

Diversity for Resistance to Stem and Leaf Rusts in Indian Wheat Germplasm

AN Mishra, SR Yadav, GS Shirsekar, VG Dubey, K Kaushal and SV Sai Prasad

Indian Agricultural Research Institute, Regional Station, Indore-452 001, Madhya Pradesh

(Received: 26 June 2010; Revised: 9 November 2010; Accepted: 14 March 2011)

In India, three wheat species –*Triticum aestivum* L. emend. Fiori & Paol (bread wheat), *T. durum* Desf. (durum wheat) and *T. dicoccum* Schrank (khapli wheat) are under cultivation, which are attacked by stem rust (*Puccinia graminis* Pers. f. sp. *tritici* Eriks. & Henn.) and leaf rust (*P. triticina* Eriks). Out of 120 genotypes each of durum and bread wheats tested including released varieties, advanced generation lines, genetic stocks and landraces, 67 bread wheat and 71 durum genotypes showed resistance to stem rust; and 45 bread wheat and 50 durum genetic stocks showed resistance to leaf rust, based on field scores of five successive crop seasons (2004-2009) under rust epiphytotic conditions. On the basis of patterns of their seedling responses to 24 pathotypes of stem rust and 40 of leaf rust, at least 17 diverse groups among bread wheats and 18 among durums could be recognised for resistance to stem rust, while 12 groups among bread wheats and nine among durums could be identified for leaf rust resistance, indicating wider resistance base of Indian wheat germplasm. In all, 31 bread wheat and 36 durum genotypes showed resistance to both the rusts, which can serve as donors in wheat crop improvement.

Key Words: Diversity, Donors, Leaf rust, Stem rust, Wheat

Introduction

Rust diseases could potentially be most serious destabilizing factors in wheat production. Of the three rust diseases attacking wheat crop, leaf rust occurs throughout the country, while stem rust is more common in the warmer central and peninsular parts of India. Like other biotic and abiotic stresses, monoculture practice might lead to vulnerability against rust pathogens, and thus, diversity is the only safeguard to it. Search for diverse sources of rust resistance is, therefore, a prerequisite for any wheat improvement programme. Hence, a comprehensive study involving a large number of durum and bread wheat genotypes representing a cross section of the Indian wheat germplasm was conducted to: 1) identify genotypes showing high levels of stable resistance under heavy rust inoculum pressure in the field and; 2) explore diversity for resistance to stem and leaf rusts through glasshouse seedling tests of these genotypes with the most of the variability of stem rust and leaf rust populations in India. The present communication reports the results of this study, which can be useful to wheat workers in the country for selecting effective and diverse rust resistant donors.

Materials and Methods

A total of 240 genotypes (120 each of durum and bread wheats) were used in the study. These were selected carefully to represent a cross section of the Indian wheat germplasm and included recent and old released cultivars,

advanced generation lines, indigenous as well as commonly used exotic genetic stocks, and land races. To ensure the genetic purity, seeds of most of these genotypes were procured from the respective wheat breeders/originating centres. The test genotypes are listed in Table 1 and 2 along with their respective seed source.

Screening of Wheat Genotypes for Field Resistance to Stem and Leaf Rusts

Seeds of the test genotypes were hand-sown in each crop season during November 2nd fortnight, with ~2 cm seed to seed spacing in 1.0 m rows, spaced 30 cm apart. Recommended agronomic practices were followed for raising the crop. Rust spreader rows consisting of mixtures of susceptible wheat varieties were planted all around the experimental plot, and after every 20th test entry. These were inoculated using hypodermic syringes and sprays with aqueous suspension of uredospores of most of the important pathotypes of stem and leaf rusts, freshly collected from the glasshouse. The spore suspension was sprayed onto the test rows as well, but no syringe inoculations were made on them. Disease scores were recorded, combining rust severity as per the modified Cobb's scale (Peterson *et al.*, 1948) and field response. Disease severity was multiplied by respective field response value to obtain co-efficient of infection (Nayar *et al.*, 1997) for each line. Averages of the co-efficient of infection values of the five crop seasons were computed to determine the Average

*Author for Correspondence: E-mail: anmishra53@yahoo.co.in

Table 1. List of bread wheat genotypes tested along with their seed source

Bread wheat genotypes	Seed source
AKW 381, AKW 1071, AKW 2951, AKW 3294	PKV-Akola
CSP 44, Frontana, IWP 72, Nainari 60, Pavon 76, PBW 175, PBW 343, PBW 498, WG 138, WL 410, WL 711	PAU-Ludhiana
DWR 16, DWR 162, DWR 195	UAS-Dharwad
GW 120, GW 173, GW 190, GW 273, GW 322, GW 326, J 405	SDAU-Vijapur
CPAN 1235, CPAN 1676, CPAN 1796, CPAN 1842, CPAN 3004, DL 153-2, DL 803-3, HD 1941, HD 1949, HD 1982, HD 2009, HD 2135, HD 2189, HD 2270, HD 2278, HD 2285, HD 2307, HD 2329, HD 2380, HD 2402, HD 2428, HD 2501, HD 2687, HD 2733, HDR 77, Kalyan Sona, Sonalika	IARI-New Delhi
HI 385, HI 617, HI 784, HI 1077, HI 1123, HI 1418, HI 1434, HI 1479, NP 4	IARI-Indore
HP 1209, HP 1731, HP 1744, HP 1761	IARI-Pusa
HPW 155	HPKV-V-Palampur
HS 86, HS 295, HS 365, HS 375, HS 420, HS 1097-17, HS 1138-6-1	IARI-Shimla
HUW 37, HUW 206, HUW 234, HUW 468	BHU-Varanasi
HW 517	IARI-Wellington
JOB 666	RAU-Jobner
K 68, K 7410, K 7827, K 8020, K 8027, K 8962, K 9006, K 9107, K 9465, K 9644	CSAUA&T-Kanpur
KRL 1-4	CSSRI-Karnal
Lok 1	Lok Bharti-Sanosara
MACS 2496	ARI-Pune
MP 1048, MP 1109	JNKVV-Powarkhedra
NI 5439, NI 5643, NI 9406, NIAW 34	MPKV-Niphad
Raj 1482, Raj 1972, Raj 3077, Raj 3765, Raj 3777	RAU-Durgapura
UP 262, UP 301, UP 2003, UP 2113, UP 2338, UP 2390, UP 2425, UP 2473	GBPUA&T-Pantnagar
VL 404, VL 421, VL 804, VL 832	VPKAS-Almora
WH 147, WH 283, WH 416, WH 542, WH 712	CCSHAU-Hisar

Coefficient of Infection (ACI) values. Genotypes having ACI value of <5.1, and highest disease score upto 50R / 40RMR / 30MR / 20MRMS / 20X / 15MSS / 10S, were classified as 'resistant'.

Glasshouse Evaluation of Wheat Genotypes for Seedling Resistance to Rust Pathotypes

Seedling tests were conducted at 22°C±3°C in an air-conditioned glasshouse during November-February months, using standard glasshouse procedures (Nayar *et al.*, 1997). Wheat genotypes were tested with 24 pathotypes of stem rust, and 40 of leaf rust as given below. These included all the pathotypes of the two rusts being currently maintained and supplied by the Directorate of Wheat Research, Regional Station, Flowerdale, Shimla.

Stem Rust Pathotypes

11 (79G31), 11A (203G15), 14 (16G2), 21-1 (24G5), 21A-2 (75G5), 24 (18G3), 24A (5G19), 34-1 (10G13),

40A (62G29), 40-1 (62G29-1), 42 (19G35), 42B (7G35), 117 (37G3), 117-1 (166G2), 117-2 (33G3), 117-3 (167G3), 117-4 (166G3), 117-5 (166G2-2), 117-6 (37G19), 117A (38G2), 117A-1 (38G18), 122 (7G11), 184 (53G1), and 295 (7G43).

Leaf Rust Pathotypes

10 (13R19), 11 (0R8), 12 (5R5), 12-1 (5R37), 12-2 (1R5), 12-3 (49R37), 12-4 (69R13), 12-5 (29R45), 12-6 (5R45), 12A (5R13), 17 (61R24), 20 (5R27), 63 (0R8-1), 77 (45R31), 77-1 (109R63), 77-2 (109R31-1), 77-3 (125R55), 77-4 (125R23-1), 77-5 (121R63-1), 77-6 (121R55-1), 77-7 (121R127), 77-8 (253R31), 77A (109R31), 77A-1 (109R23), 104 (17R23), 104-1 (21R31-1), 104-2 (21R55), 104-3 (21R63), 104A (21R31), 104B (29R23), 106 (0R9), 107 (45R3), 107-1 (45R35), 108 (13R27), 108-1 (57R27), 162 (93R7), 162-1 (93R47), 162-2 (93R39), 162-3 (29R7), and 162A (93R15).

Table 2. List of durum wheat genotypes tested along with their seed source

Durum wheat genotypes	Seed source
AKDW 2997-16, AKDW 3347, and AKDW 4256	PKV-Akola
DW 1001	DWR-Karnal
A 9-30-1, A 28, GW 1, GW 12, GW 1114, GW 1128, GW 1139, GW 1158, GW 1163, GW 1170, GW 1172, GW 1175, GW 1182, GW 1189, GW 1207, GW 1209, and VD 97-15	SDAU-Vijapur
B 662, Baxi 288-18, Bijaga Red, Castel Porziano, DBP 02-08, ED 2398-A, Guji 'S', HD 4502, HD 4530, HD 4672, HD 4676, HD 4687, HD 4692, HD 4694, HD 4696, HD 4701, HG 110, HI 7483, HI 7747, HI 8381, HI 8498, HI 8540, HI 8550, HI 8591, HI 8592, HI 8620, HI 8622, HI 8630, HI 8651, HI 8653, IWP 5019, Line 1172, Malvi Local, Motia, NP 404, Sarangpur Local, Trinakaria and Yuk	IARI-Indore
Bijaga Yellow, DWR 1006, KDW 137, Local Red, and UAS 2021	UAS-Dharwad
MACS 9, MACS 1967, MACS 2778, MACS 2788, MACS 2846, MACS 2884, MACS 3061, MACS 3063, MACS 3125, MACS 3208, MACS 3453, and MACS 3503	ARI-Pune
JNK 4W-184, MPO 215, MPO 615, and MPO 1106	JNKVV-Powarkheda
NI 146, NI 5749, NIDW 9, NIDW 15, NIDW 70, and NIDW 295	MPKV-Niphad
DWL 5023, PBW 34, PDW 215, PDW 233, PDW 245, PDW 251, PDW 254, PDW 269, PDW 271, PDW 272, PDW 273, PDW 274, PDW 275, PDW 277, PDW 278, PDW 283, PDW 287, PDW 289, and WG 7143	PAU-Ludhiana
Raj 911, Raj 1555, Raj 6516, Raj 6560, Raj 6562, Raj 6566, and RKD 97	MPUA&T-Kota
RD 930, and RS 749	IARI-New Delhi
UPD 45	GBPUA&T-Pantnagar
P 6046, P 7073, WH 896, WH 913, and WH 929	CCSHAU-Hisar

Infection types (ITs) on the seedlings were recorded 12–15 days after inoculation, on a 0–4 scale. Differential sets 'A' and 'B', and the desired lines from set '0' in respect of stem rust and leaf rust (Nayar *et al.*, 2001) were also tested simultaneously for ascertaining the purity of the test pathotypes. The Infection Types (ITs) 3, 3⁺, 34 and 4 produced by a pathotype on a host line indicated latter's susceptibility to that pathotype, whereas lower ITs ('0', '1', '2' and 'X') indicated resistance (Nayar *et al.*, 1997).

Results and Discussion

In all, 67 bread wheat and 71 durum genotypes showed resistance to stem rust; and 45 bread wheats and 50 durums were classified as resistant to leaf rust, based on the above mentioned ACI and highest disease score limits. On the basis of their patterns of seedling reaction to 24 pathotypes of stem rust, and 40 of leaf rust, at least 17 diverse groups among bread wheats (Table 3) and 18 among durums (Table 5) could be recognised for stem rust resistance, while a minimum of 12 groups among bread wheats (Table 4) and nine among durums (Table 6) could be identified for leaf rust resistance. Responses to rust pathotypes found 'virulent' on the two wheat species in the present and earlier study (Mishra *et al.*, 2001) formed the basis of delineation of resistance groups. Some of

the groups can be further classified, based on magnified resolution of differences in resistance to various pathotypes of a race group.

In all, 31 bread wheats (Table 7) and 36 durum genotypes (Table 8) showed resistance to both stem and leaf rusts. Many of these being released varieties, can serve as donors for resistance and other desired traits. The bread wheat genotypes belonged to nine diverse groups for stem rust resistance and to 11 for leaf rust resistance (Table 7). The durum genotypes belonged to 15 groups for stem rust resistance, and to eight for leaf rust resistance (Table 8). However, these groups can be further classified, based on differences in highest disease score. For example, three distinct sub-groups can be recognized within group A-2 for stem rust resistance among bread wheats (Table 7).

Among more than 40 designated genes for stem rust resistance, the genes *Sr2*, *Sr11* and *Sr31* are most common among Indian bread wheat genotypes, while *Sr2*, *Sr7b*, *Sr9e*, *Sr11* and *Sr12* have been commonly postulated in durum genotypes (Nayar *et al.*, 2001). Of these, only *Sr31* is effective against all Indian stem rust pathotypes, *Sr2* provides a moderate level of adult-plant resistance, while others are ineffective. Genotypes carrying *Sr31* are listed in group A-1 of Table 3, and those having *Sr2* in Tables 3, 5, 7 and 8. *Sr2* has been the most important gene for stem

Table 3. Diverse groups for stem rust resistance in bread wheat (at least 17 groups)

A Resistant to all stem rust pathotypes	
A-1 Genotypes carrying stem rust resistance gene <i>Sr31</i>	AKW 1071, CPAN 3004*, DL 803-3, DWR 162*, DWR 195*, GW 190*, HD 2687*, HD 2733, HP 1761, HS 365, HS 375*, HUW 206*, MACS 2496*, PBW 343*, PBW 498, UP 2338*, UP 2425*, VL 804, and WH 542.
A-2 Genotypes not carrying stem rust resistance gene <i>Sr31</i>	AKW 2951, DWR 16, HD 2380*, HD 2402*, HI 1418*, HI 1434*, HP 1731, HS 295*, HS 420*, NI 9406*, Raj 3765*, and UP 2390.
B Resistant to all stem rust pathotypes except pathotypes 40A/40-1	
CPAN 1235, CPAN 1676, CPAN 1796, GW 273, HD 2009, HD 2135*, HD 2270, HD 2278*, HI 1479*, HW 517*, J 405, K 9107*, K 9465, NIAW 34, Raj 3777, UP 301, UP 2473*, and VL 421.	
C Resistant to all stem rust pathotypes except 40A / 40-1 + 117-complex pathotypes	
GW 173* (Susceptible to pathotypes 40-1 and 117-1)	
HD 2501* (Susceptible to 40-1 and 117-4)	
HD 2285 (Susceptible to 40A, 117-1, 117-4, and 117-5)	
D Resistant to all stem rust pathotypes except 40A / 40-1 + 295 + 117-complex pathotypes	
AKW 3294* (Susceptible to pathotypes 40-1, 295, 117-1, and 117-4)	
HI 1077* (Susceptible to pathotypes 40A, 40-1, 295, 117-3, and 117-4)	
E Resistant to most stem rust pathotypes except 40A / 40-1 + others	
E-1	HI 784 and UP 2003 (Susceptible to pathotypes 40-1 and 11)
E-2	K 9006* (Susceptible to 40A, 40-1 and 184)
E-3	WH 712 (Susceptible to 40A, 40-1, 11, 184, and 295)
E-4	Pavon 76* (Susceptible to 40A, 40-1, 11, 24, 117-3, and 117-4)
E-5	HI 1123 (Susceptible to 40-1, 11, 24, 117-5, and 295)
E-6	CPAN 1842 (Susceptible to 40A, 40-1, 11, 11A, 24, 24A, 42B, and 117-6)
F Resistant to stem rust pathotypes 40A and 40-1, but susceptible to others	
F-1	HD 2189* (Susceptible to pathotype 11)
F-2	GW 322* (Susceptible to 117-1)
F-3	K 8020* (Susceptible to 11, and 42B)
F-4	K 7827 (Susceptible to 11, 11A, and 24)
F-5	GW 326* (Susceptible to 117-1, 117-4, 117-5, and 295)
F-6	HD 2307 (Susceptible to 11, 24, 42B, 117-1, 117-4, 117-5, and 295)

*Stem rust resistance gene *Sr2* postulated (after Nayar *et al.*, 2001; Bhardwaj *et al.*, 2003)

Table 4. Diverse groups for leaf rust resistance in bread wheat (at least 12 groups)

A Resistant to all leaf rust pathotypes (pts)	
HP 1761, HS 365, HUW 468, and PBW 498	
B Resistant to all leaf rust pts except 77-complex (77-c) pt(s)	
B-1. Resistant to 77-5, but susceptible to other 77-c pt(s)	
GW 326 and K 7827 (Susceptible to pathotype 77-6)	
Raj 3765 and UP 1109 (Susceptible to 77-6 and 77-7)	
VL 832# (Susceptible to 77-6 and 77A-1)	
B-2 Susceptible to 77-5 and other 77-c pt(s)	
UP 2473 (Susceptible to pathotypes 77-5 and 77-6)	
HP 1209# and Raj 3777 (Susceptible to 77-2, 77-5, and 77-6)	
HI 1418 and UP 2390 (Susceptible to 77-5, 77-6 and 77-7)	
GW 322, HD 2380, HD 2402, and HI 1434 (Susceptible to 77-2, 77-5, 77-6 and 77-7)	
Raj 1972 (Susceptible to 77-2, 77-5, 77-6, 77-7, and 77-8)	
CPAN 1235 (Susceptible to 77-4, 77-5, 77-6, and 77-7)	
CPAN 1796 (Susceptible to 77, 77A-1, 77-5, and 77-6)	
Frontana# (Susceptible to 77A-1, 77-1, 77-3, 77-5, 77-6, and 77-8)	
UP 301 (Susceptible to 77A, 77-1, 77-2, 77-3, 77-4, 77-5, 77-6, and 77-8)	
HI 784 (Susceptible to 77, 77A-1, 77-1, 77-3, 77-4, 77-5, 77-6, and 77-8)	

Contd...

Contd. from page ...

C Resistant to all leaf rust pts except 77-c and 104-c pts

HS 295# (Susceptible to 77-1, 77-3, 77-4, 77-5, 77-6, 77-7, 77-8, 104B, and 104-2)
 KRL 1-4 (Susceptible to 77, 77A-1, 77-1, 77-3, 77-4, 77-5, 77-6, 77-7, 77-8, 104, and 104A)
 UP 2003 (Susceptible to 77, 77A, 77A-1, 77-1, 77-3, 77-4, 77-5, 77-6, 77-8, 104A, 104B, and 104-2)

D Resistant to all leaf rust pts except 12-c, 77-c and 104-c pt(s)

HD 2135 (Susceptible to 12A, 12-2, 77-2, 77-5, 77-6, 77-7, and 104-2)
 HD 2501# (Susceptible to 12A, 77-2, 77-5, 77-6, 77-7, 104B, and 104-2)
 Nainari 60# (Susceptible to 12-4, 77-1, 77-2, 77-3, 77-4, 77-5, 77-6, and 104-3)

E Resistant to all leaf rust pts except 12-c, 77-c, 104-c, and 162-c pt(s)

HD 2733 (Susceptible to 12-3, 12-5, 77-1, 77-5, 77-6, 104-2, and 162-2)
 HP 1731# (Susceptible to 12-5, 77-1, 77-5, 77-6, 77-7, 104-2, and 162-2)
 VL 804 (Susceptible to 12-1, 77-1, 77-5, 77-6, 77-7, 104-2, and 162-2)
 HPW 155 (Susceptible to 12A, 12-5, 77A-1, 77-3, 77-4, 77-6, 77-8, 104B, 162-2, and 162-3)
 K 9107# (Susceptible to 12-1, 12-4, 77, 77A-1, 77-1, 77-2, 77-3, 77-5, 77-6, 77-8, 104-3, and 162-3)

F Resistant to various leaf rust pathotypes

F-1 WG 138 (Susceptible to pathotypes 20, 77-1, 77-5, and 77-6)
F-2 HI 1479 (Susceptible to 77, 77A-1, 77-1, 77-3, 77-4, 77-5, 77-6, 77-8, and 107)
F-3 CPAN 1842 (Susceptible to 77, 77A-1, 77-1, 77-2, 77-3, 77-4, 77-5, 77-6, 77-8, 162-2, and 162-3)
F-4 WH 542# (Susceptible to 12-1, 12-5, 12-6, 77-1, 77-5, 77-6, 77-7, and 162-2)
F-5 Similar resistance patterns
 NIAW 34# (Susceptible to 12-1, 12-5, 77A-1, 77-1, 77-3, 77-5, 77-6, 104B, 108, and 162A)
 HP 1744# (Susceptible to 12-2, 12-5, 20, 77A-1, 77-2, 77-5, 104-2, 104-3, 108, 162, and 162A)
 VL 404# (Susceptible to 12, 12A, 12-2, 12-4, 77A-1, 77-1, 77-3, 77-5, 77-6, 104A, 104B, 104-2, 104-3, 108, 108-1, 162, 162-2, and 162-3)
F-6 Similar resistance patterns
 WH 283 (Susceptible to 10, 20, 77, 77A-1, 77-1, 77-2, 77-3, 77-5, 77-6, 104A, 108, and 108-1)
 JOB 666 (Susceptible to 10, 12-5, 77, 77A, 77A-1, 77-1, 77-2, 77-3, 77-5, 77-6, 77-8, 107, and 162-2)
 K 9465 (Susceptible to 10, 12, 12A, 12-1, 12-2, 12-3, 17, 77A-1, 77-3, 77-5, 77-6, 77-7, 104A, 104-3, 107-1, 108, 162A, 162-2, and 162-3)

#Leaf rust resistance gene *Lr34* postulated (after Nayar *et al.*, 2001)**Table 5. Diverse groups for stem rust resistance in durum wheat (at least 18 groups)****A. Resistant to all stem rust pathotypes**

AKDW 3347, B 662, GW 1114, GW 1139*, GW 1182, HD 4672, JNK 4W-184,
 MACS 2788*, MACS 2846, MACS 2884*, MPO 615, NIDW 9, P 6046, PDW 289,
 Raj 911, Raj 1555, Raj 6562, RS 749, UPD 45, and Yuk.

B. Resistant to all stem rust pathotypes except 117-complex pathotypes

B-1 Resistant to all stem rust pathotypes except the pathotype 117-6
 GW 1128, GW 1163, HD 4530, HI 8550, MACS 2778, MACS 3208, and MACS 3453

B-2 Resistant to all stem rust pts except 117-6 and other 117-c pt(s)

HD 4696 and HI 8498* (Susceptible to pathotypes 117-6 and 117A)
 HG 110, Line 1172, and MACS 1967 (Susceptible to 117-6 and 117A-1)
 DBP 02-08 (Susceptible to 117-6 and 117-3)
 HI 8651* and HI 8653 (Susceptible to 117-6, 117A, and 117-1)
 NIDW 70 (Susceptible to 117-6, 117A, and 117-4)
 MACS 3061* (Susceptible to 117-6, 117-1, and 117-2)
 PDW 245 (Susceptible to 117-6, 117A, 117-2, and 117-3)
 AKDW 4256 (Susceptible to 117-6, 117A, 117A-1, 117-1, and 117-3)
 GW 1170 (Susceptible to 117-6, 117A, 117A-1, 117-1, 117-2, and 117-3)
 MACS 3063* (Susceptible to 117-6, 117, 117A, 117-2, 117-3, and 117-5)
 GW 1209 (Susceptible to 117-6, 117A, 117-1, 117-2, 117-3, and 117-5)
 PDW 283 (Susceptible to 117-6, 117, 117A, 117-2, 117-4 and 117-5)
 PDW 215 (Susceptible to 117-6, 117A, 117A-1, 117-1, 117-3, 117-4, and 117-5)
 HI 8591* (Susceptible to 117-6, 117, 117A, 117-1, 117-3, 117-4, and 117-5)

B-3 Resistant to all stem rust pts except pt(s) of 117-c other than 117-6

GW 1207, NIDW 15*, and RKD 97 (Susceptible to pathotype 117)
 HI 8592, Raj 6516*, RD 930, and UAS 2021 (Susceptible to 117A)
 GW 1172 (Susceptible to 117A-1)
 MACS 3125* (Susceptible to 117 and 117A)
 PBW 34 (Susceptible to 117-1, 117-3 and 117A-1)
 HI 8540 (Susceptible to 117, 117A, 117-1, 117-2, 117-3 and 117-4)
 Resistant to different pts except one or more of 117-c + other selected pt(s)

- C-1** Trinakaria (Susceptible to pathotypes 11 and 117-6)
C-2 ED 2398-A (Susceptible to 21-1, 24, and 117-1)
C-3 HD 4676 (Susceptible to 24, 117, and 117A)
C-4 WG 7143 (Susceptible to 24, 42B, 122, 117A, 117-3, and 117-6)
C-5 PDW 277 (Susceptible to 42B, 117, 117A, 117A-1, 117-1, and 117-6)
C-6 IWP 5019 (Susceptible to 184, 117A, 117A-1, 117-1, 117-4, 117-5, and 117-6)
C-7 HI 8381* (Susceptible to 40A, 117, 117A, 117-1, 117-2, 117-3, 117-5, and 117-6)
C-8 NI 5749 (Susceptible to 11A, 40A, 122, 295, 117, 117A-1, 117-1, 117-3, 117-4, and 117-5)
C-9 HD 4502 (Susceptible to 11, 11A, 14, 21-1, 21A-2, 24, 24A, 34-1, 42, 42B, 184, 117A, 117A-1, 117-1, 117-3, 117-4, 117-5, and 117-6)
- D Resistant to 117-complex and most of the other stem rust pathotypes**
D-1 Guji 'S' and VD 97-15 (Susceptible to pathotype 122)
D-2 Castel Porziano (Susceptible to 21-1)
D-3 Bijaga Red (Susceptible to 40A)
D-4 NIDW 295* (Susceptible to 184)
D-5 HI 7747 (Malavraj) (Susceptible to 14 and 122)

*Stem rust resistance gene *Sr2* postulated (after Nayar *et al.* 2001)

Table 6. Diverse groups for leaf rust resistance in durum wheat (at least nine groups)

- A Resistant to all leaf rust pathotypes**
 AKDW 3347, Bijaga Red, DWR 1006, ED 2398-A, GW 1114, GW 1189, HD 4502, HD 4530, HD 4672, HD 4676, HD 4692, HD 4696, HI 8592, HI 8653, IWP 5019, MACS 2778, MACS 3063, MPO 615, MPO 1106, NIDW 9, NIDW 295, PDW 251, PDW 278, PDW 287, PDW 289, Raj 6562, Raj 6566, RD 930, RS 749, Trinakria, UAS 2021, WG 7143, and Yuk.
- B Resistant to most of the leaf rust pathotypes**
B-1 HD 4701 and HI 8630 (Susceptible to pathotype 12-5)
B-2 Castel Porziano, Guji 'S', HI 8498, and Raj 6560 (Susceptible to pathotype 162-2)
B-3 GW 1209 and HI 8381 (Susceptible to pathotype 11)
B-4 DBP 02-08 (Susceptible to pathotype 10)
B-5 AKDW 4256 and WH 929 (Susceptible to 12-5 and 162-2)
B-6 UPD 45 (Susceptible to 162-2 and 162-3)
B-7 Similar resistance patterns
 VD 97-15 (Susceptible to 11, 12-2, 12-5, 106, and 162-2)
 MACS 3061 (Susceptible to 11, 12-5, 104-3, 106, and 162-2)
 GW 1170 (Susceptible to 11, 12-2, 12-5, 104-3, 106, 162-2, and 162-3)
B-8 Similar resistance patterns
 MACS 3503 (Susceptible to 12-2, 104-2, 104-3, and 162-2)
 Raj 6516 (Susceptible to 12-5, 104-3, 162-2, and 162-3)

^aNumber of genotypes included in each group are given in parentheses

rust resistance and one of the most commonly deployed ones in modern plant breeding (McIntosh *et al.*, 1995). A stem rust race 'Ug99', carrying virulence to several resistance genes including *Sr31*, is a potential threat to wheat crop in many countries including India. "Rebuilding the *Sr2*-complex", that is pyramiding diverse resistance genes in combination with *Sr2* has been recommended as the long term strategy for achieving durable resistance to stem rust including Ug99 (Joshi *et al.*, 2008). Five genotypes viz., GW 273, GW 322, HD 4672, HI 8498, and MACS 2846, found resistant to stem rust, are among the nine Indian genotypes that showed resistance to Ug99 at

Kenya (Joshi *et al.*, 2008). It may be noted that these five genotypes belonged to four diverse groups; and GW 322 and HI 8498 carried the gene *Sr2* (Tables 3 and 5), and hence, need to be encouraged in cultivation and utilization in wheat improvement.

Out of more than 60 named genes for leaf rust resistance, *Lr13*, *Lr23*, *Lr26*, and *Lr34* are more common in Indian bread wheat genotypes (Nayar *et al.*, 2001). With the exception of the partially effective adult-plant resistance gene *Lr34*, others are not effective against the recent pathotypes of leaf rust races 12, 77 and 104 (Nayar *et al.*, 2001). The gene *Lr34* has been postulated in 12 of

the 45 leaf rust resistant bread wheat genotypes (Tables 4 and 7). Among bread wheat genotypes resistant to both stem and leaf rusts, HD 2501, HS 295 and K 9107 carried both *Sr2* and *Lr34* (Table 7). The gene *Lr23*, most commonly postulated in Indian durum genotypes, is ineffective against recent leaf rust pathotypes (Nayar *et al.*, 2001). However, several studies (see Mishra *et al.*, 2002) indicated that durum wheat carries unique leaf rust resistance genes, which can contribute to our resistance gene pool.

Diversity for rust resistance in Indian wheat germplasm was reported in earlier studies, based on seedling/adult-plant tests, generally involving a limited number of host

genotypes and rust pathotypes. Seven patterns for stem rust resistance were observed among 97 bread wheats resistant to all the stem rust pathotypes (Bhardwaj *et al.*, 2003). Sixteen bread wheat genotypes could be classified into three groups based on their seedling and adult-plant reactions to leaf rust pathotypes 77-2, 77-5 and 104-2 (Singh *et al.*, 2000). In another study, 37 bread wheat genotypes were placed in five groups on the basis of seedling infection types and field responses to three leaf rust pathotypes 77-1, 77-2 and 104B (Bahadur, 2000). On the basis of infection types to leaf rust pathotypes 77, 77A, 77-1 and 77-2, at seedling and adult plant stages, 22 groups were recognized among 37 bread wheats (Shiwani

Table 7. Bread wheat genotypes resistant to both stem and leaf rusts

S. No.	Genotype	Stem rust			Leaf rust		
		Highest disease score ^x	ACI	Group (Table 3)	Highest disease score	ACI	Group (Table 4)
1	CPAN 1235	10MR	1.90	B	5R	0.28	B-2
2	CPAN 1796 (R)	40RMR	5.04	B	20MRMS-TS	5.08	B-2
3	CPAN 1842	TS	0.36	E-6	10MRMS	2.04	F-3
4	GW 322* (R)	20RMR	2.48	F-2	10MSS	3.94	B-2
5	GW 326*	10RMR-TS	1.78	F-5	10MRMS	2.36	B-1
6	HD 2135* (R)	15MR-TS	3.08	B	5MSS	3.10	D
7	HD 2380* (R)	20MR	5.00	A-2	5MSS	3.50	B-2
8	HD 2402 (R)	20MR	4.64	A-2	5MRMS-TS	1.34	B-2
9	HD 2501*# (R)	5MR	2.20	C	10MSS	5.08	D
10	HD 2733 (R)	20R-TMR	1.48	A-1	20MRMS-TS	4.24	E
11	HI 784 (R)	30RMR-TS	4.20	E-1	5MSS	1.98	B-2
12	HI 1418* (R)	30RMR	3.04	A-2	5MRMS	0.92	B-2
13	HI 1434*	10R	0.52	A-2	10S	4.04	B-2
14	HI 1479* (R)	10R	1.24	B	10R-TMS	0.72	F-2
15	HP 1731# (R)	20R-5MR	1.74	A-2	10S	5.00	E
16	HP 1761 (R)	10R-TMR	0.76	A-1	TMR	0.12	A
17	HS 295*# (R)	20MRMS	4.16	A-2	10MRMS	1.81	C
18	HS 365 (R)	15R-TMR	0.92	A-1	TR	0.04	A
19	K 7827	20MRMS	4.64	F-4	5S	1.66	B-1
20	K 9107*# (R)	20RMR	3.64	B	5MRMS-TS	1.32	E
21	K 9465 (R)	40RMR-TMS	3.16	B	TMS	0.32	F-6
22	NIAW 34# (R)	30RMR-TMS	3.24	B	5MSS	4.66	F-5
23	PBW 498	20RMR	3.60	A-1	TMR	0.20	A
24	Raj 3765* (R)	20MRMS	4.84	A-2	10MSS	2.76	B-1
25	Raj 3777 (R)	20MR	3.28	B	20MRMS-TS	3.22	B-2
26	UP 301 (R)	20RMR	2.56	B	10S	3.66	B-2
27	UP 2003 (R)	20RMR	2.76	E-1	10S	4.40	C
28	UP 2390	20RMR	3.28	A-2	5S	2.32	B-2
29	UP 2473*	15MR	3.04	B	5MRMS	0.84	B-2
30	VL 804 (R)	20MR-5MRMS	4.84	A-1	5MSS	2.82	E
31	WH 542# (R)	5MR	1.58	A-1	10MSS	4.08	F-4

(R) = Released variety; *Stem rust resistance gene *Sr2* postulated (after Nayar *et al.*, 2001; Bhardwaj *et al.*, 2003); #Leaf rust resistance gene *Lr34* postulated (after Nayar *et al.*, 2001); ^x Rust severity: T = trace infection, 5, 10, 15, 20, 30 etc. indicate per cent host tissue infected; Host response: R=Resistant, MR=Moderately Resistant, MS=Moderately Susceptible, S=Susceptible

and Saini, 1993). Seven groups were recognized among 61 bread wheat cultivars, based on field tests with leaf rust pathotypes 12-2, 77-1, 77-2 and 104-2 (Sawhney *et al.*, 1992).

On the basis of evaluation with leaf rust race 77 in glasshouse and under field conditions, 362 durum wheat

accessions were classified into three groups (Honrao and Rao, 1996). Seedling tests with five to ten leaf rust cultures revealed 23 reaction patterns among 43 durum wheat accessions (Singh *et al.*, 1992). In another study, 36 durum wheat stocks could be classified into nine groups based on responses to eight leaf rust cultures (Sharma *et al.*, 1986).

Table 8. Durum wheat genotypes resistant to both stem and leaf rusts

S. No.	Genotype	Stem rust			Leaf rust		
		Highest disease score*	ACI	Group (Table 5)	Highest disease score	ACI	Group (Table 6)
1	AKDW 3347	5R	0.64	A	20RMR-TMS	4.88	A
2	AKDW 4256	10MSS	3.10	B-2	20MR-TS	5.00	B-5
3	Bijaga Red (R)	10MSS	4.60	D-3	10MRMS-TS	1.82	A
4	Castel Porziano	5R-TMR	0.36	D-2	10MSS	4.70	B-2
5	DBP 02-08	5MR-TS	0.95	B-2	10MSS	4.87	B-4
6	ED 2398A	TR	0.08	C-2	5MRMS-TS	0.96	A
7	Guji 'S'	TMR	0.16	D-1	TMS	0.44	B-2
8	GW 1114	10RMR-TMS	0.92	A	5MRMS	2.20	A
9	GW 1170	5MSS	2.02	B-2	10MRMS-TS	4.56	B-7
10	GW 1209	5MSS	1.70	B-2	10MRMS	5.00	B-3
11	HD 4502 (R)	5S	2.10	C-9	5MSS	2.88	A
12	HD 4530 (R)	10MSS	4.10	B-1	5MRMS-TS	0.96	A
13	HD 4672 (R)	5MSS	3.30	A	10MRMS	4.80	A
14	HD 4676	10S	4.60	C-3	10MRMS	2.32	A
15	HD 4696	10MRMS-TS	2.80	B-2	15RMR-TMS	1.62	A
16	HI 8381* (R)	10MSS	4.72	C-7	10MSS	4.40	B-3
17	HI 8498* (R)	10MSS	3.10	B-2	10MSS	4.82	B-2
18	HI 8592	10MR-TS	1.56	B-3	20MRMS	3.68	A
19	HI 8653	20MRMS-TS	3.36	B-2	10MRMS-TS	2.12	A
20	IWP 5019	10MRMS	2.24	C-6	5R	0.20	A
21	MACS 3061*	5S	1.72	B-2	10MRMS-TS	3.80	B-7
22	MACS 3063*	10MSS	3.00	B-2	20MRMS	4.80	A
23	MPO 615	20MR-TMS	2.24	A	TR	0.20	A
24	NIDW 9	10RMR-TS	1.60	A	5S	2.36	A
25	NIDW 295* (R)	20MRMS-TS	4.16	D-4	10MRMS	4.80	A
26	PDW 289	10MSS	4.90	A	20MRMS-TS	4.60	A
27	Raj 6516*	5MS	2.6	B-3	10MSS	5.06	B-8
28	Raj 6562	5MR-TMS	0.72	A	10MRMS-TS	2.70	A
29	RD 930	10S	4.84	B-3	5MSS	4.10	A
30	RS 749	30MR-TMS	3.16	A	10MRMS	4.50	A
31	Trinakaria	5MR-TS	0.68	C-1	10MRMS	2.28	A
32	UAS 2021	10MRMS-TS	2.32	B-3	20MR-10X	4.96	A
33	UPD 45	10S	3.40	A	5MSS	3.24	B-6
34	VD 97-15	20R	0.92	D-1	10MRMS-TS	3.0	B-7
35	WG 7143	5S	2.44	C-4	5MSS	4.96	A
36	Yuk	5S	2.16	A	20MRMS-TS	4.90	A

(R) = Released variety

* Stem rust resistance gene *Sr2* postulated (after Nayar *et al.* 2001); * Rust severity: T = trace infection, 5, 10, 15, 20, 30 etc. indicate per cent host tissue infected; Host response: R=Resistant, MR=Moderately Resistant, MS=Moderately Susceptible; S=Susceptible, X=Mesothetic response (different types of pustules on the same leaf)

However, the present study adopted a more comprehensive approach, as seedling responses to most of our stem and leaf rust variability in general, and to the 'virulent' pathotypes in particular, formed the basis for assessing diversity for resistance in both durum and bread wheat genotypes with proven field resistance. Hence, wheat workers in the country can choose effective and diverse rust resistance donors from the ones under report.

The genotypes listed below, resistant to both stem and leaf rusts, showed resistance to all the three rusts in multilocation tests conducted during 1997-2003 (Singh *et al.*, 2004).

Bread wheat: HI 1434, HI 1479, HP 1761, HS 295, HS 365, K 9107, NIAW 34, PBW 498, UP 2473, and VL 804.

Durum wheat: GW 1170, HD 4672, HD 4696, HI 8498, MACS 3061, MACS 3063, NIDW 9, PDW 289, Raj 6516, and UAS 2021.

Hence, these genotypes can be utilized as sources of multiple rust resistance throughout the country.

Acknowledgements

We are grateful to the Indian Council of Agricultural Research, New Delhi, for the financial and human resource support through the AP Cess Fund Project "Identification of diverse sources of resistance to stem rust and leaf rust in durum wheat" (2003-2005).

We acknowledge with sincere thanks receipt of the seeds of test genotypes from the institutions (see source in Table 1 and 2). Receipt of nucleus inoculum of the rust pathotypes from the Head, Directorate of Wheat Research, Regional Station, Flowerdale, Shimla, is gratefully acknowledged.

References

- Bahadur P (2000) Adult plant resistance to leaf rust in 37 Indian wheats. Proceedings of the International Conference on Integrated Plant Disease Management for Sustainable Agriculture. Vol I. Indian Phytopathological Society, IARI, New Delhi, pp 644-649.
- Bhardwaj SC, SK Nayar, M Prashar, SK Jain and SB Singh (2003) Diversity of resistance for *Puccinia graminis tritici* in wheat (*Triticum aestivum*) and triticale material. *Indian J. Agric. Sci.* **73**: 676-679.
- Honrao BK and VSP Rao (1996) Sources of resistance to race 77 of leaf rust (*Puccinia recondita* f. sp. *tritici*) in durum wheat. II. Adult plant resistance. *Cereal Rusts Powdery Mildews Bull.* **24**: 44-48.
- Joshi AK, B Mishra, M Prashar, SMS Tomar and RP Singh (2008) Ug99 race of stem rust pathogen: Challenges and current status of research to sustain wheat production in India. *Indian J. Genet.* **68**: 231-241.
- McIntosh RA, CR Wellings and RF Park (1995) Wheat Rusts: An Atlas of Resistance Genes. CSIRO Publications, East Melbourne, Australia, 200 p.
- Mishra AN, K Kaushal and HN Pandey (2001) Appropriate pathotypes of stem rust and leaf rust for evaluating resistance in durum wheat and bread wheat. *Wheat Information Service* **93**: 38-39.
- Mishra AN, K Kaushal and HN Pandey (2002) "Complementary" resistance of bread wheat and durum wheat to stem rust and leaf rust and its role in disease management. *Cereal Rusts and Powdery Mildews Bulletin* [www.crpmb.org/] 2002/0906mishra, Accessed on May 14, 2009.
- Nayar SK, S Nagarajan, M Prashar, SC Bhardwaj, SK Jain and D Datta (2001) *Revised Catalogue of Genes that Accord Resistance to Puccinia species in Wheat*. Research Bulletin No. 3, Directorate of Wheat Research, Regional Station Flowerdale, Shimla, India, 48 p.
- Nayar SK, M Prashar and SC Bhardwaj (1997) *Manual of Current Techniques in Wheat Rusts*. Research Bulletin No. 2, Directorate of Wheat Research, Regional Station, Flowerdale, Shimla, India, 32 p.
- Peterson RF, AB Campbell and AE Hannah (1948) A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. *Canadian J. Res.* **26**: 496-500.
- Sawhney RN, JB Sharma and DN Sharma (1992) Genetic diversity for adult plant resistance to leaf rust (*Puccinia recondita*) in near-isogenic lines and in Indian wheats. *Plant Breeding* **109**: 248-254.
- Sharma DL, RG Saini, AK Gupta and S Gupta (1986) Diversity for resistance to leaf rust in *Triticum durum* (Desf.). *Cereal Rusts Bull.* **14**: 53-57.
- Shiwani and RG Saini (1993) Diversity for resistance to leaf rust in *Triticum aestivum*. *Plant Disease* **77**: 359-363.
- Singh DP, AK Sharma, VC Sinha, SS Karwasra, MS Beniwal, KP Singh, AN Tewari, PS Bagga, SK Mann, SK Pant, PS Shekhawat, RN Brahma, AN Mishra, IK Kalappanavar, KP Singh, VS Shinde and A Singh (2004) Confirmed sources of adult plant multiple rust resistance in wheat (*Triticum aestivum* L., *T. dicoccum* and *T. durum*) and Triticale X. *SAARC J. Agric.* **2**: 89-108.
- Singh H, HS Dhaliwal and KS Gill (1992) Diversity for leaf rust resistance in *Triticum durum* germplasm. *Cereal Rusts Powdery Mildews Bull.* **20**: 62-67.
- Singh SS, Harsh Mehta, DN Sharma and N Chand (2000) Interaction of an adult plant partial resistance gene *Lr34* with seedling resistance genes providing durable resistance to *Puccinia recondita* f. sp. *tritici*. *Proceedings of International Conference on Integrated Plant Disease Management for Sustainable Agriculture*. Vol I. Indian Phytopathological Society, IARI, New Delhi, pp 612-615.