CHARACTERIZATION OF STRIPE RUST (*Puccinia striiformis*) RESISTANCE IN ELITE WHEAT GENOTYPES

BY

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J-17-M-513

Thesis submitted to Faculty of Postgraduate Studies
in partial fulfillment of requirements
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PLANT PATHOLOGY

-

DIVISION OF PLANT PATHOLOGY

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Main Campus, Chatha, Jammu-180009

2020

CERTIFICATE -I

This is to certify that the thesis entitled **"Characterization of stripe rust (*Puccinia striiformis)* resistance in elite wheat genotypes"** submitted in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture (Plant Pathology),** to the Faculty of Post Graduate studies, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu is a record of bonafideresearch carried out by **Ms. Neeru Sadotra,** Registration Number **J-17-M-513,** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that such help and assistance received during the course of thesis investigation have been duly acknowledged.

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ABSTRACT

Stripe rust (*Puccinia striiformis*) is one of the major constraints for enhancing production of the wheat crop under cold weather conditions in North western plain zone of India. Present study was conducted at Research Farm, SKUAST-J with the objective characterization of stripe rust *(Puccinia striiformis)* resistance in elite wheat genotypes.

The present investigation comprising advance breeding lines from CIMMYT in the form of IBWSN (International Bread Wheat Screening Nursery), cultivars of NWPZ and susceptible varieties (Agra Local, WL-711, Kharchia-65 and PBW-343) were selected for detailed study. The genotypes IBWSN-1046, 1059,1086,1102,1129,1284,1286,1287, 1288, 1293, 1294 were immune infection type at seedling stage and also adult plant stage against all three pathotypes 78S84, 46S119 and 110S119. Genotypes IBWSN-1160, 1164, 1038, 1168,1041, 1042, 1175, 1046,1049,1242,1067, 1081, 1082, 1253, 1086, 1087, 1290, 1291, 1098,1105, 1298, 1114, 1300, 1115, 1118, 1148, 1153 and PBW-752 showed R, MR, MS and S infection type with quite slower rate and low level of severity (<20). Such genotypes may exhibit better field durability than those possessing vertical (immune) resistance genes only. Genotypes IBWSN-1021, 1154, 1033, 1165, 1167, 1039, 1030, 1161, 1163, 1169, 1172, 1043, 1173, 1044, 1174, 1045, 1177, 1178, 1048, 1239, 1268,1094,1097, 1099, 1295, 1103, 1296, 1299,1109, 1122, 1141, 1144, 1145, 1149, 1151, 1152 and WH-1080 truly represents acceptable levels of slow rusting, which restricts the evolution of new virulent races of the pathogen because multiple point mutations are extremely rare in nature. Total sugars and non-reducing sugars were higher in susceptible genotypes but reducing sugars and phenols were higher in resistant genotypes at 40 and 70 days after sowing. At 70 days after sowing, amount of total sugars, reducing sugars and non-reducing sugars were reduced but total phenols were increased in comparison to 40 DAS in both resistant and susceptible genotypes.

Keywords: Stripe rust, *Puccinia striiformis*, Infection Type, Pathotype

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Chapter-1

Introduction

CHAPTER-I

INTRODUCTION

Wheat (*Triticum aestivum L.*) is most important food grain crop which occupies first position in terms of global acreage. It represents approximately 19 percent of global major cereal crop production. It is cultivated on 15.4 percent of the arable land in the world in almost all countries, except the humid and high-temperature areas in the tropics and high-latitude environments. Wheat is produced for a wide range of end-users and it is a critical staple food for a large proportion of the world's poor farmers and consumers. It contributes 30 percent of the world's edible dry matter and 60 percent of the daily calorie intake in several developing countries (FAO STAT, 2015). India is the second largest wheat producing country in the world. With the advent of Green revolution in the 1960's, India's wheat crop production and productivity increased at a great level. In the year 2018-19, wheat production has made a landmark achievement by producing 101.20 million metric tonnes with an average national productivity 3424 kg/ha. In Jammu and Kashmir, wheat is grown over an area of 288 thousand hectare with 504 thousand quintals production and 17.51 quintals per hectares productivity (Anonymous, 2018-19). Demand for wheat in the world continues to grow rapidly with increasing population growth. Increasing wheat yield potential in the developing world is a primary aim for food security concern (Duveiller *et al.*, 2007). It is predicted that the world population will surpass 8 billion by 2025 and the demand is expected to exceed 880 million metric tons by 2050 (Dixon *et al*., 2009), thus the production needs to increase at least by 50 percent by the year 2025 (Yadav *et al.*, 2017).

Diseases are one of the major factors, which restrict the increment in the productivity of wheat. Wheat crop is attacked by a number of diseases, but three rusts of wheat i.e. black (stem) rust (*Puccinia graminis* Pers. f. sp *tritici* Eriks. & Henn.), brown (leaf) rust (*P. triticina* Eriks.) and stripe rust (*P. striifromis* Westend.) are known to cause significant losses in wheat worldwide. Stripe rust fungus, mainly infects wheat, but can also cause infection in barley, rye, and triticale. It is an important disease of wheat in most of cool wheat producing regions (Joshi *et al.*, 1970 and 1974). It was first reported in USA (Carleton, 1915) and later on, the infections were also reported from other parts of the world. In early 1970

and mid 1980's, the stripe rust epidemics occurred in North Africa, Indian subcontinent, Middle east, East Africa highland and China due to the breakdown of resistance genes (*Yr2* and *Yr9*) which were present in most of the cultivated varieties (Saari and Prescott, 1985; McIntosh, 2009; Chen *et al.*, 2009). Yield losses caused by stripe rust epidemic were estimated at around 40 per cent and losses due to black and stripe rust epidemics can be as great as 100 per cent depending upon the level of resistance of cultivars.

In India, stripe rust is the most damaging disease under cold weather conditions in north-western plain zone of India (Dutta *et al*., 2014). Stripe rust oversummers throughout the Himalaya, Hindukush, and Sulaiman mountain ranges and north-western Frontier Province, but the largest amounts are in the mountain and valleys of Indus and its tributaries (Mehta, 1952; Joshi *et al*., 1984). It also over summers in the Palany and Nilgiri hills in southern part of the country (Nagarajan and Singh, 1990).

Efforts are always made to reduce the yield losses in wheat caused by the rusts. There are two main practices that can be employed to manage stripe rust of wheat: the use of fungicides and genetic control through host resistance. Fungicides are effective, but expensive and environmentally unfriendly. Application of resistance genes in wheat is the most effective, economic and environmentally safe approach for controlling rusts (Chen *et al.*, 2005).

In India, it has been shown that functional life of a commercially grown rust resistant wheat variety is only 3-5 years (Rao *et al*., 1981). The frequent break-down of major seedling resistance gene e.g. yellow rust resistance gene *Yr*9 in 1996 was reported by Nayar *et al.* (1997) and *Yr*27 in 2001 by Prashar *et al*. (2007). However, varieties with a specific resistance gene usually remain effective only for a few years because the extreme selection pressure on the pathogen population with mutants results in gain in virulence in the pathogen population for that particular gene. With the domestication of wheat, new rust resistance genes were introgressed and some of these form alien sources. However, there had been a consequential evolution of rust pathogens also. Both wheat and rusts have undergone a series of steps in the course of evolution. Different types of resistance such as seedling or all-stage resistance, adult plant resistance (APR) and high temperature adult plant

resistance (HTAP) are common in wheat germplasm. Seedling resistance is effective throughout the growth stage of the plant (Imatiaz *et al.,* 2003). New physiological races of the rust fungi have consistently arisen to render seedling resistant varieties fully susceptible in nature. This directs attention to the need for plant characters other than seedling resistance, whereby rust damage may be prevented or minimized on a more permanent basis. Adult plant resistance genes individually provide low levels of resistance and combinations of three or more genes are essential to express commercially adequate levels of resistance (Bariana *et al.,* 2007). Quantitative/polygenic resistance is believed to be difficult to breakdown by the pathogen (Knott, 1989). Slow rusting is a partial or incomplete resistance that permits the fungus to sporulate, although on a reduced scale, and epidemic can proceed but at a reduced rate (Van der Plank, 1984). It is generally not affected by the types of pathotypes i.e. non-specific in nature (Knott, 1989) and keep the diseases below threshold level and decreases the chances of selection of new pathotypes (Nayar *et al.,* 2003).

Considering the potential of seedling resistance, adult plant resistance and slow rusters on wheat varieties, the present investigation was undertaken to address the following objectives:

1. To evaluate wheat genotypes against stripe rust at seedling stage.
2. To identify promising wheat genotypes against stripe rust at adult plant stage.
3. To characterize identified resistant genotypes for biochemical attributes related to resistance.

Chapter-2

Review of Literature

CHAPTER-II

REVIEW OF LITERATURE

2.1 Rust

Rusts have been a major disease of various crops since times immemorial. It is assumed that cereal rusts have been present and evolving during domestication of cereal crops as a major segment of agriculture. Kislev (1982) reported archeological evidence of *Puccinia graminis* on wheat lemma fragments dated 1400-12000 B.C. In Rome, the sacred festival, Robigalia was celebrated annually from about 700 B.C. for satisfying rust god. This ceremony, founded by Numa Prompilins, the second king of Romans was held on 25th April every year, when wheat crop began to head. Rusts of wheat have always been most destructive in comparison to the other crop diseases. Since it is a multicyclic disease, under favorable environmental conditions it spreads quickly in a large area and the resultant epidemics causing great losses in yield and yield components.

2.2 Historical background of stripe rust

Yellow rust (*Puccinia striiformis* West.) of wheat was commonly known as "golden rust" among British plant pathologists and occasionally known as yellow rust. In Sweden and Denmark, it was known as "Gulrost", in France as "Routille Janne", in Germany and Austria as "Gel brost" (yellow rust) and in Italy as "Ruggins Striata del grano". Humphery and Hungerford (1924) proposed the name stripe rust. In current literature, both names, yellow and stripe rust have been used.

2.3 Taxonomy of stripe rust pathogen

Gadd and Bjerkander first designated stripe rust pathogen in 1777 (Eriksson and Henning, 1896), since then its nomenclature has undergone numerous changes. Schmidt in 1827 designated the first-time stripe rust pathogen infecting barley glumes as *Uredo glumarum* (Humphrey *et al*., 1924). Afterwards, in 1854, Western drop named the stripe rust pathogen of rye as *P. striiformis.* Later on, in 1894 Eriksson and Henning showed that stripe rust resulted from a distinct pathogen, which they named *Puccinia glumarum* (Schm.) in a significant document on the taxonomic work (Stubbs, 1985). Hylander *et al*., (1953) and Cummins and

Stevenson (1956) revived the name that is currently in use, *P. striiformis* West (Manners, 1960). Nowadays, the forma specialis is added after the scientific name and is currently written as *Puccinia striiformis* f.sp. *tritici.*

2.4 Causal organism

The causal organism of stripe rust of wheat is *P. striiformis* West. The uredospores of this fungus are nearly round, binucleate and unicellular. The size is variable being 23-35 x 20-25 µ. Spore wall is colorless, minutely echinulated, and may possess 6-16 germ pores. On germination of the spores, the germ tube forms a small fragile appressorium over a stoma of the leaf (Stubbs, 1985). A tube from the appressorium enters through the stomatal opening and forms a large, thick walled cylindrical sub-stomatal vesicle which is placed just below the stomatal silt. The hyphae collect beneath the epidermis to form the uredosori. Teleutospores are dark brown, often flattened at the tip and have two cells. They measure 35-63 x 12-30 µ in size. They are capable of immediate germination when mature (Singh, 1990). Jin *et al.* (2010) proved that the pycnial and aecial stages of the fungus also occur on berbaris plant. But in India, survival of rust fungus is through uredospores, formed on collateral hosts including *Bromus japonicas* (Joshi and Manchanda, 1963).

2.5 Symptomatology

The disease is characterized by small yellow coloured uredial pustules, arranged in streaks, mainly on leaf lamina but under severe infections uredial pustules may appear on the leaf sheath, stalk, glumes, awns and even on grains. The yellow streak consists of a number of oval, lemon yellow pustules lined along with the veins. In severe infections, arrangements of streaks are not easily distinguishable as the pustules are crowded together. The uredospores do not break through the epidermis as quickly as in other rusts, but do so eventually and a yellow spore mass is exposed for wind dispersal. The telia appear late as dull black patches or spots chiefly on the under surface of the leaf and also on other parts of the host. Like uredia, telia are also arranged in rows, but remain covered by host epidermis as a flat black crust (Pal, 1966; Singh, 1990).

2.6 Distribution and Economic importance

The stripe rust is restricted in distribution in contrast to both the stem rust and leaf rust of wheat. Stripe rust was first reported in USA (Carleton, 1915). Later on, its outbreak has been reported from more than 60 countries of the world and all the continents except Antarctica (Chen, 2005). However, it is most important disease of wheat in Britain and North West Europe. This rust is found along the pacific coast and inter-mountain areas of North America, Rocky Mountains in the North, cooler section of Canada, cooler plain area of Southern Argentina and Britain and North West Europe (Dickson, 1947). It is also prevalent in the temperate South America, China, Kenya, Mediterranean area and India (Hassebrauk, 1965). Stripe rust is spreading rapidly in vast tracts stretching from Turkey, Syria and Northern Iraq to Southern Uzbekistan and the potential crop loss is in billions of dollars (Chen, 2005). In China, stripe rust is the most destructive on common wheat (*T. aestivum* L.) and can cause severe yield losses when susceptible cultivars are widely grown and weather condition are favorable for the disease. Significant yield losses have occurred in the North West, South West and North of China in 1950, 1964, 1990 and 2002 (Wan *et al*., 2004). It is reported from Henan (China) that the relative incidence of the pathogen *P. striiformis* West. was maximum in comparison to *P. recondite* and *Erysiphe graminis* in the year 1987 and 1988 under field trial (Dong *et al*., 1989).

Stripe rust is restricted more towards the cooler parts of the country where low temperature prevails during the crop season (Joshi *et al.*, 1970; 1974, Sagar, 1980). In India, stripe rust is the most damaging disease under cold weather conditions in North western plain zone of India (Dutta *et al*., 2014). Stripe rust over summers throughout the Himalayas, Hindukush, and Sulaiman mountain ranges and in the northwestern Frontier Province, but the largest amounts are in the mountain and valleys of Indus and its tributaries (Mehta, 1952; Joshi *et al*., 1984). In India, stripe rust is distributed in North and North Western regions comprising Western Uttar Pradesh, Punjab, Haryana and Rajasthan **(**Joshi and Saari, 1970). It also over summers in the Palany and Nilgiri hills in southern part of the country (Nagarajan and Singh, 1990).

The ability of this fungus to mutate, multiply rapidly and spread over large areas has led to widespread epiphytotic conditions in India (Nagarajan and Joshi,

1975). The first rust epidemic in the Indian subcontinent was reported by Major Sleeman (1839). Rust epidemic in 1946-47 in Maharashtra, Madhya Pradesh, Rajputana and part of Uttar Pradesh, which destroyed nearly 2 million metric tons or approximately one fifth of total production of wheat (Asthana, 1948). During 1971-72 and 1972-73 stripe rust appeared in epidemic form in Punjab, Haryana and Western Uttar Pradesh and nearly 0.5 to 0.8 million metric tons of wheat was lost (Joshi *et al.*, 1985). In 1982, yellow rust was severe in Punjab, Haryana and Western Utter Pradesh and Jammu and Kashmir (Nagarajan *et al.*, 1984). The stripe rust epidemics in 1994-95 and 1995-96 crop seasons caused grain yield losses worth of 2.0 billion rupees in Pakistan (Ahmed, 2000). In India the work on losses was done in earlier 1970's and losses up to 70 per cent were reported (Nagarajan and Joshi, 1975; Aujla *et al*., 1975). During 2010-11, yellow rust appeared in severe form in the plains of Jammu, foot-hills of Himachal Pradesh, parts of Haryana, Punjab and Tarai region of Uttarakhand (Sharma and Saharan, 2011). Long season epidemics of stripe rust affect all the yield parameters (total grains per plot, 1000 grain weight, number of grains produced per head, tiller number, test weight and grain yield/plant) with losses up to 50 percent in grain yield being recorded in susceptible cultivars **(**Ash and Brown, 1990). Average annual yield due to the disease loss was four per cent (Hacke, 1992). It is reported from CIMMYT (Mexico) that stripe rust reduced yield up to 58% in commercial bread wheat variety "Dashew" in 1988. It also reduced germination ability and 1000 grain weight by 72 per cent and 56 per cent respectively (Badebo and Bayu, 1992). Yellow rust is one of the major constraints in enhancing production of the wheat cultivar RR21 in the eastern hills of Nepal. In one location, at low altitude 40-78 percent reduction in yield occurred under natural epiphytotic conditions (Duwadi *et al*., 1993). Murray *et al.* (1994) reported that stripe rust was associated with mean losses of up to 84 percent in the yield of wheat in Southern New South Wales, Australia during 1984-87. Stripe rust causes regular crop losses ranging from 0.1 to 5 percent with rare events accounting for much higher losses (Wellings, 2011).

2.7 Physiological races

Stakman *et al.* (1962) defined the physiological race as a biotype or a group of biotypes with in a species or lower taxon and can be distinguished from the other biotypes by physiological characters including pathogenicity. Genetically, the term

biotype denotes the population of individuals of the same genetic constitution. Further, each formae speciale of rust species contains enormous variation. These variants are called races which are differentiated on the basis of avirulence/ virulence on a set of hosts called differentials. The first authenticated report of distinct physiologic race of rust pathogen was given by Main and Jackson in 1926. In India, the identification of races in different wheat rusts was initiated by Mehta (1923). With the discovery of gene for gene theory of Flor (1955) and its use later by Stakman *et al.* (1962), it was realized that pathotypes identification system requires modification in order to be more meaningful. Consequently, numerous methods using near isogenic lines were suggested around the world (Watson and Luig, 1963; Johnson *et al.*, 1972; Roelfs and Mcvery, 1974). A reevaluation of race identification and race nomenclature of wheat stripe rust was made by Johnson *et al*. (1972), introducing the binary notation, which is also being used in India (Nagarajan, 1983; Nagarajan *et al.*, 1985) and was, modified subsequently (Prashar *et al.*, 2007). The constituents of this system have been placed in three groups that are named as Set-A, Set-B and Set-0. Presently Set-A has 9, Set-B has 8 and Set-0 has 7 entries. Set-A consists of the old world differentials, which helps in maintaining a link to that of naming system of other countries, Set-B accommodated few European supplemental entries, Indian varieties and Tc**Yr9* (Thatcher with *Yr7* and *Yr9*), and Set-0 has popular varieties of wheat in India (Table.1) (Bhardwaj, 2011).

Table 1: Wheat differential lines and their *Yr*-genes used for pathotype identification of *Puccinia striiformis* f.sp. *tritici* in India

Set O	Set A	Set B
WH147	Chinese 166 *Yr1*	Hybrid 46 *Yr4*
Bilara	Lee *Yr7*	Heines VII *Yr2+*
WH416	Heines Kolben *Yr6*	Compare *Yr8*
HD2329	Vilmorin 23 *Yr3*	*T. spelta album Yr5*
HD2667	Moro Yr10	Tc* 6/*Lr26 Yr9+*
PBW343	Strubes Dickkopf	Sonalika *Yr2+*
HS240	Suwon 92 x Omar	Kalyansona *Yr2*
Anza	Riebesel 47/51 *Yr9+*	-
A-9-30-1	-	-

2.8 Pathotype distribution

Monitoring of the yellow rust virulence in different regions help to understand the current genetic variability of host-pathogen interactions. In addition, information on virulence is also useful in screening cultivars or breeding lines for the determination of resistance levels and exploitation of new resistance genes (Sharma-Poudyal *et al*., 2013). Deployment of trap nurseries utilizing isogenic lines for the assessment of pathogenic variation in *P. striiformis* offers several advantages as it provides a cost-effective means of pathogenicity assessment by alleviating reliance on sample collection, multiplication and processing through expensive environmentally controlled greenhouses (Wellings *et al*., 2000). In India, 28 pathotypes were identified up to 2012-13 (Bhardwaj, 2011). Besides these, five new pathotypes of *P. striiformis* have been identified and confirmed during the year 2014 (Anonymous, 2014). These have been designated as 46S117, 110S119, 238S119, 110S247 and 110S84 (Anonymous, 2014). These new pathotypes were more virulent than the existing pathotypes and appeared to have mutation in existing pathotypes on Suwon x Omar and Riebesel 47/51.

Over the years, diversity of pathotypes has decreased. The pathotype 46S119 was predominant before 2004-05, thereafter pathotype 78S84 was dominant up to 2010-11 seasons (Prashar *et al.,* 2015). In India, during crop year 2018-19 six pathotypes (46S119, 110S119, 110S84, P, and T) of wheat stripe rust pathogen were identified from eight Indian states and Nepal. They were avirulent to *Yr*5, *Yr*10, *Yr*15 and *Yr*Sp. The frequency of pathotypes 46S119 (virulent on *Yr*2, *Yr*3, *Yr*4, *Yr*6, *Yr*7, *Yr*8, *Yr*9, *Yr*17, *Yr*18, *Yr*19, *Yr*21, *Yr*22, *Yr*23, *Yr*25 and *Yr*A) was maximum (47.3%) in this cropping season. Pathotype 110S119, first identified in 2013-14, was present in 34.3 percent samples. Remaining four pathotypes were observed in 13.3 percent samples only (Anynomous, 2019). The pathotypes of North India displayed differences in distribution, frequencies and diversity across the states.

Table 2: Pathotypes of stripe rust (*P. striformis)* in India

Designation		Detection detail		Isolated from Line/Variety	Susceptible *Yr* gene/line
Old	**New**	**Year**	**Place**		
13	67S 8	1937	Palney Hill	Wheat Local	*Yr5*
14	66S 0	1965	Kangra	-	S. Omar
14A	66S 64	1970	Punjab	Kalyansona	KalyanSona
19	70S 0-2	1936	Rawalpindi	PB-8A	Wheat and Barley
20	70S 0	1937	Nilgiris	Wheat Local	S. Omar
20A	70S 64	1970	Punjab	-	KalyanSona
24	0S 0-1	1965	-	Barley Local	Barley
31	67S 64	1936	Shimla	Wheat Local	2
38	66S 0-1	1965	HP	-	S. Omar
38A	66S 64-1	1970	Punjab	Kalyansona	KalyanSona
57	0S 0	1965	-	Barley Local	Barley
A	70S 4	1937	Gurdaspur	Wheat Local	8
G	4S 0	1965	-	Barley Local	Barley
G-1	4S 0-3	1990	Nilgiris	Aeg. Searsii	Barley
I	38S 102	1973	Nilgiris	Sonalika	Chinese Spring
K	47S 102	1982	Punjab	-	Sonalika
L	70S 69	1988	Dalang Maidan	-	Hyb.46
M	1S 0	1987	Shimla	-	Barley
N	46S 102	1988	Dalang Maidan	-	Sonalika, KalyanSona
P	46S 103 46S 119 78S 84	1990 1996 2000	Dalang Maidan Gurdaspur Gurdaspur	- CPAN 3004 A. kotschyei	Sonalika, KalyanSona Sonalika, KalyanSona, *Yr*9 *Yr*9,27, PBW 343
Q	5S 0	1990	Bhowali	A. kotschyei	Barley
T	47S 103	1992	Nepal	-	Sonalika, KalyanSona
U	102S 100	1992	Nilgiri	-	Sonalika, KalyanSona
CI	-	1993	Leh	-	KalyanSona
CII	-	1993	Leh	-	KalyanSona
CIII	-	1993	Leh	-	KalyanSona
-	110S119	2014	-	-	-
-	238S119	2014	-	-	-
-	46S117	2014	-	-	-
-	110S84	2014	-	-	-

2.9 Management of wheat rusts

Wheat rust can be managed either by chemicals or by disease resistance in the host plant. A large number of highly effective fungicides like propiconazole (Tilt 25EC), tridemifon (Bayleton, 25EC) tebuconazole (Folicur, 250WP) etc. are available, which can control the rusts fungi easily (Abedel-Hak *et al*., 1987; Andenow, 1988; Chaudhary and Khan, 1989; Bockus *et al*., 1992). Chemical control is not practical and economically feasible for large scale applications. Further, it is not environmental-friendly and increases the selective effect on pathogen populations which results in emergence of new pathotypes (Alekseeva *et al*., 1990). On the other hand, management of wheat rust through host resistance by application of resistance genes in wheat is most effective, economic, environment friendly and practical approach for controlling rusts (Chen *et al*., 2005).

2.10 Disease resistance in host plant

Resistance to rusts could be morphological, structural, physiological, biochemical, functional and genetic. It may operate at the time of entrance or after entrance of the pathogen into the host. In a resistance host, the entry or development of the pathogen may be restricted mechanically or physiologically. Van der Plank (1963) classified resistance under "Vertical" and "Horizontal" that includes both genetic and epidemiologic concepts of resistance. Van der Plank (1963) defined vertical resistance as the one which is effective against some, but not all races of a pathogen i.e. it implies a differential interaction between races of the pathogen and host variety. In horizontal resistance, there is no differential interaction; it is effective against all races. Vertical resistance delays start of the epidemic, while the horizontal resistance slows down the epidemic after it has started. On the basis of growth stage, rust resistance can be classified as seedling resistance (resistance that is usually effective at all the growth stage) and adult plant resistance (effective at adult plant growth only) (Nayar *et al*., 2005; Amin and park, 2006; Datta *et al.*,2009; Bhardwaj *et al*., 2010). So many seedling rust resistance genes have been overcome in recent years, like yellow rust resistant gene *Yr*9 in 1996 (Nayar *et al.*, 1997), brown rust resistance genes *Lr*9 in 1999 (Nayar *et al*., 2003), *Lr*19 in 2004 (Bhardwaj *et al*., 2005) and *Lr*28 in 2008 (Bhardwaj *et al.*, 2010). Most of the race specific genes become ineffective over a period of time when extensively used in

production due to appearance of different virulent races (Chen *et al.*, 2001; Daolin *et al.*, 2009). Shift in virulence and emergence of new pathotypes may render the resistant genes susceptible, generally due to their race specific nature (McIntosh *et al*., 1998).

Much more efforts have gone into the genetic studies of seedling rust resistance and many sources of adult plant resistance remain uncharacterized (Amin and Park, 2006). Adult plant resistance genes individually provide low levels of resistance and combination of 3 to 4 genes are essential to express commercially adequate level of resistance (Bariana and McIntosh, 1993; Singh *et al*., 2000; Bariana *et al*., 2007). Adult plant resistance genes are considered to be potentially more durable (Singh and Rajaram, 1992; Park and McIntosh, 1994; Huerta-Espino, 1996). Adult plant resistance with low terminal severity or hypersensitivity reaction or both observed in many cultivars which apparently do not carry effective seedling resistance genes against the existing pathotypes (Singh and Rajaram, 2002; Nayar *et al*., 2004) have the potential to provide alternative resistance (Datta *et al*., 2007). Adult-plant resistance (APR) to cereal rusts is conditioned by the additive and/or epistatic effects of multiple genes often conferring low levels of resistance individually. Therefore, APR is thought to provide more durable resistance than seedling (i.e. major gene) resistance, which is often pathotype specific and so may be overcome by mutations within the pathogen population (McIntosh 1992, Hong and Singh 1996, Lagudah *et al.*, 2006, Pretorius *et al*., 2007). Johnson (1981) proposed the descriptive term "durable resistance" as resistance that remains effective when deployed over extensive acreage and time, in an environment favorable for the disease. Durable resistance sometimes represents adult plant resistance (APR), which is associated by combinations of several minor genes acting additively and shows non-hypersensitive reactions. However, some APR genes provide partial resistance that is effective against specific races of a given pathogen species i.e. race specific. Seedlings of plants with HTAP resistance are susceptible to stripe rust (high IT) at both low (6 to 21^{o}C) and high (13 to 32^{o}C) temperatures, and adult plants are susceptible at low temperatures, but resistant (low IT) at high temperatures in the greenhouse (Line, 2002). In the field, expression of HTAP resistance begins at stem elongation and becomes stronger at later stages of growth when weather becomes warm. This type of resistance is effective when

average night temperatures are above 10°C and day temperatures are between 25 and 30°C (Line and Chen, 1995). The level of resistance conferred by HTAP resistance is usually incomplete and is affected by plant growth stage, temperature, humidity and the inoculum load. In the Pacific Northwest of the United States, HTAP resistance has consistently proven to be durable against all *P. striiformis* f. sp. *tritici* races. For more than 40 years, there has been no evidence of race specificity for HTAP resistance in wheat. Like slow-rusting resistance, HTAP resistance is also inherited in a quantitative fashion (Line, 2002).

Rust resistance genes have been identified progressively in wheat and currently 61 yellow rust resistance genes have been designated so far (McIntosh *et al*., 2012). For the development and management of disease resistance, the first requirement is a source of resistance, or the means of developing a level of resistance that results in less disease and/or a reduction in crop losses. Common wheat that includes present day varieties, land races and old cultivars are the major source of rust resistance genes. Many yellow rust resistance genes like *Yr1, Yr2, Yr3a, Yr3b, Yr4a, Yr4b, Yr6, Yr10, Yr16, Yr18* are identified from common wheat (McIntosh *et al*., 1995, 2009). Other source of resistance is wild related species of wheat. These are *Secale cereal* (*Lr25*, *Lr26/Yr9/Sr31*, *Lr45*), *Aegilops ventricosa* (*Lr*37/*Yr*17), *Triticum spelta* (*Lr*44, *Yr*5), *Triticum turgidum* (*Lr59, Yr15*), and *Triticum comosum* (*Yr15*) (McIntosh *et al*., 1995, 2009, 2010, 2011, 2012).

APR gene *Yr*30 was identified from Parula, while cultivar Pavon 76 is also the source of the gene. The chromosomal location of the gene is 3BS (Singh *et al.*, 2001). *Yr36,* first discovered in wild emmer wheat (*T. turgidum* sp. *Dicoccoides* accession FA15–3, henceforth DIC) is an example of HTAP resistance gene (McIntosh *et al.,* 2005). In controlled environments, plants with *Yr36* are resistant at relatively high temperatures (25 to 35^{o}C), but susceptible at lower temperatures (15^{o}C). *Yr39* gene was identified in cultivar Alpowa (Lin and Chen, 2007). It is non-race specific high-temperature adult-plant (HTAP) stripe rust resistance gene. Chromosomal location is 7BL. Two RGAP markers, Xwgp36 and Xwgp45 with the highest R2 values were closely linked to Yr39 (Lin and Chen, 2007). *Yr48* gene was identified from Synthetic wheat 205 (Jankuloski *et al*., 2011). The chromosomal location of this gene is 5AL. It is partial stripe rust resistance gene effective at adult plant stage. Another APR Yr49 gene was identified in Avocet S*3 / Chuanmai 18

AUS91433 (Spielmeyer *et al.*, 2010). The chromosomal location of this gene is 3DS. The molecular map of this gene is *Xgpw7321-3D/Yr49* – 1 cM – *Xgwm161-3D. Yr*52 gene for high-temperature adult-plant resistance to stripe rust in spring wheat germplasm PI 183527 (Ren *et al*., 2012). The chromosomal location of this gene is 7BL. The molecular map of this gene is *Xbarc182-7B* – 1.2 cM – *Yr52* – 1.1 cM – *Xwgp5258* – 5.7 cM – *Xcfa2040-7B.*

Kumar *et al.* (2014) reported that resistance genes *Yr2, Yr9* and *Yr18* were postulated singly or in combination with other genes. Gene *Yr2* was postulated in nine varieties namely GW173, HUW234, HW741, K8027, K9107, Lok-1, Raj3077, Raj3065 and VL616. In two varieties GW173 and K9107, *Yr2* was characterized in combination with *Yr18*. Adult plant resistance gene *Yr18* was postulated in six varieties namely GW173, K9006, K9107, NIAW34, VL738 and WH542 where, it occurred in combination with other genes in the four varieties. Gene *Yr18* has interactive action and is found to be more effective in combination with other resistance genes (McIntosh, 1992; Bhardwaj *et al*., 2010).

Khanna *et al.* (2005) reported that one of the stripe rust resistance gene in line CSP44 is allelic to the gene *Yr18* in RL6058. The linked non-hypersensitive adult plant resistance genes *Lr34* and *Yr18* are also linked with a gene for morphological marker, leaf tip necrosis (*Ltn*) (Singh 1992a; b). The non-hypersensitive adult plant resistance conferred by the gene *Yr18* is believed to be durable (McIntosh, 1992), but the level of resistance conferred by *Yr18* alone is not adequate for commercial exploitation (Singh *et al*., 2001). Bariana and McIntosh (1995) suggested that a genotype with acceptable levels of adult plant resistance frequently carries at least two or more genes that often act additively. Khanna *et al.* (2005) revealed that the presence of a new stripe rust resistance gene in CSP44 in addition to *Yr18*, which may also confer long lasting resistance and thus increase diversity for genes conferring durable resistance. Bux *et al.* (2011) observed that stripe rust resistance genes *Yr3, Yr5, Yr10, Yr15, Yr26, YrSp* and *YrCv* were resistant, while *Yr18*showed moderate susceptibility. Genes *YrA, Yr2, Yr6, Yr7, Yr8, Yr9, Yr17, Yr27*and gene combinations Opata (*Yr27+Yr18*) and Super Kauz (*Yr9, Yr27, Yr18)* were found susceptible. Linked rust resistance genes are *Lr*26/*Sr*31/*Yr*9/*Pm*8 (Most used gene in the world), *Lr*24/*Sr*24, *Lr*19/*Sr*25, *Lr*37/*Sr38*/*Yr*17 (Very good adult plant resistance gene), *Lr*52/*Yr*47 (Bansal *et al*.,

2011). Pleotropic or tightly linked, slow rust, durable rust resistance genes are *Lr*34/*Yr*18/*Sr*57/*Pm*38, *Lr*46/*Yr*29/*Pm*39 and *Lr*67/*Yr*46/*Sr*55 (Sybil *et al*., 2011).

Johnson and Wilcoxson (1981) suggested "Area Under Disease Progress Curve" (AUDPC) as a measure for the identification of slow rusting cultivars. Yang *et al.*, (1987) compared AUDPC with the "r" value from a logistic equation and "k" from a Gompertz equation, the Area Under Disease Progress Curve (AUDPC) provided the best description of slow leaf rusting resistance. Singh and Rao (1989) studied differences between the AUDPC (A-value) and the rate of disease development (r value), the commonly used measure of slow rusting resistance with the help of theoretical models. A study of development of leaf rust on two sets of bread wheat breeding lines showed that the A-value and r-value (calculated as the slope of the regression line of disease progress data) are not necessarily correlated and that the initial inoculum level can have a marked effect on the A-value. The result suggested that "A" and "r" values measure different aspects of resistance and should, therefore, be used with discrimination. Prabhu *et al*., (1993) evaluated slow rusting resistance to brown rust in six cultivars of wheat. Cultivars S-69, S-57 and HB 208 expressed stable slow rusting resistance as measured by AUDPC. Yang *et al.* (1987) reported that slow rise in the infection rate and low infection frequency is important characteristics of slow-rusting phenomenon. Luo and Zeng (1988) also included infection frequency as resistant components in wheat cultivars.

Sugars are the precursor for the synthesis of phenolics, phytoalexins, lignin and callose. Hence, they play an important role in defense mechanism of plants. Beniwal *et al.* (2008) reported in wheat that the decrease in total soluble sugars and reducing sugars was minimum in resistant variety WH 283 but in varieties WH 147 and WH 542 a steady decrease was observed after 20 days of symptom appearance of flag smut and the reduction was maximum after 50 days of disease appearance. Mallikarjun (2002) reported in wheat that resistant genotypes recorded high amount of proteins, total and O.D phenols, sugars and epicuticular wax as compared to susceptible ones. Nagaveni (2005) reported leaf blight resistant genotypes of Barley had higher total protein, total phenol, reducing sugar compared to susceptible genotypes. According to Grassner and Franke (1934) the plants were susceptible when they contained specific proteins required by the rust. So the resistant variety is one which has lower proportions of specific proteins and will not become

susceptible even under favorable conditions. Positive correlation between the amount of phenolic content and degree of resistance to plant disease had been evidenced by several workers.

Chapter-3

Material and Methods

CHAPTER-III

MATERIAL AND METHODS

The experimental material and the methods which were adopted to accomplish these experiments are described below:

3.1 Plant material

The experimental plant material consisted of CIMMYT genotypes, elite genotypes, cultivars of NWPZ and susceptible varieties (Agra Local, WL-711, Kharchia-65 and PBW- 343) of wheat obtained from the Division of Plant Breeding & Genetics (AICRP-wheat), SKUAST-Jammu. The name of genotypes and their pedigrees are tabulated below

Table 3: List of wheat genotypes and their pedigrees

Genotypes	Pedigree
IBWSN-1021	*INQALAB 91*2/KUKUNA // PFAU/ WEAVER/3/…*
IBWSN-1023	*GRACK /3 / TRCH /SRTU // KACHU*
IBWSN-1030	*BAV92//IRENA/KAUZ/3/HUITES/4/DOLL/5/SERI.1B/…*
IBWSN-1031	*BAV92 // IRENA / KAU /3/HUITES /4/ PVN /5/ TRC…*
IBWSN-1032	*ROLF07 / SAUAL /5/ SERI.1B // KAUZ / HEVO /3/AMAD*2…*
IBWSN-1033	*KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/SAUAL/5/…*
IBWSN-1034	*KAUZ // ALTAR 84 /AOS /3/MILAN/KAUZ /4/ SAUAL /5/…*
IBWSN-1038	*KACHU/SAUAL/3/TACUPETO F2001/ BRAMBLING// …*
IBWSN-1039	*KACHU/SAUAL/3/TACUPETO F2001 / BRAMBLING // …*
IBWSN-1040	*KACHU/SAUAL/5/SERI.18//KAUZ/HEV/3/AMAD*2/4 /…*
IBWSN-1041	*KACHU/SAUAL/5/SER.1B//KAUZ/HEVO/3/AMAD*2/4/…*
IBWSN-1042	*KACHU/SAUAL/3/TRCH/SRTU//KACHU*
IBWSN-1043	*KACHU/SAUAL/3/TRCH/SRTU//KACHU*
IBWSN-1044	*KACHU/SAUAL/3/TRCH/SRTU//KACHU*
IBWSN-1045	*KACHU/SAUAL/3/TRCH/SRTU//KACHU*
IBWSN-1046	*KACHU/SAUAL/3/TRCH/SRTU//KACHU*
IBWSN-1047	*SAUAL/MUTUS/3/TACUPETO F2001 / BRAMBLING / / …*
IBWSN-1048	*WBLL1*2/VIVITSI/4/D67.2/PARANA66.270//…*
IBWSN-1049	*TRCH/5/REH/HARE//2*BCN/3/CROC_1/…*
IBWSN-1059	*SOKOLL/WBLL1/6/OASIS/5*BORL95/5/CNDO/R143//…*
IBWSN-1067	*TRCH/SRTU//KACHU/3/PVN/4/TRCH/SRTU//KACHU*
IBWSN-1081	*ELVIRA/5/CNDO/R143//ENTE/MEX175/3/AE.SQ/4/…*
IBWSN-1082	*WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1*2/8/…*
IBWSN-1085	*PBW343*2/KUKUNA//PBW343*2/KUKUNA*2/6/C80.1/…*
IBWSN-1086	*WHEAR/SOKOLL/3/TRCH/SRTU//KACHU/4/TRCH/SRTU/…*

IBWSN-1087	*QUAIU#1//2*WHEAR/KRONSTAD F2004*
IBWSN-1094	*ATTILA*2/PBW65//KIRITATI/3/QUELEA*
IBWSN-1097	*BECARD/KACHU/3/UP2338*2/KKTS*2//YANAC*
IBWSN-1098	*BECARD/KACHU/3/UP2338*2/KKTS*2//YANAC*
IBWSN-1099	*UP2338*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/…*
IBWSN-1100	*LOCAL CHECK ** CHECK**
IBWSN-1102	*BECARD/KACHU/3/UP2338*2/KKTS*2//YANAC*
IBWSN-1103	*KIRITATI/4/2*BAV92//IRENA/KAUZ/3/HUITES/5/…*
IBWSN-1105	*PF74354//LD/ALD/4/2*BR12*2/3/JUP//KUKUNA*2//…*
IBWSN-1109	*UP2338*2/VIVITSI/3/FRET2/TUKURU//FRET2/4/…*
IBWSN-1114	*ROLF07/4/PRL/2*PASTOR//SRTU/3/PRINIA/PASTOR/…*
IBWSN-1115	*PRL/2*PASTOR/3/2*TRCH/SRTU//KACHU*
IBWSN-1118	*KACHU/3/WHEAR//2*PRL/2* PASTOR/4/BECARD /KACHU*
IBWSN-1122	*FRANCOLIN#1/3/PBW343*2/KUKUNA*2//YANAC/4/…*
IBWSN-1129	*PRL/2*PASTOR//SUNSTATE/8/2*ATTILA*2/PBW65/6/…*
IBWSN-1141	*WBL11*2/4/YACO/PBW65/3/KAUZ*2/TRAP//KAUZ/5/…*
IBWSN-1144	*WBL11*2/4/YACO/PBW65/3/KAUZ*2/TRAP//KAUZ/5/…*
IBWSN-1145	*TRAP#1/BOW/3/VEE/PJN//2*TUI/4/BAV92/RAYON/5/…*
IBWSN-1147	*TRAP#1/BOW/3/VEE/PJN//2*TUI/4/BAV92/RAYON/5/…*
IBWSN-1148	*BAV92//IBRENA/KAUZ/3/HUITIES/4/DOLL*2/6/FRET2/…*
IBWSN-1149	*ELIVRA/CHIBIA//DIAMONDBIRD/4/2*MARCHOUCH*4/…*
IBWSN-1150	*LOCAL CHECK **CHECK**
IBWSN-1151	*ATTILA*2/PBW65/5/CNO79//PF70354/MUS/3/…*
IBWSN-1152	*ATTILA*2/PBW65/5/CNO79//PF70354/MUS/3/…*
IBWSN-1153	*ATTILA*2/PBW65/5/CNO79//PF70354/MUS/3/…*
IBWSN-1154	*ROLF07/SAUAL/3/TRCH/SRTU//KACHU/4/ROLFO07/…*
IBWSN-1160	*ROLF07/SAUAL*2/5/SERI.1B//KAUZ/HEVO/3/…*
IBWSN-1161	*TACUPETO F2001/BRAMABLING/5/NAC/TH.AC//3*PVN/…*
IBWSN-1163	*TACUPETO F2001/BRAMABLING/5/NAC/TH.AC//3*PVN/…*
IBWSN-1164	*TACUPETO F2001/BRAMABLING/5/NAC/TH.AC//3*PVN/…*
IBWSN-1165	*TACUPETO F2001/BRAMABLING/5/NAC/TH.AC//3*PVN/…*
IBWSN-1166	*TACUPETO F2001/BRAMABLING/5/NAC/TH.AC//3*PVN/…*
IBWSN-1167	*TACUPETO F2001/BRAMABLING/5/NAC/TH.AC//3*PVN/…*
IBWSN-1168	*KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/SAUAL/5/…*
IBWSN-1169	*KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/SAUAL/5/…*
IBWSN-1170	*KAUZ //ALTAR 84/ AOS / 3/ MILAN /KAUZ/4/ SAUAL/5/…*
IBWSN-1172	*KAUZ //ALTAR 84/ AOS / 3/ MILAN /KAUZ/4/ SAUAL/5/…*
IBWSN-1173	*KAUZ //ALTAR 84/ AOS / 3/ MILAN /KAUZ/4/ SAUAL/5/…*
IBWSN-1174	*KAUZ //ALTAR 84/AOS /3/MILAN/KAUZ /4/SAUAL /5/…*
IBWSN-1175	*LOCAL CHECK ** CHECK **
IBWSN-1177	*KACHU/SAUAL*2/3/TACUPETO f2001/BRAMBLING//…*
IBWSN-1178	*KACHU/SAUAL*2/3/TACUPETO f2001/BRAMBLING//…*
IBWSN-1179	*KACHU/SAUAL*2/3/TACUPETO f2001/BRAMBLING//…*
IBWSN-1239	*FRET*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/…*
IBWSN-1242	*FRET2/KUKUNA//FRET2/3/PARUS/5/FRET2*2/4/SNI/…*
IBWSN-1253	*SIALIA/4/PBW343*2/KUKUNA//SRTU/3/PBW*2/…*
IBWSN-1268	*SOKOLL/3/PASTOR//HXL7573/2*BAU/5/SNI/TRAP#1/…*
IBWSN-1284	*CROC_1/AE.SQUARROSA (205) //BORL95/3/PRL/…*

IBWSN-1286	*CROC_1/AE.SQUARROSA (205) //BORL95/3/PRL/…*
IBWSN-1287	*BAVIS#1*2/4/PASTOR//HXL7573/2*BAU/3/PASTOR/4/…*
IBWSN-1288	*CROC 1/AE.SQUARROSA (224) //OPATA/3/PASTOR/4/…*
IBWSN-1290	*PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/…*
IBWSN-1291	*PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/…*
IBWSN-1292	*SLVS/PASTOR/3/PASTOR//MUNIA/ALTAR84/4/…*
IBWSN-1293	*D67.2/PARANA66.2270 //AE. SQUARROSA (320)/3/…*
IBWSN-1294	*D67.2/PARANA66.2270 //AE. SQUARROSA (320)/3/…*
IBWSN-1295	*FRET2/KUKUNA//FRET2/3/PARUS/5/FRET2*2/4/SNI/…*
IBWSN-1296	*SIALIA/4/PBW343*2/KUKUNA//SRTU/3/PBW*2/…*
IBWSN-1298	*SOKOLL/3/PASTOR//HXL7573/2*BAU/5/SNI/TRAP#1/…*
IBWSN-1299	*CROC_1/AE.SQUARROSA (205) //BORL95/3/PRL/…*
IBWSN-1300	*SLVS/PASTOR/3/PASTOR//MUNIA/ALTAR84/4/…*
WH-1105	*MILAN/S87230//BABAX*
HD-3086	*DBW14/HD2733//HUW468*
DPW621-50	*KAUZ//ALTAR 84/AOS/3/MILAN/KAUZ/4/HUITES*
DBW-88	*KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES*
PBW-752	*PBW621//GLUPRO/3*PBW568/3/PBW621*
WH-1021	*NYOT95/SONAK*
WH-1080	*21SAWSN151*
PBW-644	*PBW-175/HD2643*
HD-2967	*ALD/COC//URES/HD2160M/HD2278*
Agra Local	----------
PBW-343	*PBW 343*3/KS90 H450/Moro/HW4444(HUW234*3/Clr19)*
WL-711	*S308/CHR//KAL*
Kharchia-65	*KHLC*5/EG953*

3.2 Pathogen

Separate pathotypes (78S84, 46S119 and 110S119) and mixed pathotypes of *Puccinia striiformis* were used to identify promising wheat genotypes at seedling and adult plant stages respectively. Viable urediospores of pathotypes were obtained from Regional Station, Indian Institute of Wheat & Barley Research (ICAR), Flowerdale, Shimla (HP). Pathotypes 46S119 and 110S119 were multiplied on susceptible host cultivar Agra Local and pathotype 78S84 was multiplied on susceptible host cultivar PBW-343 in separate polyhouses for the evaluation of infection types of tested material at seedling stage. Mixed pathotypes were multiplied on susceptible host cultivar Agra Local for identify promising wheat genotypes against stripe rust at adult plant stage.

3.3 General information

3.3.1 Inoculation method

A spore suspension was prepared in a clean Petri plate by mixing the spore dust with few drops of water. To break the film, a pinch of soap was added so as to make a uniform suspension of spores. Ten-day old seedlings were selected for inoculation having completely open primary leaf. Prior to inoculation, the leaves were sprayed with ordinary tap water and rubbed with moistened fingers to remove the thin layer of cuticular wax to provide uniform layer of moisture on leaf surface. The inoculation was carried out by following 'Spatula method' (Joshi *et al.,* 1988). In Spatula method, the wet end point of lancet needle was loaded with urediospore dust and applied gently on the surface of the leaf as uniformly as possible. Inoculated seedlings were sprayed with a thin mist of water and kept for inoculation in moist chambers for 48 hours at 16-18°C temperature with high relative humidity.

To ensure purity of pathotypes, one pathotype was inoculated at a time. Inoculation was purely carried out under aseptic conditions. The seedling pots inoculated with different races were kept in isolated chambers at 16±2°C temperature. Their purity was tested on differential sets before their utilization.

3.3.2 Collection and storage of inoculum

The fresh urediospore dust was collected on a butter paper by tapping the infected leaves with the help of lancet needle. The butter paper was then folded to make the packet. Kind of rust, name of pathotypes and date of collection was marked on each packet. Such packets were kept on the polyhouse bench for 24hrs for air drying and then stored Fresh inoculation was carried out from time to time to keep the continuous supply of inoculam. Clipping of leaves was done regularly just after taking the dust to harness more dust from the inoculated seedling.

3.4 Seedling Test

3.4.1 Sowing and inoculation of seedlings

For seedling studies, four to five plants of each genotypes were raised in aluminum trays (29 cm long, 12 cm wide and 7 cm deep) using fine loam soil and farmyard manure (3:1) containing 5 g NPK (12:32:16). About 10 lines were drawn by a wooden marker in each tray and sowing was done at the rate of 10 seeds per

grove, totaling to 100 seeds per tray. While sowing the seeds in the tray, endothermic end of seeds was kept pointing downwards in order to have quick and uniform germination. The seeds were placed about half an inch below the soil surface. Watering was done at regular intervals and the trays were ready for inoculation after 8-10 days of sowing. Before inoculation, seedlings of insufficient growth and weeds were plucked out.

When the seedlings were 8-10 days old with fully expanded primary leaves, they were inoculated using a glass atomizer that contained 15 mg spores of specific pathotypes of *P. striiformis* suspended in 2 ml light grade mineral oil (Soltrol170) ® (Chevron Phillips Chemicals Asia Pte. Ltd., Singapore). The oil was allowed to evaporate for 10 minutes. Then the plants were sprayed with a fine mist of water and placed for 48 hours in dew chamber at 15±2°C for yellow rust, maintaining 100 percent relative humidity and 12 hours day light (Bhardwaj *et al*., 2010b). The plants were then transferred to a poly house and grown at 16±2°C for yellow rust under relative humidity of 40-60%.

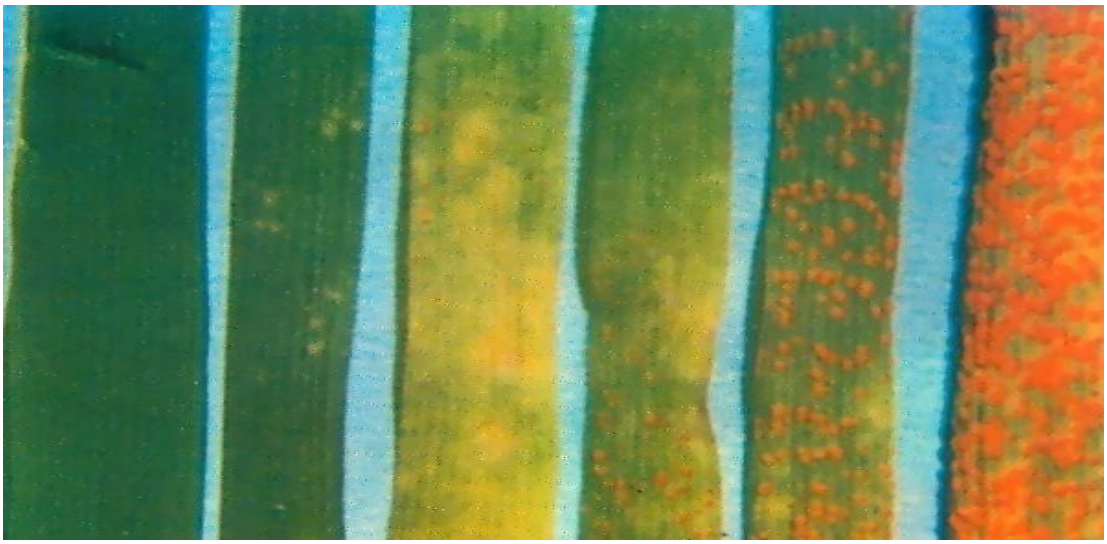
3.4.2 Recording of host-pathogen interaction

The inoculated seedlings were ready for observation after 14-15 days of incubation. The infection types were recorded against different pathotypes. For an easy categorization of resistant and susceptible reaction types, Infection types (IT) on the tested genotypes were recorded according to the classification of Jonston and Mains (1932) after 14 days inoculation with modifications (Nayar *et al*., 1997). Infection types 0 to 2 (small hypersensitive flecks to small-moderate uredial pustules with chlorosis) were considered resistant and Infection types of 3 to 3+ (moderate to large uredial pustules without chlorosis) were considered susceptible. Infection types 33+ were classified where both 3 and 3+ pustules were found together. For an easy categorization of resistant and susceptible reaction types, the following Table 4 was used.

Table 4: Rust infection types at seedling stage (Nayar *et al.*, 1997).

Reaction types	Category	Visible symptoms
0; (naught fleck)	Immune	No visible infection
;- (fleck minus)	Nearly immune	Slight necrosis/micro flecking visible
; (fleck)	Highly resistant	No uredia but hypersensitive flecks are present
1 (one)	Highly resistant	Uredia minute, surrounded by distinct necrotic areas
2 (two)	Moderately resistant	Uredia small to medium, surrounded by chlorotic
3 (three)	Moderately susceptible	Uredia small to medium in size, chlorotic areas may be present.
33+ (three three plus)	Susceptible	Uredia medium to large, profusely sporulating, no chlorosis or necrosis
3+/4 (three plus/ four)	Highly susceptible	Uredia large, no chlorosis or necrosis, profusely sporulating, rings may be formed in brown rust.
X	Heterogeneous	Variable types of uredia
Y	Heterogeneous	Susceptible types of uredia at the tip and resistance towards the base of leaf
Z	Heterogeneous	Resistant types of uredia at the tip and susceptible type towards the leaf base

Infection type of yellow rust



0; **1** **2** **2+** **3** **3+**

3.5 Adult plants screening

3.5.1 Layout and sowing in field

Selected wheat genotypes to be tested for resistance against mixed stripe rust pathotypes was sown in the experimental field of Research Farm, Division of Plant Breeding and Genetics during the 2nd week of November, 2018. Seeds of each genotype will be sown by dibbling in two rows (row to row distance of 20-22 cm) of 1m long. After every 20 rows of genotypes, the mixture of susceptible varieties (checks) was sown. Mixed susceptible checks were sown around the border of experimental material to ensure uniform spread of rust inoculum.

All cultural practices viz., fertilizer dose, weedicide application as prescribed in Package and Practices of SKUAST- Jammu, were used in the experimental area. Irrigation was done regularly at fortnight intervals to delay maturity and maintain high humidity for adequate rust development.

3.5.1.1 Inoculation methods

3.5.1.2 Lancet needle

In this method, plants were sprayed with water and gently rubbed to remove thin layer of cuticular wax allowing the fine mist settle down and to

minimize surface run-off . By holding the leaves between the fingers, inocula were effectively collected by simple scraping with lancet needle. This inoculum was applied on the leaves to be inoculated by holding the leaf between the fingers and gently moving lancet needle from the lower end of the leaf up to the tip.

3.5.1.3 Spraying method

Spores collected from the infected leaves were suspended in water. Few drops of Tween 20 were added in spore suspension. The spore suspension was sprayed with fine mist of water. Rust epidemic was created by repeated spray inoculum.

3.5.2 Combining severity and response reading

The observations on yellow rusts severity at adult stage were recorded as severity and infection type (response) randomly from individual lines according to the modified Cobb's scale given by Peterson *et al*. (1948). Loegering, 1969 gave a detailed outline for recording rusts on the basis of severity and response. Severity was recorded as per cent of infection based on the percentage scale. Below 5 per cent severity, the intervals used were trace to 2. Usually 5 per cent intervals were used between 5 to 20 per cent severity and 10 per cent intervals for higher readings. The response of a variety refers to the type of infection (reaction) and is recorded by capital letters (Table 5). Observations at adult plant stage were recorded by using Modified Cobb's scale presented as follows in Table 5.

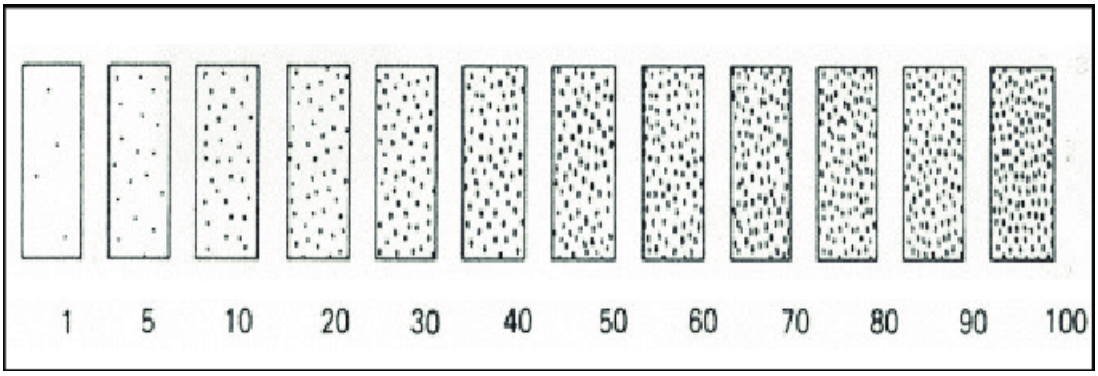
Table 5: Rust infection types at adult plant stage

Reaction types	**Response value**	**Category**	**Visible symptoms**
0	(0.0)	Immune	No visible infection on plant
R	(0.2)	Resistant	Necrotic areas with or without minute uredia present
MR	(0.4)	Moderately resistant	Small uredia present surrounded by necrotic areas
MS	(0.8)	Moderately susceptible	Medium uredia with no necrosis but possibly some distinct chlorosis
X	(0.6)	Intermediate	Variable sized uredia, susceptible

The readings on per cent severity and infection type (response) were recorded at the same time. The severity was recorded first as follows.

Scale		Description
TR		Trace severity of a resistant type of infection.
5 MS		5 per cent severity of a moderately susceptible type of infection.
10MR		10 per cent severity of a moderately resistant type of infection.
30S or 100S		30 per cent or 100 per cent severity of a susceptible type of infection

The Rust Severity Scale of Yellow Rust



3.6 Biochemical studies

3.6.1 Sampling of leaves

For biochemical analysis sampling of leaves was done at 40 and 70 days after sowing. Selected stripe rust resistant and susceptible genotypes were used for estimation of total sugars, reducing sugar, non-reducing sugar and total phenols.

3.6.2 Estimation of Total sugars

Carbohydrate estimation was done by following Anthrone method (Yemm and Willis, 1954) Glucose was used as standard.

Reagents:

(1). 2.5 N HCL

(2). Anthrone reagent: 200 mg anthrone dissolved in 100 ml of ice cold 95% H_2SO_4. Prepare fresh before use.

Procedure:

100mg of the sample was weighed and hydrolyzed by keeping it in a boiling water bath for three hours with 5 ml of 2.5 N HCl and cooled to room temperature. The content was neutralized with solid sodium carbonate until the effervescence ceased and the volume was made up to 100ml with distilled water. One ml of the sample was taken to 4 ml of anthrone reagent was added and kept for eight minutes in a boiling water bath. The content was cooled rapidly and colour developed was measured at 630 nm against a reagent blank.

3.6.3 Estimation of Reducing sugar:

The reducing sugar was estimated following Nelson's modification of Somogyi's method (Nelson, 1944).

Reagents:

(A) Alkaline copper reagent

Solution A: twenty-five gram of anhydrous sodium carbonate, 25 g of sodium potassium tartarate, 20 g of sodium bicarbonate and 200 g of sodium sulphate were dissolved in about 800 ml of distilled water and final volume was made up to one litre.

Solution B: Fifteen grams of copper sulphate was dissolved in distilled water and one or two drops of concentrated sulphuric acid was added and made up to100ml with distilled water.

(B) Arsenomolybdate reagent

(1) Ammonium molybdate (25g) was dissolved in 450 ml of distilled water, 21 ml of concentrated sulphuric acid was added and mixed with above solution.

(2) Sodium orthoarsenate (3g) was dissolved in 25 ml of distilled water. These above two solutions were mixed with stirring and placed in an incubator at 37^{o}C for 24-48 hr. The reagent was stored in brown bottle.

Procedure:

one ml of each sample (alcoholic extract) was pipetted to a test tube. To each 1ml of extract, 1 ml of mixture of solution A and B was added. The test tubes were heated on a hot water bath for 20 min. The tubes were then cooled under running tap water. After cooling, 1 ml of Arsenomolybdate reagent was added. The above solution was diluted to 20 ml after 15 min. The absorbance of the solution was measured in spectrophotometer at 510 nm. The amount of reducing sugars was determined by using standard curve prepared by using glucose.

3.6.4 Estimation of total phenol

The total phenols present in plant samples was estimated by Folinciocalteau reagent method (Bray and Thorpe, 1954). Catechol was used as the standard.

Reagents:

(1) Folin- ciocalteau reagent (FCR, 1N)

(2) Sodium carbonate (2%)

Procedure:

One ml of each alcoholic extract was taken in a test tube to which one ml of folinciocalteau reagent was added followed by 2 ml of sodium carbonate solution (2%). The tubes were shaken well and heated in a hot water bath for exactly one minute and then cooled under running tap water. The content developed was diluted to 25ml with distilled water and its absorbance was read at 650 nm in spectrophotometer. The amount of phenols present in sample was calculated from a standard curve prepared from Catechol.

3.7 Analysis of variance (ANOVA)

The analysis of variance was done to find out the statistical differences among the treatments for area under disease progress curve (A-values), coefficient of disease level (CDL) and infection rate per day (r' values).

3.7.1 Determination of coefficient of disease level (CDL)

To quantify rust observations including disease rating and disease incidence, coefficient of disease level was calculated. Average coefficient of disease level is expected to give a good estimate of the relative resistance of varieties and this takes into account both the reaction (response) and the percentage of rust infection, calculated from the field rust readings. The reaction (response) value for different infection types are assigned from 0-1 (Loegering, 1969).

For each variety coefficient of disease level (CDL) was calculated according to the formula given by Gupta (1979):

CDL = UIV x MCI

CDL = Coefficient of Disease Level

UIV = Unit incidence value

MCI = Modified coefficient of infection

Where,

$$\text{Unit Incidence Value} = \frac{\%\ incidence}{100}$$

$$\text{Modified Coefficient of Infection} = \frac{\text{Loegering's coefficient of infection}}{100}$$

Where,

Loegering's Coefficient of Infection = Severity x Response value

The maximum CDL will be 1.0. The CDL values were used for calculating the rate of infection (r).

3.7.2 Determination of rate of infection (r) of disease

The rate of infection of disease was calculated by the following formula given by Vander Plank (1963).

$$r = \frac{2.3}{t}\left(\log_{10}\frac{X_2}{1-X_2} - \log_{10}\frac{X_1}{1-X_1}\right)$$

Where,

r = Average rate of infection of disease per days

t = Total days between the first and last date of observation of

the disease

X_1 = CDL at the first date of disease observation

X_2 = CDL at the last date of disease observation

Where,

1- X_1 and 1- X_2 are the correction factors in which one is considered as the maximum disease.

3.7.3 Area under disease progress curve (A-values)

The area under disease progress curve was calculated for the cultivars by using the formula given by Wilcoxson *et al*. (1975).

$$A = \sum K/i=1\ 1\ /2\ (Si - Si-1)$$

Where,

Si = Rust severity at the end of the week, and

K = Number of successive evaluations of rust

Chapter-4

Results

CHAPTER- IV

RESULTS

The detailed results based on Master's research investigation entitled "Characterization of stripe rust (*Puccinia striiformis*) resistance in elite wheat genotypes" are presented here under the following heads.

4.1 Evaluation of wheat genotypes against stripe rust at seedling stage

Ninetynine wheat genotypes along with susceptible genotypes were evaluated on 8-10 days old wheat seedlings inoculated with individual pathotypes of stripe rust pathotypes (78S84, 46S119 and 110S119) in poly-house at Division of Plant Pathology, SKUAST-Jammu in the month of November, 2018. The infection type data was recorded after about 15 days of inoculation. The experiments were repeated to confirm the infection types. The reaction against 78S84, 46S119 and 110S119 for seedling is presented in table 6.

Table 6: Seedling reaction of different genotypes of wheat against 78S84, 46S119 and 110S119 pathotypes of stripe rust (*P. striiformis*)

Cultivar	Pathotype			Cultivars	Pathotype		
	78S84	46S119	110S119		78S84	46S119	110S119
IBWSN- 1021	1	;	3	IBWSN-1082	;-	1	3
IBWSN-1023	3	3	3+	IBWSN-1085	3	2	33+
IBWSN-1030	0;	0;	2	IBWSN-1086	0;	0;	;
IBWSN-1031	3	3+	3+	IBWSN-1087	0;	0;	2
IBWSN-1032	1	0;	33+	IBWSN-1094	1	1	3
IBWSN-1033	0;	;	3	IBWSN-1097	0;	;-	2
IBWSN-1034	3	1	3+	IBWSN-1098	3	2	2
IBWSN-1038	0;	0;	2	IBWSN-1099	2	1	3
IBWSN-1039	1	1	3	IBWSN-1100	0;	;-	3
IBWSN-1040	3	3	3+	IBWSN-1102	0;	0;	0;
IBWSN-1041	0;	;	2	IBWSN-1103	2	2	3
IBWSN-1042	;	;	2	IBWSN-1105	;	;	2

IBWSN-1043	2	1	3	IBWSN-1109	2	1	3
IBWSN-1044	3	1	33+	IBWSN-1114	1	2	2
IBWSN-1045	2	2	33+	IBWSN-1115	1	1	2
IBWSN-1046	0;	0;	;	IBWSN-1118	0;	0;	1
IBWSN-1047	3	1	33+	IBWSN-1122	2	1	3
IBWSN-1048	;	1	3	IBWSN-1129	0;	0,	;-
IBWSN-1049	1	1	3	IBWSN-1141	1	0;	3
IBWSN-1059	0;	0;	;-	IBWSN-1144	2	;	3
IBWSN-1067	1	0;	2	IBWSN-1145	2	0;	3
IBWSN-1081	;	;	2	IBWSN-1147	3	3	3
IBWSN-1148	2	2	1	IBWSN-1179	2	2	2,3+
IBWSN-1149	3	2	3	IBWSN-1239	1	1	3
IBWSN-1150	1	1	3	IBWSN-1242	0;	0;	3
IBWSN-1151	1	1	3	IBWSN-1253	2	2	2
IBWSN-1152	3	2	2,3+	IBWSN-1268	0;	0;	33+
IBWSN-1153	1	1	2	IBWSN-1284	0;	0;	0;
IBWSN-1154	2	0;	2,3+	IBWSN-1286	0;	0;	0;
IBWSN-1160	;	;	2	IBWSN-1287	0;	0;	;
IBWSN-1161	2	0;	2,3+	IBWSN-1288	0;	0;	0;
IBWSN-1163	;	2	2,3+	IBWSN-1290	0;	0;	2
IBWSN-1164	2	2	3	IBWSN-1291	0;	0;	2
IBWSN-1165	2	3	2,3+	IBWSN-1292	3	3	3
IBWSN-1166	0;	3	2,3+	IBWSN-1293	0;	0;	0;
IBWSN-1167	2	1	2,3+	IBWSN-1294	0;	0;	0;
IBWSN-1168	0;	0;	1	IBWSN-1295	0;	3	3
IBWSN-1169	2	0;	3	IBWSN-1296	2	;	3
IBWSN-1170	3+	2	33+	IBWSN-1298	;	2	2
IBWSN-1172	0;	2	3	IBWSN-1299	1	1	2
IBWSN-1173	2	;	2,3+	IBWSN-1300	2	2	2
IBWSN-1174	2	;	2,3+	WH-1105	2	2	33+
IBWSN-1175	2	1	2	HD-3086	1	3	3
IBWSN-1177	2	2	2	DPW-621-50	2	3+	3+

IBWSN-1178	2	;	2, 3+	DBW-88	2	1	3+
PBW-752	;	0;	0;	Agra Local	3+	3+	3+
WH-1021	3	3	3	PBW-343	3+	;	3+
WH-1080	3	2	2	WL-711	3+	3+	3+
PBW-644	33+	1	33+	Kharchia-65	3+	3	3+
HD-2967	33+	;	3+				

- 0; , ;, ;- = Immune, 1, 2 = Resistant, 2,3+ = Moderately resistant, 3, 33+and 3+ = Highly susceptible

4.1.1 Reaction against stripe rust pathotypes 78S84

Genotypes were screened for pathotype 78S84 at seedling stage under artificial epiphytotic conditions. Out of 99 wheat genotypes, 36 were recorded immune with infection types (IT) ranging 0;,; and ;- .These genotypes included IBWSN-1030, IBWSN-1033, IBWSN-1038, IBWSN-1041, IBWSN-1042, IBWSN-1046, IBWSN-1048, IBWSN-1059, IBWSN-1081, IBWSN-1082, IBWSN-1086, IBWSN-1087, IBWSN-1097, IBWSN-1100, IBWSN-1102, IBWSN-1105, IBWSN-1118, IBWSN-1129, IBWSN-1160, IBWSN-1163, IBWSN-1166, IBWSN-1168, IBWSN-1172, IBWSN-1242, IBWSN-1268, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1290, IBWSN-1291, IBWSN-1293, IBWSN-1294, IBWSN-1295, IBWSN-1298 and PBW-752. Forty two genotypes were recorded resistant with infection types 1 and 2. These genotypes included IBWSN-1021, IBWSN-1032, IBWSN-1039, IBWSN-1043, IBWSN-1045, IBWSN-1047, IBWSN-1049, IBWSN-1067, IBWSN-1094, IBWSN-1099, IBWSN-1103, IBWSN-1109, IBWSN-1114, IBWSN-1115, IBWSN-1122, IBWSN-1141, IBWSN-1144, IBWSN-1145, IBWSN-1148, IBWSN-1150, IBWSN-1151, IBWSN-1153, IBWSN-1154, IBWSN-1161, IBWSN-1164, IBWSN-1165, IBWSN-1167, IBWSN-1168, IBWSN-1169, IBWSN-1172, IBWSN-1173, IBWSN-1174, IBWSN-1175, IBWSN-1177, IBWSN-1178, IBWSN-1179, IBWSN-1239, IBWSN-1253, IBWSN-1296, IBWSN-1299, IBWSN-1300, DPW-621-50, DBW-88, HD-3086 and WH-1105. Twenty five genotypes namely, IBWSN-1023, IBWSN-1031, IBWSN-1034, IBWSN-1040, IBWSN-1044, IBWSN-1047, IBWSN-1085, IBWSN-1098, IBWSN-1147, IBWSN-1149, IBWSN-1152, IBWSN-1170, IBWSN-1292, WH-1021, WH-

1080, PBW-644, HD-2967, Agra local, PBW-343, WL-711 and Kharchia-65 showed highly susceptible reaction with score 3, 3+ and 33+.

4.1.2 Reaction against stripe rust pathotype 46S119

Reaction against 46S119 pathotype of stripe rust at seedling stage, out of 99 genotypes of wheat 43 were recorded immune with score ranging 0;,; and ;-.These included IBWSN-1021, IBWSN-1030, IBWSN-1032, IBWSN-1033, IBWSN-1038, IBWSN-1041, IBWSN-1042, IBWSN-1046, IBWSN-1059, IBWSN-1067, IBWSN-1081, IBWSN-1086, IBWSN-1087, IBWSN-1097, IBWSN-1100, IBWSN-1102, IBWSN-1105, IBWSN-1118, IBWSN-1129, IBWSN-1141, IBWSN-1144, IBWSN-1145, IBWSN-1154, IBWSN-1160, IBWSN-1161, IBWSN-1168, IBWSN-1169, IBWSN-1173, IBWSN-1174, IBWSN-1178, IBWSN-1242, IBWSN-1268, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1290, IBWSN-1291, IBWSN-1293, IBWSN-1294, IBWSN-1296, HD- 2967 and PBW-343. Forty-two genotypes recorded resistant reaction. These included IBWSN-1034, IBWSN-1039, IBWSN-1043, IBWSN-1044, IBWSN-1045, IBWSN-1047, IBWSN-1048, IBWSN-1049, IBWSN-1082, IBWSN-1085, IBWSN-1094, IBWSN-1098 IBWSN-1099, IBWSN-1103, IBWSN-1109, IBWSN-1114, IBWSN-1115, IBWSN-1122, IBWSN-1148, IBWSN-1149, IBWSN-1150, IBWSN-1151, IBWSN-1152 IBWSN-1153, IBWSN-1163, IBWSN-1164, IBWSN-1167, IBWSN-1170, IBWSN-1172, IBWSN-1175, IBWSN-1177, IBWSN-1179, IBWSN-1239, IBWSN-1253, , IBWSN-1298, IBWSN-1299, IBWSN-1300, HD-3086, DBW-88, PBW-752, WH-1105, DPW-621-50, WH- 1080 and PBW-644. Twelve genotypes IBWSN-1023, IBWSN-1031, IBWSN-1040, IBWSN-1147, IBWSN-1165, IBWSN-1166, IBWSN-1292, IBWSN-1295, WH-1021, Agra local, WL-711 and Kharchia-65 showed highly susceptible reaction with score 3, 3+ and 33+.

4.1.3 Reaction against stripe rust pathotype 110S119

Infection type against 110S119 pathotype of stripe rust at seedling stage, out of 99 genotypes of wheat 11 were recorded immune with score ranging 0;,; and ;-. These included IBWSN-1046, IBWSN-1059, IBWSN-1086, IBWSN-1102, IBWSN-1129, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1293 and IBWSN-1294. Twenty-seven genotypes recorded as resistant infection type with score 1 and 2. These genotypes included IBWSN-1030, IBWSN-1038, IBWSN-

1041, IBWSN-1042, IBWSN-1067, IBWSN-1081, IBWSN-1087, IBWSN-1097, IBWSN-1098 , IBWSN-1105, IBWSN-1114, IBWSN-1115, IBWSN-1118, IBWSN-1148, IBWSN-1153, IBWSN-1160, IBWSN-1168, IBWSN-1175, IBWSN-1177, IBWSN-1253, IBWSN-1290, IBWSN-1291, IBWSN-1298, IBWSN-1299, IBWSN-1300, PBW-752 and WH- 1080.

Fifty genotypes showed highly susceptible reaction with score 3, 3+ and 33+. These included IBWSN-1021, IBWSN-1023, IBWSN-1031, IBWSN-1032, IBWSN-1033, IBWSN-1034, IBWSN-1039, IBWSN-1040, IBWSN-1043, IBWSN-1044, IBWSN-1045, IBWSN-1047, IBWSN-1048, IBWSN-1049, IBWSN-1082, IBWSN-1085, IBWSN-1094, IBWSN-1099, IBWSN-1100, IBWSN-1103, IBWSN-1109, IBWSN-1122, IBWSN-1141, IBWSN-1144, IBWSN-1145, IBWSN-1147, IBWSN-1149, IBWSN-1150, IBWSN-1151, IBWSN-1164, IBWSN-1169, IBWSN-1170, IBWSN-1172, IBWSN-1239, IBWSN-1242, IBWSN-1268, IBWSN-1292, IBWSN-1295, IBWSN-1296, WH-1105, HD-3086, DPW-621-50, DBW-88, WH-1021, PBW-644, HD-2967, Agra local, PBW-343, WL-711 and Kharchia-65. Eleven genotypes IBWSN- 1152, IBWSN-1154, IBWSN-1161, IBWSN-1163, IBWSN-1165, IBWSN- 1166, IBWSN-1167, IBWSN-1173, IBWSN-1174, IBWSN-1178 and IBWSN-1179 showed moderately resistant reaction with score 2 and 3+.

The genotypes IBWSN-1046, IBWSN-1059, IBWSN-1086, IBWSN-1102, IBWSN-1129, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1293, IBWSN-1294 were immune at seedling stage against all the three stripe rust pathotypes 78S84, 46S119 and 110S119. The genotypes IBWSN-1023, IBWSN-1031, IBWSN-1040, IBWSN-1147, IBWSN-1292, WH-1105, WH-1021, Agra local, WL-711 and Kharchia-65 were highly susceptible at seedling stage to all three pathotypes 78S84, 46S119 and 110S119. The genotypes IBWSN-1114, IBWSN-1115, IBWSN-1148, IBWSN-1153, IBWSN-1175, IBWSN-1177, IBWSN-1253, IBWSN-1299 and IBWSN-1300 were resistant at seedling stage to all three-stripe rust pathotypes 78S84, 46S119 and 110S119.

4.2 Identification of promising wheat genotypes against stripe rust at adult plant stage

The first sign of stripe rust disease was observed on 16th December, 2018 in the experimental plot. The data on stripe rust severities and infection type were recorded at 15 days interval. Data is presented in Table 7.

Table 7: Disease severity of stripe rust on different genotypes of wheat during rabi season.

Genotypes	Date of disease observation						
	16-12-18	1-1-19	16-1-19	30-1-19	15-2-19	2-3-19	17-3-19
IBWSN- 1021	0 (0.0)	0 (0.0)	TMS (0.0)	5MS (4.0)	10MS (8.0)	20MS (16.0)	20MS (16.0)
IBWSN-1023	TMS (0.0)	20MS (16.0)	40MS (32.0)	40S (40.0)	60S (60.0)	60S (60.0)	80S (80.0)
IBWSN-1030	0 (0.0)	TMR (0.0)	5MS (4.0)	10MS (8.0)	20MSMR (12.0)	20MR (8.0)	20MR (8.0)
IBWSN-1031	TMS (0.0)	10MS (8.0)	20MS (16.0)	40S (40.0)	40S (40.0)	60S (60.0)	60S (60.0)
IBWSN-1032	0 (0.0)	0 (0.0)	10MS (8.0)	20MS (16.0)	20S (20.0)	40S (40.0)	40S (40.0)
IBWSN-1033	0 (0.0)	TMS (0.0)	5MR (2.0)	10MR (4.0)	10MR (4.0)	20MRMS (12.0)	20MS (16.0)
IBWSN-1034	TMS (0.0)	20MS (16.0)	40MS (32.0)	40S (40.0)	60S (60.0)	60S (60.0)	60S (60.0)
IBWSN-1038	0 (0.0)	0 (0.0)	TMS (0.0)	2MS (0.8)	5MS (2.0)	10MSMR (4.0)	10MSMR (4.0)
IBWSN-1039	0 (0.0)	TS (0.0)	5S (5.0)	10S (10.0)	10S, MS (8.0)	20S, MS (16.0)	20S, MS (16.0)
IBWSN-1040	TMS (0.0)	2MS (1.6)	10MS (8.0)	20S (20.0)	40S (40.0)	60S (60.0)	60S (60.0)
IBWSN-1041	0 (0.0)	0 (0.0)	TR (0.0)	2R (0.4)	5R (1.0)	10MR (4.0)	10MR (4.0)
IBWSN-1042	0 (0.0)	0 (0.0)	TMR (0.0)	2MR (0.8)	5MS (4.0)	10MS (8.0)	10MS (8.0)
IBWSN-1043	TS (0.0)	2S (0.8)	5S, MS (2.0)	10S, MS (6.0)	10MS (8.0)	20MS (16.0)	20MS (16.0)
IBWSN-1044	0 (0.0)	0 (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1045	0 (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	20S (20.0)	20S (20.0)	20S (20.0)
IBWSN-1046	0 (0.0)	0 (0.0)	TR (0.0)	5R (1.0)	5R (1.0)	5R (1.0)	5R (1.0)
IBWSN-1047	TMS (0.0)	2MS (1.6)	5MS (4.0)	10S (10.0)	20S (20.0)	40S (40.0)	40S (40.0)
IBWSN-1048	0	2MS	5MS	10MS	10MS	20MSMR	20MSMR

	(0.0)	(1.6)	(4.0)	(8.0)	(8.0)	(16.0)	(16.0)
IBWSN-1049	0 (0.0)	0 (0.0)	TMS (0.0)	TMS (0.0)	2MS (1.6)	5MS (4.0)	10MS (8.0)
IBWSN-1059	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	TR (0.0)	TR (0.0)	TR (0.0)
IBWSN-1067	0 (0.0)	TMR (0.0)	TMR (0.0)	2MR (0.8)	5MR (2.0)	10MR (4.0)	10MR (4.0)
IBWSN-1081	0 (0.0)	TMR (0.0)	TMR (0.0)	2MR (0.8)	5MR (2.0)	10MR (4.0)	10MR (4.0)
IBWSN-1082	0 (0.0)	TMR (0.0)	TMR (0.0)	2MR (0.8)	5MS (4.0)	10MS (8.0)	10MS (8.0)
IBWSN-1085	TMS (0.0)	2MS (1.6)	5MS (4.0)	10S (10.0)	20S (20.0)	40S (40.0)	40S (40.0)
IBWSN-1086	0 (0.0)	TR (0.0)	TR (0.0)	TR (0.0)	2R (0.4)	5R (1.0)	5R (1.0)
IBWSN-1087	0 (0.0)	TMR (0.0)	TMR (0.0)	2MR (0.8)	5MR (2.0)	10MR (4.0)	10MR (4.0)
IBWSN-1094	TMS (0.0)	TMS (0.0)	2MS (1.6)	10MS (8.0)	10MS (8.0)	20MS (16.0)	20MS (16.0)
IBWSN-1097	0 (0.0)	TR (0.0)	TR (0.0)	5RRMR (1.5)	10RMR (3.0)	10MR (4.0)	10MR (4.0)
IBWSN-1098	0 (0.0)	0 (0.0)	TMS (0.0)	TMS (0.0)	10MS (8.0)	10MS (8.0)	10MS (8.0)
IBWSN-1099	0 (0.0)	TMR (0.0)	2MR (0.8)	5MR (2.00)	10MRMS (6.0)	20MS (16.0)	20MS (16.0)
IBWSN-1100	TMS (0.0)	2MS (1.6)	5MS (4.0)	10S (10.0)	20S (20.0)	40S (40.0)	40S (40.0)
IBWSN-1102	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
IBWSN-1103	0 (0.0)	TMR (0.0)	2MR (0.8)	5MR (2.0)	10MRMS (6.0)	20MS (16.0)	20MS (16.0)
IBWSN-1105	0 (0.0)	0 (0.0)	TMR (0.0)	2MS (1.6)	2MS (1.6)	10MS (8.0)	10MS (8.0)
IBWSN-1109	0 (0.0)	2MS (1.6)	5MS (4.0)	10MS (8.0)	10MS (8.0)	20MS (16.0)	20MS (16.0)
IBWSN-1114	TMS (0.0)	TMS (0.0)	2MS (1.6)	3MS (2.8)	5MS (4.0)	10MSS (9.0)	10S (10.0)
IBWSN-1115	TMS (0.0)	TMS (0.0)	2MS (1.6)	5MS (4.0)	10MSMR (6.0)	10MSMR (6.0)	10MSMR (6.0)
IBWSN-1118	0 (0.0)	0 (0.0)	0 (0.0)	TR (0.0)	2R (0.4)	5RMR (1.5)	5MR (2.0)
IBWSN-1122	0 (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	10S (10.0)	20S, MS (18.0)	20MS (16.0)
IBWSN-1129	0 (0.0)	0 (0.0)	0 (0.0)	TR (0.0)	TR (0.0)	TR (0.0)	TR (0.0)
IBWSN-1141	0 (0.0)	0 (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1144	0 (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1145	0 (0.0)	0 (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1147	TS (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	20SMS (18.0)	40SMS (36.0)	40MS (32.0)

IBWSN-1148	0 (0.0)	TMS (0.0)	TMS (0.0)	TMS (0.0)	2MS (1.6)	5MS (4.0)	10MS (8.0)
IBWSN-1149	0 (0.0)	2MS (1.6)	5MS (4.0)	10MS (8.0)	10MS (8.0)	20MS (1.6)	20MS (1.6)
IBWSN-1150	0 (0.0)	TS (0.0)	5S (5.0)	5S (5.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1151	0 (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1152	0 (0.0)	TS (0.0)	2S (2.0)	5S (5.0)	10S (1.0)	20S (20.0)	20S (20.0)
IBWSN-1153	0 (0.0)	0 (0.0)	TR (0.0)	TMR (0.0)	5MR (2.0)	10MR (4.0)	10MR (4.0)
IBWSN-1154	0 (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1160	TS (0.0)	TS (0.0)	2SMS (1.8)	5MSMR (3.0)	5MR (2.0)	10MR (4.0)	10MR (4.0)
IBWSN-1161	0 (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1163	0 (0.0)	TS (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1164	0 (0.0)	0 (0.0)	TMS (0.0)	2MS (1.6)	5MS (4.0)	10MS (8.0)	10MS (8.0)
IBWSN-1165	0 (0.0)	TS (0.0)	5S (5.0)	5S (5.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1166	0 (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1167	0 (0.0)	TS (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1168	0 (0.0)	0 (0.0)	TR (0.0)	TR (0.0)	2RMR (0.6)	5MR (2.0)	5MR (2.0)
IBWSN-1169	TS (0.0)	TS (0.0)	5MS (4.0)	10SMS (9.0)	20MS (16.0)	20MS (16.0)	20MS (16.0)
IBWSN-1170	0 (0.0)	0 (0.0)	10MS (8.0)	20MS (16.0)	20S (20.0)	40S (40.0)	40S (40.0)
IBWSN-1172	TS (0.0)	TS (0.0)	5MS (4.0)	10SMS (9.0)	20MS (16.0)	20MS (16.0)	20MS (16.0)
IBWSN-1173	TS (0.0)	TS (0.0)	2S (2.0)	2S (2.0)	5S (5.0)	10S (10.0)	20S (20.0)
IBWSN-1174	0 (0.0)	0 (0.0)	2S (2.0)	10S (10.0)	20S (20.0)	20S (20.0)	20S (20.0)
IBWSN-1175	0 (0.0)	TR (0.0)	TR (0.0)	2RMR (0.6)	5RMR (1.5)	10MR (4.0)	10MR (4.0)
IBWSN-1177	0 (0.0)	TMS (0.0)	2MS (1.6)	5MS (4.0)	10MRMS (6.0)	20MR (8.0)	20MR (8.0)
IBWSN-1178	0 (0.0)	0 (0.0)	2S (2.0)	10S (10.0)	20S (20.0)	20S (20.0)	20S (20.0)
IBWSN-1179	0 (0.0)	0 (0.0)	TS (0.0)	10S (10.0)	20S (20.0)	20S (20.0)	20S (20.0)
IBWSN-1239	TS (0.0)	TS (0.0)	5MS (4.0)	10SMS (9.0)	20MS (16.0)	20MS (16.0)	20MS (16.0)
IBWSN-1242	0 (0.0)	TMR (0.0)	TMR (0.0)	2MR (0.8)	5MRMS (3.0)	5MS (4.0)	5MS (4.0)

IBWSN-1253	0 (0.0)	TS (0.0)	TS (0.0)	2S (2.0)	2S (2.0)	5S (5.0)	10S (10.0)
IBWSN-1268	TS (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	10S (10.0)	20S (20.0)	20S (20.0)
IBWSN-1284	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
IBWSN-1286	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
IBWSN-1287	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	TMR (0.0)	TMR (0.0)
IBWSN-1288	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
IBWSN-1290	0 (0.0)	0 (0.0)	TMS (0.0)	TMS (0.0)	5MS (4.0)	5MS (4.0)	5MS (4.0)
IBWSN-1291	0 (0.0)	0 (0.0)	TS (0.0)	TS (0.0)	2S (2.0)	5S (5.0)	5S (5.0)
IBWSN-1292	0 (0.0)	2S (2.0)	10S (10.0)	20S (20.0)	20SMS (18.0)	40SMS (36.0)	40MS (32.0)
IBWSN-1293	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
IBWSN-1294	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	TMS (0.0)	TMS (0.0)
IBWSN-1295	TS (0.0)	TS (0.0)	5MS (4.0)	10SMS (9.0)	20MS (16.0)	20MS (16.0)	20MS (16.0)
IBWSN-1296	0 (0.0)	TMS (0.0)	2MS (1.6)	5MS (4.0)	10MS (8.0)	20MS (16.0)	20MS (16.0)
IBWSN-1298	0 (0.0)	TMS (0.0)	TMS (0.0)	2MS (1.6)	5MS (4.0)	10MS (8.0)	10MS (8.0)
IBWSN-1299	0 (0.0)	0 (0.0)	TMS (0.0)	5MS (4.0)	10MS (8.0)	10MS (8.0)	10MS (8.0)
IBWSN-1300	0 (0.0)	0 (0.0)	TS (0.0)	2S (2.0)	2S (2.0)	5S (5.0)	5S (5.0)
WH-1105	0 (0.0)	TMS (0.0)	2S (2.0)	5S (5.0)	10S (10.0)	20S (20.0)	40S (40.0)
HD-3086	TMS (0.0)	2MS (1.6)	5MS (4.0)	5MS (4.0)	10MS (8.0)	20MS (16.0)	20MS (16.0)
DPW-621-50	2S (2.0)	5S (5.0)	10S (10.0)	20S (20.0)	30S (30.0)	40S (40.0)	40S (40.0)
DBW-88	0 (0.0)	0 (0.0)	10MS (8.0)	20MS (16.0)	20S (20.0)	40S (40.0)	40S (40.0)
PBW-752	0 (0.0)	0 (0.0)	TR (0.0)	2RMR (0.6)	5MR (2.0)	5MR (2.0)	5MR (2.0)
WH-1021	0 (0.0)	0 (0.0)	10MS (8.0)	20MS (16.0)	20S (20.0)	40S (40.0)	40S (40.0)
WH-1080	TMS (0.0)	TMS (0.0)	2MS (1.6)	5MS (4.0)	15MS (12.0)	20MS (16.0)	20MS (16.0)
PBW-644	0 (0.0)	0 (0.0)	2MS (1.6)	5MS (4.0)	10MS (8.0)	20MS (16.0)	40MS (32.0)
HD-2967	0 (0.0)	2S (2.0)	5S (5.0)	20S (20.0)	40S (40.0)	50S (50.0)	60S (60.0)
Agra Local	2S (2.0)	10S (10.0)	20S (20.0)	40S (40.0)	60S (60.0)	80S (80.0)	80S (80.0)

PBW-343	TS (0.0)	5S (5.0)	10S (10.0)	20S (20.0)	40S (40.0)	60S (60.0)	80S (80.0)
WL-711	0 (0.0)	2S (2.0)	10S (10.0)	40S (40.0)	60S (60.0)	60S (60.0)	80S (80.0)
Kharchia-65	5S (5.0)	10S (10.0)	20S (20.0)	40S (40.0)	60S (60.0)	80S (80.0)	90S (90.0)

Figure in the parentheses are Loegering's coefficient of infection

Rust severity in trace (TS, TMS, TMR and TR) evaluated as zero.

Nintynine wheat genotypes viz., IBWSN-1021, IBWSN- 1030, IBWSN-1032, IBWSN-1033, IBWSN-1038, IBWSN-1039, IBWSN-1041, IBWSN-1042, IBWSN-1043, IBWSN-1045, IBWSN-1046, IBWSN-1047, IBWSN-1048, IBWSN-1049, IBWSN-1059, IBWSN-1067, IBWSN-1081, IBWSN-1082, IBWSN-1086, IBWSN-1087, IBWSN-1094, IBWSN-1097, IBWSN-1099, IBWSN-1100, IBWSN-1102, IBWSN-1103, IBWSN-1105, IBWSN-1109, IBWSN-1114, IBWSN-1115, IBWSN-1118, IBWSN-1122, IBWSN-1129, IBWSN-1141, IBWSN-1144, IBWSN-1145, IBWSN-1148, IBWSN-1150, IBWSN-1151, IBWSN-1153, IBWSN-1154, IBWSN-1160, IBWSN-1161, IBWSN-1163, IBWSN-1164, IBWSN-1165, IBWSN-1166, IBWSN-1167, IBWSN-1168, IBWSN-1169, IBWSN-1172, IBWSN-1173, IBWSN-1174, IBWSN-1175, IBWSN-1177, IBWSN-1178, IBWSN-1179, IBWSN-1239, IBWSN-1242, IBWSN-1253, IBWSN-1268, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1290, IBWSN-1291, IBWSN-1293, IBWSN-1294, IBWSN-1295, IBWSN-1296, IBWSN-1298, IBWSN-1299, IBWSN-1300, PBW-752, IBWSN-1023, IBWSN-1031, IBWSN-1034, IBWSN-1040, IBWSN-1044, IBWSN-1047, IBWSN-1085, IBWSN-1098, IBWSN-1147, IBWSN-1149, IBWSN-1152, IBWSN-1170, IBWSN-1292, WH-1105, HD-3086, DPW-621-50, DBW-88, WH-1021, WH-1080, PBW-644, HD-2967, Agra Local, PBW-343, WL-711 and Kharchia-65 were taken.

On first disease observation on 16th December 2018, yellow rust severity ranged from 0 to traces. On the second date of disease observation on 1stJanuary 2019, yellow rust severity varied from 0 to10S. During the third interval of disease observations on 16th January 2019, rust severity ranged from traces to 20S. Maximum severity was recorded on the genotype Kharchia-65, followed by PBW-343, Agra Local and WL-711.

By the end of fourth disease observation on 30th January 2019, yellow rust severity varied from 0 to 40S. Higher rust severity was recorded on the genotypes IBWSN-1023, IBWSN-1031, IBWSN-1034, Agra Local, WL-711and Kharchia-65. During this time of disease observation infection types changed from susceptible to moderately susceptible on the genotypes IBWSN-1021, IBWSN-1030, IBWSN-1032, IBWSN-1039, IBWSN-1048, IBWSN-1094, IBWSN-1109, IBWSN-1122, IBWSN-1149 and DBW-88. Moderately resistant type of reaction was observed on the genotypes IBWSN-1033, IBWSN-1042, IBWSN-1067, IBWSN-1081, IBWSN-1082, IBWSN-1087, IBWSN-1103 and IBWSN-1242.

By the end of fifth disease observations on 15th February 2019, stripe rust severity ranged from 0 to 60S. Higher rust severity was observed on the genotypes IBWSN-1023, Agra local, WL-711 and Kharchia-65. On the sixth date of disease observation on 2ndMarch, 2019, stripe rust severity varied from traces to 80S. Maximum severity (80S) was recorded on the susceptible checks Agra Local and Kharchia-65. Moderately resistance type of infection was observed on the genotypes IBWSN-1030, IBWSN-1041, IBWSN-1067, IBWSN-1081, IBWSN-1087, IBWSN-1038, IBWSN-1153, IBWSN-1175, IBWSN-1169 and PBW-752. At the end on seventh and last date of disease observations on 17th March 2019, Final Rust Severity varied from traces to 90S. Maximum severity (90S) was recorded on the susceptible check Kharchia-65.

4.3 Average area under disease progress curve (A-values)

Average area under disease progress curve (A-values) of stripe rust on different genotypes of wheat during 2018-19 crop season was calculated as according to Wilcoxson *et al.* (1975) presented in Table 8.

Table 8: Average area under disease progress curve (A-values) of stripe rusts on different genotypes of wheat during 2018-19

S. No.	Genotype	AUDPC Value	S. No.	Genotypes	AUDPC Value
1.	IBWSN-1021	187.50	51.	IBWSN-1154	165.00
2.	IBWSN-1023	450.00	52.	IBWSN-1160	82.50
3.	IBWSN-1030	150.00	53.	IBWSN-1161	165.00

4.	IBWSN-1031	525.00	54.	IBWSN-1163	157.50
5.	IBWSN-1032	300.00	55.	IBWSN-1164	90.00
6.	IBWSN-1033	150.00	56.	IBWSN-1165	112.50
7.	IBWSN-1034	300.00	57.	IBWSN-1166	165.00
8.	IBWSN-1038	90.00	58.	IBWSN-1167	157.50
9.	IBWSN-1039	150.00	59.	IBWSN-1168	37.50
10.	IBWSN-1040	465.00	60.	IBWSN-1169	150.00
11.	IBWSN-1041	90.00	61.	IBWSN-1170	300.00
12.	IBWSN-1042	90.00	62.	IBWSN-1172	150.00
13.	IBWSN-1043	165.00	63.	IBWSN-1173	135.00
14.	IBWSN-1044	157.50	64.	IBWSN-1174	195.00
15.	IBWSN-1045	165.00	65.	IBWSN-1175	90.00
16.	IBWSN-1046	75.00	66	IBWSN-1177	157.50
17.	IBWSN-1047	315.00	67.	IBWSN-1178	195.00
18.	IBWSN-1048	165.00	68.	IBWSN-1179	225.00
19.	IBWSN-1049	75.00	69.	IBWSN-1239	150.00
20.	IBWSN-1059	0.00	70.	IBWSN-1242	52.50
21.	IBWSN-1067	90.00	71.	IBWSN-1253	90.00
22.	IBWSN-1081	90.00	72.	IBWSN-1268	165.00
23.	IBWSN-1082	90.00	73.	IBWSN-1284	0.00
24.	IBWSN-1085	315.00	74.	IBWSN-1286	0.00
25.	IBWSN-1086	37.50	75.	IBWSN-1287	0.00
26.	IBWSN-1087	90.00	76.	IBWSN-1288	0.00
27.	IBWSN-1094	195.00	77.	IBWSN-1290	37.50
28.	IBWSN-1097	112.50	78.	IBWSN-1291	37.50
29.	IBWSN-1098	75.00	79	IBWSN-1292	315.00
30.	IBWSN-1099	157.50	80.	IBWSN-1293	0.00
31.	IBWSN-1100	315.00	81.	IBWSN-1294	0.00
32.	IBWSN-1102	0.00	82.	IBWSN-1295	150.00
33.	IBWSN-1103	157.50	83.	IBWSN-1296	157.50
34.	IBWSN-1105	90.00	84.	IBWSN-1298	90.00
35.	IBWSN-1109	165.00	85.	IBWSN-1299	112.50

36.	IBWSN-1114	67.50	86.	IBWSN-1300	52.50
37.	IBWSN-1115	82.50	87.	WH-1105	307.50
38.	IBWSN-1118	37.50	88.	HD-3086	277.50
39.	IBWSN-1122	165.00	89.	DPW621-50	472.50
40.	IBWSN-1129	0.00	90.	DBW-88	300.00
41.	IBWSN-1141	157.50	91.	PBW-752	52.50
42.	IBWSN-1144	165.00	92.	WH-1021	300.00
43.	IBWSN-1145	157.50	93.	WH-1080	157.50
44.	IBWSN-1147	450.00	94.	PBW-644	307.50
45.	IBWSN-1148	75.00	95.	HD-2967	540.00
46.	IBWSN-1149	165.00	96.	Agra Local	660.00
47.	IBWSN-1150	112.50	97.	PBW-343	637.50
48.	IBWSN-1151	165.00	98.	WL-711	765.00
49.	IBWSN-1152	157.50	99.	Kharchia-65	712.50
50.	IBWSN-1153	75.00			

AUDPC (A-values) of yellow rust development varied significantly between different varities during 2018-19 cropping season. Highest A-values were observed in genotype WL-711 (765.00), Kharchia-65 (712.50), PBW-343 (637.50) and Agra local (660.00). Lowest A-values (0.0) were obtained in the 9 genotypes viz., IBWSN-1059, IBWSN-1129, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1102, IBWSN-1293 and IBWSN-1294. A-values (11-100) were obtained in the 20 genotypes viz., IBWSN-1160, IBWSN-1164, IBWSN-1038, IBWSN-1168, IBWSN-1041, IBWSN-1042, IBWSN-1175, IBWSN-1046, IBWSN-1049, IBWSN-1242, IBWSN-1067, IBWSN-1081, IBWSN-1082, IBWSN-1253, IBWSN-1086, IBWSN-1087, IBWSN-1290, IBWSN-1291, IBWSN-1098, IBWSN-1105, IBWSN-1298, IBWSN-1114, IBWSN-1300, IBWSN-1115, IBWSN-1118, IBWSN-1148, IBWSN-1153 and PBW-752. A-values (101-200) were obtained in 37 genotypes viz., IBWSN-1021, IBWSN-1154, IBWSN-1033, IBWSN-1165, IBWSN-1167, IBWSN-1039, IBWSN-1030, IBWSN-1161, IBWSN-1163, IBWSN-1169, IBWSN-1172, IBWSN-1043, IBWSN-1173, IBWSN-1044, IBWSN-1174, IBWSN-1045, IBWSN-1177, IBWSN-1178, IBWSN-1048, IBWSN-1239, IBWSN-1268, IBWSN-1094, IBWSN-1097, IBWSN-1099, IBWSN-1295, IBWSN-1103,

IBWSN-1296, IBWSN-1299, IBWSN-1109, IBWSN-1122, IBWSN-1141, IBWSN-1144, IBWSN-1145, IBWSN-1149, IBWSN-1151, IBWSN-1152 and WH-1080.

4.4 Coefficient of disease level (CDL) and average infection rate 'r' per day

From the data of stripe rust severity, CDL values and Average infection rate 'r' per day, calculated according to the formula given by Gupta (1979) have been presented in Table 9. The stripe rust was first observed in the experimental plots on 16th December, 2018 at that time disease in DPW 621-50 was (0.0004), Agra local (0.0004) and Kharchia-65 (0.0025).

Table 9: Coefficient of disease level (CDL) and average infection rate 'r' of stripe rust in different genotypes of wheat during 2018-19

Genotype	Coefficient of disease level (CDL)							Average infection rate 'r'
	16-12-18	1-1-19	16-1-19	30-1-19	15-2-19	2-3-19	17-3-19	
IBWSN-1021	0.0	0.0	0.0	0.0020	0.0080	0.0320	0.0320	0.1000
IBWSN-1023	0.0	0.0320	0.1280	0.1600	0.3600	0.3600	0.6400	0.0880
IBWSN-1030	0.0	0.0	0.0020	0.0080	0.0240	0.0160	0.0160	0.1340
IBWSN-1031	0.0	0.0080	0.0320	0.1600	0.1600	0.3600	0.3600	0.0810
IBWSN-1032	0.0	0.0	0.0080	0.0320	0.0400	0.1600	0.1600	0.0830
IBWSN-1033	0.0	0.0	0.0010	0.0040	0.0040	0.0240	0.0320	0.1000
IBWSN-1034	0.0	0.0320	0.1280	0.1600	0.3600	0.3600	0.3600	0.0750
IBWSN-1038	0.0	0.0	0.0	0.00008	0.0010	0.0040	0.0040	0.7920
IBWSN-1039	0.0	0.0	0.0020	0.0080	0.0080	0.0320	0.0320	0.0840
IBWSN-1040	0.0	0.0003	0.0080	0.0400	0.1600	0.3600	0.3600	0.2320
IBWSN-1041	0.0	0.0	0.0	0.00008	0.0005	0.0040	0.0040	0.5870
IBWSN-1042	0.0	0.0	0.0	0.0001	0.0020	0.0080	0.0080	0.7370
IBWSN-1043	0.0	0.0001	0.0010	0.0060	0.0080	0.0320	0.0320	0.1520
IBWSN-1044	0.0	0.0	0.0004	0.0025	0.0100	0.0400	0.0400	0.1980
IBWSN-1045	0.0	0.0004	0.0025	0.0100	0.0200	0.0400	0.0400	0.1530
IBWSN-1046	0.0	0.0	0.0	0.0005	0.0005	0.0005	0.0005	0.0
IBWSN-1047	0.0	0.0003	0.0020	0.0100	0.0400	0.1600	0.1600	0.2140

IBWSN-1048	0.0	0.0003	0.0020	0.0080	0.0080	0.0320	0.0320	0.1250
IBWSN-1049	0.0	0.0	0.0	0.0	0.0003	0.0020	0.0080	0.1250
IBWSN-1059	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IBWSN-1067	0.0	0.0	0.0	0.0001	0.0010	0.0040	0.0040	0.5390
IBWSN-1081	0.0	0.0	0.0	0.0001	0.0010	0.0040	0.0040	0.5390
IBWSN-1082	0.0.0	0.0	0.0	0.0001	0.0020	0.0080	0.0080	0.7370
IBWSN-1085	0.0	0.0003	0.0020	0.0100	0.0400	0.1600	0.1600	0.2140
IBWSN-1086	0.0	0.0	0.0	0.0	0.00008	0.0005	0.0005	0.1250
IBWSN-1087	0.0	0.0	0.0	0.0001	0.0010	0.0040	0.0040	0.5390
IBWSN-1094	0.0	0.0	0.0003	0.0080	0.0080	0.0320	0.0320	0.1040
IBWSN-1097	0.0	0.0	0.0	0.0007	0.0030	0.0040	0.0040	0.3320
IBWSN-1098	0.0	0.0	0.0	0.0	0.0080	0.0080	0.0080	0.0530
IBWSN-1099	0.0	0.0	0.0001	0.0010	0.0060	0.0320	0.0320	0.2390
IBWSN-1100	0.0	0.0003	0.0020	0.0100	0.0400	0.1600	0.1600	0.2140
IBWSN-1102	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IBWSN-1103	0.0	0.0	0.0001	0.0010	0.0060	0.0320	0.0320	0.2390
IBWSN-1105	0.0	0.0	0.0	0.0003	0.0008	0.0080	0.0080	0.2670
IBWSN-1109	0.0	0.0003	0.0020	0.0080	0.0080	0.0320	0.0320	0.1250
IBWSN-1114	0.0	0.0	0.0003	0.0008	0.0020	0.0090	0.0100	0.1430
IBWSN-1115	0.0	0.0	0.0003	0.0020	0.0060	0.0060	0.0060	0.1650
IBWSN-1118	0.0	0.0	0.0	0.0	0.00008	0.0007	0.0010	0.1320
IBWSN-1122	0.0	0.0003	0.0020	0.0080	0.0080	0.0320	0.0320	0.1250
IBWSN-1129	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IBWSN-1141	0.0	0.0	0.0004	0.0025	0.0100	0.0400	0.0400	0.1980
IBWSN-1144	0.0	0.0004	0.0025	0.0100	0.0100	0.0400	0.0400	0.1220
IBWSN-1145	0.0	0.0	0.0004	0.0025	0.0100	0.0400	0.0400	0.1980
IBWSN-1147	0.0	0.0040	0.0025	0.0100	0.0360	0.1440	0.1280	0.1560
IBWSN-1148	0.0	0.0	0.0	0.0	0.0003	0.0020	0.0080	0.1250
IBWSN-1149	0.0	0.0003	0.0020	0.0080	0.0080	0.0032	0.0032	0.1190
IBWSN-1150	0.0	0.0	0.0025	0.0025	0.0100	0.0400	0.0400	0.0970
IBWSN-1151	0.0	0.0004	0.0025	0.0100	0.0100	0.0400	0.0400	0.1220
IBWSN-1152	0.0	0.0	0.0004	0.0025	0.0100	0.0400	0.0400	0.1980

IBWSN-1153	0.0	0.0	0.0	0.0	0.0010	0.0040	0.00400	0.0920
IBWSN-1154	0.0	0.0004	0.0025	0.0100	0.0100	0.0400	0.0400	0.1220
IBWSN-1160	0.0	0.0	0.0003	0.0015	0.0010	0.0040	0.0040	0.1260
IBWSN-1161	0.0	0.0004	0.0025	0.0100	0.0100	0.0400	0.0400	0.1220
IBWSN-1163	0.0	0.0	0.0004	0.0025	0.0100	0.0400	0.0400	0.1980
IBWSN-1164	0.0	0.0	0.0	0.0003	0.0020	0.0080	0.0080	0.4990
IBWSN-1165	0.0	0.0	0.0025	0.0025	0.0100	0.0400	0.0400	0.0970
IBWSN-1166	0.0	0.0004	0.0025	0.0100	0.0100	0.0400	0.0400	0.1220
IBWSN-1167	0.0	0.0	0.0004	0.0025	0.0100	0.0400	0.0400	0.1980
IBWSN-1168	0.0	0.0	0.0	0.0	0.0001	0.0010	0.0010	0.1230
IBWSN-1169	0.0	0.0	0.0020	0.0090	0.0320	0.0320	0.0320	0.1440
IBWSN-1170	0.0	0.0	0.0080	0.0320	0.0400	0.1600	0.1600	0.0830
IBWSN-1172	0.0	0.0	0.0020	0.0090	0.0320	0.0320	0.0320	0.1440
IBWSN-1173	0.0	0.0	0.0004	0.0004	0.0025	0.0100	0.0400	0.1380
IBWSN-1174	0.0	0.0	0.0004	0.0100	0.0400	0.0400	0.0400	0.2460
IBWSN-1175	0.0	0.0	0.0	0.0001	0.0007	0.0040	0.0040	0.5590
IBWSN-1177	0.0	0.0	0.0003	0.0020	0.0060	0.0160	0.0160	0.1760
IBWSN-1178	0.0	0.0	0.0004	0.0100	0.0200	0.0400	0.0400	0.1730
IBWSN-1179	0.0	0.0	0.0	0.0100	0.0400	0.0400	0.0400	0.2200
IBWSN-1239	0.0	0.0	0.0020	0.0090	0.0320	0.0320	0.0320	0.1440
IBWSN-1242	0.0	0.0	0.0	0.0001	0.0015	0.0020	0.0020	0.6430
IBWSN-1253	0.0	0.0	0.0	0.0004	0.0004	0.0025	0.0100	0.0350
IBWSN-1268	0.0	0.0004	0.0025	0.0100	0.0100	0.0400	0.0400	0.1220
IBWSN-1284	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IBWSN-1286	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IBWSN-1287	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IBWSN-1288	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IBWSN-1290	0.0	0.0	0.0	0.0	0.0020	0.0020	0.0020	0.0680
IBWSN-1291	0.0	0.0	0.0	0.0	0.0004	0.0025	0.0025	0.1070
IBWSN-1292	0.0	0.0004	0.0100	0.0400	0.0360	0.1440	0.1280	0.1460
IBWSN-1293	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IBWSN-1294	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

IBWSN-1295	0.0	0.0	0.0020	0.0090	0.0320	0.0320	0.0320	0.1440
IBWSN-1296	0.0	0.0	0.0003	0.0020	0.0080	0.0320	0.0320	0.2000
IBWSN-1298	0.0	0.0	0.0	0.0003	0.0020	0.0080	0.0080	0.4990
IBWSN-1299	0.0	0.0	0.0	0.0020	0.0080	0.0080	0.0080	0.2870
IBWSN-1300	0.0	0.0	0.0	0.0004	0.0004	0.0025	0.0025	0.0200
WH-1105	0.0	0.0	0.0004	0.0025	0.0100	0.0400	0.1600	0.2150
HD-3086	0.0	0.0003	0.0020	0.0020	0.0080	0.0320	0.1280	0.1570
DPW621-50	0.0004	0.0025	0.0100	0.0400	0.0900	0.1600	0.2400	0.0960
DBW-88	0.0	0.0	0.0080	0.03200	0.0400	0.1600	0.1600	0.0830
PBW-752	0.0	0.0	0.0	0.0001	0.0010	0.0010	0.0010	0.0250
WH-1021	0.0	0.0	0.0080	0.0320	0.0400	0.1600	0.1600	0.0830
WH-1080	0.0	0.0	0.0003	0.0020	0.0180	0.0320	0.0320	0.2480
PBW-644	0.0	0.0	0.0003	0.0020	0.0080	0.0320	0.1280	0.2170
HD-2967	0.0	0.0004	0.0025	0.0400	0.1600	0.2500	0.3600	0.2700
Agar Local	0.0004	0.0100	0.0400	0.1600	0.3600	0.6400	0.6400	0.1280
PBW-343	0.0	0.0025	0.0100	0.0400	0.1600	0.3600	0.6400	0.1910
WL-711	0.0	0.0004	0.0100	0.1600	0.3600	0.3600	0.6400	0.2470
Kharchia-65	0.0025	0.0100	0.0400	0.1600	0.3600	0.6400	0.8100	0.1170
CD at 5%							0.0629	0.092

On the last date of stripe rust observation on 17th March, 2019 (FRS) significantly different CDL values were recorded in different genotypes. Highest CDL value was observed on Kharchia-65 followed by IBWSN-1023 (0.6400), Agra local (0.6400), PBW-343(0.6400) and WL-711(0.6400).

The CDL values of 77 genotypes were statistically significant at 5% CD value viz., IBWSN-1021, IBWSN-1030, IBWSN-1033, IBWSN-1038, IBWSN-1039, IBWSN-1041, IBWSN-1042, IBWSN-1043, IBWSN-1044, IBWSN-1045, IBWSN-1046, IBWSN-1048, IBWSN-1049, IBWSN-1059, IBWSN-1067, IBWSN-1081, IBWSN-1082, IBWSN-1086, IBWSN-1087, IBWSN-1094, IBWSN-1097, IBWSN-1098, IBWSN-1099, IBWSN-1102, IBWSN-1103, IBWSN-1105, IBWSN-1109, IBWSN-1114, IBWSN-1115, IBWSN-1118, IBWSN-1122, IBWSN-1129, IBWSN-1141, IBWSN-1144, IBWSN-1145, IBWSN-1148, IBWSN-1149, IBWSN-

1150, IBWSN-1151, IBWSN-1152, IBWSN-1153, IBWSN-1154, IBWSN-1160, IBWSN-1161, IBWSN-1163, IBWSN-1164, IBWSN-1165, IBWSN-1166, IBWSN-1167, IBWSN-1168, IBWSN-1169, IBWSN-1172, IBWSN-1173, IBWSN-1174, IBWSN-1175, IBWSN-1177, IBWSN-1178, IBWSN-1179, IBWSN-1239, IBWSN-1242, IBWSN-1253, IBWSN-1268, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1290, IBWSN-1291, IBWSN-1293, IBWSN-1294, IBWSN-1295, IBWSN-1296, IBWSN-1298, IBWSN-1299, IBWSN-1300, PBW-752 and WH-1080. The lower CDL values indicate higher resistance capacity in the cultivars to stripe rust. The infection rate of twenty-one genotypes were statistically significant at 5% CD value viz., IBWSN-1023, IBWSN-1031, IBWSN-1034 IBWSN-1039, IBWSN-1046, IBWSN-1059, IBWSN-1098, IBWSN-1102, IBWSN-1129, IBWSN-1170, IBWSN-1253, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1290 IBWSN- 1293, IBWSN- 1294, IBWSN-1300, DBW-88, WH-1021 and infection rate equal to 0.092 were obtained in IBWSN-1150, IBWSN-1153, IBWSN-1165 and DPW 621-50 which were statistically at par and related with the resistance to stripe rust in the cultivars

4.5 Biochemical analysis of some adult plant resistant genotypes

Studies on biochemical analysis of total sugars, reducing sugars, non-reducing sugars and phenol content in resistant and susceptible genotypes of wheat at 40 and 70 days after sowing (DAS) as described in Material and Methods have been presented in Table 10.

Table 10: Total sugars, reducing sugars, non-reducing sugars, and phenol content in resistant and susceptible genotypes of wheat at 40 and 70 DAS.

S.No.	Genotype	Total Sugars (µg/ml)		Reducing Sugars(µg/ml)		Non-Reducing Sugars (µg/ml)		Phenols (µg/ml)	
		40DAS	70DAS	40DAS	70DAS	40DAS	70DAS	40DAS	70DAS
1.	IBWSN-1038	14.35	13.33	8.38	7.36	6.53	5.97	17.35	18.53
2.	IBWSN-1041	14.16	13.24	8.43	7.44	6.30	5.80	13.06	14.46
3.	IBWSN-1042	15.21	14.12	8.45	7.46	7.33	6.66	17.64	19.46
4.	IBWSN-1046	14.08	13.01	7.66	6.67	7.70	5.31	17.03	18.30
5.	IBWSN-1059	14.51	13.13	8.11	7.09	6.96	6.04	17.77	19.32
6.	IBWSN-1067	14.55	13.53	7.76	6.74	7.35	6.18	17.12	19.20

7.	IBWSN-1081	14.06	13.04	8.86	7.84	6.30	5.20	17.22	19.60
8.	IBWSN-1086	15.01	13.99	8.28	7.26	7.38	6.61	16.23	17.18
9.	IBWSN-1087	15.16	14.14	8.68	7.66	7.05	6.48	13.18	14.81
10.	IBWSN-1097	15.05	13.10	8.60	7.61	7.01	5.49	16.64	17.46
11.	IBWSN-1098	14.93	13.91	7.86	6.87	7.63	7.04	13.38	14.58
12.	IBWSN-1102	15.00	13.05	7.91	6.92	7.65	6.13	17.27	18.72
13.	IBWSN-1115	14.20	13.18	8.15	7.13	6.55	6.05	16.18	17.81
14.	IBWSN-1118	14.45	13.46	8.35	7.33	6.43	6.13	17.44	18.33
15.	IBWSN-1129	14.17	13.88	8.33	7.34	6.30	6.54	17.62	19.26
16.	IBWSN-1153	15.19	14.17	7.55	6.53	7.40	7.64	16.55	18.29
17.	IBWSN-1153	14.23	13.24	7.11	6.12	7.20	7.12	16.75	17.55
18.	IBWSN-1160	14.10	13.11	8.76	7.77	7.32	5.34	16.09	17.68
19.	IBWSN-1168	15.12	14.10	8.23	7.24	7.43	6.80	16.27	19.70
20.	IBWSN-1175	14.04	13.02	7.72	6.73	7.55	6.29	17.09	18.50
21.	IBWSN-1242	15.10	14.08	7.81	6.82	7.62	7.26	17.31	19.18
22.	IBWSN-1284	14.16	13.96	7.63	6.64	7.55	7.32	14.29	15.62
23.	IBWSN-1286	14.08	13.06	7.56	6.54	6.41	6.32	14.25	15.52
24.	IBWSN-1287	14.20	13.18	7.54	6.59	6.34	6.29	16.24	17.42
25.	IBWSN-1288	15.09	14.07	7.35	6.40	6.39	6.21	15.43	16.33
26.	IBWSN-1290	14.21	13.19	7.66	6.67	7.30	6.52	15.26	17.62
27.	IBWSN-1291	15.07	14.19	8.62	7.60	7.45	6.59	16.21	18.22
28.	IBWSN-1293	15.04	14.08	8.65	7.69	7.31	6.39	15.35	16.55
29.	IBWSN-1294	15.08	14.12	8.56	7.57	7.54	6.55	15.21	16.41
30.	IBWSN-1300	15.03	14.01	8.46	7.47	7.38	6.54	15.03	16.05
31.	PBW-752	14.86	13.84	8.05	7.06	6.60	6.78	15.08	16.80
32.	Agra local	16.93	14.91	6.55	3.53	10.95	10.38	11.36	11.96
33.	PBW-343	16.10	15.10	5.91	3.92	10.75	10.16	13.24	14.21
34.	WL-711	16.76	14.74	5.89	4.87	10.65	10.57	13.16	13.26
35..	Kharchia-65	16.98	14.96	5.83	3.25	10.80	10.71	12.14	13.24

Biochemical analysis indicated that total sugars and non-reducing sugars were recorded higher in susceptible genotypes compared to resistant genotypes but reducing sugars and phenols were higher in resistant genotypes in compared to susceptible genotypes. The amount of total sugars and non- reducing sugars present in the leaves of genotypes varied considerably, but remained higher in both resistant and susceptible genotypes at 40 and 70 days after sowing. The amount of phenols and reducing sugars always remained higher in resistant genotypes after 40 and 70 days of sowing in both resistant and susceptible genotypes. At 70 days after sowing, amount of total sugars, reducing sugars and non-reducing sugars were reduced but total phenols were increased in comparison to 40 DAS in both resistant and susceptible genotypes.

Chapter-5

Discussion

CHAPTER-V

DISCUSSION

Stripe rust caused by *Puccinia striiformis* Westend is an important disease of wheat in North India and is present throughout the world. In India, it has been shown that functional life of a commercially grown rust resistant wheat variety is only 3-5 years (Rao *et al*., 1981). Varieties with a specific resistance gene usually remain effective only for a few years because the extreme selection pressure on the pathogen population with mutants attaining virulence in the pathogen population for that particular gene. The frequent breakdown of major stripe rust seedling resistance gene *Yr9* in 1996 which is virulent on mega wheat variety KalyanSona (Nayar *et al.*, 1997) becoming susceptible. In 2001, another new stripe rust pathotype 78S84 was detected, which is virulent on *Yr9* and *Yr27* on resistant mega wheat variety PBW-343. This pathotype defeated the resistance of major cultivars like PBW-343, PBW-502, PBW-550 and WL-711. In India during 2008-2012 more than 7 million hactare area was under PBW 343 mega variety. The continuous cultivation of mega variety PBW-343 on vast area exerted pressure on the pathogen population resulting in the evolution of another new pathotype. The disease became widespread on about one million hectares of wheat crop and posed serious threat on mega variety PBW-343 (Prashar *et al*., 2007). Pathotype 78S84 overcame resistance conferred by gene *Yr27* and *Yr9*, while 46S119 is virulent on *Yr9* only (Prashar *et al*., 2007). In 2014, another new 4 pathotypes viz., 110S119, 238S119, 46S117 and 110S84 were detected (Anynomous, 2014). During crop season 2018-19, six pathotypes (46S119, 110S119, 110S84, P, and T) of wheat stripe rust pathogen were identified from eight Indian states and Nepal. They were avirulent to *Yr5, Yr10, Yr15* and *YrSp*. The frequency of pathotypes 46S119 (virulent on *Yr2, Yr3, Yr4, Yr6, Yr7, Yr8, Yr9, Yr17, Yr18, Yr19, Yr21, Yr22, Yr23, Yr25 and YrA)* was maximum (47.3%). Pathotype 110S119, first identified in 2013-14, was increased year by year and present in 34.3 percent samples in cropping season 2018-19. Remaining four pathotypes were observed in 13.3 percent samples only (Anynomous, 2019). Therefore, development of resistant cultivars of wheat is the most preferred method of management of stripe rust as it is economical and environmentally safe (Lin and Chen, 2007).

The delay in progress of epiphytotic development is attributed to several factors including latent period, number of uredosori per unit area, size of uredosori, rate of sporulation etc. Chances of new variants or pathotypes are minimized due to reduced selection pressure. A convenient option of identifying slow ruster lines is the estimation of the Area Under Disease Progress Curve (AUDPC), which takes into account all the factors collectively leading to manifestation of slow rusting in a genotype. Johnson and Wilcoxson (1981) suggested a table for use of the "Area Under Disease Progress Curve" (AUDPC) as a measure for the identification of slow rusting cultivars. Yang *et al.* (1987) compared with the 'r' value from a logistic equation and 'k' from a Gompertz equation, the Area Under Disease Progress Curve (AUDPC) and provided the best description of slow rusting resistance.

For this, identification of the resistant genotypes, understanding of the genetics of the host pathogen interaction at seedling and adult plant stage and utilization of such genotypes in mainstream breeding material is required.

Evaluation of wheat genotypes against stripe rust at seedling stage

Ninety-nine wheat genotypes were screened with three pathotypes viz., 78S84, 46S119 and 110S119 of stripe rust at seedling stage. Out of 99 wheat genotypes, 36 were recorded immune with infection types (IT) ranging 0; , ; and ;-. Thirty-eight genotypes recorded resistant with score ranging 1and 2 against 78S84. Forty three genotypes were recorded immune response with 0;, ; and ;- infection type and 42 genotypes recorded resistant reaction against 46S119 pathotype of stripe rust at seedling stage. Eleven genotypes were recorded immune and 27 resistant infection type against 110S119 pathotype of stripe rust at seedling stage respectively. The genotypes IBWSN-1046, IBWSN-1059, IBWSN-1086, IBWSN-1102, IBWSN-1129, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1293, IBWSN-1294 were immune infection type to all the three pathotypes (78S84, 46S119 and 110S119) at seedling stage. The genotypes IBWSN-1114, IBWSN-1115, IBWSN-1148, IBWSN-1153, IBWSN-1175, IBWSN-1177, IBWSN-1253, IBWSN-1299 and IBWSN-1300 were resistant infection type at seedling stage against all the three pathotypes (78S84, 46S119 and 110S119). Rest of the genotypes exhibited moderately or susceptible infection type.

Immune infection type reaction suggests the presence of one or more seedling resistance genes in the cultivars. The seedling resistance gene was detected during seedling stage of the plant and these genes are known to exhibit phenotypes of major effect with varying infection types. Seedling resistance is race specific and thus short-lived due to frequent changes of virulence in the pathogen population (Line and Chen, 1995; Singh *et al.,* 2000). Race specificity is much more common in the seedling resistance genes. Gupta *et al.* (2019) also reported that PBW 752 recorded resistant reaction against two virulent pathotypes (78S84 and 46S119) of stripe rust. Tiwari *et al.* (2014) reported that DBW 88 has shown resistance against prevalent pathotypes 78S84 and 46S119 of stripe rust. AICWBIP Crop Protection Report (2017-18) also confirmed that DPW 621-50, WH 1105 and DBW 88 were resistant to 46S119 and 78S84 pathotypes and susceptible for 110S119 at seedling stage. Variety HD 3086 and HD 2967 were susceptible to 46S119 and 110S119 but resistant to 78S84 (Anynomous, 2018).

Identification of promising wheat genotypes against yellow rust at adult plant stage

A considerably high disease pressure was observed as revealed from severity on susceptible checks (90% FRS). Nine genotypes having '0' or 'TR' infection type, 2 genotypes having 'R' infection type, 12 genotypes having 'MR' infection type, while 29 genotypes having 'MS' infection type were observed (Table 5). The cultivars which had MS or MR infection type may carry durable resistance genes (Singh *et al.,* 2005). Gupta *et al.* (2019) reported that PBW-752 a high yielding variety possessed with high degree of resistance against stripe rust under natural and artificial epiphytotic conditions.

Based on FRS, the tested genotypes were grouped into four group ranges i.e., Immune, high resistant, moderate resistance and susceptible having 0%, 1-20% , 21- 40% and more than 40% respectively. The genotypes IBWSN 1059, 1102, 1129, 1286 1288 1287 1294 and 1293 were marked as Immune, while genotypes IBWSN-1021, IBWSN-1030, IBWSN-1033, IBWSN-1038, IBWSN-1039, IBWSN-1041, IBWSN-1042, IBWSN-1043, IBWSN-1044, IBWSN-1045, IBWSN-1048, IBWSN-1049, IBWSN-1067, IBWSN-1081, IBWSN-1082, IBWSN-1087, IBWSN-1094, IBWSN-1097, IBWSN-1098, IBWSN-1099, IBWSN-1103, IBWSN-1105,

IBWSN-1109, IBWSN-1114, IBWSN-1115, IBWSN-1122, IBWSN-1141, IBWSN-1144, IBWSN-1145, IBWSN-1148, IBWSN-1149, IBWSN-1150, IBWSN-1151, IBWSN-1152, IBWSN-1153, IBWSN-1154, IBWSN-1160, IBWSN-1161, IBWSN-1163, IBWSN-1164, IBWSN-1165, IBWSN-1166, IBWSN-1167, IBWSN-1168, IBWSN-1169, IBWSN-1172, IBWSN-1173, IBWSN-1174, IBWSN-1177, IBWSN-1178, IBWSN-1179, IBWSN-1239, IBWSN-1242, IBWSN-1253, IBWSN-1268, IBWSN-1290, IBWSN-1291, IBWSN-1295, IBWSN-1296, IBWSN-1298, IBWSN-1299, WH-1080, PBW-752 and HD-3086 were included in 1-20% with R, MR, MS and S group designated as having high level of partial resistance. According to plant protection report, published by IIWBR, Karnal that DBW 621-50, HD-2967, WH-1021, DBW-88, WH-1105 were rated as susceptible varieties, while PBW-752, WH-1080 HD-3086 were low rust severity under artificial conditions (Anynomous, 2018). FRS is assumed to represent the cumulative result of all resistance factors during the progress of epidemic (Parlevliet, 1979). Many researchers used FRS as a parameter to assess slow rusting behavior of wheat lines (Herrera-Foessel *et al.,* 2010; Shah *et al.,* 2014; Subodh *et al.,* 2014). They observed low value for wheat lines exhibiting slow rusting as compared to susceptible germplasms. Similarly, Singh *et al.* (2015) also conducted field assessment of slow rusting to yellow rust for ranking wheat cultivars and as per the resistance level based on FRS along with other slow rusting parameters, they found that resistance level ranged from very low to very high among the tested lines.

AUDPC (A-values) of stripe rust development varied significantly between different varieties. Lowest A-values (0) were obtained in the genotypes IBWSN-1059, IBWSN-1129, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1102, IBWSN-1293 and IBWSN-1294. This is also confirmed from seedling resistance, these genotypes also immune in seedling test against three pathotypes as well as at adult stage. On the basis of growth stage, seedling resistance that is usually effective at all the growth stage of crop (Nayar *et al.,* 2005; Bhardwaj *et al.,* 2010). Zero A-value represents high level of resistance controlled by major genes. This type of resistance exerts a strong selection pressure on pathogen, compelling it to mutate, resulting in short field life of a cultivar. Genotypes possessing this kind of resistance should be particularly avoided in

inoculum source area; however, they can be satisfactorily grown in target areas to seek protection against specified pathotypes.

A-values (11-100) were obtained in the genotypes IBWSN-1160, IBWSN-1164, IBWSN-1038, IBWSN-1168, IBWSN-1041, IBWSN-1042, IBWSN-1175, IBWSN-1046, IBWSN-1049, IBWSN-1242, IBWSN-1067, IBWSN-1081, IBWSN-1082, IBWSN-1253, IBWSN-1086, IBWSN-1087, IBWSN-1290, IBWSN-1291, IBWSN-1098, IBWSN-1105, IBWSN-1298, IBWSN-1114, IBWSN-1300, IBWSN-1115, IBWSN-1118, IBWSN-1148, IBWSN-1153 and PBW-752. AUDPC range from 11 to 100 shows incipient reaction and appears as pustules of moderately susceptible (MS) infection type. Subsequent progression of disease occurs at a quite slower rate as compared to the fast ruster check genotype. Such genotypes possess adult plant resistance (APR) genes in addition to the vertical resistance genes. Such genotypes may exhibit a better field durability than those possessing the vertical resistance genes only.

A-values (101-200) were obtained in the genotypes IBWSN-1021, IBWSN-1154, IBWSN-1033, IBWSN-1165, IBWSN-1167, IBWSN-1039, IBWSN-1030, IBWSN-1161, IBWSN-1163, IBWSN-1169, IBWSN-1172, IBWSN-1043, IBWSN-1173, IBWSN-1044, IBWSN-1174, IBWSN-1045, IBWSN-1177, IBWSN-1178, IBWSN-1048, IBWSN-1239, IBWSN-1268, IBWSN-1094, IBWSN-1097, IBWSN-1099, IBWSN-1295, IBWSN-1103, IBWSN-1296, IBWSN-1299, IBWSN-1109, IBWSN-1122, IBWSN-1141, IBWSN-1144, IBWSN-1145, IBWSN-1149, IBWSN-1151, IBWSN-1152 and WH-1080. Rest of the genotypes showed more than 40S severity. Genotypes falling in this range of 101 to 200 value of AUDPC truly represent the slow rusters. Disease initiates in the form of susceptible (MR, MS and S) type pustules on these genotypes, but subsequent progression remains slower than the fast ruster check. The terminal severity in these genotypes does not exceed 20S as compared to 40-100S in fast rusting genotypes. Genotypes belonging to this category carry a longlasting field resistance and must be preferred while breeding to develop cultivars possessing durable resistance. Cultivars with acceptable levels of slow rusting restrict the evolution of new virulent races of the pathogen because multiple point mutations are extremely rare in nature (Ali *et al.,* 2007). Johnson and Wilcoxson (1981) suggested a table for use of the "Area Under Disease Progress Curve" (AUDPC) as a measure for the identification of slow rusting cultivars. Yang

et al. (1987) compared with "r" value from a logistic equation and "k" from a Gompertz equation, the Area Under Disease Progress Curve (AUDPC) provided the best description of slow stripe rust resistance.

CDL values (0) were obtained in the genotypes IBWSN-1294, IBWSN-1293, IBWSN-1291, IBWSN-1290, IBWSN-1288, IBWSN-1287, IBWSN-1286, IBWSN-1284, IBWSN-1129, IBWSN-1059 and IBWSN-1102. The infection rate of 21 genotypes were statistically significant at 5% CD value viz., IBWSN-1023, IBWSN-1031, IBWSN-1034 IBWSN-1039, IBWSN-1046, IBWSN-1059, IBWSN-1098, IBWSN-1102, IBWSN-1129, IBWSN-1170, IBWSN-1253, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1290 IBWSN- 1293, IBWSN-1294, IBWSN-1300, DBW-88, WH-1021 and infection rate of 0.092 was obtained in IBWSN-1150, IBWSN-1153, IBWSN-1165 and DPW 621-50, which were statistically at par and related with the resistance to yellow rust in the cultivars. Adult plant resistance which was susceptible with predominant and virulent pathotypes of stripe rusts, but expressed high resistance at adult plant stage (Zhang and Knott, 1993; Sawhney and Sharma, 1997; Kaur *et al.,* 2000; Nayar *et al.,* 2005; Amin and park, 2006; Datta *et al.*, 2009; Bhardwaj *et al.* ,2010a).

Saharan *et al.* (2014) also reported that out of 58 released cultivars grown in different zones of the country, 15 lines (HS 507, DBW 90, HD 3086, WH 1080, WH 1124, WH 1142, HD 4728, HI 8737, MPO 1215 (D), NIDW 295 (D), UAS 428 (D), UAS 446 (D), DBW 71, KRL 210) showed stripe rust ACI < 10.00 (average coefficient of infection). But among advance 88 wheat lines, there was good level of resistance in 50 lines (ACI < 10.00). Lines having AUDPC values < 20 percent of those of the susceptible checks (maximum AUDPC value 200 on susceptible checks) were considered to be slow rusters. In the present study, some of the wheat varities (DBW 93, HS 490, PBW 723, PBW 644, VL 829, VL 892, WH 1105, WR 544) grown at present in northern India were identified as slow ruster lines.

Characterization of identified resistant genotypes for biochemical attributes related to resistance

Result from (Table 10) reveled that total sugars were higher in susceptible cultivars when compared to resistant cultivars. Decrease in total sugars was lower in resistant genotypes as compare to susceptible genotypes at 70 day. Our finding

corroborates with the earlier studies of Mishra *et al.* (2008) who reported in Taro plant that total sugars were higher in susceptible cultivar when compared to resistant cultivar. Total sugar content was observed higher in both resistant and susceptible genotypes at 40 days after sowing, but reduction was observed at 70 days. In susceptible genotypes, total sugar and reducing sugar was more decreased than resistant genotypes. Beniwal *et al.* (2008) reported in wheat that the decrease in total soluble sugars and reducing sugars was minimum in resistant variety WH 283, but in varieties WH 147 and WH 542 a steady decrease was observed after 20 days of symptom appearance of flag smut and the reduction was maximum after 50 days of disease appearance. The reduction of sugar content in infected leaves can be attributed to the fact that a major part of these sugars is being shifted to polyphenol synthesis (Neish, 1964). The post inflectional reduction in reducing sugar might be due to rapid hydrolysis of sugars during pathogenesis through the enzymes secreted by the pathogen. (Jaypal and Mahadevan,1968). Reducing sugar content was recorded lower in resistant genotypes when compared with susceptible genotypes. These results are in conformity with the reports of Ramdayal and Joshi (1968) in barley against leaf spot pathogen, Sindhan and Jaglan (1987) in ground nut against Tikka disease and Subramanyam *et al.* (1990) in wheat against *Exerohilum hawaiiensis* and Mandokhot *et al.* (1979) in maize against leaf spot pathogens.

Our finding on total phenols showed that amount of phenolics present in the leaves of resistant varieties varied considerably but always higher than the susceptible varieties. The amount of phenol in the rust infected leaves have more reduced in susceptible genotypes than in resistant genotypes 70 days after sowing. It has been frequently observed that phenol accumulation takes place in all the infected plant tissues, but more rapid accumulation of phenolics takes place in incompatible host pathogen complex than in the compatible ones (Kiraly and Farkas,1962). Newton and Anderson (1929) proposed the phenol hypothesis to explain resistance. They suggested that rust resistance in wheat was effected by liberation of phenolics in the host cells due to invasion of the fungus and that the liberated phenol killed the host cell and inhibited the growth of the pathogen.

Venkateshwaralu and Setohi (1976) found that brown rust infection in wheat increased the phenol content considerably in susceptible varieties under normal day conditions and decreased under long day conditions Beniwal *et al*. (2008) reported

in wheat that total phenol and O.D phenols were more in the flag smut resistant variety than the susceptible one and highly susceptible varieties at all three stages viz. 20, 35 and 50 days after disease appearance. Lal *et al*. (2008) reported rust infected leaves of lentil recorded lower level of total phenol than healthy leaves. Healthy leaves of susceptible varieties recorded lower total phenol as compared to resistant varieties. Our findings on biochemical analysis also corroborates with Matho *et al.* (1987) who analyzed total phenolics, sugars and reducing sugars from alcoholic and aqueous extracts of resistant and susceptible rice varieties infected with bacterial blight pathogen. They observed higher phenol content in IR-20, a resistant variety and lowest in Anand, the highly susceptible check. The amount of phenolics and sugars present in the leaves of resistant varieties varied considerably, but always higher than the susceptible varieties.

Chapter-6

Summary and Conclusion

CHAPTER-VI

SUMMARY AND CONCLUSION

Stripe rust (*Puccinia striiformis*) is one of the major constraints for enhancing production of wheat crop under cold weather conditions in North western plain zone of India. Yield losses caused by stripe rust epidemic are estimated at around 40 per cent and losses due to severe epidemics can be as great as 100 per cent depending upon the level of resistance of cultivars. Development of new cultivars with diverse resistance against stripe rust is the most economical and environmentally safe method for reducing losses.

In India, it has been shown that functional life of a commercially grown rust resistant wheat variety is only 3-5 years. The frequent breakdown of major seedling resistance gene e.g. stripe rust resistance gene *Yr9* in 1996 and*Yr27* in 2001 and difficulties in quick replacement of susceptible wheat varieties led to the investigations of other forms of disease resistance like seedling and adult plant resistance and slow rusting. Slow rusting is a partial or incomplete resistance permits the fungus to sporulate, at a reduced rate. It is generally not affected by the types of pathotypes i.e. non-specific in nature and keeps the diseases below threshold level and decreases the chances of selection of new pathotypes. Rust resistance can be described as seedling and adult plant resistance (APR). Seedling resistance is effective through the growth stage of the plant. Adult plant Resistance genes individually provide low levels of resistance and combinations of three or more genes are essential to express commercially adequate levels of resistance. Therefore, 99 CIMMYT genotypes, elite genotypes, cultivars of NWPZ and susceptible varieties (Agra Local, WL-711, Kharchia-65 and PBW-343) were selected for detailed characterization of stripe rust *(Puccinia striiformis)* resistance in elite wheat genotypes at seedling stage and adult plant stage.

The genotypes IBWSN-1046, IBWSN-1059, IBWSN-1086, IBWSN-1102, IBWSN-1129, IBWSN-1284, IBWSN-1286, IBWSN-1287, IBWSN-1288, IBWSN-1293, IBWSN-1294 were immune infection type at seedling stage and also adult plant stage against all three pathotypes 78S84, 46S119 and 110S119. Such genotypes possess seedling as well as adult plant resistant that means all time resistance at different crop stages.

Genotypes IBWSN-1160, IBWSN-1164, IBWSN-1038, IBWSN-1168, IBWSN-1041, IBWSN-1042, IBWSN-1175, IBWSN-1046, IBWSN-1049, IBWSN-1242, IBWSN-1067, IBWSN-1081, IBWSN-1082, IBWSN-1253, IBWSN-1086, IBWSN-1087, IBWSN-1290, IBWSN-1291, IBWSN-1098, IBWSN-1105, IBWSN-1298, IBWSN-1114, IBWSN-1300, IBWSN-1115, IBWSN-1118, IBWSN-1148, IBWSN-1153 and PBW-752 showed R, MR, MS and S infection type with quite slower rate and low level of severity (<20). Such genotypes may exhibit a better field durability than those possessing the vertical (immune) resistance genes only.

Genotypes IBWSN-1021, IBWSN-1154, IBWSN-1033, IBWSN-1165, IBWSN-1167, IBWSN-1039, IBWSN-1030, IBWSN-1161, IBWSN-1163, IBWSN-1169, IBWSN-1172, IBWSN-1043, IBWSN-1173, IBWSN-1044, IBWSN-1174, IBWSN-1045, IBWSN-1177, IBWSN-1178, IBWSN-1048, IBWSN-1239, IBWSN-1268, IBWSN-1094, IBWSN-1097, IBWSN-1099, IBWSN-1295, IBWSN-1103, IBWSN-1296, IBWSN-1299, IBWSN-1109, IBWSN-1122, IBWSN-1141, IBWSN-1144, IBWSN-1145, IBWSN-1149, IBWSN-1151, IBWSN-1152 and WH-1080 truly represent acceptable levels of slow rusting, restrict the evolution of new virulent races of the pathogen because multiple point mutations are extremely rare in nature. These identified genotypes will be considered exploitation in future rust resistant breeding programmes.

Biochemical analysis indicated that total sugars and non-reducing sugars were recorded higher in susceptible genotypes compared to resistant genotypes but reducing sugars and phenols were higher in resistant genotypes in compared to susceptible genotypes. The amount of total sugars and non- reducing sugars present in the leaves of genotypes varied considerably, but remained higher in both resistant and susceptible genotypes at 40 and 70 days after sowing. The amount of phenols and reducing sugars always remained higher in resistant genotypes after 40 and 70 days of sowing in both resistant and susceptible genotypes. At 70 days after sowing, amount of total sugars, reducing sugars and non-reducing sugars were reduced but total phenols were increased in comparison to 40 DAS in both resistant and susceptible genotypes.

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CERTIFICATE – IV

Certified that all the necessary corrections as suggested by the external aminer/evaluator and the Advisory committee have been duly incorporated in the thesis titled **"Characterization of stripe rust (*Puccinia striiformis*) resistance in elite heat genotypes"** submitted by **Ms. Neeru Sadotra,** Registration No. **J-17-M-513.**

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EDUCATIONAL QUALIFICATION

Bachelor's degree	B.Sc. (Agriculture)
University and year of award	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (2017)
OGPA	7.60/10.00
Master's degree	M.Sc. Agriculture (Plant Pathology)
OGPA	7.90/10.00
Title of Master's Thesis	**Characterization of stripe rust (*Puccinia striiformis)* resistance in elite wheat genotypes.**