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SEEDLING AND ADULT PLANT RESISTANCE TO STRIPE RUST IN UTTARAKHAND LANDRACES OF WHEAT

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ABSTRACT

In present study, twenty-six landraces of wheat collected from different parts of Uttarakhand (India) were tested for stripe rust resistance. Initially, field resistance test was carried out at two locations, namely Hawalbagh and Dalang-Maidan (India), during 2013-14 and 2014-15 under natural conditions. The landraces were also tested against 3 pathotypes of stripe rust pathogen (110S119, 46S119 and 78S84) at seedling and adult plant stage under controlled conditions. In field, 13 landraces were found highly resistant, of which 8 were immune. The remaining 13 landraces showed varying levels of partial resistance and expressed significant genotype x environment interactions. Of the 26 landraces, only one landrace (VHC 6285) was immune against all the three pathotypes both at seedling and adult plant stages. Five landraces (VHC(BD)2, VAH-CW 3166, VRB-CW-2106, VHC 6178 and VHC 6185) showed seedling resistance against 78S84, and adult plant resistance (APR) against 110S119 and 46S119. Some landraces showed both seedling and adult plant resistance against 46S119 and 78S84. Thus, apart from reporting new sources of resistance against existing pathotypes, the current study seems to be first to report resistance sources (both seedling and APR) against new pathotype 110S119.

Key words: Landraces, pathotypes, stripe rust, Uttarakhand, wheat

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a major food crop grown in many countries around the world (Shiferaw *et al.,* 2013). India is the world's 2nd largest producer of wheat and its annual production is limited by many biotic and abiotic stresses (Singh *et al.,* 2008; Singh *et al.,* 2011a). Amongst the several diseases affecting wheat, yellow or stripe rust caused by *Puccinia striiformis* Westend. f. sp. *tritici* Erikss. (*Pst*) is an economically important foliar disease, especially in cooler regions of the country (Joshi *et al.,* 1970). It can cause total crop failure during outbreak years and inflict economic loss up to100% (Chen, 2005). Appearance of stripe rust in severe form was reported from plains of Jammu & Kashmir, foothills of Punjab and Himachal Pradesh and *tarai* region of Uttarakhand, India (Sharma and Saharan, 2011). Timely intervention can save the crop through essential chemical control measures but breeding for rust resistance is most economical, eco-friendly and sustainable method of disease control (Kolmer, 1996).

Two *Pst* pathotypes, 46S119 and 78S84, reported during 1995-2004 (Prashar *et al.,* 2007), were responsible for high incidence of stripe rust in India. In addition, 5 new pathotypes, 46S117, 110S119, 238S119, 110S247 and 110S84, have been identified from India in 2014 (Gangwar *et al.*, 2016). Among these, pathotype 110S119 has been found to be the most dominant, aggressive and its population builds up very fast (Gangwar *et al.*, 2016). Therefore, it warrants rapid search for new sources of resistance against new and predominant virulent pathotypes of *Pst* in India. In this direction, wild progenitors, non-progenitors and indigenous bio-resources (landraces and farmer's varieties) of wheat may provide source of novel resistance (McIntosh *et al.*, 2013). The landraces of Uttarakhand are known to harbour resistance to stripe rust (Routray *et al.*, 2007; Kumar *et al.*, 2016). Therefore, the objective of this study was to identify new sources of stripe rust resistance among landraces of wheat collected from different parts of Uttarakhand (India).

MATERIALS AND METHODS

Plant materials

The experimental materials consisted of 26 landraces of wheat which were collected from the farmer's fields of different hilly areas of Uttarakhand, India as detailed as under:

S. No.	Collection name	Institute ID	Collection year	Collection area		
				District	Block	Village
1	VHC 6045	VLPGR_05004	1978	Tehri	Fakot	Kalkod
2	VHC 6102	VLPGR_05019	-do-	Almora	Dwarahat	Dunagiri
3	VHC 6105	VLPGR_05020	-do-	-do-	-do-	-do-
4	VHC 6126	VLPGR_05029	-do-	Chamoli	Tharali	Lolti
5	VHC 6135	VLPGR_05034	-do-	-do-	Gairsair	Malsi,
6	VHC 6142 Amb	VLPGR_05039	-do-	-do-	-do-	Ramali
7	VHC 6149	VLPGR_05043	-do-	-do-	-do-	Jungalchatti
8	VHC 6152	VLPGR_05045	-do-	-do-	-do-	-do-
9	VHC 6153	VLPGR_05046	-do-	-do-	-do-	-do-
10	VHC 6160	VLPGR_05048	-do-	-do-	Karanpriyag	Sirser
11	VHC 6178	VLPGR_05054	-do-	Pithoragarh	Lohaghat	Lohaghat
12	VHC 6185	VLPGR_05056	-do-	-do-	-do-	Chiriyadunga
13	VHC 6195	VLPGR_05062	-do-	-do-	Barakot	Gusor
14	VHC 6234	VLPGR_05080	-do-	Champhawat	Champhawat	Shera
15	VHC 6267	VLPGR_05091	1981	Pithoragarh	Gangolihat	Chamandugara
16	VHC 6270	VLPGR_05092	-do-	-do-	-do-	Sunargaon
17	VHC 6285	VLPGR_05096	1988	Chamoli	Simli	Simli
18	VHC 6408	VLPGR_05136	1989	Bageshwar	Garur	Darsari
19	VHC(BD)2	VLPGR_05146	2000	Almora	Hawalbagh	Sibnaula
20	VHC(BD) 12 Amb	VLPGR_04942	-do-	Chamoli	Tharali	Guramn
21	VHC(BD) 17 Amb	VLPGR_04944	-do-	-do-	-do-	Lolti
22	VHC(BD) 17 Red	VLPGR_04945	-do-	-do-	-do-	Tharali
23	VHC(BD) 21 Red	VLPGR_04951	-do-	-do-	Naranbagat	Kulsyari
24	VRB-CW-1633	VLPGR_03093	2003	Bageshwar	Gawan	Gawan
25	VAH-CW 3166	VLPGR_03205	-do-	-do-	Kapkot	Song,
26	VRB-CW-2106	VLPGR_03162	-do-	Champawat	Suyalkhark	Suyalkhark

These landraces were collected during different exploration trips by crop breeders/economic botanists from ICAR-Vivekananda Parvatiya Krishi Anusandan Sansthan (VPKAS) and were preserved in the medium-term gene bank module after assigning unique germplasm identification number (I.D.) of the institute.

Stripe rust pathogens

Three pathotypes *viz.,* 78S84, 46S119 and 110S119 of *Puccinia striiformis* f. sp. *tritici* were used in this study. Currently, pathotypes 46S119 and 110S119 are most predominant and widely distributed in major wheat growing states of Northern India including Punjab, Haryana, Rajasthan, Uttar Pradesh, Himachal Pradesh, Jammu & Kashmir, Uttarakhand and Delhi (Gangwar *et al.,* 2016). Among these, pathotype 110S119 was identified and confirmed as more aggressive and virulent than existing *Pst* pathotypes (Gangwar *et al.,* 2015).

Experimental site

The present study was conducted at Experimental Farm of ICAR-VPKAS, Hawalbagh, Almora, Uttarakhand, India ($29^0$36'N, $79^0$40'E; 1250 m masl). Hawalbagh is considered a hot spot location for *Pst* and incidence of *Pst* is reported higher naturally on susceptible cultivars every year. Dalang-Maidan, in Lahul-Spiti, Himachal Pradesh ($32^0$21'N, $77^0$14'E; 2347 m masl), was chosen as another site for this study. Dalang Maidan is a recognized national dedicated research station for cultivating off-season nurseries of wheat and barley materials for screening of yellow rust, brown rust and for generation advancement. Every year, incidence of *Pst* is reported higher naturally on susceptible cultivars at Dalang Maidan; and it is also considered a hot spot location for *Pst*.

Field evaluation under natural infection

The initial evaluation for adult plant stage resistance in wheat Uttaralkand landraces under natural field conditions was carried out at Hawalbagh during winter season (November-April) of the year 2013-14 and 2014-15 and at Dalang-Maidan during rainy season (May-August) of the year 2014 and 2015. The experiment was laid out in a randomized complete block design with 3 replications. Each replication consisted of 26 landraces and a susceptible check (Agra Local). Seeds of each landrace were sown by dibbling in two rows each of 1 m length with row spacing of 30 cm. Homogeneous mixture of highly susceptible wheat lines, namely NI5439, Avocet and Agra Local (infectors) were used a *Pst* spreader in field trials. The infectors were planted around the experimental plot to increase inoculums load.

The infection type and severity data were recorded using modified Cobb scale (Peterson *et al.,* 1948; Roelfs *et al.,* 1992) at boot to milk stage. The infection types were recorded as 0 = no visible infection (immune); R = necrotic areas with or without uredia (resistant); MR = necrotic areas with small uredia (moderately resistant); MS = medium sized uredia with no necrosis but some chlorosis (moderately susceptible); S = large sized uredia with no necrosis and chlorosis (susceptible); X = variable sized uredia with necrosis or chlorosis and fully susceptible (intermediate). The severity was assessed by visual observations. Below 5% severity the intervals were trace and usually 5% interval was used from 5 to 20%, and 10% interval between 20-100% severities. The response value of 0.0, 0.2, 0.4, 0.8 and 1.0 were assigned for 0, R, MR, MS and S, respectively.

The coefficient of infection (CI) of a landrace was determined by multiplying response value with the severity of infection (Pathan and Park, 2006). The average coefficient of infection (ACI) of a landrace was derived by dividing the sum of CI values with corresponding data recording years (Stubbs *et al.,* 1986). In this study, mean over replications values of CI were used and sum of CI values were divided by 4 to determine ACI, as each entry was tested in 4 seasons. Grouping of landraces into resistance and susceptible categories was done based on ACI values (Sajid-Ali *et al.,* 2009). The landraces with ACI value of zero was considered immune. The landraces with ACI values of 0-5 and CI value of zero in some locations was considered to possess strong vertical resistance instead of partial resistance. However, ACI values >5 were taken as partial resistance, in which ACI values less than 20, 21-40 and 41-60 was considered as high, moderate and low levels of partial resistance, respectively. Varieties with ACI values > 60 were considered susceptible.

Seedling resistance test (SRT)

The experiment was carried out during winter season, 2016-17 under glasshouse conditions at ICAR-IIWBR, Regional Station, Flowerdale, Shimla, India. Seedlings were raised in aluminum trays containing sterilized mixture of fine loam and farmyard manure (3:1). These trays were sufficiently large to accommodate 18 genotypes, including a susceptible check (Agra Local). For each genotype, 5-6 seeds were sown in hills. Ten days old seedlings were inoculated by spraying suspension containing 10 mg spores of a *Pst* pathotype using a glass atomizer and incubated at dew chambers for 48 h at 16±2°C. After incubation, plants were transferred into a greenhouse where temperature of 18±2°C, relative humidity of 60-75% and illumination of about 15,000 lux for 12 h were maintained. Later, the individual seedlings were scored for stripe rust reaction (infection type) at 16 days post-inoculation using standard procedure (Nayar *et al.*, 1997) where 0 (naught fleck) = no visible infection, ;- (fleck minus) = slightly necrosis /micro-flecking visible, ; (fleck) = no uredia but small hypersensitive flecks present, 1 (one) = uredia minute, surrounded by distinct necrotic areas, 2 (two) = small to medium uredia surrounded by chlorotic or necrotic boarder, 3 (three) = uredia small to medium and chlorotic areas may be present, 3+ (three+) = uredia large with or without chlorosis, sporulating profusely and forming rings. Infection type 33+ is classified when both 3 and 3+ pustules occur together. The ITs 0 to 2 ratings were considered resistant and 3 to 3+ as susceptible while 2+, 22+ and 3− were considered intermediate ITs.

Field evaluation under artificial infection

Adult plant resistance in wheat landraces against 3 pathotypes *viz*., 46S119, 110S119 and 78S84 was carried out at Hawalbagh during winter, 2016-17 under artificially infected field conditions. For this, 26 landraces along with suitable susceptible checks (Agra Local and PBW343) were planted in three separate experimental plots. The experiment was laid out in an augmented design where susceptible checks Agra Local and PBW343 were repeated in each block of 15 test entries. A sufficient isolation distance was provided between the experimental plots to avoid cross infection.

In each plot, seeds of each landrace were sown by dibbling method in 2 rows each 2 m long with row spacing between two genotypes as 30 cm. Single row of infectors was repeatedly planted after every entry and then field was surrounded by same infector's rows to increase inoculum load. During late January to early March, uredospores of pathotypes 46S119, 78S84 and 110S119 were repeatedly sprayed in three separate experimental plots. Disease severity and infection types were recorded four times at 15 days interval at boot to milk stage. The scales for disease severity, infection types and the procedure for calculating coefficient of infection (CI) was same as described. Area under disease progress curve (AUDPC) was calculated using CI values (Gyawali *et al*., 2018).

Statistical analysis

Location-wise and combined ANOVA for CI values of natural infection in wheat landraces along with check (Agra Local) was performed by using PROC GLM of SAS (SAS Institute, 1988) statistical software package. AUDPC value of landraces and checks (Agra Local and PBW 343) against 3 *Pst* pathotypes was subjected to ANOVA using augmented block design. Cut-off of rust resistance and susceptible genotype was determined by significant *t* test of susceptible checks and test genotypes at 0.05 probability plus least significant difference at 0.05 probability. Cut-off AUDPC for pathotypes 46S119, 78S84 and 110S119 were 2910, 1940 and 2911, respectively. Genotypes with rust severity less than cut-off AUDPC were considered as adult plant resistant.

RESULTS AND DISCUSSION

High reproductive rate of rust pathogen causes the evolution and spread of new pathotypes at rapid rates (Duveiller *et al.*, 2007). Changing climate causes drift in pathotype dynamics and leads to the evolution of highly virulent pathotypes of stripe rust in India (Prashar *et al.*, 2015; Gangwar *et al.*, 2016). The new pathotypes appear more virulent than the existing ones and pose major threat to food security by causing heavy yield loss in wheat. Fast spread of new pathotypes and breakdown of major resistance genes have accelerated the research investments in identification and transfer of new sources of resistance (James *et al.*, 2008; Joshi *et al.*, 2011). Earlier, an attempt was made to evaluate a large number of germplasm accessions of wheat (19,460 accessions, both exotic and indigenous) to identify novel sources of rust resistance (Kumar *et al.*, 2016). Moreover, the emphasis was laid upon the requirement of more exploration trips in the state of Uttarakhand (India) to explore novel sources of rust resistance in wheat (Kumar *et al.*, 2016). In addition, a few attempts were made in past to evaluate agro-morphological diversity, grain quality traits, and level of leaf and stripe rust resistance under natural field conditions among Uttarakhand landraces of wheat (Routray *et al*., 2007: Bisht and Gahalain, 2009; Bisht *et al*., 2009). However, detailed study on stripe rust resistance among Uttarakhand landraces of wheat has not been reported previously.

In present study, 13 wheat landraces of Uttarakhand showed high level of field resistance under natural conditions over locations and years with CI values and ACI <5.0 indicating the presence of strong vertical resistance (Table 1). Of these, 8 landraces namely VHC 6045, VHC 6102, VHC 6135,

Table 1: Terminal stripe rust severity (highest score), coefficient of infection (CI) and average coefficient of infection (ACI) of wheat in Uttarakhand landraces under field conditions

S. No.	Collection name of wheat landraces	CI-value[a] Hawalbagh (Winter season) 2013-2014		Dalang Maidan (Rainy season) 2014		AIC value[b]	HS[c]
		2013-2014	2014-2015	2014	2015		
Group 1[d]							
1	VHC 6045	0.0	0.0	0.0	0.0	0.0	0
2	VHC 6102	0.0	0.0	0.0	0.0	0.0	0
3	VHC 6135	0.0	0.0	0.0	0.0	0.0	0
4	VHC 6142 Amb	0.0	0.0	0.0	0.0	0.0	0
5	VHC 6153	0.0	0.0	0.0	0.0	0.0	0
6	VHC 6270	0.0	0.0	0.0	0.0	0.0	0
7	VHC 6285	0.0	0.0	0.0	0.0	0.0	0
8	VRB-CW-1633	0.0	0.0	0.0	0.0	0.0	0
Group 2[e]							
9	VAH-CW 3166	0.7	0.3	4.0	4.0	2.3	10MR
10	VRB-CW-2106	0.7	0.3	4.0	4.0	2.3	10MR
11	VHC 6178	0.7	0.7	3.0	4.0	2.1	10MR
12	VHC 6185	0.3	1.0	3.0	4.0	2.1	10MR
13	VHC(BD)2	0.7	1.0	3.0	4.7	2.4	20MR
Group 3[f]							
14	VHC 6105	6.7	26.7	4.0	4.0	10.3	40MS
15	VHC 6149	32.0	32.0	4.0	4.0	18.0	40MS
16	VHC 6152	8.0	32.0	32.0	6.7	19.7	40MS
17	VHC 6195	6.7	28.0	28.0	6.7	17.3	40MS
18	VHC 6234	5.3	24.0	6.7	28.0	16.0	40MS
19	VHC 6267	4.0	5.3	28.0	8.0	11.3	40MS
20	VHC(BD) 17 Red	28.0	6.7	4.0	4.0	10.7	40MS
Group 4[g]							
21	VHC 6126	26.7	26.7	26.7	6.7	21.7	40MS
22	VHC(BD) 12 Amb	31.3	28.0	24.0	46.7	32.5	60S
Group 5[h]							
23	VHC(BD) 17 Amb	53.3	32.0	53.3	28.0	41.7	60S
24	VHC 6408	0.7	73.3	73.3	42.7	47.5	80S
25	VHC 6160	1.0	53.3	73.3	42.7	42.6	80S
26	VHC(BD) 21 Red	28.0	50.7	53.3	73.3	51.3	80S
	Check - Agra Local[i]	80.0	100.0	100.0	80.0	90.0	100S

[a]Mean value of replications; [b]Combined mean; [c]Highest terminal stripe rust severity across all four seasons; [d]Group 1 - Landraces showing immune reaction in all seasons at two locations to *Pst;* [e]Group 2 - Landraces showing CI<5.0 in all seasons at two locations and ACI<5 to stripe rust indicating strong vertical resistance; [f]Group 3 - Landraces with ACI <20 indicating high partial resistance; [g]Group 4 - Landraces with ACI 20-40 indicating medium partial resistance; [h]Group 5 - Landraces with ACI 40-60 indicating low partial resistance; and [i]Check Agra Local with CI >60 and ACI >60 indicating susceptible reaction

Table 2: Mean square values of location-wise and combined ANOVA of CI values for terminal stripe rust severity in wheat Uttarakhand landraces

Sources	Location 1 (Hawalbagh)		Location 2 (Dalang maidan)		Combined	
	DF	Mean square	DF	Mean square	DF	Mean square
Genotypes	26	2954.34**	26	3913.80**	26	6477.76**
Replications	2	118.91	2	13.52	2	106.12
Years	1	1963.55**	1	597.04**	3	935.92**
Genotypes x years	26	572.73**	26	311.87**	78	424.99**
Error	106	22.43	106	22.45	214	22.48
CV		29.83		29.84		28.30

Significant at *P = 0.05 and **P = 0.01 levels of probability.

VHC 6142 Amb, VHC 6153, VHC 6270, VHC 6285 and VRS-CW-1633 showed immune response. The remaining 13 landraces showed partial resistance, in which 7 landraces (VHC 6105, VHC 6149, VHC 6152, VHC 6195, VHC 6234, VHC 6267 and VHC(BD) 17 Red) expressed high partial resistance and 2 landraces, namely VHC 6126 and VHC(BD) 12 Amb showed moderate partial resistance (Table 1). Four landraces with ACI >40 but <60 indicated low level of partial resistance. None of the landraces had fallen into susceptible category (ACI >60). However, susceptible check Agra Local was highly susceptible to *Pst* under natural field conditions with ACI >80. The infector's lines showed disease severity of 60S-100S in all tested locations indicating the presence of high disease pressure in chosen locations for *Pst*.

It was observed that 13 landraces showing partial resistance (ACI >5 and <60) expressed location and year specific disease responses indicating a strong genotype x environment (G x E) interactions (Table 1). It was further confirmed by significance of means square values for years and genotypes x years in both location-wise and combined ANOVA at 0.05 and 0.01 probabilities (p < 0.05) (Table 2). The differential response of landraces over locations could be attributed mainly to the variation in racial compositions of *Pst* populations in tested locations (Prashar *et al*., 2015). As the check Agra Local and infector's lines found highly susceptible at both locations, the variation due to different agroclimatic and weather conditions could be overruled. In a similar kind of study, the differential response of wheat varieties to *Pst* over locations due to variation in yellow rust populations was reported (Sajid *et al.*, 2009).

The partial resistance is usually expressed at adult plant stage (post-seedling), and is referred as adult plant resistance (APR), horizontal resistance, durable resistance and non-race specific. It is believed to be governed by several additive minor genes and generally more durable than vertical resistance (Singh and Rajaram, 1992). However, exceptions to partial resistance were reported (Singh *et al.*, 2011b), in which several single gene based partial resistance for *Pst* was identified in wheat (Singh, 1992; Singh *et al*., 1998; Hiebert *et al*., 2010; Herrera-Foessel *et al*., 2011). Further, varying level of partial resistance in different wheat breeding lines and varieties to *Pst* has been reported (Hovmoller, 2007). Thus, in present study, a further detailed pathotyping of landraces was done under controlled conditions to understand more on vertical and partial resistance that was observed under natural field conditions.

Out of 8 landraces found immune during natural field screening (Table 1), only one landrace VHC 6285 showed immune (IT:0;) to all three pathotypes at both seedling and adult plant stage (Table 3). This indicated that the landrace VHC 6285 might be carrying vertical or seedling resistance against existing pathotypes (46S119 and 78S84) as well as against new virulent pathotype (110S119). Thus, the present study seems to be first to report a resistance against new virulent pathotype 110S119 of stripe rust pathogen in India. Whereas, five out of seven remaining immune landraces, namely VHC 6045, VHC 6102, VHC 6135, VHC 6153 and VRS-CW-1633 were found immune against two pathotypes 46S119 and78S84 (IT:0;) at both seedling and adult plant stage, but were highly susceptible (IT: 3+ to 3++) to new pathotype 110S119 (Table 3). This indicated that these landraces seem to possess vertical resistance only against 46S119 and 78S84.

Table 3: Resistance reactions of Uttarakhand landraces of wheat to three *Puccinia striiformis* f. sp. *tritici* pathotypes at seedling and adult-plant screenings in winter season, 2016-17

S. No.	Wheat landraces	stripe rust pathotypes								
		46S119			78S84			110S119		
		SRT*	APR^		SRT	APR		SRT	APR	
			TRS**	AUDPC$		FRS	AUDPC		FRS	AUDPC
Group 1[a]										
1	VHC 6285	0;	0	0	0;	0	0	0;	0	0
Group 2[b]										
2	VHC 6045	;	0	0	0;	0	0	3+	80S	3150
3	VHC 6102	0;	0	0	0;	0	0	3+	80S	3000
4	VHC 6135	;	0	0	0;	0	0	3+	100S	3750
5	VHC 6153	0;	0	0	0;	0	0	3++	100S	3150
6	VRB-CW-1633	0;	0	0	0;	0	0	3++	80S	3000
Group 3[c]										
7	VHC 6142 Amb	3+	80S	3750	0;	0	0	3++	100S	3000
8	VHC 6270	3	80S	3000	0;	0	0	3++	80S	3300
9	VHC 6160	3	80S	3300	0;	0	0	3+	100S	3450
Group 4[d]										
10	VHC(BD)2	3	10MR	105	0;	0	0	3+	40MS	600
11	VAH-CW 3166	3+	10MR	150	0;	0	0	3+	40MS	840
12	VRB-CW-2106	3	10MR	150	0;	0	0	3+	20MR	180
13	VHC 6178	3+	10MR	150	0;	0	0	3+	60MS	1800
14	VHC 6185	3+	10MR	150	0;	0	0	3+	60MS	1200
15	VHC 6408	3	40MS	840	0;	10MR	90	3+	40MS	840
Group 5[e]										
16	VHC 6152	3+	40MS	960	3+	10MR	120	3+	40MS	840
17	VHC(BD) 17 Red	3	40MS	960	3+	10MR	75	3+	60MS	1800
18	VHC 6195	3	40MS	960	3+	10MR	165	3++	60MS	1800
19	VHC 6234	3	40MS	720	3-	20MR	180	3+	40MS	600
20	VHC 6267	3	40MS	720	3+	10MR	90	3+	40MS	1440
21	VHC 6105	3+	40MS	615	3	10MR	45	3++	40MS	600
22	VHC 6126	3+	40MS	600	3+	10MR	165	3+	40MS	600
23	VHC 6149	3	40MS	960	3+	10MR	30	3+	60MS	2400
Group 6[f]										
24	VHC(BD) 12Amb	3+	80S	3300	3+	80S	2100	3+	100S	3150
25	VHC(BD) 21 Red	3	80S	3000	3+	80S	2700	3+	80S	3600
26	VHC(BD) 17Amb	3+	80S	4050	3+	100S	3750	3++	80S	3000
	Agra Local[h]	3+	80S	3075	3+	80S	2775	3+	100S	3300
	PBW 343[i]	0;	5R	7.5	3+	80S	2825	3+	80S	3075
Cut-off AUDPC value[g]				2910			1940			2911

*SRT = Seedling resistance test; **TRS = Terminal rust severity; ^APR = Adult plant resistance, $AUDPC = Area under disease progress curve; [a]Group 1 - Immune to all three pathotypes at seedling and adult plant stage; [b]Group 2 - Immune to 46S119 and 78S84 but highly susceptible to 110S119; [c]Group 3 - Immune to 78S84 but highly susceptible to 46S119 and 110S119; [d]Group 4 - Immune to 78S84 but APR to 46S119 and 110S119; [e]Group 5 - APR to all three pathotypes; [f]Group 6 - Highly susceptible to all three *Pst* pathotypes; [g]Cut-off of resistance and susceptibility was determined by significant *t* test of susceptible checks and test genotypes at 0.05 probability ($p < .05$) plus $LSD_{0.05}$; [h]Check Agra local susceptible at seedling and adult plant stage to all three pathotypes; and [i]Check PBW 343 resistant to 46S119 but high susceptibility to 78S84 and 110S119.

The remaining two landraces, namely VHC 6142 Amb and VHC 6270 were found resistant against pathotype 78S84 but susceptible to 46S119 and 110S119 pathotypes. This shows that VHC 6142 Amb and VHC 6270 may carry vertical resistance against pathotype 78S84. However, check Agra

Local showed highly susceptible reaction both at seedling and adult plant stage against all the 3 pathotypes tested. The check PBW 343 showed differential expression against *Pst* pathotypes. It showed susceptible reaction at seedling and adult plant stage to pathotypes 110S119 and 78S84, but found resistant to pathotype 46S119. The response of checks against pathotypes 46S119 and 78S84 was in line with Prashar *et al.* (2007).

The occurrence of seedling or race-specific or vertical resistance for *Pst* in numerous wheat germplasms conserved in national gene bank, India, has been reported (Kumar *et al.,* 2016). Another study revealed that out of 652 spring wheat accessions from 54 countries tested for stem rust and stripe rust, 30 accessions had race-specific dual resistance (Newcomb *et al.,* 2013; Sthapit *et al.,* 2014). A major QTL, *QYr.wrsggl1-1BS confirming race-specific resistance* to *Pst* has been identified on chromosome 1B of spring wheat landrace PI 480035 (Sthapit *et al.,* 2017). Seedling or race-specific resistance is effective only to particular races of a pathogen and is often based on the genes that are expressed at seedling stage and remain effective at all post-seedling stages of plants (Chen, 2005; Lagudah, 2010). So far, 78 stripe rust race-specific resistance genes, based on seedling resistance test, have been identified in wheat (McIntosh *et al.*, 2010, Singh *et al.*, 2011b). Further, another 5 landraces, namely VHC(BD)2, VAH-CW 3166, VRB-CW-2106, VHC 6178 and VHC 6185 (Table 1), which showed strong vertical resistant under natural field conditions expressed seedling resistance against 78S84 and adult plant resistance against 46S119 and 110S119 (Table 3). These were the important set of landraces identified through present study, as they carry a combination of durable and seedling resistance against new and existing *Pst* pathotypes of India. Additionally, 8 more landraces, [VHC 6152, VHC (BD) 17 Red, VHC 6195, VHC 6234, VHC 6267, VHC 6105, VHC 6126 and VHC 6149] showed adult plant resistance against all the 3 pathotypes of *Pst.*

Gyawali *et al*. (2018) evaluated world collections of barley genotypes against 6 races of stripe rust at seedling and adult plant stage resistance and identified barley genotypes showing resistance response to all 6 races at seedling and adult-plant stages. Similarly, Wigoire *et al.* (1999) conducted similar study on adult field resistance of different wheat lines and some of these lines were thought to possess different *Yr* genes, conferring partial resistance. Therefore, a detailed inheritance study is necessary to understand the nature and number of genes controlling seedling and adult plant resistance in Uttarakhand wheat landraces. The present study has combined greenhouse and field tests in identifying the source of resistance to stripe rust in wheat landraces. This kind of combined tests facilitates the understanding of types and extent of rust resistance in a given set of cultivars (Mesterhazy *et al*., 2000; Barts *et al*., 2001; Singh *et al*., 2001). This study has sufficiently combined the seedling and field tests in identifying the nature, magnitude and types of stripe rust resistance in Uttarakhand wheat landraces. The study identified seedling and adult plant resistance sources against new virulent *Pst* pathotype 110S119. A number of new sources of seedling and adult plant resistance for existing predominant *Pst* pathotypes 46S119 and 78S84 were also identified. Particularly, landrace VHC 6285 possessing seedling resistance and 5 landraces [VHC(BD)2, VAH-CW 3166, VRB-CW-2106, VHC 6178 and VHC 6185] expressing adult plant resistance against new pathotype 110S119 could play a crucial role in resistance breeding in wheat in India.

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