Research Article

# Northern Himalayan Region of Pakistan with Cold and Wet Climate Favors a High Prevalence of Wheat Powdery Mildew

**Muhammad Rameez Khan[1], Muhammad Imtiaz[2], Farhatullah[3], Sohail Ahmad[1] and Sajid Ali[1]***

*[1]Institute of Biotechnology and Genetic Engineering, The University of Agriculture, Peshawar, Khyber Pakhtunkhwa, Pakistan; [2]International Maize and Wheat Improvement Center (CIMMYT), Mexico; [3]Department of Plant Breeding and Genetics, The University of Agriculture, Peshawar, Khyber Pakhtunkhwa, Pakistan.*

**Abstract** | Wheat diseases remains the major constraint to wheat production across Pakistan, including rusts and powdery mildews. Although significant attention is given to rust diseases, powdery mildew is a less considered diseases so far, mainly due to lack of information on the prevalence across Pakistan. Surveillance for powdery mildew status assessment was conducted across Pakistan during three wheat crop seasons i.e., 2015-2016 to 2017-2018. A total of 437 fields (from 63 districts) were surveyed in 2016, 480 fields (from 69 districts) in 2017 and 294 fields (from 34 districts) in 2018, revealing a high prevalence of powdery mildew in the northern Himalayan parts of Pakistan. Powdery mildew was more severe during 2018 followed by 2017, while it was the minimum during 2016. In Sindh province, none of the 253 fields surveyed over three years, had powdery mildew, while in Punjab the disease was absent in more than 98% fields. In Khyber Pakhtunkhwa, the disease was detected in 17% fields, while in Kashmir the disease was present in only 11% of surveyed fields. In Gilgit-Baltistan, the disease was detected in four fields from three surveyed districts. Among the five provinces and Azad Jammu and Kashmir, powdery mildew was a major problem in Northern Khyber Pakhtunkhwa and Kashmir. Among the cultivated varieties surveyed, severe infestation (>40% severity) was observed for wheat varieties Galaxy-2013, PS-2005, Faisalabad-2008, Shahkar and some local lines. Future wheat improvement programmes must be encouraged to consider resistance to powdery mildew, particularly for lines to be cultivated in the Himalayan region of Pakistan.

**Received** | October 09, 2018; **Accepted** | January 13, 2019; **Published** | February 10, 2019
***Correspondence** | Sajid Ali, Institute of Biotechnology and Genetic Engineering, The University of Agriculture, Peshawar, Khyber Pakhtunkhwa, Pakistan; **Email:** bioscientist122@yahoo.com
**Citation** | Khan, M.R., M. Imtiaz, Farhatullah, S. Ahmad and S. Ali. 2019. Northern Himalayan region of Pakistan with cold and wet climate favors a high prevalence of wheat powdery mildew. *Sarhad Journal of Agriculture,* 35(1): 187-193.
**DOI** | http://dx.doi.org/10.17582/journal.sja/2019/35.1.187.193
**Keywords** | *Triticum aestivum*, *Blumaria graminis*, Field survey, Host reaction, Disease

## Introduction

Wheat being the most important food crop of Pakistan, remains the strong component of national food security. High wheat production in Pakistan is threatened by wheat diseases, particularly rusts and powdery mildew. Both rusts and powdery mildew are obligate parasites causing important wheat diseases like leaf/brown rust (LR) caused by *Puccinia triticina*, yellow/stripe rust (YR) caused by *P. striiformis*, stem/black rust (SR) caused by *P. graminis* f.sp. *tritici* and powdery mildew (PM) caused by *Blumeria graminis* f.sp. *tritici*. Although several efforts have been made to assess the prevalence of rusts on wheat varieties, limited information is available on the distribution of powdery mildew in various wheat growing regions of Pakistan.

The wheat powdery mildew was considered to be of immense economic importance during the era of 1980's

and early 1990's, prevailing in many wheat fields, with further sporadic prevalence associated with favorable climatic conditions. During early 2000 the disease prevailed again wherever the wheat is cultivated in the country in humid and sub-humid areas (Rattu et al., 2009). Powdery mildew of wheat has also worldwide distribution and is especially important in areas with cool and dry climates, including China, Europe, and South America (Dubin and Duveiller et al., 2011). It was considered as devastating disease in northern Europe where cool and mild climate prevails, leading to damage of grain yield and quality (Morgounov, 2012). The disease occurs more frequently in wheat growing areas with a moist environment. The disease is favored by cool and humid weather with optimal temperatures ranging from 15°C to 18°C and with relative humidity ranging from 75-100%. Such conditions are more prevalent in the northern Himalayan region of Pakistan. The growth of pathogen is negatively affected by temperatures above 25°C, leading the disease progression to slow down as the growing season progresses into the hotter months (Leath and Bowen, 1989). In recent decades, this disease is becoming of more importance even in areas with warmer and drier regions because of intensive production with higher plant densities, replacement of long by semi dwarf varieties, nitrogen fertilizers, and irrigation (Cowger, 2016). The high prevalence at the time of grain filling or earlier could lead to impart substantial losses on wheat crop.

Commercial yield losses due to powdery mildew in Western Europe are usually below 10%, with the maximum 20% losses in the United Kingdom. The reported yield losses in North Carolina ranged between 5–17%, generally 10 to 15% in Russia but sometimes reaches up to 35%, up to 62% in Brazil, and 30 to 40% in China under severe epidemics (Mehta, 2014). The yield reductions of higher than 40% are unusual, but infections at early stage may lead to the complete loss of seedlings or tillers ultimately failing to produce seeds (Cunfer, 2002). In areas of high disease prevalence, the disease may impart significant yield reductions, which needs to be controlled to avoid economic losses.

Various practices including agricultural and chemical controls have been utilized to reduce the effect of diseases, but increasing production costs, polluting the environment and encouraging the speedy evolution of new pathogen races (Hardwick et al., 1994; Parks et al., 2008; Ryabchenko et al., 2003). Host resistance is the only cost effective and economical way to restrict the disease (Huang et al., 2000; Huang and Röder, 2004). Genes conferring resistance against powdery mildew are known as *Pm* genes. Sixty *Pm* genes have been identified, formally named as *Pm1* to *Pm50*, and some other temporarily designated genes (McIntosh et al., 2012; Mohler et al., 2013; Xiao et al., 2013). Wheat genetic background narrowed with the passage of time by selecting high yielding wheat varieties with more homogeneous genetic backgrounds throughout the world, and replacing highly variable landraces leading to unpredicted challenges in resistance breeding (Johnson, 1992; Gupta et al., 2010; Muhammad et al., 2011; Karsai et al., 2012). The effectiveness of these powdery mildew resistance genes has been reduced with the passage of time owing excessive deployment of single resistance genes with race-specific nature (Xiao et al., 2013). Therefore, it is mandatory to continuously identify and transfer new and effective sources of powdery mildew resistance into improved wheat germplasm to counter the continuous evolution of virulence in powdery mildew pathogen. However, it could only be attained to identify the relative prevalence of powdery mildew across location of Pakistan in major wheat growing regions and the status of various wheat varieties grown in the powdery mildew hot spot regions.

In the past, breeding programmes in Pakistan has little consideration to utilize powdery mildew resistance in improved genetic stocks and thus genetic improvement of wheat varieties against powdery mildew was limited. This was mainly due to little information on distribution of the disease and the regional risks of epidemics across Pakistan. During the present study a countrywide surveillance effort was made to (i). identify the relative distribution of powdery mildew across the country and (ii). assess the status of powdery mildew infection on various wheat varieties grown in powdery mildew prone areas.

## Materials and Methods

Wheat powdery mildew surveillance was carried out in major wheat growing areas of Pakistan during the year 2016, 2017 and 2018 (Figure 1). The surveillance was carried out in mainly farmer fields and to some extent at research institutes and stations, all under natural field conditions. Surveillance activities were carried out from March to July starting from southern

part of the country and ending in the north, spanning mainly from heading to grain filling duration. A total of 1211 fields were surveyed during the three years from different locations of Pakistan.

**Figure 1:** *Powdery mildew symptoms of infected wheat fields in northern part of Pakistan.*

*Disease scoring*

Evaluation of disease was based on foliar infection. For scoring powdery mildew, two parameters were taken in consideration i.e., host reaction and disease severity, which was recorded on leaves of each wheat variety in a field (Ali and Hodson, 2017). Modified Cobb scale (0-100 scale) was used to estimate disease severity and percentage of infected tissue of plant in a field (Peterson et al., 1948), while considering the overall field infestation.

*Analyses of data*

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 powdery mildew across various geographical locations and different hosts was analysed based on its relative prevalence as a function of geography and host.

## Results and Discussion

Surveillance of powdery mildew disease allowed to measure the relative importance of disease at regional and country level. An overall low powdery mildew was detected in the southern half of Pakistan, while its prevalence was high in the northern Himalayan regions of Khyber Pakhtunkhwa and Azad Jammu and Kashmir.

*Surveillance details*

Surveillance enabled to assess the relative distribution of powdery mildew across locations and the status of different varieties in different geographical regions. Surveillance was carried out in 63 districts during 2016, 69 districts during 2017 and 34 districts of Pakistan during 2018 (Table 1 and Figure 2). A total of 1211 wheat fields were surveyed during three years. In AJK 27 fields, Baluchistan 4 fields, Gilgit-Baltistan 15 fields, Khyber Pakhtunkhwa 516 fields, Punjab 396 and Sindh 253 fields were surveyed over three years (Table 2).

**Table 1:** *Number of districts covered during the surveillance effort made over three years across different provinces of Pakistan to assess the relative prevalence of powdery mildew.*

| Province | 2016 | 2017 | 2018 | Over three years* |
|---|---|---|---|---|
| AJK | 2 | 2 | 2 | 6 |
| Baluchistan | 0 | 2 | 0 | 2 |
| Gilgit-Baltistan | 0 | 0 | 3 | 3 |
| Khyber-Pakhtunkhwa | 22 | 22 | 19 | 63 |
| Punjab | 20 | 24 | 10 | 54 |
| Sindh | 19 | 19 | 0 | 38 |
| Pakistan | 63 | 69 | 34 | 166 |

** The value shows total over three years; as not exactly same fields were surveyed over three years.*

**Table 2:** *Number of fields covered during the surveillance effort made over three years across different provinces of Pakistan to assess the relative prevalence of powdery mildew.*

| Province | 2016 | 2017 | 2018 | Overall |
|---|---|---|---|---|
| AJK | 8 | 10 | 9 | 27 |
| Baluchistan | 0 | 4 | 0 | 4 |
| Gilgit-Baltistan | 0 | 0 | 15 | 15 |
| Khyber-Pakhtunkhwa | 171 | 158 | 187 | 516 |
| Punjab | 135 | 178 | 83 | 396 |
| Sindh | 123 | 130 | 0 | 253 |
| Pakistan | 437 | 480 | 294 | 1211 |

*Relative distribution of powdery mildew across locations*

The powdery mildew incidence and severity varied over the two years, across provinces and districts. Significant levels of powdery mildew were observed at most of the locations in northern KP surveyed during 2018 followed by wheat season of 2017, however, a lower disease pressure was observed during 2016 (Table 3). A total of 51 fields out of 1211 fields had a high

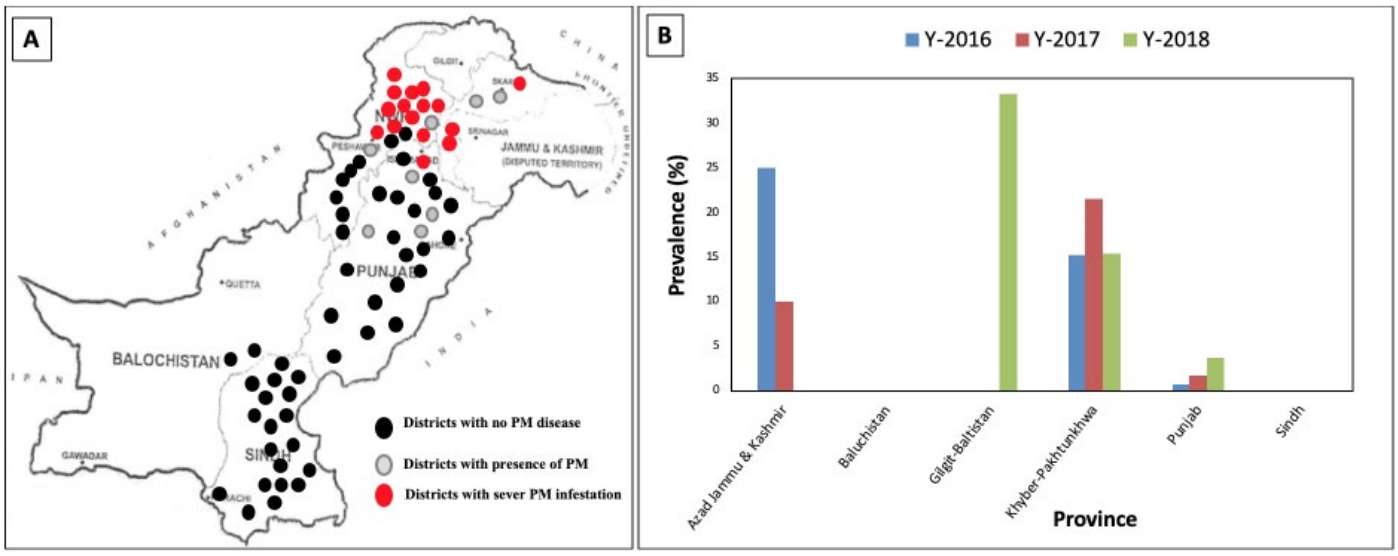


**Figure 2:** *Distribution of powdery mildew across Pakistan. A: Map of Pakistan with locations surveyed over the three years. Each point represents districts surveyed, while the red dots represent locations with high powdery mildew (>4% infection), grey dot represents detection of powdery mildew (<40%) and black dots shows location with no powdery mildew. B: Percent of fields surveyed where powdery mildew was detected.*

disease pressure with a powdery mildew severity score of 40 and above (Table 4). In 2016, 8 fields were recorded with high powdery mildew severity out of total 437 field surveyed. While in 2017, 13 fields were recorded with high powdery mildew severity out of 480 fields and during 2018, 21 fields were recorded with high severity out of 294 total fields surveyed (Table 3). In AJK, three fields in Hattian Bala and Muzzafarabad districts were recorded with high powdery mildew severity in 2016 and 2017. In KP, the maximum numbers of fields with high disease severity was observed in district Mansehra (10 fields), followed by Dir Lower (9 fields) and Dir Upper (8 fields) over three years. In Gilgit-Baltistan, in five fields powdery mildew was detected with only one field with high severity. The number of fields with high disease severity in other districts of Khyber Pakhtunkhwa ranged from one to five. In Punjab, powdery mildew severity was observed in Rawalpindi, Bhakar, Mandi Bahaudin, Hafizabad and Chakwal districts, while in Sindh none of the field was infected with powdery mildew disease (Table 4).

*Status of host varieties against powdery mildew infection*

Powdery mildew incidence varied on different hosts across different locations. The disease was observed on many varieties in KP, where wheat fields with varieties PS-2005, Shahkar and some unknown lines were observed with high disease severity over three years. In 2016 and 2017 high disease was observed on Galaxy-13 along with some local lines, while on Faisalabad-08 and PS-2008, the disease was observed only during 2016. The maximum numbers of infected fields were recorded for Galaxy-13 followed by Shahkar. In AJK and Punjab, only some local and unknown varieties were recorded with powdery mildew (Table 5).

**Table 3:** *Number of wheat fields where powdery mildew was detected in high severity (>40%) during the surveillance effort made over three years across different provinces of Pakistan.*

| Province | District | 2016 | 2017 | 2018 | Total |
|---|---|---|---|---|---|
| AJK | Hatian Bala | 1 | 1 | - | 2 |
| | Muzafferabad | 1 | - | - | 1 |
| Gilgit-Baltistan | Shegar | - | - | 1 | 1 |
| Khyber-Pakh-tunkhwa | Battagram | - | - | 1 | 1 |
| | Buner | - | - | 1 | 1 |
| | Charsadda | - | 2 | - | 2 |
| | Dir Lower | 2 | 3 | 4 | 9 |
| | Dir Upper | 1 | 3 | 4 | 8 |
| | Haripur | - | 1 | - | 1 |
| | Kala Dhaka | 1 | - | - | 1 |
| | Malakand | 1 | 2 | - | 3 |
| | Mansehra | 4 | 2 | 4 | 10 |
| | Mardan | - | 1 | - | 1 |
| | Shangla | - | 1 | 4 | 5 |
| | Swat | 1 | - | 2 | 3 |
| Punjab | Rawalpindi | - | 2 | - | 2 |
| Overall | | 12 | 17 | 21 | 51 |

Powdery mildew is an important disease of wheat and cereals with a worldwide distribution, but the

**Table 4:** *Number of wheat fields severely (>40%) infected with powdery mildew during the surveillance effort made over three years across different provinces of Pakistan.*

| | 2016 | | 2017 | | 2018 | | Total | |
|---|---|---|---|---|---|---|---|---|
| Province | Fields Surveyed | Severely infected (>40%) Fields | Fields Surveyed | Severely infected (>40%) Fields | Fields Surveyed | Severely infected (>40%) Fields | Fields Surveyed | Severely infected (>40%) Fields |
| AJK | 8 | 2 | 10 | 1 | 9 | - | 27 | 3 |
| Gilgit-Baltistan | - | - | - | - | 15 | 1 | 15 | 1 |
| Baluchistan | - | - | 4 | - | - | - | 4 | 0 |
| Khyber-Pakhtunkhwa | 171 | 10 | 158 | 15 | 187 | 20 | 516 | 45 |
| Punjab | 135 | - | 178 | 2 | 83 | - | 396 | 2 |
| Sindh | 123 | - | 130 | - | 0 | - | 253 | - |
| Overall | 437 | 8 | 480 | 13 | 279 | 21 | 1196 | 51 |

disease is of significant importance in regions with dry and cool climatic conditions, including China, Europe, and the Southern areas of South America (Dubin and Duveiller et al., 2011). In recent decades, this disease is becoming more prevalent even in areas with warmer and drier climates because of extensive use of nitrogen fertilizers, intensive production with higher plant densities, and irrigation (Cowger et al., 2012). Its global frequency remained stable over time, but increased by 10% in the last 10 years in Central and Eastern Europe (Morgounov et al., 2012). Relatively cold environment and high humidity favors disease development (Jones and Clifford, 1983; Wiese, 1987), which was the case in the present study, the disease was more prevalent in cold and humid areas.

Powdery mildew was dominated in the cool areas of Pakistan, particularly the Himalayan region, which could be attributed to the prevalent weather conditions, which favors successful establishment of the disease. Temperature ranging between 12°C to 20°C with average temperature of 16°C in wheat season would result in damaging epidemics of powdery mildew (Te-Beest et al., 2008). Our results are also in broad agreement with previous reports of the optimal temperature which suggested range for mildew between 15°C and 22°C (Jones and Clifford, 1983; Wiese, 1987). On contrary, the disease was absent in the warmer areas of Sindh and Punjab. Only in Rawalpindi division, powdery mildew was observed with few locations which could be attributed to the favorable microclimate developed during rainfall in vigorous crops with high fertilize application (Cowger et al., 2012).

High rain falls enable to maintain desirable humidity for powdery mildew infestation, which occurs in the Himalayan regions of Pakistan, creating good conditions for powdery mildew development. This high humidity is also absent in the southern part of the country, resulting in low powdery mildew infestation (Jones and Clifford, 1983; Wiese, 1987). Thus, in the northern part, the prevalent high humidity and cold climate would be responsible for the onset of disease (Ali et al., 2009).

**Table 5:** *Number of fields with high infection (>40%) of powdery mildew on different wheat varieties, detected during the surveillance effort made across Pakistan from 2016 to 2018.*

| Province | Varieties | 2016 | 2017 | 2018 | Overall |
|---|---|---|---|---|---|
| AJK | Local | 2 | - | - | 2 |
| | Unknown | - | 1 | - | 1 |
| Khyber-Pakhtunkhwa | Faisalabad-08 | 1 | - | - | 1 |
| | Galaxy-13 | 5 | 7 | - | 12 |
| | Local | 8 | 3 | - | 11 |
| | Mixture | 1 | 2 | - | 3 |
| | Narc-13 | - | - | 1 | 1 |
| | PS-2005 | 3 | 3 | 3 | 9 |
| | PS-2013 | - | 4 | 1 | 5 |
| | PS-2008 | 3 | - | - | 3 |
| | Shahkar | 2 | 4 | 1 | 7 |
| | Unknown | 3 | 11 | 19 | 33 |
| | Wadan | - | - | 1 | 1 |
| Punjab | Local | - | 1 | - | 1 |
| | Mixture | 1 | 1 | - | 2 |
| | Unknown | - | 1 | 1 | 2 |
| Overall | - | 29 | 38 | 27 | 94 |

Seasonal variability in temperature and humidity could result in differential onset of various diseases

(de Vallavielle-Pope et al., 2012). Powdery mildew dominated in cold regions all the three years, with a slight increase in frequency of powdery mildew during 2017 as compared to 2016. This seasonal variability in the Himalayan region could be attributed to the cool and mild climatic conditions of the area.

## Conclusions and Recommendations

This study concludes that wheat powdery mildew is emerging as potential threat to high yielding of wheat especially in northern part of the country. The disease incidence fluctuated oven the surveyed years. No disease was observed in the Sindh and was absent at maximum locations in Punjab because of the relatively high temperature during wheat season in those areas. The disease incidence was also low in southern KP, while in Northern KP and AJK where cool and humid climatic conditions prevail, the disease was more prevalent. Severe infestation was observed on some wheat varieties i.e., Galaxy-2013, PS-2005, Faisalabad-2008, Shahkar and some local lines, mainly deployed in those areas. The information should be considered while breeding wheat for genetic resistance against major diseases, particularly in breeding programmes for northern part of the country.

## Acknowledgements

The project was financially supported by CIMMYT-USDA. We also acknowledge the support of Dr. Attiq ur Rehman Rattu, Dr. Muhammad Fayyaz and Shafi M. Kathi during surveillance.

## Authors Contribution

The study was perceived by Muhammad Imtiaz, Farhatullah and Sajid Ali; The study was conducted by M. Rameez Khan and Sajid Ali; Data analyses was conducted by M. Rameez Khan, Sohail Ahmed and Sajid Ali; The manuscript was written by M. Rameez Khan and Sajid Ali; The manuscript was revised by M. Rameez Khan, Farhatullah, Sohail Ahmed and Sajid Ali.

## References

Ali, S., S.J.A. Shah and H. Rahman. 2009. Multi-locations variability in Pakistan for partial resistance in wheat to *Puccinia striiformis* West. *tritici*. Phytopathol. Mediterr. 48: 269–279.

Ali, S. and D. Hodson. 2017. Wheat rust surveillance; field disease scoring and sample collection for phenotyping and molecular genotyping. Methods Mol. Biol. (ed. Periyannan S). Humana Press.

Cowger, C., L. Miranda, C. Griffey, M. Hall, J.P. Murphy, J. Maxwell, 2012. Wheat powdery mildew. In: Disease Resistance in Wheat. ed. I. Sharma (Oxfordshire: CABI). pp. 84–119

Cowger, C., R. Parks and E. Kosman. 2016. Structure and migration in U.S. *Blumeria graminis* f. sp. *tritici* populations. Phytopathol. 106: 295-304. https://doi.org/10.1094/PHYTO-03-15-0066-R

Cunfer, B.M. 2002. Powdery mildew. Bread wheat: Improve. Prod. Plant prod. Prot. Ser. 317-330.

De Vallavieille-Pope, C., S. Ali, M. Leconte, J. Enjalbert, M. Delos and J. Rouzet. 2012. Virulence dynamics and regional structuring of Puccinia striiformis f. sp. tritici in France between 1984 and 2009. Plant Dis. 96: 131-140. https://doi.org/10.1094/PDIS-02-11-0078

Dubin, H.J. and E. Duveiller. 2011. Fungal, bacterial and nematode diseases of wheat: breeding for resistance and other control measures. In *The World Wheat Book*: Hist. Wheat Breeding, Vol. 2, ed. A.P. Bonjean, W.J. Angus, M. Van Ginkel, pp. 1131–81. Paris: Lavoisier.

Gupta, P.K., P. Langridge and R.R. Mir. 2010. Marker-assisted wheat breeding: present status and future possibilities. Mol. Breed. 261: 145–161. https://doi.org/10.1007/s11032-009-9359-7

Hardwick, N.V., J.E.E. Jenkins, B. Collins and S.J. Groves. 1994. Powdery mildew (*Erysiphe graminis*) on winter wheat: control with fungicides and the effects on yield. Crop. Prot. 13: 93–98. https://doi.org/10.1016/0261-2194(94)90157-0

Huang, X.Q. and M.S. Röder. 2004. Molecular mapping of powdery mildew resistance genes in wheat: Review. Euphytica. 137: 203–223. https://doi.org/10.1023/B:EUPH.0000041576.74566.d7

Huang, X.Q., S.L.K. Hsam, F.J. Zeller, G. Wenzel and V. Mohler. 2000. Molecular mapping of the wheat powdery mildew resistance gene *Pm24* and marker validation for molecular breeding. Theor. Appl. Genet. 101: 407–414. https://doi.org/10.1007/s001220051497

Johnson, R. 1992. Past, present and future

opportunities in breeding for disease resistance, with examples from wheat. Euphytica. 63: 3–22. https://doi.org/10.1007/BF00023908

Jones, D.G. and B.C. Clifford. 1983. Cereal disease. Their pathology and control. 2nd ed. John Wiley and Sons, New York.

Karsai, I., G. Vida, S. Petrovics, E. Petcu, B. Kobiljski, S. Ivanovsk, Z. Bedö and O. Veisz. 2012. Assessment of the spatial genotypic and phenotypic diversity present in the various winter wheat breeding programs in Southeast Europe. Euphytica. 186: 139–151. https://doi.org/10.1007/s10681-011-0510-2

Leath, S. and K.L. Bowen. 1989. Effects of powdery mildew, triadimenol seed treatment and triadimefon foliar sprays on yield of winter wheat in North Carolina. Phytopathol. 79(12): 152–155. https://doi.org/10.1094/Phyto-79-152

McIntosh, R.A., J. Dubcovsky, W.J. Rogers, C. Morris, R. Appels and X. C. Xia. 2012. Catalogue of gene symbols for wheat: 2012 supplement. http://www.wheat.pw.usda.gov

Mehta, N. 2014. Epidemiology and forecasting for the management of rapeseed-mustard diseases. J. Mycol. Plant Pathol. 44: 131.

Mohler, V., C. Bauer, G. Schweizer, H. Kempf and L. Hartl. 2013. *Pm50*: a new powdery mildew resistance gene in common wheat derived from cultivated emmer. J. Appl. Genet. 54: 259–263. https://doi.org/10.1007/s13353-013-0158-9

Morgounov, A., H.A. Tufan, R. Sharma, B. Akin, A. Bagci, H.J. Braun, Y. Kaya, M. Keser, T.S. Payne and K. Sonder. 2012. Global incidence of wheat rusts and powdery mildew during 1969-2010 and durability of resistance of winter wheat variety Bezostaya 1. Eur. J. Plant Pathol. 132: 323-340. https://doi.org/10.1007/s10658-011-9879-y

Muhammad, I.K., A.K. Mir, H.X. Ma, S.S.K. Gul, J.K. Abdul and M. Tila. 2011. Selection of parents for crossing based on genotyping and phenotyping for stripe rust (*Puccinia striiformis*) resistance and agronomic traits in bread wheat breeding. Cytol. Genet. 45: 379–394. https://doi.org/10.3103/S0095452711060065

Parks, R., I. Carbone, J.P. Murphy, D. Marshall and C. Cowger. 2008. Virulence structure of the eastern US wheat powdery mildew population. Plant Dis. 92: 1047–1082. https://doi.org/10.1094/PDIS-92-7-1074

Peterson, R.F., A.B. Campbell and A.E. Hannah. 1948. A diagrammatic scale for rust intensity on leaves and stems of cereals. Can. J. Res. 26: 496-500. https://doi.org/10.1139/cjr48c-033

Ryabchenko, A.S., G.V. Serezhkina, G.N. Mishina and L.N. Andreev. 2003. Morphological variability of wheat powdery mildew in the context of its parasitic adaptation to wheat-*Aegilops* lines with different resistance. Biol. Bull. Acad. Sci. 30: 255–261. https://doi.org/10.1023/A:1023807828980

Rattu, A.R., S. Asad and M. Fayyaz. 2009. Status of foliar diseases in Punjab, Pakistan. Report, CDRP, IPEP, NARC, Islamabad.

Te-Beest, D.E., N.D. Paveley, M.W. Shaw and F. van den Bosch. 2008. Disease–Weather relationships for powdery mildew and yellow rust on winter wheat. Ecol. Epidemiol. 98(5): 609-617. https://doi.org/10.1094/PHYTO-98-5-0609

Wiese, M.V. 1987. Compendium of wheat diseases. 2nd ed. Am. Phytopathol. Soc. St. Paul, MN.

Xiao, M.G., F.J. Song, J.F. Jiao, X.M. Wang, H.X. Xu and H.J. Li. 2013. Identification of the gene *Pm47* on chromosome 7BS conferring resistance to powdery mildew in the Chinese wheat landrace Hongyanglazi. Theor. Appl. Genet. 126: 1397–1403. https://doi.org/10.1007/s00122-013-2060-6