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DIFFERENTIAL DISTRIBUTION OF LEAF RUST ACROSS MAJOR WHEAT GROWING REGIONS OF PAKISTAN REVEALED THROUGH A THREE YEAR SURVEILLANCE EFFORT

MUHAMMAD RAMEEZ KHAN[1], MUHAMMAD IMTIAZ[2], IQBAL MUNIR[1], IZHAR HUSSAIN[3] AND SAJID ALI[1*]

[1]*Institute of Biotechnology & Genetic Engineering, The University of Agriculture, Peshawar, Pakistan*
[2]*International Maize and Wheat Improvement Center (CIMMYT), CSI Building, NARC, Park Road, Islamabad 44000, Pakistan*
[3]*Department of Agriculture, University of Haripur, Haripur, Pakistan*
**Corresponding author's email: bioscientist122@yahoo.com*

Abstract

Considering the important role of wheat leaf rust disease in reducing wheat yields, the present study was designed to assess the countrywide distribution of wheat leaf rust across Pakistan, based on the surveillance conducted during 2016, 2017 and 2018. A total of 1202 fields were surveyed from 95 districts over the three years. The surveillance revealed that both spatial and temporal variability were present across Pakistan in terms of incidence and severity of leaf rust. The disease was more prevalent in Sindh and Punjab than other parts, with little infestation in the northern cold wheat growing regions. The disease was more prevalent in 2017 than both 2016 and 2018. In the Sindh province, 20% fields surveyed over three years had the severe leaf rust infestation (with >60% severity), while in Punjab the disease was absent in more than 95% fields. In Khyber Pakhtunkhwa and Kashmir, the disease was detected in less than 1% of the total surveyed fields. Our results revealed that among the four provinces and the Kashmir state, leaf rust was a major problem in Sindh and Southern Punjab, while over the three years, it was more prevalent in 2017. Among the major cultivated varieties surveyed, severe infestation was observed for wheat varieties Galaxy-2013, Morocco, TD_1, Sehar, Yecora, Aas-11, Inqilab-91, Kiran-95, Shafaq, Sarsabz, TJ-83, Marvi, Sassi and some local lines. The information should be useful for both breeders, farmers and extension workers to devise a better leaf rust management strategy considering the relative regional risk of the disease.

Key words: *Puccinia triticina*, Himalayan region, Temperature, Disease surveillance.

Introduction

Pakistan being an agricultural country, mostly relies on agriculture for its economy, where wheat is one of the most important commodities vital for food security. Despite of this intense importance, the average yield of wheat per hectare is much lesser than progressive countries (Brian, 2006). Wheat is cultivated on more than 40% of the total cropped area by more than four million farmers in Pakistan in diverse environmental and ecological conditions (Faruqee *et al*., 1997). Thus, reduction in wheat production impact a large tranche of the Pakistani society, with direct repercussions for the farming community. Higher yields than the present ones on the other hand is of dire need in the context of increasing population creating a challenging situation for agriculture sector to meet the food demand.

Many challenges are faced by farmers to achieve high yields of wheat including biotic and abiotic factors. Among biotic factors, the rust diseases of wheat are of intense importance (Ali *et al*., 2014; Hovmøller *et al*., 2010). There are three major rust diseases that affect adversely on wheat yield and prevails in most of the wheat growing areas i.e. stem/black rust, yellow/stripe rust and brown/leaf rust (Ali *et al*., 2014; Singh *et al*., 2016). The widespread epidemics of wheat rust in early 20th century provided the motivation for primary advancements in genetics of plants disease resistance, plant pathogens epidemiology and genetics of host pathogen interactions. The sustainable wheat production is still highly threatened by rust diseases because of continuous global yield losses (Singh *et al*., 2016), where the wheat leaf rust is a widely prevalent and an extensively distributed disease, particularly in the mild to warm climatic conditions, representing the wheat basket of Asia.

Wheat leaf rust causing agent is the fungal pathogen, *Puccininia triticana*, which is adapted to climatic conditions of wheat growing region throughout the Europe, Americas, South & North Africa, South, Central & North Asia, and Australia, causing different levels of damages (McCallum *et al*., 2012). Between 2000 and 2004, leaf rust caused 350 million US dollars economic losses in the United States. Annual yield losses in China by leaf rust are estimated at three million tons. In Mexico and South Asia it was a devastating disease in the past but it is becoming negligible in current situations because of introduction of slow rusting resistance genes in new wheat cultivars (Huerta-Espino *et al*., 2011). However, production losses in case of severe leaf rust epidemic in Pakistan caused 86 million USD losses in 1978 (Hussain *et al*., 1980). Although in Pakistan the disease onset is delayed in the northern part, its onset is regular in the major wheat growing region of Punjab.

Leaf rust pathogen *P. triticina* is adapted to mild cold climate. Variability in pathogen population can further intensify the situation, where pathogen variants from exotic and diverse genetic background may have adaptability to diverse climatic conditions, as observed in case of yellow rust (Milus *et al*., 2009; Walter *et al*., 2016; Brar *et al*., 2018).

Climatic changes and subsequent variability in crop duration require rigorous wheat leaf rust surveillance to keep an eye on the disease and its emergence in previously unaffected areas. Thus, the present study was designed to assess the countrywide situation of leaf rust in different geographical and climatic situation with the response of host to disease.

Materials and Methods

Wheat rusts scoring and surveillance: Field scoring of leaf rust was carried out using standardized protocol (Ali & Hodson, 2017). The surveillance was carried out during the peak of rust infection in major wheat growing areas of Pakistan starting from the southern districts in Sindh to northern districts in Kashmir, Hazara and Swat for 2016 and 2017, while during 2018 Gilgit Baltistan, KP and central Punjab were covered. During 2016, surveillance was carried out in 63 districts, during 2017 in 69 districts and during 2018, 34 districts were covered (Fig. 1). Considering the aerial dispersal of leaf rust pathogens, an attempt was made to cover the maximum area of the representative wheat growing region. After every 10 to 20 kilometers depending on presence of wheat fields, surveillance was conducted.

For scoring leaf rust infection, two parameters were taken in consideration i.e. host reaction and rust severity, which was recorded on leaves of each wheat variety in a field (Ali & Hodson, 2017). Modified Cobb scale (0-100 scale) was used to estimate disease severity and percentage of rusted tissue of plant in a field, while considering the field infestation (Peterson *et al*., 1948). To score host response to infection, the infection types was measured (Singh, 1993). The host reaction types in the order of R (resistance), MR (moderately resistant), MRMS (moderately resistant-moderately susceptible), MS (moderately susceptible) and S (susceptible) was recorded.

Analyses of surveillance data and average coefficient of infection (ACI): The surveillance data was analysed in MS Excel and in R-statistical environment. The disease status was analysed in relation to provinces, districts and host varieties. The geographical distribution of the leaf rust across various geographical locations and different hosts was analysed based on its relative prevalence as a function of geography and host. Average coefficient of infection was calculated by multiplying disease severity and an incrimental value for each infection types (Pathan & Park, 2007; Saari & Wilcoxson, 1974).

Results

The relative importance of wheat leaf rust disease in various parts of Pakistan along with the response of major wheat varieties was revealed through surveillance of leaf rust in farmer fields and research station over a period of three years 2016-18 (Fig. 2). Relatively a high disease was observed during 2017 as compared to 2016, while the pressure and number of highly infected field was low in the northern part of Pakistan i.e., AJK and Khyber Pakhtunkhwa, during 2018.

The numbers of districts and wheat fields surveyed in different provinces varied in each year of surveillance, depending on the availability of wheat crop in the region. A total of 63 districts were covered during 2016, 69 districts during 2017, while surveillance during 2018 covered 34 districts across country (Fig. 3a). The number of fields surveyed during 2016 were 437, 480 during 2017 while surveillance during 2018 covered 285 fields across AJK, Gilgit Baltistan, Baluchistan, KP, Punjab and Sindh (Fig. 3b).

Leaf rust prevailed in most of the areas during 2017 while in 2016 and 2018 relatively low disease pressure was recorded. A total of 69 fields with high disease pressure were recorded across country during three years. The number of fields with high disease severity across the whole country was higher in 2017 (41 out of 299 fields) than in 2016 and 2018 (21 out of 275 and 1 out of 156 fields) in high disease occurring districts. A total of 14 varieties were found susceptible to leaf rust in three years along with some breeding lines, mixtures and some unknown varieties, showing a high disease pressure at different locations in different provinces. In case of varieties surveyed over multiple locations, the response of the host to leaf rust varied across locations. Galaxy-13 was recorded with high disease severity at most locations surveyed (KP, Sindh and Punjab). A high disease was also observed on Sehar in Sindh and Punjab. High leaf rust was also observed on TD-1 and Morocco in Sindh and Punjab (Table 1).

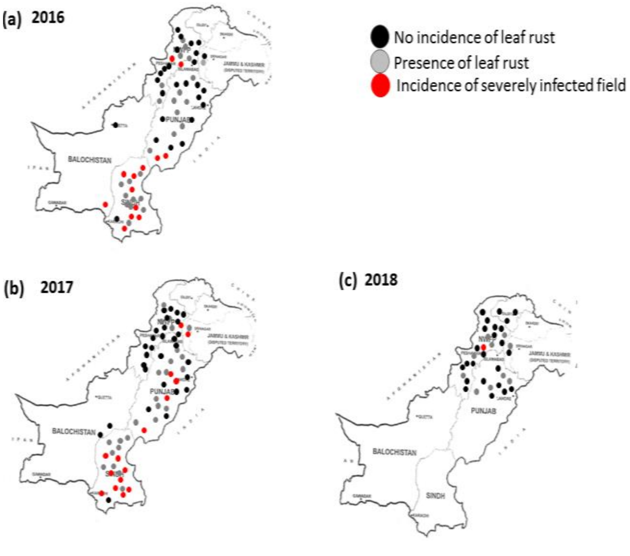

Fig. 1. Map of Pakistan showing the districts covered during 2016, 2017 and 2018 along with the relative distribution of wheat leaf rust disease.

Fig. 2. Wheat leaf rust symptoms observed in a wheat field during countrywide surveillance effort of 2016 to 2018.

Table 1. Number of wheat varieties with >60% LR during 2016, 2017 and 2018 in AJK, Baluchistan, Gilgit-Baltistan, KP, Punjab and Sindh.

Province	Varieties	2016		2017		2018		Total	
		Field surveyed	Fields with >60% LR	Field surveyed	Fields with >60% LR	Field surveyed	Fields with >60% LR	Field surveyed	Fields with >60% LR
AJK	Mixture	1	0	2	1	4	0	7	1
KP	Galaxy-13	34	1	25	0	34	0	93	1
	Unknown	31	0	50	1	52	1	133	2
Punjab	Galaxy-13	33	2	42	1	5	0	80	3
	Mixture	12	0	18	3	7	0	37	3
	Morocco	0	0	2	1	0	0	2	1
	Sehar	14	1	14	2	3	0	31	3
	TD-1	18	0	5	1	2	0	25	1
	Unknown	44	1	43	1	49	0	136	2
	Yecora	0	0	1	1	0	0	1	1
Sindh	Aas-11	0	0	3	2	0	0	3	2
	Galaxy-13	8	4	11	6	0	0	19	10
	Inqilab	5	1	4	1	0	0	9	2
	Kiran-95	12	1	12	8	0	0	24	9
	Marvi	2	1	1	0	0	0	3	1
	Mixture	25	4	6	0	0	0	31	4
	Morocco	3	2	4	1	0	0	7	3
	Multiple breeding lines	3	0	8	1	0	0	11	1
	Sarsabz	4	3	2	0	0	0	6	3
	Sassi	0	0	2	1	0	0	2	1
	Sehar	16	5	5	1	0	0	21	6
	Shafaq	1	0	1	1	0	0	2	1
	TD-1	4	0	21	3	0	0	25	3
	TJ-83	5	1	14	3	0	0	19	4
	Zincol	0	0	3	1	0	0	3	1
Overall		**275**	**27**	**299**	**41**	**156**	**1**	**730**	**69**

Table 2. Number of fields in various districts recorded with >60% leaf rust infestation during 2016, 2017 and 2018 in AJK, Baluchistan, Gilgit-Baltistan, KP, Punjab and Sindh.

Province	Districts	2016		2017		2018		Total	
		Field surveyed	Fields with >60% LR	Field surveyed	Fields with >60% LR	Field surveyed	Fields with >60% LR	Field surveyed	Fields with >60% LR
AJK	Muzafferabad	5	0	8	1	16	0	29	1
KP	Mansehra	29	0	10	1	6	0	45	1
	Nowshera	8	1	4	0	6	1	18	2
Punjab	Attock	7	1	6	0	0	0	13	1
	Bahawalpur	9	1	18	3	0	0	27	4
	Faisalabad	0	0	8	1	0	0	8	1
	Hafizabad	7	0	17	4	10	0	34	4
	Jhang	8	0	5	1	0	0	13	1
	Lodhran	13	2	0	0	0	0	13	2
	Nankana Sahib	0	0	9	1	0	0	9	1
Sindh	Badin	11	5	5	2	0	0	16	7
	Dadu	6	1	0	0	0	0	6	1
	Gotki	6	1	4	0	0	0	10	1
	Hyderabad	4	2	19	3	0	0	23	5
	Jamshoro	5	3	0	0	0	0	5	3
	Karachi	5	0	4	1	0	0	9	1
	Khairpur	4	0	2	1	0	0	6	1
	Larkana	10	1	4	0	0	0	14	1
	Metiari	6	0	12	1	0	0	18	1
	Mir Purkhas	7	1	4	3	0	0	11	4
	Nawab Shah	5	1	19	0	0	0	24	1
	Noshero Ferozo	8	0	5	1	0	0	13	1
	Qamber Shehdadkot	5	0	2	1	0	0	7	1
	Sajawal	0	0	4	3	0	0	4	3
	Sanghar	8	2	8	6	0	0	16	8
	Shikarpur	9	1	4	0	0	0	13	1
	Tando Allahyar	0	0	11	2	0	0	11	2
	Tando Muhammad Khan	5	0	3	2	0	0	8	2
	Thatta	9	1	0	0	0	0	9	1
	Umer Kot	9	3	14	3	0	0	23	6
Overall		**208**	**27**	**209**	**41**	**38**	**1**	**455**	**69**

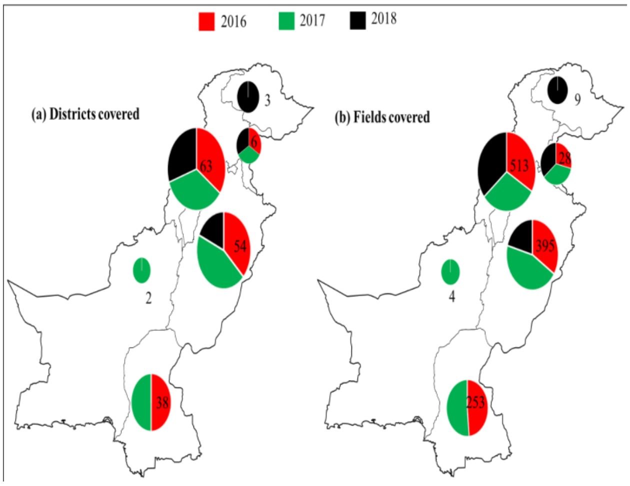

Fig. 3. Relative distribution of districts (a) and (b) fields covered over various geographical regions of Pakistan (AJK, Baluchistan, Gilgit Baltistan, KP, Punjab and Sindh) during 2016, 2017 and 2018.

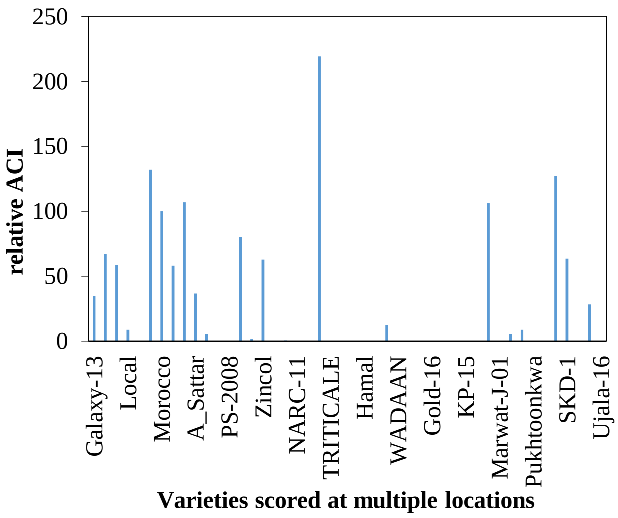

Fig. 4. Relative ACI of major wheat varieties grown across Pakistan during 2016, 2017 and 2018.

In AJK highly infected wheat field were observed in Muzafferabad only during 2017, while in KP high disease was observed in Nowshera during 2016 and 2018 and in Mansehra during 2017. In Punjab, a high disease was recorded in seven districts. The maximum numbers of fields with high disease were observed in Bahawalpur and Hafizabad. In Sindh, the disease prevailed in most of the districts surveyed and was recorded in 20 districts during different years. The maximum numbers of highly infected fields were observed in Sanghar where 8 out 16 fields were highly infected. In Badin, seven fields, and six fields in Umerkot were observed with severe disease infestation. In other districts of Sindh, the number of highly infected fields ranged from 1 to 5 (Table 2).

Overall the numbers highly infected fields observed in AJK was one during 2017 (Table 3). In Gilgit Baltistan none of the field was observed with high disease out of nine fields surveyed during 2018. In KP one field with high disease was recorded in each year. The number of highly infected fields in Punjab was four during 2016, 10 during 2017 while none of the field was recorded with high disease during 2018 out of total 82 fields surveyed. In Sindh, 22 fields in 2016 and 29 fields with high disease were recorded during 2017. Surveillance was not carried in Sindh during 2018.

Concerning with ACI values, it could be concluded that the varieties Sehar, TD-1, Kiran-95, Morocco, Inqilab-91, TJ-83, Sarsabz, Marvi and Shafaq were recorded with high susceptibility to leaf rust in different growing seasons having ACI values greater than 20. Other major wheat varieties like PS-05, PS-13, Ujala-16, Zincol-16, Gold-16, Khaista, Pukhtunkhwa, Bezair 13, Pak-13 and Punjab-11 were marked as resistant having ACI value below 20 (Table 4; Fig. 4).

Discussion

The present study enabled to identify the countrywide distribution of leaf rust across Pakistan. Leaf rust prevailed at most of the areas of Sindh, southern Punjab and some parts of KP and northern Punjab. The high leaf rust prevalence in Sindh and southern Punjab may be attributed to warm environmental conditions of those areas (Khalil & Jan, 2003). Leaf rust genes are influenced by environmental conditions especially temperature, where warm climate with cold weather could help development of the disease (Agarwal *et al*., 2003). The temperature of southern and central parts of Pakistan is high as compared to the northern part (Khalil & Jan, 2003), which is suitable for leaf rust pathogen growth and development. Additionally, certain leaf rust resistance genes expression ceases with the increase in temperature (Browder, 1980; Johnson & Schafer, 1965; Jones & Deverall, 1977), giving the pathogen a free hand to establish a strong disease. Certain leaf rust resistance genes are temperature sensitive especially high temperatures, while some leaf rust resistance (Lr) gene expression is also halted at lower temperatures (Dyck & Johnson, 1983). Change of temperature during early penetration phase alters the host-pathogen interaction (Hyde, 1982). Most of the Lr genes are affected by post infection temperatures; where Lr11, Lr12, Lr13, Lr14a, Lr16, Lr17 and Lr18 are particularly sensitive to high temperature (Dyck & Johnson, 1983).

For leaf rust most of major varieties grown in southern country showed susceptible reaction. Wheat varieties Galaxy-13, TD-1, TJ-83, Kiran-95, A. Sattar, Naya Amber, Inqilab-91, Sassi, Skd-1, Sarsabz and Sehar were found with high disease severity in Sindh and Punjab, while Galaxy-13 was found susceptible at all locations surveyed. The susceptibility of major wheat varieties to leaf rust can be due to the presence of virulence against the Lr genes or down expression of Lr genes at higher temperatures. Moreover, the presence of highly susceptible varieties like Galaxy-13, TD-1, Morocco etc. could have contributed to maintain inoculum in the region (Ali *et al*., 2009b; Khan *et al*., 2019). Morocco is not common in Pakistan, only grown in trap nurseries in research stations but some susceptible varieties like TD-1 is commonly grown in Sindh and southern Punjab. Susceptibility in these cultivars may be due to high pathogen diversity related to the long-term use of wheat cultivation with diverse genetic background for leaf rust resistance genes.

Table 3. Total number of fields and fields recorded with >60% leaf rust during 2016, 2017 and 2018 in AJK, Baluchistan, Gilgit-Baltistan, KP, Punjab and Sindh.

Province	2016		2017		2018	
	Fields surveyed	Fields with >60% LR	Fields surveyed	Fields with >60% LR	Fields surveyed	Fields with >60% LR
AJK	8	0	10	1	10	0
Baluchistan	0	0	4	0	0	0
Gilgit Baltistan	0	0	0	0	9	0
KP	171	1	158	1	184	1
Punjab	135	4	178	10	82	0
Sindh	123	22	130	29	0	0
Pakistan	437	27	480	41	285	1

Table 4. Resistance traits in major wheat varieties grown across Pakistan during 2016, 2017 and 2018.

Variety	2016		2017		2018		Overall	
	ACI	No of fields	ACI	No of fields	ACI	No of fields	ACI	No of fields
Galaxy-13	10.3	35.0	10.5	40.0	0.1	21.0	8.3	60
Sehar	20.8	25.0	15.1	18.0	0.1	4.0	15.8	37
TD-1	0.1	12.0	26.6	18.0	0.0	1.0	13.8	26
Local	2.2	20.0	2.1	10.0	0.0	2.0	2.1	25
PS-05	0.0	8.0	0.0	9.0	0.1	9.0	0.0	18
Kiran-95	12.0	9.0	50.2	8.0	-	-	31.1	12
Morocco	40.0	4.0	18.9	8.0	0.0	1.0	23.6	12
Inqilab	10.9	7.0	27.0	4.0	0.0	1.0	13.7	11
TJ-83	18.8	3.0	27.5	10.0	-	-	25.2	11
A_Sattar	9.0	7.0	8.0	4.0	-	-	8.7	10
Shahkar	0.0	7.0	2.3	7.0	1.0	3.0	1.3	10
PS-13	-	-	0.0	5.0	0.0	5.0	0.0	7
PS-2008	0.0	7.0	-	-	-	-	0.0	7
Aas-11	-	-	22.1	5.0	0.0	1.0	18.9	6
Benazir	0.0	1.0	0.4	5.0	-	-	0.4	6
Zincol	-	-	17.8	5.0	0.0	1.0	14.8	6
Johar-16	-	-	0.0	5.0	-	-	0.0	5
Atta Habib	0.2	3.0	0.0	1.0	-	-	0.1	4
NARC-11	0.0	1.0	0.0	3.0	-	-	0.0	4
PS-15	-	-	0.0	1.0	0.0	3.0	0.0	4
Sarsabz	66.3	3.0	22.5	2.0	-	-	51.7	4
Triticale	0.0	2.0	0.0	2.0	0.0	1.0	0.0	4
Barlay	-	-	-	-	0.0	3.0	0.0	3
FSD-08	-	-	0.0	1.0	0.0	2.0	0.0	3
Hamal	0.0	1.0	0.0	2.0	-	-	0.0	3
Khaista	-	-	-	-	0.0	3.0	0.0	3
Khattakwal	8.1	3.0	0.0	2.0	0.0	3.0	3.0	3
Wadaan	-	-	-	-	0.0	3.0	0.0	3
Amin-10	-	-	0.0	1.0	0.0	1.0	0.0	2
Ghanimat-IBGE	-	-	0.0	2.0	0.0	1.0	0.0	2
Gold-16	-	-	0.0	2.0	-	-	0.0	2
Imdad-05	0.0	1.0	0.0	1.0	-	-	0.0	2
IV-II	-	-	0.0	2.0	-	-	0.0	2
KP-15	-	-	0.0	2.0	0.0	1.0	0.0	2
Lakki-03	-	-	0.0	1.0	0.0	1.0	0.0	2
Marvi	37.5	1.0	0.0	1.0	-	-	25.0	2
Marwat-J-01	-	-	0.0	1.0	0.0	1.0	0.0	2
Moomal-02	2.5	1.0	0.0	1.0	-	-	1.3	2
PAK-13	2.1	2.0	-	-	-	-	2.1	2
Pukhtoonkwa	-	-	-	-	0.0	2.0	0.0	2
Punjab-11	-	-	0.0	2.0	-	-	0.0	2
Shafaq	0.0	1.0	60.0	1.0	-	-	30.0	2
SKD-1	-	-	15.0	2.0	-	-	15.0	2
SKD-2	-	-	0.0	2.0	-	-	0.0	2
TJ-1	6.7	2.0	-	-	-	-	6.7	2
Ujala-16	-	-	0.0	2.0	-	-	0.0	2

The severity and frequency of leaf rust in northern part of country was noticeable during 2017. The disease was not a major problem previously in KP and northern part of country but currently becoming a threat to crop yield, because of the climate change and cultivation of most susceptible cultivars. The postulated genes in Pakistani wheat varieties and breeding lines are Lr1, Lr3, Lr9, Lr10, Lr13, Lr14a, Lr16, Lr17, Lr23, 255 Lr26 and Lr27+Lr31 (Rattu *et al*., 2010). In another study the genes Lr1, Lr10, Lr16, Lr14a, Lr17, Lr24 and Lr26 were postulated to be present in recent Pakistani wheat varieties and breeding lines (J. Kolmer, unpublished data). However, virulence to many of these genes have been reported (Kolmer *et al*., 2017). Partial resistance has been advocated by many researchers to confer a more durable resistance, influencing the pathogen adaptation pace (Ali *et al*., 2009; de Vallavieille-Pope *et al*., 2012). The future development of wheat germplasm in Pakistan with high levels of durable leaf rust resistance will depend on the ability to select genotypes that have combinations of effective resistance genes along with the adult plant resistance genes.

Conclusion

The present study revealed the countrywide distribution of wheat leaf rust across Pakistan, based on a three year surveillance effort. The disease showed both spatial and temporal variability in terms of presence and severity. The disease was more prevalent in Punjab than other parts, with little infestation in the northern cold wheat growing regions. The disease was more prevalent in 2017 than both 2016 and 2018. The information should be useful for both breeders to devise wheat improvement strategies and farmers and extension workers to select improved wheat varieties for high yields, while considering the potential risk of wheat leaf rust to attain higher wheat yields.

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