Diverse sources of resistance to Indian pathotypes of stem rust and leaf rust in durum wheat

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Diverse sources of resistance to Indian pathotypes of stem rust and leaf rust in durum wheat

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Abstract. Stem rust (*Puccinia graminis* f. sp. *tritici*) and leaf rust (*P. triticina*) are among the most serious biotic stresses for durum wheat cultivation in India. Constant broadening of resistance base is necessary for maintaining effective and longer lasting rust resistance in view of the continued evolution of rust pathogens. Hence, Mendelian inheritance and extent of diversity for resistance were studied among five rust resistant durum wheat genetic stocks of diverse origin viz., 'B 662', 'ED 2398-A', 'HG 110', 'IWP 5019' and 'Line 1172'. Of these, B 662, IWP 5019, and Line 1172 were derived from inter-specific hybridization involving crosses of different durum wheat genotypes with *Triticum aestivum*, *T. turgidum* var. *dicoccum*, and *T. militinae* lines, respectively. HG 110 was developed from an intra-specific (durum wheat / durum wheat) cross, while ED 2398-A was an Ethiopian durum wheat land race. The test pathotypes included *40A* (*62G29*) and *117-6* (*37G19*) of stem rust, the former being the most predominant in nature and the latter being the most virulent one on Indian durum wheat; and the prevalent and durum-specific leaf rust pathotypes, *12-2* (*1R5*) and *104-2* (*21R55*). While seedling tests were conducted with the pathotypes *40A*, *12-2* and *104-2*, adult-plant studies were made with the pathotype *117-6*. Analysis of the F_2 populations and F_3 families derived from the crosses of the aforesaid resistant stocks with three suscept ble durum wheat varieties- 'Motia', 'Malvi Local' and 'Sarangpur Local' showed that resistance was governed by one or two genes. In all, four genes for resistance to the pathotype *40A*, and eight genes each for resistance to *117-6* and *12-2* were identified among the five resistant stocks studied; while three genes for resistance to *104-2* were identified among B 662, ED 2398 A and IWP 5019, based on the allelic tests. Though the identity of these genes is not known, the ones for stem rust resistance are different from *Sr2*, *Sr7b*, *Sr9e* and *Sr11*, and those for leaf rust resistance are different from *Lr23*, the documented stem rust and leaf rust resistance genes commonly postulated among Indian durum wheat genotypes. Thus, the reported genetic stocks should contr bute to enrich the gene pool in durum wheat improvement as diverse sources of resistance to stem rust and leaf rust.

Keywords. Durum wheat – Stem rust resistance – Leaf rust resistance – Genetic diversity – Indian rust pathotypes.

Diverses sources de résistance aux pathotypes indiens de la rouille noire et de la rouille brune du blé dur

Résumé. *La rouille noire (Puccinia graminis f. sp. Tritici) et la rouille brune (P. triticina) sont parmi les plus graves contraintes biotiques pour la culture du blé dur en Inde. Un élargissement constant de la base de la résistance est nécessaire pour assurer une résistance efficace et plus durable aux rouilles vu l'évolution continue de ses agents. Par conséquent, l'héritage mendélien et l'étendue de la diversité de la résistance ont été étudiés parmi cinq stocks génétiques de blé dur de diverse origine résistant aux rouilles, à savoir 'B 662', 'ED 2398-A', 'HG 110', 'IWP 5019' et 'Lignée 1172'. Parmi ceux-ci, B 662, IWP 5019, et Lignée 1172 ont été obtenus par l'hybridation inter-spécifique impliquant des croisements de différents génotypes de blé dur avec Triticum aestivum, T. turgidum var. dicoccum, et les lignées T. militinae, respectivement. HG 110 a été développé à partir d'un croisement intra-spécifique (blé dur/blé dur) tandis que ED 2398-A était un blé dur de race primitive éthiopienne. Les pathotypes testés comprenaient le 40A (62G29) et le 117-6 (37G19) de la rouille noire, le premier étant prédominant dans la nature et le dernier plus virulent sur le blé dur indien ainsi que les pathotypes de la rouille brune plus répandus et spécifiques du blé dur, 12-2 (1R5) et 104-2 (21R55). Alors que les tests de semis ont été réalisés avec les pathotypes 40A, 12-2 et 104-2, les études sur les plantes adultes ont été réalisées avec le pathotype 117-6. L'analyse des populations* F_2 *et des familles* F_3 *issues des croisements de ces stocks résistants avec trois variétés de blé dur sensibles 'Motia', 'Malvi local' et 'Sarangpur local' a montré que la résistance est contrôlée par un ou deux gènes. Au total, quatre gènes de* *résistance au pathotype 40A, et huit gènes de résistance pour chaque race, 117-6 et 12-2, ont été identifiés parmi les cinq stocks résistants étudiés ; en plus, trois gènes de résistance à 104-2 ont été identifiés parmi B 662, ED 2398 A et IWP 5019, sur la base des tests alléliques. Bien que leur identité ne soit pas encore connue, les gènes pour la résistance à la rouille noire sont différents de Sr2, Sr7b, Sr9e et Sr11, et ceux pour la résistance à la rouille brune sont différents de Lr23, les gènes de la résistance à la rouille noire et à la rouille brune documentés parmi les génotypes de blé dur indiens. Ainsi, les stocks génétiques explorés devraient contribuer à enrichir le patrimoine génétique pour l'amélioration du blé dur comme sources différentes de résistance à la rouille noire et à la rouille brune.*

Mots-clés. *Blé dur – Résistance à la rouille noire – Résistance à la rouille brune – Diversité génétique – Pathotypes de rouille indiens.*

I – Introduction

India produces >90 million tons of wheat from an area of >25 million hectares, to which the contribution of durum wheat is about 5%. However, durum wheat has a special niche in Indian wheat economy for at least two reasons. Indian durum wheat is typically purchased by the private trade at a price premium, mainly for processing of high value products. In addition, durum wheat is preferred over bread wheat for several local food preparations. In India, durum wheat is mainly grown in the central and peninsular parts of India including the states of Madhya Pradesh, Rajasthan, Gujarat, Uttar Pradesh (Bundelkhand region), Maharashtra, and Karnataka, where stem rust and leaf rust are the major disease problems affecting the wheat crop. Relatively little work has been done on the inheritance of rust resistance in durum wheat, compared to bread wheat. Hence, studies were conducted using appropriate rust pathotypes to determine the mode of inheritance and extent of diversity for resistance to stem and leaf rusts among five durum wheat genetic stocks *viz*. 'B 662', 'ED 2398-A', 'HG 110', 'IWP 5019' and 'Line 1172', which have been showing high levels of resistance to both the rusts in the disease screening nurseries under heavy inoculum pressure since 1997. Results of these studies are presented in this communication.

II – Material and Methods

1. Host material

Five rust resistant durum wheat genetic stocks viz., 'B 662', 'ED 2398-A', 'HG 110', 'IWP 5019' and 'Line 1172' of diverse origins were selected for the present studies (Table 1). Three durum wheat land races viz., Motia, Malvi Local, and Sarangpur Local were used as 'susceptible' parental lines in crosses with the above listed 'resistant' stocks.

2. Rust pathotypes chosen for the studies

Stem rust pathotypes 40A (62G29) and 117-6 (37G19) since the former is currently the most prevalent one (Anonymous, 2012), while the latter is highly virulent to Indian durum wheat germplasm (Mishra *et al*., 2001a; Mishra *et al*., 2009) among the stem rust pathotypes occurring in India.

Leaf rust pathotypes 12-2 (1R5) and 104-2 (21R55) since the former is durum-specific (Mishra *et al.*, 2001a; Mishra *et al*., 2009), while the latter is widely prevalent (Anonymous, 2012), and durum-virulent (Mishra *et al*., 2001a; Mishra *et al*., 2009) among the Indian leaf rust pathotypes.

The avirulence / virulence characteristics of these pathotypes on the stem rust and leaf rust differentials being currently used in India, based on seedling tests, are as follows (Nayar *et al*., 2001):

40A (62G29): P Sr13, Sr30, Sr37, Einkorn (Sr21), Khapli (Sr7a, Sr13, Sr14) / p Sr8b, Sr9b, Sr9e, Sr11, Sr28, Marquis (Sr7b+), Kota (Sr28+), Reliance (Sr5+), Charter (Sr11+),

117-6 (37G19): P Sr8b, Sr9b, Sr28, Sr30, Sr37, Kota (Sr28+), Reliance (Sr5+), Khapli (Sr7a, Sr13, Sr14) / p Sr9e, Sr11, Sr13, Marquis (Sr7b+), Einkorn (Sr21), Charter (Sr11+),

12-2 (1R5): P Lr10, Lr13, Lr15, Lr17, Lr18, Lr19, Lr24, Webster (Lr2a), Thew (Lr20), Malakoff (Lr1), Benno (Lr26), HP 1633 (Lr9+) / p Lr14a, Loros (Lr2c), Democrat (Lr3),

104-2 (21R55): P Lr10, Lr13, Lr15, Lr19, Lr24, Webster (Lr2a), Thew (Lr20), HP 1633 (Lr9+) / p Lr14a, Lr17, Lr18, Loros (Lr2c), Democrat (Lr3), Malakoff (Lr1), Benno (Lr26).

Table 1. List and characteristics of host material.

Genetic stock	Parentage / Source	Important phenotypic traits
ED 2398 A	Ethiopian local durum wheat variety from the germplasm collection of IARI-RS, Indore	Tall in height (>110 cm) Late in heading (~90 days) Long ears with glabrous glumes Purple pigmentation on stem and auricle
HG 110	Sarangpur Local/HI 8185 (Sarangpur Local - local durum variety, HI 8185 – an advanced generation durum line developed at Indore	Medium Tall (<110 cm) Medium early in heading (~70 days) Long ears with pubescent glumes Purple pigmentation on auricle
B 662	PBW 34*2/Chuanmai #18 (PBW 34 – a released durum cultivar, Chuanmai # 18 – a Chinese accession of *Triticum aestivum* carrying *Rht8* gene for dwarfism)	Triple dwarf (Height <50 cm) Medium late in heading (~80 days) Long ears with pubescent glumes
IWP 5019	HD 4519*2/NP 200 (HD 4519 – an advanced generation durum line NP 200 – a released cultivar *of T. dicoccum*	Double dwarf (Height 80-85 cm) Very early heading (>70 days) Short ears with Glabrous glumes Grains with high protein content and high SDS value
Line 1172	MACS 9*2/*T. militinae* (MACS 9 – a released durum wheat cultivar, *T. militinae* – a free-threshing mutant of *T. timopheevii*)	Tall in height (>110 cm) Medium late in heading (~80 days) Glabrous glumes Grains very bold

B 662, IWP 5019 and Line 1172 were developed at IARI, New Delhi through interspecific hybridization.

3. Methods

Studies were carried out in the glasshouse, and in the field at the Indian Agricultural Research Institute (IARI), Regional Station, Indore, India during the regular wheat crop season (November-April). The ‘susceptible’ varieties ‘Motia’, ‘Malvi Local’, and ‘Sarangpur Local’ were used as female parental lines in crosses with each of the five ‘resistant’ stocks, ‘B 662’, ‘ED 2398-A’, ‘HG 110’, ‘IWP 5019’ and ‘Line 1172’. Also, the resistant stocks were crossed among themselves in all possible combinations without reciprocals. A few F_1 seeds were saved for tests, while others were grown to obtain F_2 seeds from individual F_1 plants. The F_3 families were constituted from harvest of the individual F_2 plants. The parents, F_1s, F_2 populations and F_3 families were tested in the seedling stage with stem rust pathotype *40A*, and leaf rust pathotypes *12-2* and *104-2* in a glasshouse at 22°C ± 2°C using standard glasshouse procedures (Roelfs *et al*., 1992; Nayar *et al*., 1997); and in the adult-plant stage with the stem rust pathotype *117-6* in an isolated nursery following recommended crop cultivation practices.

In the adult-plant tests involving the stem rust pathotype *117-6*, seeds of the parental lines, the F_1s and the F_2 populations were dibbled with 10 cm spacing between seed-to-seed in 1.5 m long rows, planted 30 cm apart. The F_3 families derived from the F_2 plants of 'susceptible parent x resistant parent' crosses as well as the ones derived from the F_2 plants classified as "susceptible" (putative susceptible segregants) among 'resistant parent x resistant parent' crosses were tested to confirm the F_2 observations. Around 50 seeds derived from each of the F_2 plants was hand-drilled in 2.5 m long rows planted 30 cm apart. The parental lines were replicated twice along with the F_1s, F_2 populations, and F_3 families of each of the crosses. Rust spreader rows consisting of mixtures of highly susceptible wheat varieties were planted after every 20 test rows, and all around the experimental plot as well. Beginning 50-60 days after sowing, the disease spreader rows were inoculated with aqueous suspension of the uredospores of the stem rust pathotype *117-6*, freshly collected from the actively sporulating pots maintained in isolation in the glasshouse. Both hypodermic syringes and sprays were used to inoculate the disease spreader rows to ensure timely establishment of stem rust in the field. The spore suspension was sprayed on to the test rows as well, but no syringe inoculations were made in order to simulate natural stem rust epidemics. Stem rust scores were recorded combining the disease severity as per the modified Cobb's scale (Peterson *et al*., 1948), and the host response (Roelfs *et al*., 1992).

The F_2 plants were grouped in to 'resistant' and 'susceptible' classes on the basis of their infection types in seedlings or their response combined with severity in case of adult plants, and were counted to determine the F_2 ratios. The F_3 families derived from the F_2 plants were classified as homozygous resistant (R), segregating (Seg), or homozygous susceptible (S), based on the presence of exclusively resistant plants, both resistant and susceptible plants, and exclusively susceptible plants, respectively. The chi-squared test was used to test the goodness-of-fit of the observed F_2 and F_3 ratios to the expected ones on the basis of Mendelian segregation.

III – Results

1. Adult-plant resistance to stem rust pathotype 117-6

Among the five resistant durum genotypes studied, only B 662 showed seedling resistance to the stem rust pathotype *117-6,* while all the five expressed adult-plant resistance to this pathotype (Table 2). Hence, genetics of adult-plant resistance was studied using the stem rust pathotype *117-6*. The F_1s from all of the 'susceptible parent' / 'resistant parent' (S / R) crosses were resistant except the one from 'Sarangpur Local' / 'B 662' cross, indicating the dominant mode of inheritance of adult-plant resistance to stem rust pathotype *117-6* in the five resistant genotypes studied (Table 3). Analysis of F_2 and F_3 ratios involving 'S / R' crosses showed the presence of a single dominant resistance gene in B 662 and IWP 5019, while two independent dominant genes were operative for resistance in each of the three remaining resistant genotypes (Table 3). Sarangpur Local', one of the three susceptible parental lines used in the study, showed the presence of a suppressor gene against the resistance gene in B 662 (Table 3). Allelic tests involving 'resistant parent' / 'resistant parent' (R / R) crosses showed that all of these genes were different from each other (Table 3). Thus, a total of eight diverse dominant genes were identified for adult-plant resistance among the five resistant genotypes studied.

2. Seedling resistance to stem rust pathotype *40A*

All the five resistant genotypes and the F_1s from all of the S / R crosses were resistant except the one from 'Sarangpur Local' / 'B 662' cross, indicating the dominant mode of inheritance of seedling resistance to stem rust pathotype *40A* in the five resistant genotypes studied (Table 2). Study of the F_2 and F_3 populations derived from 'S / R' crosses showed the presence of a single dominant resistance gene in ED 2398-A, HG 110, and IWP 5019, while one dominant +

one recessive gene occurred each in B 662 and Line 1172 (Table 4). However, in the 'Sarangpur Local' / 'B 662' cross, the F_2 ratio fitted to 7R : 9S, indicating modification to the two recessive genes. Analysis of the F_2 ratios involving 'R / R' crosses revealed that while the dominant genes in B 662 and ED 2398-A were unique, the dominant gene was common among HG 110, IWP 5019 and Line 1172. Likewise, the recessive gene was common between B 662 and Line 1172. (Table 4). Thus, a total of four diverse genes including three dominant genes and one recessive were identified for seedling resistance to stem rust pathotype *40A* among the five durum wheat genotypes studied.

3. Seedling resistance to leaf rust pathotype *12-2*

All the five resistant genotypes and the F_1s from all of the S / R crosses were resistant, indicating the dominant inheritance of seedling resistance to leaf rust pathotype *12-2* in the five resistant genotypes studied (Table 2). Analysis of the F_2 and F_3 ratios involving 'S / R' crosses showed the presence of a single dominant resistance gene in HG 110 and Line 1172, while two independent dominant genes each conditioned resistance to this pathotype in B 662, ED 2398-A and IWP 5019 (Table 5). Allelic tests involving 'R x R' crosses showed that all of these genes were different from each other (Table 5). Thus, a total of eight diverse dominant genes were identified for seedling resistance to the leaf rust pathotype *12-2* among the five resistant genotypes studied.

Table 2. Seedling and adult-plant responses of the parental lines and the F_1s to the rust pathotypes used in the study.

	Seedling Infection Types				
Material	**40A**	**12-2**	**104-2**	**117-6**	**Adult-plant response to117-6**
Parental line					
B 662	$;1^-$	0;	;2N	;1	5RMR
ED 2398-A	;1N	;1	;1	23^+	TR
IWP 5019	;1	;1N	;2	34	10S
HG 110	;1	X^+	34	34	5S
Line 1172	;1	X	34	34	TS
Motia	34	34	34	34	80S
Malvi Local	34	34	34	34	80S
Sarangpur Local	34	34	34	34	60MSS
F_1S					
Motia / B 662	;1	;1	$;2^+N$	NT	10MR
Malvi Local / B 662	;1	;1	$;2^+N$	NT	10MR-TS
Sarangpur Local / B 662	34	;1	$;2^+N$	NT	60MSS
Motia / ED 2398-A	$;2^-N$	$;1^+$	$;1^+$	NT	TMR
Malvi Local / ED 2398-A	$;2^-N$	$;1^+$	$;1^+$	NT	5MR
Sarangpur Local / ED 2398-A	$;2^-N$	$;1^+$	$;1^+$	NT	TMR
Motia / IWP 5019	$;1^+$	$;2^-N$	$;3^-$	NT	20S
Malvi Local / IWP 5019	$;1^+$	$;2^-N$	;3	NT	20S
Sarangpur Local / IWP 5019	$;1^+$	$;2^-N$	;3	NT	20S
Motia / HG 110	$;1^+$	X^{++}	NT	NT	10S
Malvi Local / HG 110	$;1^+$	X^{++}	NT	NT	10S
Sarangpur Local / HG 110	$;1^+$	X^{++}	NT	NT	10S
Motia / Line 1172	$;1^+$	X^+	NT	NT	5S
Malvi Local / Line 1172	$;1^+$	X^+	NT	NT	5S
Sarangpur Local / Line 1172	$;1^+$	X^+	NT	NT	5S

NT – Not Tested.

4. Seedling resistance to leaf rust pathotype *104-2*

Three of the five resistant genotypes studied viz., B 662, IWP 5019, and ED 2398-A as well as the F_1s from their crosses with the susceptible parental lines were resistant, indicating the dominant inheritance of seedling resistance to leaf rust pathotype *12-2* in these three genotypes (Table 2). Seedling tests involving the F_2 and F_3 populations derived from 'S x R' crosses showed the presence of a single dominant resistance gene each in B 662 and IWP 5019, while two independent dominant genes controlled resistance to this pathotype in ED 2398-A (Table 6). Allelic tests involving 'R x R' crosses showed that while the gene in B 662 was unique, one of the genes in ED 2398-A was common with that of IWP 5019, as no susceptible segregant was observed in the 'ED 2398-A' x 'IWP 5019' cross (Table 6). Thus, at least three diverse dominant genes were identified for seedling resistance to leaf rust pathotype 104-2 among the aforesaid three resistant genotypes studied. The other two genotypes, HG 110 and Line 1172, being seedling susceptible to this pathotype, were not included in the study.

IV – Discussion

With the possible exception of the dominant gene in B 662, the genes for adult-plant resistance to the stem rust pathotype *117-6* identified are different from those detected in seedlings using stem rust pathotype *40A*, since only B 662 showed resistance to *117-6* in seedlings, while others including ED 2398-A, HG 110, IWP 5019, and Line 1172 were susceptible. Thus, a total of 11 stem rust resistance genes including 10 dominant and one recessive were identified in the present study, since the dominant gene for resistance to the pathotype *40A* among HG 110, IWP 5019 and Line 1172 was common, and the recessive gene between B 662 and Line 1172 was common for resistance to the same pathotype. In an earlier study, a single dominant gene was found to control seedling resistance in B 662 to the stem rust pathotype *117-6* (Mishra *et al*., 2005), and it could be the same gene that has been identified in the present study for the adult-plant resistance to this pathotype in B 662. Though the identity of the genes identified in the present study is not known, they are different from the stem rust resistance genes *Sr2*, *Sr7b*, *Sr9e* and *Sr11*, which have commonly been postulated in Indian durum wheat germplasm (Nayar *et al*., 2001), since *Sr2* is expressed only in adult-plants and is recessively inherited, while the other three genes are ineffective against the stem rust pathotypes *40A* and *117-6*. Presence of a suppressor gene was observed in Sarangpur Local for the dominant gene in B 662 for adult-plant resistance to stem rust pathotype *117-6*. Suppressor genes for adult-plant resistance to stem rust, and for adult-plant as well as seedling resistance to leaf rust in durum wheat have been reported earlier also (Mishra *et al*., 1989a; Mishra *et al*., 1989b).

Presence of unique genes for leaf rust resistance in HG 110 and Line 1172, since both were susceptible to the pathotype *104-2*, and presuming that the genes in B 662, ED 2398-A and IWP 5019 were common for resistance to the leaf rust pathotypes *12-2* and *104-2*, it can be inferred that at least eight diverse dominant genes were identified for leaf rust resistance among the five resistant durum genotypes studied. These genes are different from the leaf rust resistance gene *Lr23*, which has been commonly postulated in Indian durum wheat germplasm (Nayar *et al*., 2001), as *Lr23* is ineffective against both the leaf rust pathotypes *12-2* and *104-2*.

The aforesaid five durum wheat genetic stocks were reported as new sources of rust resistance in 2001 (Mishra *et al*., 2001b), based on their continued expression of resistance since 1997. It may be noted that subsequently they have been observed to maintain their resistance status till date for stem and leaf rusts in the disease screening nurseries under heavy inoculums pressure, not only at Indore, but at other hot-spot locations in the country as well. With the establishment of genetic diversity among them for resistance to both the rusts through the present study, these genotypes can contribute to broaden the rust resistance base in durum wheat leading to prolonged durability of rust resistance in future durum varieties.

Table 3. Segregation for adult-plant resistance to stem rust pathotype 117-6 in F_2 plants / F_3 families derived from 'susceptible parent' / 'resistant parent' (S / R) and 'resistant parent' / 'resistant parent' (R / R) crosses ***R: Resistant. (S: Susceptible, Seg: Segregating for resistance).***

Cross	Number of F_2 plants					Number of F_3 families					
	R	S	Total	χ^2	P	R	Seg	S	Total	χ^2	P
S / R crosses											
Motia' / 'B 662'	72	30	102	1.06 (3:1)	>0.30	25	59	15	99	5.66 (1:2:1)	>0.05
Malvi Local' / 'B 662'	85	35	120	1.11 (3:1)	>0.20	20	39	17	76	0.29 (1:2:1)	>0.50
Sarangpur Local' / 'B 662'	22	59	81	3.76 (3:13)	>0.05	5	46	30	81	1.59 (1:8:7)	>0.30
Motia' / 'ED 2398 A'	82	4	86	0.38 (15:1)	>0.50	36	34	9	79	4.25 (7:8:1)	>0.10
Malvi Local' / 'ED 2398 A'	68	7	75	1.21 (15:1)	>0.20	26	36	6	68	1.31 (7:8:1)	>0.50
Sarangpur Local' / 'ED 2398 A'	111	13	124	3.79 (15:1)	>0.05	45	51	4	100	0.87 (7:8:1)	>0.50
Motia' / 'HG 110'	97	5	102	0.32 (15:1)	>0.50	44	49	5	98	0.24 (7:8:1)	>0.80
Malvi Local' / 'HG 110'	108	12	120	2.88 (15:1)	>0.05	45	56	8	109	0.40 (7:8:1)	>0.80
Sarangpur Local' / 'HG 110'	106	11	117	1.98 (15:1)	>0.10	44	67	6	117	2.48 (7:8:1)	>0.20
Motia' / 'IWP 5019'	86	27	113	0.07 (3:1)	>0.70	25	53	22	100	0.54 (1:2:1)	>0.70
Malvi Local' / 'IWP 5019'	89	33	122	0.27 (3:1)	>0.50	28	62	29	119	0.23 (1:2:1)	>0.80
Sarangpur Local' / 'IWP 5019'	103	41	144	0.93 (3:1)	>0.30	29	69	33	131	0.62 (1:2:1)	>0.70
Motia' / 'Line 1172'	149	16	165	3.35 (15:1)	>0.05	70	80	14	164	1.46 (7:8:1)	>0.30
Malvi Local' / 'Line 1172'	60	3	63	0.24 (15:1)	>0.50	23	33	3	59	0.85 (7:8:1)	>0.50
Sarangpur Local' / 'Line 1172'	94	6	100	0.01 (15:1)	>0.90	32	49	5	86	1.71 (7:8:1)	>0.30
R / R crosses											
B 662' / 'ED 2398-A'	459	08	467	0.07 (63:1)	>0.70						
B 662' / 'HG 110'	829	19	848	2.53 (63:1)	>0.10						
B 662' / 'IWP 5019'	1104	89	1193	2.96 (15:1)	>0.05						
B 662' / 'Line 1172'	789	12	801	0.02 (63:1)	>0.80						
ED 2398-A' / 'HG 110'	1284	06	1290	0.18 (255:1)	>0.50						
ED 2398-A' / 'IWP 5019'	845	12	857	0.15 (63:1)	>0.50						
ED 2398-A' / 'Line 1172'	617	02	619	0.07 (255:1)	>0.70						
HG 110' / 'IWP 5019'	839	17	856	1.00 (63:1)	>0.30						
HG 110' / 'Line 1172'	1398	07	1405	0.41 (255:1)	>0.50						
IWP 5019' / 'Line 1172'	1397	29	1426	2.04 (63:1)	>0.10						

Susceptible F_2 plants were progeny tested to confirm the segregating F_2 ratios in the R / R crosses

Table 4. Segregation for seedling resistance to stem rust pathotype 40A in F_2 plants and F_3 families derived from 'susceptible parent' / 'resistant parent' (S / R) and 'resistant parent' x 'resistant parent' (R / R) crosses.

Crosses	F_2 plants No..					F_3 famIlles No					
	R	S	Tot	χ^2	P	R	SegR	S	TotS	χ^2	P
S / R Crosses											
Motia' / 'B 662'	69	19	88	0.47 (13:3)	>0.30	30	33	5	68	0.16 (7:8:1)	>0.90
Malvi Local' / 'B 662'	64	17	81	0.27 (13:3)	>0.50	28	34	7	69	1.85 (7:8:1)	>0.30
Sarangpur Local' / 'B 662'	38	40	78	0.78 (7:9)	>0.30	27	31	8	66	4.07 (7:8:1)	>0.10
Motia' / 'ED 2398 A'	60	19	79	0.04 (3:1)	>0.80	11	19	8	38	0.47 (1:2:1)	>0.70
Malvi Local' / 'ED 2398 A'	68	22	90	0.01 (3:1)	>0.90	15	31	13	59	0.29 (1:2:1)	>0.80
Sarangpur Local' / 'ED 2398 A'	59	26	85	1.41 (3:1)	>0.20	12	29	16	57	0.58 (1:2:1)	>0.70
Motia' / 'HG 110'	61	18	79	0.20 (3:1)	>0.50	17	40	21	78	0.46 (1:2:1)	>0.70
Malvi Local' / 'HG 110'	61	24	85	0.47 (3:1)	>0.30	15	32	18	65	0.29 (1:2:1)	>0.80
Sarangpur Local' / 'HG 110'	63	23	86	0.13 (3:1)	>0.70	13	33	16	62	0.55 (1:2:1)	>0.70
Motia' / 'IWP 5019'	52	22	74	0.88 (3:1)	>0.30	10	25	13	48	0.45 (1:2:1)	>0.70
Malvi Local' / 'IWP 5019'	53	24	77	1.56 (3:1)	>0.20	14	31	16	61	0.15 (1:2:1)	>0.90
Sarangpur Local' / 'IWP 5019'	71	20	91	0.44 (3:1)	>0.50	19	37	21	77	0.22 (1:2:1)	>0.80
Motia' / 'Line 1172'	61	15	76	0.05 (13:3)	>0.80	26	33	5	64	0.42 (7:8:1)	>0.70
Malvi Local' / 'Line 1172'	40	11	51	0.27 (13:3)	>0.50	21	24	4	49	0.31 (7:8:1)	>0.80
Sarangpur Local' / 'Line 1172'	64	22	86	2.63 (13:3)	>0.10	30	35	7	72	1.49 (7:8:1)	>0.30
R / R crosses											
B 662' / 'ED 2398-A'	124	09	133	1.29 (61:3)	>0.20						
B 662' / 'HG 110'	130	11	141	3.06 (61:3)	>0.05						
B 662' / 'IWP 5019	137	13	150	5.32 (61:3)	>0.02						
B 662' / 'Line 1172'	144	00	144	5.24 (247:9)	<0.05						
ED 2398-A' / 'HG 110'	134	15	149	3.71 (15:1)	>0.05						
ED 2398-A' / 'IWP 5019	140	09	149	0.01 (15:1)	>0.90						
ED 2398-A' / 'Line 1172'	139	07	146	0.004 (61:3)	>0.90						
HG 110' / 'IWP 5019'	145	00	145	9.66 (15:1)	<0.01						
HG 110' / 'Line 1172'	139	00	139	6.84 (61:3)	<0.01						
IWP 5019' / 'Line 1172	159	00	159	7.82 (61:3)	<0.01						

R: Resistant, S: Susceptible, Seg: Segregating for resistance.

Table 5. Segregation for seedling resistance to leaf rust pathotype 12-2 in F_2 plants / F_3 families derived from 'susceptible parent' / 'resistant parent' (S / R) and 'resistant parent' / 'resistant parent' (R / R) crosses.

Cross	**F2 plants No.**					**F3 families No.**					
	R	**S**	**Tot.**	**χ^2**	**P**	**R**	**Seg**	**S**	**Tot**	**χ^2**	**P**
S / R crosses											
'Motia' / 'B 662'	**93**	**4**	**97**	**0.75 (15:1)**	**>0.30**	**33**	**45**	**5**	**83**	**0.60 (7:8:1)**	**>0.70**
'Malvi Local' / 'B 662'	**156**	**9**	**165**	**0.18 (15:1)**	**>0.50**	**26**	**39**	**7**	**72**	**2.56 (7:8:1)**	**<0.20**
'Sarangpur Local' / 'B 662'	**147**	16	163	3.53 (15:1)	>0.05	39	45	8	92	0.94 (7:8:1)	>0.50
'Motia' / 'ED 2398 A'	158	12	170	0.19 (15:1)	>0.80	35	39	5	79	0.01 (7:8:1)	>0.99
'Malvi Local' / 'ED 2398 A'	173	13	186	0.17 (15:1)	>0.80	33	43	4	80	0.54 (7:8:1)	>0.70
'Sarangpur Local' / 'ED 2398 A'	175	13	188	0.14 (15:1)	>0.90	31	39	3	57	0.73 (7:8:1)	>0.50
'Motia' / 'HG 110'	165	59	224	0.21 (3:1)	>0.80	22	47	18	87	0.93 (1:2:1)	>0.50
'Malvi Local' / 'HG 110'	172	47	219	1.47 (3:1)	>0.30	23	52	16	91	2.94 (1:2:1)	>0.20
'Sarangpur Local' / 'HG 110'	189	54	243	1.00 (3:1)	>0.30	17	41	12	70	2.90 (1:2:1)	>0.20
'Motia' / 'IWP 5019'	99	11	110	2.65 (15:1)	>0.10	34	32	7	73	1.99 (7:8:1)	>0.30
'Malvi Local' / 'IWP 5019'	138	8	146	0.15 (15:1)	>0.90	41	51	5	97	0.36 (7:8:1)	>0.80
'Sarangpur Local' / 'IWP 5019'	138	4	142	2.86 (15:1)	>0.05	31	39	6	76	0.51 (7:8:1)	>0.70
'Motia' / 'Line 1172'	120	32	152	1.27 (3:1)	>0.20	18	43	19	80	0.47 (1:2:1)	>0.70
'Malvi Local' / 'Line 1172'	102	32	134	0.09 (3:1)	>0.70	14	41	12	67	3.48 (1:2:1)	>0.10
'Sarangpur Local' / 'Line 1172'	190	73	263	1.07 (3:1)	>0.20	20	47	16	83	1.84 (1:2:1)	>0.30
R / R crosses											
'B 662' / 'ED 2398-A'	768	3	771	0.00 (255:1)	>0.99	The F3 families from the R /R crosses not tested					
'B 662' / 'HG 110'	656	8	664	0.55 (63:1)	>0.30						
'B 662' / 'IWP 5019'	449	3	452	0.88 (255:1)	>0.30						
'B 662' / 'Line 1172'	352	6	358	0.03 (63:1)	>0.80						
'ED 2398-A' / 'HG 110'	385	3	388	1.57 (63:1)	>0.20						
'ED 2398-A' / 'IWP 5019'	611	3	614	0.15 (255:1)	>0.90						
'ED 2398-A' / 'Line 1172'	379	4	383	0.67 (63:1)	>0.70						
'HG 110' / 'IWP 5019'	344	3	347	1.10 (63:1)	>0.20						
'HG 110' / 'Line 1172'	652	49	701	0.66 (15:1)	>0.30						
'IWP 5019' / 'Line 1172'	593	14	607	2.19 (63:1)	>0.10						

R: Resistant, S: Susceptible, Seg: Segregating for resistance.

Table 6. Segregation for seedling resistance to leaf rust pathotype 104-2 in F_2 plants / F_3 families derived from 'susceptible parent' / 'resistant parent' (S / R) and 'resistant parent' / 'resistant parent' (R / R) crosses.

Cross	F_2 plants No.					F_3 famIlles No.					
	R	S	Tot	χ^2	P	R	Seg	S	Tot	χ^2	P
S / R crosses											
Motia' / 'B 662'	48	11	59	1.27 (3:1)	>0.20	15	30	10	83	1.37 (1:2:1)	>0.50
Malvi Local' / 'B 662'	96	29	125	0.22 (3:1)	>0.50	16	41	21	78	0.85 (1:2:1)	<0.50
Sarangpur Local' / 'B 662'	121	45	166	0.39 (3:1)	>0.50	17	46	22	85	1.17 (1:2:1)	>0.50
Motia' / 'ED 2398 A'	77	4	81	0.24 (15:1)	>0.50	33	39	3	75	0.67 (7:8:1)	>0.70
Malvi Local' / 'ED 2398 A'	103	10	113	1.30 (15:1)	>0.20	39	57	8	104	1.76 (7:8:1)	>0.30
Sarangpur Local' / 'ED 2398 A'	78	5	83	0.01 (15:1)	>0.90	41	37	7	85	1.64 (7:8:1)	>0.30
Motia' / 'IWP 5019'	71	29	100	0.85 (3:1)	>0.30	16	52	21	89	3.09 (1:2:1)	>0.20
Malvi Local' / 'IWP 5019'	48	17	65	0.05 (3:1)	>0.80	12	32	15	59	0.72 (1:2:1)	>0.50
Sarangpur Local' / 'IWP 5019'	59	18	77	0.11 (3:1)	>0.70	16	36	13	65	1.03 (1:2:1)	>0.50
R / R crosses											
B 662' / 'ED 2398-A'	320	8	328	.65 (63:1)	>0.10	The F_3 families from R /R crosses not tested					
B 662' / 'IWP 5019'	285	21	306	0.20 (15:1)	>0.50						
ED 2398-A' / 'IWP 5019'	257	0	257	4.02 (63:1)	<0.05						

R: Resistant, S: Susceptible, Seg: Segregating for resistance.

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References

Anonymous, 2012. Progress Report of All India Coordinated Wheat & Barley Improvement Project 2011-12, Vol. III, *Crop Protection*. Sharma A.K. *et al.* (eds). Directorate of Wheat Research, Karnal, India, , pp. 259.

Mishra A.N., Kaushal K., Shirsekar G.S., Yadav S.R., Pandey H.N., 2005. Diverse sources of stem rust resistance identified in durum wheat. *Indian Phytopathology,* 58, pp. 335-338**.**

Mishra A.N., Kaushal K., Pandey H.N., 2001a. Appropriate pathotypes of stem rust and leaf rust for evaluating resistance in durum wheat and bread wheat. *Wheat Information Service,* 93, pp. 38-39.

Mishra A.N., Pandey H.N., Kaushal K., Varma P.K., Thakur R.S., 2001b. New germplasm of durum wheat with stem rust resistance. *Wheat Information Service,* 93, pp. 35-37.

Mishra A.N., Shirsekar G.S., Yadav S.R., Dubey V.G., Kaushal K., Sai Prasad S.V., Pandey H.N., 2009. Protocols for evaluating resistance to leaf and stem rusts in durum and bread wheats. *Indian Phytopathology,* 62(4), pp. 461-468.

Mishra A.N., Thakur R.S., Upadhyaya Y.M., 1989a. Genetic diversity in *Triticum durum* (Desf.) In: *I. Studies on stem rust resistance.* Cereal Rusts and Powdery Mildews Bulletin, 17, pp. 27-35.

Mishra A.N., Thakur R.S. Upadhyaya Y.M., 1989b. Genetic diversity in *Triticum durum* (Desf.) In: *II*. *Studies on leaf rust resistance.* Cereal Rusts and Powdery Mildews Bulletin 17, pp. 36-45.

Nayar S.K., Prashar M., Bhardwaj S.C., 1997. Manual of current techniques in wheat rusts*. Research Bulletin No. 2, Directorate of Wheat Research, Regional Station, Flowerdale, Shimla* - 171002, India, pp. 32.

Nayar S.K., Nagarajan S., Prashar M., Bhardwaj S.C., Jain S.K., Datta D., 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* - 171002, India, pp. 48.

Peterson R.F., Campbell A.B., Hannah A.E., 1948. A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. *Canadian J. Research,* 26(C), pp. 496-500.

Roelfs A.P., Singh R.P., Saari E.E., 1992. Rust Diseases of Wheat: *Concepts and methods of disease management.* Mexico, D.F.: CIMMYT, pp.81.