giza-168, Misr-1 and Misr-2 and sixteen resistance monogenic lines; *Lr2a, Lr9, Lr18,*

Lr19, Lr22a, Lr21, Lr24, Lr25, Lr28, Lr29, Lr34, Lr36, Lr43, Lr45, Lr46 and *Lr47* were tested at the seedling stage using 15 pathotypes of *P. triticinia* obtained from collected samples during 2010/2011 growing season.
All plant materials were grown in (10 cm) plastic pots. Each contained four varieties, one in each corner clockwise. Inoculation procedures and rust data were carried out according to the methods adopted by Stakman *et al*., (1962). Genes were postulated adopted by the methods of Browder and Eversmyer (1980) and Statler (1984).

RESULTS

During the three seasons 2009/2010, 2010/ 2011 and 2011/2012. The highest mean in collected leaf rust samples was in Kafr el-Sheikh followed by Dakahlia and Sharqia while Sohag was the lowest one. On the other hand, Sharqia was the highest successive in uredial cultural followed by Kafr el-Sheikh and Dakahlia while Sohag was the lowest one in uredial cultural during the three seasons. Moreover, the highest number of collected samples were during season 2009/2010 followed by season 2010/2011 and season 2011/2012 (Table 1). Thirty three physiological races identified during three seasons 2009/2010, 2010/ 2011 and 2011/2012. Therefore, race TT was the most common virulence race while, BB was the lowest one. On the other hand, race TK was the most frequent race (10%) followed by race BB (7.58%), PK (6.55%), TT (4.82%), PT (3.79%) and MT (3.44%). Whereas, the proportion of rest races were ranged between (0.68–2.41%) of the total isolates during the three seasons. Moreover, races; BB, TT and PT were present during three seasons but these races appeared in some Governorates and disappeared in the others (Table 2).

Table 1. Number of leaf rust samples collected and the succeeded cultures during the three seasons 2009/2010, 2010/ 2011 and 2011/2012.

No.	Location	Season/Number of samples and cultures per location						Total	
		2009-2010		2010-2011		2011-2012			
		samples	cultures	Samples	cultures	samples	cultures	samples	cultures
	Dakahlia	17	44	9	17	7	12	33	73
	Kafr el-Sheikh	27	28	9	19	10	25	46	72
	Sharqia	11	21	9	22	11	51	31	94
	Beheira	2	5	10	27	5	9	17	41
	Sohag	2	3	3	4	3	3	8	10
	Total	59	101	40	89	36	100	135	290

Gene postulation: The matching between both local wheat cvs. and Lr genes against the tested physiological races of leaf rust at seedling stage under greenhouse condition indicated that postulated genes in cultivar Misr-2 were *Lr19*, *Lr22a*, *Lr27*, *Lr34*, *Lr35*. Likewise, two cvs. Sids-12 and Giza 168 probably have a single Lr gene, four cultivars Sakha-94, Sakha-95, Gemm.-10 and Sids-13 have two Lr genes, one cultivar Misr-1 has three Lr genes and two cultivar Gemm.-9 and Gemm.-11 have four Lr genes. On the other hand, *Lr19* and *Lr34* were the most likely contributing genes for resistance against leaf rust in which *Lr19* present in cvs. Sakha-95, Misr-1 and Misr-2 and *Lr34* in Gemm.-11, Giza-168 and Misr-2 (Table 3). Therefore, these cultivars are considered as resistance to leaf rust disease. As also shown in Table 3. *Lr35* was the most common leaf rust resistance gene, being postulated in seven wheat cultivars, i.e., Sakha-94, Gemm.-9, Gemm.-10, Gemm.-11, Sids-12, Sids-13 and Misr-2 among ten Egyptian wheat cvs. and this gene exhibited frequency 70%. Others common Lr genes include *Lr22a* postulated in six cultivars exhibited frequency 60%, *Lr27* postulated in four cvs. having frequency 40%, *Lr19* and *Lr34* postulated in three cvs. having frequency 30% and *Lr18, Lr36* and *Lr46* postulated in one cultivar exhibited frequency 10%. However, eight genes (*Lr2a, Lr9, Lr25, Lr28, Lr29*, *Lr43, Lr45* and *Lr47*) out of sixteen Lr genes were not present in any of the tested cvs.

Table 2. Geographical distribution and virulence formual of *Puccinia triticina* races in five Egyptian wheat growing governorates during three seasons 2009 – 2012.

No.	Race	Virulences	Dakahlia			Kafr el-Sheikh			Beheira			Sharqia			Sohag			Total/ season			Final total	
			A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	No.	%
1	BB..	*	1	1		2	3	1		4		1	4	4	1			5	12	5	22	7.58
2	BG..	16	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	2	-	2	0.68
3	CB..	3a	-	-	-	-	2	-	-	1	-	-	2	-	-	-	-	-	5	-	5	1.72
4	CF..	3a, ,24,26	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	2	-	2	0.68
5	CK..	3a,16,24,26	-	1	-	-	-	-	-	1	-	-	1	-	-	-	-	-	3	-	3	1.03
6	FD..	2c,3a,24	2	-	-	1	-	-	-	-	-	-	-	-	-	-	-	3	-	-	3	1.03
7	FK..	2c,3a,16,24,26	2	-	-	5	-	-	-	-	-	-	-	-	-	-	-	7	-	-	7	2.41
8	KK..	2a,2c,3a,16,24,26	1	-	-	1	-	-	-	-	-	2	-	-	-	-	-	4	-	-	4	1.37
9	LB..	1	-	-	-	-	-	1	-	-	-	-	-	4	-	-	-	-	-	5	5	1.72
10	LC..	1,26	-	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-	3	-	3	1.03
11	LH..	1, 16,26	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	2	-	2	0.68
12	LK..	1, 16,24,26	-	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-	3	-	3	1.03
13	LS..	1, 9,16,24	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	3	3	1.03
14	LT..	1,9,16,24,26	-	-	-	-	-	3	-	2	-	-	-	2	-	-	-	-	2	5	7	2.41
15	MB..	1,3a	-	-	-	-	1	-	-	-	-	-	2	-	-	-	-	-	3	-	3	1.03
16	MH..	1,3a,16,26	-	-	-	-	1	-	-	1	-	-	2	-	-	-	-	-	4	-	4	1.37
17	MK..	1,3a,16,24,26	-	1	-	1	2	-	-	-	-	2	1	-	-	-	-	3	4	-	7	2.41
18	MT..	1,3a,9,16,24,26	-	6	2	-	-	-	-	-	1	-	-	1	-	-	-	-	6	4	10	3.44
19	NK..	1,2c, 16,24,26	-	-	-	-	-	1	-	-	-	-	-	2	-	-	-	-	-	3	3	1.03
20	NS..	1,2c, 9,16,24	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	3	3	1.03
21	NT..	1,2c,9,16,24,26	-	-	-	-	-	1	-	-	1	-	-	1	-	-	-	-	-	3	3	1.03
22	PH..	1,2c,3a,16,26	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2	-	-	2	0.68
23	PJ..	1,2c,3a,9,16,24,26	1	-	-	2	-	-	-	-	-	-	-	4	-	-	-	3	-	4	7	2.41
24	PK..	1,2c,3a,16,24,26	8	3	-	3	1	-	1	-	-	2	-	-	1	-	-	15	4	-	19	6.55
25	PS..	1,2c,3a,9,16,24	1	-	-	1	1	-		2	-	-	-	-	-	-	-	2	3	-	5	1.72
26	PT..	1,2c,3a,9,16,24,26	1	2	1	-	1	1	-	1	1	-	-	2	-	-	1	1	4	6	11	3.79
27	RT..	1,2a,3a,9,16,24,26	-	2	-	-	-	-	-	-	-	-	-		-	-	-	-	2	-	2	0.68
28	SK..	1,2a,2c,16,24,26	-	-	1	-	-	-	-	-	-	-	-	2	-	-	-	-	-	3	3	1.03
29	SS..	1,2a,2c,9,16,24	-	-	1	-	-	-	-	-	-	-	-	1	-	-	1	-	-	3	3	1.03
30	ST..	1,2a,2c,9,16,24,26	-	-	1	-	-	-	-	-	-	-	-	3	-	-	-	-	-	4	4	1.37
31	TK..	1,2a,2c,3a,16,24,26	16	-	1	4	-	3	1	-	-	4	-	-	-	-	-	25	-	4	29	10.0
32	TS..	1,2a,2c,3a,16,24,26	-	-	-	-	-	2		-	1	-	-	-	-	-	-	-	-	3	3	1.03
33	TT..	1,2a,2c,3a,9,16,24,26	4	-	-	-	-	2	1	-		2	-	2	1	2	-	8	2	4	14	4.82
Others (less than 1)			6	-	5	8	6	10	2	10	2	7	6	20		1	1	23	23	38	84	28.9
Total			44	17	12	28	19	25	5	27	9	21	22	51	3	4	3	101	89	100	290	100

Table 3. The postulated Lr genes that may be or probably present within ten wheat cultivars at seedling stage during season 2010/2011.

Genes / Cultivars	*Lr2a*	*Lr9*	*Lr18*	*Lr19*	*Lr22a*	*Lr25*	*Lr27*	*Lr28*	*Lr29*	*Lr34*	*Lr35*	*Lr36*	*Lr43*	*Lr45*	*Lr46*	*Lr47*	Postulated resistance genes
Sakha-94	+	+	+	+	0	+	+	-	+	+	0	+	+	+	+	-	22a, 35
Sakha-95	+	+	+	0	+	+	0	+	+	+	+	+	+	+	+	+	19,27
Gemmeiza-9	+	+	+	+	0	+	+	+	+	+	0	0	+	+	0	-	22a,35,36,46
Gemmeiza-10	-	+	+	+	0	+	+	-	+	+	0	-	+	-	+	-	22a,35
Gemmeiza-11	+	+	+	+	0	+	0	-	+	0	0	+	+	+	+	-	22a,27,34,35
Sids-12	+	+	+	+	+	+	+	+	+	+	0	+	+	+	+	+	35
Sids-13	+	+	+	+	0	+	+	-	+	+	0	+	-	+	+	-	22a,35
Giza-168	-	+	+	+	+	-	+	-	+	0	+	+	+	+	+	+	34
Misr-1	+	+	0	0	+	+	0	+	+	+	+	+	+	+	+	+	18,19,27
Misr-2	+	+	+	0	0	+	0	+	+	0	0	+	+	+	+	-	19,22a,27,34,35
No. of cultivars carrying Lr genes	0	0	1	3	6	0	4	0	0	3	7	1	0	0	1	0	-
Frequency %	0	0	10	30	60	0	40	0	0	30	70	10	0	0	10	0	

(-) = indicated the absence of such gene in the cultivar; (O) = indicated the presence of such gene in host B and it may have another one and (+) =indicates that either of hosts did not have the same gene.

DISCUSSION

One of the most important steps in breeding programs for rust resistance in wheat is the identification of the prevailing physiological races in the region. Such program will be successful if all physiological isolates of the disease are included (Kolmer, 1992 and Kolmer, 2001). Generally, new races of leaf rust developed by mutation (Park *et al*., 2002); heterokaryosis (Kolmer 1992); recombination (McIntosh *et al*., 1995 and Park *et al*., 1999); migration (Park *et al*., 1995) and natural selection of virulence race against resistance of growing wheat varieties in the region (Kolmer *et al*.,2005).

Survey for wheat leaf rust in Egypt during three growing seasons 2009-2012, indicated the presence of the disease incited by *P. triticina* in different governorates i.e., Dakahlia, Kafr el-Sheikh, Beheira, Sharqia and Sohag. Most of diseased samples were collected from farmer fields and trap nurseries. The three annual surveys, 2009/01, 2010/11 and 2011/12 indicated the presence of thirty three physiologic races. Race TT was the most common virulence race while, BB was the lowest one. This result was in accordance with those of (Nazim *et al*., 2003 and Nazim *et al*., 2010) who cleared that race TT was the most virulent one. Similar results were reported also by Kassem *et al*., 2011 and Kolmer, *et al*., 2011.

The most frequent race was TK through the three seasons followed by races; BB, PK, TT, PT and MT. Regardless of the presence of these races during the three seasons, they appeared in some Governorates and disappeared in the others. This may be due to climate changes i.e., temperature and rainfall in different Governorates which are necessary for the disease occurrence (Nazim and Clifford, 1983 and Manninger, 2001) and ability of *P. triticina* to form new races that can attack resistant varieties and their potential to develop rapidly under optimal environmental conditions and cause serious losses (El-Daoudi *et al*. 1994). For example in the present study, Sohag was the lowest Governorate in collected samples and physiological races. This may be due to high temperature and lack of rain in this Governorate and therefore we advise to grow high-yield susceptible varieties in Upper Egypt because the severe infection will be very low in this area due to the environmental conditions.

The wheat leaf rust population in Egypt is made up of a great diversity of races and that the most common races reappear year after year. The similar levels of diversity of leaf rust races in Egypt and the United States, particularly in the Southern Plains, may be cause to reinvestigate the possibility of over summering of

leaf rust in Egypt. Leaf rust inoculum arrives in Egypt from external sources each year and transferred from area to area in the same year (McVey *et al.,* 2004).

Resistance gene expression is dependent on the genetics of host-pathogen interaction, temperature conditions, plant developmental stage, and interaction between resistance genes with suppressors or other resistance genes in the wheat genomes (Kolmer, 1996). Gene postulation is the most frequent method to determine the presence of the probable race-specific seedling resistance genes (Lr genes) in a host cultivar, many researchers have used this method for identifying Lr genes in a group of wheat genotypes (Kolmer, 2003; Oelke and Kolmer, 2004; Wamishe *et al*. 2004 and Hysing *et al*. 2006). Therefore, in this study we identified eight known genes and several unidentified genes for seedling leaf rust resistance in a range of wheat cvs. grown in Egypt. Genes masked by suppression in the seedling stage or under the given environment conditions could remain undetected, although they may still have an effect on resistance in the field (Kolmer, 2003).

The gene *Lr35* (70%) was the most commonly postulated gene in the Egyptian wheat cvs. followed by *Lr22* (60%), *Lr27* (40%), *Lr34* (30%), *Lr19* (30%), *Lr18* (10%), *Lr36* (10%) and *Lr46* (10%). On a global scale, *Lr19* is probably the most widely distributed gene for resistance to *P. triticina* (McIntosh *et al*., 1995; Winzeler *et al*., 2000). Therefore, it is still considered important gene because it is present in several bred cultivars in CIMMYT in combination with other adult plant resistance genes which continue to give excellent leaf rust protection (Huerta-Espino *et al*., 2011). In Egypt, this gene is important gene of resistance and postulated in cvs. Sakha-94, Misr-1 and Misr-2 (present study) which are considered resistance to leaf rust disease.

Pyramiding genes has been suggested as a method to achieve more durable resistance against pathogens with low genetic diversity, high gene flow and asexual mating systems (McDonald & Linde, 2002; Hysing *et al*., 2006). The combination of several effective resistance genes into a single cultivar should extend the period of resistance i.e., Misr-2 have *Lr19*, *Lr22a*, *Lr27*, *Lr34*, and *Lr35*, Gemm.-9 have *Lr22a*, *Lr35*, *Lr36* and *Lr46* and Gemm-11 have *Lr22a*, *Lr27*, *Lr34*, and *Lr35*. Slow rusting or partial resistance has been reported to be a more durable resistance than single seedling resistance genes (Li *et al*., 2010). The pyramiding of such differently functioning genes is simplified by the use of molecular markers that have been developed for most genes for leaf rust resistance. These markers already have been developed for slow rusting resistance genes *Lr34* and *Lr46* (Lind & Gultyaeva, 2007 and Boroujeni *et al*., 2011). In this study, these genes were postulated in cvs. Gemm-11, Giza-168 and Misr-2. Similar results were recorded by (Bainotti *et al*. 2009) who indicated the presence of gene *Lr34* in cultivar Biointa2004.

Concerning the matching within commercial cvs., the obtained results gave evidence to the presence of common genes *Lr22a* and *Lr35* between Sakha-94 and Sids-13, Gemm.-9 and Gemm.-10, Gemm.-11 and each of Sakha-94 and Sids-13, Misr-2 and each of Sakha-94, Gemm.-11 and Sids-13. These common genes *Lr22a* and *Lr35* were already postulated in the tested cvs. (Table 3). Therefore, this result gives evidence to the presence of these genes in these cvs.

The knowledge of which leaf rust seedling resistance genes are present facilitates future studies and the use of adult plant resistance genes in the wheat cvs. The genes *Lr22*, *Lr35*, *Lr27*, *Lr34*, *Lr19*, *Lr18*, *Lr36* and *Lr46* were the most frequent seedling leaf rust resistance genes postulated to be present in Egyptian wheat cvs. Therefore, there is relatively inadequate variation in Lr genes carried by wheat cvs. commercially grown in Egypt. Future host selection pressure on the pathogen could be further decreased by rotating genes through time and space by mixtures or regional deployment of cultivars with different effective resistance genes. Nevertheless, classical genetic and molecular marker analyses will be needed to further validate and expand the findings of the present study regarding the Lr genes responsible for both seedling and adult plant resistance to leaf rust in the Egyptian wheat cvs.

REFERENCES

Bainotti, C.T., J. Fraschina, J. Salines, J. Nisi, J. Dubcovsky, S. Lewis, L. Bullrich, L.S. Vanzetti, M. Cuniberti, P. Campos, M.B. Formica, B. Masiero, E. Alberione & M. Helguera. 2009. Registration of 'BIOINTA 2004' wheat. J. Plant Reg. 3, 165-169.

Boroujeni, F. R., A. Arzani, F. Afshari M. Torabi. 2011. Postulation of leaf rust resistance genes in Iranian wheat cultivars and breeding lines. Can. J. Plant Pathol. 33, 550–558.

Browder, L.E & M.G. Eversmeyer. 1980. Sorting of Puccinia recondite : *Triticum* infection type data

sets toward the gene-for-gene model. Phytopathology 70, 666-670.

El-Daoudi, Y.H., O.F. Mamluk, E. Bekele, Enayat, H. Ghanem, M.B. Solf & E.H. Ikhlas Shafik. 1994. Preliminary results for leaf and stem rust of wheat, their prevalence and resistance in the Nile Valley Countries and Yemen. Fifth Arab Cong. Plant. Prot., Fez Morocco, Nov. 27-Dec. 2(Abstr.).

Flor, H.H. 1956. The complementary gene systems in flax and flax rust. Adv. Genet. 8, 29–54.

Huerta-Espino, J., R.P. Singh, S. German, B.D. Mccallum, R.F. Park, W.Q. Chen, S.C. Bhardwaj & H. Goyeau. 2011. Global status of wheat leaf rust caused by *Puccinia triticina*. Euphytica, 179, 143–160.

Hysing, S.C., R. Singh, J.H. Espino, A. Merker, E. Liljeroth, & O. Diaz. 2006. Leaf rust (*Puccinia triticina*) resistance in wheat (*Triticum aestivum*) cultivars grown in Northern Europe 1992–2002. Hereditas 143, 1–14.

Kassem, M., A. El-Ahmed, M.S. Hakim, M. El-Khaliefa & M. Nachit. 2011. Identification of prevalent races of *Puccinia triticina* Eriks. in Syria and Lebanon. Arab J. Plant Prot. 29, 7-13.

Kolmer, J.A. 1992. Effect of sexual recombination in two population of the wheat leaf rust fungus *Puccinia recondita*. Can. J. Bot. 70, 359-363.

Kolmer, J.A. 1996. Genetics of resistance to wheat leaf rust. Annu. Rev. Phytopathol., 34, 435–455.

Kolmer, J.A. 2001. Physiologic specialization of *Puccinia triticina* in Canada in 1998. Plant Dis. 85,155–158.

Kolmer, J.A. 2003. Postulation of leaf rust resistance genes in selected soft red winter wheats. Crop Sci., 43, 1266–1274.

Kolmer, J.A., D.L. Long & M.E. Huges. 2005. Physiological specialization of *Puccinia triticina* on wheat in the united states in 2003. Plant Dis. 89, 1201-1206.

Kolmer, J.A., D.L. Long & M.E. Hughes. 2011. Physiologic specialization of *Puccinia triticina* on wheat in the United States in 2009. Plant Dis. 95, 935-940.

Li, Z.F., Z.H. He, L.J. Li, X.; Zhang, H.Y. Wang, Q.F. Meng, W.X. Yang, G. Li & D.Q. Liu. 2010. Seedling and Slow Rusting Resistance to Leaf Rust in Chinese Wheat Cultivars. Plant Dis. 94, 45-53.

Lind, V. & A.E. Gultyaeva. 2007. Virulence frequencies of *Puccinia triticina* in Germany and the European regions of the Russian Federation. J. Phytopathology 155, 13–21.

Long, D.L. & J.A. Kolmer. 1989. A North American system of nomenclature for *Puccinia recondita* f. sp. *tritic*i. Phytopathology 79, 525-529.

Manninger, K. 2001. Occurrence and virulence of wheat leaf rust in Hungary. Plant Prot. Institute, Hungarian Acad. Of Sciences, H. 1525 Budapest, P.O. Box 102, Hungary.

Mcdonald, B.A. & C. Linde. 2002. The population genetics of plant pathogens and breeding strategies for durable resistance. Euphytica 124, 163–180.

Mcintosh, R.A., C.R. Wellings & R.F. Park. 1995. Wheat rusts: An atlas of resistance genes. London: Kluwer Academic Publishers.

McVey, D.V., M. Nazim, K.J. Leonard & D.L. Long. 2004. Patterns of virulence diversity in *Puccinia triticina* on wheat in Egypt and the United States in 1998 - 2000. Plant Dis. 88, 271 - 279.

Nazim, M. & B.C. Clifford. 1983. Effect of temperature on the interaction between *Puccinia recondita* f.sp. *tritici* and *Triticum aestivum*. Minufiya J. Agric. Res. 7, 69-83.

Nazim, M., M.M. Aly, E.H. Ikhlas Shafik & I. Abed- Malak Nagwa. 2010. Frequency of virulence and virulence formula of wheat leaf rust races identified in Egypt during 2004/2005-2007-2008. Egypt. J. Phytopathol. 38, 77-88.

Nazim, M., A.A. El-Shehidi, Y.A. Abdou & Y.H. El-Daoudi. 1983. Yield loss caused by leaf rust on four wheat cultivars under epiphytotic levels. 4th Confer. Microbiol. Cairo, 17-27.

Nazim, M., I.A. Imbaby & T. Mohmoud, Somaya. 2003. Geographic distribution and virulence survey of races of *Puccinia triticina* f.sp. *tritici* leaf rust of wheat in Egypt during 2000/01-2001/02. J. Environ. Sci. 79, 847-864.

Oelke, L.M. & J.A. Kolmer. 2004. Characterization of leaf rust resistance in hard red spring wheat cultivars. Plant Dis. 88, 1127–1133.

Park, R.F., H.S. Bariana, C.R. Weltings & H. Wallwork. 2002. Detection and occurrence of a new pathotype of Puccinia triticina with virulence for Lr 24 in Australia. Aust. J. Agric. Res. 53, 1069-1076.

Park, R.F., J.J. Burdon & R.A. Mcintosh. 1995. Studies in the origin, spread and evolution of an important group of *Puccinia recondita* f.sp. *tritici* pathotypes in Australia. Eur. J. Plant Pathol. 101, 613-622.

Park, R.F., J.J. Burdon & A. Jahoor. 1999. Evidence for somatic hybridization in nature in *Puccinia recondita* f.sp. *tritici*, the leaf rust pathogen of wheat. Mycol. Res. 103, 715-723.

Pathan, A.K. & R.F. Park. 2006. Evaluation of seedling and adult plant resistance to leaf rust in European wheat cultivars. Euphytica 149, 327–342.

Samsampour, D., B. Maleki Zanjani, J.K. Pallavi, A. Singh, A. Charpe, S.K. Gupta & K.V. Prabhu. 2010. Identification of molecular markers linked to adult plant leaf rust resistance gene Lr48 in wheat and detection of Lr48 in the Thatcher near-isogenic line with gene Lr25. Euphytica 174, 337-342.

Singh, D., R.F. Park R.A. Mcintosh. 2001. Postulation of leaf (brown) rust resistance genes in 70 wheat cultivars grown in the United Kingdom. Euphytica 120, 205–218.

Stakman, E.C., D.M. Stewart & W.Q. Loedering. 1962. Identification of physiologic races of *Puccinia graminis* f.sp. *tritici.* A.R.S. USA Agric. Res. Service. Bulletin 617, 53.

Statler, G.D. 1984. Probable genes for leaf rust resistance in several hard red spring wheats. Crop Sci. 24, 883-886.

Wamishe, Y.A. & E.A. Milus. 2003. Seedling resistance genes to leaf rust in soft red winter wheat. Plant Dis. 88, 136–146.

Wamishe, Y.A., K.C. Thompson & E.A. Milus. 2004. A computer program to improve the efficiency and accuracy of postulating race-specific resistance genes. Plant Dis. 88, 545–549.

Winzeler M., A. Mysterhazy & R.F. Park. 2000. Resistance of European winter wheat germplasm to leaf rust. Agronomie 20, 783–792.