

Wheat Stripe Rust Virulence and Varietal Resistance in the Foot Hill Himalayas of Nepal

Sarala Sharma¹, Etienne Duveiller², Chandra Bahadur Karki¹, Dhruva Bahadur Thapa³, Ram Chandra Sharma⁴ and Arun Kumar Joshi⁵

1. Plant Pathology Division, Nepal Agricultural Research Council, Lalitpur 44700, Nepal

2. CIMMYT, Global Wheat Program, Apdo Postal 6-641, Mexico 06600, DF, Mexico

3. Agriculture Botany Division, Nepal Agricultural Research Council, Lalitpur 44700, Nepal

4. ICARDA, Central Asia and the Caucasus Regional Program, Tashkent 10000, Uzbekistan

5. CIMMYT South Asia Regional Office, Kathmandu 44600, Nepal

Abstract: Stripe rust, caused by *Puccinia striiformis* f. sp. *tritici* (*Pst*) is an important disease of wheat (*Triticum aestivum*) in Nepal, which is a part of the Himalayas stretching over the North of Nepal, India, Pakistan, Bhutan and beyond. Wheat production plays a crucial role in food security of the marginal hill farmers of Nepal. Frequent epidemics of the rust have caused huge loss in farmer's field. Periodic monitoring during 1980-2008 showed that changes in virulence occurred during this period. The objective of this study was to evaluate *Pst* resistance and its effective genes in wheat genotypes. For this, trap nurseries, wheat stripe rust differentials, commercial cultivars and advanced breeding lines were tested under artificial epiphytotic and natural hot spots conditions during 2005 to 2010. Four genes (*Yr5*, *Yr10*, *Yr15* and *YrSp*) consistently showed resistance to the prevailing races. The gene *Yr9* and *Yr27* in combinations with *Yr18* were found effective. Other lines with combination of minor genes were also found effective. The genotypes Amadina, Kukuna, Tukuru, Kakatsi and Buck Buck widely used in breeding program were resistant. The cultivation of varieties WK1204, Gautam, Gaura and Dhaulagiri have ensured genetic diversity for the rust resistance and slowed down frequent occurrence of epidemics. The findings of these studies could help in developing effective varietal resistance program in the sub-continent.

Key words: *Puccinia striiformis*, resistance, virulence, stripe rust, *Triticum aestivum*, wheat.

1. Introduction

Stripe rust caused by *Puccinia striiformis* West. f. sp. *tritici* Eriks. & Henn. (*Pst*) has posed a great threat to wheat (*Triticum aestivum* L.) cultivation in South [1, 2], West [3] and Central Asia [4]. The farmers of mid and high hills in Nepal had been facing significant wheat yield losses due to rust and sometimes abandoned the crop when the rust occurred at seedling stage [5]. The wheat agro-ecosystem in Nepal is broadly divided into lowlands (Terai), foothills including valleys, mid-hills and high hills. Wheat is grown all the ways from 60 m up to 3,000 m above the sea level that is from warm subtropical to

temperate climates. The lowland of Nepal is a part of the vast Eastern Gangetic Plains (EGP) in South Asia, whereas mid hills and high hills mountains are continuum of the Himalayas in the sub-continent. Due to climatic diversity in Nepal, wheat crop is grown in the field throughout the year [6], and thus presents a unique set of environments favouring survival and development of the rust. The seriousness of wheat stripe rust in the hills is reflected through several epidemics of the rust in Nepal in the past 25 years [5]. High humidity caused by heavy dew in the winter months and cool temperatures during spring season creates conducive environment for frequent outbreak of the rust in the hills and high hills, and occasionally in the lowlands [7]. Epidemics of the rust in

Corresponding author: Sarala Sharma, senior scientist (S-4), research field: plant pathology.

Sindhupalchok and Dolakha districts in Nepal during 1980s were mainly due to summer wheat grown in that region [6] and the cultivation of a single cultivar RR21 in more than 70% of the area year after year. The rust developed and produced abundant inoculum in the summer wheat for the next normal season (November-June) wheat crop. Summer wheat acts as a bridge for the rust to the normal season wheat, and so epidemics of the rust in the normal season wheat was experienced in the hills during 80s and 90s [8, 9].

Studies done at Agricultural Research Farm, Kavre have shown 30% and 15% reductions, respectively, in wheat grain yield and 1,000-kernel weight (TKW), due to the rust [10]. The maximum loss was recorded on Morocco at both Kavre and Khumaltar. There was no grain formation at Kavre and there was as much as 95% grain yield loss at Khumaltar [6]. Several stripe rust resistant lines developed by the International Maize and Wheat Improvement Center (CIMMYT) and the national programs, like Annapurna-1, Annapurna-3, Annapurna-4 and Kanti, were deployed for Nepal hills. However, these varieties showed poor adoption by farmers [5] and became susceptible when *Yr9* virulent race appeared. Some varieties like BL1473 had wider coverage in Kathmandu valley, but became susceptible to the rust due to occurrence of a new race [5]. During 2000-2004, there was relatively lesser incidence of the rust due to wider coverage of the resistant cultivar Nepal 297. Due to lack of farmers' preferred criteria in the new cultivar, the varietal replacement in the hills of Nepal was slow, resulting in growing the same old cultivars RR21 and Nepal 297 till the end of the 20th century [11] and until the early years of this century, respectively [5]. Inoculum source from susceptible cultivars, congenial environment, less genetic diversity and occurrence of virulent race resulted in epidemics during the 2004-2007 wheat growing seasons [12]. Hence, the present study was conducted to identify effective stripe rust resistant genes and lines/cultivars against new stripe rust races, and minimize wheat yield losses

faced by hill farmers of Nepal.

2. Materials and Methods

Five studies were conducted using stripe rust differentials, commercial cultivars and advanced breeding lines from various sources. Seeds of the stripe rust wheat differentials were obtained from the International Center for Agriculture Research in the Dry Areas (ICARDA), Syria, CIMMYT, Mexico, the DLO Research Institutes for Plant Protection, the Netherlands (IPO-DLO) and the Plant Breeding Institute, Sydney, Australia. Seeds of the wheat commercial varieties and advanced breeding lines for seedling and adult plant resistance tests were obtained from the National Wheat Research Programs, Bhairahawa and Agriculture Botany Division, Khumaltar, Lalitpur. The senior author scored the rust severity and reactions in all experiments. Three trap nurseries were evaluated at Khumaltar Research Station, Lalitpur and in farmers' fields at Ramkot, Kathmandu valley. International differential sets of wheat lines containing known stripe rust resistance genes were also evaluated, and elite lines and cultivars were screened under heavy epiphytotic conditions. The scoring was performed by using modified Cobb's scale, where resistant is considered as "R", moderate resistant as "MR", moderately susceptible as "MS" and susceptible as "S". R is considered as visible chlorosis, no uredia present. MR is small uredia present and surrounded either by chlorosis or necrosis. MS is medium sized uredia present and surrounded by chlorotic area. S is large uredia present with no chlorosis or necrosis.

2.1 Effective Stripe Rust Resistance Genes Evaluation Using Near-Isolines (NILs) Set

A set of 19 Avocet NILs set received from Plant Breeding Institute, the University of Sydney, Australia was planted at Khumaltar (27.65° N, 85.02° E, 1,369 m above the sea level) in rod row design of 2 m length with 0.25 m row to row spacing.

2.2 Monitoring Yellow Rust Resistant Genes Using International Yellow Rust Trap Nursery (IYRTN)

The IYRTN containing 50 wheat lines was planted at Ramkot during 2007-2008 (27.43° N and 85.15° E) and Khumaltar during 2007-2009.

2.3 Monitoring Different Promising Wheat Lines and Commercial Cultivars in International Disease Trap Nursery (IDTN)

Likewise, IDTN containing 110 wheat lines was evaluated at Khumaltar during 2006-2010 wheat seasons planting in simple two rows of 1.5 m long at 0.25 m row spacing.

2.4 Virulence and Avirulence Analysis of Stripe Rust between 2005 and 2006

The international wheat stripe rust differential set (20 lines) composed at IPO-DLO, the Netherlands were evaluated at Khumaltar in 2005 and 2006 wheat seasons using two rows of 1.5 m long planted at 0.25 m row spacing. Virulence and avirulence reaction types were recorded as the methods described by Danial and Broers [13].

2.5 Evaluation of Wheat Lines/Cultivars for Stripe Rust Resistance

Screening of advanced wheat breeding lines from the Wheat Research Improvement Program in Nepal and CIMMYT was done at Khumaltar under artificial epiphytotic condition. Individual plot size was 0.75 m² consisting of two rows of 1.5 m long at 25 cm row to row spacing. Two rows of susceptible varieties (Agra local, Morocco and WK594) were planted as border, while the susceptible check Morocco variety was planted every after the 10th entry. Two-week-old seedlings of Morocco grown in pots were inoculated and covered with polythene sheets and kept inside the polyhouse at 9 °C. Inoculated plants were checked for the rust after two weeks of inoculation, and the spores were collected when the plants showed high production of spores. Spore suspension was made in distilled water

with one drop of Tween 20. Inoculation was done by spraying using Ulva sprayer. Disease scores on adult plants were recorded using the modified Cobb's scale. *Yr* genes in the cultivars and the differential lines were mentioned based on gene postulation done at IPO-DLO [14] and the field book of IYRTN compiled by ICARDA as well as Louwers et al. [15].

3. Results and Discussion

3.1 Effective Stripe Rust Resistance Genes Evaluation Using NILs Set

Host reaction and stripe rust severity differed for different *Yr* genes in different years (Table 1). Stripe rust resistance genes *Yr1*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr17*, *Yr18*, *Yr27* and *Yr32* were ineffective against the prevalent races. Similarly, *Yr24* and *Yr26* showed variation in reactions and severities in the tested years with usually resistant to moderately susceptible reactions. However, some genes (*Yr5*, *Yr10*, *Yr15* and *YrSp*) consistently showed resistant reactions in all tested years.

3.2 Monitoring Yellow Rust Resistant Genes Using IYRTN

The majority of lines in the nursery showed resistant to moderately resistant reactions in 2007-2009 at both sites (Table 2). The lines with different *Yr* gene combinations, such as Oyata 85 (*Yr27* + *Yr18*), Super Kauz (*Yr9* + *Yr27* + *Yr18*), Pastor (*Yr31* + APR), Vilmorin 23 (w; *Yr3a*, 4a + other) and Moro (w; *Yr10*), were resistant in all testing years (Table 3). Anza though has two genes including *Yr18*, showed moderate infection. Susceptible cultivar Morocco had high score of the rust during the test years, while Kalyansona also showed susceptible reaction [9].

3.3 Monitoring Different Promising Wheat Lines and Commercial Cultivars in IDTN

Fifteen of the 110 lines in the IDTN showed resistant reactions to the rust in all five years (Table 3). Oyata

Table 1 Stripe rust severities and reactions on NILs, Australia recorded at Khumaltar, Nepal during 2005-2010 wheat seasons.

Isoline/cultivars	Donor source	Stripe rust severities and reaction during 2005-2010					
		2005	2006	2007	2008	2009	2010
<i>Yr1/6*</i> Avocet S	Chinese 166	60MS-S	40MS	60S	40MS	40S	40S
<i>Yr5/6*</i> Avocet S	<i>Triticum</i> sp. Album	TR	5R	TR	0	TR	TR
<i>Yr6/6*</i> Avocet S	Oxley	100S	80S	80S	80S	80S	60S
<i>Yr7/6*</i> Avocet S	Lee	100S	80S	80S	80S	80S	60S
<i>Yr8/6*</i> Avocet S	Compare	100S	40MS	80S	80S	60S	60S
<i>Yr9/6*</i> Avocet S	Clement	NA	20R	80S	60S	60S	60S
<i>Yr10/6*</i> Avocet S	Moro	TR	20R	TR	TR	TR	TR
<i>Yr15/6*</i> Avocet S	<i>Triticum dicoccoides</i> derivative V 763-251-wb	TR	20R	TR	TR	TR	TR
<i>Yr17/6*</i> Avocet S	Shortim/VPM derivative	100S	40MS	90S	60MS	60S	60S
<i>Yr18/6*</i> Avocet S	Jupateco R	60MS-S	40MS	80S	60S	60S	60S
<i>Yr24/6*</i> Avocet S	Meering 2*/K733/ <i>Triticum tauschii</i> (CPI 18911)	40MR	20R	TR	50MS	20MS	20MS
<i>Yr26/3*</i> Avocet S	<i>Triticum turgidum</i>	40MR	20R	TR	0	TR	TR
<i>Yr27/6*</i> Avocet S	Oyata 85	80S	60S	80S	80S	80S	80S
<i>Yr32/6*</i> Avocet S	Carstens V	100S	40MS	80S	60MS	60MS	60MS
<i>YrSP/6*</i> Avocet S	Spaldings prolific	TR	20R	TR	TR	TR	TR
Jupateco R (<i>Yr18</i>)		20R	40MR	60S	TR	60S	TR
Jupateco		80S	40S	60S	60S	60S	60S
Avocet R (<i>YrA</i>)		100S	80S	80S	80S	80S	80S
Avocet S		100S	80S	80S	40MS	80S	80S

NA = not available; TR = trace resistance; R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; 40MR: 40% severity with moderately resistant reaction.

Table 2 Severities and reactions recorded on some wheat lines included in the IYRTN at Ramkot and Khumaltar, Nepal during 2007-2009 wheat seasons.

Cultivar/line	Stripe rust scores at Ramkot and Khumaltar during 2007-2009				
	2007		2008		2009
	Ramkot	Khumaltar	Ramkot	Khumaltar	Khumaltar
Oyata 85 (<i>Yr18</i> + <i>Yr27</i>)	10R	10R	0	5MR	0
Super Kauz (<i>Yr9</i> + <i>Yr27</i> + <i>Yr18</i>)	10R	10R	TR	0	-
Pastor (<i>Yr31</i> + APR)	40R	20R	20MR	10R	10MR
Attila (CM85836-50Y-OM-OY-3M-OY)	40R	10R	30MR	10MR	0
Vilmorin 23 (W) (<i>Yr3V</i>)	10R	10R	0	10MR	TR
Moro (W) <i>Yr10</i>	10R	10R	0	0	TR
Strubes Dickkopf (W) SD	20R	20R	0	20MR	20MS
Nord Desprez (W) 3N	10R	20R	0	0	0
Compair (S) (<i>Yr8</i> + <i>Yr19</i> + APR)	20R	10R	0	0	TR
Carstens V (W) CV	20R	10R	0	0	0
Spaldings Prolific (W) Sp	10R	10R	20R	10R	TR
Kalyansona (S) (<i>Yr2</i>)	60MS-S	80S	80S	60S	10MR
Tatara (<i>Yr3</i>)	-	-	TR	10R	0
Anza (<i>YrA</i> + <i>Yr18</i>)	40R	40MS	50MS	50MS	0
Cook (S) APR	20R	10R	40R	40R	0
Morocco	80S	80S	80S	80S	80S

MS = moderately susceptible; MR = moderately resistant; TR = trace resistance; R = resistant, - = data not available.

Table 3 Stripe rust severities and reactions recorded on wheat genotypes in the IDTN at Khumaltar, Nepal during 2006-2010.

Genotype/pedigree	Stripe rust severity and host reaction				
	2006	2007	2008	2009	2010
CS2D-2M	10R	40MR	R	40MS	5MR
TC*6/P158548 (RL6058)	5MR	20R	10R	10MS	10MR
RL5711	10R	40MS	10R	40MS	40MS
Noroeste	40MS	40MR-MS	10R	80S	40MS-S
Jupateco 73R	40R	20MR	R	20R	20MR
Anahuac 75	40R	40MR	10MR	40R	40MR
Genaro 81	20R	20MR	R	R	20MR
Seri 82	10R	40MR	R	R	10MR
Babax # 2	30R	40MR	20MR	R	20MR
Tonichi 81	20R	20MR	10MR	R	20MR
Parula	20R	40MR	10MR	20MR	20MR
Pavon 76	60MS-S	40MS-S	60MS-S	20MR	20MR
Attila (CM85836-50Y-0M-0Y-3M-0Y)	10R	10MR	10MR	R	10MR
Amadina (CRG682-8Y-3B-3Y-2B-0Y-0Y)	20R	R	R	R	R
Buck Buck	10R	R	R	R	R
Chapio = CAR422/ANA/YACO/3/KAUZ*2/TRAP//KAUZ	R	10R	R	R	R
Tukuru = TRAP#1/YACO/3/KAUZ*2/TRAP//KAUZ	R	10R	R	R	20MR
Kukuna = NI/PBW65/3/KAUZ*2/TRAP//KAUZ	R	R	R	10R	10MR
Kakatsi = VN/YACO/3/KAUZ*2/TRAP//KAUZ	R	R	R	R	R
Morocco	100S	80S	60S	80S	80S
PBW343	R	R	R	R	20MR
PBW373	R	R	R	R	R
RAJ3765	R	R	R	R	R
WL1562	20R	10R	R	R	R
Bhrikuti	R	10R	10MR	R	R
Inquilab	40R	40R	10MS	R	R
Bakhtawar	10R	R	R	40MS	R
Kohistan 97	80S	80S	20MS	R	R
Punjab 85	60S	60S	10R	60MS	R
Kanchan	40R	60S	10MR	60MS	60MS
Gaurab	40MS	10R	R	R	10MR

MS = moderately susceptible; MR = moderately resistant; R = resistant.

85, Jupateco R, Genaro 81, Seri 82, Super Kauz, Babax 2, Tonichi 81, Parula and Buck Buck were resistant, whereas Pavon 76 was moderately susceptible. Other lines, like Amadina, Kukuna, Kakatsi and PBW343 (*Yr27*), also showed resistant reactions. The widely grown cultivar of Nepal, Bhrikuti and Inqalab of Pakistan mostly showed resistant to moderately resistant reactions.

3.4 Virulence and Avirulence Analysis of Stripe Rust between 2005 and 2006

Out of 19 differential lines, Clement (*Yr9*), Triticum

spelta-album (*Yr5*), Hybrid 46 (*Yr4+*), Reichersberg 42 (*Yr7+*), Heines Peko (*Yr6+*), Compair (*Yr8+*), Spaldings Prolific (*Yrsp*) and Heines V11 (*Yr2+*) showed resistant reactions in both years. The pathotype had virulence to *Yr1*, *Yr7*, *Yr6*, SU and CV. It is avirulent to *Yr3+*, *Yr10+*, *YrSd*, *Yr9+*, *Yr5+*, *Yr4+*, *Yr6+*, *Yr3N*, *Yr8+*, *YrSp*, *Yr2+* and *Yr7+*. Present race was different than previous, so Hybrid 46, Heines Peko, Compiar and Heines VII showed susceptible reactions during 80s-90s, indicating a variation in virulence during these 2005 and 2006 years (Table 4). This race is quite different from the

previous ones. It was highly virulent to *Yr27* and Carsten V.

3.5 Evaluation of Wheat Lines/Cultivars for Stripe Rust Resistance

Long-term monitoring study showed differences in stripe rust severity on a set of cultivar known to possess major genes (Table 5). The two cultivars BL1473 and Nepal 297 possessing *Yr2* showed higher rust severity in 2006, 2007 and 2008. Among 22 commercial varieties and advanced breeding lines

from Nepal, WK1123, WK1182, BL2739, BL2879 and WK1504 were resistant to the rust in all four years (Table 5). The pipeline variety BL3503 showed moderately resistant to moderately susceptible reactions, while BL3235 showed no infection at all. The wheat lines with *Yr9* and additional genes, like Annapurna-1 and BL1022, showed low rust scores. They showed susceptible reactions earlier, probably due to prevalence of new *Yr27* virulent race. They may be useful for release and also for breeding purpose.

Table 4 Stripe rust virulence factors to *Yr* resistance in the differential set from IPO-DLO in 2005 and 2006.

Year	Virulence factor ¹	No. of virulence factors
2005	1, 7, 6+, SU, CV (<i>Yr32</i>)	5
2006	1, SU, CV (<i>Yr32</i>)	3

¹ Refers to resistant genes in the differential cultivar: *Yr1* in Chinese 166, 7 in Lee 6 in H. Kolben, SU in Suwon/Omar, CV in Carstens V according to Danial and Broers [13] and Louwers et al. [15].

Table 5 Responses of commercial cultivars and advanced wheat breeding lines from Nepal tested against prevalent races of stripe rust at Khumaltar, Nepal, during 2005-2008.

Cultivars	Pedigree	Stripe rust score			
		2005	2006	2007	2008
Gautam	Siddhartha/Ning/8319/NL297	10R	10R	10R	20MR
Pasang Lhamu	Papago/Seri	TR	10R	10R	0
Annapurna-1	KVZ/BUHO/KAL/BB	TR	40MR	10R	10MR
Annapurna-4	KVZ/3/CC/INIA/CNO/ELGAU/4/SN64	40MS	40MS	40S	60MS
Nepal 297	HD 2137/HD 2186/HD 2160	60S	80S	80S	80S
BL1473	Nepal 297/NL352	60MS	40MS	60S	20MS
WK1204	SW89.3064/STAR	10R	10R	10R	20MR
BL3503	BL1961/NL867	-	-	20MR	20MR
BL3235	NL872/NL868	-	-	TR	0
BL1022	PVN/BUC	10MS	10MS	10MS	10MS
Advanced lines					
WK1123	87Zhong215/WK686	TR	TR	TR	TR
BL2089	NL297*2//Danial88/HLB25	10R	10R	40MS	40MS
WK1320	87Zhong212/WK685	20R	40MS-S	40MR-MS	30MS
WK1182	CMH25.2578/WK685	TR	10R	10R	TR
WK1156	87Zhong215/WK686	TR	TR	TR-40MS	TR-20MS
BL2739	BL1473/NL765	20R	10MR	10R	0
BL2879	LGP71AB(WG)/NL759//NL781	TR	TR	10R	0
WK1504	3BW27/G4M-1M-6;4-3-2-1-1-2//RR21	10R	10R	10R	10R
WK1023	SDY/ALD/3/NAI60/HNC7//BUC/4/Alucan	20MR-40MS	TR-40R	20MR	20MR
WK1444	Bhrikuti/Simal4058	20R	20MR	10R	20MS
WK936	Sincron/F287x11F285N	20MR-MS	TR	20MR-5MS	20MR
Susceptible check					
Morocco		80S	100S	80S	80S

MS = moderately susceptible; MR = moderately resistant; R = resistant; - = not tested; 0 = no infection.

They are selected because they are promising lines and pipeline genotypes.

High severity of stripe rust on standard differentials and other wheat lines in 1980s as well as in the recent studies confirmed that the rust is an endemic problem in the hills and high hills due to frequent changes of new pathotype [5]. Resistances shown by several differential lines possessing more than one gene or combination of genes could be an option to develop the rust resistant wheat varieties for the hills and high hills.

The change in reaction of the cultivar possessing *Yr2* and *Yr9* from 1980 to 2008 suggests that *Pst* population could have changed over that period. The most prevalent races during the mid 1980s were 7E150, 7E158 and 15E158 [15], and before that period, were some primitive races, like 2EO and 4EO [16-18]. The cultivar Annapurna-1 possessing *Yr9* was resistant in 1980 [6], and it was recorded susceptible in 1997 due to change in the race of 46S119 [19], but it was again resistant in 2007 and 2008. It is also suggested that most of the Veery's lines are heterogeneous, which shows different rust reactions at different times, especially on Annapurna-1 and Annapurna-3. On the other hand, Pasang Lhamu showed consistently resistant from 1989 till 2008, suggesting that this cultivar has other resistance genes in addition to *Yr9*. Since Pasang Lhamu has remained resistant to the rust over 20 years under severe rust epidemic conditions, it could be considered as a durable source of stripe rust resistance and useful for the hills and high hill wheat growing environments. This cultivar has been widely used in the breeding program. Similarly, Plant Pathology Division had tested wild emmer derivative (*Triticum dicoccoides*) to broaden the genetic base of wheat cultivars in Nepal [8, 20]. The lines V763 and V879 were resistant to the rust and they have *T. dicoccoides* G-25 in their pedigree which carries *Yr15* [21]. This gene was incorporated in high yielding disease susceptible wheat varieties, such as UP262, RR21, Triveni and Vaskar.

A number of advanced breeding lines and

promising commercial cultivars developed in the last few years, proved resistant to the rust. This suggests that resistant germplasms are being introduced to wheat improvement program in Nepal. A few of these lines that originated from CIMMYT, Mexico possess minor genes based stripe rust resistant parents in their pedigree, which could be valuable sources of resistance in the hill and high hill regions. One of the examples is WK1204 released for the hills in 2007, which is resistant to the rust under this environment [5]. This cultivar got wider coverage within a short period using faster dissemination through participatory varietal selection (PVS) method. Soon after 2005's epidemic of the rust, wheat cultivar Gautam also emerged as a potential rust resistant wheat cultivar and seeds were extensively distributed to farmers in the rust prone area, though it was released for warmer area of Terai. During seed scarcity period, Gautam and WK1204 were proved as miracle cultivars and led to quick replacement of old susceptible ones in Nepal. Additionally, many other lines, such as WK1182, WK 1444, BL3235 and BL3503, were also promoted through extensive PVS method. Because of all these efforts, significant minimization of the rust was observed after 2007. This work of enhancing genetic diversity for the rust resistance in Nepal hills was further strengthened by the release of two more resistant varieties Gaura (BL3235) and Dhaulagiri (BL3503) in 2012. Further elite lines originating from CIMMYT and possessing minor genes could be valuable sources for resistance to the rust in the hills and high hills region in future.

There are important implications of development of new races or change in population structure of *Pst* in the hills of Nepal. Stripe rust present in the summer grown wheat, maturing in October and November in the hills, could move down to the lower hills, foot hills and eventually to the low-lands which are parts of the vast Gangetic Plains [22]. It is experienced that the early multiplication of the rust inoculum in Nepal directly affects wheat in India [23]. Since urediospores

of the rust are carried over long distances, change in virulence in one country has epidemic effects in the other [7] and needs common strategies to tackle the problems. The extensive cultivation of the Veery 5 selection created a vulnerable situation, and stripe rust epidemic was recorded in the Middle East in 1990s and in Pakistan during and after 1994 [7]. The new *Yr9* virulence caused heavy outbreak in India and Nepal during 1996 and 1997 [7, 19]. Therefore, it is important to monitor the virulence pattern of the rust in the hills and high hills belt of Nepal and identify sources of resistance. This may also help to develop common strategies, like increasing genetic diversity of varieties, race monitoring and increasing adult plant resistance to minimize the epidemics of the rust in the region [22, 24]. Faster seed delivery to farmers and researchers as demonstrated in case of Ug99 resistant wheat varieties can also be replicated for stripe rust resistant for quick management of rust [25].

4. Conclusions

Since there is little published information on the long-term monitoring of *Pst* in South Asia, the findings of this study is valuable to manage stripe rust in the subcontinent. Four genes (*Yr5*, *Yr10*, *Yr15* and *YrSp*) consistently showed resistance to the prevailing races. The gene *Yr9* and *Yr27* in combinations with *Yr18* were found effective. Other lines with combination of minor genes were also found effective. The genotypes Amadina, Kukuna, Tukuru, Kakatsi and Buck Buck have been widely used in breeding program. Resistant varieties WK1204, Gautam, Gaura and Dhaulagiri have wider adoption even at remote rust prone areas, which replaced susceptible varieties, increased genetic diversity for the rust resistance and ultimately enhanced food security in the country. Information on effective genes and resistant varieties could be helpful in developing stripe rust resistant wheat. The advanced breeding lines which are identified as resistant to the rust could be further tested for their agronomic performance and to release

as commercial cultivars or use in the wheat breeding programs.

Acknowledgments

The authors are grateful to Nepal Agricultural Research Council (NARC) and Plant Pathology Division, National Agriculture Research Institute (NARI), Lalitpur, Khumaltar, Nepal for all cooperation extended during the research conduction. They are very thankful to CIMMYT, ICARDA and Plant Breeding Institute, Sydney, Australia, National Wheat Research Program, Bhairahwa, Nepal, Agriculture Botany Division, NARI, Lalitpur, Khumaltar, Nepal for providing germplasm for this study and all kinds of cooperation. The authors also would like to convey their thanks to Mr. Surath Pradhan, program coordinator of CIMMYT, Nepal and Santosh Sanjel, research assistant for their support in preparation of this manuscript. Finally, the authors are grateful to Mr. Manoj Sapkota, research assistant for making this paper in shape.

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