Available online at http://www.journalijdr.com

International Journal of
DEVELOPMENT RESEARCH

ISSN: 2230-9926

International Journal of Development Research
Vol. 5, Issue, 03, pp. 3651-3657, March, 2015

Full Length Research Article

VIRULENCE PATTERNS OF WHEAT YELLOW RUST AND EFFECTIVE RESISTANCE GENES TO *PUCCINIA STRIIFORMIS* F. SP. *TRITICI* IN PAKISTAN

[1,2]Muhammad Ibrahim, *[1]Syed Jawad Ahmad Shah, [2]Shaukat Hussain, [2]Musharaf Ahmad and [3]Farhat Ullah

[1,2]Department of Plant Pathology, The University of Agriculture, Peshawar, Pakistan
[1]Nuclear Institute for Food and Agriculture (NIFA) Tarnab, Peshawar (Khyber Pakhtunkhwa), Pakistan
[2]Department of Plant Pathology, The University of Agriculture, Peshawar, Pakistan, Pakistan
[3]Department of Plant Breeding and Genetics, The University of Agriculture, Peshawar, Pakistan

ARTICLE INFO

Article History:
Received 28th December, 2014
Received in revised form
04th January, 2015
Accepted 10th February, 2015
Published online 17th March, 2015

Key words:
Wheat,
Yellow rust,
Virulence,
Resistance,
Genes.

ABSTRACT

Yellow rust caused by *Puccinia striiformis* f. sp. *tritici* is a damaging wheat disease in many countries including Pakistan. Monitoring of pathogen virulences over time and space provides information for the host resistance improvement and deployment. Virulences were monitored in three wheat growing zones close to Himalayan region in Pakistan using yellow rust differentials AvSYr1NIL, AvSYr5NIL, AvSYr6NIL, AvSYr7NIL, AvSYr8NIL, AvSYr9NIL, AvSYr10NIL, AvSYr15NIL, AvSYr17NIL, AvSYr18NIL, AvSYr24NIL, AvSYr26NIL, AvSYr27NIL, AvSYr32NIL, AvSYrSPNIL, Jupateco R, Jupateco S, Avocet R and Avocet S during 2010 to 2013. No virulence was observed for *Yr1* and *Yr17* in the southern zone while *Yr10* and *Yr15* were found clean in the central and northern (Abbotabad) zones. *Yr15* indicated susceptibility during 2011 and 2013 in northern zone (Swat). Performance of other genes fluctuated among locations and years. Virulences were observed for *Yr5*, *Yr24*, *Yr26* and *YrSp* at different locations and years but rust severity of these genes were below 20% during 2010 to 2013 except *Yr5* which was high at one location in the central zone. Similarity index (SI) among locations of three zones indicated a high degree of similarity between Peshawar 1 and Abbotabad (SI=0.13). All locations have little similarity among each other's except Peshawar 1 and Bannu (SI=27.72) and Bannu and Abbotabad (SI=27.6) which had highest dissimilarity to each other. Both *Yr10* and *Yr15* can be used in the wheat improvement programs along with *Yr18* to prolong the effective life span of cultivars for durable protection against yellow rust in Pakistan.

Copyright © 2015 Muhammad Ibrahim et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

INTRODUCTION

Wheat is an import crop worldwide and is being grown on 223 million ha (http://www.indexmundi.com/agriculture/?commodity=wheat). Yellow rust caused by *Puccinia striiformis* Westend. f. sp. *tritici* Erikss., is an economically important wheat disease in different regions of the world and its epidemics are common and repeatedly occur in many countries (Wellings, 2011). Yellow rust is the most damaging in reducing grain yields (Singh *et al*., 2000b) and posing a major threat to wheat production in Asia where 43 million ha of farmland is vulnerable to it. Pakistan lies in Asia and occupies the top 9th and 8th positions in the world with regard to wheat acreage and production, respectively.

***Corresponding author: Dr. Syed Jawad Ahmad Shah**
Nuclear Institute for Food and Agriculture (NIFA) Tarnab, Peshawar (Khyber Pakhtunkhwa), Pakistan

Wheat diseases are one of the major production constraints and yellow rust is a high profile economically important disease capable of attacking 70% of the wheat area in Pakistan (Singh *et al*., 2005). Thirteen yellow rust epidemics were reported from Pakistan (Afzal *et al*., 2008; Duveiller *et al*., 2007). Four major epidemics were recorded in 1978, 1997-98 and 2005 and caused respective losses of US$244 million, $33 million and $100 million to Pakistan economy (Duveiller *et al*., 2007; Bahri *et al*., 2011). Yellow rust pathogen exhibit two major biological characteristics that make continued monitoring as an essential and absolute requirement. Firstly, they have the capacity of rapid and long distance movements, either by air or by accidental human transmission. Secondly, rust pathogens have the potential to change and evolve new virulences through mutation or sexual recombination (Park 2007). Monitoring of the yellow rust virulences in different regions help to understand the current genetic variability of host-pathogen interactions. In addition, information on virulence is also useful in screening cultivars or breeding lines for the determination of resistance levels and exploitation of new resistance genes (Sharma-Poudyal *et al*., 2013). Yellow rust pathogen virulence monitoring using trap nurseries is a well adopted practice in many parts of the world including Kyrgyzstan, Turkey, Hungary, Pakistan, Morocco, Russia, Iraq, Iran and Nepal (Absattarova *et al*., 2002; Cetin *et al*., 2002; Manninger 2002; Anonymous 2002; Ramdani *et al*., 2011b; Volkova *et al*. 2011; Nori and Maaroof 2012; Aslanova *et al*., 2012; Sharma *et al*., 2012).

Deployment of trap nurseries utilizing isogenic lines for the assessment of pathogenic variation in *P. striiformis* offers several advantages as it provides a cost-effective means of pathogenicity assessment by alleviating reliance on sample collection, multiplication and processing through expensive environmentally controlled greenhouses (Wellings *et al*., 2000). At least 53 yellow rust resistance genes have been identified (McIntosh *et al*., 2010 and USDA 2010) but very few were exploited in Pakistan (Shah *et al*., 2010; Bahri *et al*., 2011). Northwest of Pakistan is an important region with regard to yellow rust occurrence and is located close to the center of diversity of the pathogen (Ali 2012).Therefore an initiative was undertaken on a regular bases to monitor pathogen virulences, potential of resistance genes and to compare test locations for yellow rust similarity. A recent four year result (i. e 2010-2013) under this initiative are reported which may be useful for the national wheat improvement in Pakistan and neighboring countries for developing new cultivars with effective genes.

MATERIALS AND METHODS

Study area

Experiments were carried out at six wheat growing locations in three zones i.e. Southeren (Bannu, Elevation: 360 m), Central (Peshawar 1, Elevation: 316m; Peshawar 2, Elevation: 316m; Nowshara, Elevation: 331m) and Northern (Abbotabad, Elevation: 1256m; Swat, Elevation: 880m). These locations fall within CIMMYT mega-environment 1, 2B, 4 and 8 (http://wheatatlas.org/search) and are located close to Himalayan region in the northwest of Pakistan where yellow rust is more serious (Chatrath *et al*., 2007), over-summering is common (Hassan 1968), prevalence of alternate host (Ali *et al*., 2014) and is also located at the gateway of the new rust races entering from neighboring countries (Rajaram *et al*., 1998; Singh *et al*., 2002, 2005).

Host material and sowing

Yellow rust near isogenic differentials (NILs) including AvSYr1NIL, AvSYr5NIL, AvSYr6NIL, AvSYr7NIL, AvSYr8NIL, AvSYr9NIL, AvSYr10NIL, AvSYr15NIL, AvSYr17NIL, AvSYr18NIL, AvSYr24NIL, AvSYr26NIL, AvSYr27NIL, AvSYr32NIL, AvSYrSPNIL, Jupateco R (Yr18), Jupateco S (Null), Avocet R(YrA) and Avocet S (Null) were provided by Dr. Colin R. Wellings of Plant Breeding Institute, Cobbitty NSW, Australia. A plot with 19 differentials was planted at each location and year. Each differential was planted in a mini-plot consisting of two parallel rows 2 m long and 60 cm apart at a rate of 4 g of seed per row. Two rows of a yellow rust susceptible wheat cultivar "Morocco" were sown around experimental plot at each location during the study years to enhance rust development.

Yellow rust scoring and virulence frequency

Inspection of the differentials was started as soon as the first yellow rust symptoms appeared on the leaves. Several inspections were made over time during the cropping seasons. Infection types (ITs) were scored on flag leaves using 0-9 scale, where 0 = no symptoms and 9 = abundant sporulation without necrosis or chlorosis. In this scale, ratings between 0 and 3 are considered to be resistant reactions; 4 to 6 are intermediate and 7 to 9 are susceptible (Line and Qayoum 1992). Infection type was considered avirulent when IT falls within 0-6 while 7-9 indicate presence of virulence in the natural rust population at each location to the respective gene. Yellow rust severity was also estimated visually on flag leaves using a modified Cobb scale of 0-100%, where 0% = no symptoms and 100% = maximum symptoms (Peterson *et al*., 1948). The frequency of infection of each genotype was calculated as the relative percent frequency of infection of susceptible lines over four years at all the testing sites in northwest of Pakistan (Yahyaoui *et al*., 2002).

Similarity index and rust severity analyses

Yellow rust severity of the 19 differentials recorded from 2010 to 2013 at six locations in three zones was compared in all pair-wise combinations. For these comparisons, a similarity index (SI) was calculated for each pair based on absolute differences in the percent rust severity on the differential series using the following equation:

$$\mathbf{SI=}\quad \mathbf{1/N} \sum_{\mathbf{i=1}}^{\mathbf{N}} \left| \boldsymbol{P_{iA}\text{-}P_{iB}} \right|$$

where N is the number of host lines in the differential set (=19), *P* the percentage of rust severity of the *i*th differential line at site A, and *PiB* the percentage of rust severity of the *i*th differential line at site B (Leonard *et al*., 2005). Thus locations among three zones with the same percentage of rust severity for all differential lines would have a SI of 0.0. A greater difference in the percentage of rust severity between a pair of sites indicates a lower similarity of the yellow rust population between these sites. The mean percentage of rust severity for the 19 differential lines cultivated at six locations in three zones from 2010 to 2013 was analyzed and treatment means were compared using Fisher least significant difference test using Minitab 17 Statistical Software (2010).

RESULTS

Yellow rust mean severity and infection types varied among test locations and years (Fig.1a & b) in three zones. Three locations (i.e. Peshawar 1, Peshawar 2 and Abbotabad) had almost similar mean rust severity (around 40%) which was followed by Swat (20.17%), Nowshara (16.57%) and Bannu (13.33%). Maximum mean IT (i.e. 6.32) was recorded in Peshawar 2 while both Peshawar 1 and Abbotabad had IT little higher than 5.

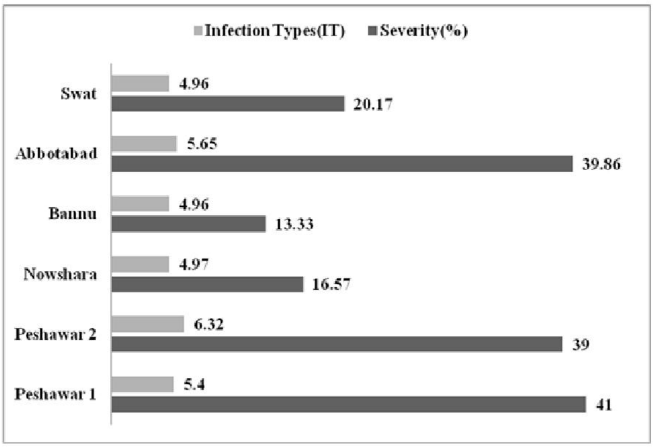

Fig. 1a. Yellow rust mean infection types (IT) and severity at six locations in northwest of Pakistan during 2010-2013

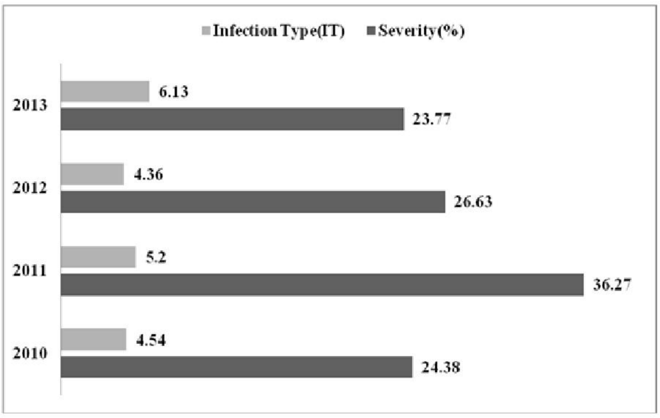

Fig. 1b. Yellow rust mean infection types (IT) and severity over six locations in four years in northwest Pakistan

Bannu, Nowshara and Swat had almost similar mean ITs around 4.96. Lowest mean rust severity was recorded during 2013 (23.77%) which was little less than 2010 while maximum was observed in 2011 (36.27%) (Fig.1b). In Bannu (Southeren zone), virulences were recorded for each of the 9 genes during 2011 and 2012 while susceptibility in number of genes increased to 17 during 2013 (Table 1). Over three years, high IT of '8' was displayed by genes *Yr5, Yr6, Yr7, Yr8, Yr26, Yr27* and Avocet S while their corresponding mean rust severities were 16.67%, 50%, 33.33%, 18.33%, 11.67%, 18.33% and 30%, respectively (Table 2). During both 2011 and 2012, no rust was observed on *Yr9*, *Yr10*, *Yr18*, *YrSp* and Jupateco R while *Yr1* and *Yr17* were found rust free over the study period at Bannu. In the Central zone, virulences were recorded over four years for 12-16 genes at Peshawar 1, 9-17 genes at Peshawar 2 and 8-16 genes at Nowshara. At Peshawar 1, Peshawar 2 and Nowshara, genes *Yr1*, *Yr6*, *Yr7*, *Yr8*, *Yr18*, *Yr32*, Jupateco S, Avocet R and Avocet S were found susceptible and their corresponding mean rust severities over four years were 6.25-55%, 30-85%, 37.5-85%, 10-57.5%, 15-37.5%, 6.25-60%, 27.5-55%, 37.5-77.5% and 45-70%, respectively (Table 1and 2). *Yr5* was found susceptible at Peshawar 1, *Yr9* at Peshawar 2, *Yr17* at both Peshawar 2 and Nowshara, *Yr27* at Peshawar 2, *YrSp* at Peshawar 1, and Jupateco R at both Peshawar 1 and Nowshara while ITs and rust severity of these genes fluctuated and remained inconsistent over years and locations in the central zone. Rust severity of both *Yr24/Yr26* was low at the three test locations; however, their infection types fluctuated within years. No virulence was detected for both *Yr10* and *Yr15* in the central zone during the study period. Number of genes for which virulences were found varied between 10-14 in the Northern Zone. At Abbotabad and Swat, genes *Yr1*, *Yr6*, *Yr7*, *Yr8*, *Yr18*, Jupateco S, Avocet R and Avocet S were found susceptible and the mean rust severities for the corresponding genes reached up to 35%, 90%, 60%, 37.5%, 45%, 90% and 85% (Table 1 and 2). Both *Yr5* and *Yr15* were found susceptible at Swat while *Yr24* and *Yr32* displayed susceptibility at Abbotabad and Swat respectively. ITs and rust severity for *Yr9*, *Yr17*, *Yr26*, *Yr27* and *YrSp* varied among years/locations in the northern zone. No virulence was observed for *Yr5* (Abbotabad), *Yr10* (Abbotabad & Swat), *Yr15* (Abbotabad) and *Yr24* (Swat). The frequency of virulence to *Yr* resistance genes (Table 1) was determined based on infection of genes under field conditions over locations and years in Northwest Pakistan. Virulence frequency for most of the genes i.e. *Yr1*, *Yr5*, *Yr6, Yr7, Yr8, Yr9, Yr17, Yr27, Yr32,* Jupateco R (*Yr18*) Jupateco S (lacking *Yr18*), Avocet R (*YrA*) Avocet S (lacking *YrA*) were >50%. Virulence frequencies for *Yr10* and *Y15* were 5 and 20% respectively and resistance of both these genes was effective. Virulence frequencies to the remaining genes *Yr24/Yr26* and *YrSp* were upto 50% and carried moderate resistance. During each year from 2010 to 2013, mean rust severity for *Yr10*, *Yr15*, *Yr24*, *Yr26* and *YrSp* remained below 20%. Mean rust severity for *Yr5* was 43% during 2012 while in 2011 and 2013 it was around 20%. Severity means for *Yr18* was less than 30% for each year (Fig 2).

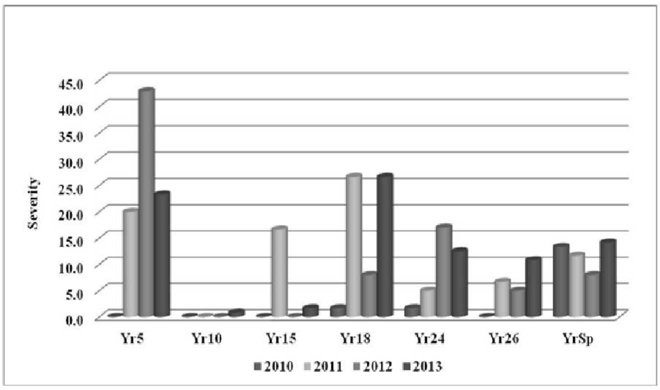

Fig. 2. Yellow rust severity means of selected genes over four years for six locations in northwest Pakistan

The SI was calculated as the mean absolute difference in the percentage of natural yellow rust on the differential series. Spatial similarity in degree of virulence profiles of *P. striformis* f. sp. *tritici* populations among pair of test locations in descending order were Peshawar1:Abbotabad (SI= 0.13), Nowshara: Swat (SI=3.60), Bannu: Swat (SI=6.84), Peshawar1: Peshawar2 (SI= 8.16), Nowshara: Bannu (SI=12.07), Peshawa1: Nowshere (SI=12.5), Peshawar1: Swat (SI=15.53), Peshawar2: Swat (SI=18.77), Abbotabad: Swat (SI=20.74), Peshawar2:Nowshara (SI=22.37), Nowshara: Abbotabad (SI=24.34), Peshawar2: Abbotabad (SI=22.43), Peshawar2: Bannu (SI=25.61), Bannu: Abbotabad (SI=27.6), Peshawa1: Bannu (SI=27.72) (Table 3).

Table 1. Infection types of 19 Near Isogenic wheat differential lines cultivated at six locations in three zones of northwest Pakistan from 2010 to 2013

Differentials	Yr genes	Southern zone			Central zone												Northern zone					Virulence Frequency (%)
		Bannu			Peshawar 1				Peshawar 2				Nowshara				Abbotabad		Swat			
		2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2011	2013	2011	2012	2013	
AvSYr1NIL	*Yr1*	0	0	0	7	7	8	8	0	8	8	8	0	7	8	8	8	8	7	8	8	75
AvSYr5NIL	*Yr5*	8	8	8	0	8	8	8	0	0	8	8	0	0	8	7	0	0	0	8	7	60
AvSYr6NIL	*Yr6*	8	8	8	7	8	8	8	8	8	0	8	7	8	8	8	8	8	8	8	8	95
AvSYr7NIL	*Yr7*	6	8	8	8	8	8	8	8	8	0	8	8	8	8	8	8	8	8	8	8	90
AvSYr8NIL	*Yr8*	8	8	8	8	7	8	8	8	8	8	8	8	8	0	8	8	8	7	8	8	95
AvSYr9NIL	*Yr9*	0	0	8	8	0	8	0	7	8	8	8	7	8	0	0	8	0	8	0	0	55
AvSYr10NIL	*Yr10*	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
AvSYr15NIL	*Yr15*	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8	20
AvSYr17NIL	*Yr17*	0	0	0	8	7	0	0	7	8	8	8	7	8	0	7	8	0	8	0	0	55
AvSYr18NIL	*Yr18*	0	0	8	8	7	8	7	0	8	8	8	8	8	0	8	8	8	7	0	7	75
AvSYr24NIL	*Yr24*	0	8	7	0	8	0	5	0	0	8	8	6	0	0	8	8	8	0	0	0	40
AvSYr26NIL	*Yr26*	8	8	8	0	7	8	8	0	0	0	8	0	0	0	7	0	8	0	0	8	50
AvSYr27NIL	*Yr27*	8	8	8	8	8	0	0	8	8	8	8	7	7	0	8	8	0	0	8	8	75
AvSYr32NIL	*Yr32*	8	0	8	8	8	8	8	0	8	8	8	7	0	8	8	8	0	8	8	8	80
AvSYrSPNIL	*YrSp*	0	0	8	8	7	0	8	0	0	8	8	0	0	0	8	0	8	8	0	0	45
Jupateco R	*Yr18*	0	0	8	0	7	8	8	0	7	0	8	7	8	8	8	8	8	0	0	8	65
Jupateco S	*Null*	0	8	8	0	8	8	8	8	8	0	8	7	7	0	8	8	8	8	8	8	80
Avocet R	*YrA*	8	0	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	0	8	8	90
Avocet S	*Null*	8	8	8	8	8	8	0	8	8	8	8	8	8	7	8	8	8	8	8	8	95

Table 2. Mean natural yellow rust severity percentage on 19 Near Isogenic wheat differential lines cultivated at six locations in three zones of northwest Pakistan from 2010 to 2013

Differentials	Yr genes	Southern zone		Central zone						Northern zone			
		Bannu		Peshawar 1		Peshawar 2		Nowshara		Abbotabad		Swat	
AvSYr1NIL	*Yr1*	0	D	55	ABCDE	42.5	ABCD	6.25	DEF	35	AB	30	ABC
AvSYr5NIL	*Yr5*	16.67	BCD	67.5	ABC	22.5	BCD	3.75	EF	0	B	16.67	ABC
AvSYr6NIL	*Yr6*	50	A	85	A	50	ABC	30	ABC	90	A	46.67	A
AvSYr7NIL	*Yr7*	33.33	AB	85	A	52.5	ABC	37.5	AB	60	AB	40	AB
AvSYr8NIL	*Yr8*	18.33	BCD	37.5	BCDEFG	57.5	AB	10	CDEF	37.5	AB	21.67	ABC
AvSYr9NIL	*Yr9*	1.67	D	42.5	BCDEF	50	ABC	15	BCDEF	50	AB	13.33	ABC
AvSYr10NIL	*Yr10*	1.67	D	0	G	0	D	0	F	0	B	0	C
AvSYr15NIL	*Yr15*	8.33	D	0	G	0	D	0	F	0	B	28.33	ABC
AvSYr17NIL	*Yr17*	0	D	22.5	DEFG	57.5	AB	18.75	BCDEF	50	AB	13.33	ABC
AvSYr18NIL	*Yr18*	10	CD	37.5	BCDEFG	37.5	ABCD	15	BCDEF	45	AB	16.67	ABC
AvSYr24NIL	*Yr24*	5	D	7.5	FG	30	ABCD	2.5	EF	10	B	0	C
AvSYr26NIL	*Yr26*	11.67	CD	15	EFG	5	D	1.25	F	2.5	B	1.67	C
AvSYr27NIL	*Yr27*	18.33	BCD	30	CDEFG	70	A	25	ABCDE	80	A	8.33	BC
AvSYr32NIL	*Yr32*	10	CD	60	ABCD	37.5	ABCD	6.25	DEF	25	AB	11.67	ABC
AvSYrSPNIL	*YrSp*	6.67	D	25	DEFG	12.5	CD	2.5	EF	2.5	B	16.67	ABC
Jupateco R	*Yr18*	1.67	D	25	DEFG	17.5	BCD	31.25	ABC	30	AB	1.67	C
Jupateco S	*Null*	13.33	BCD	37.5	BCDEFG	55	ABC	27.5	ABCD	90	A	40	AB
Avocet R	*YrA*	16.67	BCD	77.5	AB	72.5	A	37.5	AB	85	A	30	ABC
Avocet S	*Null*	30	ABC	70	ABC	70	A	45	A	85	A	46.67	A

Table 3. Average similarity (%) of natural infection on Near Isogenic wheat differential lines cultivated at six locations in three zones of northwest Pakistan from 2010 to 2013

Regions	Peshawar 2	Nowshara	Bannu	Abbotabad	Swat
Peshawar 1	8.16	12.5	27.72	0.13	15.53
Peshawar 2		22.37	25.61	22.43	18.77
Nowshara			12.07	24.34	3.60
Bannu				27.6	6.84
Abbotabad					20.74

DISCUSSION

Effective and relevant surveys of variability of the pathogens are fundamental to the achievement of genetic control of the cereal rusts (McIntosh *et al*., 1995). Yellow rust severity, infection types and number of virulences varied for the tested genes among years and test locations in Pakistan. Among tested genes, virulence frequency was upto 90% for *Yr6, Yr7, Yr8* and *YrA* in the natural rust populations across locations and years in northwest of Pakistan. Pathotypes carrying virulences for *Yr6*, *Yr7* and *Yr8* are known previously from Pakistan (Ahmad, 2002) and elsewhere (El-Daoudi *et al*., 1996; Hakim *et al*., 2002). Virulence for *YrA* was prevalent in the current study which was detected in 1977 for the first time in Pakistan (Hussain *et al*., 2004), soon after introduction of the resistance gene *YrA* in old wheat cultivars (Wellings *et al*., 1988). Virulence for *Yr8* was detected in Pakistan during 1970 (Hussain *et al*., 2004) and its widespread prevalence in this study could be due to the worldwide use of this gene from *Aegilops comosa* and its common presence in grasses (Stubbs 1985). Virulence for *Yr8* was also reported from Middle East (Hakim and Mamluk, 1996), England (Johnson *et al*., 1978), Australia (Wellings, 1988), Iran (Nazari and Torabi, 2000) and United States (Chen *et al*., 2002).

Virulences for *Yr1* and *Yr17* were reported from parts of Pakistan (Sharma-Poudyal *et al*., 2013) but current study has shown their effectiveness over three years in the southern zone. Similar results regarding both *Yr1* and *Yr17* were reported from Iran (Elyasi-Gomari and Petrenkova, 2011) and Egypt (Shahin *et al*., 2014). Virulence for *Yr9* was observed in the current study but it was inconsistent among locations and years. Despite the breakdown of *Yr9*, the migration of this new pathotype from the Eastern African highlands to North Africa, West Asia and South Asia up to Nepal (Singh *et al*., 2005) was damaging. In Pakistan, two *Yr9* based cultivars (i.e. Pirsabak-85 and Pak-81) resistance broke down which were extensively grown during 1994-95 in the northwest and rainfed areas of Punjab (Shah *et al*., 2003; 2005) and race 134E150 was responsible for the epidemic (Hussain *et al*., 2004). However, virulence for *Yr9* has declined since 2008 in northwest Pakistan (Shah, 2010) which may be due to the withdrawal of *Yr9* based cultivars from the seed production system. It is not wise to promote *Yr9* in the national wheat germplasm which was recently confirmed in several candidate lines (Begum *et al*., 2014). Several resistant cultivars released in the region (Inqilab-91 in Pakistan) following the epidemics on *Yr9* which were protected by *Yr27*. Evidence of the presence of virulence for *Yr27* started emerging in Pakistan under field conditions during 2003 which was confirmed in 2004 and was also reported from neighboring countries (Duveiller *et al*., 2007). Cultivation of Inqilab-91 carrying race specific resistance gene *Yr27* on a larger scale lead to greater genetic uniformity and consequently greater vulnerability resulted in an epidemic during 2005 when resistance of Inqilab-91 broke down in northwest Pakistan (Duveiller *et al*., 2007). Virulence frequency of *Yr27* was >70% in the current study which is a great threat to Attila and Kauz based varieties. Virulences were not observed in the central zone during 2010 for *Yr5*, *Yr10*, *Yr15* and *Yr24/Yr26* which is in agreement (except *Yr15*) with (Ali 2012). Field evidence of virulences for *Yr5*, *Yr10*, *Yr15, Yr18, Yr24/Yr26*, *Yr32* and *YrSp* started emerging in different zones/years after 2010 in northwest of Pakistan. In the current study, virulence frequency for *Yr5* was 60% and that of *Yr15* remained 20%. Both *Yr5* and *Yr15* were effective in many countries including Pakistan (Shah *et al*. 2010; Sharma-Poudyal *et al*., 2013; Wan and Chen 2014). However, yellow rust isolates virulent to *Yr5* have been reported in India and Australia and isolates virulent to *Yr15* has been reported from Afghanistan (McIntosh *et al*., 1995). Virulence frequency for *Yr10* was low (5%) in the current study and the presence of *Yr10* virulence in Southeast Asia, Nepal, and Pakistan differed from the findings of Stubbs (1985) and Hovmøller *et al*. (2008).

Virulence frequency for *Yr24*/*Yr26* was up to 50% and that of *Yr32* was 80% in the present study, isolates virulent to these genes have been reported from many countries including Pakistan (Sharma-Poudyal *et al*., 2013). Virulence frequency for *YrSp* was <50% in the current study but no information regarding this virulence existed in Pakistan during the past. Virulence to Spaldings Prolific, which is being used in the European set of differentials, was reported in many other countries in late 1960s and early 1970s (McIntosh *et al*., 1995). Furthermore, it was also reported recently from China, Turkey and Uzbekistan (Sharma-Poudyal *et al*., 2013). Virulence frequency for adult plant slow rusting resistance gene *Yr18* was 65%, however, less disease severity was recorded across northwest of Pakistan on *Yr18* in comparison with differential lacking this gene. Significant effect of *Yr18* on latent period and infection frequency is reported (Qamar *et al*., 2012) which is more pronounced at flag leaf and the gene is more effective at later stages of plant growth.

Dissimilarity among the virulence profiles of *P. striiformis*. f. sp. *tritici* at test locations in the current study may be due to several facts. Wheat cropping cycle has variability depending on the region in northwest Pakistan and it stretches from November to July and the crop is also available during summer from May to September in some areas. Frequent yellow rust occurrence is common in areas where weather favors over summering of the pathogen. Under suitable climate, about 80 species of rust fungi (including *P. striiformis*. f. sp. *tritici*) are reported from Pakistan on 93 poaceous host plant (Afshan and Khalid, 2013) while around the world, yellow rust fungus can over season on more than 300 species of grasses from 50 genera in addition to its primary host wheat (Sharma-Poudyal *et al*., 2013). Apart from this, occurrence of yellow rust alternate host *Berberis* is reported in the adjacent areas of Bannu (Shah *et al*., 2013), Peshawar and Nowshara (Sher *et al*., 2011), Abbotabad and Swat (Ali and Khan, 1978).

Virulence to most of the specific resistance genes was common and location factor as assessed by similarity index of yellow rust was not consistent in northwest Pakistan. However, *Yr10* and *Yr15* were considered to have very high to high resistance level and can be used in combination with race-non-specific genes (like *Yr18*) for wheat-breeding to achieve sustainable control of stripe rust in Pakistan. Further detailed study is needed to investigate the climatic suitability among locations/zones for confirming the degree of dissimilarity recorded in the virulence profiles of *P. striiformis*. f. sp. *tritici* in the current study

REFERENCES

Absattarova, A., Baboyev, S., Bulatova, K. *et al.* 2002. Improvement of wheat yellow rust resistance in Kazakhstan and Uzbekistan through subregional co-operation. Meeting the challenge of yellow rust in cereal crops. *In*: Proceedings of the First Regional Conference on Yellow Rust in the Central and West Asia and North Africa Region, Karaj, Iran, 8-14, May 2001. Pp 34-41

Afshan, NS. and Khalid, AN. 2013. Checklist of the rust fungi on Poaceae in Pakistan. Mycotaxon125:303

Afzal, SN., Haque, MI., Ahmedani, MS. *et al.* 2008. Impact of stripe rust on kernel weight of wheat varieties sown in rainfed areas of Pakistan. Pakistan Journal of Botany 40: 923-929

Ahmad, I. 2002. Yellow rust research in Pakistan: An Overview. *In*: Johnson R., Yahyaoui A, Wellings C, Saidi A. and Ketata H. (eds). Proceedings of the first regional conference on yellow rust in the Central and West Asia and North Africa region, 8-14 May 2001, Karaj, Iran, p. 143-149

Anonymous, 2002. Termination Report of the Project "Near Isogenic lines for assessment of pathogenic variation in the wheat stripe (yellow) rust pathogen" Australian Center for International Agricultural Research. (CSI/1996/023). 20pp

Ali, S. 2012. Population biology and invasion history of *Puccinia striiformis* f. sp. *tritici* at worldwide and local scale. PhD Dissertation. UNIVERSITE PARIS-SUD – UFR des Sciences – France

Ali, S., Leconte, M., Rahman, H. *et al.* 2014. A high virulence and pathotype diversity of *Puccinia striiformis* f.sp. *tritici* at its centre of diversity, the Himalayan region of Pakistan. European Journal of Plant Pathology. 140: 275-290

Ali, MN. and Khan, AA. 1978. Pharmacognostic studies of *Berberis lycium* Royle and its importance as a source of raw material for the manufacture of berberine in Pakistan. Pak. J. For. p.26

Aslanova, K., Nazari, K., Hodson, D. *et al.* 2012. Distribution of wheat rusts in Azerbaijan. *In*: McIntosh R. (ed) Proceedings Poster Abstracts *Theme 5:* Rust Surveillance BGRI 2012 Technical Workshop September 1-4 Beijing, China, pp. 223

Bahri, B., Shah, SJA., Hussain, S. *et al.* 2011. Genetic diversity of wheat yellow rust population in Pakistan and its relationship with host resistance. Plant Pathology 60: 649-660

Begum, S., Iqbal, M., Ahmed, I. *et al.* 2014. Allelic variation at loci controlling stripe rust resistance in spring wheat. J. Genet. 93, xx–xx]

Chatrath, R., Mishra, B., Ortiz Ferrara, G. *et al.* 2007. Challenges to wheat production in South Asia. Euphytica. 157:447-456

Cetin, L., Dusunceli, F., Albustan, S. *et al.* 2002. Virulence of wheat yellow rust on field grown yellow rust differentials, Turkish and regional wheat varieties in Ankara. Improvement of wheat yellow rust resistance in Kazakhstan and Uzbekistan through subregional co-operation. Meeting the challenge of yellow rust in cereal crops. In Proceedings of the First Regional Conference on Yellow Rust in the Central and West Asia and North Africa Region, Karaj, Iran, 8-14, May 2001. Pp 78-89

Chen, X. M., Moore, M., Milus, EA. *et al.* 2002. Wheat stripe rust epidemics and races of *Puccinia striiformis* f. sp. *tritici* in the United States in 2000. Plant Dis. 86:39-46

Duveiller, E., Singh, RP. and Nicol, JM. 2007. The challenges of maintaining wheat productivity: pests, diseases, and potential epidemics. Euphytica 157: 417-430

Elyasi-Gomari, S. and Petrenkova, VP. 2011. Virulence of *Puccinia striiformis* f. sp. *tritici* in Khuzestan Province of Iran American Journal of Experimental Agriculture 4: 281-293

El-Daoudi, YH., Shafik, I., Ghanemi, HE. *et al.* 1996. Stripe rust occurence in Egypt and assessment of grain yield loss in 1995. In: Ezzahiri B, Lyamani A, Farih A, El Yamani M, eds. *Proceedings of the Symposium régional sur les maladies des céréales et des légumineuses Alimentaires*, 1996. Rabat, Maroc, 11-14 November: 341-51

Hakim, MS. and Mamluk, OF. 1996. Virulence of wheat yellow rust pathogen in Syria and Lebanon. Page 141 in: Proc. 9th Eur. Mediterr. Cereal Rusts Powdery Mildew Conf. G. H. J. Kema, R. E. Nike, and R. A. Daamen, eds. European and Mediterranean Cereal Rust Foundation, Lunteren, The Netherlands.

Hakim, MS., Yahyaoui, A., El-Naimi, M. and Maaz, I. 2002. Wheat yellow rust Pathotypes in Western Asia. *In*: Johnson R., Yahyaoui A, Wellings C, Saidi A. and Ketata H. (eds). Proceedings of the first regional conference on yellow rust in the Central and West Asia and North Africa region, 8-14 May 2001, Karaj, Iran, p. 55

Hassan, SF. 1968. Cereal rusts situation in Pakistan. *In*: Proceedings of Europpean. and Mediterranean Cereal Rusts Conf Oeiras, Portugal, pp.124-25

Hovmøller, MS., Yahyaoui, AH., Miles, EA. and Justesen, AF. 2008. Rapid global spread of two aggressive strains of a wheat rust fungus. Mol. Ecol. 17:3818-3826

Hussain, M., Kirmani, MAS. and Haque, E. 2004. Pathotypes and man guided evolution of *Puccinia striiformis* West sp. *tritici* in Pakistan. Abstracts, Second Regional Yellow Rust Conference for Central &West Asia and North Africa, 22–26 March 2004, Islamabad, Pakistan. 21

Johnson, R., Priesley, RH. and Taylor, EC. 1978. Occurrence of virulence in *Puccinia striiform*is for Compair wheat in England. Cereal Rusts Bull. 3:4-6

Leonard, KJ., Huerta-Espino, J. and Salmeron, JJ. 2005. Oat crown rust virulence in Mexico. Plant Disease 89: 941-948.

Line, RF. and Qayoum, A. 1992. Virulence, aggressiveness, evolution, and distribution of races of *Puccinia striiformis* (the cause of stripe rust of wheat) in North America, 1968–87. United States Department of Agriculture. Agricultural Research Service. Technical Bulletin. 1788

Manninger, K. 2002. Effective resistance genes as source of resistance against Hungarian wheat rusts. Czech Journal of Genetic Plant Breeding, 38: 153-154

McIntosh, RA., Dubcovsky, J., Rogers, WJ. *et al*. 2010. Catalogue of gene symbols. KOMUGI Integrated Wheat Science Database. http://www.shigen.nig.ac.jp/wheat/komugi/genes/symbol ClassList.jsp;jsessionid=689B192F53CED7CB561A9DC624FB9518.lb1,%202010

McIntosh, RA., Wellings, CR. and Park, RF. 1995. Wheat rusts: an atlas of resistance genes, Melbourne, CSIRO Publications.

Minitab 17 Statistical Software, 2010. [Computer software]. State College, PA: Minitab, Inc. (www.minitab.com)

Nazari, K. and Torabi, M. 2000. Distribution of yellow rust (*Yr*) resistance genes in Iran. Acta Phytopathol. Entomol. Hung. 35:121-131

Nori, A. and Maaroof, EA. 2012. Epidemic and development of yellow rust on different wheat genotypes. In: McIntosh R. (ed) Proceedings Poster Abstracts *Theme 5:* Rust Surveillance BGRI 2012 Technical Workshop September 1-4 Beijing, China, pp. 214

Park, RF. 2007. Stem rust of wheat in Australia. Crop Pasture Sci. 58:558-566

Peterson, RF., Campbell, AB. and Hannah, AE. 1948. A diagrammatic scale for rust intensity on leaves and stems of cereals. Canadian Journal of Research, 26: 496-500

Qamar, M., Gardezi, DA. and Iqbal, M. 2012. Determination of Rust Resistance Gene Complex *Lr34/Yr18* in Spring Wheat and its Effect on Components of Partial Resistance. Journal of Phytopathology 160: 628-636

Ramdani, A., Nazari, C., Hodson, D. *et al.* 2011b. The reason behind the serious outbreak of wheat yellow rust in Morocco: Yr27 is no longer effective. *In*: McIntosh R (ed) Abstract of Oral Papers and Posters, Theme 1: Rust Surveillance and Genetics 2011 Technical Workshop, BGRI, Cd. Obrego´n, Sonora Mexico, pp 156

Rajaram, S., Hobbs, PR. and Heisey, PW. 1998. Report on Review of Pakistan wheat and maize research system. 32pp.

Shah, SJA. 2010. Characterization of *Puccinia striiformis* Westend. f. sp. *tritici* Eriks population and its control through host resistance. PhD Dissertation. The University of Agricuture, Peshawar

Shah, SJA., Khan, AJ., Azam, F. *et al*. 2003. Stability of rust resistance and yield potential of some ICARDA bread wheat lines in Pakistan. Pak. J. Sci. Ind. Res. 46: 443-446

Shah, SJA., Imtiaz, M. and Hussain, S. 2010. Phenotypic and Molecular Characterization of Wheat for Slow Rusting Resistance against Pu*ccinia striiformis* Westend. f. sp. *tritici*. Journal of Phytopathology 158: 393-402

Shah, SJA., Mohmmad, T. and Azam, F. 2005. Evaluation of commercial and candidate bread wheat varieties for durable resistance to rusts in Pakistan. Pak. J. Sci. Ind. Res. 48:366-367

Shahin, AA., Youssef, WA., Abu Aly, AA. and Ashmawy, MA. 2014. Virulence and diversity of the stripe rust pathogen in Egypt, 2009 to 2013.2014 Technical Workshop 22-25 March Universidad La Salle NoroesteCd. Obregón, Mexico

Sharma-Poudyal, D., Chen, XM., Wan, AM. *et al.* 2013. Virulence characterization of international collections of the wheat stripe rust pathogen, *Puccinia striiformis* f. sp. *tritici*. Plant Dis. 97:379-386

Sharma, S., Thapa, DB., Bhatta, MR. *et al.* 2012. Effect of climate and virulence changes on wheat rust epidemics in Nepal. *In*: McIntosh R. (ed) Proceedings Poster Abstracts *Theme 5:* Rust Surveillance BGRI 2012 Technical Workshop September 1-4 Beijing, China, pp. 226

Shah, A., Marwat, SK., Gohar, F. *et al.* 2013. Ethnobotanical Study of Medicinal Plants of Semi-Tribal Area of Makerwal & Gulla Khel (Lying between Khyber Pakhtunkhwa and Punjab Provinces), Pakistan. American Journal of Plant Sciences 4: 98-116

Sher, Z., Hussain, F. and Badshah, L. 2011. Micro-mineral contents in eight forage shrubs at three phenological stages in a Pakistan's rangeland. African Journal of Plant Science 10: 557-564

Singh, RP., William, HM., Huerta-Espino, J. and Rosewarne, G. 2005. Wheat rust in Asia: meeting the challenges with old and new technologies. Proc 4th Int Crop Science Congress, Brisbane, Australia, 26 September–1 October 2004. Gosford, NSW, The Regional Institute Ltd. Crop Sci 40:1148-1155

Singh, RP., Nelson, JC. and Sorrells, ME. 2000b. Mapping Yr28 and other genes for resistance to stripe rust in wheat.

Singh, RP., Huerta-Espino, J. and Roelfs, AP. 2002. The wheat rusts. *In*: Curtis BC, Rajaram S, Gomez Macpherson H (eds) Bread Wheat: Improvement and Production, Plant Production and Protection Series No. 30. Rome, FAO, pp 227-249

Stubbs, RW. 1985. Stripe rust. Page 61-101 *In*: The Cereal Rusts II. Diseases, Distribution, Epidemiology and Control. A. P. Roelfs and W. R. Bushnell, eds. Academic Press, New York.

USDA, 2010. Catalog of Rust Resistance Genes in Small Grains http://www.ars.usda.gov/Main/docs.htm?docid=10342

Volkova, GV., Anpilogova, LK., Sinyak, EV. and Shumilov, YV. 2011. Distribution of wheat rusts and effectiveness of resistance genes in the Russian North Caucasus region. *In*: McIntosh R (ed) Abstract of Oral Papers and Posters, Theme 1: Rust Surveillance and Genetics 2011 Technical Workshop, BGRI, Cd. Obrego´n, Sonora Mexico, pp 161

Wan, AM. and Chen, XM. 2014. Virulence characterization of *Puccinia striiformis* f. sp. *tritici* using a new set of *Yr* single-gene line differentials in the United States in 2010. Plant Dis. 000:000-000.

Wellings, CR. 2011. Global status of stripe rust: a review of historical and current threats. Euphytica 179:129-141

Wellings, CR., McIntosh, RA. and Hussain, M. 1988. A new source of resistance to *Puccinia striiformis* f. sp. *tritici* in spring wheats (*Triticum aestivum*). Plant Breeding 100: 88-96

Welling, CR., McIntosh, RA., Singh, RP. and Yahyaoui, A. 2000. International surveillance to detect pathogenic variation in *Puccinia striiformis*. 6th International wheat conference. Budapest, Hungary, June 4-6

Yahyaoui, AH., Hakim, MS., El Naimi, M. and Rbeiz, N. 2002. Evolution of physiologic races and virulence of *Puccinia striiformis* on wheat in Syria and Lebanon. Plant Disease. 86:499-504.

****