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Research Article

Stable sources of resistance to yellow rust and powdery mildew in Indian and exotic wheat germplasm

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Abstract

Yellow rust (*Puccinia striiformis* f. sp. *tritici*) and powdery mildew (*Blumeria graminis tritici*) of wheat can be effectively managed by the cultivation of resistant varieties. However, such resistant varieties become susceptible due to evolution and spread of new and matching virulences of these pathogens after a short period of their commercial cultivation. Hence, breeding for disease resistance tends to be a continuous process with pre-requisite of identification of diverse resistant donors. In this context, more than 500 genotypes comprising advanced breeding material form CIMMYT and those developed in India were subjected to multilocational screening at hot spot locations of yellow rust and powdery mildew (Dhaulakuan, Malan and Ludhiana) under artificial epiphytotic conditions during the *Rabi* cropping season 2014-15 to 2016-17. Five genotypes from advanced Indian wheat breeding material were free from both the diseases whereas, 8 genotypes of CIMMYT origin showed mean terminal yellow rust (TYR) severity ≤5S and terminal powdery mildew (PM) reaction ≤3 and were highly resistant whereas 30 genotypes among Indian wheat breeding material showed mean terminal YR severity ≤5S and terminal PM reaction ≤5 were found resistant. Agronomically superior genotypes may be directly utilized as varieties and sources with multiple resistance may be used as donors in breeding program.

Keywords: *Bbumeria graminis tritici,* powdery mildew, *puccinia striiformis tritici,* resistance, wheat, yellow rust.

1. Introduction

Crop pathogens with worldwide prevalence and potential for long distance migration and invasions into new areas may pose a serious threat to food security regionally or globally (Dean *et al*., 2012; Beddow*et al*., 2015). Wheat (*Triticum aestivum* L.) is an important food crop worldwide (Juliana *et al.,* 2017) and it is persistently threatened by attack from diverse rapidly evolving pathogens (Riaz *et al.,* 2018). Wheat pathogens like rusts and powdery mildew are generally managed through large-scale breeding efforts to improve disease resistance, which is economical, eco-and farmer friendly, practically feasible and sometimes the only available option to prevent disease related yield losses (Kumar *et al.,* 2016; Juliana *et al.,* 2018; Singh *et al.,* 2018). Growing of resistant varieties to these diseases in the NHZ is of paramount importance to safeguard yield potential of the varieties cultivated in other zones, as hills act as a foci of infection for these as per the knowledge available so far. Large scale deployment of varieties with narrow genetic disease resistance have been reported to result in evolution of new virulences at regional and continental scales (Singh *et al*., 2004; Chen, 2005; Wellings, 2007). Yellow rust (YR) and Powdery mildew (PM), caused by *Puccinia striiformis* f. sp. *tritici* (*Pst*) and *Blumeria graminis* f. sp. *tritici* (*Bgt*), respectively are the most important pathogens and are the continuous threat to wheat production in cool climate regions (Basandrai and Basandrai, 2018; Wan *et al*., 2007;

Kumar *et al.,* 2016). In India, both the diseases are major constraints of wheat in NHZ and NWPZ, including Himachal Pradesh. These biotrophic fungal pathogens needs the living host for both on-season and off-season survival (Ali *et al.,* 2017). In Himachal Pradesh, wheat can be grown throughout the year in both summer and winter seasons and the resistant varieties induces strong selection pressure favoring virulence mutants of the pathogens. Hence, breeding for resistance against both the diseases requires a continuous process. It requires identification of new and diverse resistance donors for their effective use in the breeding program. Hence, the present study was undertaken to identify stable sources of resistance to YR and PM in some Indian and exotic wheats based on their screening at different hotpot locations.

2. Materials and methods

Experimental material comprising more than 500 genotypes of wheat received form CIMMYT (46th IBWSN) and of some advanced Indian wheat breeding material. The material was evaluated against yellow rust at hot spot locations of national importance (CSK HP Agricultural University HAREC, Dhaulakuan; RWRC, Malan and PAU Ludhiana) and powdery mildew (CSK HP Agricultural University HAREC Dhaulakuan during 2014-15 and RWRC, Malan during 2015-16 and 2016-17) under artificial epiphytotic conditions.

The test genotypes were grown in one meter long rows spaced 20 cm apart, following standard package and practices followed for irrigated conditions (http://www.hillagric.ac.in/extension/ dee/pdf_files/Rabi_28-8-09.PDF). The susceptible check (SC) varieties PBW 343/ HD 2967/Agral Local (YR) Lehmi/HPW 155/HS 240 (PM) were sown after every 20th test genotypes and the experimental plots were surrounded on the outer boundaries by the susceptible checks, which served for the multiplication and spread of inoculum. However, to avoid escape artificial epiphytotics were created for both the diseases. The inoculum of the yellow rust (mixture of pathotypes) was procured from ICAR-IIWBR, Regional Station, Flowerdale, Shimla. It was multiplied on the susceptible varieties Agra Local//PBW 343/HD 2967 and mixture of local field population of *P. striiformis* was also used to create epidemic. The uredosporic suspension of *P. striiformis* (1x10^6uredospores/ml of water) was sprayed onto the test genotypes and susceptible checks in the evening hours following the standard procedure (Kumar *et al*., 2017).

2.1 Powdery mildew

The pots of PM susceptible varieties, heavily infected with local isolates of the pathogen, were randomly placed in the experimental plots near the susceptible checks. As the season advanced, the infected susceptible checks were tapped with a stick in the evening hours so as to dislodge the pathogen conidia which served as inoculums for the test genotypes.

2.2 Data recording

The data for yellow rust were recorded on terminal disease severity (TDS) using the modified Cobb's scale (Peterson *et al.* 1948), while the data for powdery mildew were recorded on terminal disease reaction (TDR) on 0-9 scale as described by Saari and Prescott (1975).

3 Results and discussion

3.1 CIMMYT Material

3.1.1. Yellow rust resistance : Three hundred and 125 genotypes of 46th IBWSN (CIMMYT) and Indian origin, respectively were evaluated at Ludhiana and Dhaulakuan during 2013-14 against yellow rust. Among these, 162 genotypes showing resistance to yellow rust were screened at Dhaulakuan (2014-15) and at Malan during the cropping seasons 2015-16 and 2016-17 to confirm their resistance. Based on data of all the years over all the locations, 23 genotypes CMSS07Y00419S-0B-099Y-099M-099Y-10M-0WGY, CMSS07B00191S-099M-099Y-099M-25WGY-0B, CMSS07B0 0211S-099 M-099Y-099M-5WGY-0B, CMSS07B00232S-099M-099Y-099M-8WGY-0B, CMS S07B 003 11S-099M-099Y-099M-4WGY-0B, CMSS07B00612T-099TOPY-099M-099Y-099M-1WGY-0B, CMSS07B00800T-099TOPY-099M-099Y-099M-3WGY-0B, CMSS07Y00129S-0B-099Y-099M-099NJ-099NJ-14WGY-0B, CMSS07Y01083T-099TOPM-099Y-099M-099Y-40M-0W GY, CMSS07Y00096S-0B-099Y-099M-099NJ-099NJ-17WGY-0B, CMSS07Y0 0126S-0B-099Y-099M-099Y-11M-0WGY, CMSS07Y00419S-0B-099Y-099M-099Y-2WGY-0B, CMSS 07Y00938T-099TOPM-099Y-099M-099NJ-099NJ-1WGY-0B, CMSS07Y01226T-099TOPM-099Y-099M-099Y-1M-0WGY, CMSS07B00207S-099M-099Y-099M-15WGY-0B, CMSS 07B 00232S-099M-099Y-099M-23WGY-0B, CMSS07B00240S-099M-099Y-099M-12WGY-0B, CMSS07B00577T-099TOPY-099M-099NJ-099NJ-14WGY-0B, CMSS07B0 05 79T-099TOPY-099M-099Y-099M-5WGY-0B, CMSS07B00601T-099TOPY-099M-099Y-099M-28WGY-0B, CMSS07B00636T-099TOPY-099M-099NJ-099NJ-10WGY-0B, CMSS07 B00674T-099TOPY-099M-099Y-099M-15WGY-0B and CMSS07B00755T-099TOPY-099M-099Y-099M-1WGY-0B were free from disease at all the locations (Fig 1). Eighty five and fifty two genotypes showing mean disease severity ≤5S and ≤10S were highly resistant and resistant,

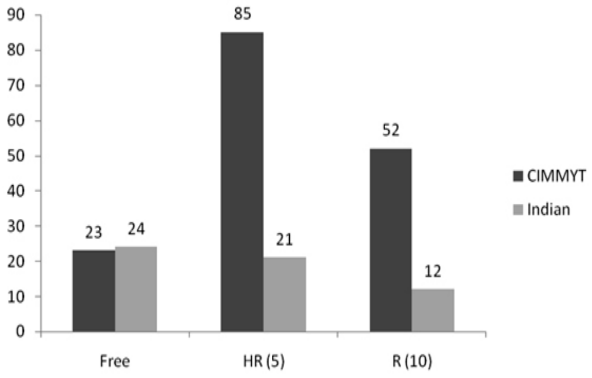

Fig 1. Mean percent yellow rust severity on CIMMYT (46th IBWSN) and of some advanced Indian wheat breeding material

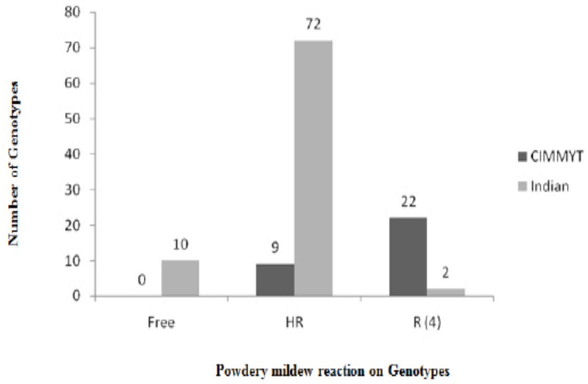

Fig 2. Mean powdery mildew disease reaction on CIMMYT (46th IBWSN) and of some advanced Indian wheat breeding material

respectively.

3.1.2. Powdery mildew resistance (Dhaulakuan Malan) : The genotypes showing stable resistance to YR at Dhaulakaun and Ludhiana were also evaluated against powdery mildew during the year 2014-15 at Dhaulakuan and 2015-16 and 2016-17 at Malan. Based on the multilocation and multi-year data, no genotype was free from the disease. However, nine genotypes CMSS07B00825T-099TOPY-099M-099Y-099M-11WGY-0B, CMSS 07Y00066S-0B-099Y-099M-099Y-8M-0WGY, CMSS07Y00284S-0B-099Y-099M-099Y-1M-0WGY, CMSS07Y00419S-0B-099Y-099M-099Y-10M-0WGY, CMSS07Y01240T-099TOPM-099Y-099M-099Y-8M-0WGY, CMSS07B00211S-099M-099Y-099M-5WGY-0B, CMSS07B 00279S-099M-099NJ-099NJ-6WGY-0B, CMSS07B00594T-099TOPY-099M-099Y-099M-25 WGY-0B and CMSS07B00612T-099TOPY-099M-099Y-099M-1WGY-0B showing terminal disease reaction ≤3 were categorized highly resistant (Fig 2). Moreover 22 genotypes CMSS06Y01171T-099TOPM-099Y-099ZTM-099Y-099M-8WGY-0B, CMSS07B00101S-099 M-099NJ-099NJ-10WGY-0B, CMSS07B00374S-099M-099NJ-099NJ-8WGY-0B, CMSS07 B00577T-099TOPY-099M-099Y-099M-2WGY-0B, CMSS07B00655T-099TOPY-099M-099Y-099M-11WGY-0B, CMSS07Y00124S-0B-099Y-099M-099Y-11M-0WGY, CMSS 07Y00143S-0B-099Y-099M-099Y-9M-0WGY, CMSS07Y00236S-0B-099Y-099M-099Y-1M-0WGY, CMS 07Y00419S-0B-099Y-099M-099Y-1WGY-0B, CMSS07Y00433S-0B-099Y-099M-099NJ-099 NJ-4WGY-0B, CMSS07Y00686T-099TOPM-099Y-099M-099NJ-099NJ-10W GY-0B, CMSS 07Y00704T-099TOPM-099Y-099M-099NJ-099NJ-9WGY-0B, CMSS07Y00794T-099TOPM-099Y-099M-099Y-3M-0WGY, CMS S07Y00926T-099TOPM-099Y-099M-099Y-19M-0WGY, CMSS07Y00941T-099TOPM-099Y-099M-099Y-2M-0WGY, CMSS07B00191S-099M-099Y-099M-22WGY-0B, CMSS07B00232S-099M-099Y-099M-8WGY-0B, CMSS07 B00235S-099 M-099Y-099M-11WGY-0B, CMSS07B00235S-099M-099Y-099M-12WGY-0B, CMSS07 B00548T-099TOPY-099M-099Y-099M-7WGY-0B, CMSS07B00622T-099TOPY-099M-099Y-099M-14WGY-0B and CMSS07B00833T-099TOPY-099M-099NJ-099NJ-3WGY-0B were showing terminal disease reaction ≤ 4 and were categorized under resistant genotypes as compared to susceptible check which was showing powdery mildew disease reaction >7.

3.2. Advanced Indian breeding material

3.2.1. Yellow rust and powdery mildew resistance in Indian wheats at Malan: One hundred twenty Indian genotypes were evaluated against YR and PM at Malan, and twenty five genotypes i.e. HW 1098, UP 2719, HD 2181, HI 8638, VL 912, WH 913, ISWRN 277, NW 1013, DW 172, DW 173, DW 174, DW 176, DW 177, DW 178, DW 179, DW 180, DW 183, DW 184, HPW 403, HPW 404, HPW 405, HPW 410, HPW 411 and HPW 412 were free from yellow rust. Twenty one genotypes with disease severity ≤5S were highly resistant and 12 genotypes i.e. CPAN 4071, HS 365, DK 1031, CPAN 6065, FLW 1, HPW 89, CPAN 4036, FLW 4, CPAN 2031, CPAN 4049, VL 907 and HPW 400 with disease severity ≤10s were categorized as resistant (Fig 1). Ten genotypes i.e. CW 90, NW 1013, DW 180, DW 181, DW 182, DW 176, DW 174 DW 172, FLW 1 and CPAN 4049 were free from powdery mildew and 72 genotypes with terminal disease reaction ≤ 3 and were highly resistant (Fig 2).

It was observed that among the CIMMYT material, no genotype was free from both the diseases. 8 genotypes i.e. CMSS07B00825T-099TOPY-099M-099Y-099M-11WGY-0B, CMSS 07Y 000 66S-0B-099Y-099M-099Y-8M-0WGY, CMSS07Y00284S-0B-099Y-099M-099Y-1M-0WGY,

Table 1: Genotypes with combined resistance to yellow rust and powdery mildew in exotic and Indian wheats

CIMMYT material	
Highly resistant (8)	**YR severity ≤5S and PM reaction ≤3:** CMSS07B00825T-099TOPY-099M-099Y-099M-11WGY-0B, CMSS07Y00066S-0B-099Y-099M-099Y-8M-0WGY, CMSS07Y00284S-0B-099Y-099M-099Y-1M-0WGY, CMSS07Y00419S-0B-099Y-099M-099Y-10M-0WGY, CMSS07Y01240T-099TOPM-099Y-099M-099Y-8M-0WGY, CMSS07B00211S-099M-099Y-099M-5WGY-0B, CMSS07B00279S-099M-099NJ-099NJ-6WGY-0B and CMSS07B00612T-099TOPY-099M-099Y-099M-1WGY-0B
Resistant (20)	**YR severity ≤10S and PM reaction ≤4:** CMSS06Y01171T-099TOPM-099Y-099ZTM-099Y-099M-8WGY-0B, CMSS07B00101S-099M-099NJ-099NJ-10WGY-0B, CMSS07B00374S-099M-099NJ-099NJ-8WGY-0B, CMSS07B00577T-099TOPY-099M-099Y-099M-2WGY-0B, CMSS07B00655T-099TOPY-099M-099Y-099M-11WGY-0B, CMSS07Y00124S-0B-099Y-099M-099Y-11M-0WGY, CMSS07Y00236S-0B-099Y-099M-099Y-1M-0WGY,CMSS07Y00419S-0B-099Y-099M-099Y-1WGY-0B,CMSS07Y00433S-0B-099Y-099M-099NJ-099NJ-4WGY-0B, CMSS07Y00704T-099TOPM-099Y-099M-099NJ-099NJ-9WGY-0B, CMSS07Y00794T-099TOPM-099Y-099M-099Y-3M-0WGY, CMSS07Y00926T-099TOPM-099Y-099M-099Y-19M-0WGY, CMSS07Y00941T-099TOPM-099Y-099M-099Y-2M-0WGY, CMSS07B00191S-099M-099Y-099M-22WGY-0B, CMSS07B00232S-099M-099Y-099M-8WGY-0B, CMSS07B00235S-099M-099Y-099M-11WGY-0B, CMSS07B00235S-099M-099Y-099M-12WGY-0B, CMSS07B00548T-099TOPY-099M-099Y-099M-7WGY-0B, CMSS07B00594T-099TOPY-099M-099Y-099M-25WGY-0B and CMSS07B00833T-099TOPY-099M-099NJ-099NJ-3WGY-0B
Indian material	
Free (5)	**Free:** NW 1013, DW 180, DW 176, DW 174 and DW 172
Highly resistant (25)	**YR severity ≤5S and PM reaction ≤5:** HW 1098, HI 8638, HPW 285, HI 9007, HPW 236, DW 181, DW 182, DW 183, DW 184, DW 177, DW 173, DW 172, DW 178, HPW 403, UP 2719, C040, HD 2181, VL 912, DWL 5010, WH 913, DW 179, HPW 410, HPW 405, HPW 412, HPW 411 and HPW 404

CMS S07Y00419S-0B-099Y-099M-099Y-10M-0WGY, CMSS07Y01240T-099TOPM-099Y-099M-099Y-8M-0WGY, CMSS07B00211S-099M-099Y-099M-5WGY-0B, CMSS07B00279S-099M-099NJ-099NJ-6WGY-0B and CMSS07B00612T-099TOPY-099M-099Y-099M-1WGY-0B showing mean terminal YR severity ≤5S and PM reaction ≤3, were categorized as highly resistant. Ninteen genotypes i.e. CMSS06Y01171T-099TOPM-099Y-099ZTM-099Y-099M-8WGY-0B, CMSS07B00101S-099M-099NJ-099NJ-10WGY-0B, CMSS 07B00374S-099M-099 NJ-099NJ-8WGY-0B, CMSS07B00577T-099TOPY-099M-099Y-099M-2WGY-0B, CMSS 07B 00655T-099TOPY-099M-099Y-099M-11WGY-0B, CMSS07Y00124S-0B-099Y-099M-099Y-11M-0WGY, CMSS07Y00236S-0B-099Y-099M-099Y-1M-0WGY, CMSS07Y00419S-0B-099 Y-099M-099Y-1WGY-0B, CMSS07Y00433S-0B-099Y-099M-099 NJ-099NJ-4WGY-0B, CMSS07Y00704T-099TOPM-099Y-099M-099NJ-099NJ-9WGY-0B, CMSS07Y00794T-099 TOPM-099Y-099M-099Y-3M-0WGY, CMSS07Y00926T-099TOPM-099Y-099M-099Y-19M-0WGY, CMSS07Y00941T-099TOPM-099Y-099M-099Y-2M-0WGY, CMSS07B00191S-099M -099Y-099M-22WGY-0B, CMSS07B00232S-099M-099Y-099M-8WGY-0B, CMSS07B 00235 S-099M-099Y-099M-11WGY-0B, CMSS07B00235S-099M-099Y-099M-12WGY-0B, CMSS 07B00548T-099TOPY-099M-099Y-099M-7WGY-0B, CMSS07B00594T-099TOPY-099M-099 Y-099M-25WGY-0B and CMSS07B00833T-099TOPY-099M-099NJ-099NJ-3WGY-0B with mean terminal YR severity ≤10 and powdery mildew reaction ≤4 and were resistant. Among the advanced Indian wheat breeding material five genotypes NW 1013, DW 172, DW 174, DW 176, and DW 180 were free from both the diseases and 25 genotypes HW 1098, HI 8638, HPW 285, HI 9007, DW 181, DW 182, DW 183, DW 184, DW 177, DW 173, DW 172, DW 178, HPW 403, UP 2719, C040, HD 2181, VL 912, DWL 5010, WH 913, DW 179, HPW 404, HPW 405, HPW 410, HPW 411 and HPW 412 with mean terminal yellow rust severity ≤5 and powdery mildew reaction ≤4 were highly resistant (Table 1). As has been observed in the present studies, resistance in wheat genotypes to YR (Safavi *et al*., 2010; Kumar *et al*., 2016; Raghu *et al*., 2018; Gupta *et al*., 2018, Kumar *et al*., 2019; Mu *et al*., 2019 and Kumar *et al*., 2020) and PM (Basandrai *et al*., 2013; 2016 and Gupta *et al*., 2016) was reported earlier also. The identification of genotypes with combined resistance to YR and PM was also supported by the studies of (Song *et al*., 2016; Yang *et al*., 2017). As has been observed in the present studies, sources and genes for APR against leaf rust, yellow rust, black rust and powdery mildew resistance i.e. Lr34/Yr18/Sr57/Pm38, Lr46/Yr29/Sr58/Pm39, Lr67/Yr46/ Sr55/Pm46 have been identified and well characterized (Sheikh *et al*., 2019), yellow rust and powdery mildew (Shamanin *et al*., 2019). Therefore, the availability of genetically diverse germplasm with broad resistance to multiple diseases is important to the success of wheat improvement programs (Polak and Bartos, 2002). In the present studies, high level of resistance to both YR and PM were identified in eight genotypes from CIMMYT and five genotypes from advanced Indian wheat breeding material. These genotypes may be used as direct varieties after agronomic evaluation or may be utilized as donors in the breeding programme to develop varieties with combined resistant to both the diseases.

4. References

1. Ali S, J Rodriguez-Algaba, T Thach, CK Sørensen, JG Hansen, P Lassen, K Nazari, DP Hodson, AF Justesen and MS Hovmøller. 2017. Yellow Rust Epidemics Worldwide Were Caused by Pathogen Races from Divergent Genetic Lineages. *Frontiers in Plant Science* **8**: 1057.

2. Basandrai AK and D Basandrai. 2018. Powdery mildew of wheat and its management. In: Management of wheat and barley diseases (Devender Pal Singh ed.). Apple Academic Press, Canada pp 173-181.

3. Basandrai AK, D Basandrai and PD Tyagi. 2013. Postulation of resistant genes for powdery mildew (*Blumeria graminis tritici*) in Indian wheats. *International Journal of Plant Protection* **6**: 171-176.

4. Basandrai D, AK Basandrai, SK Rana, BK Sharma, A Singh, D Singh and PD Tyagi. 2016. Resistance to powdery mildew (*Blumeria graminis* f. sp. *tritici* E. Marchal.) in bread wheat, durum, dicoccum and triticale genotypes. *Indian Journal of Genetics and Plant Breeding* **76**: 205-208.

5. Beddow JM, PG Pardey, Y Chai, TM Hurley, DJ Kriticos, HJ Braun, RF Park, WS Cuddy and T Yonnow. 2015. Research investment implications of shifts in the global geography of wheat stripe rust. *Nature Plants* **1**: 15132.

6. Chen XM. 2005. Epidemiology and control of stripe rust [*Puccinia striiformis* f. sp. *tritici*] on wheat. *Canadian Journal of Plant Pathology* **27**: 314-337.

7. Dean R, J Van Kan, ZA Pretorius, KE Hammond-Kosack, A Pietro, PD Spanu, JJ Rudd, M Dickman, R Kahimann, J Ellis and GD Foster. 2012. The top 10 fungal pathogens in molecular plant pathology. *Molecular Plant Pathology* **13**: 414-430.

8. Gupta V, Selvakumar R, Kumar S, Mishra CN, Tiwari V and Sharma I (2016) Evaluation and identification of resistance to powdery mildew in Indian wheat varieties under artificially created epiphytotic. *Journal of Applied and Natural Science* 8(2) 565-569

9. Gupta V, S Mahajan, VK Razdan, K Fatima and S Sharma. 2018. Characterisation of wheat germplasm for slow rust resistance against *Puccinia striiformis*. *Archives of Phytoapthology and Plant Protection* **51:** 3-4.

10. Juliana, P., Singh, R. P., Singh, P. K., Poland, J. A., Bergstrom, G. C., and Huerta-Espino, J. (2018). Genome-wide association mapping for resistance to leaf rust, stripe rust and tan spot in wheat reveals potential candidate genes. *Theoretical and Applied Genetics* 131, 1405–1422.

11. Juliana P, RP Singh, PK Singh, JA Poland, GC Bergstrom and J Huerta-Espino. 2018. Genome-wide association mapping for resistance to leaf rust, stripe rust and tan spot in wheat reveals potential candidate genes. *Theoretical and Applied Genetics.* 131, 1405–1422.

12. Joshi LM, DV Singh and KD Srivastava. 1988. Technique in wheat disease. In : Manual of Wheat. Malhotra Publishing House, New Delhi. pp. 15-75.

13. Kumar S, S Archak, RK Tyagi, J Kumar, VK Vikas, SR Jacob, K Srinivasan, J Radhamani, R Parimalan, M Sivaswamy, S Tyagi, M Yadav, J Kumari, Deepali, S Sharma, I Bhagat, M Meeta, NS Bains, AK Chowdhury, BC Saha, PM Bhattacharya, J Kumari, MC Singh, OP Gangwar, P Prasad, SC Bharadwaj, R Gogoi, JB Sharma, SGM Kumar, MS Saharan, M Bag, A Roy, TV Prasad, RK Sharma, M Dutta, I Sharma and KC Bansal. 2016. Evaluation of 19,460 Wheat Accessions Conserved in the Indian National Genebank to Identify New Sources of Resistance to Rust and Spot Blotch Diseases. *PLoS ONE* 11(12): e0167702.

14. Kumar S, Singroha G, Bhardwaj SC, Bala R, Saharan MS, Gupta V, Khan A, Mahapatra S, Sivasamy M, Rana V, Mishra CN, Sharma P, Prakash O, Verma A, Sharma I, Chatrath R and Singh GP (2019) Multienvironmental evaluation of wheat germplasm identifies donors with multiple fungal disease resistance. *Genetic Resources and Crop Evolution* 66: 797-808.

15. Kumar S, Singroha G, Bhardwaj SC, Saharan MS, Gangwar OP, Mishra CN, Khan A, Mahapatra S, Sivasamy M, Chatrath R and Singh GP (2020) Characterization of exotic germplasm lines for resistance to wheat rusts and spot blotch. *Indian Phytopathology doi* 10.1007/s42360-020-00232-z

16. Mu J, Q Wang, Wu, J, Q Zeng, S Huang, S Liu, S Yu, Z Kanag and D Han. 2019. Identification of sources of resistance in geographically diverse wheat accessions to stripe rust pathogen in China. *Crop Protection* **122**: 1-8.

17. Peterson RF, AB Champbell and AE Hannah. 1948. A diagrammatic scale for estimating rust intensity of leaves and stem of cereals. *Canadian Journal of Research* **26**: 496-500.

18. Polak J and P Bartos. 2002. Natural sources of plant disease resistance and their importance in the breeding. *Czech Journal of Genetics and Plant Breeding* **38**: 146-149.

19. Raghu BR, OP Gangwar, SC Bhardwaj and SK Jain. 2018. Seedling and Adult Plant Resistance to Stripe

Rust in Uttarakhand Landraces of Wheat. *Applied Biological Research* **20**(3): 291-301.

20. Riaz A, N Athiyannan, SK Periyannan, O Afanasenko, OP Mitrofanova, GJ Platz, EAB Aitken, RJ Snowdon, ES Lagudha, LT Hickey and KP Vossfels. 2018. Unlocking new alleles for leaf rust resistance in the vavilov wheat collection. *Theoretical and Applied Genetics* **131**: 27-144.

21. Saari EE and JM Prescott. 1975. A scale for appraising the foliar intensity of wheat disease. *Plant Disease Reporter* **59**: 372-80.

22. Safavi SA, AB Ahari, F Afshari and M Arzanlou. 2010. Slow Rusting Resistance in 19 Promising Wheat Lines to Yellow Rust in Ardabil, Iran. *Pakistan Journal of Biological Sciences* **13** (5): 240-244.

23. Shamanin V, S Shepeleva, V Pozherukovaa, E Gultyaevab, T Kolomietsc, E Pakholkovac, and A Morgounovd. 2019. Primary hexaploid synthetics: Novel sources of wheat disease resistance. *Crop Protection* **121**: 7-10.

24. Sheikh FA, ZA Dar, PA Sofi, Ajaz A Lone and NA Shiekh. 2017. Advanced Breeding Strategies to Mitigate the Threat of Yellow Stripe Rust of Wheat. *International Journal of Current Microbiology and Applied Sciences* **6**: 21-32.

25. Singh D, LA Ziems, PM Dracatos, M Pourkheirandish, S Tshewang, P Czembor, S German, RA Fowler, L Snyman, GJ Platz and RF Park. 2018. Genome-wide association studies provide insights on genetic architecture of resistance to leaf rust in a worldwide barley collection. *Molecular Breeding* **38**:43.

26. Singh RP, HM William, J Huerta-Espino and G Rosewarne. 2004. "Wheat rust in Asia: meeting the challenges with old and new technologies," in Proceedings of the 4th International Crop Science Congress; 26 Sep - 1 Oct 2004 (Brisbane, QLD). Available online at: http://www.cropscience.org .au / ics c2004/symposia/3/7/141_singhrp.htm.

27. Song, CT Qing, G Xu, W Wei, ZQ Qin and ZL Yi. 2016. Resistance of Guixie 3 against wheat scab, strip rust and powdery mildew. *Guizhou Agricultural Sciences* **44** (6): 56-59.

28. Wan AM, XM Chen and ZH He. 2007. Wheat stripe rust in China. *Australian Journal of Agricultural Research* **58**: 605-619.

29. Wellings CR. 2007. *Puccinia striiformis* in Australia: a review of the incursion, evolution and adaptation of stripe rust in the period 1979–2006. *Australian Journal of Agricultural Research* **58**: 567-575.

30. Yang L, X Zhang, J Wang, M Luo, M Yang, H Wang, L Xiang, F Zeng, D Yu, D Fu, and GM Rosewarne. 2017. Identification and evaluation of resistance to powdery mildew and yellow rust in a wheat mapping population. *PLoS ONE* 12(5): e0177905.