Research Article

Yellow Rust Surveillance and Deployment of Wheat Cultivars in the Region of Pathogen Diversity in Pakistan

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Abstract | Yellow rust, caused by *Puccinia striiformis* f.sp. *tritici*, is one of the most important diseases of wheat in many parts of the world including Pakistan. Surveillance for yellow rust occurrence, distribution and impact on wheat landscape was carried out along with recent deployment status of cultivars during 2012 in northwest Pakistan located close to the center of diversity of *P. striiformis* f.sp. *tritici*. Around 1600 wheat fields were sampled covering a geographical area of little less than 5000 acres in the southern, central and northern zones located in the Khyber Pakhtunkhwa (KPK) Province. Yellow rust occurrence was distributed over an area of 463 acres in all three wheat production zones. Maximum yellow rust impact values (estimated by Field Impact Factor (FIF) of 121, 201 and 328 were recorded in Bannu (Southeren Zone), Nowshara (Central Zone) and Mansehra (Northeren Zone), respectively. Fields with yellow rust incidence of 26% or higher than 26% were found maximum in the northeren zone (30%) which was followed by the central (6%) and southern zone (2%). Frequency of yellow rust severity of 5 (20-29% leaf area affected) to 9 (>75% of leaf area affected) was maximum in northeren zone (40%) which was followed by the central (10%) and southern zone (3.5%). A total of 35 known and unknown cultivars were deployed in the three wheat production zones and out of these, each of the 22 occupied less than 1% acreage. Remaining wheat cultivars including Atta Habib, Auqab-2002, Bhakkar-2002, Bathoor-2008, Fakhar-e-Sarhad, Hashim-2008, Inqilab-91, Pirsabak-2004, Pirsabak-2005, Sehar-2006 and Serin-2010 occupied 94% of the acreage in the three zones. Sehar-2006 was the dominant wheat cultivar occupied 54% of the total wheat area which is already susceptible and carries an undesirable *Yr9* gene. Cultivars with effective yellow rust resistance genes have negligible deployment area which included Tatara (*Yr3*, *Yr5*, *Yr26*), Shafaq-2006 (*Yr5*, *Yr10*), Pirsabak-2005 (*Yr5*, *Yr26*, *Yr30*) and Saleem-2000 (*Yr5*, *Yr18*, *Yr26*). Seeds of these cultivars should be increased and deployed on priority bases for yellow rust management in the region.

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Introduction

Yellow rust caused by *P. striiformis* f. sp *tritici* is one of the most important foliar diseases of wheat around the world (Welling, 2011) including Asia where it can affect 43 million ha (Singh et al., 2004). Out of the total 9 million ha of wheat acreage in Pakistan, 70% is prone to yellow rust (Bahri et al., 2011) and during different periods have caused 13 epidemics resulting in huge financial losses (Afzal et al., 2008).

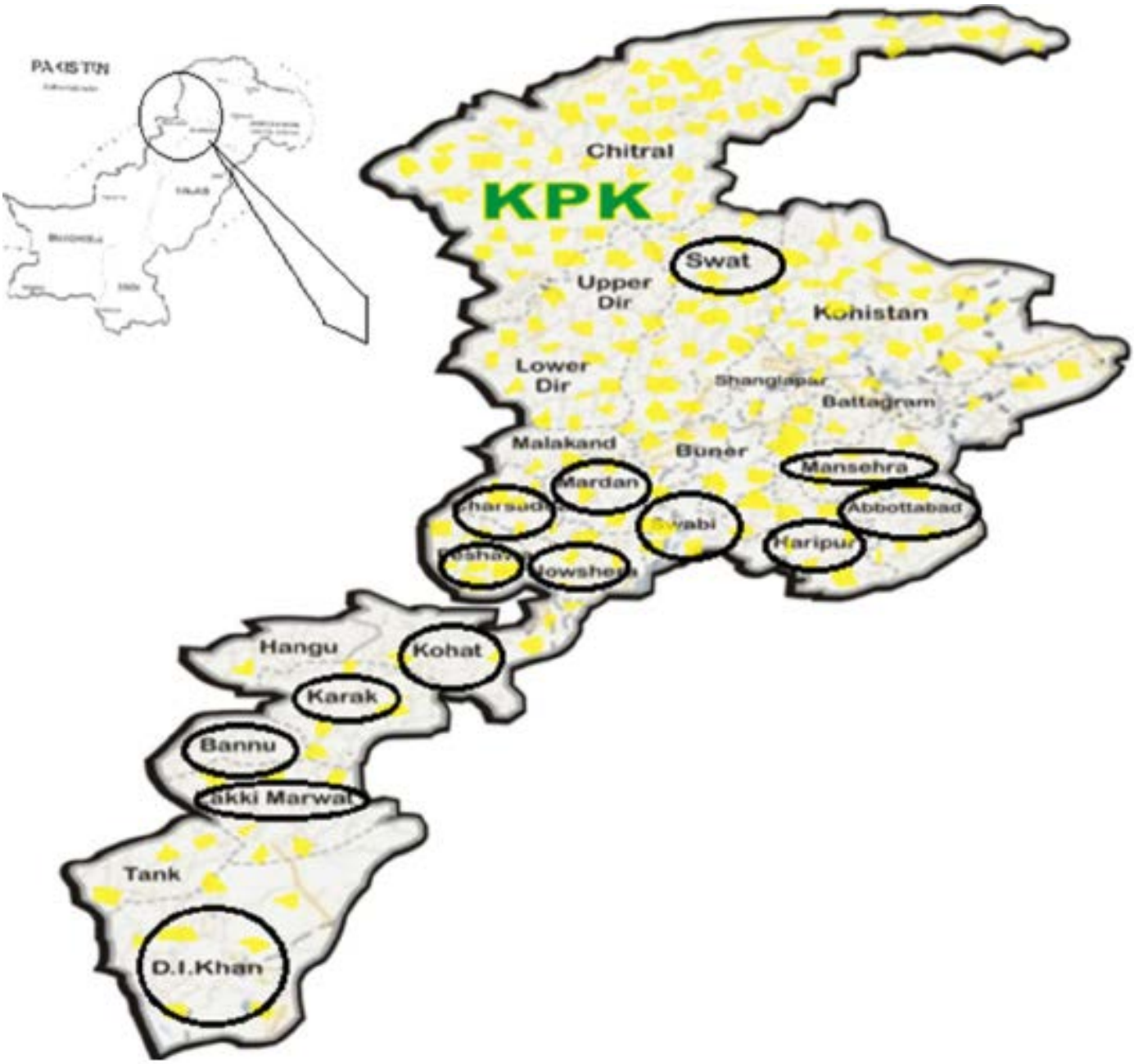

Figure 1: *Map of Pakistan and the survey districts representing southern, central and northern wheat production zone in Khyber Pakhtunkhwa (KPK) province.*

During 2005, sever yellow rust epidemic in KPK incurred 100 million US$ loss to Pakistan economy (Duveiller et al., 2007). Yellow rust is more serious in the KPK region of Pakistan and several factors contributed to these historical yellow rust epidemics including monoculture and resistance breakdown of specific cultivars (Inquilab-91: Duveiller et al., 2007; Pirsabak-85 and Pak81: Ehsan et al., 2003), pathogen migration and development of races with new virulences and new combinations of previously existing virulences that circumvent resistance genes in grown cultivars (Ali, 2012; Chen, 2007), presence of alternate host and prevalence of favorable environment (Ibrahim et al., 2015; Chatrath et al., 2007). Under these unique and peculiar regional factors and its proximity to the center of diversity of *P. striiformis* f. sp *tritici* (Ali, 2012), yellow rust surveillance for spatial-temporal development and information regarding deployed cultivars becomes much more important and are essential for sustainability of crop protection and improvement initiatives. Such surveys are well documents from other regions of the world including North America, Central Asian Republics (Aslanova et al. 2012), China, Africa (Amil et al., 2012) and Asia (Anonymous, 2015).

This paper reports recent comprehensive yellow rust surveillance results and the status of wheat cultivars

deployed in districts representing southern, central and northern wheat production zones in KPK province of Pakistan during 2012 (Figure 1).

Materials and Methods

Districts and area surveyed

Yellow rust surveillance was carried out during 2012 in 5 rainfed districts of the southern zone (Karak, DIKhan, Bannu, Lakki Marwat, Kohat), 5 medium rainfall districts of the central zone (Mardan, Sawabi, Nowshara, Charsada, Peshawar) and 4 high rainfall districts of the northeren zone (Swat, Manshera, Hari Pur, Abbotabad) of Pakistan Khyber Pakhtunkhwa (KPK) Province. Surveillance was carried out in three stage cluster sampling technique. In the 1st step, KPK was divided into 3 zones, namely southern, central and northern. In the 2nd step, districts are selected within each zone. In the 3rd stage, locations were selected within each district based on proportional allocation (the greater district area the greater number of locations/fields are selected). In the total 14 districts, a total of 1582 fields were surveyed in the three wheat production zones which corresponded to 4672 acres.

Crop growth stage and rust assessment

Wheat growth stage in each field was determined using growth stage key and plants were classified into different distinct development phases as described by Zadoks (1972). Yellow rust incidence was estimated following general procedure in the diagonal transects (Mercer and Ruddock, 2004) for each field. Disease incidence was assessed at three sites on each of the field transect by following the following formula:

$$\%\ Disease\ Incidence = \frac{Diseased\ plants}{Total\ number\ of\ plants\ observed} \times 100$$

Yellow rust severity from 1-100% of leaf tissue rusted was assessed as reported by Peterson et al. (1948). The severity was recorded four times per field and then converted into mean value.

Rust impact assessment

Field impact factor (FIF) for yellow rust of each field was quantified by adopting below mentioned procedure in an attempt to evaluate the relative damage of yellow rust in each surveyed region (http://library.ndsu.edu/tools/dspace/load/?file=/repository/bitstream/handle/10365/6159/farm_45_05_01.pdf?sequence=1).

$$FIF = \frac{Incidence \times Severity}{Zadok's\ growth\ stage}$$

Results and Discussion

Yellow rust surveillance results and the status of wheat cultivars deployed in each zone are described below.

Southeren zone

Over 500 wheat fields comprising an area of 1786 acres were inspected in Karak, Dera Ismail Khan, Bannu, Lakki Marwat and Kohat. Yellow rust was prevalent in these five districts and incidence ranging from 6-25%, 26-40% and >60% were observed in 5%, 2% and <1% of the inspected fields, respectively (Table 1). Frequency of yellow rust severity classes 3, 4, 5, 6, 7, and 9 were <1, 5, 2, 1, and <1 respectively (Table 2). In southern zone, 177 acres were affected by yellow rust which is about 10% of the total area surveyed. Maximum area of 115 acres was affected in D I Khan district which was 20% of the total inspected area in southern zone. In the remaining districts, collectively it was 62 acres which was 18% of the total area (Table 1). Maximum field impact or damage of yellow rust was estimated at field scale in Bannu (FIF: 121) which was followed by Lakki Marwat (107), Bannu (45), Kohat (34.5) and Karak (6.25) (Table 1).

In this zone, different known and unknown wheat cultivars were deployed. Nine cultivars in Karak, 15 in Dera Ismail Khan 12 each in Bannu and Lakki Marwat and 13 in Kohat (Table 3) Prominent cultivars in Kohat (Pirsabak-2004 and Sehar-2006), Karak (Sehar-2006 and Bhakkhar-2002), Bannu (Siren-2010, Inqilab-91 and Sehar-2006), Laki Marwat (Bhakkhar-2002, Inqilab-91, Fakhar-e-Sarhad and Sehar-2006) and D.I. Khan (Hashim-08 and Sehar-2006) occupied 63, 71, 69, 78 and 72% of the area in each district, respectively.

Central zone

Surveillance of 743 wheat fields was carried in Mardan, Sawabi, Nowshara, Charsada and Peshawar which corresponded 2481 acres. Yellow rust was prevelent in these five districts and. incidence ranging from 6-25%, 26-40%, 42-60% and >60% were observed in 7%, 4%, 1% and <1% of the inspected fields, respectively (Table 1). Frequency of yellow rust severity classes 3, 4, 5, 6, 7, 8 and 9 were <1, 3, 5, 3, and <1, respectively (Table 2). In the central zone, area of 153 acres was affected by yellow rust which is about 6% of the total area surveyed. Maximum area of 39.6 acres was affected in Nowshara district which was 10% of the total inspected area in the central zone which was followed by Mardan (31 acres equal to 10%),

Table 1: *Yellow rust % incidence, wheat affected area and field impact factor (FIF) in the three zones of Khyber Pakhtunkhwa during 2012.*

Districts	Area surveyed	No of fields visited	Percent of fields with incidence (%)							Area affected (in acres)	% total area	FIF
			0	1 - 2	3 - 5	6 - 25	26-40	42-60	> 60			
Southren Zone												
Karak	120.20	47	97.90	0	0	2.13	0	0	0	2	1.7	6.25
DIKhan	565.40	118	95.80	0	0	1.69	2.54	0	0	115	20.3	45.80
Bannu	378.20	133	93.00	0	0	2.25	3.76	0	0.75	25.5	6.7	121.6
Lakki Marwat	346.40	142	88.70	0	0	8.45	2.82	0	0	13.6	3.9	107.9
Kohat	375.50	74	85.10	0	0	12.16	1.35	0	0	21	5.6	34.50
Total/Means	1785.50	514	92.10	0	0	5.34	2.09	0	0.15	177.1	9.9	63.20
Central Zone												
Mardan	328.02	145	91.00	0	0	5.52	3.45	0	0	31	9.5	42.20
Sawabi	287.00	120	90.83	0	0	3.33	2.5	2.50	0.83	30	10.5	117.3
Nowshara	380.60	173	86.70	0	0	8.67	4.05	0.58	0.58	39.6	10.4	201.2
Charsada	1097.55	131	85.50	0	0	9.92	2.29	1.53	0.76	24.25	2.2	90.50
Peshawar	388.35	174	83.90	0	0	6.90	8.62	0.57	0	28.5	7.3	107.6
Total/Means	2481.52	743	87.60	0	0	6.87	4.18	1.04	0.43	153.35	6.2	111.8
Northern Zone												
Swat	261.40	201	64.68	0	0	2.98	8.46	16.92	6.96	80.75	30.9	416.9
Manshera	30.10	37	62.16	0	0	16.22	8.11	8.11	5.40	10.1	33.6	328.0
Hari Pur	54.00	37	56.76	0	0	13.51	18.92	2.70	8.10	19.1	35.4	334.7
Abbotabad	59	50	50.00	0	0	12.00	16.00	6.00	16	23.4	39.7	498.6
Total/Means	404.5	325	58.40	0	0	11.2	12.87	8.43	9.12	133.35	33.0	394.6

Table 2: *Yellow rust severity recorded in the three wheat production zones of Khyber Pakhtunkhwa during 2012.*

Rust	Southeren Zone						Central Zone						Northern Zone				
Severity	Kohat	DI Khan	Bannu	Lakki Marwat	Karak	Mean	Mardan	Sawabi	Nowshara	Charsada	Peshawar	Mean	Swat	Manshera	Hari Pur	Abbotabad	Mean
classes	Frequency (%)						Frequency (%)						Frequency (%)				
1	98	96	93	89	98	95	91	91	87	85	84	88	65	62	56.8	50	58
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	2.1	0.4	0	0.8	0	0	0	0.2	0	0	0	0	0
4	17	0.8	4.5	3.5	0	5.2	4.8	0.8	1.2	2.3	3.4	2.5	1.5	0	0	2.0	1
5	2.1	2.5	0	4.2	0	1.8	2.8	4.2	3.5	6.1	6.3	4.6	2.0	10.8	10.8	14.0	9
6	2.1	0.8	1.5	0.7	0	1.0	1.4	3.3	3.5	5.3	3.4	3.4	8.0	13.5	10.8	6.0	10
7	0	0	0	0.7	0	0.1	0	0	1.2	0.8	1.1	0.6	3.5	0	2.7	2.0	2
8	0	0	0	0	0	0	0	0	0.6	0	1.7	0.5	9.5	5.4	0	2.0	4
9	0	0	0.8	2.1	0	0.6	0	0	4.0	0	0	0.8	10.9	8.1	18.9	24.0	15

Rust severity classes 1: *No disease;* **2:** *Disease affecting 1 to 4% leaf area;* **3:** *5 to 9%;* **4:** *10 to 19%;* **5:** *20 to 29%;* **6:** *30 to 44%;* **7:** *45 to 59%;* **8:** *60 to 75%; and* **9:** *>75% of leaf area affected.*

Sawabi (30 acres, 11%), Peshawar (28.5 acres, 7%) and Charsada (24.25 acres, 2%). Maximum field impact of yellow rust was estimated at Nowshara (FIF: 201) Sawabi (117), Peshawar (108), Charsada (90), and Mardan (42) in the central zone (Table 1).

In this zone, different known and unknown wheat cultivars were deployed. Five cultivars in Charsada, 6 in Mardan, 8 in Sawabi, 9 in Nowshara and 13 in Peshawar (Table 3). Prominent cultivars in Charsada (Sehar-2006), Mardan (Sehar-2006 and Fakher-e-Sarhad), Sawabi (Sehar-2006, Fakher-e-Sarhad and Atta Habib), Nowshara (Sehar-2006 and Pirsabak-2004) and in Peshawar

Table 3: *Cultivar based wheat cultivated landscape composition and spread in Khyber Pakhtunkhwa during 2012.*

Districts	Cultivars	Names and % area covered in each district deployed
Southeren Zone		
Karak	9	Sehar-2006(58.7), Bahakkar-2002 (12.5), Auqab 2000 (8.3), Inqilab-91(7.3), KT-2000(5), Hashim-2008 (5%), Lasani (1.7), Faisalabad-2008 (1.2) and Unknown (0.2)
D I Khan	15	Hashim-2008 (38.1), Sehar-2006(34.3), Serin-2010(8.4), Bathoor-2008(6.1), Zam(5.9), Unknown(2.1), Pirsabak-04(1.3), Dera 98(1.2), Bhakkar-2002 (0.8), Barsat-2009 (0.7), Fakhar-e-Sarhad(0.4), Gomal-2008 (0.3), Auqab-2000 (0.2), Shafaq-2006 (0.2) and Tatara (0.1)
Bannu	12	Serin-2010(33.5), Inqilqb-91(20.8), Sehar-2006(14.7), Auqab-2000(10.7), Pirsabak-2004(7.4), Amin-2010 (3.4), Bhakkar-2002(2.9), AS-2000(2.6), Pirsabak-05(0.8),Gomal-2008(1.1), Zam-2004(1.1)& Unknown(1.1).
Lakki Marwat	12	Bhakkar-2002(27.3), Inqilab-91(21.7), Fakhar-e-Sarhad(16.7), Sehar-2006(12.3), Naseer-2000(6.6), Hashim-2008(5.9), Unknown(4.7), Auqab-2000(1.8), Pirsabak-2004(1.5), Pirsabak-2005(1.0), Changaz(0.3) and Siren-2010(0.3)
Kohat	13	Pirsabak-2004(34.4),Sehar-2006(28.4),Bathoor-2008(17.4),AttaHabib(9.5),Pirsabak-2005(2.9),-Saleem-2000(1.7), Inqilab-91(1.3),Serin-2010(1.3),Bhakkar-2002(1.1),Hashim-2008(1.1),Auqab-2000(0.5),KT-2000(0.2) and Unknown (0.2).
Central Zone		
Mardan	6	Sehar-2006(38), Fakhar-e-Sarhad(30), Zam-2004(13), Pirsabak-2004(11), Bhakkar-2002(6) and Unknown (3).
Sawabi	8	Sehar-2006(42.5), Fakhar-e-Sarhad (23.2), Atta Habib (21.6), Serin-2010 (6), Unknown (3.7), Auqab-2000 (2), Faisalabad-2008 (0.5) and Meraj (0.5).
Nowshara	9	Sehar-2006 (73.4), Pirsabak-2004 (17.4), Pirsabak-2005 (3.4), Unknown (2.4), Bathoor-2008 (1.3), Bhakkar-2002 (1.2), Auqab-2000 (0.6), Barsat-2009 (0.3) and Fakhar-e-Sarhad (0.1).
Charsada	5	Sehar-2006 (96.3), Bhakkar-2002 (2.5), Pirsabak-2004 (0.7), Fakhar-e-Sarhad (0.5) and Tatara (0.1).
Peshawar	13	Sehar-2006(69.2), Unknown (13.4), Janbaz (5.2), Pirsabak-2004(3.2), Bhakkar-2002 (2.7), Pirsabak-2005(2.2), Atta Habib(1.7), Auqab-2000(0.6), Ghaznavi-98(0.4), AUP-5008(0.3), AUP-4008(0.3), Faisalabad-2008(0.3) and Shafaq-2006 (0.1).
Northern Zone		
Swat	10	Sehar-2006 (46.1), Paisalabad-2004 (26.2), Pirsabak-2005(9.2), Inqilab-91 (6.2), Bhakkar-2002 (3.3), Pirsabak-2008 (2.4), Atta Habib (2.3), Auqab-2000 (2.0), Unknown (1.9) and Fakhar-e-Sarhad (0.4).
Manshera	4	Auqab-2000 (75.08), Pirsabak-2004(11.62), Sehar-2006(8.30) & Unknown (4.98).
Hari Pur	7	Sehar-2006(40.0), Atta Habib (20.7), Serin-2010 (14.8), Pirsabak-2005 (13.9), Faisalabad-2006(5.6), Pirsabak-2004(3.7) and Bhakkar-2002 (1.3).
Abbotabad	8	Atta Habib (24.57), Paisalabad-2005(24.57), Sehar-2006(22.88), Bathoor-2008 (9.32), Pirsabak-2004(6.77), Unknown (6.77), Serin-2010(3.38) and Fakhar-e-Sarhad(1.69).

(Sehar-2006) occupied 96, 68, 87, 91 and 70% of the area in each district, respectively.

Northeren zone

In Swat, Manshera, Hari Pur and Abbotabad, 325 wheat fields were inspected having an area of 404 acres. Yellow rust was also prevelent in these four districts and the incidence ranging from 6-25%, 26-40%, 42-60% and >60% were observed in 11, 13, 8 and 9% of the inspected fields, respectively. (Table 1). Frequency of yellow rust severity classes 4, 5, 6, 7, 8 and 9 were 1, 9, 10, 2, 4 and 15%, respectively (Table 2). In the northeren zone, an area of 133 acres was affected by yellow rust which is about 33% of the total area surveyed. Maximum area of 81 acres was affected in Swat district which was 31% of the total inspected area in the northeren zone which was followed by Abbotabad (23.4 acres equal to 40%), Hari Pur (19.1 acres, 35%) and Manshera (10.1 acres, 34%). Maximum field impact of yellow rust was estimated for Abbotabad (FIF: 499) which was followed by Swat (417), Hari Pur (335) and Manshera (328) in the northeren zone (Table 1).

In this zone, different known and unknown wheat cultivars were deployed. Four cultivars were deployed in Manshera, 7 in Hari Pur, 8 in Abbottabad and ten in Swat (Table 3). Prominent cultivars in Man-

shera (Auqab-2000), Hari Pur (Sehar-2006, Atta Habib, Serin-2010 and Pirsabak-2005), Abbotabad (Atta Habib, Pirsabak-2005, Sehar-2006 and Bathoor-2008) and Swat (Sehar-2006, Pirsabak-2004, Pirsabak-2005 and Inqilab-91) occupied 75, 89, 81 and 88% of the area in each district, respectively.

Wheat rust surveillance is important to know about the distribution of wheat rust and status of resistance of already deployed cultivars in a particular region. Such information are fundamental to formulate and adopt suitable policies, investments and strategies for wheat protection, wheat breeding, and seed systems (Park et al., 2011). Wheat production sustainability needs deployment of rust resistant sources and withdrawal of existing wheat cultivars possessing defeated resistant genes. In northern Pakistan (Khyber Pakhtunkhwa), yellow rust is considered as the most important and serious disease affecting wheat production and resulted into heavy losses in the past (Bahri et al., 2011). This region is considered as center of diversity for yellow rust pathogen (Ali, 2012) where rust races carried virulences for *Yr2, Yr6, Yr7, Yr8, Yr9, Yr10, Yr15, Yr27, Yr31, Yr32, YrA* (Bahri et al., 2011; Ali, 2012; Ibrahim et al., 2015).Yellow rust occurrence and distribution was recorded low in the current surveillance during 2012 in Khyber Pakhtunkhwa. Disease occurrence fluctuated between rainfed (southern), rainfall (central) and highly rainfall (northern) zones of Khyber Pakhtunkhwa. Similarly, low yellow rust occurrence was also reported from the region during 2012 compared to 2011 (Rattu et al., 2012). The main spring precipitation ranges from 1100 mm in the northern zone to as low as 100 mm in the southern zone during wheat season 2012 (Qaiser, 2012) while in the central zone, wheat is grown under irrigated conditions. Apart from moisture, other factors that may have contributed in less impact and distribution of yellow rust in southern zone could have been less dense stands due to low seeding rates, low humidity, and drought conditions during early growth stages, followed by high day temperatures which were also reported previously (Boshoff et al., 2002).

One of the prime reasons for low wheat productivity and instability is the unavailability and unawareness of good quality seed (Hameed, 2013). Old and undesirable susceptible wheat varieties like Inqilab-91, Bhakkar-2002, Zam-2004, and Sehar-2006 were still deployed in farmer's field during the surveillance 2012. It is hoped that with the approval of Seed Act 2015 by the government of Pakistan, this act will provide an effective deterrence against the sale of fake and substandard seed (http://www.technologyreview.pk/state-seed-pakistan/). Sehar-2006 possessing undesirable susceptible Yr9 gene (Iqbal et al., 2016) was the major variety grown on maximum % covered area in all the three zones of KPK as recorded during 2012 surveillance. This variety was distributed by Non-Governmental Organizations (NGOs) free of cost for sowing purpose among flood affected people during December 2010 through an emergency project "Livelihood Initiative for Flood-Affectees' Empowerment" (Anonymous, 2011). Variety Sehar-2006 was thus cultivated on a large area of KPK in the three zones by chance as seeds of local varieties were damaged by the flood. During 2011-12 wheat season, farmers used their own seed of Sehar-2006 which was thus gown on the largest areas and resultantly emerged as major wheat variety grown in the province. Cultivars with effective yellow rust resistance genes have negligible deployment area which included Tatara possessing *Yr3*, *Yr5*, *Yr26 genes* (Iqbal et al., 2016; Afzal et al., 2010), Shafaq-2006 carrying *Yr5*, *Yr10* (Iqbal et al., 2016), Pirsabak-2005 possessing *Yr5*, *Yr26*, *Yr30* (Ejaz et al., 2012; Iqbal et al., 2016) and Saleem-2000 having *Yr5*, *Yr18*, *Yr26, Yr30* (Iqbal et al., 2016; Ejaz et al., 2012). Seeds of these cultivars should be increased and deployed on priority bases for yellow rust management in the region.

Authors Contribution

Muhammad Ibrahim presented the basic idea, planned the experiments, analyzed data and wrote the manuscript. Syed Jawad Ahmad Shah and Shaukat Hussain helped in refinement of the basic idea, planning experiments and data analysis and critical editing of the mnauscript. Musharaf Ahmad and Farahtullah helped in experiment paln and data alanysis.

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