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WHEAT POWDERY MILDEW DISEASE PREVALENCE ACROSS THE HINDUKUSH REGION OF PAKISTAN DURING THE FOUR YEARS PERIOD OF 2019 TO 2022

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Abstract

Powdery mildew is one of the most devastating diseases of wheat that causes huge economic losses to wheat production not only on global scale but also in the Hindukush region of Pakistan. Although no significant attention was given to the disease, mainly due to the lack of information on its prevalence in Pakistan, particularly in the Afghanistan bordering Hindukush region. Disease surveillance was carried out to find the status of powdery mildew in the Hindukush region viz. Ex PATA, Ex FATA, Central and South KP of Pakistan during the four wheat seasons in 2019 to 2022. A total of 291 fields (from 22 districts) were covered in 2019, 278 fields (from 21 districts) were surveyed in 2020, 279 fields (from 21 districts) in 2021 and 297 fields (from 23 districts) were covered in 2022. Powdery mildew was detected with high prevalence in 14% fields in Ex PATA where 7% fields were found with high disease, followed by Ex FATA (6%) while the disease was detected in 1% and 2% fields in South and Central KP, respectively. Considering the overall four years, the disease was detected with high prevalence (in 9.0% fields) during 2021 followed by 2022 (8.0% fields), while the disease was found with low pressure (in 2.0% fields) during 2020. Among the surveyed varieties, most had low disease severity with the maximum observed for AAS-2011 and Triticale lines as reveled by the ACI values of 13.3 and 11.4 respectively. The information obtained from the study could be utilized in future breeding programs aimed at developing resistant varieties.

Key words: Fields survey, Wheat, Powdery mildew, Host reaction.

Introduction

Wheat is an important food crop grown in diverse agro-ecological zones around the world (Singh *et al*., 2016). Wheat plays key role in the provision of calories and proteins for human nutrition of the growing populations (Motallib *et al*., 2023). However, the crop of wheat is challenged by several biotic and abiotic factors causing huge losses (Ali *et al*., 2014; Hodson, 2011; Hovmøller *et al*., 2010). Among the biotic factors, the fungi causing diseases are considered the major constraints for wheat growth and thus production around the world (Dean *et al*. 2012; Fisher *et al*. 2012). Among these threats, the powdery mildew, caused by the biotrophic fungus *Blumeria graminis* f. sp. *tricitici*, is an important and severe foliar disease causing huge losses to wheat yield (Awad *et al*., 2015; Ali *et al*., 2022; Yao *et al*., 2023). Powdery mildew is worse on wheat crops grown in the cooler and dry climatic conditions particularly in Europe, China and South America (Dubin & Duveiller, 2011). The disease has tended to be more severe in China since the late 1970s (Cao *et al*., 2013) and has spread from South-Western China into the Eastern and Northern regions (Liu *et al*., 2019; Costamilan 2005). The disease occurs frequently in the Eastern states of the USA; severe epidemics occurred most often in the mid-Atlantic region, although widespread planting of susceptible cultivars has caused outbreaks from Georgia to Oklahoma to Montana (Cowger *et al*., 2018). Among the pathogens of wheat in Argentina, powdery mildew practically occurs every year in the wheat cropping area, particularly in the first growth stages and less frequently in later stages (Molteni *et al*., 1996). In New Zealand, Cromey. (1992) reported losses in winter wheat of up to 35% due to powdery mildew infection of susceptible cultivars. The disease is a major problem for growers in the western regions of Australia (Anon., 2012).

In Pakistan the disease is more common in regions with cold climatic conditions particularly in the Northern Himalayan regions of Khyber Pakhtunkhwa (Iqbal *et al*., 2023; Khan *et al*., 2019b). The disease was dominated in the cool areas of Pakistan with temperatures ranging between 15ºC and 18ºC and relative humidity of 75 to 100%. Although limited efforts have been made to inspect the status of powdery mildew across Pakistan (Iqbal *et al*., 2023; Khan *et al*., 2019b), no study has been made on the Afghanistan bordering Hindukush region, where the relatively colder climate may encourage the onset of the disease, where it may pose a huge risk to wheat production.

Several disease management strategies could be used to control the disease including fungicides and genetic resistance. The use of fungicides is recommended but it is costly and environmentally unfriendly including the risk of emergence of resistant strains (Cook *et al*., 2021). Therefore, genetic resistance could be the most efficient control method for the disease (Ali *et al*., 2022; Yao *et al*., 2023). Breeding durable resistance to pathogens and pests is a major task for modern plant breeders and pyramiding different resistance genes into a genotype is one way of achieving this (Liu *et al*., 2000). More than 91 powdery mildew resistant genes known as *Pm* genes have been identified (Li *et al*., 2019) but only few of them have been introduced into wheat germplasm including *Pm2*, *Pm4a*, *Pm8*, *Pm21*, and *Pm2+Pm6* (Li *et al*., 2020; Khan *et al*., 2019b) but still a number of *Pm* genes are no longer effective against the disease (Xiao *et al*., 2013). The effectiveness of these genes can be overcome by the emergence of new virulent races of the pathogen, posing a challenge for identification and utilization of new resistant genes by plant breeders to generate resistant cultivars (Costamilan, 2005). Thus, a regular surveillance is required to track the disease on locally released varieties as well as the candidate lines, to highlight any novel pathogen variants infecting the previously resistant lines.

This study was designed to assess the relative distribution of powdery mildew in different geographical areas in the Hindukush region of Pakistan during the four cropping seasons (2019-20 to 2021-22). The major objectives of the study were: i). to evaluate the status of powdery mildew across different locations in the Hindukush region of Pakistan. ii). to assess the status of the disease on different host varieties in farmers' fields in the study area.

Material and Methods

Wheat disease surveillance was carried out to find the distribution of status of wheat powdery mildew at different geographical regions of the Hindukush region of Pakistan viz. Ex FATA, Ex PATA and Southern and Central districts of Khyber Pakhtunkhwa during the wheat growing seasons in 2019-2022 (Fig. 1). Scoring was made for the powdery mildew in farmers' and research fields.

Districts surveyed in different regions of Hindukush: A total of 1145 fields were surveyed in the different districts of Hindukush during the four cropping seasons from 2019-20 to 2021-22. Most of the districts in different regions of Hindukush were surveyed over all the four years. In Central KP, the districts covered included Nowshera, Charsadda, Mardan, Peshawar and Swabi. The districts of Bajaur, Mohmand, Khyber, Lower Kurrum, Upper Kurrum, North Waziristan and South Waziristan were surveyed in the Ex-FATA region. The districts of Lower Dir, Upper Dir, Malakand, Swat, Buner and Shangla were covered from Ex-PATA region. In the South KP, Bannu, DI Khan, Karak, Kohat, Lakki Marwat, Hangu, Dara Adam Khel and Tank were covered during the study (Fig. 1).

Field inspection and scoring of powdery mildew: Farmers' fields across these locations were surveyed to find out the severity of the fields as infected by powdery mildew. Attempt was made to score the disease at different locations in a given region. The disease status was measured on the basis of visual scoring by using two parameters i.e., disease severity and host reaction following the standard protocol of Ali and Hodson (2017). Disease severity was measured on the basis of percentage of leaf area infected using a 0-100 scale (Peterson *et al.*, 1948). The infection types (IT) reflected the host response (Singh, 1993), ranging from resistant to moderately resistant to moderately susceptible and susceptible. Co-efficient of infection was estimated using severity and host response values (Ali & Hodson, 2017).

Analyses of relative distribution of powdery mildew: The data on diseases severity and infection types recorded were formatted in MS Excel spreadsheet for further analysis. The relative distribution of powdery mildew across locations and over years was analyzed through generation of tables and various summary statistics.

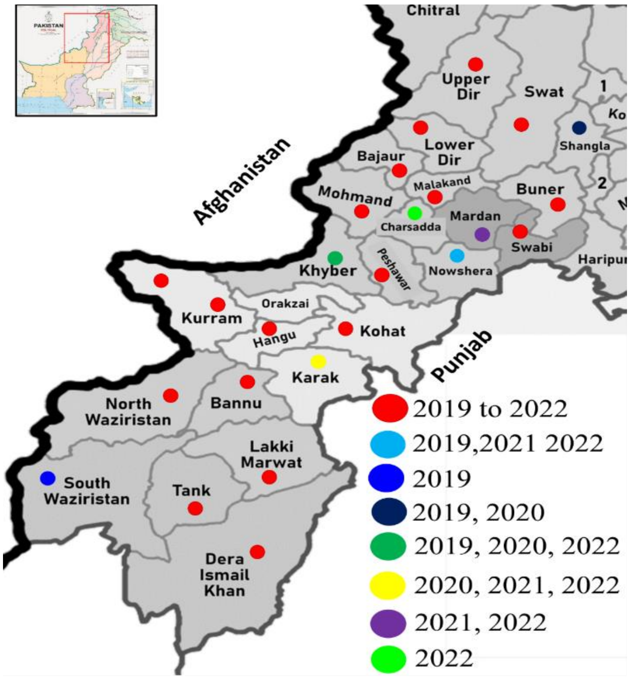

Fig. 1. Map of Khyber Pakhtunkhwa showing the surveyed regions in newly merged districts, Central and South KP of Pakistan over the four years surveillance made during 2019 to 2022.

Results

Status of powdery mildew in different regions of Hindukush range of Pakistan: Variable disease pressure was observed in different regions of Hindukush range of Pakistan over the four years. Considering the overall four years, the disease was found in the maximum fields in Ex PATA (14%) where the disease was found with high severity (>50%) in 7% fields followed by Ex FATA (6.0%), while the minimum fields were found infected in South KP (1%) followed by Central KP (2.0%).

Considering the within year variations, the disease was found in the maximum fields during 2021 (9.0%) followed by 2022 (8.0%), while the disease was detected in the minimum fields during 2020 (2.0%). During 2019 the disease was found in the maximum fields in Ex PATA (18.0%) followed by Ex FATA (6.0%), while the disease was not detected in Central and South KP. In 2020, the disease was found in the maximum fields in Ex PATA (6.0%) followed by Ex FATA (1.0%), while the disease was again not detected in Central and South KP. The disease was detected in the maximum fields in Ex FATA (15%) during 2021, followed by Ex PATA (9.0%), while it was found in the minimum fields in South KP (1.0%). During 2022, the disease was found in the maximum fields in Ex PATA (23.0%) followed by Ex FATA (4.0%) and South KP (2.0%), however, the disease was not found in Central KP (Table 1).

Mean powdery mildew severity (%): The prevalence of powdery mildew was further explored by powdery mildew severity (%) and co-efficient of infection. Considering the overall period, the disease was found the maximum powdery mildew severity in Ex PATA (5.9%) followed by Ex FATA (1.5%), while the minimum mean powdery mildew severity was recorded for South KP (0.1%) followed by Central KP (0.9%).

Considering the within year variations, the mean powdery mildew severity was found the maximum during 2019 (2.8%), followed by 2021 (2.5%) while it was found the minimum during 2020 (1.0%). During 2019, the mean severity was found the maximum for Ex PATA (9.1%) followed by Ex FATA (2.0%), while it was found the minimum for Central and South KP (0.0%). In 2020, the mean severity was found again the maximum for Ex PATA (3.6%) followed by Ex FATA (0.2%), while the minimum for Central and South KP (0.0%). The mean severity was found the maximum for Ex PATA (3.9%) during 2021 while the minimum for South KP (0.3%). During 2022, the mean severity was again found the maximum for Ex PATA (7.4%) followed by Ex FATA (1.7) while the minimum of 0.0 for Central and South KP (Table 2).

Powdery mildew co-efficient of infection: The co-efficient of infection for powdery mildew was also determined using disease severity and host response values. Considering the overall four years, the co-efficient of infection was recorded the maximum for Ex PATA (5.5) followed by Ex FATA (1.3), while the minimum was recorded for South-KP (0.1).

Considering the within year variations, the co-efficient of infection for powdery mildew was found the maximum during 2019 (2.4), followed by 2021 and 2022 (2.3 each) while the minimum was recorded during 2020 (0.9). During 2019, the co-efficient of infection was found the maximum for Ex PATA (7.8) followed by Ex FATA (1.8), while it was found the minimum for Central and South KP (0.0). In 2020, the co-efficient of infection was found again the maximum for Ex PATA (3.4) followed by Ex FATA (0.2), while the minimum for Central and South KP (0.0). The co-efficient of infection was found the maximum for Ex PATA (3.9) during 2021 while the minimum for South KP (0.2). During 2022, the co-efficient of infection was again found the maximum for Ex PATA (7.4) followed by Ex FATA (1.7), while the minimum of 0.0 for Central and South KP (Table 2).

Table 1. Number of fields surveyed percent of fields without powdery mildew disease (%) and percent of fields severely (>50%) infected (%) across the Ex Tribal districts and Central & Southern region of Khyber Pakhtunkhwa, surveyed during the disease seasons of 2019 to 2022.

Region	2019			2020			2021			2022			All years		
	Fields sampled	Fields without infection (%)	Fields severely (>50%) infected (%)	Fields sampled	Fields without infection (%)	Fields severely (>50%) infected (%)	Fields sampled	Fields without infection (%)	Fields severely (>50%) infected (%)	Fields sampled	Fields without infection (%)	Fields severely (>50%) infected (%)	Fields sampled	Fields without infection (%)	Fields severely (>50%) infected (%)
Central KP	110	100	0	19	100	0	56	93	4	39	100	0	224	98	1
Ex FATA	82	94	1	106	99	0	85	85	0	99	96	1	372	94	1
Ex PATA	66	82	12	88	94	5	66	91	5	78	77	8	298	86	7
South KP	33	100	0	65	100	0	72	99	0	81	98	0	251	99	0
Total	291	94	3	278	98	1	279	91	2	297	92	2	1145	94	2

Table 2. Mean powdery mildew severity (%) and co-efficient of infection as observed across the Ex Tribal districts and Central & Southern region of Khyber Pakhtunkhwa, surveyed during the disease seasons of 2019 to 2022.

Powdery mildew severity (%)					
Region	**2019**	**2020**	**2021**	**2022**	**All years**
Central KP	0.0	0.0	3.4	0.0	0.9
Ex FATA	2.0	0.2	2.2	1.8	1.5
Ex PATA	9.1	3.6	3.9	7.4	5.9
South KP	0.0	0.0	0.3	0.0	0.1
Total	**2.8**	**1.0**	**2.5**	**2.3**	**2.1**
Powdery mildew co-efficient of infection (%)					
Region	**2019**	**2020**	**2021**	**2022**	**All years**
Central KP	0.0	0.0	3.4	0.0	0.9
Ex FATA	1.8	0.2	1.8	1.7	1.3
Ex PATA	7.8	3.4	3.9	7.4	5.5
South KP	0.0	0.0	0.2	0.0	0.1
Total	**2.4**	**0.9**	**2.3**	**2.3**	**1.9**

Status of powdery mildew in different districts of KP: Powdery mildew also varied across districts and over years. Considering the overall four years, the disease was found in the maximum fields (32.0%) with 14% fields detected with high disease in Upper Dir followed by Mohmand (22.0%), while the minimum of 0% were observed in Charsadda, Nowshera and Swabi of Central KP, Khyber, North and South Waziristan of Ex FATA, Shangla of Ex PATA and DI Khan, Hangu, Karak and Tank of South KP.

Considering the district wise variations over the years, the disease was found in the maximum fields during 2019 in Upper Dir (80.0%) where 40% fields were reported with high disease followed by Malakand (50.0%) and Mohmand (34%), while the disease was found in the minimum (0.0%) fields in all districts of Central KP and South KP and some districts of Ex FATA and Ex PATA. During 2020, the disease was detected in the maximum fields in Buner (17.0%) where 17.0% fields were found with high disease followed by Malakand (12%) fields with 13.0% severely infected fields, while the minimum of 0.0% fields were found in Central KP, South KP and Ex FATA (except Mohmand). In 2021 the disease was found in the maximum fields in Mohmand (50.0%) followed by Peshawar (37.0%) and Upper Dir (23.0%), while the minimum (0.0%) fields were found in Nowshera and Swabi of Central KP, North Waziristan of Ex FATA, all districts of Ex PATA (except Upper Dir) and South KP (except Lakki Marwat). During 2022, the disease was found in the maximum fields in Upper Dir (45.0%) followed by Lower Dir (25.0%) and Swat (23.0%), while the minimum (0.0%) fields were found in all districts of Central KP, Khyber, Lower Kurrum, Mohmand and North Waziristan of Ex FATA and all districts of South KP (except Bannu and Kohat) (Table 3).

Mean powdery mildew severity (%) as observed across different districts: The disease incidence was further explored by mean powdery mildew severity percentage. Considering the period of overall four years, the maximum mean powdery mildew severity of 11.9% was found for Upper Dir followed by Malakand (9.4%) of Ex PATA and Upper Kurrum (5.8%) of Ex- FATA, while it was found with the minimum mean severity of 0.0% at Charsadda, Nowshera and Swabi of Central KP, Khyber, North Waziristan and South Waziristan of Ex FATA and Shangla of Ex PATA and in all the districts of South KP except for Lakki Marwat (0.8%). Considering the within year variations, the maximum mean severity was reported for 2019 (5.3%) followed by 2021 (2.3%), while the minimum mean severity was recorded during 2020 (1.3%) followed by 2022 (1.9%).

Considering the district wise variations over years, the mean powdery mildew severity was found the maximum for Malakand (50.0%) followed by Upper Dir (30.0%) and Upper Kurrum (16.7%) during 2019, while it was found the minimum for all districts of Central and South KP (0.0%). In 2020, the mean severity was found the maximum for Buner (13.3%) followed by Malakand (7.5%), while it was found again the minimum for all districts of Central and South KP (0.0%). During 2021, the disease mean severity was detected the maximum for Peshawar (23.8%) followed by Upper Dir (9.9%), while it was found the minimum (0.0%) for Nowshera and Swabi of Central KP, North Waziristan of Ex FATA and all districts of Ex PATA (except Upper Dir) and South KP (except Lakki Marwat). In 2022, the mean severity was found the maximum for Upper Dir (14.0%) followed by Swat (13.1%), while it was found the minimum (0.0%) for all districts of Central KP and Ex FATA (except Bajaur and Upper Kurrum) and all districts of South KP (except Bannu and Kohat) (Table 4).

Co-efficient of powdery mildew infection recorded for different wheat varieties: The host varieties response to Powdery mildew was found to be variable for the surveyed varieties. Considering the overall four years, the disease was found with the maximum ACI value of 13.3 for AAS-2011 followed by Triticale (11.4) and Pirsabak-2008 (5.5), while it was found the minimum of 0.0 for most of the surveyed varieties including Akbar-19, Faheem-19, pirsabak-2021, Abaseen-2021, Zarghoon-2021 and some experimental lines indicated as PR-114, PR-123, PR-126, PR-129 and PR-130. The overall low ACI recorded for the surveyed varieties shows either resistance of the varieties to the disease or the allocation of the varieties to regions where the disease was found with low prevalence (Table 5).

Discussion

The present study identified the status of powdery mildew in a total of 1145 fields in different districts of Khyber Pakhtunkhwa covering four distinct regions in the Hindukush ranges of Pakistan during the wheat growing season of 2019-2022 (Fig. 2). Over the four years, the disease was found with high pressure in Ex PATA followed by Ex FATA and with a low pressure in South KP followed by Central KP. The high disease in Ex PATA and Ex FATA could be due to the cool weather conditions prevailing in the region providing favorable environmental conditions for survival of powdery mildew pathogen resulting in disease epidemics in the regions (Khan *et al*., 2019b).

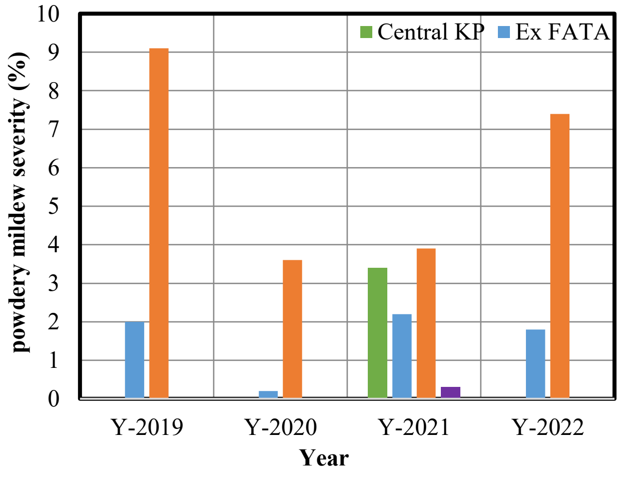

Fig. 2. Powdery mildew severity (%) across different geographical areas in the Hindukush region of Pakistan.

The incidence of the disease were further confirmed by the mean powdery mildew severity (%) and co-efficient of infection which shows an overall low powdery mildew severity for South KP reflecting the dry weather conditions causing reduction in the pathogen viabity to cause the disease while the higher disease severity was detected for Ex PATA followed by Ex FATA showing these regions to be the favorable environmental conditions needed for the occurrence of the disease (Ali *et al*., 2009; Khan *et al*., 2019b; Ali *et al*., 2022). The higher co-efficient of infection was recorded for Ex PATA followed by Ex FATA while it was found the lower for South KP and Central KP.

The similar explanations could be given to the variability observed across different districts. Considering the overall period the disease was found with more prevalence in Upper Dir of Ex PATA and Mohmand of Ex FATA while the disease was not detected in most districts of

South KP and some districts of Central KP. The disease was found with more prevalence in 2021 followed by 2022, however, it was found with less prevalence during 2019 while with least prevalence during 2020. During 2019 the disease was found in the maximum (80.0%) fields in Upper Dir, Malakand (50.0% fields) and Mohmand (34.0%) while the disease was absent in Central and South KP. During 2020, the disease was found with high prevalence in some districts of Ex PATA while it was absent in all districts of Central KP, South KP and Ex FATA (except Mohmand). During 2021 and 2022, the disease was detected with high prevalence in the colder regions of KP while the lower prevalence was observed for the dry and warmer districts of South KP and Central KP (Khan *et al*., 2019b; Jones & Clifford, 1983; Wiese, 1987), however, some districts in the Central KP were found with high disease pressure during 2021. It could be explained by the local microclimate along with the susceptibility of varieties, which may have encouraged the infestation of the disease.

Variable disease pressure was also observed for the surveyed host varieties/lines with the maximum ACI value of 13.1 recorded for AAS-2011 followed by Triticale (11.4) and Pirsabak-2008 (5.5) while no disease was found in most of the surveyed varieties including Akbar-19, Faheem-19, pirsabak-2021, Abaseen-2021, Zarghoon-2021 and some experimental lines were reported to possess partial resistance. The variability observed for the surveyed varieties depends on several factors like the virulence profile of the pathogen, genetic background of the host and climatic conditions in the regions (de Vallavieille-Pope *et al*., 2012). The ACI for most of the surveyed varieties calculated was below 10, showing high level of partial resistance to the disease, which is an essential element for durable resistance-based disease control (Singh *et al*., 2004).

Table 3. Number of fields surveyed, percent of fields without powdery mildew disease (%) and percent of fields severely (>50%) powdery mildew infected (%) across different districts representing the Ex Tribal districts and Central & Southern region of Khyber Pakhtunkhwa, surveyed during the disease seasons of 2019 to 2022.

		2019			2020			2021			2022			All years		
Region	**District**	**Fields sampled**	**Fields without infection (%)**	**Fields severely (>50%) infected (%)**	**Fields sampled**	**Fields without infection (%)**	**Fields severely (>50%) infected (%)**	**Fields sampled**	**Fields without infection (%)**	**Fields severely (>50%) infected (%)**	**Fields sampled**	**Fields without infection (%)**	**Fields severely (>50%) infected (%)**	**Fields sampled**	**Fields without infection (%)**	**Fields severely (>50%) infected (%)**
Central KP	Charsadda	**-**	**-**	**-**	-	-	-	-	-	-	10	100	0	10	100	0
	Mardan	**-**	**-**	**-**	-	-	-	6	83	0	9	100	0	15	93	0
	Nowshera	**36**	100	0	-	-	-	21	100	0	7	100	0	64	100	0
	Peshawar	**38**	100	0	11	100	0	8	63	25	9	100	0	66	95	3
	Swabi	**36**	100	0	8	100	0	21	100	0	4	100	0	69	100	0
Ex FATA	Bajaur	**22**	100	0	46	100	0	33	94	0	31	97	0	132	98	0
	Khyber	**5**	100	0	11	100	0	-	0	0	8	100	0	24	100	0
	Lower Kurrum	**5**	100	0	5	100	0	13	92	0	11	100	0	34	97	0
	Mohmand	**17**	76	0	17	94	0	18	50	0	11	100	0	63	78	0
	North Waziristan	**17**	100	0	12	100	0	11	100	0	16	100	0	56	100	0
	South Waziristan	**10**	100	0	-	-	-	-	-	-	-	-	-	10	100	0
	Upper Kurrum	**6**	83	17	15	100	0	10	90	0	22	86	5	53	91	4
Ex PATA	Buner	**20**	100	0	12	83	17	10	100	0	24	96	0	66	95	3
	Lower Dir	**13**	85	15	22	100	0	17	100	0	16	75	6	68	91	4
	Malakand	**2**	50	50	8	88	13	3	100	0	5	80	0	18	83	11
	Shangla	**10**	100	0	11	100	0	-	0	0	-	0	0	21	100	0
	Swat	**11**	91	9	17	94	6	10	100	0	13	77	15	51	90	8
	Upper Dir	**10**	20	40	18	94	0	26	77	12	20	55	15	74	68	14
South KP	Bannu	**7**	100	0	9	100	0	14	100	0	11	91	0	41	98	0
	DI Khan	**5**	100	0	11	100	0	12	100	0	9	100	0	37	100	0
	Hangu	**6**	100	0	14	100	0	9	100	0	8	100	0	37	100	0
	Karak	**-**	**-**	**-**	7	100	0	5	100	0	9	100	0	21	100	0
	Kohat	**6**	100	0	19	100	0	12	100	0	20	95	0	57	98	0
	Lakki Marwat	**2**	100	0	2	100	0	9	89	0	12	100	0	25	96	0
	Tank	**7**	100	0	3	100	0	11	100	0	12	100	0	33	100	0
Total		**291**	**94**	**3**	**278**	**98**	**1**	**279**	**91**	**2**	**297**	**92**	**2**	**1145**	**94**	**2**

Table 4. Mean powdery mildew severity (%) as observed across different districts representing the Ex Tribal districts and Central & Southern region of Khyber Pakhtunkhwa, surveyed during the disease seasons of 2019 to 2022.

Region	District	2019	2020	2021	2022	Overall period
Central KP	Charsadda	-	-	-	0.0	0.0
	Mardan	-	-	0.3	0.0	0.1
	Nowshera	0.0	-	0.0	0.0	0.0
	Peshawar	0.0	0.0	23.8	0.0	2.9
	Swabi	0.0	0.0	0.0	0.0	0.0
Ex FATA	Bajaur	0.0	0.0	1.2	0.2	0.3
	Khyber	0.0	0.0	-	0.0	0.0
	Lower Kurrum	0.0	0.0	0.4	0.0	0.1
	Mohmand	3.5	1.2	5.7	0.0	2.9
	North Waziristan	0.0	0.0	0.0	0.0	0.0
	South Waziristan	0.0	-	-	-	0.0
	Upper Kurrum	16.7	0.0	4.0	7.7	5.8
Ex PATA	Buner	0.0	13.3	0.0	1.7	3.0
	Lower Dir	11.5	0.0	0.0	5.1	3.4
	Malakand	50.0	7.5	0.0	2.0	9.4
	Shangla	0.0	0.0	-	-	0.0
	Swat	4.5	3.5	0.0	13.1	5.5
	Upper Dir	30.0	2.2	9.9	14.0	11.9
South KP	Bannu	0.0	0.0	0.0	0.1	0.0
	DI Khan	0.0	0.0	0.0	0.0	0.0
	Hangu	0.0	0.0	0.0	0.0	0.0
	Karak	-	0.0	0.0	0.0	0.0
	Kohat	0.0	0.0	0.0	0.1	0.0
	Lakki Marwat	0.0	0.0	2.2	0.0	0.8
	Tank	0.0	0.0	0.0	0.0	0.0
Total		**5.3**	**1.3**	**2.3**	**1.9**	**1.9**

Table 5. Co-efficient of powdery mildew infection recorded for different crop varieties as surveyed in various regions of Khyber Pakhtunkhwa, during the disease seasons of 2019 to 2022, along with the average co-efficient of infection.

Variety	2019	2020	2021	2022	ACI
AAS-2011	13.3	-	-	-	13.3
Akbar-19	-	-	0.0	-	0.0
Annaj-2017	0.0	-	0.0	-	0.0
Barani-17	-	-	0.0	-	0.0
Barley	0.0	-	0.2	0.0	0.1
Borlaug-2016	0.0	-	-	-	0.0
Dharabi-2011	0.0	-	-	-	0.0
Faheem-19	-	-	0.0	-	0.0
Faisalabad-2008	0.0	-		-	0.0
Fakhre Bakkar-17	-	-	0.0	-	0.0
Fateh-Jang	0.0	-	-	-	0.0
Galaxy	6.9	1.1	0.0	0.0	2.4
Ghaneemat-e-IBGE	0.0	0.0	7.5	0.0	1.5
Ghazi-19	-	-	0.0	-	0.0
Gold-2016	0.0	-	-	-	0.0
Gulzar-19	-	-	0.0	-	0.0
Ihsan-2016	0.0	-	0.0	-	0.0
Inqilab	0.0	-	-	-	0.0
Israr-2017	0.0	-	-	-	0.0
Johar-2016	0.0	-	-	-	0.0
Khaista-2017	0.0	-	0.0	-	0.0
Kohat-17	-	-	0.0	-	0.0
Kohat-2008	0.0	-	-	-	0.0
Mix	0.0	0.0	-	-	0.0
NARC-2011	0.0	0.0	-	-	0.0
NIFA-Aman	0.0	-	0.0	-	0.0
NIFA-Lalma	0.0	-	0.0	-	0.0

Table 5. (Cont'd.).

Variety	2019	2020	2021	2022	ACI
Pakhtunkhwa-2015	0.0	-	-	-	0.0
Pakistan-2013	0.0	-	0.0	-	0.0
Paseena-2017	0.0	-	0.0	-	0.0
Pirsabak-2005	4.4	4.0	0.0	0.0	3.4
Pirsabak-2008	5.5	-	-	-	5.5
Pirsabak-2013	0.0	5.6	0.0	0.0	1.7
Pirsabak-2015	0.0	0.0	0.0	-	0.0
PR-114	0.0	-	-	-	0.0
PR-123	0.0	-	-	-	0.0
PR-126	0.0	-	-	-	0.0
PR-129	0.0	-	-	-	0.0
PR-130	0.0	-	-	-	0.0
Sahar	0.0	0.0	-	-	0.0
Shahid-2017	0.0	-	-	-	0.0
Shahkar-2013	0.9	0.0	0.0	-	0.7
Sumai-03	-	-	0.0	-	0.0
Triticale	-	-	0.0	20.0	11.4
Ujala	0.0	-	-	-	0.0
Unknown	2.2	0.8	2.8	2.5	2.1
Wadaan-2017	0.0	-	0.0	-	0.0
Wild barley	0.0	-	-	-	0.0
Zincol-2016	0.0	-	-	-	0.0
Landrace	5.2	0.0	0.0	0.1	3.0
Pirsabak-2019	0.0	-	0.0	0.0	0.0
WW-11	-	-	-	0.0	0.0
Abaseen-2021	0.0	-	-	-	0.0
Pirsabak-2021	0.0	-	-	-	0.0
Zarghoon-2021	0.0	-	-	-	0.0

Conclusions

The study concluded that powdery mildew is threatening wheat crops resulting in its low overall yield especially in the colder areas in the Northern regions of Khyber Pakhtunkhwa particularly in Ex PATA and Ex FATA regions where the disease was found with more prevalence. The disease incidence fluctuated in the surveyed years. Powdery mildew was observed with low prevalence in Southern and Central KP because of the relatively higher temperatures during the wheat growing seasons in the regions. Severe infestation was observed for AAS-2011, Triticale and Pirsabak-2008 deployed in the regions. The information provided in the study could be useful to be deployed in future breeding programs for crop improvement.

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