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Physiologic specialization of *Puccinia triticina* on wheat (*Triticum* species) in India

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ABSTRACT

During 2005–08 physiologic variation of brown rust of wheat (*Puccinia triticina* Eriks.) in India was studied. Samples of brown rust were obtained from *Triticum* species and triticale, grown in different parts of India. Pathotypes 121R63–1 (THTTS), 21R55 (PHTTL) and 21R63 (PHTKL) virulent on *Lr1, Lr3, Lr13, Lr16, Lr17, Lr23, Lr26* were most common among the 31 pathotypes identified in 2630 samples. Eight new pathotypes with 377R60–1 (MHTTS) virulent on *Lr28* were identified during this period. Though virulence for *Lr9* existed earlier, however, virulent phenotypes on *Lr9, Lr24, Lr25, Lr32, Lr39, Lr42* and *Lr45* were not observed in the field population of brown rust from India.

Key words: Leaf rust, Pathotypes, *Puccinia triticina*, Resistance, Virulence

Wheat rusts are the historic diseases. Brown (leaf) rust caused by *Puccinia triticina* Eriks. is of worldwide occurrence and probably causes more yield losses than other wheat rusts (Bhardwaj e*t al*. 2006b). In India it is prevalent in all the wheat-growing areas. Breeding for rust resistance and cultivation of rust resistant varieties is a very viable proposition to manage wheat rusts. However, frequently occurrence of new variants and shift in virulence pattern render resistant varieties susceptible (Bhardwaj e*t al*. 2005). Therefore, monitoring pathogenic variability warrants continuous analysis to replace the susceptible varieties with resistant ones. As a follow up action of pathotype situation, deployment of varieties with diverse resistance is put into practice for management of wheat rusts.

Variability in wheat rusts is being monitored since 1930 and latest results of pathotype distribution of *P. triticina* were documented in 2006 (Bhardwaj *et al*. 2006b). Present report aims at studying the virulence and diversity in *P. triticina* during 2005–08.

MATERIALS AND METHODS

Brown rust infected wheat samples (2 630) were collected or received from wheat disease trap plots, farmers' fields, breeders' plots and research farms both from regular and summer crop areas. Rust samples were established on 7 day-old seedling of susceptible 'Agra Local' variety when the primary leaves were fully opened. After a fortnight fresh uredospores from 'Agra Local' was used to inoculate the individual isolates on the sets of differentials (Nagarajan *et al.* 1983; Nayar *et al*. 1997). Five plants of each of the differentials were hill sown in aluminum trays or bread pans (29 cm×12×cm 7cm) using loam soil. Inoculation was done using a lancet needle. Inoculated plants were sprayed with a fine mist of water and placed overnight in dew chambers at 20±2°C, 100% relative humidity and 12 hr day light. To prevent powdery mildew infection, fine sulphur was dusted on the plants immediately after taking out of the dew chambers.

The trays with plants were then transferred onto the greenhouse bench and kept at 22± 2°C, in relative humidity 40–60% and illuminated at 15,000 lux for 12 hr. Infection types (resistant or susceptible) on the differentials were recorded 14 days after inoculation following modified method of Stakman *et al.* (1962). 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.

Wherever a sample showed different infection types other than the pathotypes earlier reported, single pustule isolations were taken and its novelty was further checked. To facilitate international communication, Indian pathotypes of *P. triticina* were also assessed on 5 host sets of *Lr* lines (McVey *et al.*

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2004) to know their international equivalents.

Per cent effectiveness of common *Lr* genes was also calculated on the basis of avirulent population. To know the performance of resistance genes or to detect further variation, 6–8 samples of a location were bulked and inoculated onto the material which included *Lr9, Lr19, Lr24, Lr 25, Lr 28, Lr 29, Lr 32, Lr 39, Lr 42* and *Lr 45*.

RESULTS AND DISCUSSION

Thirtyone pathotypes of *P. triticina* were identified in 2630 samples of brown rust from 17 states, one union territory and Nepal (Table 1). Pathotype 121R63-1, followed by 21R55, 21R63 and *Lr19* virulent pathotype 253R31 were most common. The first 3 pathotypes are virulent on *Lr1, Lr 3, Lr 10, Lr 13, Lr 14a, Lr 23, Lr 26, Lr 34* but avirulent on *Lr24* the common resistance genes in Indian wheat material.

During 2004–05, 785 samples were analyzed from 16 states, union territories and Nepal (Table 1). Seventeen pathotypes were detected in the samples analyzed and Uttar Pradesh had maximum diversity of pathotypes. More than 90% of the samples showed virulence for *Lr26*. Pathotype 121R63-1 was the most widespread and frequent in Chhatisgarh, Gujarat, Karnataka, Madhya Pradesh, Rajasthan and Tamil Nadu and accounted for more than 41.5% of the population. Pathotype 21R55 was also detected in many states and was predominant in Chandigarh, Delhi, Haryana, Himachal Pradesh, Punjab, Uttar Pradesh, Uttarakhand and Nepal and was identified in 38.8% of the samples. Pathotype 21R63 though picked up from 8 states but was not found in large numbers. The proportion of pathotype 253R31, identified in 2004 increased during the year and was intercepted in 29 samples. Two new pathotypes 29R45 (FHTKL) from Karnataka and 93R39 (KHTTL) from Uttar Pradesh were identified during the year. Pathotype 29R45 isolated from Karnataka has rendered some of the brown rust resistant lines susceptible and has virulence for many durum wheat lines and barley material also.

In Karnataka pathotype 121R63-1 was observed on 'DWR162', 'DWR195', 'HD2160', 'MACS2496', pathotype 109RR63 on HD2189, Pathotype 29R45 on HD2329, pathotype 253R31 on 'DWR162', 'HD2189', and 'NIAW34'. Brown rust infection on Triticale was found to be of pathotype 121R63-1. In Maharashtra pathotype 253R31 was observed on 'NI5439', 'NI5463', *Triticum sphaerococcum*, pathotype 109R63 on *T. persicum*, pathotype 49R37 on *T. carthlicum* and pathotype 121R63-1 on 'HD2189'. Pathotype 121R63-1 was identified on cultivars 'GW273', 'Lok1' and 'WH147' in Madhya Pradesh and Gujarat. From Punjab and Uttar Pradesh both pathotypes 121R63-1 and 21R55 were identified on 'PBW343'. In Uttarakhand pathotypes 21R55 and 21R63 were observed on 'HD2687', 'PBW343', pathotype 21R63 on 'HS240', 'HS295' and pathotype

Table 1 Pathotype distribution of *Puccinia triticina* in India during 2004–05

Epidem. area	State/country	No. of isolates analyzed	Pathotypes observed																
			5 R 27	1R 5	49R 37	69R 13	29R 45	109 R 63	109 R 31 -1	125 R 23 -1	121 R 63 - 1	121 R 55 - 1	253 R 31	109 R 31	21 R 55	21 R 63	0 R 9	93 R 15	93R 47
1	Tamil Nadu	70									70								
2	Karnataka	91	1				4	1			54		29		2				
	Maharashtra	63			12		1	1			30		18		1				
3	Gujarat	71		1							47	9			12	2			
	Chhattisgarh	6									6								
	Madhya Pradesh	51		1							39		3		8				
	Rajasthan	7									6				1				
4	Bihar	5		1			1								1	2			
5	Uttar Pradesh	81	1			1					31	3		1	38	6			
	Delhi	37									15				19	2			1
	Haryana	29				1					1	1			24	1	1		
	Punjab	98									7				86	5			
	Chandigarh	18													18				
6	Uttarakhand	65								1	13				36	14		1	
	Himachal Pradesh	82	1						1		5			13	50	12			
	Jammu and Kashmir	2								1	1								
Other country																			
	Nepal	9							1		2				5	1			
	Total	785	3	3	12	2	6		2	1	326	13	50	14	302	46	1	1	1

*5R37= 12-1, 1R5=12-2, 49R37=12-3, 69R13=12-4, 29R45=12-5,109R63=77-1, 109R31-1=77-2, 125R23-1=77-4,121R63-1=77-5, 121R55-1=77-6, 253R31=77-8, 109R31=77A, 21R55=104-2, 21R63=104-3, 0R9=106, 93R15=162A, 93R47=162-1

Table 2 Pathotype distribution of *Puccinia triticina* in India during 2005–06

Epidem. area	State/ country	No. of isolates analyzed	Pathotypes observed*																		
			5 R 37	1R 5	49R 37	69R 13	5R 45	109 R 31 -1	125 R 55	121 R 63 - 1	12 1R 55 - 1	253 R 31	109 R 31	21 R 55	21 R 63	21 R 31	29 R 23	93R 7	93R 9	29R 7
1	Tamil Nadu	201								198	1					1		1		
2	Karnataka	88					1			33		40	1	11	1		1			
	Maharashtra	23	1		2					6		13	1							
3	Gujarat	14						2		3		2		5				1		1
	Rajasthan	3	1											2						
4	Bihar	4												2	2					
	West Bengal	2												2						
5	Uttar Pradesh	49			1	1				22				23	2					
	Delhi	42								12	1			25	4					
	Haryana	20								2				16	2					
	Punjab	96			1				1	33			1	56	4					
	Chandigarh	15												13	2					
6	Uttarakhand	104								68	1			30	3				2	
	Himachal Pradesh	56		1				5		19				29	2					
	Jammu and Kashmir	1												1						
	Total	718	2	1	4	1	1	7	1	396	3	55	3	215	22	1	1	2	2	1

*5R37= 12-1, 1R5=12-2, 49R37=12-3, 69R13=12-4, 5R45=12-6,109R31-1=77-2, 125R55=77-3, 121R63-1=77-5, 121R55-1=77-6, 253R31=77-8, 109R31=77A, 21R55=104-2, 21R63=104-3, 21R31=104A, 29R23=104B, 93R7=162, 93R39=162-2, 29R7=162-3

121R63-1 on 'UP2425'.

More than 710 samples of brown rust of wheat were analyzed during 2005–06 from 15 states. Among the 18 pathotypes identified pathotype 21R55 was most widespread and was observed from 13 states, whereas pathotype 121R63-1 was found in 10 states (Table 2).Two new pathotypes 5R45 (FHRTQ) from Karnataka and 29R7 (KGTKL) from Gujarat were identified during the year. Barring Nilgiri hills, where pathotype 121R63-1 was most frequent, overall pathotype 21R55 was more prevalent in rest of India. In Karnataka and Maharashatra pathotype 253R31 was most frequent, followed by pathotypes 121R63-1 and 21R55. Five other pathotypes occurred in a few samples, whereas pathotypes 49R37 was observed in 2 samples from Maharashtra. In Gujarat among the 5 pathotypes identified 21R55 was the most common, followed by 121R63-1. In 2 samples each pathotypes 253R31 and 109R23-1 were observed, whereas 93R7 occurred in one sample. Pathotype 21R55 was found in 2 samples whereas pathotype 5R37 was observed in one sample only from Rajasthan. In east Indian states of Bihar and West Bengal, pathotype 21R55 was frequent, whereas pathotype 21R63 also occurred in equal frequency in Bihar.

In northern India though 5 pathotypes were recorded in Uttar Pradesh, however, pathotypes 21R55 and 121R63-1 were most frequent. Pathotype 21R63 was observed in 2, whereas pathotypes 49R37 and 69R13 in one sample each. Except for Uttarakhand where pathotype 121R63-1 was predominant, pathotype 21R55 was most frequent in remaining states. Except for Jammu and Kashmir pathotype 21R63 was also recorded everywhere. Barring pathotype 109R31-1 which occurred in 5 samples from Himachal Pradesh, one sample each of pathotypes 49R37, 125R55 and 109R31 from Punjab, one sample each of pathotype 121R55-1 from Uttarakhand and Delhi were also identified.

In Karnataka, pathotype 121R63-1 was observed on 'MACS2496', whereas 21R55 occurred on 'DWR162'. In Maharashtra pathotype 253R31 was isolated from 'Kenphad', *T. sphaerococcum*, 'MACS9', whereas 121R63-1 from 'HD2189' and 'Lok1' Pathotype 21R55 was identified from cultivars 'HD2733' and 'PBW343'. In Uttarakhand pathotype 21R55 was observed on 'HD2204', 'HD2329', 'HD2687', 'PBW343', 'PBW373', 'PBW502', 'UP2425', 'WH542', *T. sphaerococcum*, *T. boeoticum*, 121R63-1 on 'HD2687', 'HS295', 'HUW234', 'Lok1', 'UP1109', 'UP2338', 'VL616', 'VL738' and 'VL804'. Pathotype 21R55 was detected on 'PBW343', 'PBW373', 'PBW502' whereas 121R63-1 on 'HD2329', 'HD2204', 'PBW34', 'UP2338', 'PBW343' and 'UP2338' was found to harbour pathotype 21R55 and 'PBW502' had pathotype 121R63 in Haryana. From Himachal Pradesh, pathotype 21R55 occurred on 'HS420', 'PBW343', 'VL738', 'WH542' whereas 121R63-1 on 'VL832'.

During 2006–07, 812 samples were analyzed. Seventeen pathotypes were identified from 14 states of India (Table 3). Pathotype 21R63 was most widespread, followed by 121R63-1 and 21R55. In Nilgiri hills (Tamil Nadu) pathotype 121R63-1 was most predominant, whereas it was 21R63 in Karnataka and Maharashtra. Other pathotypes like 5 R37, 21R55, 121R55-1, 109R23 and 109R63 were picked up in a few samples from Karnataka, Maharashtra and Madhya

Pradesh but their proportion has reduced as compared to previous years. Similarly in Gujarat, Rajasthan and Madhya Pradesh, pathotype 21R63 was most common, followed by 121R63-1 and 21R55. Maximum prevalence of pathotype 21R55 was observed in Bihar. Two samples from Jharkhand were of pathotypes 109R31-1 and 121R63-1. Predominance of pathotype 21R55 was observed in Uttar Pradesh, Uttarakhand, Haryana, Punjab and Himachal Pradesh, whereas pathotypes 21R63 and 121R63-1 were also recorded in substantial number of samples. Other pathotypes, like 121R55-1, 109R31-1, 69R13, 5R37, 109R63 and 93R7 were observed in very low frequency.

In Karnataka, pathotype 21R63 was observed on 'Amrut', 'DWR39', 'DWR195', 'Khapli', 'NI5439', 'N59', whereas from Maharashtra on 'HD2189', 'HD2501', 'MACS 2496', *T. turgidum, T. carthelicum*. Pathotype 121R63-1 was also

Table 3 Pathotype distribution of *Puccinia triticina* during 2006–07

Epidem. area	State/union territory	Samples analyzed	Pathotypes observed																
			5 R 37	69R 13	29 R 45	109 R 63	109 R 31 -1	121 R 63 - 1	121 R 55 - 1	253 R 31	109 R 31	109 R23	21 R R 55	21R 63	13 R 27	93 R 7	93R 15	93R 7	93R 39
1	Tamil Nadu (Wellington)	86	1					85											
2	Karnataka	128				1		11	1	3		1	8	103					
	Maharashtra	162			1	1	1	33		2	1		1	122					
3	Gujarat	23						8					7	8					
	Madhya Pradesh	78				3		28		1	1		6	37	2				
	Rajasthan	25	1					7	1				3	13					
4	Bihar	28		1			4	6					14	3					
	Jharkhand	2					1	1											
5	Uttar Pradesh	88					1	31	2				37	17					
	Delhi	10						4	2				4						
	Haryana	9											6	3					
	Punjab	82	2	1		1		6	1				61	10					
6	Uttarakhand	68		1				14	1				27	21			1	1	2
	Himachal Pradesh	23						3					17	1		1			1
	Total	812	4	3	1	6	7	237	8	6	2	1	191	338	2	1	1	1	3

*5R37=12-1, 69R13=12-4, 29R45= 12-5, 109R63=77-1, 109R31-1=77-2, 121R63-1=77-5, 121R55-1=77-6, 253R31=77-8, 109R31=77A, 109R23=77A-1, 21R55=104-2, 21R63=104-3, 13R27=108, 93R7=162, 93R15=162A, 93R47=162-1, 93R39=162-2.

Table 4 Pathotype distribution of *Puccinia triticina* during 2007–08

State/union territory	Samples analyzed	Pathotypes observed[8]																				
		5R 37	49R 37	69 R 13	29 R 45	93R 45	49R 45	5 R 13	109 R 31	121 R 63-1	121 R 55-1	121 R 60-1	377 R 60-1	109 R 23-1	21 R 55	21 R 63	21R 31	29 R 23	93 R 7	93 R 47	93 R 39	93 R 15
Tamil Nadu (Wellington)	28								1	17		8	2									
Karnataka	79	1		8	24	3		3	1	9	2	4			7	11			1	3	1	1
Maharashtra	35			5				3		13		3			5		1	2				3
Gujarat	1								1													
Uttar Pradesh	13									2					11							
Delhi	8								1	2					4	1						
Punjab	35									5					21	9						
Haryana	1														1							
Uttarakhand	42		1				1			30					9				1		1	
Himachal Pradesh	72				1					3				1	47	12			4		4	
Total	315	1	1	13	25	3	1	6	4	81	2	15	2	1	105	33	1	2	6	3	6	4

*5R37=12-1,49R37=12-3, 69R13=12-4, 29R45= 12-5, 93R45=12-7,49R45=12-8,5R13=12A, 109R31-1=77-2, 121R63-1=77-5, 121R55-1=77-6,121R60-1=77-9,377R60-1=77-10,109R23=77A-1, 21R55=104-2, 21R63=104-3,21R31=104A, 29R23=104B, 93R7=162, 93R15=162A, 93R47=162-1, 93R39=162-2.

recorded on 'DWR 162', 'HD2189', 'Lok1', 'NI5439', 'Raj4083' from Maharashtra. In Madhya Pradesh pathotype 21R63 was identified on 'Lok1', 'Pissi Local', 'Sujata' and 'WH 147'. From Punjab both pathotypes 21R55 and 121R63-1 were observed on 'PBW343', 'PBW373' and 'PBW502', 21R55 was also recorded on 'CPAN3004' and pathotype 121R63-1 on 'HD2329'. Brown rust samples of 'Lok1' from Rajasthan yielded pathotype 21R63. In Bihar pathotype 21R55 was identified on 'HD2733', 'Janak', 'PBW 343', 109R31 on 'HDR77' and 121R63-1 on 'Janak'.

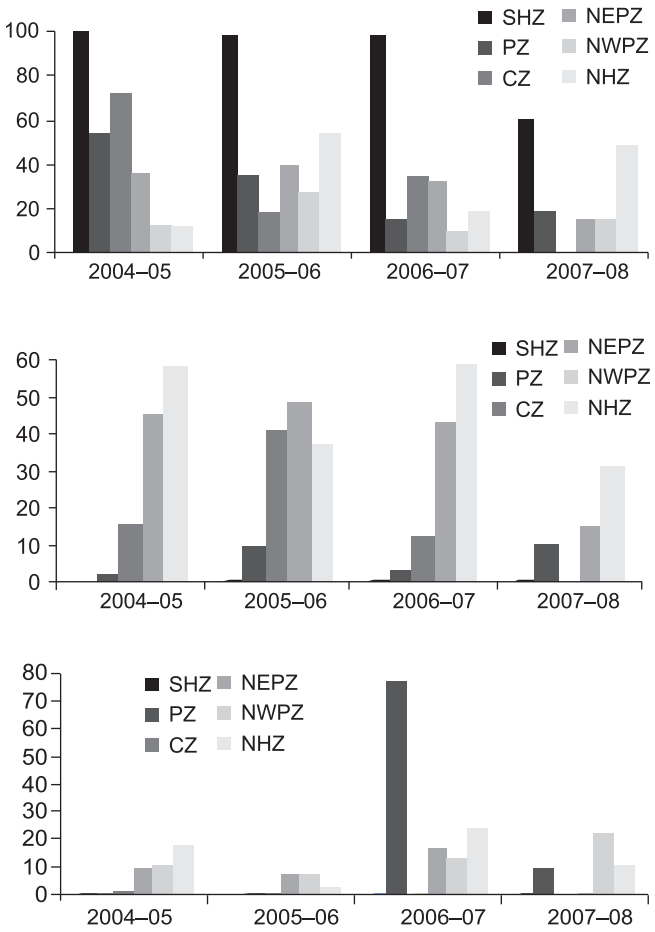
During 2007–08, 315 samples of brown rust of wheat were analyzed for knowing the pathotype situation in 10 states of India (Table 4) Twenty pathotypes including 4 new 93R45 (FHTTL),49R45 (FHRPQ),121R60-1 (MHTTS) and 377R60-1 (MHTTS) were identified during the year. Pathotype 377R 60-1 is virulent on *Lr28*, which earlier used to confer brown rust resistance in India. Pathotype 21R55 was picked up in maximum number of samples, followed by 121R63-1 and 21R63. These 3 predominant pathotypes were detected in samples from 8 states. Maximum diversity was found in Karnataka where 15 pathotypes were identified, followed by Maharashtra and Himachal Pradesh with 8 and 7 pathotypes, respectively.

In Nilgiri hills, pathotype 121R63-1 was most common followed by new pathotype 121R60-1. In Karnataka pathotype 29R45 was most frequent, followed by 21R63, 121R63-1, 69R13 and 21R55. In Maharashtra, pathotype 121R63-1 was most common, followed by pathotype 69R13. Maximum prevalence of 21R55 was recorded in Himachal Pradesh and Punjab. Remaining pathotypes were observed in low frequency.

Wheat lines 'HW5207' and 'HW5212' from Nilgiri hills harboured a new pathotype 377R60-1 which is virulent on earlier known resistance gene *Lr28.* Pathotype 29R45 was observed on 'MACS 2846', 'N 59' and 'NIDW15' in Karnataka. In Maharashtra pathotype 121R63-1 occurred on *T. sphaerococcum,* 'UAS310', pathotype 69R13 on 'NIDW2951', pathotype 93R15 on 'N 59' and 121R60-1 on UAS310. In Gujarat pathotype 109R31 was identified on 'Lok1'. Pathotype 121R63-1 was identified on 'PBW343 'in Himachal Pradesh, whereas pathotype 21R55 was detected on 'PBW343', 'PBW373' from Uttar Pradesh. International equivalents of 31 pathotypes observed in India during 2005–08 are given in Table 5.

Among the 3 most predominant pathotypes, there had been predominance of pathotype121R63-1 in different parts of India during these years and it occurred in nearly all the samples from southern hills zone (Fig 1) Pathotype 21R55 was more prevalent in north, central parts and in some years in Peninsular India (Fig 2). Frequency of pathotype 21R63 was the minimum among the 3 predominant pathotypes. However, during 2006–07 there was unusual built-up of this pathotype in Peninsular zone (Fig 3).

Evaluation of resistance genes/lines against field isolates



Figs 1–3 **1.** Frequency of pathotype 12R63-1 (77-5) in different zones (SHZ=Southern hills zone, PZ= Peninsular zone, CZ=Central zone, NEPZ=North-eastern plains zone, NWPZ = North-western plains zone, NHZ= Northern hills zone) during 2004–08. **2.** Frequency of pathotype 21R55 (104-2) in different zones* during 2004–08. **3.** Frequency of pathotype 21R63 (104-3) in different zones during 2004–08

revealed that *Lr9, Lr24, Lr25, Lr32, Lr39, Lr42* and *Lr45* were resistant to the Indian population of brown rust of wheat. Effectiveness of common resistance genes is depicted in Table 6. *Lr3, Lr13, Lr14a* have become ineffective whereas whereas *Lr1, Lr23* and *Lr26* are also not of much use. *Lr 10* also does not offer much protection. Though the virulence for *Lr9* has been recorded earlier in India, however, *Lr9* was effective against the brown rust during 2005–08. Now *Lr19* has become susceptible in Karnataka, Maharashtra and Madhya Pradesh, *Lr28* in Tamil Nadu and Karnataka but both the *Lr* genes remain effective to brown rust of wheat in rest of India. Pathotypes THTTS, THTTL and PHTKL were common (Table 5), during these years. Pathotype 21R55 was mostly observed on durum wheat material (*T. durum* Desf.) and triticale. Some of the durum lines harboured pathotype 21R63 also.

During 2005–08, though 31 pathotypes were identified

in 2, 630 samples however, the population was dominated (91%) by 4 pathotypes, viz 121R63-1 (THTTS), 21R55 (PHTTL), 21R63 (PHTKL) and 253R31-1 (TGTTQ) comprising 39.6, 30.7, 16.6 and 4.2%, respectively of brown rust population. In the United States of America, pathotypes TDBJG, TDBGG, and TDBJH were frequent (Kolmer *et al.* 2008), indicating that the population of two countries is entirely different. Eight new virulent pathotypes were recorded, of which one 377R60-1 (MHTTS) has rendered *Lr28* susceptible, which was earlier effective against brown rust in India (Bhardwaj *et al.* 2006b). Pathotype 29R45 (FHTKL) isolated from Karnataka has rendered some of the brown rust resistant lines susceptible and has virulence for many durum wheat lines and barley material too (Bhardwaj *et al.* 2006a). Virulence on common resistance genes *Lr23* and *Lr26* in Indian wheat material has increased. Now there are 15 pathotypes virulent on *Lr23*, 18 on *Lr26* and 9 pathotypes with combined virulence for *Lr23* and *Lr26.*

Table 5 International equivalents of Indian pathotypes* observed during 2005–08

Indian pathotype	International equivalent
5R37 (12-1)	FHPTL
1R5 (12-2)[a]	FGTTL
49R37 (12-3)	FHTTQ
69R13 (12-4)	FGTTN
29R45 (12-5)	FHTKL
5R45 (12-6)	FHRTQ
93R45 (12-7)	FHTTL
49R45 (12-8)	FHRPQ
5R13 (12A)[b]	FGTTL
109R63 (77-1)	THTTQ
109R31-1 (77-2)[c]	TGTTQ
125R55 (77-3)	THTTS
125R23-1 (77-4)[d]	TGTTQ
121R63-1 (77-5)	THTTS
121R55-1 (77-6)	THTTQ
253R31 (77-8)[e]	TGTTQ
121R60-1 (77-9)[f]	MHTTS
377R60-1(77-10)[g]	MHTTS
109R31 (77A)[h]	TGTTQ
109R23 (77A-1)[i]	TGTTQ
21R55 (104-2)	PHTTL
21R63 (104-3)	PHTKL
21R31 (104A)	MGTGL
29R23 (104B)	MGTQN
0R9 (106)	BBBBB
13R27 (108)	SGKTB
93R7 (162)[j]	KGTTL
93R15 (162A)[k]	KGTTL
93R47 (162-1)[l]	KHTTL
93R39 (162-2)[m]	KHTTL
29R7 (162-3)	KGTKL

* [a] virulent on *Lr23*, [b]avirulent on *Lr23*, [c] virulent on Thew, [d] avirulent on Thew,[e] virulent on *Lr19* and Thew, [f] avirulent on *Lr28*, [g]virulent on *Lr28*,[h]virulent on Thew,[I] virulent on Thew, [j] avirulent on Thew, [k]avirulent on *Lr26*, [l]virulent on *Lr26*,[m]avirulent on Thew

Population of pathotype 21R55 has increased in northern India but it does not occur in Nilgiri hills. It is indicative of the fact that some additional foci of rust infection other than hilly areas of Tamil Nadu are functional. Some active foci of infection may be functional in areas of Karnataka and Maharashtra where the population is quite diverse and different and at the same time similar to many wheat-growing areas. Earlier role of Karnataka in epidemiology of black rust of wheat was observed in black rust also (Bhardwaj *et al.* 1989). Built-up of population of pathotype 21R55 has been recorded in earlier surveys also (Bhardwaj *et al.* 2006b). No virulence existed in Pakistan for *Lr9, Lr19* and *Lr28* (Fayyaj *et al*. 2008). Virulence for *Lr9, Lr11, Lr18, Lr24* and *Lr 26* were common in United States (Kolmer *et al*. 2008). Though virulence for most of these resistance genes except *Lr24* occurred in India, however, virulence for *Lr9* was not recorded during this period. Virulence for *Lr24* and *Lr28* has been reported in Slovakia during 1994–2004, whereas *Lr2a, Lr9, Lr19, Lr23, Lr24* and *Lr28* were found effective in Hungary (Manninger, 2006). In Czech Republic *Lr9* and *Lr19* were effective, whereas virulence for *Lr24* and *Lr28* existed during 2001–04 surveys. Among these only *Lr24* is effective under Indian conditions.

Since a rust-resistant variety generally lasts for 3–5 years, therefore, identification of new pathotypes and pathotype

Table 6 Effectiveness* of *Lr* genes in Indian wheat material against brown rust in different areas during 2005–08

Area	States	Effectiveness of resistance genes					
		Lr1	*Lr10*	*Lr19*	*Lr23*	*Lr26*	*Lr28*
1	Tamil Nadu	0.2	0.5	100	0.5	0.5	99.5
2	Karnataka Gujarat Maharashtra	10.8	45.6	86.7	19.5	19.2	100
3	Chhattisgarh, Madhya Pradesh, Rajsthan	3.5	44.1	97.6	6.4	3.5	100
4	Bihar, Jharkhand, Asom, West Bengal	7.3	68.2	100	2.4	14.6	100
5	Uttar Pradesh, Haryana, Punjab, Chandigarh	1.7	73.6	100	2.8	1.2	100
6	Jammu and Kashmir, Himachal Pradesh	4.6	61.0	100	6.6	5.8	100
7	Nepal	0	60.0	100	1.1	1.1	100

**Lr3, Lr13, Lr14a* were ineffective whereas *Lr9, Lr24* were effective against brown rust of wheat during 2005–08

distribution becomes an integral part of anticipatory breeding. In addition to the vertical resistance genes (Datta *et al*. 2008), slow rusting, durable resistance genes like *Lr34, Lr46* and incorporation of minor resistance genes (Singh and Heurto Espino, 2004) will confer lasting resistance against brown rust of wheat and also reduce the threat of new variants.

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