Journal
of the
Plant Protection Society

Volume 5 2018

Plant Protection Society Nepal

Research Article

CHARACTERIZATION OF YELLOW RUST (*PUCCINIA STRIIFORMIS*) RESISTANCE AND GENETIC DIVERSITY IN NEPALESE WHEAT GENOTYPES

Suraj Baidya[1], Subash C. Bhardwaj[2], Sundar M. Shrestha[3], Baidya N. Mahto[4], Hira K. Manandhar[3]

ABSTRACT

Wheat (*Triticum aestivum* L.) is third important crop in Nepal after rice and maize. Yellow rust caused by *Puccinia striiformis* Westend. is a major disease of hills and adjoining foot hills. Both seedling and adult plant stage evaluations were carried out to characterize yellow rust resistance (*Yr*) genes in 105 Nepalese wheat genotypes at ICAR- Indian Wheat and Barley Research Institute, Regional Station, Shimla India. Eleven pathotypes of *P. striiformis* were used in seedling evaluation for identifying the resistance gene/s for yellow rust disease. Two most virulent and predominant pathotypes 78S84 and 46S119 were used to screen for adult plant resistance (APR). Four different resistance genes were inferred in tested material viz, *Yr*A, *Yr*2, *Yr*9 and *Yr*27 by the seedling test. The postulated genes were observed either singly or in combination with other gene/s. The resistance genes *Yr*A and *Yr*2 were detected alone whereas *Yr*27 was postulated in combination with *Yr*9. Among them, *Yr*9 was most dominant gene and was postulated in 48 genotypes either singly or in combination with *Yr*27. Twenty-one genotypes were found to confer low infection types (*ITs*) with hypersensitive and non-hypersensitive reaction against all the tested pathotypes. Twenty two of genotypes showed APR to both the pathotypes whereas 43 genotypes showed susceptibility to both pathotypes. In which 16 genotypes had susceptible response both seedling and Adult plant stage against both the pathotypes. Likewise, 53 genotypes had APR to one or other pathotype.

Key words: Genotypes, pathotypes, resistance, wheat, yellow rust

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the third important crop in Nepal after rice and maize (CBS, 2016). In Nepal, the yellow rust caused by *Puccinia striiformis* Westend. was first recorded in 1964 and it remained under check when RR 21, a rust resistant cultivar was popularly grown in both Terai and hills (Karki *et al.,* 2004). Suddenly, in mid 1980, the

---

[1] Plant Pathology Division, Khumaltar, Nepal Agricultural Research Council (NARC), Nepal.
[2] ICAR- Indian Wheat and Barley Research Institute, Reg. Station, Shimla India,
[3] Agriculture and Forestry University (AFU), Chitwan, Nepal;
[4] Nepal Agricultural Research Council (NARC), Plaza, Kathmandu
Email for correspondence: *suraj_baidya222@yahoo.co.in*

virulence of the rust pathogen began to change and epidemic of rust was encountered due to prevalence of 7E150 race and RR21 became susceptible (Sharma *et. al*., 1995). Subsequently continuous researches were carried out with an objective to accomplish the management of newly emerged yellow rust pathotype and some high yielding and resistant genotypes were developed. As a result, Annapurna 1, Annapurna 3 and Annapurna 4 with *Yr*9 gene and Annapurna 2 and Kanti with *Yr*2 gene were released. But in mid 1990, the *Yr*9 virulent race was identified in the region (Prashar *et al*., 2007). The genotype like Annapurna 1, Annapurna 4 and Kanti resistant to the race 7E150 were rendered susceptible by yellow rust due to the appearance of a new race 46S119 in Baglung, Parbat, Myagdi and other districts during 1996/97 (Sharma, 2001). Currently, several yellow rust resistant wheat cultivars having *Yr*27 gene located on chromosome 2BS (Singh *et al.*, 2004) have been released for cultivation in different areas. Recently, appearance of a new race 71E32, resulted in *Yr*27 containing CIMMYT germplasm/genotypes ineffective but again found resistance gene *Yr*9 effective against this pathotype (PPD, 2008, 2009). The year to year appearance of different races of yellow rust of wheat in South Asian countries indicates that the fight against this devastating disease of wheat is far from over and warrants an attention on monitoring of pathotypes/races in order to develop genotypes with durable resistance and avoid epidemic of disease. Therefore, a research study was carried out to characterize the genetic diversity of resistance against yellow rust in wheat genotypes from Nepal at ICAR-IIWBR, Regional station, Flowerdale, Shimla, India.

MATERIALS AND METHODS

Seedling Resistance Test (SRT)

One hundred and five bread wheat genotypes from advanced nurseries along with some recommended varieties from Nepal were evaluated for characterizing *Yr* genes. Four seeds of each line was clump planted in an aluminum bread pan tray. Each tray contained 18 genotypes and a susceptible check (A-9-30-1). Each set of testing material had a sets of differentials which act as a check for the purity of pathotypes and behavior of common resistant genes under that set of condition (Prashar *et al*., 2007). Eleven pathotypes of *P. striiformis* were used for identifying the resistance gene/s on the tested genotypes for yellow rust disease. The pathotypes were selected from different avirulence and virulence groups (Table 1). A small quantity (20 mg) of rust urediospores were suspended in light weight non phytotoxic 4 ml paraffin oil (soltrol) mixed thoroughly and inoculated by spraying the spore suspension with the help of a conical glass atomizer connected with a compressor pump and sprayed with water and incubated for 48 hours in a glass chamber. The seven days old plants were then transferred on to the glasshouse benches and dusted with elemental dust powder of sulphur to avoid powdery mildew infection. The glasshouse temperature was maintained at 15±1°C for congenial environment for disease development. The response of host-pathogen interactions were recorded infection types after 16-20 days of inoculations of pathotypes of yellow rust disease (Nayar *et al*., 1994). Infection types were characterized as

0;= no visible infection, ;= small hypersensitive flecks, 1=uredia minute surrounded by necrotic areas, 2= small to medium uredia surrounded by chlorotic areas, 3= uredia small medium in size and chlorotic areas may be present, 3+= Uredia large with or without chlorosis, sporulating profusely, 4= Uredia large, excessive sporulation coalescence frequent, chlorotic areas may be present. Infection 33+ is classified when both 3 and 3+ type pustules are present. The infection type matrices of the test hosts were compared with those of the differential hosts and postulated the gene/s by using the gene matching technique (Nagarajan *et al*., 1987; Nayar *et al*., 1991).

Adult plant resistance (APR)

Adult plants of all lines were grown as a clump containing 5 seeds in a controlled poly-house, maintained at 15±1ºC temperature and light intensity of about 15000 lux for 12 hours. The distance between the clumps in each row was 25 cm. Near- isogenic lines (NILs) carrying known APR genes and yellow rust susceptible cultivar A-9-30-1 were also planted for comparing adult plant resistance. The adult plants were inoculated with two most predominant and virulent yellow rust pathotypes 78S84 and 46S119 on booting stage of the modified Zadok's scale (Tottman and Makepeace, 1979). The poly- house was kept with saturated for humidity by using a humidifier. The infection pattern in the adult plants and seedling were recorded 22 days after inoculation. APR was inferred on the basis of the reactions of the seedlings and the adult plants. APR was considered hypersensitive when necrosis was associated with the infection types (; , ;1) and non-hypersensitive when only chlorosis was observed with the infection types (2, 2+). APR response was recorded as per the scale of Loegering (1959).

RESULTS

Seedling resistance test

Most of the genotype showed resistant reaction to the pathotypes of *P. striiformis*. Resistance gene *Yr*9 showed avirulent IT reaction (0; to ;-) to pathotypes 13 (67S8), K (47S103) and L (70S69) whereas it had higher IT reaction to 46S119 and 79S84. The pathotypes 13 (67S8), 31 (67S64), 14A (66S64), N (46S64) and L (70S69) supported resistant infection types on *Yr*2 whereas higher IT reaction against pathotypes 46S119, K (47S102), 20A (70S64) and T (47S103). Gene *Yr*27 was avirulent to pathotypes T, I, 13, 31, K, N, 14A, 20A and 28S84.Four different resistance genes were postulated in the Nepalese wheat material viz, *Yr*A, *Yr*2, *Yr*9 and *Yr*27 in the seedling test. These genes were observed either singly or in combination with other gene/s. The gene *Yr*A and *Yr*2 were detected alone whereas *Yr*27 was postulated in combination with *Yr*9. The gene *Yr*9 was identified in both single and in combination to other genes. *Yr*27 was postulated only in combination with *Yr*9 gene. Likewise, *Yr*2 gene alone was inferred in 39 genotypes (31.2%). Gene *Yr*A was also detected in singly in nine genotypes (8.8%). Among them *Yr*9 gene was predominantly postulated in 48 genotypes (38.4%) either singly or in combination with *Yr*27 in 11 genotypes (9.6%) whereas in WK 1686, it was postulated with other resistant gene/s (Table 2, 3, 4 & 5).

Adult plant resistance test

Wheat genotypes lacking seedling resistance or possessing genes for which virulence(s) were available were subjected to adult plant resistance tests in polyhouse. These genotypes were classified into three categories based on the yellow rust response at seedling and adult plant stages.

Group A1: This group comprised of 21 wheat genotypes (Bicard 1, BL 2879, BL 3063, BL 3623, Doteli, Nayapati, NL 1007, BL 3778, BL 3819, WK 1182, WK 1204, WK 1444, WK 1627, WK 1670, WK 1809, Chonte, Chonte 1, Kiskarde, Chewink 1, Chyakhura 1, BL 3960 and BL 4070) and showed susceptibility at seedling stage but resistance response at adult plant stage. The genotypes were found highly resistant to both the predominant and virulent pathotypes at adult stage (Table 6).

Group A2: This group included 16 genotypes (Gautam, WK 1504, WK 1518, WK 1710, WK 1716, WK 1719, WK 1720, WK 1721, WK 1723, WK 1740, WK 1743, BL 4086, BL 4118, BL 4123, BL 4131 and BL 4183,) had resistant reaction at both seedling and adult plant stages for both the pathotypes (Table 7).

Group A3: This group, relatively a large group comprised of 43 genotypes (Achyut, Aditya, Bangari, BL 1473, BL 3472, Danphe 1, Hanse, Munal 1, BL 3555, Seto ghaun, BL 3840, WK 936, WK 1123, WK 1481, WK 1505, WK 1544, WK 1639, WK 1663, WK 1686, WK 1691, WK 1712, WK 1713, WK 1723, WK 1772, WK 1775, WK 1776, WK 1792, WK 1804, WK 1915, WK 1968, WK 1970, WK 1973, WK 1974, WK 1996, WK 1997, WK 2005, WK 2007, BL 4040, BL 4110, WK 4176, NL 1067, RR-21 and NL 971) were susceptible to both the pathotypes. Wheat genotypes BL 3472, Hanse, Munal-1, BL 3555, Seto Gahun, WK 1481, WK 1712, WK 1723, WK 1792 and WK 1974 showed more susceptibility to pathotype 78S84 than other genotypes. Similarly, Hanse, WK 936, WK 1544, WK 1712, WK 1776, WK 1792, WK 1915, WK 1996 and BL 4040 were more susceptible to pathotype 46S119 than other lines. Among these genotypes, WK 1792 and WK 1996 were found 100 percent susceptible to both the pathotype (Table 8).

DISCUSSION

Seedling test

Gene *Yr*9 was characterized as a dominant resistance gene in most of the genotypes. In previous reports related on gene postulation also showed that the gene *Yr*9 was present as a common gene in most of the Nepalese wheat genotypes (Karki, 1994; Mahto, 1996; Sharma, 1997; Mahto and Prashar, 1999). Most of the Nepalese wheat genotypes had crosses with CIMMYT-derived germplam/genotypes which have wide presence of *Yr*A, *Yr*9 and *Yr*2 genes (Badebo *et al*., 1990; Danial *et al*., 1994). *Yr*9 resistance derived from rye has been introduced in CIMMYT materials through the 1B/1D translocation (Zeller, 1973). The genotypes which contained *Yr*9 also indicated the presence of tightly linked genes *Sr*31 and *Lr*26 (McIntosh *et al.*, 1995). *Yr*A gene is temporarily designated yellow rust resistance gene in a differential line Avocet and Anza. It has resistance conferred by complementary dominant genes one of which is located in chromosome 3D. It showed ;CN to 2+ avirulent infection types in second leaf as compared to primary leaf (Wellings *et al.*, 1988). The tested genotypes were selected on the basis of their resistance performance under epidemic field conditions and the tested pathotypes were also predominant in the south Asian territories. So, the result showed most of the genotypes conferred resistant reaction against the pathotypes. The genotypes, Danphe-1, BL-3404, Gautam, Godawari, NL-1073, WK-1123, WK-1156, WK-1504, WK-1505, WK-1686, WK-1710, WK-1716, WK-1719, WK-1720, WK-1721, WK-1723, WK-1726, WK-1727, WK-1743, WK-1964 and WK-1967 showed low infection types with hypersensitive and non-hypersensitive reaction against all the tested pathotypes. These genotypes must be associated some resistance gene/s or factors which imparted resistance against most of the pathotypes. The characterization of resistance gene/s on the basis of gene matching technique offer vital information for use in breeding programme to diversify the wheat material. In seven genotypes (WK-1915, BL-4088, BL-4095, BL-4110, NL-1053, NL-1067 and RR-21) resistance gene/s could not be postulated due to irreconcilable reaction on the tested pathotypes. Mahto and Prashar (1999) were also not able to postulate resistance gene/s in genotype RR-21 however, earlier studies has already been concluded that it possess *Yr*A and *Yr*2 genes (Wellings *et al*., 1988; Singh *et al*., 1990).

Adult plant resistant test

Twenty one wheat genotypes showed the presence of resistance genes at seedling stages for both pathotypes. The pathotype specific gene/s could be utilized for developing durable genotypes. Thirty eight genotypes showed APR reaction to pathotypes 46S119 and 78S84 in which 22 had susceptible response at seedling stage. Forty three genotypes had no APR against the both pathotypes and rest showed APR response to one of them. Those wheat genotypes showed APR with both pathotypes possessed either *Yr*2 or *Yr*9 genes with or without associated other genes. It showed that *Yr*2 and *Yr*9 are still effective genes against common pathotypes of *P. striiformis* in the country. But a report showed genes, *Yr*1, *Yr*2, *Yr*6, *Yr*7, *Yr*8, *Yr*15, *Yr*Su and *Yr*A+ are ineffective in Nepal whereas *Yr*4,*Yr*5,*Yr*9, *Yr*10, *Yr*27, *Yr*SP, *Yr*SD are still effective (Sharma *et al.*, 1995; PPD, 2009). Simialrly, gene *Yr*4 is no longer effective in India (Kumer *et al*., 1993) and Pakistan (Lourwers *et al*., 1992). The performance of resistance genes vary with the evolution of new pathotypes in different time intervals at different locations.

Some genotypes which contained resistance genes (R) showed resistance to both the pathotypes from seedling to adult plant stage (Table 7). However, WK 1518, WK 1740, BL 4183, BL 4118 had *Yr*2 gene and BL 4086 and BL 4131 had *Yr*9 and *Yr*9+27, respectively also showed APR to both the pathotypes in seedling and adult stages. The gene *Yr*27 was found ineffective against 78S84 and 46S119 pathotypes because the genotypes which possessed *Yr*27 were susceptible to both the pathotypes at adult stage. Likewise, *Yr*A gene also was ineffective to pathotype 46S119, however, the genotypes BL 2879, WK 1204, Chonte which contained *Yr*A gene were resistant to both the pathotypes and it could be due to additive effect of other genes presence in genotypes.

Fifteen genotypes (BL 1473, BL 3063, BL 3468, BL 3978, BL 4095, BL 4118, BL 4154, NL 1073, Pasang Lhamu, WK 1628, WK 1710, WK 1909, WK 1970, WK 1998 and Chonte 1) also showed the presence of slow rusting gene *Lr*34 on the basis of phenotypic characteristics. Phenotypic marker can be observed in the genotypes which possessing *Yr*18/*Lr*34 genes generally produce broken stripes of yellow rust infection at adult plant stage and progressive leaf tip necrosis (Nayar *et al*., 2001). The gene *Yr*18 is commonly known to confer slow rusting response. So, these genotypes could be utilized in the breeding program for developing durable resistance. Most of the genotypes have resistance based on one or two genes which makes vulnerable to yellow rust of wheat in the country. Similarly, Indian wheat genotypes have also resistance base on one to two genes (Bhardwaj, 2011), so they have chances of yellow rust out-break in the south Asian territories. The pattern of evolution of the pathotypes of *P. striiformis* in the country showed wide variation and a clear increase in the number of virulence factors. Due to the evolution of new virulences, the erosion of resistance gene/s to the pathotypes was rapid and the formation of highly complex pathotypes was evident. The evolution of new virulence pathotype has been closely associated with *Yr* resistance gene development in new cultivars. It needs quantitative level of resistance gene/s for long term resistance against the changing virulence pathotypes nature. The combination of seedling resistance and adult plant resistance has potential to keeps the initial population of the year round epidemic pathotypes in low level. The selection of adult plant resistance in hypersensitive and non-hypersensitive genotypes could help in reducing mutations and somatic recombination within the pathogen and can impart lasting resistance. Varietal diversification and identification of different resistance genes for different environments are needed for better management of yellow rust. Hence, gene postulation can be a useful tool to help breeders to identify the resistance factors for developing durable resistance cultivar.

CONCLUSION

The results indicated that the tested lines have yellow rust resistant gene/s. Most of the genotypes base on one or two genes which makes wheat vulnerable to yellow rust. Nepalese wheat lines are genetically diverse for rust resistance, however, further efforts are also needed to broaden the genetic base in future. The resistance genes postulated in the present study could be helpful for breeders and pathologists in strategic planning of the wheat breeding program and reducing the avoidable loss caused by wheat rust disease.

ACKNOWLEDGEMENTS

We thank the ICAR- Indian Wheat and Barley Research Institute, Regional Station, Flowerdale, Shimla, India for greenhouse facilities and National Wheat Research Programme (NWRP), Bhairahawa & Agricultural Botany Division, Khumaltar, NARC for providing wheat germplasm and CIMMYT, Mexico for funding the studies.

LITERATURE CITED

PPD. 2008. Annual Report 2006/07, Plant Pathology Division, Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur, Nepal.

PPD. 2009. Annual Report 2007/08, Plant Pathology Division, Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur, Nepal.

CBS. 2011. Central Bureau of Statistics, Planning Commission, Nepal Government, Kathamndu, Nepal.

Badebo, A., R.W. Stubbs, and M. Gebegeu. 1990. Identification of resistance genes to *Puccinia striiformis* in seedling of Ethopian and CIMMYT bread varieties and lines. Neth. J. Pl. Path. 96:199-210.

Bhardwaj, S.C. 2011. Resistance genes and adult plant rust resistance of released wheat varieties of India. Regional Station, Directorate of Wheat Research, Flowerdale, Shimla-171002 (India). Research Bulletin No. 5:31.

Daniel, D.L., R.W. Stubbs and J.E. Parlevliet. 1994. Evolution of virulence patterns in yellow rust races and its implication for breeding for resistance in wheat in Kenya. Euphytica 80:165-170.

Karki, C.B. 1994. Genetics of rust resistance of some Nepalese wheat and barley cultivars. A research study carried out at Directorate of Wheat Research (DWR), Regional Station, Flowerdale, Shimla-171002, H.P. India.

Karki, C.B., S. Sharma and E. Duveiller. 2004. Yellow rust of wheat in Nepal: An Overview. Regional Yellow Rust Conference, Islambad, Pakistan, March 22-26, 2004.

Kumar, J., S.K. Nayar, M. Prashar, S.C. Bhardwaj and R. Bhatnagar. 1993. Virulence survey of *Puccinia striifromis* in India during 1990-92. Cereal Rust and Powdery Mildew Bulletins 21:17-24.

Loegering, W.Q. 1959. Method for recording cereal rust data,USDA, Internatinal Spring Wheat Rust Nursery. USDA, USA.

Louwers, J.M., C.H. Van Silfhout and R.W. Stubbs. 1992. Race analysis of yellow rust in developming countries, Report 1990-1992, IPO-DLO report. pp.11-23.

Mahto, B.N. 1996. Genetics of rust resistance of selected wheat lines and mapping of pathotypes flora of rust in Nepal. A research study carried out during July 4-September15, 1996 at DWR, Regional Station, Flowerdale, Shimla- 171002, H.P. India.

Mahto, B.N. and M. Prashar. 1999. Genetics of stripe rust resistance in Nepalese wheat. Cereal and Powdery Mildews Bulletin 26:27-34.

McIntosh, R.A., C.R. Wellings and R.F. Park. 1995. Wheat rusts: An Atlas of resistance genes. Plant Breeding Institute, the University of Sydney, CSIRO publication, Victoria, Australia 200.

Nagarajan, S., S.K. Nayar, P. Bahadur and S.C. Bhardwaj. 1987. Evaluation of some Indian wheats for *Yr, Lr, Sr* genes by matching technique an genetic uniformity observed. Cereal Rust Bulletin 15(2):53-64.

Nayar, S.K., S.C. Bhardwaj, M. Prashar, J. Kumarand S. Nagrajan. 1991. Rust resistance genes *Lr*, *Sr* and *Yr* in some Indian wheat. Cereal Rusts and Powdery Mildews Bulletin 19(1):1-8.

Nayar, S.K., J.P. Tandon, J. Kumar, M. Prashar, S.C. Bhardwaj, L.B. Goel and S. Nagarajan. 1994. Basis of rust resistance in indian Wheats. Research Bulletin No. 1, Regional Station, DWR, Flowerdale, Shimla-171002, India. 32p.

Nayar, S.K., S. Nagarajan, M. Prashar, S.C. Bhardwaj, S.K. Jain and D Data. 2001. Revised catalogue of genes that accord resistance to *Puccinia* species in wheat. Directorate of Wheat Research, Regeional Station, Flowerdale, Shimla -171002 (India). Research Bulletin 3:48.

Prashar, M., S.C. Bhardwaj, S. K. Jain and D. Datta. 2007.Pathotypic evolution in *Puccinia striiformis* in India during 1995-2004. Australian J. Agr. Res. 58:602-604.

Sharma, S. 1997. Virulence monitoring and detection of leaf and yellow rust resistance genes in Nepalese wheat varieties. A Research Study carried out during July 4 to August 11, 1997. Directorate of Wheat Research, Regional Station, Flowerdale, Simla, India.

Sharma, S. 2001. Yellow rust of wheat in western hills of Nepal. Advances in Agricultural Research in Nepal. Proceeding of the first SAS/N Convention. Society of Agricultural Scientist. 170-175p. Indian Agricultural Research Institute (IARI), Regional Station, Flowerdale, Shimla-171002. 12p.

Sharma, S., J.M. Louwers, C.B. Karki and C.H.A. Snijders. 1995. Postulation of resistance genes to yellow rust in wild emmer wheat derivatives and advanced wheat lines from Nepal. Kluwer Academic publishers, The Netherland. Euphytica 81:271-277.

Singh, H., R. Johnson and D. Sethi. 1990. Genes for race-specific resistance to yellow rust (*Puccinia striiformis*) in Indian wheat cultivars. Plant Pathology 39:424-433.

Singh, R.P., E. Duveiller and E. Huerta-Espino. 2004. Virulence to yellow rust resistance gene *Yr*27: A new threat to stable wheat production in Asia. Regional Yellow rust Conference, Islambad, Pakistan, March 22-26, 2004.

Tottman, D.R. and R.J. Makepeace. 1979. An explanation of the decimal code for the growth stages of cereals with illustrations. Ann. Appl. Biol. 93:221-234.

Wellings, C.R., R.A. McIntosh and M. Hussain. 1988. A new source of resistance to *Puccinia striiformis* f. sp. *tritici* in spring wheat (*Triticum aestivum*). Plant breeding 100:88-96.

Zeller, F.J. 1973. Wheat – rye chromosome substitutions and translocations. Proceeding of 4th International Wheat Genetics Symposium, Columbia. pp.209-221.

Table 1. Avirulence/virulence structure for pathotypes of P. striiformis f. sp. tritici

Pathotypes (x)	**Avirulence/virulence *Yr* genes (y)**
P (46S103)	*Yr*1, *Yr*5, *Yr*9, *Yr*10/*Yr*2KS, *Yr*2, *Yr*3, *Yr*4, *Yr*6, *Yr*7, *Yr*8
T (47S103)	*Yr*5, *Yr*9, *Yr*10, *Yr*18, *Yr*27/*Yr*2KS, *Yr*2, *Yr*3, *Yr*4, *Yr*6, *Yr*7
I (38S102)	*Yr*3, *Yr*6, *Yr*9, *Yr*10, *Yr*18, *Yr*27/ *Yr*1, *Yr*2KS, *Yr*2, *Yr*4, *Yr*6, *Yr*7
31 (67S67)	*Yr*4, *Yr*5, *Yr*9, *Yr*10, *Yr*18, *Yr*27/*Yr*2KS, *Yr*2, *Yr*3, *Yr*7
K (47S102)	*Yr*1, *Yr*3, *Yr*4, *Yr*9, *Yr*10, *Yr*18, *Yr*27/*Yr*2KS, *Yr*2, *Yr*6, *Yr*7, *Yr*8
L (70S69)	Yr1, Yr2KS, *Yr*2, Yr5, Yr9, Yr10/Yr3, Yr4, Yr6, Yr7, Yr8
N (46S102)	*Yr*1, *Yr*4, *Yr*5, *Yr*9, *Yr*10, *Yr*18, *Yr*27/*Yr*2KS, *Yr*2, *Yr*6, *Yr*7, *Yr*8
14A (66S64)	*Yr*2, *Yr*4, *Yr*5, *Yr*9, *Yr*10, *Yr*18, *Yr*27/*Yr*2KS, *Yr*3, *Yr*6, *Yr*7, *Yr*8
20A (70S64)	*Yr*2, *Yr*4, *Yr*5, *Yr*9, *Yr*10, *Yr*18, *Yr*27/*Yr*1, *Yr*2KS, *Yr*3, *Yr*6, *Yr*7, *Yr*8
*Yr*9 (46S119)	*Yr*1, *Yr*5, *Yr*10/*Yr*2KS, *Yr*2, *Yr*3, *Yr*4, *Yr*6, *Yr*7, *Yr*8, *Yr*9
78S84	Yr1, Yr2, Yr3, Yr4, Yr8, Yr9, Yr10/Yr2KS, Yr2, Yr5, Yr6, Yr7
13 (67S8)	Yr2KS, Yr2, Yr3, Yr4, Yr6, Yr8, Yr9, Yr10, Yr18, Yr27/Yr1, Yr5, Yr7

Table 2. List of Nepalese wheat genotypes having Yr9+ gene/s with their seedling infection types (ITs) against tested pathotypes

SN	Genotypes	P	T	I	31	K	L	N	14A	20A	Yr9	13	Gene/s
1	BL-3472	0;	0;	;	0;	0;	0;	0;	0;	3-	3 C	0;	*Yr9+*
2	BL-3503	0;	0;	0;	2 CN	0;	0;	0;	0;	3	3 C	0;	*Yr9+*
3	BL-3623	0;	0;	0;	0;	0;	0;	0;	-	3	;	0;	*Yr9+*
4	BL-3629	0;	0;	0;	0;	0;	0;	0;	0;	3-	0;	0;	*Yr9+*
5	Ghiling	0;	0;	0;	0;	0;	3	0;	2CN	0;	;	0;	*Yr9+*
6	Kanti	0;	0;	0;	0;	0;	0;	0;	0;	3-	3 C	0;	*Yr9+*
7	BL-3555	0;	0;	0;	-	0;	0;	0;	0;	3-	3 C	0;	*Yr9+*
8	Pasang Lhamu	0;	0;	0;	0;	0;	0;	0;	0;	2 CN	;	0;	*Yr9+*
9	BL- 3819	0;	0;	0;	0;	0;	0;	0;	0;	3-	; N	0;	*Yr9+*
10	BL- 3840	0;	0;	0;	0;	0;	0;	-	-	0;	3-	0;	*Yr9+*
11	WK- 1639	-	0;	0;	0;	0;	0;	0;	0;	3+	3 , 0;	0;	*Yr9+*
12	WK- 1663	0;	0;	0;	0;	0;	0;	0;	0;	2 CN	0;	0;	*Yr9+*
13	WK- 1670	0;	0;	0;	0;	0;	0;	0;	0;	3+	3- , 0;	0;	*Yr9+*
14	WK- 1672	0;	0;	0;	0;	0;	0;	0;	0;	3+	3- , 0;	0;	*Yr9+*
15	WK- 1691	0;	0;	0;	0;	0;	0;	0;	0;	3-	0;	0;	*Yr9+*
16	WK- 1701	0;	0;	0;	0;	0;	0;	0;	0;	3+	-	0;	*Yr9+*
17	WK- 1712	0;	0;	0;	0;	0;	0;	0;	0;	3+	2 CN	0;	*Yr9+*
18	WK- 1772	0;	0;	0;	0;	0;	0;	0;	0;	3 C	0;	0;	*Yr9+*
19	WK- 1776	0;	0;	0;	0;	0;	0;	0;	0;	3+	0;	0;	*Yr9+*
20	WK- 1792	0;	0;	0;	0;	0;	0;	-	0;	3+	3-	0;	*Yr9+*
21	WK- 1803	0;	0;	0;	0;	0;	0;	0;	0;	3+	3-	0;	*Yr9+*
22	WK- 1804	0;	0;	0;	0;	0;	0;	0;	0;	3+	3-	0;	*Yr9+*
23	WK- 1970	0;	0;	0;	0;	0;	0;	0;	0;	3 C	3-	0;	*Yr9+*
24	WK- 1974	0;	0;	0;	0;	0;		0;	0;	3 C	3	0;	*Yr9+*

SN	Genotypes	P	T	I	31	K	L	N	14A	20A	Yr9	13	Gene/s
25	WK- 1996	0;	0;	0;	0;	0;	0;	0;	-	3+	3-	0;	*Yr9+*
26	WK- 2000	0;	0;	0;	0;	2CN	0;	0;	-	3	; CN	0;	*Yr9+*
27	Kiskardee 1	0;	0;	;	0;	0;	0;	0;	0;	3+	0;	0;	*Yr9+*
28	BL- 3945	0;	0;	-	0;	0;	0;	0;	0;	3+	3-	0;	*Yr9+*
29	BL- 3978	-	1-	-	-	0;	0;	2 CN	2CN	0;	3-	0;	*Yr9+*
30	BL- 4009	0;	0;	0;	0;	0;	0;	0;	0;	3	3-	0;	*Yr9+*
31	BL- 4040	0;	0;	0;	0;	0;	0;	0;	0;	3	-	0;	*Yr9+*
32	BL- 4061	0;	0;	0;	0;	0;	0;	0;	0;	2 CN	; CN	-	*Yr9+*
33	BL- 4085	0;	0;	0;	0;	0;	0;	0;		2 CN	; N	0;	*Yr9+*
34	BL- 4086	0;	-	;	0;	0;	0;	0;	0;	; CN	;	0;	*Yr9+*
35	BL- 4123	0;	0;	0;	-	0;	0;	0;	0;	0;	; N	0;	*Yr9+*
36	BL- 4171	0;	0;	0;	-	0;	0;	0;	0;	-	; N	0;	*Yr9+*

Table 3. List of Nepalese wheat genotypes having *Yr*2+ gene/s with their seedling infection types (ITs) against tested pathotypes

SN	Genotypes	P	T	I	31	K	L	N	14A	20A	Yr9	13	Gene/s
1	Achyut	0;	3 C	0;	0;	0;	0;	3-	0;	3 C	3 C	0;	*Yr2+*
2	Bangari	0;	3 C	0;	3-	0;	0;	0;	3	3 C	3	0;	*Yr2+*
3	Becard-1	2 CN	3 C	3	0;	0;	0;	0;	3	3 C	3	0;	*Yr2+*
4	Bhrikuti	0;	3 C	3	0;	0;	0;	0;	3	3 C	3+	0;	*Yr2+*
5	Bire	3	-	0;	3-	0;	0;	0;	3	3+	0;	0;	*Yr2+*
6	BL-1473	0;	0;	3	0;	0;	0;	0;	0;	0;	0;	0;	*Yr2+*
7	BL-3063	0;	0;	2 CN	3-	0;	0;	0;	-	3+	0;	0;	*Yr2+*
8	Doteli	0;	0;	3+	0;	0;	0;	0;	0;	3+	3 C	0;	*Yr2+*
9	Hanse	0;	0;	0;	0;	0;	0;	3	0;	0;	3-	0;	*Yr2+*
10	Munal-1	0;	0;	0;	-	0;	2 CN	0;	0;	3-	3 C	0;	*Yr2+*

SN	Genotypes	P	T	I	31	K	L	N	14A	20A	Yr9	13	Gene/s
11	Nayapati	0;	0;	0;	0;	0;	0;	-	3	3-	3 C	0;	*Yr2+*
12	NL-1007	0;	0;	0;	2 CN	0;	0;	0;	0;	3-	3-	0;	*Yr2+*
13	Rohini	0;	0;	0;	0;	0;	;	0;	0;	3-	2 CN	0;	*Yr2+*
14	BL-3778	0;	0;	0;	0;	0;	; CN	0;	0;	3-	3-	;	*Yr2+*
15	WK- 936	0;	0;	0;	0;	0;	; CN	0;	0;	3-	3 C	0;	*Yr2+*
16	WK-1182	0;	0;	0;	2 CN	0;	0;	0;	3	3+	3-	0;	*Yr2+*
17	WK-1444	0;	0;	0;	2 CN	0;	0;	2 CN	3+	3-	3 C	0;	*Yr2+*
18	WK- 1518	0;	2 CN	0;	; N	0;	0;	0;	0;	2 CN	3- , 0;	0;	*Yr2+*
19	WK- 1544	0;	; CN	0;	3-	0;	0;	0;	0;	3+	3- , 0;	0;	*Yr2+*
20	WK- 1627	0;	0;	0;	0;	0;	0;	0;	0;	3-	3- , 0;	0;	*Yr2+*
21	WK- 1643	0;	0;	0;	0;	0;	2 CN	0;	3-	0;	3 , 0;	;	*Yr2+*
22	WK- 1661	0;	0;	3	0;	0;	0;	0;	0;	0;	3- , 0;	0;	*Yr2+*
23	WK- 1713	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	*Yr2+*
24	WK- 1714	0;	3	3	0;	3-	0;	0;	0;	3+	2 CN	0;	*Yr2+*
25	WK- 1733	0;	0;	2 CN	0;	0;	3-	0;	0;	; CN	; CN	0;	*Yr2+*
26	WK- 1739	0;	0;	0;	0;	0;	0;	0;	3-	2 CN	0;	0;	*Yr2+*
27	WK- 1740	0;	0;	0;	;	0;	0;	0;	3	2 CN	0;	0;	*Yr2+*
28	WK- 1775	0;	0;	0;	0;	0;	0;	0;	0;	3+	3-	0;	*Yr2+*
29	WK- 1809	0;	0;	-	0;	-	0;	-	3	0;	3-	-	*Yr2+*
30	Danphe 2	0;	3+	0;	0;	0;	0;	0;	2 CN	3	; CN	0;	*Yr2+*
31	Chonte	0;	3	;	3-	0;	0;	0;	0;	3+	3 C	0;	*Yr2+*
32	Chewink 1	0;	0;	;	0;	0;	0;	0;	0;	3	3-	0;	*Yr2+*
33	Chyakhura 1	0;	3	3	0;	0;	0;	0;	0;	0;	3-	;	*Yr2+*
34	BL- 3960	-	0;	0;	-	0;	0;	0;	0;	3-	0;	0;	*Yr2+*
35	BL- 3989	0;	3-	0;	-	0;	0;	0;	0;	3	3-	0;	*Yr2+*

SN	Genotypes	P	T	I	31	K	L	N	14A	20A	Yr9	13	Gene/s
36	BL- 4091	0;	2 CN	0;	-	0;	0;	0;	; CN	2 CN	3-	0;	*Yr2+*
37	BL- 4118	0;	2 CN	;	-	0;	0;	0;	2 CN	2 CN	; N	;	*Yr2+*
38	BL- 4176	0;	0;	3-	2 CN	0;	0;	0;	2 CN	3-	2 CN	0;	*Yr2+*
39	BL- 4183	0;	2 CN	2 CN	0;	0;	0;	0;	0;	3-	0;	0;	*Yr2+*

Table 4. List of Nepalese wheat genotypes having *Yr*9+27+ gene/s with their seedling infection types (ITs) against tested pathotypes

SN	Genotypes	P	T	I	31	K	L	N	14A	20A	Yr9	13	Gene/s
1	WK- 1654	0;	0;	0;	0;	0;	0;	0;	0;	;	3- , 0;	0;	*Yr9+27*
2	WK- 1675	0;	0;	0;	0;	0;	0;	0;	0;	0;	3- , 0;	0;	*Yr9+27*
3	WK- 1797	0;	0;	0;	0;	0;	0;	0;	0;	0;	3-	0;	*Yr9+27*
4	WK- 1961	0;	0;	0;	0;	0;	0;	0;	0;	3+	3-	0;	*Yr9+27*
5	WK- 1968	0;	0;	0;	0;	0;	0;	0;	0;	0;	3-	0;	*Yr9+27+*
6	WK- 1973	0;	0;	0;	0;	0;	0;	0;	0;	0;	3- , ;	0;	*Yr9+27+*
7	WK- 1997	0;	0;	0;	0;	0;	0;	0;	0;	0;	2 CN	0;	*Yr9+27+*
8	WK- 1998	0;	-	0;	0;	0;	0;	0;	-	0;	2 CN	0;	*Yr9+27+*
9	WK- 2005	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	*Yr9+27+*
10	WK- 2007	0;	0;	0;	0;	0;	0;	0;	0;	0;	3-	0;	*Yr9+27+*
11	BL- 4131	0;	0;	0;	-	0;	0;	0;	0;	0;	2 CN	0;	*Yr9+27+*

Table 5. List of Nepalese wheat genotypes having *Yr*A+ gene/s with their seedling infection types (ITs) against tested pathotypes

SN	Genotypes	P	T	I	31	K	L	N	14A	20A	Yr9	13	Gene/s
1	Aditya	0;	3 C	0;	3-	0;	0;	0;	;	0;	0;	0;	*YrA+*
2	BL-2879	0;	0;	0;	;	0;	0;	0;	0;	3+	0;	0;	*YrA+*
3	BL-3467	0;	2 CN	0;	0;	0;	0;	0;	2 CN	3-	;	0;	*YrA+*
4	Seto Gahun	0;	0;	0;	0;	0;	0;	-	0;	1p 3C	;-	0;	*YrA+*
5	WK- 1204	0;	0;	0;	0;	0;	0;	0;	0;	3-	-	0;	*YrA+*
6	WK- 1481	0;	0;	0;	2 CN	0;	0;	0;	0;	0;	; N	0;	*YrA+*
7	WK- 1628	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	0;	*YrA+*
8	Chonte 1	0;	3+	;	0;	0;	0;	0;	0;	3	CN	0;	*YrA+*
9	NL- 971	0;	3	0;	0;	0;	0;	-	2 CN	3+	;	0;	*YrA+*

Table 6. Adult-plant infection types and disease responses on genotypes in Group A1 with two *Puccinia striiformis* pathotypes

Genotypes	Pathotypes (Seedling stage)		Pathotypes (Adult plant stage)	
	46S119	78S84	46S119	78S84
Bicard 1	3C	3	;R	0
BL2879	3+	0	0	0
BL3063	3+	0;	0	0
BL3623	3	;	0	0
Doteli	3+	3C	0	0
Nayapati	3	3C	TMR	0
NL1007	3	3	TR	0
BL3778	3	3	0	0
BL3819	3	;N	0	0
WK1182	3+	3	0	0

Genotypes	Pathotypes (Seedling stage)		Pathotypes (Adult plant stage)	
	46S119	78S84	46S119	78S84
WK1204	3-	-	0	0
WK1444	3	3C	0	0
WK1627	3	3	0	0
WK1670	3+	0;	0	0
WK1809	0;	3	;R	;R
Chonte 1	3	;CN	0	0
Kiskardee	3+	3C	0	0
Chewink 1	3+	0;	0	0
Chyakhura 1	3	3	0	TMR
BL3960	3	0;	TR	0
BL4078	3	3	TR	;R

Table 7. Adult-plant infection types and disease responses on genotypes in Group A2 with two *Puccinia striiformis* pathotypes

Genotypes	Pathotypes (Seedling stage)		Pathotypes (Adult plant stage)	
	46S119	78S84	46S119	78S84
GAUTAM	;N	0;	0	0
WK1504	0;	0;	0	0
WK1518	2CN	0;	5MR	0
WK1710	0;	0;	;R	0
WK1716	0;	0;	0	;R
WK1719	0;	0;	0	0
WK1720	0;	;	0	0
WK1721	0;	;	0	0

Genotypes	Pathotypes (Seedling stage)		Pathotypes (Adult plant stage)	
	46S119	78S84	46S119	78S84
WK1723	0;	0;	0	0
WK1740	2CN	0;	0	0
WK1743	;CN	0;	0	0
BL4086	;CN	;	TR	0
BL4118	2CN	;N	0	10MR MS
BL4123	0;	;N	0	0
BL4131	0;	2CN	0	0
BL4183	2CN	;N	;R	;R

Table 8. Adult-plant infection types and disease responses on genotypes in Group A5 with two *Puccinia striiformis* pathotypes

SN	Wheat genotypes	RACES									
		78S84					46S119				
	Date	11-2	25-2	08-3	22-3	06-4	11-2	25-2	08-3	22-3	06-4
1.	Achyut	;R	;R	;R	;R	20S	0	0	TS	40S	40S
2.	Aditya	;R	;R	20MS	20S	20S	TS	5S	10S	10S	10S
3.	Bangari	;R	;R	5S	40S	40S	TS	10S	20S	40S	40S
4.	BL1473	TS	10S	20S	40S	40S	0	TS	5S	10S	10S
5.	BL3472	5S	20S	30S	40S	60S	0	0	TS	5S	5S
6.	Danphe-1	TS	5S	5S	10S	10S	0	0	0	40S	40S
7.	Hanse	TS	5S	20S	60S	80S	TS	10S	30S	80S	80S
8.	Munal-1	0	TS	20S	80S	80S	TS	10S	20S	40S	40S
9.	BL3555	0	0	5S	20S	60S	0	5S	10S	40S	40S
10.	Seto Gahun	0	0	0	40S	60S	0	TS	TS	10S	40S

SN	Wheat genotypes / Date	RACES									
		78S84					46S119				
		11-2	**25-2**	**08-3**	**22-3**	**06-4**	**11-2**	**25-2**	**08-3**	**22-3**	**06-4**
11.	BL3840	0	0	5S	10S	40S	TS	10S	10S	10S	40S
12.	WK936	0	0	0	5S	10S	TS	10S	30S	40S	60S
13.	WK1123	0	0	5MR	5MS	5MS	0	0	TMS	5MS	5MS
14.	WK1481	0	5S	30S	80S	80S	0	5S	15S	40S	60S
15.	WK1505	0	0	0	10S	20S	0	0	5S	20S	40S
16.	WK1544	0	0	5S	20S	40S	TS	10S	10S	40S	60S
17.	WK1639	0	0	0	5MS	10MS	TS	10S	20S	40S	40S
18.	WK1663	;R	;R	;R	10S	10S	TS	10S	10S	20S	20S
19.	WK1686	0	5S	5S	10MS	40S	0	0	0	0	20S
20.	WK1691	0	0	0	0	20S	TS	5S	10S	40S	40S
21.	WK1712	0	5S	10S	40S	60S	0	0	15S	40S	60S
22.	WK1713	0	;R	5S	20MS	20S	0	5MS	5MS	5MS	5MS
23.	WK1723	0	0	10S	40S	60S	0	0	0	20S	20S
24.	WK1772	0	0	0	0	10S	0	0	0	0	20S
25.	WK1775	0	0	TMS	10MS	20S	0	0	0	0	20S
26.	WK1776	0	0	0	0	20S	0	5S	5S	40S	60S
27.	WK1792	0	0	30S	80S	80S	5S	20S	30S	80S	100S
28.	WK1804	0	0	10S	10S	10S	0	TR	5MS	5MS	10S
29.	WK1915	0	0	5S	10S	10S	TS	10S	40S	60S	80S
30.	WK1968	0	0	0	20S	20S	5S	10S	15S	40S	40S
31.	WK1970	0	0	0	20S	20S	10S	20S	30S	40S	40S
32.	WK1973	0	TS	5S	40S	40S	0	0	5MS	10S	10S

SN	Wheat genotypes / Date	RACES									
		78S84					46S119				
		11-2	25-2	08-3	22-3	06-4	11-2	25-2	08-3	22-3	06-4
33.	WK1974	0	5S	20S	80S	80S	0	0	0	10S	10S
34.	WK1996	0	0	0	5S	40S	TS	10S	30S	80S	100S
35.	WK1997	0	TS	5S	10S	20S	0	TS	5S	40S	40S
36.	WK2005	0	TS	TMR	TMR	20S	0	TS	TS	TS	40S
37.	WK2007	0	0	TMS	TMS	20S	0	5S	5S	5S	10S
38.	BL4040	0	TS	5S	40S	40S	10S	20S	30S	80S	80S
39	BL4110	0	0	0	0	10S	0	0	0	0	20S
40.	BL4176	0	;R	10S	40S	60S	0	5S	10S	20S	20S
41.	NL1067	0	0	0	5MS	10MS	0	0	5MS	20MS	20S
42.	RR-21	0	0	TMR	5S	5S	0	0	0	20S	40S
43.	NL971	0	TS	TS	20S	20S	0	0	0	40S	40S