



Patterns of physiologic diversity of *Puccinia triticina* on wheat in Indian subcontinent during 2008-2013

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ABSTRACT

Brown (leaf) rust of wheat, caused by *Puccinia triticina* was widely distributed in all the wheat growing areas. To identify new pathotypes and determine the virulence pattern of *Puccinia triticina*, rust samples were analyzed from the wheat growing areas in India, Bangladesh, Bhutan and Nepal. A new pathotype 93R57 (104-4=NHKSP) was identified from Arki area of Solan district in Himachal Pradesh. Among the 37 pathotypes identified in 2124 samples analyzed during 2008-2013, four predominant pathotypes 121R63-1(77-5=THTTS), 21R55 (104-2=PHTTL), 121R60-1(77-9=MHTTS) and 21R63 (104-3=PHTKL) accounted for 68% of the population. These four pathotypes have virulence to *Lr1*, *Lr3*, *Lr10*, *Lr11*, *Lr12*, *Lr13*, *Lr14a*, *Lr16*, *Lr17*, *Lr23*, *Lr26*. Virulence on *Lr19* was found in 7 samples only whereas the proportion of pathotype 121R60-1 (77-9=MHTTS) has increased recently in Tamil Nadu and was identified in about 40% of the samples from that area. Virulent pathotypes on *Lr9*, *Lr24*, *Lr25*, *Lr32*, *Lr39* and *Lr45* were not observed in the field population of brown rust in the Indian subcontinent during the last five cropping seasons.

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

Rusts are constant threat to wheat production throughout the world. Brown (leaf) rust of wheat caused by *Puccinia triticina* is a major biotic constraint in wheat production. It is of widespread occurrence and probably causes more damage than any other wheat rust (Samborski 1985). Most of the brown rust resistance genes derived from the bread wheat are susceptible to brown rust. Even resistance genes *Lr9*, *Lr19*, *Lr28* derived from alien sources could not become durable and new virulences emerged much before the commercial use of these resistance genes (Bhardwaj *et al.* 2005, Nayar *et al.* 2003, Bhardwaj *et al.* 2010a). In India, brown rust generally appears in late December in Peninsular India whereas in the main wheat belt of Northern and Central India during the first fortnight of January. Cultivating resistant varieties of wheat is the most economic, ecologically safe and effective way to manage brown rust. However, frequent emergence of new

virulent pathotypes renders resistant varieties susceptible (Bhardwaj *et al.* 2005). On an average, field life of a rust resistant wheat variety is about 5 years (Sawhney 1995).

To cope up with the shifting virulence pattern, monitoring of pathotypes in initial stages, development and deployment of rust resistant varieties is a continuous pursuit. Variability in wheat rusts is being monitored in India since 1920's and latest results of pathotype distribution of *P. triticina* were documented in 2010 (Bhardwaj *et al.* 2010b). The observations on physiologic specialization in rust pathogens are being reported since 1930 in India. Patterns of physiologic diversity observed during 2008-2013 in the Indian subcontinent are described in this publication.

MATERIALS AND METHODS

Brown rust infected samples were collected/received from different wheat growing areas of India, Bangladesh, Bhutan and Nepal during 2008-13. These samples were established on seven day old seedlings of Agra Local (local bread wheat). After a fortnight, fresh uredospore inoculum collected from individual sample was used to inoculate host lines of three sets of differentials. The pathotype in different wheat brown rust samples were designated using the

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Table 1 The revised composition of sets of differentials for the identification of pathotypes of *Puccinia triticina* on wheat in India

Set 0	Set A	Set B
IWP 94 (<i>Lr23+</i>)	<i>Lr14a</i>	Loros (<i>Lr2c</i>)
Kharchia Mutant	<i>Lr24</i>	Webster (<i>Lr2a</i>)
Raj 3765	<i>Lr18</i>	Democrat (<i>Lr3a</i>)
PBW 343	<i>Lr13</i>	Thew (<i>Lr20</i>)
UP 2338	<i>Lr17a</i>	Malakoff (<i>Lr 1</i>)
K 8804	<i>Lr15</i>	Benno (<i>Lr26</i>)
Raj 1555	<i>Lr10</i>	HP1633 (<i>Lr 9+</i>)
HD 2189	<i>Lr19</i>	
Agra Local	<i>Lr28</i>	

binomial notation system of nomenclature (Nagarajan *et al.* 1983) and modified (Table 1) to account for the fast evolving pathotypes of *P. triticina* in India (Bhardwaj *et al.* 2012). All the standard greenhouse procedures of inoculation, incubation, maintenance and recording of infection types were followed (Stakman *et al.* 1962, Nayar *et al.* 1997). For the better communication with the international community, equivalent designation of the identified pathotypes according to the North American nomenclature system (Kolmer *et al.* 2013) are also deciphered. It would help in understanding and translating the virulence pattern by the Scientists of other countries in the world.

Samples of brown rust were established on Agra Local grown in plastic pots of 4 inch size. Sets of differentials were grown in aluminum bread pans (29 cm long × 12 cm wide × 7 cm deep size) in a mixture of fine loam and farmyard manure (3:1). Week old seedlings were inoculated using a lancet needle. Plants were then sprayed with a fine mist of water and placed overnight in dew chambers at 22 + 2°C. Saturated relative humidity and 12 hours of daylight were maintained. The plants were then transferred to a greenhouse where temperature of 22 + 2 °C, relative humidity of 40-60% and illumination of about 15000 lux for 12 hr were maintained. Infection types (low or high) on the test lines were recorded 14 days after inoculation (Stakman *et al.* 1962) with some modifications. Infection types 0 to 2 (small hypersensitive flecks to small-moderate uredial pustules with chlorosis) were considered low indicating resistance and infection types of 3 to 4 (moderate to large uredial pustules without chlorosis) were considered high indicating susceptibility. Infection type 33+ was classified where both 3 and 3+ pustules were found together. Pathotypes were identified by comparing the reaction matrix with the known pathotypes. When the reaction matrix did not resemble with the known pathotypes, these were designated as new pathotype.

RESULTS AND DISCUSSION

To know the distribution of pathotypes, 2124 samples of brown rust of wheat were analyzed during 2008-2013. Among the thirty seven pathotypes identified (Table 2),

Table 2 International equivalents of Indian pathotypes* observed during 2008-13

Indian pathotype	International equivalent	Indian pathotype	International equivalent
5R5(12)	FGTTB	121R60-1 (77-9) ^l	MHTTS
5R37 (12-1)	FHPTL	377R60-1(77-10) ^m	MHTTS
1R5 (12-2) ^a	FGTTL	125R28(77-11)	MGTTT
49R37 (12-3)	FHTTQ	109R23 (77A-1) ⁱ	TGTTQ
69R13 (12-4)	FGTTN	17R23(104)	PGTKL
29R45 (12-5)	FHTKL	21R31-1(104-1)	PGTTL
5R45 (12-6)	FHRTQ	21R55 (104-2)	PHTTL
93R45 (12-7) ^c	FHTTL	21R63 (104-3)	PHTKL
49R45 (12-8)	FHRPQ	93R57(104-4)	NHKSP
93R37(12-9) ^d	FHTTL	21R31 (104A)	MGTGL
5R13 (12A) ^b	FGTTL	29R23 (104B)	MGTQN
45R31(77)	TGTKQ	45R3(107)	JBGHQ
109R63 (77-1) ^e	THTTQ	45R35(107-1)	JCGKG
109R31-1 (77-2) ^g	TGTTQ	57R27(108-1)	SGTKS
125R55 (77-3) ^j	THTTS	93R7 (162) ⁿ	KGTTL
125R23-1 (77-4) ^h	TGTTQ	93R15 (162A) ^o	KGTTL
121R63-1 (77-5) ^k	THTTS	93R47 (162-1) ^p	KHTTL
121R55-1 (77-6) ^f	THTTQ	93R39 (162-2) ^q	KHTTL
253R31 (77-8) ^e	TGTTQ		

*^aavirulent on *Lr23*, ^bavirulent on *Lr23*, ^cvirulent on Thew, ^davirulent on Thew, ^eavirulent on *Lr23*, ^fvirulent on *Lr23*, ^gvirulent on Thew, *Lr23*, ^havirulent on *Lr23*, ⁱavirulent on *Lr23*, virulent on *Lr19* and Thew, ^javirulent on *Lr23*, ^kvirulent on *Lr23*, ^lavirulent on *Lr28*, ^mvirulent on *Lr28*, ⁿavirulent on Thew, ^ovirulent on Thew, ^pvirulent on Thew, ^qavirulent on Thew

pathotype 121R63-1(77-5) followed by 21R55 (104-2), 121R60-1(77-9) and 21R63 (104-3) were most predominant. In the later part, the proportion of 21R55 (104-2), 21R63 (104-3) has drastically reduced whereas 121R60-1(77-9) has increased. Decline in the population of 121R63-1(77-5) is less steep in comparison to aforesaid two pathotypes (Fig 1). These pathotypes were virulent to *Lr1*, *Lr3*, *Lr10*, *Lr13*, *Lr14a*, *Lr23*, *Lr26*, whereas behaved differentially on *Lr2a*, *Lr15* and *Lr20* and accounted for 68% of the sampled population (Table 3). When compared as a group of pathotypes, 77 group was the most predominant, observed in about 50% of the samples followed by 104, 12 and 162 group (Fig 2). Pathotype group 77 has evolved very fast over the years and has now 15 members in total. A perusal of variability in each group (Table 2), reveals that 77 group was most variable in which 12 pathotypes were identified, whereas 11, 7, 4 pathotypes were identified in 12, 104 and 162 groups of pathotypes, respectively during 2008-2013.

New pathotype identified

A new pathotype of *P. triticina* was identified in few samples of last year from district Solan in Himachal Pradesh. This pathotype appears to differ from 21R63 (104-3) in avirulence to *Lr3* and *Lr2a*. The new pathotype has been designated as 93R57 and has been added to the National repository at Flowerdale, Shimla, India. Resistance sources

Table 3 Avirulence/virulence structure and frequencies of predominant races of *Puccinia triticina* in Indian wheat fields

Pathotype	Avirulence/virulence structure	Percentage
121R63-1(77-5)	<i>Lr9, Lr 18*, Lr 19, Lr 24, Lr 25, Lr 28, Lr 29, Lr 32, Lr39, Lr 40, Lr 45/ Lr 1, Lr 2a, Lr 2b, Lr 2c, Lr 3, Lr 10, Lr 11, Lr 12, Lr 13, Lr 14a, Lr 14b, Lr 14ab, Lr 15, Lr 16, Lr 17a, Lr 20, Lr 21, Lr 22a, Lr 22b, Lr 23, Lr 26, Lr 27+31, Lr 30, Lr 33, Lr 34, Lr 35, Lr 36, Lr 37, Lr 38, Lr 42, Lr 43, Lr 44, Lr 48, Lr 49</i>	33.4
21R55 (104-2)	<i>Lr9, Lr 10*, Lr 13*, Lr 15, Lr 19, Lr 20, Lr 24, Lr 25, Lr 28, Lr 29, Lr 32, Lr 36, Lr39, Lr 40, Lr 43, Lr 45/ Lr 1, Lr 2a*, Lr 2 Lr b, Lr 2c, Lr 3, Lr 11, Lr 12, Lr 14a, Lr 14b, Lr 14ab, Lr 16, Lr 17a, Lr 18, Lr 21, Lr 22a, Lr 22b, Lr 23, Lr 26, Lr 27+31, Lr 30, Lr 33, Lr 34, Lr 35, Lr 37, Lr 38, Lr 42, Lr 44, Lr 48, Lr 49</i>	19.4
121R60 (77-9)	<i>Lr2a, Lr2b, Lr2c, Lr9, Lr19, Lr24, Lr25, Lr28, Lr32, Lr39, Lr45/Lr1, Lr3, Lr10, Lr11, Lr12, Lr13, Lr14a, Lr14b, Lr14ab, Lr15, Lr16, Lr17a, Lr17b, Lr18, Lr20, Lr21, Lr22a, Lr22b, Lr23, Lr26, Lr27+31, Lr30, Lr33, Lr34, Lr35, Lr36, Lr37, Lr38, Lr42, Lr44, Lr46, Lr48, Lr49</i>	9.3
21R63 (104-3)	<i>Lr9, Lr 10*, Lr 13*, Lr 15, Lr 19, Lr 24, Lr 25, Lr 28, Lr 29, Lr 32, Lr 36, Lr39 Lr 40, Lr 43, Lr 45/ Lr 1, Lr 2a*, Lr 2b, Lr 2c, Lr 3, Lr 11, Lr 12, Lr 14a, Lr 14b, Lr 14ab, Lr 16, Lr 17a, Lr 18, Lr 20, Lr 21, Lr 22a, Lr 22b, Lr 23, Lr 26, Lr 27+31, Lr 30, Lr 33, Lr 34, Lr 35, Lr 37, Lr 38, Lr 42, Lr 44, Lr 48, Lr 49</i>	7.2

against the new pathotype have been identified.

Pathotype distribution

During 2008-09, more than 580 samples were analyzed during this period. Twenty-seven pathotypes were identified from 15 states of India. Fourteen pathotypes each were detected both from Karnataka, Maharashtra and Madhya Pradesh (Table 4). Six pathotypes were identified in Gujarat and Punjab. In samples from Wellington (Tamil Nadu) and Uttarakhand five pathotypes were identified.

Pathotype 21R55 (104-2) was found the most prevalent followed by 121R63-1(77-5). Both these pathotypes have been increasing in their prevalence and distribution since last decade. Pathotype 21R63 (104-3), which was also increasing in proportion, has now declined in frequency but was spread over ten states. Two groups of pathotypes namely 12 and 162 group pathotypes have recently been building up in the Peninsular and Central parts of the country. Though pathotype 121R63-1(77-5) remained the most prevalent in this region but there has been an increase

Table 4 Pathotype distribution of *Puccinia triticina* during 2008-09

State/ Union Territory	Samples analyzed	Pathotypes observed														
		12-4	12-5	12-7	77-1	77-2	77-5	77-9	77-10	104-2	104-3	104A	162	162-1	192A	162-2
Wellington (Tamil Nadu)	87						15	59	10							-
Karnataka	118	20	9	18	1		21	10		1	3		1	6	23	-
Maharashtra	93	3	2	2	3	4	28	2		3	4			6	33	-
Gujarat	11				3		2				1	1			2	-
Madhya Pradesh	53	3		1	9	3				7	6	2	1	2	12	2
Chhattisgarh	3						1			1						
Bihar	10						1			6	3					
Jharkhand	2						1			1						
Uttar Pradesh	25				1		4			15	5					
Delhi	4									4						
Haryana	7									6	1					
Punjab	86	1		2	1		3			67	12					
Jammu and Kashmir	2									1						
Himachal Pradesh	25						4			11	10					
Uttarakhand	55						25			24	4		1	1		
Total	581	27	11	23	18	7	105	71	10	147	49	3	3	15	70	3

Besides this, pt. 49R45 was picked up in Karnataka in three samples, one sample from Wellington and two samples from Gujarat of 109R31, two samples of 121R55-1 from Wellington, four samples of 17R23 (three from MP and one from J&K), 1 isolate each of 5R37 (12-1), 49R37 (12-3), 5R45 (12-6), 5R13 (12A), 125R55(77-3), 29R23 (104B), 57R27 (108-1), were also picked up from Karnataka, Madhya Pradesh, Maharashtra, Madhya Pradesh, Karnataka, Maharashtra, Maharashtra, respectively. #69R13=12-4, 29R45= 12-5, 5R13=12A, 109R31-1=77-2, 121R63-1=77-5, 121R55-1=77-6, 17R23=104, 21R55=104-2, 21R63=104-3, 21R31=104A, 29R23=104B, 93R7=162, 93R15=162A, 93R47=162-1, 93R39=162-2.

Table 5 Pathotype distribution of *Puccinia triticina* in India during 2009-10

State/ Union Territory	Samples analyzed	Pathotypes observed										
		12-4	12-7	77-1	77-5	77-9	77-11	104-2	104-3	162-1	162-2	
Wellington (Tamil Nadu)	16*				11	5						
Karnataka	81*	3	25	2	18	18		2	1	8	4	
Maharashtra	36*	1	6	2	14	1	9	2		1		
Gujarat	13*				1				12			
Madhya Pradesh	15*	1	1		3	2	2	2	1	1	2	
Rajasthan	1				1							
West Bengal	20				6			7	7			
Bihar	6							3	3			
Jharkhand	6				2			4				
Uttarakhand	34				3			23	8			
Delhi	3				1			2				
Punjab	5				3			1	1			
Uttar Pradesh	7*				1			2	3	1		
Himachal Pradesh	14*				4			5	5			
Total	257+28*	5	32	4	68	26	23	53	29	11	6	

*1R5(12-2)= 1 each from Gujarat and MP, 29R45(12-5) = 1 from Karnataka and 2 from Maharashtra, 49R45= 1 each from Karnataka and MP, 93R37-1(12-9) = 1 each from Uttarakhand and M.P., 121R55-1(77-6) = 4 from Wellington(Tamil Nadu), 125R23-1(77-4) = 1 from M.P., 377R60-1(77-10) = 2 from Wellington and 1 from Karnataka, *New pathotype* *104-4 from HP, 93R15(162A) = 2 from Karnataka and 1 from MP and 1 sample each of 109R31-1(77-2), 21R31-1(104-1), 29R23 (104B), 93R7 (162) were also detected from MP, Maharashtra, MP and UP. *12-1(5R37), 12-3(49R37), 12-5(29R45), 12A(5R13), 77(45R31), 77-1(109R63), 77-2(109R31-1), 77-3(125R55), 77-4(125R23-1), 77-5(121R63-1), 77-6(121R55-1), 77-9(121R60-1), 77-10(377R60-1), 77-11(125R28), 77A-1(109R23), 104-1(21R31-1), 104-2(21R55), 104-3(21R63), 104-4(93R57), 104A(21R31), 104B(29R23), 108-1(57R27), 162(93R7), 162-1(93R47), 162-2(93R39), 162A(93R15)

in pathotypes belonging to both 12 and 162 groups. Pathotype 93R15 (162A) was widespread in Peninsular India. Pathotypes 93R45 (12-7) and 49R45 (12-8) were also picked up in a few samples. In the North Eastern parts of the country, both 121R63-1(77-5) and 21R55 (104-2) were predominant in the states of Jharkhand, Bihar, Chhattisgarh and Uttar Pradesh. Pathotype 21R63 (104-3) was identified in Uttar Pradesh and Bihar. In Northwestern parts of India, both these pathotypes were prevalent and pt. 21R63 (104-3) appears to be increasing.

More than 280 samples belonging to 14 states were analyzed during 2009-10. Twenty-four pathotypes belonging to 4 different groups were identified. Among these 77 group was the most predominant and constituted almost 45% of the population followed by 104 group contributing for 31% of the analyzed samples. A new pathotype close to 104 group was identified in 2 samples from Himachal Pradesh and has been designated as 104-4(93R57). Among the pathotypes, 121R63-1(77-5) was the most predominant followed by 21R55 (104-2), 21R63 (104-3), and newly identified pathotype 125R28-1(77-11). Maximum variation was observed in Karnataka where 17 pathotypes were detected followed by Madhya Pradesh (13) and Maharashtra (Table 5).

Twenty six pathotypes were identified in more than 423 samples of brown rust of wheat analyzed from 13 states of India and Nepal during 2010-11(Table 6). Pathotype 121R63-1(77-5) was most predominant in most of the states and occurred in more than 45% of the samples followed by

21R55 (104-2) which was observed in 23% samples. Remaining 24 pathotypes constituted 32% of the population. Four groups of pathotypes (12, 77, 104 and 162) were widely distributed. Madhya Pradesh had most diverse pathotypes (11).

In addition to pt. 121R63-1(77-5) pts 121R60-1(77-9), 377R60-1(77-10) (virulent on *Lr28*) and 109R31-1(77-2) occurred in Nilgiri hills. Pathotypes 377R60-1 was restricted to Nilgiri hills only whereas pathotype 121R60-1(77-9) was observed in Maharashtra also. Along with pt. 121R63-1(77-5), pts of 104 group (21R55, 21R63, 21R31-1, 29R23, 21R31) were observed in Karnataka and Maharashtra. Three samples of 162 group pts from Maharashtra and 4 of 77 groups from Karnataka were also recorded. The flora of Gujarat was nearly similar to that of Karnataka and Maharashtra and 77, 104 group of pathotypes were found. In Madhya Pradesh and Rajasthan few samples of 104 and 77 groups were identified in addition to predominant pathotype 121R63-1(77-5). In Bihar and Jharkhand one sample each of 121R63-1(77-5) and 21R31 (104A), respectively, were analyzed. Pathotypes of 77 and 104 groups occurred in few samples in addition to the predominant pathotype 121R63-1(77-5) in Uttar Pradesh.

Pathotype 21R55 (104-2) was most predominant in Uttarakhand followed by pathotype 121R63-1(77-5) whereas other pathotypes occurred in few samples only. Pathotypes 21R55 (104-2) and 21R63 (104-3) were detected in 3 samples each from Haryana. In Punjab, pathotype 21R55 (104-2) was more common followed by pathotype

Table 6 Pathotype distribution of *Puccinia triticina* in India during 2010-11

State/Country	No. of isolates	Pathotypes observed*																								
		12-1	12-3	12-5	12A	77	77-1	77-2	77-3	77-4	77-5	77-6	77-9	77-10	77-11	77A-	104-	104-3	104-4	104A	104B	108-1	162	162-1	162-2	162A
Tamil Nadu	49						1	1		37		8	2				18	8								
Karnataka	61						6	1		22	1						11	3		4	7					5
Maharashtra	90	1					3	2		55		5				1	11	3		4	7		1			1
Gujarat	36					3	2			13							12	3			3					
Madhya Pradesh	29	1				3	1	2	1	8	1				2		4	3		2						
Rajasthan	7									4																
Bihar	1							1		1																
Jharkhand	1																				1					
Uttarakhand	24					1				6							14	2		1						
Haryana	6																3	3								
Punjab	30									13							16	1								
Uttar Pradesh	16					1		1	1	10							1	2								
Himachal Pradesh	19									1							1						3	13		
Nepal	38	2			1	2		1	1	15							12	2		1						1
Total	407	2	2	1	1	10	9	7	2	1	2	13	2	1	2	1	94	27	1	8	15	1	1	3	14	1

*12-1(5R37),12-3(49R37), 12-5(29R45), 12A(5R13), 77(45R13), 77-1(109R63), 77-2(109R31-1), 77-3(125R55), 77-4(125R23-1), 77-5(121R63-1), 77-6(121R55-1), 77-9(121R60-1), 77-10(377R60-1), 77-11(125R28), 77A-1(109R23), 104-1(109R23), 104-2(21R31-1), 104-3(21R63), 104-4(93R57), 104A(21R31), 104B(29R23), 108-1(57R27), 162(93R7), 162-1(93R47), 162-2(93R39), 162A(93R15)

121R63-1(77-5). Contrarily pathotype 93R39 (162-2) was most frequent in Himachal Pradesh, other pathotypes occurred in few samples only.

Pathotype 121R63-1(77-5) was also predominant in Nepal. While pathotype 21R55 (104-2) occurred in many samples, 8 other pathotypes were also recorded, however, in few samples only.

More than 410 samples of brown rust of wheat were analyzed from 13 states of India, Bhutan, Nepal and Bangladesh during 2011-12. Among the 23 pathotypes identified this year (Table 7), pathotype 121R63-1 (77-5) was the most widely distributed and was observed in all the areas followed by pathotypes 21R55 (104-2) and 21R63 (104-3). These pathotypes constituted more than 74 percent population of *P. triticina* in this part of Asia. Pathotype 93R57 (104-4), which was identified in 2010 from Solan district in Himachal Pradesh has further spread to Uttarakhand, Delhi and Uttar Pradesh and was identified in 22 samples. Another pathotype which was recorded in few samples was 121R60-1 (77-9) which occurred only in three states and Bangladesh. Pathotype 121R55-1(77-6) was also identified in 11 samples from four states. Other pathotypes were observed in few samples only.

In Nepal, Bangladesh and Bhutan pathotype 121R63-1(77-5) which was predominant in India was also common in these areas. Pathotype flora of Bangladesh was the most diverse where 10 pathotype were identified in 34 samples. In Nepal and Bhutan four pathotypes each were identified in 20 and 10 samples, respectively.

During 2012-13, more than 439 samples of brown rust of wheat were analyzed. The proportion of pathotypes 21R55 (104-2) and 21R63 (104-3) has reduced significantly whereas there was built up of population of pathotypes 121R60-1(77-9), 121R55-1 (77-6) and 12 (5R5) in comparison to the previous years. Flora of Karnataka was most diverse with 15 pathotypes observed in 85 samples. Among the 30 pathotypes observed in 439 samples, pathotype 121R63-1(77-5) (38% of the samples) followed by 121R60-1(77-9) (17%) were the most predominant pathotypes (Table 8). Pathotype 21R55 (104-2) was observed in 14% samples only. Other pathotypes were

Table 7 Pathotype distribution of *Puccinia triticina* in India and neighbouring countries during 2011-12

State/Country	No. of Isolates	Pathotypes observed																				
		12A	12-3	12-5	12-8	12-9	77	77-2	77-3	77-5	77-6	77-9	77-10	77A-1	104-2	104-3	104-4	104B	162	162-1	162-2	
Tamil Nadu	91							2	70	4	12	3										
Karnataka	71*	1	1	1	1				43	3	1		1	8	1		2	1				3
Maharashtra	10								3					5	2							
Madhya Pradesh	1																	1				
Gujarat	1								1													
Rajasthan	10								2					7								
Jharkhand	2								1					1								
Uttar Pradesh	53*				2	1		3	14	1				4	12	12				1		
Punjab	8													6								2
Haryana	32								6		1			21	3							
Jammu & Kashmir	15								5	3				4	1							2
Uttarakhand	32								10					6	9	6						
Himachal Pradesh	22													11	4	4				1		2
ther countries																						
Bhutan	10*								6					1	1							
Nepal	20								16					2								
Bangladesh	34*	1				1		3	10		1			6	7					1	1	1
Total	412	2	1	2	3	3	2	7	187	11	15	3	1	82	40	22	3	3	3	2	2	9

*Includes 4 samples of pt. 12-1 in Karnataka, one in UP, one of 12 in Bhutan, one each of 12-2, 12-4 in Bangladesh : 12(SR5), 12-1(SR37), 12A(SR13), 12-3(49R37), 12-4(69R13), 12-5(29R45), 12-8(49R45), 12-9(93R37-1), 77(45R31), 77-2(109R31-1), 77-3(125R55), 77-5(121R63-1), 77-6(121R55-1), 77-9(121R60-1), 77-10(377R60-1), 77A-1(109R23), 104-2(21R55), 104-3(21R63), 104-4(93R57), 104B(29R23), 162(93R7), 162-1(93R47), 162-2(93R39).

observed in few samples only. Pathotype 121R63-1(77-5) was most common in Tamil Nadu, Haryana and West Bengal, whereas pathotype 121R60-1(77-9) was frequent in Karnataka and Maharashtra. Pathotype 21R55 (104-2) was predominant in Gujarat, Uttar Pradesh and Himachal Pradesh. In Madhya Pradesh four pathotypes; 5R5 (12), 253R31 (77-8), 21R55 (104-2) and 93R15 (162A) occurred in same frequency.

Analyses of 76 samples of brown rust of wheat were accomplished from the neighbouring countries Bhutan, Nepal and Bangladesh. Here also 62% of the samples had pathotype 121R63-1(77-5). Most of the pathotypes identified from Bhutan were virulent to *Lr26*. Flora of Nepal was most diverse where 9 pathotypes were observed in 52 samples.

Pathotypes observed on different genotypes during 2008-13

Pathotypes observed on different samples collected from the entries of Wheat disease monitoring nurseries, SAARC nurseries, farmers' fields, experimental farms and some alien sources are presented in Table 10. A perusal of the data reveals that mostly pathotypes 121R63-1(77-5), 21R55 (104-2), 121R60-1 (77-9) were observed on most of the genotypes. Other pathotypes were observed only on few genotypes/varieties only (Table 9).

Percent effectiveness of *Lr* genes

A perusal of Table 10 depicts the effectiveness of *Lr* genes in Indian wheat material. *Lr19* and *Lr28* are generally effective in India and adjoining countries whereas *Lr1*, *Lr10*, *Lr23* and *Lr26* are not very effective. In addition *Lr3*, *Lr13*, *Lr14a* were susceptible to all the prevalent pathotypes whereas *Lr9* and *Lr24* were effective against brown rust population in India, Bangladesh, Bhutan and Nepal. Evaluation of resistance genes/lines against field isolates revealed that *Lr9*, *Lr24*, *Lr25*, *Lr32*, *Lr39* and *Lr45* were resistant to the brown rust population of the Indian sub continent during the period.

During 2005-2008, thirty one pathotypes of *P. triticina* were identified (Bhardwaj *et al.* 2010), whereas during 2008-13, thirty Seven pathotypes were identified in 2124 samples analyzed from India, Bangladesh, Bhutan and Nepal.

Table 9 Pathotypes of *Puccinia triticina* (brown rust of wheat) observed on different genotypes and predominant wheat varieties during 2008-13

Area	Pathotypes	Genotype/Varieties
Himachal Pradesh	77-5	HD2329,WL711
	104-2	<i>Aegilops ovata</i> , <i>Aegilops squarrosa</i> , Agra Local, C306, HD2160, HPW184, HS295, Lal Bahadur, PBW343, Sonalika, VL616, WL711, WL1562
	104-3	<i>Aegilops squarrosa</i> , C306, HD2160, Lal Bahadur, WH1021, WL711
	104-4	C306, VL738, WL711, WH1021
	162-2	HD2329, WH147
Punjab	77-5	Agra Local,DH218, Gourab, HD2160, HD3014,HS523, K0803, MACS6354, MACS6416, NIDW1594, Pak-81, PBW175, PBW373, RW3688,
	104-2	Agra Local,C306, DBW17, DH184, DH194, HD2160, HD2329, K0716, Lal Bahadur, MACS6416, PBW343, PBW502, VL935, WH147, WH711, WL711,
	104-3	DBW17, HD2687, HD2733, Lal Bahadur, PBW343, PBW502, WH147, WH542,
	162-2	W1711
Haryana	77	HD2851
	77-5	PBW343,WH711
	77-6	PBW343
	77-11	HD2329
	104-2	C306, HD2687, PBW343, PBW373, WH711
	104-3	Lal Bahadur, PBW343,UP2338,WL711
Uttarakhand	104-4	HD2851, HD2894, PBW343
	77-5	Agra Local, C306,HB208, HD2687, NW5050, PBW343, PBW502, Raj 3765,VL616, VL719, VL738,WH542,WH896, WL711
	77A-1	C306
	104-2	Agra Local, Annapurna, C306, HD2160, HD2428,HD2687, HD2932, Lal Bahadur,PBW343, PBW373,Raj3765,UP2338,WH147,WH542, WL711, WL1562,
	104-3	Agra Local, C306,
Uttar Pradesh	104-4	DBW17, HD2329,PBW343,PBW373
	77-5	HD2643, HUW206, HW234, Kharchia65, Lal Bahadur, PBW373, PBW502, UP2338, UP2687, WL711
	77-9	Kharchia 65
	104-2	Agra Local, C306, DBW17, HD2329, HD2733, K911, Kharchia 65 PBW343, PBW502, PBW618, UP2338, UP2565,
	104-3	C306, CBW38, PBW343, PBW502,WH542, WL711
	162	Lal Bahadur
	162-1	Agra Local
Bihar	77-5	WL711
	104-2	HD2733,K0806,PBW343,PBW373,PBW618,WL711
	104-3	HD3003,HD3030,PBW618
West Bengal	77-5	C306, K9107,PBW343,UP2338
	104-2	C306,K8027,K9107,PBW343
	104-3	C306,PBW343,UP2338
Madhya Pradesh	12	Sujata, WH147
	12-4	GW322, Lal Bahadur, Sujata
	12-5	Pissi Local,
	77-1	Agra Local, HD2204, HD2329, Lal Bahadur, Pissi Local, WH147, WH711,
	77-2	GW322
	77-5	C306, HD2160, HD2932, Lal Bahadur,Lok-1, Morocco, Sujata, WL1562,
	77-9	D803-3,HD2204
	77-11	Lok-1, Sujata
	104	Lok-1, Sujata
	104-2	Agra Local, C306, DL803-3, HI8498, Lok-1, MP1246, Pissi Local, Sujata,
	104-3	A-9-30-1, C306, GW322, Lok-1, HI8381, MACS2496,Raj3077, WH147
	104B	Lok-1
Chhattisgarh	162A	C306, GW322,Kite,MACS9, PUSA-4,
	12A	WL711

Continued

Table 9 (Concluded)

Area	Pathotypes	Genotype/Varieties	
Gujarat	77-5	HD2329, WH147	
	104-2	C306, D803-3, HD2160, Lal Bahadur	
	162-1	HD2204	
	77	Lal Bahadur, Lok-1	
	77-11	Agra Local, HD2329, Lok-1, WH147	
	104-2	Agra Local, HD2329	
	104-3	GW496, Lok-1, WH147	
	Maharashtra	12	A739, HI617, Local Yellow
		12-2	MACS6222
		12-3	HD2189
12-4		Lok-1	
12-5		Agra Local, Janak,	
12-7		Amber, Agra Local, BARC-2, HUW206,MACS9	
77-1		MACS3125	
77-3		C306	
77-5		A-9-30-1, Amber-28, DWR195, Gulab,HD2160,HD2189, HD2204, Hindi62, HI1580, Kharchia 65, Lal Bahadur , Lok-1, , KRL302, MACS2496, Morocco, MP3299, MACS6416, NI5439, NIAW34, PBW343, <i>T. spherococcum</i> , <i>T. turgidum</i> , WH147	
77-9		Agra Local,HD2329, WL711,WL1562	
77-11	GW496, Lok-1		
104-2	HD1949, Kalyansona, Kundan, Local Red, MACS2496		
104-3	Kite, PBN51		
104B	HD2189, Lal Bahadur, Lok-1		
162A	Agra Local, Bansil103, Bansil168, C306, GW496, HD2189, Khapli, Kite, Lal Bahadur, MACS9,N59, NI5439, PDW291, <i>T. polonicum</i> , Vijay		
Karnataka	12	Amrut, HD2189, Pusa-4	
	12-2	MACS9	
	12-4	Amrut, C306,Khapli, Kite, MACS9, MP1208, NIDW295, PBW343	
	12-5	Amrut, DWR225, MACS2496, MACS2846, Pusa-4	
	12-7	A-9-30-1, Agra Local, Amrut, DWR162,DWR195, DWR225, DWR1006, GW410, HD2501, HD2932, HI977, Lal Bahadur ,Local Red, , Lok-1, MACS2496, MACS2971,N59, UAS305, UAS415	
	77-1	Kite ,MACS6222, Sonalika	
	77-3	DWR162	
	77-5	A-9-30-1, Amrut, Bijaga Yellow, DWR162, DWR225,HI8692, HS295, HUW234, Lok-1, N59, NI5439, Rasi 72, UAS304, VL924, WH147, WL711,	
	77-6	Local Red, Pusa-4	
	77-9	Amrut, DWR162, DWR225, MACS2496, MP1224, NI5439, PBW343, PBW618, Pragati , Pusa-4, Sonalika, WH147,	
77-11	DWR2006		
104-2	Agra Local, C306, DWR139, HD2329, MACS2496, NIAW917		
104-3	DWR1006,UAS415		
104A	DWR2006		
104B	Amrut ,Kite, Lal Bahadur, MACS9, MACS2496, Pusa-4		
162-1	Amrut , DWR225, Kite, Lal Bahadur		
162-2	DWR162, Kite, Local Red,		
162A	Agra Local, Amrut, Bijaga Yellow, C306, DWR162, HI8692, GW1269, MACS1967, N59, NIDW295, PDW291, UAS316, WH147,		
Tamil Nadu	12-3	HD2204	
	77-2	NIAW301	
	77-5	Agra Local, DWR195, HD2687, HP1205, HS240, Lok-1, N59, NI5439,NIDW15 PBW373,	
	77-6	MACS2496, Pusa-4	
	77-9	HD2285, HD2687, HD2877,HP1205, HS240, J24, Kite,NI5439, PBW226, PBW343, <i>T. boeticum</i> , <i>T. urartu</i> ,Vijay	
	77-10	J24, NI5439,	
Nepal	77-5	BL3235, BL3819, BL4301, NL1064, Pitic 62, WK831	
	104-2	Kalyansona, Local Mudib,WK831, WK1204	

Table 10 Effectiveness* of *Lr* genes in Indian wheat material against brown rust in different areas during 2008-13

Area	States	Effectiveness of resistance genes					
		<i>Lr1</i>	<i>Lr10</i>	<i>Lr19</i>	<i>Lr23</i>	<i>Lr26</i>	<i>Lr28</i>
1	Tamil Nadu	1.3	1.3	99.5	2.6	1.8	95.3
2	Karnataka , Gujarat , Maharashtra	16.4	8.5	100	18.0	19.7	99.9
3	Chhattisgarh, Madhya Pradesh, Rajasthan	19.6	7.1	98.2	25.4	20.1	100
4	Bihar, Jharkhand, Assam, West Bengal	0	0	100	0	0	100
5	Uttar Pradesh, Delhi, Haryana, Punjab, Chandigarh	3.2	4.2	100	6.6	1.8	100
6	Jammu & Kashmir , Himachal Pradesh, Uttarakhand	10.9	0	100	10.8	2.4	100
7	Bangladesh	18.3	10.2	100	20.4	18.3	100
8	Bhutan	0	1.1	100	5.9	50.0	100
9	Nepal	7.2	12.6	100	20.4	18.3	100

Lr3, *Lr13*, *Lr14a* were ineffective, whereas *Lr9*, *Lr24* were effective against brown rust of wheat during 2008-13.

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