GENE SCOUTING FOR RUST(S) RESISTANCE IN WHEAT GERMPLASM

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
in
PLANT PATHOLOGY
(Minor Subject: Entomology)

By

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(L-2016-A-129-M)

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LUDHIANA-141 004

2018

CERTIFICATE – I

This is to certify that the thesis entitled, **“Gene scouting for rust(s) resistance in wheat germplasm”** submitted for the degree of **M.Sc.** in the subject of **Plant Pathology** (Minor Subject: **Entomology**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Sandeep Singh (L-2016-A-129-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigations have been fully acknowledged.

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CERTIFICATE – II

This is to certify that the thesis entitled, **“Gene scouting for rust(s) resistance in wheat germplasm”** submitted by **Sandeep Singh (L-2016-A-129-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.** in the subject of **Plant Pathology** (Minor subject: **Entomology**) has been approved by the Student’s Advisory Committee along with External Examiner after an oral examination on the same.

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ACKNOWLEDGEMENT

First of all I am thankful to the Almighty for showering his blessings for the successful completion of this work. It is my proud privilege to express my deep sense of gratitude and indebtness to my major advisor ***Dr Jaspal Kaur****, Plant Pathologist, Department of Plant Breeding and Genetics, PAU, Ludhiana, for her inspiring guidance and constant encouragement in planning and execution of study and research work, which helped me to successfully complete the work in time. She had been very kind to me in extending all possible helps and providing facilities for the completion of the research work as well as in the preparation of this manuscript. Her patience and persistence became an ideal for me.*

I am extremely thankful to the other members of my Advisory Committee, namely, ***Dr P.P.S. Pannu****, Additional Director of Research (NR&PHM) (Nominee, Dean PGS), PAU, Ludhiana,* ***Dr Ritu Bala****, Assistant Plant Pathologist,* ***Dr Pooja Srivastava****, Assistant Plant Breeder, and* ***Dr Gaurav Kumar Taggar,*** *Assistant Entomologist, Department of Plant Breeding and Genetics, PAU, Ludhiana for their encouragement and co-operation throughout the course of my investigation.*

I am thankful to ***Dr Narinder Singh****, Head Department of Plant Pathology for his much needed support and help all through my stay in the department. It is my privilege to express my gratitude to all the faculty members of this department for their help and encouragement.*

I am also thankful to former Head of the Department ***Dr P.S. Sekhon*** *for his support and encouragement throughout my doctorate.*

Something inexpressible, deep in my heart, the blessings of my respected grandmother ***Late Smt. Harbans Kaur,*** *parents,* ***S. Balwant Singh, Smt. Kuljinder Kaur*** *and my brother* ***Raghveer Singh,*** *for their loving nature, moral support and encouragement to join the M.Sc. Programme, their blessings have given me the strength to go ahead and achieve this goal. The selfless sacrifices and paramount affection of my family cannot be acknowledged by words.*

My boundless emotions found no words to express their gratitude to loving friends ***Harpreet****,* ***Simranjit, Sanjy, Gurveer, Harman, Jagjit, Amrit, Aman, Pooja, Harmeet, Arsh, Lovepreet, Jaswant, Navjot Kaur*** *and* ***Kuldeep,*** *for their constant moral support, effusive encouragement, firm decisions, realistic thoughts and always a source of inspiration to me throughout my studies. I am highly indebted to who helped and inspired me a lot during my study period in university.*

I also thank field staff ***Sunil, Gurmail, Vicky, Gurvir*** *and* ***Gagan*** *for their kind support and assistance during my lab and field work. It is not possible to give a mention to everybody by words but I am gratified to everyone who had been a source of moral support and inspiration directly or indirectly during the course of present study.*

Last but not least, I wish to offer my thanks to all those names which could not be included but will always be fondly remembered.

Place: Ludhiana

Dated: *(Sandeep Singh)*

Title of the Thesis	**:**	Gene scouting for rust(s) resistance in wheat germplasm
Name of the Student and Admission No.	**:**	Sandeep Singh L-2016-A-129-M
Major Subject	**:**	Plant Pathology
Minor Subject	**:**	Entomology
Name and Designation of Major Advisor	**:**	Dr. Jaspal Kaur Plant Pathologist
Degree to be awarded	**:**	M.Sc.
Year of award of Degree	**:**	2018
Total Pages in Thesis	**:**	88 + VITA
Name of University	**:**	Punjab Agricultural University, Ludhiana - 141 004, Punjab, India

ABSTRACT

During the *Rabi* crop season of the year 2016-17, six hundred and seven (607) wheat germplasm lines were evaluated in the field and found sixty six lines resistant to stripe rust, three hundred thirty six lines resistant to leaf rust and thirty four lines resistant to both stripe rust and leaf rust. In the second year (2017-18), the wheat germplasm was evaluated against different pathotypes of *Puccinia striiformis tritici (Pst)* (238S119, 110S119, 46S119 and 78S84) and *P. triticina (Pt)* (77-5 and 77-9) at seedling stage. From seedling reaction test it was observed that fifty six (56) lines and one hundred and ten lines (110) possess resistance against all the pathotypes of *Pst* and *Pt* tested respectively. All the test wheat lines were categorized into different clusters based on final rust severity (FRS), area under disease progress curve (AUDPC), relative area under disease progress curve (rAUDPC) and coefficient of infection (CI). Fifty two (52) lines were highly resistant to stripe rust and one hundred seventy one (171) lines were highly resistant to leaf rust and remaining lines showed different reaction based on the particular range of slow rusting parameters. Genotypes which showed resistance either to stripe rust or to leaf rust were further evaluated against mixture of *Pst* pathotypes (238S119, 110S119, 46S119 and 78S84) and individually against 110S119 and 46S119. For leaf rust evaluation was done by using mixture of *Pt* pathotypes (77-5, 77-9, 104-2 and 12-2) and 77-5 and 77-9 in isolation. NILs carrying known APR genes and susceptible checks for also used for comparison purpose under the field conditions. The results of the present study revealed that fifty two lines has resistance against most prevalent pathotypes of stripe rust in Punjab (238S119, 110S119, 46S119 and 78S84) and one hundred seventy one (171) lines have resistance to mixture (77-5, 77-9, 104-2 and 12-2) pathotypes of *Pt*. Reaction on NILs showed that *Yr1*, *Yr5*, *Yr10*, *Yr15*, *Yr24*, *Yr26*, *Yrsp*, *Yr31*, *Yr51*, *Yr47*, *Yr57*, *Yr63* are effective against most prevalent pathotypes of stripe rust in Punjab and *Lr2a, Lr2b, Lr8, Lr19, Lr22a, Lr23, Lr(27+31), Lr45, Lr51, Lr53, Lr57, Lr58, Lr76* are effective against leaf rust pathotypes. For deployment of resistance sources, total 40 crosses were made. Eleven lines resistant to stripe rust were crossed with PBW621 and twenty nine lines resistant to leaf rust were crossed with HD3086. F1 and F2 plants obtained were tested separately against stripe rust and leaf rust. From the disease reaction of majority of F1 and F2 populations it was concluded that resistance in these lines is controlled by single dominant gene against both stripe and leaf rust.

Keywords: Germplasm, Leaf rust**,** Stripe rust, Resistance

Signature of Major Advisor **Signature of the Student**

ਖੋਜ ਦਾ ਸਿਰਲੇਖ : ਕਣਕ ਦੇ ਜਰਮਪਲਾਜ਼ਮਾਂ ਵਿਰੁੱਧ ਪ੍ਰਤੀਰੋਧਕ ਕੁੰਗੀਆਂ ਦੀ ਪਰਖ
ਵਿਦਿਆਰਥੀ ਦਾ ਨਾਮ ਅਤੇ ਦਾਖਲਾ ਕ੍ਰਮਾਂਕ : ਸੰਦੀਪ ਸਿੰਘ
ਐਲ-2016-ਏ-129-ਐਮ
ਪ੍ਰਮੁੱਖ ਵਿਸ਼ਾ : ਪੌਦਾ ਰੋਗ ਵਿਗਿਆਨ
ਸਹਿਯੋਗੀ ਵਿਸ਼ਾ : ਕੀਟ ਵਿਗਿਆਨ
ਮੁੱਖ ਸਲਾਹਕਾਰ ਦਾ ਨਾਮ ਅਤੇ ਅਹੁਦਾ : ਡਾ. ਜਸਪਾਲ ਕੌਰ
ਪੌਦਾ ਰੋਗ ਵਿਗਿਆਨੀ
ਡਿਗਰੀ : ਐੱਮ.ਐੱਸ.ਸੀ.
ਡਿਗਰੀ ਨਾਲ ਸਨਮਾਨਿਤ ਕਰਨ ਦਾ ਸਾਲ : 2018
ਖੋਜ ਪੱਤਰ ਵਿੱਚ ਕੁੱਲ ਪੰਨੇ : 88
ਯੂਨੀਵਰਸਿਟੀ ਦਾ ਨਾਮ : ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ-141004
ਪੰਜਾਬ, ਭਾਰਤ।

ਸਾਰ ਅੰਸ਼

ਮੌਜੂਦਾ ਅਧਿਐਨ ਦੌਰਾਨ ਸਾਲ 2016-17 ਦੀ ਹਾੜ੍ਹੀ ਰੁੱਤੇ ਕਣਕ ਦੇ ਜਰਮਪਲਾਜ਼ਮ ਦੀਆਂ 607 ਲਾਈਨਾਂ ਖੇਤ ਵਿੱਚ ਜਾਂਚੀਆਂ ਗਈਆਂ ਅਤੇ 66 ਲਾਈਨਾਂ ਪੀਲੀ ਕੁੰਗੀ, 336 ਲਾਈਨਾਂ ਭੂਰੀ ਕੁੰਗੀ ਅਤੇ 34 ਲਾਈਨਾਂ ਪੀਲੀ ਅਤੇ ਭੂਰੀ ਕੁੰਗੀ ਦੋਨਾਂ ਦੇ ਪ੍ਰਤੀਰੋਧੀ ਪਾਈਆਂ ਗਈਆਂ। ਦੂਜੇ ਸਾਲ ਵਿੱਚ 2017-18 ਦੌਰਾਨ ਕਣਕ ਦੇ ਜਰਮਪਲਾਜ਼ਮ ਨੂੰ *ਪਕਸੀਨੀਆ ਸਟ੍ਰਾਈਫਾਰਮਿਸ ਟ੍ਰੀਟੀਸਾਈ* ਦੇ ਵੱਖ-ਵੱਖ ਰੋਗਾਣੂਆਂ ਦੇ ਵਿਰੁੱਧ ਪਰਖਿਆ ਗਿਆ। ਅੰਕੁਰ ਪ੍ਰਤੀਕਿਰਿਆ ਦੀ ਜਾਂਚ ਤੋਂ ਇਹ ਪਾਇਆ ਗਿਆ ਕਿ 56 ਲਾਈਨਾਂ ਅਤੇ 110 ਲਾਈਨਾਂ ਕ੍ਰਮਵਾਰ *Pst* ਅਤੇ *Pt* ਦੇ ਸਾਰੇ ਰੋਗਾਣੂਆਂ ਵਿਰੁੱਧ ਪ੍ਰਤੀਰੋਧੀ ਸਨ। FRS, AUDPC ਅਤੇ CI ਦੇ ਅਧਾਰ ਤੇ ਕਣਕ ਦੀਆਂ ਲਾਈਨਾਂ ਨੂੰ ਸੂਚੀਬੱਧ ਕੀਤਾ ਗਿਆ। 52 ਲਾਈਨਾਂ ਪੀਲੀ ਕੁੰਗੀ ਪ੍ਰਤੀ ਬਹੁਤ ਵਧੇਰੇ ਪ੍ਰਤੀਰੋਧੀ ਸਨ। 171 ਲਾਈਨਾਂ ਭੂਰੀ ਕੁੰਗੀ ਪ੍ਰਤੀ ਬਹੁਤ ਜ਼ਿਆਦਾ ਪ੍ਰਤੀਰੋਧੀ ਸਨ ਅਤੇ ਬਾਕੀ ਰਹਿੰਦੀਆਂ ਲਾਈਨਾਂ ਨੇ ਮੱਧਮ ਕੁੰਗੀ ਮਾਪਦੰਡਾਂ ਦੇ ਅਧਾਰ ਤੇ ਵੱਖ-ਵੱਖ ਪ੍ਰਤੀਕਿਰਿਆ ਦਰਸਾਈ। ਪੀਲੀ ਕੁੰਗੀ ਜਾਂ ਪੱਤਿਆਂ ਦੀ ਕੁੰਗੀ ਵਿਰੁੱਧ ਪ੍ਰਤੀਰੋਧੀ ਪਾਈਆਂ ਗਈਆਂ ਲਾਈਨਾਂ ਨੂੰ *Pst* ਰੋਗਾਣੂਆਂ ਦੇ ਮਿਸ਼ਰਣ (238S119, 110S119, 46S119 ਅਤੇ 78S84) ਅਤੇ 110S119 ਅਤੇ 46S119 ਵਿਰੁੱਧ ਪਰਖਿਆ ਗਿਆ। ਭੂਰੀ ਕੁੰਗੀ ਦੀ ਪਰਖ *Pt* ਰੋਗਾਣੂ (77-5, 77-9, 104-2 ਅਤੇ 12-5) ਦੇ ਮਿਸ਼ਰਣ ਅਤੇ 77-5 ਅਤੇ 77-9 ਨਾਲ ਕੀਤੀ ਗਈ। ਏ.ਪੀ.ਆਰ. ਜੀਨ ਵਾਲੇ NILs ਅਤੇ ਸੰਵੇਦਨਸ਼ੀਲ ਚੈੱਕ ਨੂੰ ਵੀ ਤੁਲਨਾਤਮਕ ਅਧਿਐਨ ਲਈ ਵਰਤਿਆ ਗਿਆ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਦੇ ਨਤੀਜੇ ਦਰਸਾਉਂਦੇ ਹਨ ਕਿ ਪੰਜਾਬ ਵਿੱਚ 52 ਲਾਈਨਾਂ ਪ੍ਰਮੁੱਖ ਰੋਗਾਣੂ (238S119, 110S119, 46S119 ਅਤੇ 78S84) ਦੇ ਵਿਰੁੱਧ ਪ੍ਰਤੀਰੋਧੀ ਸਨ ਅਤੇ 171 ਲਾਈਨਾਂ *Pt* (77-5, 77-9, 104-2 ਅਤੇ 12-5) ਰੋਗਾਣੂਆਂ ਦੇ ਮਿਸ਼ਰਣ ਪ੍ਰਤੀਰੋਧੀ ਸਨ। NILs ਪ੍ਰਤੀਕਿਰਿਆ ਦਰਸਾਉਂਦੀ ਹੈ ਕਿ *Yr1, Yr5, Yr10, Yr15, Yr24, Yr26, YrSP, Yr31, Yr51, Yr47, Yr57* ਅਤੇ *Yr63* ਜੀਨ, ਪੰਜਾਬ ਵਿੱਚ ਮੌਜੂਦਾ ਪੀਲੀ ਕੁੰਗੀ ਦੇ ਪ੍ਰਮੁੱਖ ਰੋਗਾਣੂਆਂ ਪ੍ਰਤੀ ਪ੍ਰਤੀਰੋਧੀ ਸਨ ਅਤੇ *Lr2a, Lr2b, Lr8, Lr19, Lr22a, Lr23, Lr(27+31), Lr45, Lr51, Lr53, Lr57, Lr58* ਅਤੇ *Lr76* ਜੀਨ ਭੂਰੀ ਕੁੰਗੀ ਦੇ ਰੋਗਾਣੂਆਂ ਪ੍ਰਤੀ ਪ੍ਰਤੀਰੋਧੀ ਸਨ। ਰੋਗ ਦਾ ਟਾਕਰਾ ਕਰਨ ਵਾਲੇ ਬੀਜ ਤਿਆਰ ਕਰਨ ਲਈ ਕੁੱਲ 40 ਕਰਾਸ ਵਿਕਸਤ ਕੀਤੇ ਗਏ। ਪੀਲੀ ਕੁੰਗੀ ਦਾ ਟਾਕਰਾ ਕਰਨ ਵਾਲੀਆਂ 11 ਪ੍ਰਤੀਰੋਧਕ ਲਾਈਨਾਂ ਨੂੰ PBW621 ਨਾਲ ਕਰਾਸ ਕੀਤਾ ਗਿਆ ਅਤੇ ਭੂਰੀ ਕੁੰਗੀ ਦਾ ਟਾਕਰਾ ਕਰਨ ਵਾਲੀਆਂ 29 ਪ੍ਰਤੀਰੋਧਕ ਲਾਈਨਾਂ HD3086 ਨਾਲ ਕਰਾਸ ਕੀਤਾ ਗਿਆ। ਪ੍ਰਾਪਤ ਹੋਈਆਂ F1 ਅਤੇ F2 ਪੌਦਿਆਂ ਨੂੰ ਪੀਲੀ ਕੁੰਗੀ ਅਤੇ ਭੂਰੀ ਕੁੰਗੀ ਵਿਰੁੱਧ ਵੱਖ-ਵੱਖਰੇ ਤੌਰ ਤੇ ਪਰਖਿਆ ਗਿਆ। F1 ਅਤੇ F2 ਦੇ ਜ਼ਿਆਦਾਤਰ ਪੌਦਿਆਂ ਦੇ ਰੋਗ ਪ੍ਰਤੀਕਿਰਿਆ ਤੋਂ ਇਹ ਸਿੱਟਾ ਕੱਢਿਆ ਜਾ ਸਕਦਾ ਹੈ ਕਿ ਇਹਨਾਂ ਲਾਈਨਾਂ ਵਿੱਚ ਪ੍ਰਤੀਰੋਧੀ ਇੱਕ ਜੀਨ ਨਾਲ ਸੰਚਾਲਿਤ ਹੁੰਦੇ ਹਨ।

ਮੁੱਖ ਸ਼ਬਦ: ਜਰਮਪਲਾਜ਼ਮ, ਭੂਰੀ ਕੁੰਗੀ, ਪੀਲੀ ਕੁੰਗੀ, ਪ੍ਰਤੀਰੋਧਕਤਾ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ

ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER – I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a self-pollinated plant belonging to family Gramineae or Poaceae. It is an important staple food of India among the cereals. India has become an importer to exporter after green revolution. Wheat ranks second after rice in area and production in India. India has second position after China in wheat production. In India, during the year 2017-18, the area under wheat was 29.72 million hectare and production 98.61 million tonnes (Anonymous 2018a). In Punjab, wheat is a major cereal crop, being grown over an area of 3.50 million hectares and production 16.80 million tonnes (Anonymous 2018b).

Wheat crop is attacked by a number of diseases and insects. The major diseases are rusts, karnal bunt, loose smut, flag smut, powdery mildew, ear cockle and yellow ear rot etc (Anonymous 2018b). Among the diseases, rust pathogens are very devastating ones to the wheat in the whole world. These are responsible for causing serious economic losses in all wheat growing regions throughout the world. Wheat rust pathogens belong to genus *Puccinia,* family *Pucciniaceae*, order Pucciniales and class Pucciniomycetes. The crop is attacked by three types of rusts namely; stripe rust/yellow rust caused by *Puccinia striiformis* f. sp. *tritici (Pst),* brown rust/leaf rust caused by *Puccinia triticina (Pt)* and stem rust/black rust caused by *Puccinia graminis* f. sp. *tritici* (Roelfs and Bushnell 1985). The pathogens of all the three rusts are obligate in nature, utilizes water and nutrient from host plant. Each requires optimum range of temperature, humidity and free water on foliage for development of symptoms.

Yellow rust is the most damaging disease under cool and humid weather conditions (Singh *et al* 2001) attack wheat crop in more than 60 countries in all continents except Antarctica (Chen 2005). Stripe rust mainly infects wheat, but can also cause infection in barley, rye and triticale. Yield losses vary from 4.2 to 68.8 per cent in north-western parts of India due to stripe rust (Prashar *et al* 2007). In Punjab, disease has occurred in moderate to severe form in 2008, caused losses of Rs 236 crore (Jindal *et al* 2012). It caused significant losses up to 50 per cent due to shriveled grains and damaged tillers and in extreme cases, it can cause complete loss. The symptoms of the yellow rust mainly appear on the upper side of leaves, first the green colour of leaves fades in long streaks on which rows of small uredio-pustules appear. The uredio-pustules are oval in shape and pustule colour changes from yellow to orange and black telio-pustules are formed due to higher temperature (Saha 2002). Temperature influences the germination, infection and survival of the urediniospores as well as sporulation and host resistance. Germination of urediniospores is best at 9.7 ºC, although germination can occur at 2.8 to 21.7 ºC. Subsequent growth of the pathogen is best at 12 ºC to

15 ºC although the minimum and maximum temperature requirements for the pathogen growth are 3 ºC and 20 ºC, respectively (Roelfs *et al* 1992 and Line 2002)

Leaf/brown rust is major constraint in many wheat growing regions (Kolmer *et al* 2007, Sumikova and Hanzalova 2010) and cause up to 50 per cent yield losses (Nayar *et al* 2002). The Sonalika epidemic of brown rust which swept over the entire Uttar Pradesh and parts of Bihar in 1980 caused a loss of one million tonnes (Joshi *et al* 1984). The symptoms of brown rust appear on leaves in the form of bright orange, small and round pustules which are irregularly scattered all over the leaf surface and leaf sheath. In a compatible *P. triticina* interaction, large uredinia are produced while in an incompatible interaction no uredinia or small to medium size uredinia along with chlorotic and necrotic halos are observed (Bolton *et al* 2008). Vallavieille-pope *et al* (1995) reported that optimum temperature for germination of urediospores of *P. triticina* is 12-15 ^{0}C, but they do not germinate at temperature more than 35 ^{0}C. The fungus need free water and high light for sporulation. Moisture affects spore germination, infection and survival.

Stem rust is favored by warm temperature (15 to 30 ^{0}C) and humid conditions caused losses up to 50 per cent, complete loss can occur when susceptible cultivars are grown. The symptoms of black rust appear in the form of elongated, narrow, elliptical reddish-brown pustules on stem and leaf sheath (Nagarajan 1993). Subsequently late in season reddish-brown coloured pustules turn black and telia are formed containing teliospore. The stem rust of wheat is more destructive in south India than in north India. The wheat rust fungus is heterocious in nature and complete its life cycle on different hosts like an urediospores and teliospores on cereal hosts and pycniospores and aeciospores on alternate hosts (Kolmer 2013a).

Wind can affect stripe rust and leaf rust by drying urediospores, which reduces on site germination and infection, but also increase the duration of spore viability and plays important role in the dispersal of urediniospores. Rain can also be helpful in dispersal of urediniospores because raindrops release urediniospores either by direct impact or by splashing (Chen 2005). Light intensity also has an effect on the disease. Plants show a resistant reaction at high light intensities and susceptible reaction at low light intensities (Stubbs 1985).

The major objective of plant pathologists, breeders and agronomists is to manage the disease epidemics (Martin *et al* 2003). Different management strategies can be followed to delay the development of the disease epidemic and reduce yield losses. Do not sow the crop in the month of October in the disease prone areas and monitor the crop from 2nd week of December onward particularly after irrigation (Anonymous 2018b). Eriksson and Henning

(1896) concluded that partial control of rust was possible with sulfur, but its use was infeasible. A variety of chemicals have been tested against rust diseases, which include Dithane M-45, Propiconazole (Tilt/Shine 25EC), Tebuconazole (Folicur 25EC) or Triadimefon (Bayleton 25EC) at 0.1 per cent and have been found effective against all the rusts (Brahma *et al* 1991). Recently developed fungicide formulations, such as Topguard (Flutriafol + Propyleneglycol), Aproach (cyproconazole + picoxystrobin), Prosaro (Prothioconazole + Tebuconazole) and Quilt (Azoxystrobin + Propiconazole) are effective against stripe rust and have two or more targets in their modes of action (Chen *et al* 2016). The chemicals are more economical, but not ecologically sound. The use of resistant varieties is the most effective, environment friendly and low cost method for the management of rusts (Pink 2002).

Different approaches have been used by many workers for deployment of non-race specific (HR) and race specific (VR) resistance genes against wheat rusts. Race specific resistance gave hyper sensitive reaction, simple to breed and it is effective against specific race of pathogen. Such resistance genes express themselves at seedling stage and after certain years, the race specific/vertical resistant variety became susceptible due to development of new physiological race(s) of pathogen by gene mutation, recombination, heterokaryosis and parasexuality (Kumar *et al* 2014) e.g. 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* 2010b) and yellow rust resistance gene *Yr*9 in 1996 (Nayar *et al* 1997), *Yr*27 in 2001 (Prashar *et al* 2007). Non race specific resistance shows moderate level of resistance against different pathotypes at adult plant stage (Dyck and Kerber 1985). The horizontal/non race specific resistance is controlled by minor genes. Each of these genes may be rather ineffective against the pathogen and may play a minor role in the total horizontal resistance. Generally, horizontal resistance does not protect plants from becoming infected, but it slows down the development and spread of the disease and this type of resistance cannot be easily overcome/breakdown by new races of pathogen due to its polygenic nature. Both type of resistance gene has been identified in wheat and wild species by various workers. This has been transferred to susceptible high yielding cultivars through different breeding methods. Judicious use of genetic resistance has been proposed as gene pyramiding of vertical/major and horizontal/minor genes, resulting varieties with combination of several major genes and minor genes. This conclusion provides protection against several new races that may develop in pathogen. Continuous identification, characterization and deployment of new resistance genes is essential, to keep pace with variation in pathogen.

The present study was aimed to investigate genes in indigenous and exotic wheat germplasms against widely prevalent races of *P. striiformis tritici* and *P. triticina* with following objectives.

- To know the presence of rust(s) resistance gene(s) in germplasm by seedling reaction test and adult plant response to different pathotype(s)
- To study the genetic inheritance for leaf rust and stripe rust resistance in population(s) derived from crosses with resistant germplasm

CHAPTER-II

REVIEW OF LITERATURE

Wheat ranks second after rice in area and production. Wheat attacked by number of diseases however rust pathogens are very devastating ones to the wheat in the worlds. The rust diseases of wheat such as stripe rust, leaf rust and stem rust have historically been among the major biotic constraints in the world. The rusts of wheat are caused by fungal pathogens that can be disseminated thousands of kilometers by wind and are capable of causing considerable economic loss throughout the world under favorable environmental condition. The available literature relevant to the present investigations on gene scouting for rust(s) resistance in wheat germplasm is being reviewed under following heads.

2.1 Taxonomic Position
2.2 Epidemic and Yield Losses
2.3 Races of Pathogen(s)
2.4 Host Range
2.5 Symptoms and Signs
2.6 Life Cycle
2.7 Epidemiology
2.8 Management
2.9 Rust Resistance Genes

2.1 Taxonomic Position

According to Ainsworth (1975) wheat rusts are classified into Kingdom Fungi, Subdivision Basidiomycotina, Order Uredinales, Class Teliomycetes, Family Pucciniaceae and Genus *Puccinia*. According to Kirk *et al* (2008) wheat rusts are classified into Kingdom Fungi, Phylum Basidiomycota, Subphylum Pucciniomycotina, Class Pucciniomycetes, Order Pucciniales, Family Pucciniaceae and Genus *Puccinia*.

2.2 Epidemic and Yield Losses

Stripe and leaf rusts are capable of causing epidemic and yield losses from time to time in different parts of the world. Stripe rust caused yield losses in more than 60 countries (Stubbs 1985). In the Pacific Northway, it caused more than 70 per cent losses in the late 1950 and early 1960 (Chen *et al* 1995). In China, the most severe epidemic due to stripe rust occurred in 1950, 1964 and 1990 which caused yield losses up to 1.8-6.0 million tonnes (Wan *et al* 2004). In the United States, it was major problem in the California, Idaho, Washington and Oregon prior to 2000. Since 2000, the disease has become severe in the central great plains (Colorado, Kansas, Nebraska and Missouri) and south central states

(Oklahoma, Arkansas and Texas). In Arkansas, the only significant epidemic and yield losses 2.5 per cent were recorded before 2000. Similarly, Nebraska had 10 per cent yield loss in 2003, and Colorado had 8 per cent yield losses in 2001. In Central Asia (Tajikistan, Turkmenistan, Kyrgyzstan Uzbekistan and Kazakhstan) it caused yield losses 20 to 40 percent in 1999-2000 (Chen 2005). Yield losses 4.2 to 68.8 per cent were recorded in north-western parts of India due to stripe rust (Prashar *et al* 2007). Singh *et al* (2010) recorded yield losses up to 82 per cent on highly susceptible variety PBW 343 due to stripe rust. In Punjab disease has occurred in moderate to severe form in 2008 and caused losses up to Rs 236 crore (Jindal *et al* 2012).

Puccinia triticina (*Pt)* caused more significant losses in yield and occurred epidemic in several regions worldwide (Kolmer *et al* 2009). In Pakistan, yield losses up to 10 per cent were reported due to breakdown of leaf rust resistance gene *Lr16* in the 1978 (Hasson *et al* 1979). In United States, leaf rust caused serious losses and estimated at over 3 million tonnes in 2000 to 2004 and worth over 350 million dollars. In Kansas City, losses were estimated at 13.7 per cent in 2007, 4.7 per cent in 2008 and 1.37 per cent in 2009 (Chen 2005). Leaf rust is also an important in northern Africa, particularly in Egypt, Morocco and Tunisia. In Egypt, yield losses up to 50 per cent were estimated. In Central Asia, more than 90 per cent area of 13.3 million hectare and 30 per cent area of 21 million hectare in the West Asia under leaf rust (Huerta-Espino *et al* 2011). In India, yield losses upto 2 million tonnes of total production in Rajasthan, Uttar Pradesh (UP), Madhya Pradesh (MP) and Maharashtra was recorded due to leaf rust epidemic in 1946-1947 (Asthana 1948). In 1971-72, leaf rust epidemic caused yield losses up to 0.37 million tonnes in Kalyansona variety in north-western parts of the India (Joshi and Pathak 1975). In glass house trials, maximum yield losses were recorded in the susceptible varieties Lal Bahadur (65.1%), Kalyansona (60.9%) and WL711 (60.8%) following infection by *P. triticina* at tillering stage (Kumari *et al* 1992).

2.3 Races of Pathogen

Line and Qayoum (1992) identified the one hundred nine (109) races of stripe rust in the North America, out of these fifty nine (59) races were identified before 1950 and other races were identified in the previous 40 years before 2000. Wan *et al* (2004) analysed the virulence of stripe rust races CYR31 and CYR32 on different wheat cultivars in China in 2002. Shah *et al* (2014) analysed the variability in the virulence composition of six pathotypes (N1 to N6) of *Puccinia striiformis* (*Pst*) from Nepal and pathotypes N1 and N2 represented 88 per cent of the Nepalese population and pathotypes showed that virulence on *Yr1*, *YrSU*, *Yr2*, *Yr*6, *Yr7* and *Yr27* genes and avirulence on *Yr5*, *Yr10*, *Yr15*, *Yr24*, *YrEp* and

Yr26 genes. The study on Eight hundred and eighty seven (887) genetically diverse *Puccinia striiformis* isolates sampled from 35 countries during 2009–2015 and reported that *PstS1* was predominant in North America, *PstS2* in West Asia and North Africa, both *PstS1* and *PstS2* in East Africa, *PstS4* was prevalent in Northern Europe, *PstS5* and *PstS9* were prevalent in Central Asia and *PstS6* was prevalent in epidemics in East Africa. *PstS7*, *PstS8* and *PstS10* represented genetic lineages prevalent in Europe (Ali *et al* 2017).

In India, Mehta (1940) initiated the studies on physiological specialization of rust in 1923 and started systemic virulence analysis in 1931. He found that in India, alternate host does not play important role in survival of rust, but evolution of new race or pathotype is either through introduction, hybridization, mutation, recombination, heterokaryosis and parasexuality. Earlier, pathotypes L (70S69), T (47S103) and P (46S103) on cultivar Hybrid 6, pathotypes 38A (66S64-1), 20A (70S64) and 14A (66S64) on Kalyansona and pathotypes I (38S102) and K (47S102) on Sonalika were detected. A new pathotype (78S84) of stripe rust virulent on PBW 343 carrying *Yr27* gene was identified in Punjab by Prashar *et al* (2007). The frequency of two races of stripe rust namely 78S84 and 46S119 varied in proportional of 75:25 per cent in 2010-11, 35:65 per cent in 2011-12 and 20:80 per cent in 2012-13 in Punjab (Pannu *et al* 2014). The reason behind the increased prevalence of race 78S84 was more area under the variety PBW 343. More than 80 per cent of the infected samples yielded 78S84 during 2008-09 and 2009-10. However, from 2011 onwards as the PBW343 got replaced with other cultivars carrying R genes other than *yr27*, again 46S119 became more prevalence and 78S84 become least (<5%) prevalent (Kaur *et al* 2018). Along with these two races two other races namely 46S117 and 110S119 of stripe rust were also detected during the crop seasons 2014-15 and 2015-16. Similarly, Prashar *et al* (2015) reported the dominance of three races of stripe/yellow rust, 46S119 and 78S84 in northern India and 38S102 in Tamil nadu (TN) from 2004-2011. The frequency of 38S102 was constantly decreased over the year and was not detected in crop season 2009-10. The pathotype 46S119 was predominant in Rajasthan, Haryana, Delhi and Uttarakhand (UK) whereas race/pathotype 78S84 was prevalent in Jammu and Kashmir (JK), Uttar Pradesh (UP), Himachal Pradesh (HP) and Punjab and their frequency remained higher on yearly. Gangwar *et al* (2016) reported some new pathotypes of stripe rust (238S119, 46S117, 110S247, 110S84, 6S0 and 7S0) identified from southern hills, northern hills and northern-western plain zones of India during 2011-15.

In Mexico, leaf rust race BBG/BN showed virulence on *Lr26* was identified in low frequency during 2001 (Singh *et al* 2004). Different races of *Puccinia triticina* were found in North America and in US and 50 to 60 races are identified annually (Kolmer *et al* 2007). Races of leaf rust MDR-10, 20 caused epidemics on INIA Torcaza (*Lr10*, *Lr24*) and INIA Churrinche and race MFP-20 on INIA Tero (*Lr17a*, *Lr24*) in Uruguay (German *et al* 2007).

Leaf rust races (TNM/KP, TMB/JP, TLB/JP, TNB/JN, TNM/JP, TNR/JP and MLJ/SP) were identified in commercial cultivars and trap nurseries grown in Mexico close to the southern USA border and these races were virulent to *Lr9*, *Lr24* and *Lr25* (Huerta-Espino *et al* 2008). The analysis of 2,630 samples collected from 17 states, one union territory and Nepal in 2005-2008 and identified 31 races including eight new races (Bhardwaj *et al* 2010b). MFP-20 (Brazilian designation: B56) was the first race found to be virulent on variety BRS 194, widely grown in Brazil from 1988 to 1994 (Chaves *et al* 2009). Kolmer *et al* (2013b) identified 44 virulence pathotypes of leaf rust on 20 lines of Thatcher wheat in Turkey in 2009-10.

The race virulent on *Lr19* was designated 253R31 (77-8) on international differentials in 2003 and may have evolved through mutation from race 109R31 in India (Bhardwaj *et al* 2005). Jain *et al* (2008) reported two new pathotypes 5R45 and 29R7 of leaf rust in India by using fresh urediniospores to inoculate the O, A and B sets of differentials. Bhardwaj *et al* (2010a) reported two more races of leaf rust namely R60-1 and 377 R60 having virulence on *Lr28* gene of wheat cultivar in India. Gupta *et al* (2018) reported that 77-9 was found to possess less incubation period, latent period, produced more uredinio-pustules as compared to other pathotypes and It is indicative of the fact that the pathotype 77-9 followed by 104-2 is more competitive and can overtake other pathotypes in the years to come. In Punjab, leaf rust was not observed in many years. However, during the years 2014-15 and 2015-16, it was recorded on certain cultivars (Kaur *et al* 2018).

2.4 Host Range

The Primary hosts of stripe rust are bread wheat (*T. aestivum* L.), cultivated emmer wheat (*T. dicoccum* Schrank), durum wheat (*T. turgidum* L.), wild emmer wheat (*T. dicoccoides* Korn), triticale (*T. secale*), rye (*S. cereale* L.) and barley (*H. vulgare* L.). The alternative (Pycnial/aecial) hosts of stripe (yellow rust) are barberry (*Berberis koreana*, *B. holstii, B. vulgaris*, *B. shensiana*, *B. potaninii*, *Berberis chinensis*, *B. dolichobotrys* and *B. heteropoda* etc.) and Oregon grape (*Mahonia aquifolium*) (Chen *et al* 2014).

The primary hosts of *P. triticina* include bread wheat, cultivated emmer wheat (*T. dicoccum*), wild emmer wheat (*T. dicoccoides*), *Aegilopes speltoides*, durum wheat (*T. turgidum*), goat grass (*Aegilopes cylindrical*), and triticale (*X. triticosecale*) (Bolton *et al* 2008). *P. triticina* requires an alternate host to complete the sexual stages of its life cycle, which helps in the evolution of new races or pathotypes through genetic recombination. The most common alternate host of *P. triticina* is *Thalictrum speciosissimum L.*, while *Isopyrum fumaroides* has been reported as an alternate host of leaf rust pathogen only in Siberia, Russia. However, the role of alternate host is not considered significant to the disease epidemics in the case of *P. triticina* (Zhao *et al* 2016). The leaf rust mostly infects and spreads through asexual spores (urediniospores) and survives on the volunteer wheat plants to carry over the inoculum in the next season.

2.5 Symptoms

The disease is characterized by small yellow coloured uredial pustules, arranged in streaks mainly on leaf lamina but under severe infection uredial pustules may appear on the leaf sheath, stalk, glumes, awns and grains. The yellow streak consists of a number of oval, lemon yellow pustules lined along with the veins (Plate 2.1). The urediniospores do not break through the epidermis as quickly as in other rusts but do so eventually and a spore mass is exposed for wind dispersal. The telia appear late as dull black pustules mainly 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.

Uredia of leaf rust are irregularly scattered on leaves, rarely on the leaf sheath and the stalk. Uredo-pustules are smaller, circular, round to oblong in shape and bright orange to orange brown in color (Plate 2.1). The uredia are larger than those of stripe rust (0.5 to 2.3 mm). These are never in rows but may be assembled in small clusters. Rust pustules may develop on both side of leaves, but usually, common on the upper surface of leaf than the lower surface. When temperature rises, the uredosori are gradually replaced by the small, oval or linear, dull black and sub epidermal teliosori (Pal 1966 and Singh 1990).

2.6 Life cycle

The wheat rusts are heterocious in nature and have five different types of spores namely pycniospore, aeciospore, urediniospores, teliospores and basidiospores. The urediniospores are the repeating spores of cereal rusts. The teliospores are resting spores and after germination, meiosis occurs and leads to development of four haploid basidiospores which can disperse through wind and other agencies also. The basidiospores lands on the upper surface of alternate host and leads to development of pycnial structure having flexous hyphae and haploid pycniospores. The pycniospores are often carried by various agencies to the receptive hyphae of opposite mating type where plasmogamy may occur. After plasmogamy dikaryotic aecium develops underside of leaf surface. When the aecium matures, the aeciospores get released, get dispersed through wind, infects their cereal host and the cycle runs continuously through the formation of urediniospores (Kolmer 2013).

2.7 Epidemiology

In disease triangle, specific weather conditions, pathogen inoculum (urediniospores) and susceptible host are essential for disease development. Among these, weather conditions are most important factors. The main components of weather are temperature, moisture and wind effecting the development of stripe rust and leaf rust. Temperature influences the germination, infection and survival of the urediniospores as well as sporulation and host resistance. Germination of urediniospores is best at 9.7 ºC, but it can occur at 2.8 to 21.7 ºC. Later growth of the pathogen is best at 12 ºC to 15 ºC and the minimum and maximum temperature requirements of the pathogen for growth are 3 ºC and 20 ºC respectively (Roelfs *et al* 1992 and Line 2002). Sporulation also can occur from 5 ºC to 20 ºC. The latent period of stripe rust varies from 11 days at optimum conditions to 180 days at temperatures near freezing (Roelfs *et al* 1992).

Germination of *P. triticina* urediniospores can occur at temperatures ranging from 2 to 30 ºC (optimum at 20 ºC) with free moisture on the primary hosts (bread wheat, its immediate relatives or triticale) (Roelfs *et al* 1992). Vallavieille-pope *et al* (1995) observed that *P. triticina* urediniospores germination occurred at optimum temperature ranging from 12 to 15 ^{0}C, but they do not germinate at temperature more than 35^{0}C. However, -4 to -6 ºC temperature reduced the viability of *P. triticina* urediniospores to less than 5 per cent (Eversmeyer and Kramer 1995). Free water and high light are required for sporulation. Moisture affects spore germination, infection and survival. Urediniospores require at least three hours of continuous moisture on the plant surface for germination and high relative humidity leads to adhesion of spore to the leaves. The germ tube penetrates through stomata and a haustorium develops inside the living host cell. Depending on the amount of host cells involved, the infection results in visible uredinia. New urediniospores are produced asexually in large numbers. Wind can helps in spore germination and infection due to the dryness of the urediospores. The major role of wind is in dispersal of urediospores from infected fields to healthy fields over long distances (Chen 2005).

2.8 Management

The different management strategies can be followed to reduce the interaction between host and pathogen and development of the disease. Among them use of resistant varities and fungicides are the most common ones and most exploited for the rust management. Startlingly, Eriksson and Henning (1896) concluded that partial control of rust was possible with sulfur, but its use was infeasible. Forsyth and Peturson (1958) have found effective control of wheat leaf and stem rusts in field trials by 4 to 5 applications each of nabam and zinc sulphate. Grewal and Dharmvir (1959) observed that four applications of parzate liquid plus zinc sulphate at 15 days interval can reduce the rust diseases. The high yield of wheat crop was achieved in Pacific Northwest during 1981 due to successful use of triadimefon to control wheat rust (Line 2002). Use of Penthiopyrad (Vertisan) (succinate dehydrogenase inhibitor (SDHI) fungicide) in field resulted in reduction of wheat rust due to inhibition of fungal respiration (Chen *et al* 2012). Six triazole fungicides namely: triadimefon

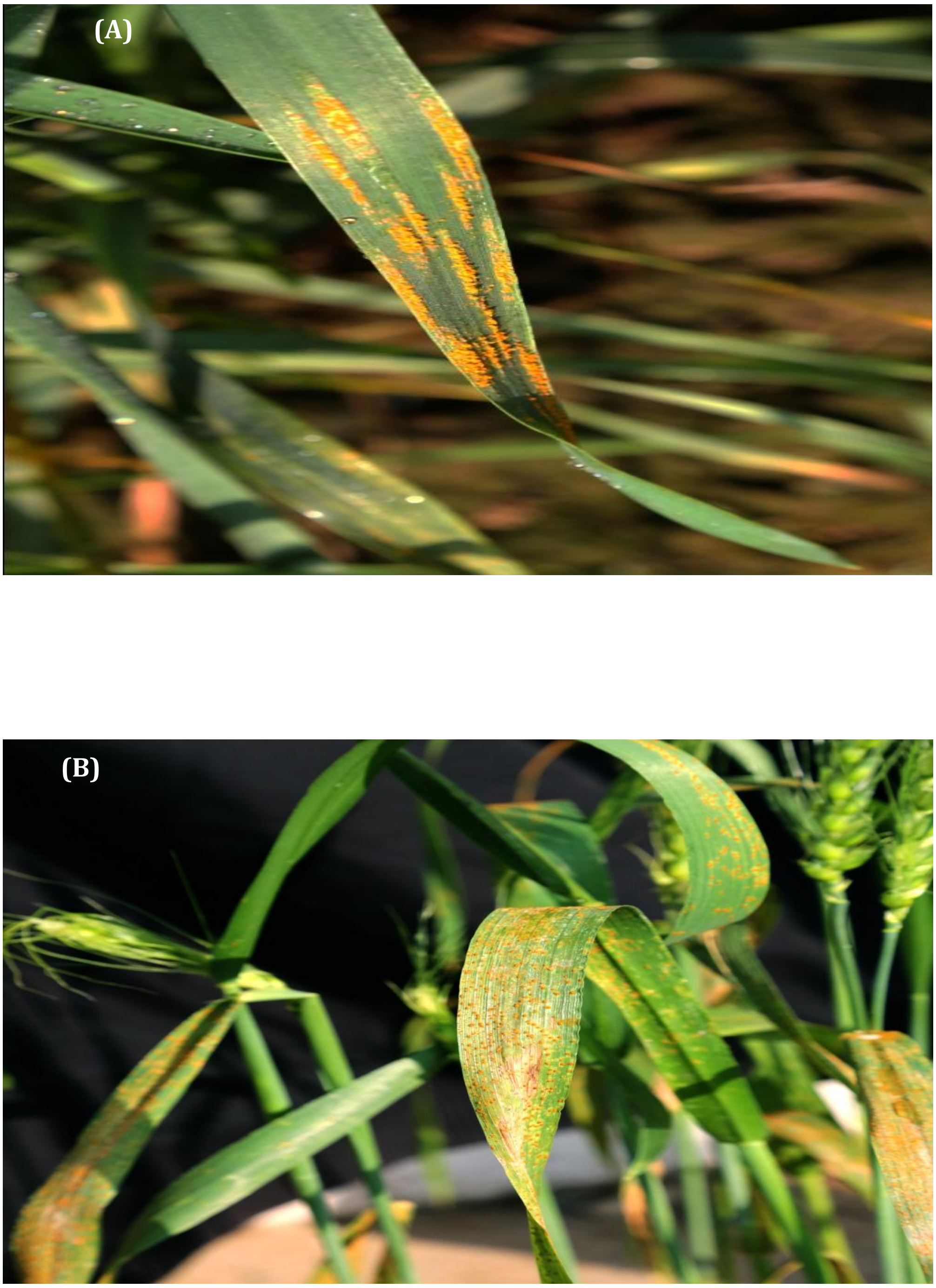

Plate 2.1: Symptoms of stripe rust (A) and leaf rust (B)

(Bayleton 25 EC), difenoconazole (Score 25 EC), propiconazol (Tilt 25EC), mono and di-potassium salt of phosphorous acid (Topaz), fenarimol (Rubigan 12.5 EC) applied at 0.1 per cent concentration and hexaconozole (Contaf 5 EC) at 0.2 per cent along with mancozeb (Indofil M-45) at 0.25 per cent were evaluated as foliar sprays for the management of stripe rust, leaf rust and powdery mildew of wheat by Basandrai *et al* (2013). Out of all fungicides tested triadimefon, propiconazole and hexaconazole effectively controlled more than 85 per cent of stripe and leaf rust and gave higher grain yield compared with unsprayed check. Pannu *et al* (2014) also evaluated different fungicides namely Bayleton 25WP, Folicur 25 EC, Amistar Xtra 280SC, Amistar Top 325SC, Opera 183SE, Orius 250EC, Ergon 443SC, Folicur 430SC (0.10%), Nativo 75WG (0.08%) and Picoxystrobin + Propiconazole 20SC (0.20 %) for management of stripe rust under field conditions. Bayleton 25WP was found more effective and controlled the disease up to 94.20 per cent, followed by Folicur 430SC with disease control up to 93.86 per cent in comparison to untreated control. Recently developed fungicide formulations, such as Topguard (Flutriafol + Propyleneglycol), Aproach (cyproconazole + picoxystrobin), Prosaro (Prothioconazole + Tebuconazole) and Quilt (Azoxystrobin + Propiconazole) were effective for control of wheat rust (Chen *et al* 2016). The chemicals are economical feasible for large scale application, but not ecologically sound and increase the selection pressure on pathogen which results in the emergence of new pathotypes. So the use of resistant varieties is the most effective, environment friendly and low cost method for the management of diseases. Biffen (1905) for the first time showed that resistance is conditioned by a single gene against the plant pathogens. Resistance genes in the host are independent of each other and if there is more than one resistance gene in the host, the gene responsible for the low infection type is expressed in comparison of other resistance genes (Flor 1955). This has been called 'false epistasis' (Knott 1989). The host plant resistance is mainly of two types “Horizontal” and “Vertical” resistance based on minor and major genes respectively (Vander plank 1963) against stripe and leaf rust. Seedling resistance is effective throughout plant's life, but unfortunately, new races develop very rapidly and have rendered single-gene resistance short-lived. Whereas adult plant resistance (APR) develops as plants mature and is considered more durable than seedling resistance (Chen *et al* 1995). Wheat genotypes showing adult plant resistant (APR) are often susceptible at the seedling stage and show moderate to high resistance at the adult plant stage (Li *et al* 2006). Resistance provided by adult plant resistant (APR) genes is not adequate in wheat cultivars, but impart high resistance when combined with 4 or 5 minor genes (Singh *et al* 2012).

2.9 Rust resistance genes

2.9.1 Stripe rust

Till date 78 permanently named *Yr* genes have been reported for resistance to stripe rust, including 24 for adult plant resistant (APR) and 54 for all stage resistant (ASR). Out of these 78 genes, 55 were derived from common wheat, 4 from durum wheat, 1 from synthetic wheat and 18 from wild species. Also, 327 QTLs with different names have been reported for resistance to stripe rust (Wang and Chen 2017). Chen and Line (1992) studied the inheritance of stripe rust in 13 wheat cultivars to differentiate nine (9) races of pathogen (*P. striiformis*). By crossing the differential cultivars having resistance to specific races with cultivar which was susceptible to specific race of pathogen and found that wheat cultivars, Chinese 166, Lemni, Riebesel 47/51 and Tyee have single dominant resistance gene as well as Druchamp, Fielder, Heines 7, Lee, Moro, Produra and Stephens have two (2) dominant resistance genes while, Pana and Yamhill have three (3) resistance genes. Stripe rust resistance genes were reported in old wheat varieties, Sonalika (*Yr2* and *YrA*) and PBW 343 (*YrSulrick* and *YrA*) from India, Lerma Rojo (*Yra*), Bluebird (*Yr6, Yr18* and *YrA*), Pavon F 76 (*Yr6,Yr7* and *Yr29*) Champingo 53 (*Yr18*) and Ciano79 (*Yr27*) from Mexico, Barani 83 (*Yr27*) and Inqilab 91 (*Yr27*) from Pakistan, Chines Spring (*Yr18*) from China and Frontana (*Yr18*) from South America (Mclntosh *et al* 1995). Nayar *et al* (1996) revealed that seedling resistance genes *Yr5, Yr10, Yr15, Yr26* and *Yr27* are effective against a mixture of prevalent Indian stripe rust races. Viljanen *et al* (1998) reported reduction in area under disease progress curves (AUDPC) in wheat cultivars possessing *Yr18* gene than cultivars without the gene but substantial stripe rust disease epidemics occurred under heavy inoculum, suggesting *Yr18* should not be used in isolation in disease control strategies based on disease resistance.

Sharma *et al* (2002) reported that wheat cultivars CPAN1922, HS208, CPAN1796 and Ollanta were resistant to all three races of *P. striiformis* namely 46S103, 47S103 and 47S102 races at seedling and adult stages. BW11 and Mukta exhibited adult plant resistance to races 47S102 and 46S103 respectively whereas seedlings of both cultivars were resistant to race 47S103. Cocoroque 75, Bounty, Tonichi 71, Oxley, Pavon 76, UP1109 and WL410 exhibited adult plant resistance to both 46S103 and 47S103 races whereas seedlings of these cultivars were resistant to race 47S102. Sener Kurt (2002) analysed the reactions of 12 wheat cultivars to stripe rust in Turkey. Wheat cultivars Seri 82 and Kaklic were susceptible and Orso, Pandas, Ege 88 and Diyarbakir 81 were resistant to stripe rust. The infection rate of stripe rust was highest in Gonen, Diyarbakir 81 and Dicle 74 and lowest in Gemini and Kaklic. *Yr36* gene was identified from *Triticum turgidum* var. *dicoccoides* and susceptible to almost all the stripe rust pathogen races tested at the seedling stage but showed adult-plant resistance to the prevalent races in California and is closely linked to the grain protein content locus Gpc-B1. The isogenic background of durum cultivar Langdon was used to map the *Yr36* gene on the short arm of chromosome 6B completely linked to Xbarc101 and within a 2-cM interval defined by PCR based markers Xucw71 and Xbarc136 (Uauy *et al* 2005). Lin and Chen (2007) identified genes for the stripe rust resistances and crossed Alpowa with Avocet Susceptible (AVS). Seedlings of the parents and F1, F2 and F3 progeny were tested with races PST 1 and PST 21 of *P. striiformis* f. sp. *tritici* under controlled greenhouse conditions. Alpowa had a single partially dominant gene designated as *YrAlp*, conferring all stage resistance and *Yr39* gene was also identified in cultivar Alpowa. *Yr39* non-race specific high-temperature adult-plant (HTAP) stripe rust resistance gene and two RGAP markers, Xwgp36 and Xwgp45 with the highest R2 values were closely linked to *Yr*39 and chromosomal location is 7BL. Kaur and Singh (2004) reported that two wheat genotypes A206 and VL404 possess seedling resistance as well as adult plant resistance to the races namely 46S103 and 46S119 whereas seven genotypes namely CIM 5, CIM 7, CIM 53, CPAN 1922, Dove, Emu and Pari 73 have seedling resistance and adult plant resistance against race 46S103 and have adult plant resistance against race 46S119. Two hundred accessions of *Triticum turgidum* (2n=4x=28AABB), forty accessions of *Aegilops tauschii* (2n=2x=14DD) and six accessions of *Aegilops triuncialis* (2n=4x=28CCUU) were screened against stripe rust of wheat at seedling stage by Rizwani *et al* (2007). Bulk inoculum collected from environmentally diverse wheat growing areas of Pakistan was used for the seedling evaluation. The inoculum of stripe rust had virulence for genes *Yr1, Yr3, Yr4, Yr5, Yr6, Yr7, Yr8, Yr9, Yr18, YrSD, YrCV and YrSp.* Infection types ranging from low to high were recorded within each germplasm category where 35 durum lines (*T. turgidum*) and 13 of *Aegilops tauschii* had good seedling resistance (0 to 2). Another 20 durum and 12 *Aegilopes tauschii* lines were found moderately resistant. Frequency distributions of the infection types were higher for *Aegilopes tauschii* lines (34 per cent) as compared to the durum wheat’s (20 per cent).

Xia *et al* (2007) reported stripe rust resistance genes *Yr6, Yr7, Yr9, Yr2, Yr3a, Yr4a, YrSel, YrSd, Yr26* and *Yr27* in seventy two advanced lines and Chinese wheat cultivars. Li *et al* (2009) reported that stripe rust resistance in cultivar C591 is controlled by a single dominant gene on the basis of seedling reaction test with five *Pst* races and the reaction patterns of C591 which were different from wheat cultivars or lines carrying *Yr2* or *Yr6*. The result indicated that the stripe rust resistance gene designated as *YrC59* and found on chromosome 7B. *Yr49* gene was identified in Avocet S 3 or Chuanmai 18 AUS91433 and chromosomal location of this gene is 3DS. The molecular map of this gene is *Xgpw7321-3D/Yr49* -1 cM - *Xgwm161-3D* (Spielmeyer *et al* 2010). Twenty wheat lines received from CIMMYT and fifty one commercial varieties of Pakistan were screened against stripe rust at four different locations during the cropping seasons 2007 to 2008 and 2008 to 2009 and observed that stripe rust resistance genes *YrSP, YrCV, Yr3, Yr5, Yr10, Yr15* and *Yr26* were effective and *Yr2, Yr6, Yr7, Yr8, Yr9, Yr17, Yr27* and gene combination Super Kauz (*Yr9, Yr18* and *Yr27*) and Opata (*Yr18* and *Yr27*) were not effective, while *Yr18* showed moderately susceptible at all locations. Among the fifty-one commercial varities Iqbal2000, Marvi2000, Barani70, Seher2006 and GA2000 were found resistant (Bux *et al* 2011). *Yr48* gene was identified from Synthetic wheat 205 and chromosomal location of this gene is 5AL. It is partial stripe rust resistance gene effective at adult plant stage (Jankuloski *et al* 2011).

Bux *et al* (2012) characterized the germplasm of wheat consisting of 20 Chinese cultivars, 95 synthetic hexaploids and 85 advanced breeding line for resistance against stripe rust at seedling stage under green house conditions. They found that synthetic hexaploids have resistance at seedling stage due to presence of *Yr3, Yr5, Yr10, Yr15, YrSP* and *YrCV* genes. But Chinese cultivars and advanced lines showed adult plant resistance under field conditions, which were susceptible at seedling stage. Both type of resistance were evaluated from wheat germplasm against stripe rust. Bansal *et al* (2011) found that Iranian common wheat AUS 28183 and AUS 28187 showed high levels of seedling resistance against Australian pathotypes of stripe rust pathogens. The resistance in these two cultivars is controlled by a single gene named as gene *Yr47*. Dawit *et al* (2012) studied the presence of different combination of stripe rust resistance genes *YrSU, Yr6, Yr7, Yr8, Yr9, Yr2, Yr3a, Yr4a, Yr27* and *Yr32* in twenty two bread wheat cultivars. Among these genes *Yr27, Yr32, Yr7, Yr8, Yr9, Yr6* and *Yr2* were not effective against yellow rust. Twenty four differential lines were tested with 20 *Pst* races and found that bread wheat cultivars webe and tusie were resistant to all 20 *Pst* races. In India *Yr9* gene provided resistance against *P. striiformis* f. sp. *tritici* for longer period but due to wider cultivation of PBW343 it was broken (Jindal *et al* 2012). *Yr52* was showed high temperature adult plant (HTAP) resistance to stripe rust in spring wheat germplasm PI 183527 and 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* (Ren *et al* 2012). Quaiu 3 common wheat line showed high resistance to predominated races of stripe rust in Mexico. This line also showed immunity to leaf rust in field trial due to presence of race specific gene *Lr42* (Basnet *et al* 2013).

Kumar *et al* (2014) studied the wheat cultivars for resistant genes at seedling stage under green house and adult stage under field conditions against stripe rust. Combination of three resistance genes *Yr2, Yr9* and *Yr18* against stripe rust were characterized by using gene mapping technique. They also observed that varieties namely GW173, HUW234, HW741, K8027, K 9006, K9107 and WH542 were having adult plant resistance. Singh *et al* (2014) evaluated three nurseries namely Australian Special Nursery (ASN), 22nd Semi-Arid Wheat Screening Nursery (SAWSN) and 12th High Temperature Wheat Yield Trial (HTWYT) for seedling and adult plant resistance against stripe/yellow rust. Among three nurseries first two ASN (51.1 per cent) and SAWSN (54 per cent) showed resistance against yellow rust. All three nurseries, possessed high level of resistance at adult plant stage against yellow rust. Herrera-Foessel *et al* (2015) identified and mapped stripe rust resistance gene *Yr60,* which confirmed resistance at seedling and adult plant stages against the two Mexican races of *P. striiformis.* Singh *et al* (2015) reported that seedling and adult plant resistance gene *Yr18* was characterized in eight cultivars and combination with other genes in the seven cultivars. Sixty two genotypes of wheat evaluated at seedling and adult stage against 10 different pathotypes of stripe rust in central Asia. Thirty four wheat genotypes also showed different levels of resistance at adult plant stage under field conditions and twenty genotypes showed less than 20 per cent severity in both Kazakhstan and Uzbekistan. Bunyodkor and Barhayot showed resistance to all pathotypes. *Yr5* combined with *Yr10* and *Yr15* genes were determined in Bunyodkor. *Yr1* in KR12 5075 and *Yr6* in KR11-03 and KR12-5003 were postulated (Kokhmetova *et al* 2017).

Stripe rust resistant genes *Yr5, Yr10* and *Yr15* are effective against prevailing races of *Pst* and thus can be deployed individually or in combination (Kaur *et al* 2017 and Tomar *et al* 2014). Gupta *et al* (2018) analysed thirty seven (37) wheat germplasm lines to stripe rust under artificial epiphytotic conditions on the basis of (FRS) final rust severity and (AURPC) area under rust progress curve and (CI) coefficient of infection during 2013-14 and 2014-15 and observed that eight cultivars (HD2307, DWR 16, VIL616, UP2121, HD2329, K65, HD2281 and Lal Bahadur) were partial resistance to stripe rust.

2.9.2 Leaf rust

Till date, 81 leaf rust resistance genes have been designated *Lr1* to *Lr79, Lrac104 and Lrac124* have been identified from different sources (Zaman *et al* 2017). Out of 81, 48 derived from *Triticum aestivum*, 28 from wild species and 3 from durum. Race specific genes, most of the designated genes are race specific e.g. *Lr1, Lr3, Lr9, Lr15, Lr19, Lr20, Lr23, Lr24, Lr25, Lr26, Lr28, Lr29, Lr30, Lr32, Lr36, Lr39, Lr42, Lr45, Lr47, Lr51,* etc. (McIntosh *et al* 1995 and 2009). Adult plant resistance genes *Lr12, Lr13, Lr21, Lr22a, Lr22b, Lr35, Lr37, Lr48, Lr49* and temperature sensitive genes *Lr10, Lr14a, Lr18* were effective at low temperature, while *Lr16, Lr17, Lr23* effective at high temperature (Dyck and Johnson 1983). Cloutier *et al* (2007) reported that partial leaf rust resistance gene *Lr1* is located at the distal end of the long arm of chromosome 5D and cloned from F1-derived doubled haploid (DH) population and recombinant inbred line (RIL) population from a cross between the susceptible cultivar AC Karma and the resistant line 87E03-S2B1. The resistance gene *Lr12* conferring adult-plant resistance was located on chromosome 4B (Dyck and Kerber 1971). It was also found in the Chinese Spring and occurs in several Eastern United States winter wheat varieties (Dyck and Samborski 1979). Leaf rust resistant gene *Lr13* is given seedling resistance and more effective at higher temperatures (Hawthorn 1984). It is located on chromosome 2BS. It was found in many cultivars such as Manitou, Neepawa, Chris and Sinton (Dyck and Samborski 1979). The APR gene *Lr22a* was originally detected in wild relative *Aegilopes tauschii* in 1960 (Dyck and Kerber 1970) and was later transferred into bread wheat and mapped to the short arm of chromosome 2D. The *Lr22a* gene confers partial resistance to a wide range of *P. triticina* pathotypes at adult plant stages (i.e. three-leaf stage or more than or equal to 25 days after germination) (Hiebert *et al* 2007). Singh and McIntosh (1984) found that *Lr27* and *Lr31* were resistance in the cultivar Gatcher conditioned only when present together. The genes were also determined to be in Hope (*Lr27)* and Chinese Spring *(Lr31*). Dyck and Kerber (1985) observed that *Lr1*, *Lr21* and *Lr10* were excellent examples of vertical or major resistance and these genes remained effective at seedling as well as at adult stage.

Kerber and Dyck (1990) reported that *Lr35* was originally derived from *Triticum speltoides* and showed resistance at the second-leaf stage and is fully expressed after the sixth-leaf stage. The chromosome location is 2B. *Lr35* and another gene *Sr39* are located on chromosome 2B with a recombination value of 3.0 per cent between them. *Lr35* has ability to decrease the size and number of uredinia, increase the latent period and reduction of historia formation in Thatcher (Rubiales and Niks 1995). Singh (1993) evaluated the leaf (brown) rust resistance genes in 26 Mexican wheat cultivars. At seedling stage, they were inoculated with 14 pathotypes of diverse virulence and avirulence combinations and at adult stage inoculated with two currently predominated pathotypes during 1991-1992 in north Mexico. The eight genes present singly or in combination: *Lr1* (in 12 cultivars), *Lr3* (in 4 cultivars), *Lr13* (in 18 cultivars), *Lr16* (in 1 cultivar), *Lr17* (in 3 cultivars), *Lr23* (in 2 cultivars), *Lr26* (in 1 cultivar) and *Lr34* (in 13 cultivars). Pathotypes showed virulence on above genes except *Lr34*, the 13 cultivars with *Lr34* gene showed low to intermediate adult plant disease severities. Leaf rust resistance genes were present in old wheat varieties namely Larma Rojo (*Lr13* and *Lr17*) Champingo 53(*Lr34*), Penjamo 62 (*Lr14a* and *Lr34*), Ciano 79 (*Lr16*), Pavon F 76 (*Lr1, Lr10, Lr13* and *Lr46*) and Sonora 64 (*Lr1*) from Maxico, Mexipak 65 (*Lr14a*) and Sonalika (*Lr13* and *Lr14a*) from India, Punjab 81 (*Lr10, Lr13* and *Lr34*) from Pakistan, Era (*Lr10, Lr13* and *Lr34*) from North America and Frontana (*Lr13* and *Lr34*) from South America (Mclntosh *et al* 1995). Singh *et al* (1995) found that two cultivars of wheat namely Ciano 79 and Papago 86 showed resistance to leaf rust but the inheritance of resistance was unknown. In order to know the inheritance, they crossed these two cultivars with susceptible cultivar Sonara 64 and adult plant resistance cultivar Fontana. They found that the gene *Lr16* showed moderate resistance but along with one of the two slow rusting genes, it showed additive effect. Barcellos *et al* (2000) studied the inheritance of leaf rust resistance in adult crop plants of wheat cultivar Toropi by crossing with susceptible cultivar IAC 13. They found that the plants were susceptible at seedling stage became resistant at adult stage due to the presence of adult plant resistance gene under field conditions. But under green house conditions, they also observed two recessive genes responsible for leaf rust resistant and dominant gene *Lr34* from Thatcher cultivar. The resistant gene *Lr48* was originated from CSP44 and mapped on chromosome arm 2BS flanked by marker loci Xgwm429b (6.1 cM) and Xbarc7 (7.3 cM) distally and proximally, respectively. It showed hypersensitive response at adult plant resistance stage, which is recessive in nature and *Lr49* gene was derived from VL404 and flanked by Xbarc163 (8.1 cM) and Xwmc349 (10.1 cM) on chromosome arm 4BL. It showed hypersensitive reaction at adult plant stage, which is dominant in nature (Saini *et al* 2002).

Lr48 and *Lr49* confirmed resistance against Indian leaf rust races, 77-1, 77-2, 77-3, 77-4, 77-5, 12, 77 and 108 (Tomar and Menon 1998). Bhardwaj *et al* (2010a) screened advances breeding lines and released varieties of wheat against different pathotypes of *P. triticina* for leaf rust resistance. They used seven genes viz., *Lr1*, *Lr3*, *Lr 10*, *Lr13*, *Lr 23*, *Lr 26* and *Lr34* in different combinations in 39 wheat lines having race specific adult plant resistance. Adult plant resistance (APR) to three most virulent pathotypes, 21R55 (104-2), 1R5 (12-2) and 121R63-1 (77-5) was given by two varieties NIAW 34 and GW 322. Twenty one wheat lines have adult plant resistance to two pathotypes and sixteen lines have adult plant resistance to only one pathotype. Boroujeni *et al* (2011) studied the 36 cultivars of wheat for postulating the resistant genes against leaf rust in Iran. They found very low variation in the *Lr* genes present among the commercially available wheat cultivars. *Lr1* (70 per cent), *Lr3* (62 per cent), *Lr10* (43 per cent), *Lr26* (38 per cent) and *Lr23* (19 per cent) most frequently occurred genes. They also postulated the eight known and some unknown genes for resistance against leaf rust. Chhuneja *et al* (2011) observed that two effective leaf rust resistant genes *Lr24* and *Lr28* in PBW 343. Herrera-Foessel *et al* (2011) reported that *Lr68* gene was derived from Parula and chromosome location is 7BL. Close linkage with several markers in chromosome arm 7BL and *Lr14b* in the Apav × Arula populations has been observed. Flanking markers are *Xpsy1-1* and *Xgwm146-7BL* at 0.4 and 0.6 cM. Gamma-irradiation induced deletion stocks of Arula 1 that lack *LrP* but have *Lr14b* were identified showing that the two genes are located at different closely linked loci. The nonspecific genes (*Lr34, Lr46* and *Lr67*) were combination with specific genes (*Lr2a, Lr29, Lr28, Lr25* and *Lr19*) would more effective and durable resistance against leaf rust (Farid *et al* 2013). Dakouri *et al* (2013) evaluated the world wheat collections with ten races of leaf rust pathogen to do the characterization of seedling and adult plant leaf rust resistance. Fourteen seedlings resistance genes were present in the wheat cultivars. Among them *Lr1*, *Lr3*, *Lr10* and *Lr20* genes were present all over the world in all wheat cultivars. While *Lr9*, *Lr14b*, *Lr3ka*, *Lr30* and *Lr26* genes were rare all over the world in wheat cultivars.

Farid *et al* (2013) concluded that strategy of pyramiding of adult plant resistance genes was developed through understanding the rust resistance mechanism in pre-existing varieties like Lerma Rojo-64, Yaqui-50 and Lyalpur -73 and recent developed varieties are Shafaz-06, Lasani-08 and AARI-11 have potential of APR gene pyramiding against stripe, leaf and stem rusts. Muhammad *et al* (2015) evaluated the genotypes to leaf rust and effect of various environmental conditions on development of leaf rust to find out the resistance genotypes. They observed that same genotypes showed different responses during the two different crop seasons due to change in environmental conditions and also showed the different reactions against leaf rust viz., from highly resistance to susceptible. Kumari *et al* (2015) screened nine hundred eighty (980) germplasm accessions against leaf rust during 2012-13. Results demonstrate that three accessions (EC-635627, EC-635621 and EC-664244) were resistance at seedling stage, four accession (EC-635627, EC-625705, EC-635721 and EC-664244) were high resistance to leaf rust at adult plant stage and other twenty nine (29) germplasm accessions were adult plant resistance due to the presence of effective race specific resistance genes. Leaf rust resistant genes (*Lr1* to *Lr29*) were identified before 1980 and most recently *Lr75* adult plant resistance (APR) gene has been characterized by Singla *et al* (2017). Kolmar *et al* (2018a) found that three leaf rust resistant quantitative trait loci (QTL) on chromosomes 3DS, 3AS and 6DS from wheat cultivar Americano 44d. 3DS and 3AS strongly interacted when present in the same genotype to decrease leaf rust severity equal to the resistant genotype. The leaf rust resistant gene *Lr77* derived from Santa Fe on chromosome 3BL by using genetic map of the RIL population was constructed using 90,000 single-nucleotide polymorphism (SNP) markers with the Illumina Infinium iSelect 90K wheat bead array (Kolmar *et al* 2018b).

Riaz *et al* (2018) evaluated that 295 bread wheat accessions from the N I Vavilov Institute of Plant Genetic Resources for leaf rust resistance and performed genome-wide association studies (GWAS) using 10,748 polymorphic DArT-seq markers. The diversity panel was evaluated at seedling and adult plant growth stages using three *Puccinia triticina* pathotypes prevalent in Australia. Genome-wide association studies (GWAS) were applied to 11 phenotypic data sets which identified 52 significant marker–trait associations representing 31 quantitative trait loci (QTL). Among them, 29 QTL were associated with adult plant resistance (APR) and two QTL were strongly associated with seedling resistance.

CHAPTER III

MATERIALS AND METHODS

The present study was conducted at the experimental area of the Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana and at PAU off-season research station, Keylong (Lahaul and Spiti, Himachal Pradesh). The main objective of the study was to identify genes for rust resistance in wheat germplasm lines against most prevalent pathotypes of stripe rust pathogen namely 46S119, 78S84, 110S119 and mixture of pathotypes (78S84, 110S84, 110S119, 46S119, 47S103 & 238S119) and leaf rust pathogen namely 77-5 , 77-9 and mixture (77-5, 77-9, 104-2 & 12-5). Experiments were conducted to evaluate and identify promising wheat cultivars on the basis of low level of stripe and leaf rusts infection at seedling and adult plant stage and carryout genetic analysis of some resistant cultivars. The experimental materials and the methods which were adopted to accomplish the said objectives are described below:

3.1 Plant Material

The experimental material consisted of six hundred and seven (607) advance wheat lines/cultivars showing resistance to stripe rust and leaf rust including susceptible cultivar PBW343, PBW550, HD2967 and BWL4444 (PBW550//Yr10/6*AVOCET/3/**PBW550// HD2967). These lines were used for monitoring the stripe and leaf rust development.

S. No.	Accession No
1	IC530005
2	IC530119
3	IC529894
4	IC530025
5	IC128153
6	IC533416
7	IC445516
8	IC47034
9	IC529090
10	IC529354
11	IC445316
12	1C539162
13	IC529908
14	IC529311
15	IC542104
16	IC530087
17	IC530086
18	IC469717
19	IC542117
20	IC530078
21	IC443681
22	IC445439
23	IC543413
24	IC543390
25	IC564090
26	IC445506
27	IC529902
28	IC549409
29	IC553914
30	IC529907
31	IC582705
32	IC128253
33	IC469420
34	IC529052
35	IC549338
36	IC443759
37	IC529094
38	IC529943
39	IC547699
40	IC530058
41	IC529213
42	IC543404

S. No.	Accession No
43	IC539168
44	IC539540
45	IC543384
46	EC178071504
47	IC260939
48	IC325997
49	IC415945
50	IC416018
51	IC416120
52	IC416143
53	IC416415
54	IC416170
55	IC416171
56	IC416244
57	IC416252
58	IC532207
59	EC183963
60	EC190996
61	EC255091
62	EC664190
63	EC660682
64	EC664198
65	EC693321
66	EC636264
67	EC662236
68	EC664239
69	EC660850
70	EC693306
71	EC635697
72	EC635701
73	EC664206

S. No.	Accession No
74	EC660874
75	EC663916
76	EC693322
77	EC692262
78	EC635577
79	EC635865
80	EC636232
81	EC660681
82	EC635750
83	EC635690
84	EC597947
85	EC660684
86	EC633778
87	EC660680
88	EC660948
89	EC635663
90	EC635569
91	EC597921
92	EC664238
93	EC635576
94	EC635653
95	EC635715
96	EC635777
97	EC664223
98	EC613049
99	EC635684
100	EC635704
101	EC635859
102	EC664291
103	EC660969
104	EC635608

S. No.	Accession No
105	EC635767
106	EC635657
107	EC635664
108	EC597933
109	IC111939
110	EC576744
111	IC252974
112	IC547602
113	EC534511
114	IC543372
115	EC10860
116	IC531941
117	IC578102
118	IC420932
119	EC577481
120	IC111691
121	IC539208
122	EC573887
123	EC576272
124	IC416046
125	IC531950
126	EC380904
127	IC535470
128	IC574775
129	IC416043
130	IC415825
131	IC335768
132	IC111745
133	IC539593
134	IC553065
135	IC542898

S. No.	Accession No
136	IC531277
137	IC535428
138	IC416040
139	IC415882
140	IC111693
141	IC534494
142	IC535498
143	IC585640
144	IC535692
145	EC374953
146	IC560681
147	EC552096
148	IC138426
149	IC533941
150	EC573599
151	EC576009
152	IC534662
153	EC534495
154	IC5391184
155	IC534601
156	IC445333
157	EC576201
158	IC582727
159	EC573569
160	IC416145
161	IC534409
162	EC534382
163	IC531236
164	IC566636
165	IC542056
166	IC534974

S. No.	Accession No
167	IC36692
168	EC576889
169	IC415859
170	IC279571
171	IC542068
172	IC553915
173	IC252887
174	EC560473
175	IC542568
176	IC445384
177	IC532680
178	EC574781
179	IC252991
180	EC295402
181	IC533797
182	IC529410
183	IC336645
184	IC549460
185	IC542799
186	EC299240
187	EC13745
188	IC529938
189	IC530026
190	EC217808
191	EC217835
192	EC582263
193	IC553110
194	IC547669
195	IC528888
196	IC329598
197	EC405393

S. No.	Accession No
198	IC530075
199	EC217699
200	IC252697
201	IC368001
202	EC180031
203	EC339611
204	IC530089
205	IC529373
206	EC582305
207	IC531945
208	EC339604
209	IC529399
210	IC540908
211	IC397300
212	IC138428
213	IC282300
214	EC217821
215	EC576894
216	EC609592
217	IC531176
218	EC574257
219	IC111717
220	IC524289
221	EC576202
222	EC425337
223	EC463381
224	EC425308
225	EC498862
226	IC574477
227	IC427824
228	IC524300

S. No.	Accession No
229	IC547602
230	IC524304
231	IC536077
232	EC573544
233	IC536373
234	IC535628
235	IC542477
236	IC128666
237	EC534432
238	IC531849
239	EC464029
240	IC531054
241	IC296538
242	EC534384
243	EC425322
244	EC190927
245	EC576171
246	EC576212
247	IC335738
248	IC252390
249	EC425309
250	IC524297
251	EC573817
252	EC523376
253	EC574785
254	EC217859
255	EC575085
256	IC543372
257	IC531189
258	IC531336
259	IC449058
260	IC310626
261	IC582907
262	IC531941
263	EC552086
264	IC539445
265	IC397983
266	IC252677
267	EC609571
268	EC574504
269	IC470134
270	IC336751
271	IC535696
272	IC321853
273	IC335970
274	IC531369
275	IC445516
276	IC415861
277	IC401979
278	IC531790
279	IC531211
280	IC415880
281	EC534451
282	IC121129
283	IC398067
284	IC445400
285	IC565812
286	IC252705
287	IC529309
288	IC542012
289	EC574259
290	EC575907
291	IC536474
292	IC535487
293	EC257883
294	IC531927
295	IC402010
296	EC576952
297	IC73571
298	IC531380
299	IC534047
300	IC416320
301	IC145954
302	IC252714
303	IC445494
304	IC252660
305	IC416046
306	IC290211
307	IC531950
308	IC531529
309	IC547588
310	EC277014
311	IC539531
312	IC75246
313	IC549385
314	IC128174
315	IC549499
316	IC296312
317	IC549520
318	IC536488
319	EC415809
320	IC531501
321	IC531257

S. No.	Accession No
322	IC531586
323	EC556482
324	IC574475
325	IC445366
326	IC416352
327	IC416409
328	IC144917
329	IC415875
330	IC529202
331	IC252419
332	IC574851
333	IC252369
334	IC335768
335	IC531432
336	IC278687
337	IC240802
338	EC582254
339	EC576298
340	IC290213
341	EC425289
342	IC35076
343	IC531542
344	IC531579
345	IC398091
346	IC547647
347	IC534364
348	IC531277
349	IC445414
350	EC463426
351	IC128187
352	IC535678

S. No.	Accession No
353	EC570328
354	EC190879
355	EC576195
356	IC533606
357	IC563970
358	IC524017
359	IC416079
360	IC416142
361	IC415860
362	EC534415
363	IC416040
364	IC416108
365	IC531201
366	IC531377
367	IC531884
368	IC214796
369	IC252609
370	IC549527
371	IC416146
372	IC445407
373	EC548666
374	IC436069
375	IC539349
376	IC415877
377	IC335781
378	IC529285
379	IC335533
380	EC217869
381	IC335694
382	IC335740
383	IC542053

S. No.	Accession No
384	EC609570
385	IC534494
386	IC303070
387	IC554659
388	EC573808
389	EC576105
390	IC542622
391	IC252742
392	IC415939
393	EC257881
394	IC416119
395	IC445374
396	IC416111
397	IC112260
398	IC445527
399	IC531471
400	EC568041
401	IC547631
402	IC547657
403	EC576651
404	IC401976
405	IC539316
406	EC575036
407	IC539486
408	IC333151
409	IC252542
410	IC335788
411	EC575881
412	EC556510
413	EC10814
414	EC217766

S. No.	Accession No
415	IC335683
416	IC539529
417	IC542052
418	IC547646
419	IC549334
420	IC536221
421	EC119958
422	IC543059
423	IC252623
424	EC38102
425	EC552096
426	IC535279
427	EC10968
428	IC138447
429	IC138426
430	IC145938
431	EC467937
432	IC533733
433	IC252441
434	IC542050
435	IC549436
436	IC542051
437	EC177723
438	EC576094
439	IC415955
440	EC574784
441	EC574756
442	IC416168
443	IC539184
444	EC534519
445	EC534408
446	EC534421

S. No.	Accession No
447	IC416071
448	IC531062
449	IC531364
450	IC531998
451	EC552088
452	IC547655
453	IC547648
454	IC553256
455	EC463974
456	IC547586
457	IC586830
458	EC576201
459	IC128211
460	IC253002
461	EC463433
462	IC335695
463	IC252844
464	IC252668
465	IC539315
466	EC415866
467	IC469485
468	IC539317
469	IC549364
470	IC443728
471	IC542045
472	EC177724
473	IC582727
474	EC573820
475	EC573604
476	EC573569
477	EC575913
478	IC416077
479	IC416145

S. No.	Accession No
480	EC575272
481	IC427401
482	EC574744
483	IC573852
484	EC276987
485	IC415876
486	EC578155
487	IC542059
488	IC445413
489	IC536122
490	IC535601
491	IC128177
492	IC539403
493	EC177766
494	IC531363
495	IC547634
496	IC547592
497	IC436077
498	EC558754
499	IC406547
500	EC464064
501	IC554661
502	IC566636
503	IC582709
504	EC574238
505	IC416159
506	IC542056
507	EC483002
508	IC443737
509	IC415859
510	IC252431
511	IC469480
512	EC573786

S. No.	Accession No
513	IC536353
514	EC573791
515	EC576093
516	EC576010
517	IC542801
518	EC534412
519	IC416013
520	IC415903
521	IC415967
522	EC534407
523	IC416167
524	IC416269
525	IC445335
526	IC445297
527	IC547675
528	IC547594
529	IC553915
530	IC547642
531	IC443633
532	IC542519
533	IC11252
534	IC542860
535	EC575714
536	EC534476
537	EC578147
538	EC560473
539	EC574029
540	EC573810
541	IC536524
542	IC528964
543	EC11093
544	IC252991

S. No.	Accession No
545	IC252699
546	IC532655
547	EC578134
548	EC578163
549	EC596305
550	EC299240
551	EC13745
552	EC479375
553	EC14104
554	EC339609
555	IC573902
556	IC547669
557	EC6894
558	EC218034
559	IC528888
560	EC217657
561	EC576231
562	EC405393
563	EC573647
564	IC543262
565	EC217997
566	EC217883
567	IC252697
568	EC575606
569	EC577049
570	EC576356
571	EC368001
572	EC575971
573	EC577629
574	EC574047
575	EC217659
576	EC573974

S. No.	Accession No
577	EC217748
578	EC217705
579	EC575747
580	EC575662
581	EC514389
582	IC529501
583	EC566309
584	EC596303
585	IC529219
586	IC362251
587	EC217772
588	EC575732
589	EC217899
590	EC582324
591	IC531945
592	EC313705
593	EC339610
594	IC529399
595	EC582280
596	IC336648
597	IC279206
598	IC423451
599	EC313710
600	EC479369
601	IC443748
602	IC144915
603	EC574742
604	IC335782
605	IC401978
606	IC416408
607	IC543290

3.1.2 Pathogen

Three pathotypes namely 46S119, 78S84, 110S119 and mixture of pathotypes (78S84, 110S84, 110S119, 46S119, 47S103 & 238S119) of stripe rust and two leaf rust pathotypes namely 77-5, 77-9 and mixture of (77-5, 77-9, 104-2 and 12-5) were obtained from IIWBR, Regional Research Station, Flowerdale, Shimla and were multiplied under aseptic conditions separately on susceptible cultivars namely Agra Local, HD2967, A-9-30-1, HS240, PBW343, WL711 and BWL4444 in separate poly chambers for the evaluation of test materials at seedling and adult plant stage for diseases resistance.

3.2 Inoculation methods

3.2.1 Inoculation with hand

In this method, plants were sprayed with water and gently rubbed to remove thin layer of cuticular wax. The inoculum was applied on leaves to be inoculated with holding the leaf between fingers and gently moving the lancet needle from lower end of the leaf up to tip.

3.2.2 Spraying method

Spores collected from the infected leaves were suspended in water. Few drops of tween 20 were added in spore suspension. The inoculated material was sprayed with fine mist of water with suspended spores of the pathogen and kept for 48 hours in water saturated chamber. Rust epidemic was created by repeated spray inoculations.

3.2.3 Inoculations in the field

Stripe and leaf rust epidemic was created by repeated spray inoculations of experimental material with urediospores of *Puccinia striiformis* West. f. sp. *tritici* (*Pst*) and *Puccinia triticina* in isolated fields. Infected leaves of susceptible host PBW343, Agra local and HD2967 for stripe rust and BWL4444, PBW343 and Agra local for leaf rust (already inoculated) were immersed in water for extracting urediospores. The inoculum was prepared by suspending rust urediospores in 10 liters of water using few drops of Tween-20. The spray inoculations were done in the evening with ultra-low volume sprayer on alternate days beginning from end of December to end January till stripe and leaf rust appeared on the susceptible checks/parents.

3.3 Environmental conditions

3.3.1 For seedlings

The inoculated seedlings were kept in dew chamber having more than 90 per cent relative humidity and temperature of 10 ºC for 48 hours for successful infection process. Relative humidity was maintained by regular irrigations.

3.3.2 Growth conditions

Standard agronomic practices were followed in the field for raising the crop (Anonymous 2018a). Irrigation was done regularly at fortnight intervals to delay maturity and maintain high humidity for adequate rust development in the field.

3.4 Scoring infection types

Observations at seedling stage were recorded by using Nayar *et al* (1997) scale and disease severity at adult plant stage was recorded by using Modified Cobb's scale presented in Table 3.1 and Table 3.2.

Table 3.1: Scale for seedling reaction test (Nayar *et al* (1997)

Host Response	Descriptions
0	Immune, No visible symptoms ; Very resistant, Hypersensitive flecks
1	Resistant, Minute uredinia surrounded by mainly necrotic tissue
2	Resistant to moderately resistant, Small- to medium-sized uredinia surrounded by chlorotic and/or necrotic tissue, often appearing as green islands
3	Moderately resistant to moderately susceptible, medium to large uredinia with surrounding chlorosis
4	Susceptible, Large uredinia, without chlorosis or necrosis
X	Resistant Mesothetic, heterogeneous infection types similarly distributed over the leaf, chlorosis and/or necrosis usually present

For adult plant reaction: Rust severity was recorded as a percentage leaf area infected and plant reaction to the disease according to the **Modified Cobb scale.**

Table 3.2: Modified Cobb scale described by Peterson *et al* (1948) for recording plant reaction to stripe and leaf rust

Infection type	Reaction	Visible symptoms
No diseases	Immune	No visible infection on plant
Resistant	R	Necrotic area with or without minute uredia
Moderately resistant	MR	Small uredia present surrounded by necrotic area
Moderately resistant to moderately susceptible	MR-MS	Small uredia present surrounded by necrotic area as well as medium with no necrosis but possibly some distinct chlorosis
Moderately susceptible	MS	Medium uredia with no necrosis but possibly some distinct chlorosis
Moderately susceptible to susceptible	MS-S	Medium uredia with no necrosis but possibly some distinct chlorosis as well as Large uredia present with little or no chlorosis present
Susceptible	S	Large uredia are present with little or no chlorosis present

3.5 Screening at seedling stage

3.5.1 Raising seedlings in glass house

Wheat seedlings were raised in plastic germination trays (14×7 cups) filled with mixture of soil having sandy loam soil, vermi compost in ratio of 24:1. Two seeds of single genotype were sown in single cup. Sowing was done in six tray sets, one each for the pathotype 46S119, 78S84, 110S119, 77-5, 77-9 and mixture of pathotypes, separately. The trays were irrigated regularly for maintaining humidity.

3.5.2 Inoculations

Fully expanded primary leaves of ten day old seedlings were inoculated with urediospores of four different pathotypes of stripe rust and two different pathotypes of leaf rust. The inoculated material was placed in a dew chamber for 48 hours in dark and transferred to a greenhouse after 48 hrs of inoculation and maintained with photoperiod of 16 hour light and 8 hour of dark for successful infection process. Inoculated seedling were sprayed with water regularly to maintain high relative humidity of 80 per cent for disease development in leaf tissue and observed regularly.

3.6 Scoring infection types

The host response for seedling infection types was recorded 14 days after inoculation by using Nayar *et al* (1997) scale. The inoculations were considered successful when the susceptible checks showed the highest infection score of 3+ or 4.

3.6.1 Screening at adult plant stage:

3.6.1.1 Raising the adult plants in field

Six hundred twenty nine lines of wheat to be tested for resistance against stripe rust and leaf rust were sown in the experimental field during the 2nd week of November. One meter long single row of each genotype having row to row distance of 20-22 cm were planted. After every 20 rows of the test material, cultivar Agra Local, HD2967 and PBW343 were planted as susceptible checks for stripe rust and BWL4444, Agra local and PBW343 etc were planted as susceptible checks for leaf rust. The susceptible checks were also planted around the border of experimental material to ensure uniform spread of rust inoculum.

3.6.1.2 Scoring disease severity

In first year (2016-17), stripe rust and leaf rust were monitored regularly at fixed intervals starting from second week of January to last week of February for stripe rust and last week of February to end of March for leaf rust. The adult plants of each wheat germplasm line were observed at regular intervals used the formula given by as per the modified Cobb"s

Scale. From area under disease progress curve (AUDPC), relative area under disease progress curve (rAUDPC) and coefficient of infection (CI) were calculated.

$$\mathrm{AUDPC} = \sum_{i=1}^{n-1}\left(\frac{X_i + X_{i+1}}{2}\right)\left(t_{i+1} - t_i\right)$$

Where,

X_i = rust intensity on date i

t_i = time in days between i and date $i + 1$

n = number of dates on which disease was recorded

rAUDPC (relative area under disease progress curve)

$$\mathrm{rAUDPC} = \frac{\text{AUDPC of line or variety}}{\text{AUDPC of infector}} \times 100$$

CI (coefficient of infection)

Coefficient of infection (CI) is calculated by multiplying disease severity (DS) and constant values of infection type (IT). The constant values for infection types were used based on Immune=0, R=0.2, MR=0.4, M=0.6, MS=0.8, S=1 (Stubbs *et al* 1985)

In second year (2017-18), all the genotypes which showed resistance either to stripe rust or leaf rust were evaluated against most prevalent pathotypes of *Puccinia striiformis* f. sp. *tritici* and *Puccinia triticina* in isolation along with NILS's carrying known genes and susceptible checks for comparison purpose. Data were recorded in term of disease reaction and disease severity.

Table 3.3: List of AVOCET and Indian set of differentials used for stripe rust studies

S. No.	**AVOCET Nils**		**Genes**
1	Morocco	MX111-12(AVOCET NILS 1)	Null
2	AVOCET-YRA(YRA)	MX111-12(AVOCET NILS 2)	-
3	AVOCET+YRA(YRA)	MX111-12(AVOCET NILS 3)	-
4	*YR1*/6*AOC(CX93.51.3.3)	MX111-12(AVOCET NILS 4)	*Yr1*
5	SIETE CERROSS T66(118156-1M-2R-4M-0Y)	MX111-12(AVOCET NILS 5)	*Yr2*
6	TATARA(CM85836-50Y-0M-0Y-2M-0Y-0PAK)	MX111-12(AVOCET NILS 6)	*Yr3*, *Yr9*, *Yr27*
7	*YR5*/6*AOC(CX86.6.1.20)	MX111-12(AVOCET NILS 7)	*Yr5*
8	*YR6*/6*AOC(CX94.2.2.25)	MX111-12(AVOCET NILS 8)	*Yr6*
9	*YR7*/6*AOC(CX93.21.3.1)	MX111-12(AVOCET NILS 9)	*Yr7*
10	*YR8*/6*AOC(-38)	MX111-12(AVOCET NILS 10)	*Yr8*
11	*YR9*/6*AOC(CX93.24.1.22)	MX111-12(AVOCET NILS 11)	*Yr9*
12	*YR10*/6*AOC(CX93.53.3.1)	MX111-12(AVOCET NILS 12)	*Yr10*
13	*YR15*/6*AOC(CX89.1.1.27)	MX111-12(AVOCET NILS 13)	*Yr15*
14	*YR17*/6*AOC(-32)	MX111-12(AVOCET NILS 14)	*Yr17*
15	YR18/3*AOC(CX94.10.1.7	MX111-12(AVOCET NILS 15)	*Yr18*
16	*YR24*/3*AOC (CX96.1.3.12)	MX111-12(AVOCET NILS 16)	*Yr24*
17	*YR26*/3*AOC (CX96.17.1)	MX111-12(AVOCET NILS 17)	*Yr26*
18	*YR27*/6*AOC(-386)	MX111-12(AVOCET NILS 18)	*Yr27*
19	*YRSP*/6*AOC(CX94.14.1.15	MX111-12(AVOCET NILS 19)	*YrSP*
20	PAVON F 76(CM8399-D-4M-3Y-1M-1Y-1M-0Y-0MEX)	MX111-12(AVOCET NILS 20)	*Yr6*, *Yr7*, *Yr29* (APR), *Yr30* (APR)
21	SERI M 82 (CM33027-F-15M-500Y-0M-87B-0Y-0MEX)	MX111-12(AVOCET NILS 21)	*Yr2*, *Yr7*, *Yr9*, *Yr29*
22	OPATA M 85 (CM40038-6M-4Y-2M-1Y-2M-1Y-0B-0MEX)	MX111-12(AVOCET NILS 22)	*Yr27*, *Yr30* (APR)
23	SUPER KAUZ(CM67458-4Y-1M-3Y-1M-3Y-0B)	MX111-12(AVOCET NILS 23)	*Yr9*, *Yr18*, *Yr27*

S. No.	**AVOCET Nils**		**Genes**
24	YRCV/6*AOC	MX111-12(AVOCET NILS 24)	*Yr1*
25	PBW343(CM85836-4Y-0M-0Y-8M-0Y-0IND)	MX111-12(AVOCET NILS 25)	*Yr3*, *Yr9*, *Yr27*, *Yr29*
26	AOC-YR*3/3/ALTAR 84/AE.SQ/OPATA (CGSS00Y00204T-099M-20Y)	MX111-12(AVOCET NILS 26)	-
27	AOC-YR*3//LALBMONO1*4/PVN(CGSS01Y000IIT-O99B-37Y)	MX111-12(AVOCET NILS 27)	-
28	AOC-YR*3/PASTOR(CGSS00Y00207T-O99M-1Y)	MX111-12(AVOCET NILS 28)	-
29	POLLMER(CTY88.547)	MX111-12(AVOCET NILS 29)	-
30	Chinese166	-	*Yr1*
31	Lee	-	*Yr7*
32	Heines kolben	-	*Yr6*
33	Vilmorin 23	-	*Yr3*
34	Moro	-	*Yr10*
35	Strubes	-	*Yrsu*
36	Dickopf	-	*Yrsd*
37	Riebesel 47/51	-	*Yr9+*
38	Hybrid 46	-	*Yr4*
39	Heines VII	-	*Yr2+*
40	Compare	-	*Yr8*
41	*T. spelta album*	-	*Yr5*
42	Tc*6/*Lr26*	-	*Yr9*
43	PBW343	-	*Yr9*, *Yr27*

Table 3.4: List of NILs-Thatcher and Indian set differentials used for leaf rust studies

S. No.	**NILS**	**Lr gene(s)**
1	THATCHER	-
2	NIL-THATCHER-*LR1*-CTR	*Lr1*
3	NIL-THATCHER-*LR2A*-WS1	*Lr2a*
4	NIL-THATCHER-*LR2B*-CARINA	*Lr2b*
5	NIL-THATCHER-*LR3C*-LOROS	*Lr3c*
6	NIL-THATCHER-*LR3*-DEMOCRAT	*Lr3*
7	NIL-THATCHER-*LR3KA*-AIV	*Lr3ka*
8	NIL-THATCHER-*LR3BG*-BAGE	*Lrbg*
9	NIL-THATCHER-*LR8*-TRANSFER	*Lr8*
10	NIL-THATCHER-*LR10*-EX	*Lr10*
11	HUSSAR	-
12	NIL-THATCHER-*LR12*-EX	*Lr12*
13	MANTTOU	-
14	NIL-THATCHER-*LR14A*-SK	*L14a*
15	RL6006	-
16	NIL-THATCHER-*LR15*-K1483	*Lr15*
17	NIL-THATCHER-*LR16*-EX	*Lr16*
18	NIL-THATCHER-*LR17*-KLLU	*Lr17*
19	NIL-THATCHER-*LR18*-AF43	*Lr18*
20	NIL-THATCHER-*LR19*-TR	*Lr19*
21	THEW	-
22	NIL-THATCHER-*LR21*-RL5406(RL6043)	*Lr21*
23	NIL-THATCHER-*LR22A*-RL5404(RL6044)	*Lr22a*
24	NIL-THATCHER-*LR23*-LEE310	*Lr23*
25	NIL-THATCHER-*LR24*-AGENT(RL6064)	*Lr24*
26	TRANSEC(AWEND0-*LR25*	*Lr25*
27	NIL-THATCHER-*LR26*-ST-1-25(RL6078)	*Lr26*
28	GATCHER(-*LR10*, *LR27*+31)	*Lr10, Lr27+31*
29	CSD-2M-*LR28*(RL6079)	*Lr28*
30	NIL-THATCHER-*LR29*-CS7AG11(RL6080)	*Lr29*
31	NIL-THATCHER-*LR30TZ10*(RL6049)	*Lr30*
32	NIL-THATCHER-*LR32*-AE.TA(RL5497)	*Lr32*
33	NIL-THATCHER-*LR33*-P158548(RL6057)	*Lr33*

S. No.	**NILS**	**Lr gene(s)**
34	NIL-THATCHER-*LR34*-P158548(RL6058)	*Lr34*
35	NIL-MARQUIS-*LR35*-T.SP (5711)	*Lr35*
36	NIL-MANITOU-*LR36*-T.SP2-9	*Lr36*
37	NIL-THATCHER-*LR37*-VPM(RL6081)	*Lr37*
38	NIL-THATCHER-*LRB*-CARINA	*Lrb*
39	WL711(-01ND)	-
40	GAZA	-
41	ALTAR 84(CD22344-A-8M-1Y-2Y-1M-0Y)	-
42	IUMILLO	-
43	LOCAL RED	-
44	*LR41*/6*TC(05.4073.*LR41*)	*Lr41*
45	TC*6/T.SPELTA 783(c93.59.LR	-
46	TC/4*ST-1(C93.58.*LR45*)	*Lr45*
47	PAVON +*LR4*(C98.006 *LR47*)	*Lr4+47*
48	C78.5(*LR51*)	*Lr51*
49	*LR53*(-98M71)	*Lr53*
50	*Lr14a*	*Lr14a*
51	*Lr24*	*Lr24*
52	*Lr18*	*Lr18*
53	*Lr13*	*Lr13*
54	*Lr17*	*Lr17*
55	*Lr15*	*Lr15*
56	*Lr10*	*Lr10*
57	*Lr19*	*Lr19*
58	*Lr28*	*Lr28*
59	Loros(*Lr2c*)	*Lr2c*
60	Webster(*Lr2a*)	*Lr2a*
61	Democrat (*Lr3*)	*Lr3*
62	Thew (*Lr20*)	*Lr20*
63	Malakoff (*Lr1*)	*Lr1*
64	Benno (*Lr26*)	*Lr26*
65	HP 1633 (*Lr9*+)	*Lr9*
66	BWL4444	-

3.7 Genetic analysis of populations of crossed material to stripe rust and leaf rust pathotypes

3.7.1 Plant Material

All genotypes were evaluated with different pathotypes of stripe and leaf rust at seedling and adult plant stage during two consecutive crop seasons i.e. 2016-17 and 2017-18. The lines which showed resistance to stripe rust and leaf rust during 2016-17 were used to makes crosses with susceptible cultivar PBW621 (stripe rust) and HD3086 (leaf rust) (Table 3.5 and plate 3.1 and 3.2).

The details of the crossing material are listed in Table 3.5.

Table 3.5: Generation of F1's and segregating generation

Cross			Cross		
S. No.	**Female**	**Male**	**S. No.**	**Female**	**Male**
1	PBW621	IC530005	21	HD3086	IC278687
2	PBW621	IC530119	22	HD3086	EC570328
3	PBW621	IC529090	23	HD3086	EC576195
4	PBW621	IC445316	24	HD3086	IC563970
5	PBW621	IC530087	25	HD3086	IC524017
6	PBW621	IC530086	26	HD3086	IC416142
7	PBW621	IC530078	27	HD3086	IC415860
8	PBW621	IC529902	28	HD3086	IC416108
9	PBW621	IC553914	29	HD3086	IC531201
10	PBW621	IC529907	30	HD3086	IC252609
11	PBW621	IC529094	31	HD3086	IC303070
12	HD3086	EC552086	32	HD3086	IC252742
13	HD3086	IC321853	33	HD3086	IC445527
14	HD3086	IC401979	34	HD3086	IC576651
15	HD3086	IC531790	35	HD3086	IC401976
16	HD3086	IC549520	36	HD3086	IC539316
17	HD3086	IC531501	37	HD3086	IC190879
18	HD3086	IC531257	38	HD3086	IC252542
19	HD3086	IC574475	39	HD3086	IC542051
20	HD3086	IC445366	40	HD3086	IC547648

Plate 3.1: Parent I (S) and parent II (R) for stripe rust

Plate 3.2: Parent I (S) and parent II (R) for leaf rust

3.7.3 Field sowing

The F1 and F2 generations were sown with row to row spacing of 22 cm in the experimental area during second week of November, 2017-18. The experimental plot was surrounded by strips of PBW 343, Agra local and HD 2967 for stripe rust and BWL 4444, PBW 343 and Agra local for leaf rust as infector rows to create homogeneous disease infection.

3.7.4 Multiplication and Inoculations of pathogen

The mixture of pathotypes (78S84, 110S84, 110S119, 46S119, 238S119 & 47S103) of stripe rust was multiplied on susceptible host PBW343, HD2967 and Agra local in separate polythene chambers. The mixture of pathotypes (77-5, 77-9, 12-5 and 104-2) of leaf rust were multiplied on susceptible host BWL4444 and Agra local in separate polythene chamber. Rust epidemic was created by repeated spray inoculations of the test materials and infector rows with urediospores of *Puccinia striiformis* f. sp. *tritici* and *Puccinia triticina* suspended in water having 2-3 drop of tween 20 (Spraying inoculation method) in isolated fields.

3.7.5 Scoring disease severity

The disease severity of individual plants in F1and F2 populations was recorded according to the Modified Cobb scale as described by Peterson *et al* (1948).

3.8 Statistical analysis

3.8.1 Chi-square

Chi-square analysis was applied to test the fitness of genetic ratios in segregating populations obtained from different crosses. The $\chi 2$ value was calculated using the following expression:

$$\chi 2 \text{ (n-1) d.f.} = \Sigma \, (O - E)^2 / E$$

Where,

O = Number of plants observed in a phenotypic class

E = Number of plants expected in a phenotypic class

n = Number of phenotypic class

d.f. = Degree of freedom.

(If $\chi 2$ calculated value > $\chi 2$ table value, the null hypothesis is rejected)

CHAPTER – IV

RESULT AND DISCUSSION

This study was done to identify promising wheat lines exhibiting high level resistance at seedling and adult plant stage against stripe and leaf rust. Based on the evaluation of previous years six hundred seven wheat lines were selected from material received from NBPGR, New Delhi. The promising seedling and adult plant resistant lines were crossed with recipient parents for stripe rust (PBW621) and leaf rust (HD3086).

4.1 Identification of promising wheat lines on the basis of disease severity and infection type of stripe and leaf rusts at adult plant stage

4.1.1 Stripe rust

During the cropping season 2016-17, the first sign of stripe rust diseases was observed on 1st January, 2017 in the field. The data of stripe rust severities and infection type were recorded at ten days intervals starting from 10th January to 1st March 2017. The perusal of the data in Table 4.1 showed that 607 wheat lines were divided into five categories based on the range of final rust severity (FRS), area under disease progress curve (AUDPC), relative area under disease progress curve (rAUDPC) and coefficient of infection (CI) to stripe rust. The first category had sixty seven highly resistant lines with zero values of final rust severity, area under disease progress curve, relative area under disease progress curve and coefficient of infection. The second category had eighty seven resistant lines with range of final rust severity of 5-10S, area under disease progress curve of 1-200, relative area under disease progress curve of 1-14 and coefficient of infection of 2-10. The third category had one hundred three moderately resistant lines with range of final rust severity of 10-20S, area under disease progress curve of 201-400, relative area under disease progress curve of 15-25 and coefficient of infection of 8-20. The fourth category had one hundred seven moderately susceptible lines with range of final rust severity of 40S, area under disease progress curve of 401 to 600, relative area under disease progress curve of 26-37 and coefficient of infection of 40. The fifth category had two hundred forty five susceptible lines with maximum range of final rust severity of 40-80S, area under disease progress curve of more than 600, relative area under disease progress curve of 40-64 and coefficient of infection of 40-80.

Table 4.1: Final rust severity (FRS), Area under disease progress curve (AUDPC), Relative area under disease progress curve (r AUDPC) and Coefficient of infection (CI) for stripe rust on wheat germplasm during the year 2016-17

S. No	Accession No	Reaction	FRS	AUDPC	r AUDPC	CI
1	PBW725, IC530005, IC530119, IC529894, IC530025, IC128153, IC533416, IC445516, IC529090, 1C539162, IC530087, IC530086, IC542117, IC530078, IC443681, IC564090, IC529902, IC549409, IC553914, IC529907, IC582705, IC443759, IC529094, IC529943, IC547699, EC664190, EC660682, EC664198, EC693321, EC662236, EC660850, EC635701, EC693322, EC660684, EC633778, EC660680, EC635576, EC664223, EC10860, IC531941, IC539208, IC535470, IC415825, IC335768, IC539593, IC553065, IC585640, EC374953, IC534662, IC534974, IC36692, IC542068, IC336645, IC547669, IC530075, IC530089, IC529399, IC531927, EC552096, IC535279, EC574756, IC542056, IC547669, IC528888, EC405393, EC313705, IC529399 (67)	Highly Resistant	0	0	0	0
2	IC445316, IC529311, IC542104, IC469717, , IC543413, IC543390, IC445506, IC128253, IC469420, IC529052, IC530058, IC543404, IC539168, IC539540, IC543384, EC178071504, IC260939, IC415945, IC416018, IC416120, IC416415, IC416170, IC416252, EC183963, EC635697, EC664206, EC635577, EC635865, EC636232, EC660681, EC635750, EC635690, EC635715, EC635704, EC635859, EC635657, IC252974, IC547602, EC534511, IC543372, EC577481, EC573887, IC542898, IC531277, IC535428, IC415882, IC111693, IC535498, EC552096, IC533941, EC573599, EC576009, IC539184, IC534601, IC445333, EC576201, IC582727, IC416145, IC445516, IC542056, IC553915, IC549460, EC299240, IC529938, IC252697, EC582305, IC531945, EC339604, IC543372, IC531941, EC570328, IC416040, EC548666, IC534494, IC145938, IC533733, IC547586, IC416077, IC128177, EC177766, IC566636, IC415859, EC299240, EC576231, EC575732, EC582324, IC531945 (87)	Resistant	5-10	1-200	1-14	2-10

S. No	Accession No	Reaction	FRS	AUDPC	r AUDPC	CI
3	IC47034, IC529908, IC549338, IC416143, IC416171, IC416244, IC532207, EC636264, EC664239, EC660874, EC663916, EC692262, EC597947, EC660948, EC635663, EC635569, EC597921, EC664238, EC635777, EC660969, EC635608, EC635767, EC597933, EC576744, IC578102, IC111691, IC416046, EC380904, IC111745, IC416040, EC534495, EC573569, IC566636, IC415859, EC560473, IC252991, EC295402, IC529410, EC582263, IC528888, EC405393, EC217699, IC368001, EC180031, EC339611, IC529373, IC111717, IC524289, IC547602, EC573544, EC534432, EC464029, IC539445, IC252677, EC576952, IC547588, IC574475, IC416352, IC416409, IC144917, IC415875, IC398091, IC534364, IC531277, EC534415, IC335781, IC542053, EC576105, IC542052, IC547646, IC543059, EC38102, EC467937, IC542051, IC415955, EC574784, IC539184, EC534421, IC553256, IC469485, IC549364, IC416145, EC464064, IC443737, EC576093, IC553915, IC542519, IC542860, EC575714, EC534476, EC560473, IC252991, EC578134, EC13745, EC573647, EC577049, EC368001, EC575971, EC514389, EC217772, EC339610, EC582280, EC313710 (103)	Moderately Resistant	10-20	201-400	15-25	8-20
4	IC529213, EC190996, EC693306, EC635653, EC613049, EC635684, EC664291, EC635664, IC111939, IC420932, IC531950, IC416043, IC534494, IC535692, IC560681, IC138426, IC534409, EC534382, EC576889, IC279571, IC252887, IC542568, IC445384, IC532680, EC574781, IC533797, EC217808, EC217835, IC553110, IC329598, EC576202, IC574477, IC524300, IC536077, IC536373, EC190927, EC576171, EC523376, EC552086, IC531369, IC415861, IC398067, IC531380, IC539531, IC128174, IC531257, IC445366, IC529202, IC252419, IC278687, IC531579, IC445414, EC190879, IC415860, IC531884, IC214796, IC529285, IC335533, IC415939, IC112260, IC445527, IC547631, IC539486, EC575881, EC10814, IC549334, IC536221, EC177723, IC547648, IC586830, IC335695, IC539315, EC415866, IC539317, IC582727, EC573604, EC573569, IC531363,	Moderately Susceptible	40	401-600	26-37	40

S. No	Accession No	Reaction	FRS	AUDPC	r AUDPC	CI
	IC547592, IC406547, IC554661, IC536353, EC576010, EC534412, IC416013, EC534407, IC416167, IC445297, EC573810, EC578163, EC339609, IC573902, EC6894, EC217657, IC543262, EC217883, EC575606, EC57574, EC575662, IC362251, EC217899, IC336648, IC279206, IC423451, EC479369, IC335782, IC543290 (107)					
5	PBW343, HD2967, IC529354, IC325997, EC255091, EC576272, IC574475, IC531236, IC542799, IC530026, IC540908, IC397300, IC138428, IC282300, EC217821, EC576894, EC609592, IC531176, EC574257, EC425337, EC463381, EC425308, EC498862, IC427824, IC524304, IC535628, IC542477, IC128666, IC531849, IC531054, IC296538, EC534384, EC425322, EC576212, IC335738, IC252390, EC425309, IC524297, EC573817, EC574785, EC217859, EC575085, IC531189, IC53133, IC449058, IC310626, IC582907, IC397983, EC609571, EC574504, IC470134, IC336751, IC535696, IC321853, IC335970, IC445439, IC401979, IC531790, IC531211, IC415880, EC534451, IC121129, IC445400, IC565812, IC252705, IC529309, IC542012, EC574259, EC575907, IC536474, IC535487, EC257883, IC402010, IC73571, IC534047, IC416320, IC145954, IC252714, IC445494, IC252660, IC416046, IC290211, IC531950, IC531529, EC277014, IC75246, IC549385, IC549499, IC296312, IC549520, IC536488, EC415809, IC531501, IC531586, EC556482, IC574851, IC252369, IC335768, IC531432, IC240802, EC582254, EC576298, IC290213, EC425289, IC35076, IC531542, IC547647, EC463426, IC128187, IC535678, EC576195, IC533606, IC563970, IC524017, IC416079, IC416142, IC416108, IC531201, IC531377, IC252609, IC549527, IC416146, IC445407, IC436069, IC539349, IC415877, EC217869, IC335694, IC335740, EC609570, IC303070, IC554659, EC573808, IC542622, IC252742, EC257881, IC416119, IC445374, IC416111, IC531471,	Susceptible	40-80	>600	40-64	40-80

S. No	Accession No	Reaction	FRS	AUDPC	r AUDPC	CI
	EC568041, IC547657, EC576651, IC401976, IC539316, EC575036, IC333151, IC252542, IC335788, EC556510, EC217766, IC335683, IC539529, EC119958, IC252623, EC10968, IC138447, IC138426, IC252441, IC542050, IC549436, EC576094, IC416168, EC534519, EC534408, IC416071, IC531062, IC531364, IC531998, EC552088, IC547655, EC463974, EC576201, IC128211, IC253002, EC463433, IC252844, IC252668, IC443728, IC542045, EC177724, EC573820, EC575913, EC575272, IC427401, EC574744, IC573852, EC276987, IC415876, EC578155, IC542059, IC445413, IC536122, IC535601, IC539403, IC547634, IC436077, EC558754, IC582709, EC574238, IC416159, EC483002, IC252431, IC469480, EC573786, EC573791, IC542801, IC415903, IC415967, IC416269, IC445335, IC547675, IC547594, IC547642, IC443633, IC11252, EC578147, EC574029, IC536524, IC528964, EC11093, IC252699, IC532655, EC596305, EC479375, EC14104, EC218034, EC217997, IC252697, EC576356, EC577629, EC574047, EC217659, EC573974, EC217748, EC217705, C529501, EC566309, EC596303, IC529219, IC443748, IC144915, EC574742, IC401978, IC416408, PBW343, HD2967, AGRA LOCAL (245)					

In the present study, wheat lines were divided into different categories based on AUDPC (Table 4.1). Similarly, Safavi *et al* (2010) also divided the nineteen (19) wheat lines based on the range of rust severity (RS), area under disease progress curve (AUDPC), relative area under disease progress curve (r AUDPC), infection type (IT) and coefficient of infection (CI) to stripe rust in Ardabil during 2008-2009. The wheat lines namely C-87-4, C-87-5, C-87-13, C-87-14 and C-87-17 were from disease and C-87-1, C-87-2, C-87-3 and C-87-18 wheat lines were having highest relative area under disease progress curve and coefficient of infection. The wheat lines C-87-6, C-87-8 and C-87-11 were moderately resistant to moderately susceptible at adult stage and rest of the wheat lines showed moderately resistant to moderately susceptible reaction. Similarly, 37 wheat lines were evaluated against stripe rust under artificial epiphytotic conditions by Gupta *et al* (2018) and they categorized them on the basis of final rust severity (FRS) and area under rust progress curve (AURPC) and coefficient of infection (CI) during 2013-14 and 2014-15. It was reported that 10, 22 and 5 genotypes were moderately resistant (MR), moderately susceptible (MS) and susceptible (S) respectively. Based on FRS, the selected genotypes were categorised into 3 groups having low (1–35 per cent), moderate (36–65 per cent) high (66–90 percent) levels of FRS. Eight genotypes exhibited low level (1–35 per cent), twenty four showed moderate (36–65 per cent) and five genotypes possessed high values of FRS (66–90 per cent).

4.2.1 Leaf rust

During the crop season 2016-17, the first sign of leaf rust disease was observed on 2nd February, in the experimental plots. The data of leaf rust severities and infection type were recorded at 10 days intervals from 10th February to 12th March, 2017. The data in Table 4.2 showed that six hundred and seven wheat lines were divided into five categories based on the range of final rust severity, area under disease progress curve, relative area under disease progress curve and coefficient of infection to leaf rust. The first category had three hundred and thirty six highly resistant lines with zero values of final rust severity, area under disease progress curve, relative area under disease progress curve and coefficient of infection. The second category had forty eight resistant lines with range of final rust severity of 5-10S, area under disease progress curve of 1-200, relative area under disease progress curve of 1-14 and coefficient of infection of 2-10. The third category had seventy two moderately resistant lines with range of final rust severity of 10-20S, area under disease progress curve of 201-400, relative area under disease progress curve of 15-25 and coefficient of infection of 8-20.

Table 4.2: Final rust severity (FRS), Area under disease progress curve (AUDPC), Relative area under disease progress curve (r AUDPC) and Coefficient of infection (CI) for leaf rust on wheat germplasm during the year 2016-17

S. No	Accession no	Reaction	FRS	AUDPC	r AUDPC	CI
1	PBW 725, IC530025, IC128153, IC533416, IC445516, IC47034, IC529090, IC539162, IC542117, IC443681, IC543413, IC543390, IC445506, IC549409, IC553914, IC582705, IC128253, IC469420, IC549338, IC443759, IC547699, IC529213, IC543404, IC260939, IC325997, IC415945, IC416120, IC416143, IC416415, IC416170, IC416171, EC183963, EC660682, EC693321, EC636264, EC662236, EC660850, EC693306, EC635697, EC635701, EC664206, EC660874, EC693322, EC635865, EC636232, EC660681, EC597947, EC660684, EC660680, EC635569, EC664238, EC635576, EC635653, EC635715, EC635777, EC664223, EC635859, EC660969, EC635608, EC635657, EC635664, EC597933, IC547602, IC543372, IC531941, IC578102, EC577481, IC574475, IC335768, IC531277, IC534494, EC552096, IC138426, EC576201, IC582727, EC573569, IC416145, EC534382, IC566636, IC542056, IC553915, EC560473, IC547669, IC528888, EC405393, IC252697, IC368001, IC529373, IC531945, IC529399, IC397300, IC138428, IC282300, EC609592, IC524289, EC576202, EC425337, EC463381, EC498862, IC574477, IC427824, IC524300, IC547602, IC524304, IC542477, EC534432, IC531849, EC464029, IC531054, EC190927, IC335738, IC524297, EC573817, IC531189, IC449058, IC310626, IC582907, EC552086, IC539445, IC397983, IC252677, EC609571, IC470134, IC336751, IC321853, IC335970, IC531369, IC415861, IC401979, IC531790, IC415880, IC445400, IC565812, IC252705, IC529309, IC542012, EC574259, IC535487, IC531927, EC576952, IC531380, IC534047, IC416320, IC252714, IC445494, IC290211, EC277014, IC539531, IC549385, IC128174, IC549499, IC296312, IC549520, EC415809, IC531501, IC531586, EC556482,	Highly resistant	0	0	0	0

S. No	Accession no	Reaction	FRS	AUDPC	r AUDPC	CI
	IC574475, IC445366, IC416352, IC416409, IC144917, IC415875, IC252419, IC252369, IC335768, IC278687, IC290213, IC531542, IC398091, IC534364, EC463426, IC128187, IC535678, EC570328, EC190879, EC576195, IC563970, IC524017, IC416079, IC416142, IC415860, IC416108, IC531201, IC214796, IC252609, IC549527, IC416146, IC445407, EC548666, IC436069, IC539349, IC415877, IC335781, IC529285, IC335533, EC217869, IC542053, EC609570, IC534494, IC303070, IC554659, EC573808, IC542622, IC252742, IC415939, EC257881, IC445374, IC416111, IC445527, IC531471, IC547631, IC547657, EC576651, IC401976, IC539316, EC575036, IC539486, IC333151, IC335788, EC575881, EC556510, EC10814, IC335683, IC542052, IC547646, IC549334, EC119958, IC543059, IC252623, EC38102, IC535279, IC138447, IC138426, IC145938, IC533733, IC542050, IC542051, EC576094, EC574756, IC416168, EC534519, IC531998, IC547648, IC553256, EC463974, IC586830, IC128211, IC445516, IC539315, EC415866, IC539317, IC549364, IC582727, IC416145, EC575272, IC573852, EC276987, IC415876, EC578155, IC542059, IC535601, IC539403, EC177766, IC547592, IC436077, EC558754, IC406547, EC464064, IC566636, EC574238, IC416159, IC443737, IC252431, IC469480, EC573786, EC576010, IC445335, IC547594, IC547642, IC443633, IC542519, IC11252, IC542860, EC534476, EC578147, EC560473, EC574029, EC573810, IC536524, EC11093, IC252991, IC532655, EC578134, EC578163, EC596305, EC299240, EC339609, IC573902, IC547669, EC217657, EC576231, EC405393, EC573647, IC543262, EC217997, EC217883, IC252697, EC576356, EC368001, EC575971, EC574047, EC217659, EC573974, EC217748, EC217705, EC514389, IC529501, EC566309, EC596303, IC362251, EC217899, IC531945, EC313705, EC339610, IC529399, EC582280, IC423451, EC313710, EC479369, IC443748, IC144915,					

S. No	Accession no	Reaction	FRS	AUDPC	r AUDPC	CI
	EC574742, IC335782, IC401978, IC416408 (336)					
2	IC542799, IC121129, IC73571, IC547675, IC445316, IC542104, EC663916, EC692262, EC633778, EC635684, IC111939, IC416046, IC415825, IC416040, EC374953, IC531236, IC279571, IC336645, IC549460, IC145954, IC547588, EC534421, EC576201, IC539168, IC532207, EC664239, EC635577, EC635750, EC635663, EC635704, EC534511, EC573887, IC416043, IC535498, IC535692, IC539184, IC534601, IC534409, EC576889, IC542068, IC532680, IC529410, IC530075, EC339611, EC339604, IC543372, EC582254, IC536353 (48)	Resistant	5-10	1-200	1-13.33	2-10
3	IC530119, EC178071504, EC613049, EC635767, EC574785, IC398067, IC335694, EC568041, IC252542, IC539529, EC552096, EC467937, IC549436, EC534408, EC573604, EC574744, IC445297, IC553915, EC575747, IC530005, IC529311, EC635690, EC597921, EC664291, EC576744, IC252974, EC10860, IC420932, IC111691, EC380904, IC535428, IC111693, EC576009, IC445333, IC252887, IC445384, EC217808, EC217835, EC217699, IC530089, IC540908, IC128666, EC534384, IC531336, EC574504, IC535696, IC445439, EC534451, IC536474, EC257883, IC531950, IC536488, IC574851, EC576298, IC35076, IC547647, EC534415, IC335740, EC576105, IC536221, EC574784, IC547586, IC252668, IC443728, IC542045, EC573820, IC128177, IC531363, IC416013, IC415903, IC528888, EC577049 (72)	Moderately resistant	10-20	201-400	15-25	8-20
4	IC529894, IC530086, IC469717, IC564090, IC530058, IC539540, IC416018, IC416252, EC664190, EC664198, EC576272, IC531950, IC535470, IC111745, IC542898, IC415882, IC585640, IC560681, IC533941, EC573599, IC534662, EC534495, IC534974, IC415859, IC542568, EC574781, EC295402, IC533797, IC529938, IC530026, EC582263, IC553110, IC329598, EC180031, EC582305, IC536373,	Moderately susceptible	40	401-600	35-38	40

S. No	Accession no	Reaction	FRS	AUDPC	r AUDPC	CI
	IC535628, IC296538, EC425322, EC425309, EC523376, EC217859, EC575085, IC531941, IC402010, IC252660, IC531529, IC529202, IC531432, IC240802, EC425289, IC531579, IC531277, IC445414, IC533606, IC531377, IC531884, IC112260, EC217766, IC252441, EC177723, IC415955, IC539184, IC531062, EC552088, IC547655, IC253002, EC463433, IC335695, IC252844, IC469485, EC573569, EC575913, IC427401, IC536122, IC547634, IC582709, EC573791, EC576093, IC415967, EC534407, IC416167, IC528964, IC252699, EC13745, EC479375, EC14104, EC218034, IC529219, IC543290 (90)					
5	HD3086, IC529354, IC529908, IC530087, IC530078, IC529902, IC529907, IC529052, IC529094, IC529943, IC543384, IC416244, EC190996, EC255091, EC660948, IC539208, IC539593, IC553065, IC36692, EC217821, EC576894, IC531176, EC574257, IC111717, EC425308, IC536077, EC573544, EC576171, EC576212, IC252390, IC531211, EC575907, IC75246, IC531257, IC416040, IC416119, EC10968, IC416071, IC531364, EC177724, IC416077, IC445413, IC554661, IC542056, EC483002, IC542801, EC534412, IC416269, EC575714, EC6894, EC575606, EC577629, EC575662, EC217772, EC575732, EC582324, IC336648, IC279206, BWL4444, AGRA LOCAL (57)	SUSCEPTIBLE	>60	>600	>64	>60

The fourth category had ninety moderately susceptible lines with final rust severity (40S), area under disease progress curve (401-600), relative area under disease progress curve (35-38) and coefficient of infection (40). The fifth category had fifty nine susceptible lines with maximum range of final rust severity (more than 60S), area under disease progress curve (more than 600), relative area under disease progress curve (more than 64) and coefficient of infection (more than 60). As has been reported in the present studies, Herrera-Foessel *et al* (2007) also evaluated seven durum wheat lines against *P. triticina* pathotype (BBG/BN) based on range of final disease severity (FDS), area under disease progress curve (AUDPC), latent period (LP), receptivity (R), and uredinium size (US). Similarly, Mutari *et al* (2018) also analysed the resistance in seventy five (75) wheat genotypes based on coefficient of infection (CI), disease incidence (DI), leaf tip necrosis (Ltn) and area under disease progress curve (AUDPC), infection response, disease severity, under natural epidemic conditions. The evaluation based on slow rusting parameters of various wheat lines or cultivars was also done by Mateen and Khan (2014) and Singh *et al* (2015).

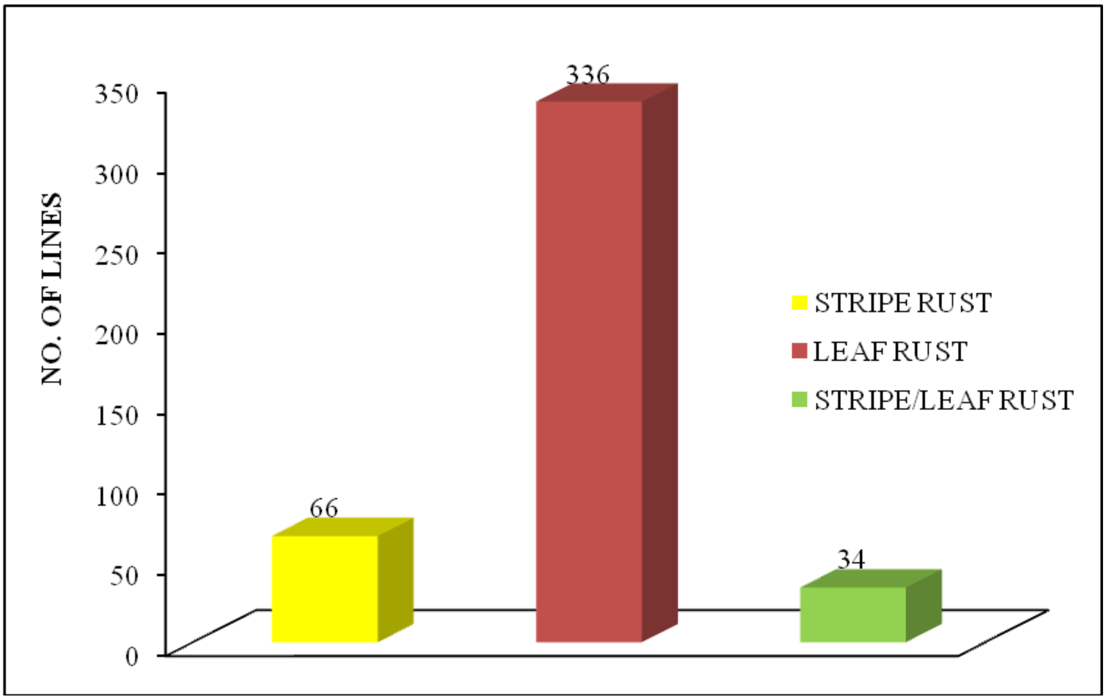

Fig 4.1: **Frequency of wheat lines with resistance to stripe rust, leaf rust and both the rusts (stripe and leaf) during the year 2016-17.**

During the crop season 2016-17, overall, sixty six lines were resistant to stripe rust, three hundred and thirty six lines were resistant to leaf rust and thirty four lines were resistant to both stripe and leaf rust (Table 4.1 & 4.2 and Fig.4.1).

During the crop season 2017-18, we divided the six hundred and seven lines in two groups, in the first group two hundred nine lines were evaluated at seedling and adult plant stage with different pathotypes of stripe rust. In the second group, three hundred ninety eight lines were evaluated at seedling and adult plant stage with different pathotypes of leaf rust.

4.3 Evaluation of wheat lines at seedling stage with different pathotypes of *Puccinia striiformis tritici* and *Puccinia tritici*

4.3.1 Seedling reaction test

4.3.2 Stripe rust

The results of evaluation of two hundred nine (209) lines at seedling stage with 238S119, 110S119, 46S119 and 78S84 pathotypes of stripe rust has been presented in the Table 4.3. From data given in the Table 4.3 it is clear that wheat lines showed different reaction to different combination of pathotypes. Out of 209 lines, fifty six lines (56) were resistant and twenty five (25) lines were susceptible to pathotypes 238S119, 110S119, 46S119 and 78S84. One hundred nine lines were resistant to 78S84, six lines showed resistance to 110S119, 46S119 and 78S84, two lines were resistant to 238S119, 110S119 and 78S84, six lines were resistant to 238S119 and 78S84, two lines were resistant to 46S119 and 78S84, one line was resistant to 238S119 and 110S119, one line was resistant to 110S119 and one line was resistant to 46S119.

Table 4.3: Seedling reaction test of wheat germplasm against different pathotypes of *Puccinia striiformis tritici* (2016-17 and 2017-18)

Pathotypes	Reaction	Accession no.
238S119	RESISTANT (<3)	IC530005, IC530119, IC529894, IC530025, IC128153, IC533416, IC529090, 1C539162, IC530087, IC530086, IC542117, IC530078, IC543413, IC564090, IC529902, IC549409, IC553914, IC529907, IC582705, IC443759, IC529094, IC529943, IC547699, IC530058, EC664190, EC660682, EC664198, EC693621, EC662236, EC660850, EC635701, EC693322, EC692262, EC635750, EC660684, EC633778, EC660680, EC635576, EC664223, EC635704, EC534511, IC539208, IC535470, IC415825, IC335768, IC539593, IC553065, IC542898, IC585640, IC534974, IC36692, IC542068, IC336645, IC530075, IC530089, EC582305 (56)
110S119		
46S119		
78S84		
238S119	SUSCEPTIBLE (>3)	IC445516, IC47034, IC529354, IC529908, IC260939, IC415945, IC416120, IC416415, IC416252, IC532207, EC635865, EC635663, EC635569, EC613049, EC635684, EC635859, EC664291, EC660969, EC635657, EC597933, EC576889, EC574781, IC542799, EC217808, IC553110 (25)
110S119		
46S119		
78S84		
78S84	RESISTANT (<3)	IC542104, IC543390, IC445506, IC128253, IC529052, IC549338, IC529213, IC543404, IC539168, IC539540, IC543384, EC178071504, IC325997, IC416018, IC416143, IC416170, IC416244, EC190996, EC255091,

Pathotypes	**Reaction**	**Accession no.**
		EC636264, C664239, EC693306, EC635697, EC664206, EC660874, EC663916, EC636232, EC660681, EC635690, EC597947, EC660948, EC597921, EC664238, EC635653, EC635608, EC635767, EC635664, IC111939, EC576744, IC543372, IC578102, IC420932, IC111691, EC576272, IC416046, IC531950, EC380904, IC574775, IC416043, IC111745, IC531277, IC535428, IC416040, IC415882, IC111693, IC534494, IC535498, IC535692, EC374953, IC560681, EC552096, IC138426, IC533941, EC576009, IC534662, EC534495, IC5391184, IC534601, IC445333, EC576201, IC445516, IC582727, EC573569, IC416145, IC534409, EC534382, IC531236, IC566636, IC542056, IC415859, IC279571, IC553915, IC252887, EC560473, IC542568, IC445384, IC532680, IC252991, EC295402, IC533797, IC529410, IC549460, EC299240, EC13745, IC529938, IC530026, EC217835, EC582263, IC528888IC329598, EC405393, EC217699, IC252697, IC368001, EC180031, EC339611, IC529373, IC531945, EC339604 (109)
110S119 46S119 78S84	RESISTANT (<3)	IC574781, EC295402, IC529410, EC190996, EC255091, EC180031 (6)
238S119 110S119 78S84	RESISTANT (<3)	IC528888, IC2609391,
238S119 78S84	RESISTANT (<3)	IC416244, IC416252, IC532207, IC553110, IC547669, EC217699 (6)
46S119 78S84	RESISTANT (<3)	IC5391184, EC573569,
238S119 110S119	RESISTANT (<3)	IC329598
110S119 78S84	RESISTANT (<3)	IC252991
46S119	RESISTANT (<3)	IC664190

In the present studies, wheat lines showed different reaction to different combination of stripe rust pathotypes at seedling stage (Table 4.3). Similarly, Safabi *et al* (2012) also evaluated thirty-six (36) wheat lines at seedling stage for resistance to stripe rust race (6E150A+, *Yr27*) during 2010-11 cropping season at Ardabil Agricultural Research Station (Iran). Zeng *et al* (2014) also evaluated one hundred sixty four (164) advanced breeding lines and three hundred thirty (330) leading cultivars at seedling stage with different pathotypes (CYR23, CYR29, CYR32, CYR33 and CH42) of stripe rust in China. Out of the four hundred ninety four (494) wheat lines, 16 (3.24 per cent) lines had all-stage resistance (ASR) to all test pathotypes.

4.4.3 Leaf rust

4.4.4 Seedling reaction test

The data of Table 4.4 presented that three hundred and ninety eight (398) lines were evaluated at seedling stage with two different pathotypes 77-9 and 77-5 of leaf rust pathogen. One hundred ten (110) lines were resistant and one hundred forty (140) lines were susceptible to both the test races i.e. 77-5 and 77-9. The forty three lines were resistant to 77-9 and one hundred five lines were resistant to 77-5 only.

Table 4.4: Seedling reaction test of wheat germplasm against different pathotypes of *Puccinia triticina* (2016-17 and 2017-18)

Pathotypes	**Reaction**	**Accession no.**
77-9, 77-5	Resistant <3	EC609592, EC498862, IC574477, IC547602, IC524304, IC531054, IC524297, EC573817,IC582907, IC539445, IC470134, IC335970, IC415861, IC401979, IC531790, IC445400, IC565812, IC534047, IC416320, IC445494, EC277014, IC539531, IC549385, IC128174, IC549499, IC531501, EC556482, IC574475, IC445366, IC416352, IC416409, IC144917, IC415875, IC278687, IC534364, EC463426, IC128187, IC535678, EC570328, EC190879, EC576195, IC563970, IC416142, IC415860, IC416108, IC531201, IC214796, IC252609, IC549527, IC529285, IC335533, EC217869, IC542053, IC303070, IC554659, EC573808, IC252742, IC415939, IC445527, IC531471, IC547631, EC576651, IC401976, IC539316, IC539486, IC333151, IC542052, IC547646, IC549334, EC119958, IC252623, IC535279, IC138447, IC145938, IC533733, IC542050, IC542051, EC574756, IC547648, IC586830, EC415866, IC539317, EC575272, IC542059, IC436077, IC406547, IC443737, IC415859, IC252431, IC469480, IC547594, IC547642, IC11252, EC534476, EC578163, EC596305, IC547669, EC217657, EC573647, EC217997, EC576356, EC575971, EC217659, EC217748, EC566309, EC596303, EC339610, IC335782, IC401978 (110)

Pathotypes	Reaction	Accession no.
77-9, 77-5	Susceptible >3	IC540908, IC282300, EC574257, EC576202, EC425337, IC524300, IC536373, IC535628, IC542477, IC128666, EC534432, IC531849, EC464029, IC296538, EC425322, EC576171, EC576212, EC425309, EC523376, EC574785, EC217859, EC575085, IC543372, IC531189, IC531336, IC531941, EC552086, IC397983, IC252677, EC574504, IC535696, IC321853, IC531369, IC531211, EC575907, IC536474, IC535487, EC257883, IC402010, EC576952, IC73571, IC252660, IC416046, IC290211, IC531529, IC75246, IC536488, EC415809, IC531257, IC531586, IC529202, IC335768, EC582254, EC425289, IC35076, IC445414, IC533606, IC416079, IC531377, IC445407, IC335694, IC335740, IC534494, EC576105, IC542622, EC257881, IC416119, IC416111, EC575036, EC556510, EC10814, EC217766, EC574784, EC534519, IC416071, EC552088, IC553256, EC463974, EC463433, IC542045, IC416145, EC574744, IC415876, IC128177, EC177766, IC531363, EC558754, IC554661, IC566636, IC582709, EC574238, IC416159, IC542056, EC483002, IC536353, EC573791, EC576093, IC542801, EC534412, IC416013, IC415903, IC415967, EC534407, IC416167, IC445297, IC547675, IC553915, IC443633, EC575714, EC578147, EC574029, IC528964, EC11093, IC252991, IC252699, EC13745, EC479375, EC14104, EC218034, IC528888, EC217883, IC252697, EC575606, EC577049, EC577629, EC573974, EC217705, EC575747, IC529501, IC529219, IC362251, EC217899, EC582324, EC313705, IC336648, IC279206, IC423451, IC443748, IC144915, IC416408, IC543290 (140)
77-9	Resistant <3	IC397300, IC138428, EC463381, EC190927, IC335738, IC310626, EC609571, IC336751, IC121129, IC398067, IC252705, IC531380, IC252714, IC296312, IC549520, IC252419, IC290213, IC398091, IC524017, EC609570, IC445374, EC575881, IC128211, IC539315, IC535601, IC539403, IC547592, EC464064, EC573786, EC576010, IC445335, IC542519, EC560473, EC573810, IC536524, EC339609, EC576231, EC405393, IC543262, IC531945, EC582280, EC479369, EC574742 (43)
77-5	Resistant <3	EC217821, EC576894, IC531176, IC111717, IC524289, EC425308, IC427824, IC536077, EC573544, EC534384, IC252390, IC449058, IC445439, IC415880, EC534451, IC529309, IC542012, EC574259, IC531927, IC145954, IC531950, IC547588, IC574851, IC252369, IC531432, IC240802, EC576298, IC531542, IC531579, IC547647, IC531277, EC534415, IC416040, IC531884, IC416146, EC548666, IC436069, IC539349, IC415877, IC335781, IC112260, EC568041, IC547657, IC252542, IC335788, IC335683, IC539529, IC536221, IC543059, EC38102, EC552096, EC10968, IC138426, EC467937, IC252441, IC549436, EC177723, EC576094, IC415955, IC416168,

Pathotypes	Reaction	Accession no.
		IC539184, EC534408, EC534421, IC531062, IC531364, IC531998, IC547655, IC547586, EC576201, IC253002, IC335695, IC252844, IC252668, IC469485, IC549364, IC443728, EC177724, IC582727, EC573820, EC573604, EC573569, EC575913, IC416077, IC427401, IC573852, EC276987, EC578155, IC445413, IC536122, IC547634, IC416269, IC542860, IC532655, EC578134, EC299240, IC573902, EC6894, EC368001, EC574047, EC575662, EC514389, EC217772, EC575732, IC529399, EC313710 (105)

From the data given in Table 4.4 it can be inferred that the test wheat lines showed varied reaction to different combinations of leaf rust pathotypes at seedling stage (Table 4.4). Similarly, Hussein and Pretorius (2005) also evaluated the 64 lines (38 bread wheat and 26 durum lines) to stripe rust (6E16A and 6E22A) and leaf rust (UVPrt2, UVPrt3, UVPrt5, UVPrt9 and UVPrt13) pathotypes were used for inoculation at seedling stage under controlled environment conditions. The result indicated that twenty (20) varieties and lines were resistant to the leaf rust and 26 lines resistance to the stripe rust pathotypes. Twelve bread wheat varieties and lines (Et-13 A2, HAR 1407 (Tusie), HAR 1775 (Tura), HAR 1920, HAR 2192, HAR 2534, HAR 2536, HAR 2561, HAR 2563 and three durum lines (DZ-114–08, AL-138, AL-69) showed resistant reactions to both stripe or leaf rust pathotypes. Li *et al* (2010) also evaluated 102 advanced lines and Chinese winter wheat cultivars to 24 pathotypes of *Puccinia triticina* for identification of leaf rust resistance genes effective at the seedling stage during 2006–07 and 2007–08 cropping seasons and found that fourteen leaf rust resistance genes *Lr2a*, *Lr3bg*, *Lr3ka*, *Lr14a*, *Lr16*, *Lr17a*, *Lr18*, *Lr20*, *Lr23*, *Lr24*, *Lr26*, *Lr34*, *LrZH84* and *Lr1* either singly or in combinations were postulated in 65 genotypes.

4.5 Identification of promising wheat lines on the basis of disease severity and infection type of stripe and leaf rusts at adult plant stage during 2016-17 and 2017-18

4.5.1 Stripe rust

The data in Table 4.5 showed that out of 209 wheat lines, 52 lines were free from rust with zero values of final rust severity, area under disease progress curve, relative area under disease progress curve and coefficient of infection and Forty eight (48) resistant lines with range of final rust severity of 5-10S, area under disease progress curve of 1-200, relative area under disease progress curve of 1-14 and coefficient of infection of 2-10.

Table 4.5: Wheat lines with less than 200 AUDPC for stripe rust during the period 2016-2018

S. NO.	LINES (2016-2018)	Reactions	AUDPC	FRS	rAUDPC	CI
1	IC530005, IC530119, IC529894, IC530025, IC128153, IC533416, IC445516, IC529090, 1C539162, IC530087, IC530086, IC542117, IC530078, IC443681, IC529902, IC549409, IC553914, IC529907, IC443759, IC529094, IC529943, IC547699, EC664190, EC660682, EC664198, EC693621, EC662336, EC635701, EC693322, EC660684, EC633778, EC660680, EC635576, EC664223, EC10860, IC531941, IC539208, IC535470, IC415825, IC539593, IC553065, IC585640, EC374953, IC534662, IC534974, IC36692, IC542068, IC336645, IC547669, IC530075, IC530089, IC529399 (52)	**Highly Resistant**	**0**	**0**	**0**	**0**
2	IC445316, IC529311, IC542104, IC445506, IC469420, IC529052, IC543404, IC539540, IC582705, EC178071504, IC416120, C416415, IC416170, EC183963, EC635697, EC636232, EC635657, IC252974, IC543372, EC573887, IC542898, IC531277, IC535428, IC533941, EC573599, EC576009, IC553915, EC299240, EC13745, IC529938, EC582305, IC543384, IC415945, IC416252, IC530058, IC635577, EC635750, EC635715, EC635859, IC547602, EC534511, EC577481, EC552096, IC445516, IC543413, IC128253, IC335768, EC660850 (48)	**Resistant**	**1-200**	**5-10**	**1-14**	**2-10**

It was observed in the present studies that highly to partial rust resistant wheat lines were observed against stripe rust (Table 4.5). Ali *et al* (2008) reported partial rust resistance in twenty lines along with Morocco susceptible check based on the infection type (IT), final rust severity (FRS), area under rust progress curve (AURPC), infection rate (IR) and co-efficient of infection (CI) to stripe rust during 2005-2006. Based on overall parameters, these lines were divided into two clusters i.e. nine lines were showed moderately resistant, while remaining 11 lines in another group showed better slow rusting lines. Shahin *et al* (2014) also evaluated twenty (20) Egyptian cultivars at adult stage to stripe rust at a rust hot spot location in Sakha Agriculture Research Station, Egypt, during the 2010-2011 and 2011-2012 crop seasons. At adult plant stage, these were assessed based on infection type (IT), disease severity (DS), coefficient of infection (CI) and relative area under disease progressive curve (rAUDPC). Results indicated that the among twenty (20) cultivars tested, Misr 1, Gemmeiza 10, Gemmeiza 11, Sids 13 and Sohag 3 showed resistance reaction and five Egyptian cultivars showed no infection, therefore it were selected under the category of immune or resistant cultivars. *i.e.* Sakha 61, Gemmeiza 10, Benisweif 4, Benisweif 5, and Sohag 3, while the rest cultivars showed moderately resistance to moderately susceptible.

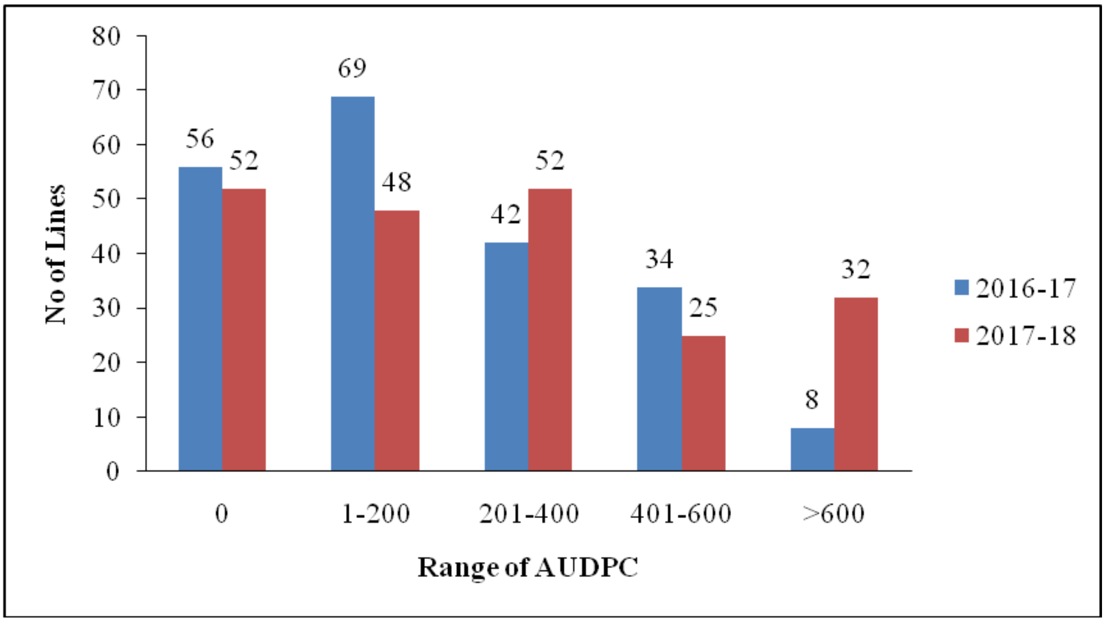

Fig 4.2: Grouping of lines based on area under diseases progress curve (AUDPC) for stripe rust during 2016-2017 and 2017-18

Fig 4.2 indicated that grouping of 209 wheat lines based on different range of area under disease progress curve (AUDPC) during 2016-17 and 2017-18. In the first category, 46 lines in the first crop season and 52 lines in the second crop season were highly resistant to stripe rust with zero value of AUDPC. In the second category, 69 lines in the first season and 48 lines in the second season were resistant with range of 1 to 200. In the third category, 42 lines in the first season and 55 lines in the second season were moderately resistant with range of AUDPC of 201 to 400. In the fourth category, 34 lines in the first season and 25 lines in the second season were moderately susceptible with range of 401 to 600. In the fifth category, 8 lines in the first season and 32 lines were susceptible with range of more the 600.

Ali *et al* (2009) evaluated 37 lines along with local check based on area under rust progress curve (AURPC) and coefficient of infection (CI). Results showed that twenty one lines were having AURPC value ranging from 300-1100, marked as partial resistant while remaining seventeen lines were having higher value of AURPC. Mateen and Khan (2014) also evaluated one hundred fifty (150) lines/varieties against stripe rust based on AUDPC. Out of one hundred fifty lines/varieties, sixty four (64) lines/varieties were immune, forty two (42) lines/varieties were resistant and remaining all was susceptible against stripe rust. Area under disease progress curve (AUDPC) of all varieties was calculated. Five lines (V-27, V-38, V-52, V-76 and V-107) were resistant with range of AUDPC (175-210) and susceptible lines (V-11, V-39, V-66, V-85 and V-108) with range of AUDPC (455-950).

4.5.2 Leaf rust

During the 2016-18 cropping season, the data in Table 4.6 showed that out of 398 wheat lines, 246 lines highly resistant with zero values in final rust severity, area under disease progress curve, relative area under disease progress curve and coefficient of infection and another category had 11 resistant lines with range of final rust severity of 5-10S, area under disease progress curve of 1-200, relative area under disease progress curve of 1-14 and coefficient of infection of 2-10.

The present study observed that highly to partial rust resistant wheat lines against stripe rust during crop season 2016-17 and 2017-18 (Table 4.6). Similarly, Shahin *et al* (2015) also evaluated six Egyptian wheat varieties based on final rust severity (FRS) and area under disease progress curve (AUDPC) for their levels of adult plant resistance to leaf rust at Sadat City during three successive growing seasons i.e. 2011-12, 2012-13 and 2013-14. Wheat varieties divided into two groups namely slow rusting varities and fast rusting varities. Gemmeiza 9, Giza 168 and Gemmeiza 7 showed the highest levels of partial resistance and lower values of area under disease progress curve (AUDPC) not more than 250 and percentage final rust severity (FRS) did not exceeded up to 30 per cent. On the other hand, Gemmeiza 1, Sakha 93 and Sids 1 were highly susceptible or fast rusting varieties. These varieties were showed the highest levels of percentage FRS and AUDPC compared with the partially resistant varieties under the same field conditions.

Table 4.6: Wheat lines with less than 200 AUDPC for leaf rust during the period 2016-2018

S. No.	LINES (2016-18)	Reactions	AUDPC	FRS	rAUDPC	CI
1	IC397300, IC138428, EC609592, EC463381, EC498862,IC574477, IC547602, IC524304, IC531054, EC190927, IC335738, IC524297, EC573817, IC310626, IC582907, IC539445, EC609571, IC336751, IC335970, IC415861, IC401979, IC531790, IC565812, IC531380, IC534047, IC416320, IC252714, EC277014, IC539531, IC549385, IC128174, IC549499, IC296312, IC549520, IC531501, EC556482, IC574475, IC445366, IC416352, IC416409, IC144917, IC415875, IC252419, IC278687, IC290213, IC534364, EC463426, IC535678, EC190879, EC576195, IC563970, IC524017, IC416142, IC415860, IC416108, IC531201, IC214796, IC252609, IC549527, IC416146, IC436069, IC539349, IC335781, IC529285, IC335533, EC217869, IC542053, EC609570, IC534494, IC303070, IC554659, EC573808, IC542622, IC252742, IC415939, EC257881, IC445374, IC445527, IC531471, IC547631, IC547657, EC576651, IC401976, IC539316, IC539486, IC333151, EC575881, IC335683, IC542052, IC547646, IC549334, EC119958, IC252623, EC38102, IC535279, IC138447, IC138426, IC145938, IC533733, IC542050, IC542051, EC576094, EC574756, IC531998, IC547648, IC553256, IC586830, IC128211, IC539315, EC415866, IC539317, EC575272, IC573852, EC578155, IC542059, IC535601, IC539403, IC436077, IC406547, EC464064, EC574238, IC443737, IC415859, IC252431, IC469480, EC573786, EC576010, IC547594, IC547642, IC443633, IC542519, IC11252, EC534476, EC560473, EC573810, EC578134, EC578163, EC596305, EC339609, IC547669, EC217657, EC576231, EC405393, EC573647, IC543262, EC217997, EC217883, IC252697, EC576356, EC368001, EC575971, EC217659, EC573974, EC217748, EC514389, IC529501, EC566309, EC596303, IC362251, EC217899, EC313705, EC582280, IC423451, EC313710, EC479369, IC144915, EC574742, IC335782, IC401978, EC570328, IC252542 (171)	Highly resistant	0	0	0	0
2	IC543372, IC531189, IC449058, IC445400, IC252705, IC529309, IC73571, IC416046, IC398091, IC128187, IC415877, IC547588 IC416111, IC416168, EC534519, EC534421, IC121129, EC463974, EC576201, IC549364, EC276987, IC547592, IC416159, IC445335, IC547675, EC578147, IC536524, EC299240, EC574047, EC217705, IC531945 (31)	Resistant	1-200	5-10	1-14	2-10

Hei (2017) also observed slow rusting resistant in 18 wheat cultivars based on final rust severity (FRS), coefficient of infection (CI), relative area under disease progress curve (rAUDPC) and infection rate (IR) for leaf rust. The results revealed that wheat cultivars Pavon 76, Africa Mayo, Bonny, Galili, Qulqulu, Hawi and Senqegna were low disease severities (less than 30 per cent) with moderately susceptible reactions, lower rAUDPC values (more than 30 per cent) and CI (less than 20) and were identified to have good level of slow rusting resistance. Cultivars Kubsa, Galama and PBW 343 had moderate values for slow rusting parameters and were identified as possessing moderate level of slow rusting.

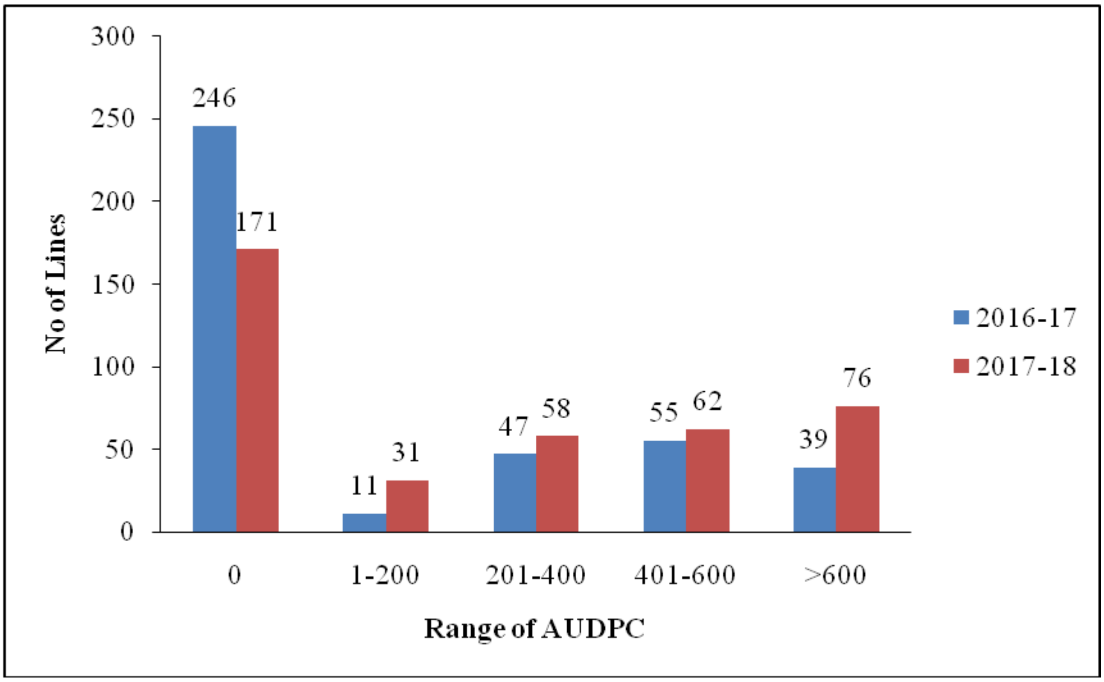

Fig. 4.3: Grouping of lines based on area under diseases progress curve (AUDPC) for leaf rust during 2016-2017 and 2017-18

Fig 4.3 indicated that grouping of three hundred and ninety eight wheat lines based on different range of area under disease progress curve (AUDPC) during 2016-17 and 2017-18. In the first category, two hundred forty six lines in the first season and one hundred and seventy one lines in the second season were highly resistant to stripe rust with zero value of AUDPC. In the second category, eleven lines were resistant in the first season and thirty one lines in the second season were resistant with range of 1-200. In the third category, forty seven lines in the first season and fifty eight lines in the second season were moderately resistant with range of 201-400. In the fourth category, fifty five lines in the first season and sixty two lines in the second season were moderately susceptible with range of 401-600. In the fifth category, thirty nine lines in the first season and seventy six lines in the second season were susceptible with range of more the 600. The present study observed that highly to partial leaf rust resistant wheat lines based on AUDPC.

The data given in Table 4.7 showed that 209 lines were evaluated with different pathotypes of stripe rust at adult plant stage during 2017-18. Fifty two lines were resistant and eighty nine lines were susceptible to 110S119, 46S119 and mixture of stripe rust, ten lines were resistant to 46S119 and mixtures of stripe rust, fourteen lines were resistant to 110S110 and 46S119, ten lines were resistant to 110S119 and mixture of stripe rust, eleven lines were resistant to 46S119, nine lines were resistant to 110S119 and fourteen lines were resistant to mixture of stripe rust. Two hundred nines (209) lines were compared with forty three (43) near isogenic lines (NILs). The data of Table 4.8 presented that stripe rust resistant genes *Yr1, Yr5, Yr10, Yr15, Yr24, Yr26* and *YrSP* were effective against most prevalent pathotypes (mixture, 110S119, 46S119) of stripe rust. Rabaninasab *et al* (2008) also observed that plants with genes *Yr1*, *Yr4*, *Yr5* and *Yr10* given avirulence response while plants with genes *Yr2, Yr6, Yr7, Yr9, Yr22, Yr23* and *YrA* given virulence response in Iran. Bux *et al* (2012) also observed that synthetic hexaploids have resistance at seedling stage due to presence of *Yr3, Yr5, Yr10, Yr15, YrSP* and *YrCV* genes. Stripe rust resistant genes *Yr5, Yr10* and *Yr15* are effective against prevailing races of *Puccinia striiformis* f. sp. *tritici* and thus can be deployed individually or in combination (Tomar *et al* 2014, Gangwar *et al* 2017 and Kaur *et al* 2017).

During 2017-18, 398 lines were compared with sixty six (66) near isogenic lines (NILs). The data of Table 4.9 presented that leaf rust resistant genes *Lr2a, Lr2b, Lr8, Lr19, Lr22a, Lr23, Lr(27+31), Lr45, Lr51, Lr53, Lr57, Lr58, Lr76* were effective against mixture of (77-9, 77-5, 104-2 and 12-2). Bhardwaj *et al* (2010a) also observed that pathotype 77-5 (121R63-1) was the most virulent and widely distributed pathotype, followed by pathotypes 104-2 (21R63) and 104-3 (21R63). These three pathotypes are avirulent on *Lr9, Lr18, Lr19, Lr24, Lr25, Lr28, Lr29, Lr32* and *Lr45* and virulent on *Lr1, Lr2a, Lr2b, Lr2c, Lr3a, Lr10, Lr11, Lr14a, Lr14b, Lr15, Lr16, Lr17a, Lr20, Lr23, Lr26, Lr27+31, Lr33, Lr36, Lr38, Lr43* and *Lr44*. Leaf rust genes *Lr34, Lr22a, Lr52, Lr60, Lr18, Lr35, Lr46 and Lr67* effective in Canada (Herrera-Foessel *et al* 2011 and McCallum *et al* 2007). Li *et al* (2018) also observed thirteen APR genes (*Lr12, Lr13, Lr22a, Lr22b, Lr34, Lr35, Lr37, Lr46, Lr48, Lr49, Lr67, Lr68* and *Lr74*) have been identified in wheat cultivars to mixture of *Puccinia triticina* at adult plant stage.

Table 4.7: **Resistance genotypes evaluated with different pathotypes of stripe rust at adult plant stage**

Pathotypes	Reaction	Accession No.
MIXTURE 110S119 46S119	Resistant	IC530005, IC530119, IC529894, IC530025, IC128153, IC533416, IC529090, 1C539162, IC530087, IC530086, IC542117, IC530078, IC443681, IC445516, IC543413, IC529902, IC549409, IC553914, IC529907, IC582705, IC128253, IC443759, IC529094, IC547699, EC664190, EC660682, EC664198, EC693621, EC662236, EC635701, EC693322, EC635750, EC633778, EC660680, EC635576, EC635777, EC664223, EC635859, EC534511, IC543372, IC539208, IC535470, IC415825, IC539593, IC553065, IC585640, IC534974, IC36692, IC336645, IC530075, IC530089, IC529399
MIXTURE 110S119 46S119	Susceptible	IC47034, IC529354, IC529908, IC549338, IC529213, IC539168, IC260939, IC325997, IC416018, IC532207, EC190996, EC255091, EC636264, EC664239, EC693306, EC664206, EC660874, EC663916, EC635865, EC636232, EC660681, EC597947, EC660948, EC635663, EC597921, EC664238, EC635684, EC664291, EC660969, EC635608, EC635767, EC635664, EC597933, EC576744, IC578102, IC420932, EC576272, IC416046, IC531950, IC574475, IC416043, IC111745, IC416040, IC415882, IC111693, IC535692, IC560681, IC138426, EC576009, EC534495, IC539184, IC445333, IC582727, EC573569, IC416145, IC534409, EC534382, IC531236, IC542056, EC576889, IC415859, IC279571, IC252887, EC560473, IC542568, IC445384, IC532680, EC574781, IC252991, EC295402, IC533797, IC529410, IC549460, IC542799, IC530026, EC217808, EC217835, EC582263, IC553110, IC528888, IC329598, EC405393, EC217699, IC252697, IC368001, EC180031, IC529373, IC531945, EC339604
MIXTURE, 46S119	Resistant	IC445316, IC469420, EC635697, EC635577, EC660684, IC252974, EC10860, IC531941, EC577481, IC531277
110S119 46S119	Resistant	IC469717, IC564090, EC635704, IC534494, IC553915, EC635715, IC335768, IC529938, IC542898, EC582305, EC660850, EC552096, IC530058, EC183963,
MIXTURE 110S119	Resistant	IC445506, IC529943, IC539540, IC416120, IC547602, EC573887, IC534662, IC542068, EC13745, IC547669
46S119	Resistant	IC529311, EC635653, EC613049, EC635657, EC635569, EC692262, EC635690, IC111939, EC380904, IC534601, EC576201
110S119	Resistant	IC542104, IC543390, IC416143, IC416415, IC416170, IC416171, IC111691, IC535498, IC566636
MIXTURE	Resistant	IC445516, IC529052, IC543404, IC543384, EC178071504, IC415945, IC416244 IC416252, IC535428, EC374953, IC533941, EC573599, EC299240, EC339611

Table 4.8: Reaction of NILs to different pathotypes of stripe rust in the field

S. No.	AVOCET NILS		GENES	46S119	110S119	MIXTURE
1	Morocco	MX111-12(AVOCET NILS 1)	Null	60S	60S	80S
2	AVOCET-YRA(YRA)	MX111-12(AVOCET NILS 2)	Null	60S	60S	80S
3	AVOCET+YRA(YRA)	MX111-12(AVOCET NILS 3)	Null	60S	60S	80S
4	*YR1*/6*AOC(CX93.51.3.3)	MX111-12(AVOCET NILS 4)	*Yr1*	0	0	0
5	SIETE CERROSS T66(118156-1M-2R-4M-0Y)	MX111-12(AVOCET NILS 5)	*Yr2*	60S	80S	60S
6	TATARA(CM85836-50Y-0M-0Y-2M-0Y-0PAK)	MX111-12(AVOCET NILS 6)	*Yr3*, *Yr9*, *Yr27*	40S	60S	40S
7	*YR5*/6*AOC(CX86.6.1.20)	MX111-12(AVOCET NILS 7)	*Yr5*	0	0	0
8	*YR6*/6*AOC(CX94.2.2.25)	MX111-12(AVOCET NILS 8)	*Yr6*	60S	60S	60S
9	*YR7*/6*AOC(CX93.21.3.1)	MX111-12(AVOCET NILS 9)	*Yr7*	60S	60S	60S
10	*YR8*/6*AOC(-38)	MX111-12(AVOCET NILS 10)	*Yr8*	60S	80S	60S
11	*YR9*/6*AOC(CX93.24.1.22)	MX111-12(AVOCET NILS 11)	*Yr9*	60S	80S	60S
12	*YR10*/6*AOC(CX93.53.3.1)	MX111-12(AVOCET NILS 12)	*Yr10*	0	0	0
13	*YR15*/6*AOC(CX89.1.1.27)	MX111-12(AVOCET NILS 13)	*Yr15*	0	0	0
14	*YR17*/6*AOC(-32)	MX111-12(AVOCET NILS 14)	*Yr17*	60S	60S	80S
15	*YR18*/3*AOC(CX94.10.1.7	MX111-12(AVOCET NILS 15)	*Yr18*	60S	60S	40S
16	*YR24*/3*AOC (CX96.1.3.12)	MX111-12(AVOCET NILS 16)	*Yr24*	0	0	0
17	*YR26*/3*AOC (CX96.17.1)	MX111-12(AVOCET NILS 17)	*Yr26*	0	0	0
18	*YR27*/6*AOC(-386)	MX111-12(AVOCET NILS 18)	*Yr27*	60S	60S	80S
19	*YRSP*/6*AOC(CX94.14.1.15	MX111-12(AVOCET NILS 19)	*YrSP*	0	0	0
20	PAVON F 76(CM8399-D-4M-3Y-1M-1Y-1M-0Y-0MEX)	MX111-12(AVOCET NILS 20)	*Yr6*, *Yr7*, *Yr29* (APR), *Yr30* (APR)	40S	60S	60S
21	SERI M 82 (CM33027-F-15M-500Y-0M-87B-0Y-0MEX)	MX111-12(AVOCET NILS 21)	*Yr2*, *Yr7*, *Yr9*, *Yr29*	60S	60S	40S
22	OPATA M 85 (CM40038-6M-4Y-2M-1Y-2M-1Y-0B-0MEX)	MX111-12(AVOCET NILS 22)	*Yr27*, *Yr30* (APR)	60S	60S	60S

S. No.	AVOCET NILS		GENES	46S119	110S119	MIXTURE
23	SUPER KAUZ(CM67458-4Y-1M-3Y-1M-3Y-0B)	MX111-12(AVOCET NILS 23)	*Yr9*, *Yr18*, *Yr27*	60S	60S	60S
24	YRCV/6*AOC	MX111-12(AVOCET NILS 24)	*Yr1*	0	0	0
25	PBW343(CM85836-4Y-0M-0Y-8M-0Y-0IND)	MX111-12(AVOCET NILS 25)	*Yr3*, *Yr9*, *Yr27*, *Yr29*	60S	60S	60S
26	AOC-YR*3/3/ALTAR 84/AE.SQ/OPATA (CGSS00Y00204T-099M-20Y)	MX111-12(AVOCET NILS 26)	-	60S	60S	60S
27	AOC-YR*3//LALBMONO1*4 /PVN(CGSS01Y000IIT-O99B-37Y)	MX111-12(AVOCET NILS 27)	-	60S	60S	60S
28	AOC-YR*3/PASTOR(CGSS00Y00207T-O99M-1Y)	MX111-12(AVOCET NILS 28)	-	40S	60S	40S
29	POLLMER(CTY88.547)	MX111-12(AVOCET NILS 29)	-	5S	60S	0
30	Chinese166	-	*Yr1*	0	0	0
31	Lee	-	*Yr7*	40S	60S	60S
32	Heines kolben	-	*Yr6*	40S	60S	60S
33	Vilmorin 23	-	*Yr3*	40S	60S	60S
34	Moro	-	*Yr10*	0	0	0
35	Strubes	-	*Yrsu*	0	60S	60S
36	Dickopf	-	*Yrsd*	40S	60S	60S
37	Riebesel 47/51	-	*Yr9+*	0	0	0
38	Hybrid 46	-	*Yr4*	40S	60S	60S
39	Heines VII	-	*Yr2+*	5MS	40S	60S
40	Compare	-	*Yr8*	40S	40S	60S
41	*T. Spelta album*	-	*Yr5*	0	0	0
42	Tc*6/Lr26	-	*Yr9*	40S	60S	60S
43	PBW343	-	*Yr9*, *Yr27*	60S	80S	80S

Table 4.9: Reaction of NILs to leaf rust in the field

S. No.	NILS	LR Genes	Reaction
1	THATCHER	-	60S
2	NIL-THATCHER-*LR1*-CTR	*Lr1*	60S
3	NIL-THATCHER-*LR2A*-WS1	*Lr2a*	0
4	NIL-THATCHER-*LR2B*-CARINA	*Lr2b*	0
5	NIL-THATCHER-*LR3C*-LOROS	*Lr3c*	60S
6	NIL-THATCHER-*LR3*-DEMOCRAT	*Lr3*	60S
7	NIL-THATCHER-*LR3KA*-AIV	*Lr3ka*	40S
8	NIL-THATCHER-*LR3BG*-BAGE	*Lrbg*	40S
9	NIL-THATCHER-*LR8*-TRANSFER	*Lr8*	0
10	NIL-THATCHER-*LR10*-EX	*Lr10*	60S
11	HUSSAR	-	80S
12	NIL-THATCHER-*LR12*-EX	*Lr12*	60S
13	MANTTOU	-	60S
14	NIL-THATCHER-*LR14A*-SK	*L14a*	60S
15	RL6006	-	60S
16	NIL-THATCHER-*LR15*-K1483	*Lr15*	60S
17	NIL-THATCHER-*LR16*-EX	*Lr16*	60S
18	NIL-THATCHER-*LR17*-KLLU	*Lr17*	60S
19	NIL-THATCHER-*LR18*-AF43	*Lr18*	60S
20	NIL-THATCHER-*LR19*-TR	*Lr19*	0
21	THEW	-	60S
22	NIL-THATCHER-*LR21*-RL5406(RL6043)	*Lr21*	40S
23	NIL-THATCHER-LiR22A-RL5404(RL6044)	*Lr22a*	0
24	NIL-THATCHER-*LR23*-LEE310	*Lr23*	0
25	NIL-THATCHER-*LR24*-AGENT(RL6064)	*Lr24*	40S
26	TRANSEC(AWEND0-*LR25*	*Lr25*	60S
27	NIL-THATCHER-LR26-ST-1-25(RL6078)	*Lr26*	60S
28	GATCHER(-LR10,LR27+31)	*Lr10, Lr27+31*	0
29	CSD-2M-LR28(RL6079)	*Lr28*	40S
30	NIL-THATCHER-LR29-CS7AG11(RL6080)	*Lr29*	60S
31	NIL-THATCHER-*LR30* TZ10(RL6049)	*Lr30*	60S
32	NIL-THATCHER-*LR32*-AE.TA(RL5497)	*Lr32*	60S

S. No.	NILS	LR Genes	Reaction
33	NIL-THATCHER-*LR33*-P158548(RL6057)	*Lr33*	40S
34	NIL-THATCHER-*LR34*-P158548(RL6058)	*Lr34*	60S
35	NIL-MARQUIS-*LR35*-T.SP (5711)	*Lr35*	60S
36	NIL-MANITOU-*LR36*-T.SP2-9	*Lr36*	60S
37	NIL-THATCHER-*LR37*-VPM(RL6081)	*Lr37*	60S
38	NIL-THATCHER-*LRB*-CARINA	*Lrb*	0
39	WL711(-01ND)	-	60S
40	GAZA	-	0
41	ALTAR 84(CD22344-A-8M-1Y-2Y-1M-0Y)	-	0
42	IUMILLO	-	0
43	LOCAL RED	-	60S
44	LR41/6*TC(05.4073.*LR41*)	*Lr41*	60S
45	TC*6/T.SPELTA 783(c93.59.LR	-	60S
46	TC/4*ST-1(C93.58.*LR45*)	*Lr45*	0
47	PAVON +*LR4*(C98.006 LR47)	*Lr4+47*	60S
48	C78.5(*LR51*)	*Lr51*	0
49	*LR53*(-98M71)	*Lr53*	0
50	*Lr14a*	*Lr14a*	80S
51	*Lr24*	*Lr24*	0
52	*Lr18*	*Lr18*	60S
53	*Lr13*	*Lr13*	60S
54	*Lr17*	*Lr17*	60S
55	*Lr15*	*Lr15*	60S
56	*Lr10*	*Lr10*	40S
57	*Lr19*	*Lr19*	0
58	*Lr28*	*Lr28*	0
59	Loros(*Lr2c*)	*Lr2c*	40S
60	Webster(*Lr2a*)	*Lr2a*	60S
61	Democrat (*Lr3*)	*Lr3*	60S
62	Thew (*Lr20*)	*Lr20*	60S
63	Malakoff (*Lr1*)	*Lr1*	60S
64	Benno (*Lr26*)	*Lr26*	60S
65	HP 1633 (*Lr9*+)	*Lr9+*	0
66	BWL4444	-	80S

4.6 Genetic analysis of wheat resistance lines to stripe and leaf rust

Eleven seedling and adult plant resistant lines namely IC530005, IC530119, IC539090, IC445316, IC530087, IC530086, IC530078, IC529902, IC553914, IC529907, IC529094 to stripe and twenty nine lines namely IC321853, IC401979, IC531790, IC549520, IC574475, EC570328, IC524017, IC252609, IC252742, IC539316, IC542051, IC547648, IC445527, EC576651, IC401976, EC415866, EC445366, IC278687 IC531201, IC252542, IC416142 lines were selected on the basis of their performance in the polyhouse and field for the genetic analysis of resistance. All the selected lines were crossed with recipient parent during the cropping season 2016-17. F1 plant tested with mixture of stripe rust and leaf rust (Plate 4.1). F1 populations raised and harvested at kellong off-season June to September 2017 in the field. For the inheritance of resistance studies, F2 seed planted in field at B. block, P.A.U. Ludhiana, were inoculated with mixture of stripe rust and leaf rust pathotypes and observed the disease rating on individual plant basis. Resistant and susceptible plant were counted separately and analyzed by Chi-square test.

4.7 The F1 and segregating F2 population against stripe rust (Table 4.10 and 4.11)

IC530005 X PBW621

F1 plants of the cross of IC530005 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study with mixture of stripe rust total numbers of plants were 165. Out of these, 125 F2 plants expressed resistant infection type and 40 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.0510, which comes under the probability 0.822 and monogenic dominant remark.

IC530119 X PBW621

F1 plants of the cross of IC530119 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study with mixture of stripe rust total numbers of plants were 116. Out of these, 87 F2 plants expressed resistant infection type and 29 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.03, which comes under the probability 1 and monogenic dominant remark.

IC529090 X PBW621

F1 plants of the cross of IC529090 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study with mixture of stripe rust total numbers of plants were 99. Out of these, 23 F2 plants expressed resistant infection type and 76 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.165, which comes under the probability 0.655.

IC445316 X PBW621

F1 plants of the cross of IC445316 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study with mixture of stripe rust total numbers of plants were 45. Out of these, 21 F2 plants expressed resistant infection type and 24 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.0510, which comes under the probability 0.822 and two complementary genes remark.

IC530087 X PBW621

F1 plants of the cross of IC530087 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study with mixture of stripe rust total numbers of plants were 123. Out of these, 123 F2 plants expressed resistant infection type and 92 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.003, which comes under the probability 0.958 and monogenic dominant remark.

IC530086 X PBW621

F_1 plants of the cross of IC530086 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study in F_2, with mixture of stripe rust total numbers of plants were 161. Out of these, 123 F2 plants expressed resistant infection type and 38 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.168, which comes under the probability 0.682 and monogenic dominant remark.

Table 4.10: Reaction of F1 population against stripe rust

Crosses	**Generation**	**Total plant**	**Reaction**	
			Resistant (R)	**Susceptible (S)**
IC530005 X PBW621	F1	9	9	0
IC530119 X PBW621	F1	7	7	0
IC529090 X PBW621	F1	5	0	5
IC445316 X PBW621	F1	17	17	0
IC530087 X PBW621	F1	21	21	0
IC530086 X PBW621	F1	10	10	0
IC530078 X PBW621	F1	7	7	0
IC529902 X PBW621	F1	8	8	0
IC553914 X PBW621	F1	14	14	0
IC529907 X PBW621	F1	9	9	0
IC529094 X PBW621	F1	5	5	0

Plate 4.1: F1 populations of stripe and leaf rust

Table 4.11: **Segregation and chi square analysis of F2** plants **from the crosses between agronomically promising wheat variety and resistant wheat cultivars under field conditions**

Crosses	Total plants	No of F2 population		Ratio tested	Chi-square values	Probability	Remarks
		Resistant	Susceptible				
IC530005 X PBW621	165	125	40	3:1	0.0510	0.822	Monogenic dominant
IC530119 X PBW621	116	87	29	3:1	0.03	1.00	
IC530087 X PBW621	123	92	31	3:1	0.003	0.958	
IC530086 X PBW621	161	123	38	3:1	0.168	0.682	
IC530078 X PBW621	132	96	34	3:1	0.09	0.761	
IC529902 X PBW621	211	159	52	3:1	0.014	0.905	
IC529907 X PBW621	197	148	49	3:1	0.002	0.967	
IC529094 X PBW621	143	96	47	3:1	4.72	0.030	
IC445316 X PBW621	45	21	24	9:7	1.68	0.195	Two complementary genes
IC553914 X PBW621	156	129	27	13:3	4.92	0.027	One dominant and One recessive genes
IC529090 X PBW621	99	23	76	1:3	0.165	0.685	-

IC530078 X PBW621

F1 plants of the cross of IC530078 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study with mixture of stripe rust total numbers of plants were 132. Out of these, 96 F2 plants expressed resistant infection type and 34 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.09, which comes under the probability 0.761 and monogenic dominant remark.

IC529902 X PBW621

F1 plants of the cross of IC529902 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study with mixture of stripe rust total numbers of plants were 211. Out of these, 159 F2 plants expressed resistant infection type and 52 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.014, which comes under the probability 0.905 and monogenic dominant remark.

IC553914 X PBW621

F1 plants of the cross of IC553914 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study with mixture of stripe rust total numbers of plants were 156. Out of these, 129 F2 plants expressed resistant infection type and 27 plants were susceptible. Ratio tested for the chi-square analysis was 13:3. The chi-square values calculated were 4.92, which comes under the probability 0.027 and one dominant and one recessive genes remark.

IC529907 X PBW621

F1 plants of the cross of IC529907 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study with mixture of stripe rust total numbers of plants were 197. Out of these, 148 F2 plants expressed resistant infection type and 49 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.002, which comes under the probability 0.967 and monogenic dominant remark.

IC529094 X PBW621

F1 plants of the cross of IC529094 X PBW621 were resistant to mixture of stripe rust. In case of inheritance study with mixture of stripe rust total numbers of plants were 143. Out of these, 96 F2 plants expressed resistant infection type and 47 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 4.72, which comes under the probability 0.030 and monogenic dominant remark.

Luo *et al* (2005) also observed that several wheat lines and cultivars of wheat originating from the southwestern region of China were found to be highly resistant to newly emerged races (H46-4, SYII-14 and SYl1-4) and prevalent races (CYR30, CYR31 and CYR32) of stripe rust. The resistant line (AIM6) was cross with susceptible line (BeiZ76) and study inheritance. Results indicated that the resistance to stripe rust was controlled by a single dominant gene. Zakeri *et al* (2016) also studied the inheritance of stripe rust resistance in recently released Iranian commercial wheat cultivars (Parsi, Sivand, Uroum, and Pishgam, Aflak) and elite bread wheat lines (M-83-6 and M-84-14). Crosses were made between these elite lines and cultivars with Avocet S and the F1, F2, and F3 generations were developed and observed that Iranian bread wheat cultivars Uroum, Parsi, Pishgam, Sivand and Aflak each carry two independent dominant seedling resistance genes to stripe rust.

4.8 The F1 and segregating F2 population against leaf rust (Table 4.12 and 4.13)

IC321853 X HD3086

F1 plants of the cross of IC321853 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 177. Out of these, 133 F2 plants expressed resistant infection type and 44 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.002, which comes under the probability 0.965 and monogenic dominant remark.

IC401979 X HD3086

F1 plants of the cross of IC401979 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 185. Out of these, 140 F2 plants expressed resistant infection type and 45 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.045, which comes under the probability 0.832 and monogenic dominant remark.

IC531790 X HD3086

F1 plants of the cross of IC531790 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 173. Out of these, 129 F2 plants expressed resistant infection type and 44 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.017, which comes under the probability 0.895 and monogenic dominant remark.

IC549520 X HD3086

F1 plants of the cross of IC549520 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 193. Out of these, 143 F2 plants expressed resistant infection type and 50 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.085, which comes under the probability 0.771 and monogenic dominant remark.

IC574475 X HD3086

F1 plants of the cross of IC574475 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 153. Out of these, 111 F2 plants expressed resistant infection type and 42 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.490, which comes under the probability 0.484 and monogenic dominant remark.

Table 4.12: Reaction of F1 population against leaf rust

Crosses	Generation	Total plant	Reaction	
			Resistant (R)	Susceptible (S)
EC552086 X HD3086	F1	9	0	9
IC321853 X HD3086	F1	12	12	0
IC401979 X HD3086	F1	22	22	0
IC531790 X HD3086	F1	14	14	0
IC549520 X HD3086	F1	8	8	0
IC531501 X HD3086	F1	6	6	0
IC531257 X HD3086	F1	5	0	5
IC574475 X HD3086	F1	5	5	0
EC445366 X HD3086	F1	15	15	0
IC278687 X HD3086	F1	11	11	0
EC570328 X HD3086	F1	8	8	0
EC190879 X HD3086	F1	10	0	10
EC576195 X HD3086	F1	7	7	0
IC563970 X HD3086	F1	12	0	12
IC524017 X HD3086	F1	7	7	0
IC416142 X HD3086	F1	6	6	0
IC416108 X HD3086	F1	4	0	4
IC531201 X HD3086	F1	15	15	0
IC252609 X HD3086	F1	13	13	0
IC303070 X HD3086	F1	5	5	0
IC252742 X HD3086	F1	12	12	0
IC445527 X HD3086	F1	9	9	0
EC576651 X HD3086	F1	11	11	0
IC401976 X HD3086	F1	7	7	0
IC539316 X HD3086	F1	5	5	0
IC252542 X HD3086	F1	16	16	0
IC542051 X HD3086	F1	3	3	0
IC547648 X HD3086	F1	7	7	0
EC415866 X HD3086	F1	17	17	0

Table 4.13: Segregation and chi square analysis of F2 plants from the crosses between agronomical promising wheat variety and resistant wheat cultivars under field conditions

Crosses	Total plant	No of F2 population		Ratio tested	Chi-square values	Probability	Remarks
		Resistant	Susceptible				
IC321853 X HD3086	177	133	44	3:1	0.002	0.965	Monogenic Dominant
IC401979 X HD3086	185	140	45	3:1	0.045	0.832	
IC531790 X HD3086	173	129	44	3:1	0.017	0.895	
IC549520 X HD3086	193	143	50	3:1	0.085	0.771	
IC574475 X HD3086	153	111	42	3:1	0.490	0.484	
EC570328 X HD3086	157	116	41	3:1	0.104	0.747	
IC524017 X HD3086	190	142	48	3:1	0.007	0.933	
IC252609 X HD3086	166	127	39	3:1	0.201	0.654	
IC252742 X HD3086	170	132	38	3:1	0.635	0.425	
IC539316 X HD3086	154	117	37	3:1	0.078	0.780	
IC542051 X HD3086	173	127	46	3:1	0.233	0.629	
IC547648 X HD3086	157	117	40	3:1	0.019	0.890	
IC445527 X HD3086	162	150	12	15:1	0.370	0.543	Two dominant Genes
EC576651 X HD3086	182	168	14	15:1	0.646	0.421	
IC401976 X HD3086	167	154	13	15:1	0.671	0.431	
EC415866 X HD3086	161	150	11	15:1	0.093	0.760	

Crosses	Total plant	No of F2 population		Ratio tested	Chi-square values	Probability	Remarks
		Resistant	Susceptible				
EC445366 X HD3086	154	144	10	15:1	0.016	0.901	
IC278687 X HD3086	152	141	11	15:1	0.253	0.615	
IC531201 X HD3086	203	165	38	13:3	0.000	0.991	One dominant and One recessive genes
IC252542 X HD3086	154	123	31	13:3	0.192	0.661	
IC416142 X HD3086	170	138	32	13:3	0.001	0.980	
IC303070 X HD3086	151	88	63	9:7	0.252	0.615	Two complementary genes
EC576195 X HD3086	173	86	87	9:7	3.006	0.083	Two complementary genes
IC531501 X HD3086	157	80	77	9:7	3.312	0.069	Two complementary genes
IC531257 X HD3086	152	40	112	1:3	0.140	0.708	-
EC190879 X HD3086	209	56	153	1:3	0.359	0.549	-
IC416108 X HD3086	182	7	175	-	-	-	-
EC552086 X HD3086	183	44	139	1:3	0.089	0.765	-
IC563970 X HD3086	180	41	139	1:3	0.474	0.491	-

IC570328 X HD3086

F1 plants of the cross of IC570328 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 157. Out of these, 116 F2 plants expressed resistant infection type and 41 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.104, which comes under the probability 0.747 and monogenic dominant remark.

IC252609 X HD3086

F1 plants of the cross of IC252609 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 166. Out of these, 127 F2 plants expressed resistant infection type and 39 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.201, which comes under the probability 0.654 and monogenic dominant remark.

IC252742 X HD3086

F1 plants of the cross of IC252742 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 170. Out of these, 132 F2 plants expressed resistant infection type and 38 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.635, which comes under the probability 0.425 and monogenic dominant remark.

IC539316 X HD3086

F1 plants of the cross of IC539316 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 154. Out of these, 117 F2 plants expressed resistant infection type and 37 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.078, which comes under the probability 0.780 and monogenic dominant remark.

IC542051 X HD3086

F1 plants of the cross of IC542051 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 173. Out of these, 127 F2 plants expressed resistant infection type and 46 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.233, which comes under the probability 0.629 and monogenic dominant remark.

IC547648 X HD3086

F1 plants of the cross of IC547648 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 157. Out of these, 117 F2 plants expressed resistant infection type and 40 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.019, which comes under the probability 0.890 and monogenic dominant remark.

EC445366 X HD3086

F1 plants of the cross of IC445366 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 154. Out of these, 144 F2 plants expressed resistant infection type and 10 plants were susceptible. Ratio tested for the chi-square analysis was 15:1. The chi-square values calculated were 0.016, which comes under the probability 0.901 and two dominant genes remark

IC278687 X HD3086

F1 plants of the cross of IC278687 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 152. Out of these, 141 F2 plants expressed resistant infection type and 11 plants were susceptible. Ratio tested for the chi-square analysis was 15:1. The chi-square values calculated were 0.253, which comes under the probability 0.615 and two dominant genes remark

IC445527 X HD3086

F1 plants of the cross of IC445527 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 162. Out of these, 150 F2 plants expressed resistant infection type and 12 plants were susceptible. Ratio tested for the chi-square analysis was 3:1. The chi-square values calculated were 0.370, which comes under the probability 0.543 and two dominant genes remark

IC576651 X HD3086

F1 plants of the cross of IC576651 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 182. Out of these, 168 F2 plants expressed resistant infection type and 14 plants were susceptible. Ratio tested for the chi-square analysis was 15:1. The chi-square values calculated were 0.646, which comes under the probability 0.421 and two dominant genes remark

IC401976 X HD3086

F1 plants of the cross of IC401976 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 167. Out of these, 154 F2 plants expressed resistant infection type and 13 plants were susceptible. Ratio tested for the chi-square analysis was 15:1. The chi-square values calculated were 0.671, which comes under the probability 0.431 and two dominant genes remark

IC415866 X HD3086

F1 plants of the cross of IC415866 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 161. Out of these, 150 F2 plants expressed resistant infection type and 11 plants were susceptible. Ratio tested for the chi-square analysis was 15:1. The chi-square values calculated were 0.093, which comes under the probability 0.760 and two dominant genes remark

IC416142 X HD3086

F1 plants of the cross of IC416142 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 170. Out of these, 138 F2 plants expressed resistant infection type and 32 plants were susceptible. Ratio tested for the chi-square analysis was 13:3. The chi-square values calculated were 0.001, which comes under the probability 0.980 and one dominant and one recessive genes remark.

IC531201 X HD3086

F1 plants of the cross of IC531201 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 203. Out of these, 165 F2 plants expressed resistant infection type and 38 plants were susceptible. Ratio tested for the chi-square analysis was 13:3. The chi-square values calculated were 0.0001, which comes under the probability 0.991 and one dominant and one recessive genes remark.

IC252542 X HD3086

F1 plants of the cross of IC252542 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 154. Out of these, 123 F2 plants expressed resistant infection type and 31 plants were susceptible. Ratio tested for the chi-square analysis was 13:3. The chi-square values calculated were 0.192, which comes under the probability 0.661 and one dominant and one recessive genes remark.

IC552086 X HD3086

F1 plants of the cross of IC552086 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 183. Out of these, 44 F2 plants expressed resistant infection type and 139 plants were susceptible. Ratio tested for the chi-square analysis was 1:3. The chi-square values calculated were 0.089, which comes under the probability 0.765.

IC531257 X HD3086

F1 plants of the cross of IC531257 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 152. Out of these, 40 F2 plants expressed resistant infection type and 112 plants were susceptible. Ratio tested for the chi-square analysis was 1:3. The chi-square values calculated were 0.140, which comes under the probability 0.708.

EC190879 X HD3086

F1 plants of the cross of EC190879 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 209. Out of these, 56 F2 plants expressed resistant infection type and 153 plants were susceptible. Ratio tested for the chi-square analysis was 1:3. The chi-square values calculated were 0.359, which comes under the probability 0.549.

IC563970 X HD3086

F1 plants of the cross of IC563970 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 180. Out of these, 41 F2 plants expressed resistant infection type and 139 plants were susceptible. Ratio tested for the chi-square analysis was 1:3. The chi-square values calculated were 0.474, which comes under the probability 0.491.

IC303070 X HD3086

F1 plants of the cross of IC303070 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 151. Out of these, 88 F2 plants expressed resistant infection type and 63 plants were susceptible. Ratio tested for the chi-square analysis was 9:7. The chi-square values calculated were 0.252, which comes under the probability 0.615 and two complimentary genes remark.

IC531501 X HD3086

F1 plants of the cross of IC531501 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 157. Out of these, 80 F2 plants expressed resistant infection type and 77 plants were susceptible. Ratio tested for the chi-square analysis was 9:7. The chi-square values calculated were 3.312, which comes under the probability 0.069 and two complimentary genes remark.

IC576195 X HD3086

F1 plants of the cross of IC576195 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 173. Out of these, 86 F2 plants expressed resistant infection type and 87 plants were susceptible. Ratio tested for the chi-square analysis was 9:7. The chi-square values calculated were 3.312, which comes under the probability 0.083 and two complimentary genes remark.

IC416108 X HD3086

F1 plants of the cross of IC416108 X HD3086 were resistant to mixture of leaf rust. In case of inheritance study with mixture of leaf rust total numbers of plants were 182. Out of these, seven F2 plants expressed resistant infection type and 175 plants were susceptible. Ratio tested for the chi-square analysis was unknown. The chi-square values and probability was unknown.

The present study revealed that majority of F1 and F2 populations showed that resistant and monogenic dominant remark to mixture leaf rust pathotype.

Shahin et al (2015) also analysed the inheritance of adult plant resistance to leaf rust, tested wheat varieties were crossed with seven adult plant leaf rust resistance monogenic lines i.e. *Lr38*, *Lr42*, *Lr43*, *Lr44*, *Lr45*, *Lr46* and *Lr47*. The resulted F1 plants were selfed to produce F2 seeds. F2 plants were tested at adult plant stage under field conditions at Sadat City location during 2012-13 growing season. Segregations of F2 plants at adult plant stage revealed that the wheat varieties Giza 168 and Gemmeiza 9 have the same three genes i.e. *Lr45*, *Lr46* and *Lr47*. While the other tested varieties Sids 1, Sakha 93, Gemmeiza 1, and Gemmeiza 7 do not carry any of the leaf rust resistance genes.

Liu-sha *et al* (2015) also studied that Chinese wheat line Yu 356-9 given high level of resistance to 15 pathotypes of leaf rust. F1 and F2 plants from the crossed of Yu 356-9 (resistant)/Zhengzhou 5389 (susceptible) were tested with leaf rust pathotype FHNQ in the greenhouse. Results indicated that 3:1 segregation ratio, indicative of the presence of a single dominant leaf rust resistance gene in Yu 356-9. Qi *et al* (2015) also studied the F1 and F2 plants from a cross between the resistant cultivar LB0288 and the susceptible cultivar Thatcher were inoculated with pathotype THTT of *P. triticina* in the greenhouse. The results indicated that LB0288 carried a single dominant resistance gene *LrLB88*, closely linked to the CAPS marker of *Lr1* (WR003) and the SSR marker Xbarc144, with genetic distances of 0 cM and 5.3 cM.

CHAPTER – V

SUMMARY

The present investigations based on "Gene scouting for rust(s) resistance in wheat germplasm" intended to found out resistant material to most prevalent pathotypes of stripe and leaf rust pathogens and to study genetic inheritance for leaf rust and stripe rust resistance in populations derived from crosses with resistant germplasm.

During crop season 2016-17, six hundred and seven (607) wheat germplasm lines were evaluated and found that sixty six lines were resistant to stripe rust, three hundred thirty six lines were resistant to leaf rust and thirty four lines were resistant to both stripe rust and leaf rust. In the second year, six hundred seven lines were divided into two main groups. In the first group two hundred and nine lines for stripe rust and three hundred and ninety eight lines in the second group for leaf rust. The first experiment was evaluation of wheat germplasm at seedling stage with different pathotypes of stripe rust 46S119, 78S84, 110S119 and mixture of pathotypes (78S84, 110S84, 110S119, 46S119, 47S103 & 238S119) and leaf rust (77-5 and 77-9). The results of this experiment showed that fifty six (56) lines were resistant and twenty five lines were susceptible to different pathotypes of stripe rust 46S119, 78S84, 110S119 and mixture of pathotypes (78S84, 110S84, 110S119, 46S119, 47S103 & 238S119) and 78S84). One hundred ten lines (110) lines were resistant and one hundred forty lines were susceptible to different pathotypes of leaf rust (77-5 and 77-9) pathogen at seedling stage.

The second experiment divided into two parts. In the first one, the test material was evaluated in field. Data was recorded in terms of disease severity and reaction at regular intervals. On the basis of final rust severity (FRS), area under disease progress curve (AUDPC), relative area under disease progress curve (rAUDPC) and coefficient of infection (CI) the material was categorized as resistant, susceptible, moderately resistant and moderately susceptible. Fifty two (52) lines were highly resistant under the zero value of all the above mentioned parameters for stripe rust and remaining lines gave different reaction based on the particular range parameters. One hundred and seventy one (171) lines were highly resistant to leaf rust and remaining lines with different reaction based on the different range parameters.

In second part of the second experiment, all the genotypes which showed resistance either to stripe rust or leaf rust were further evaluated against most prevalent pathotypes of *Pst* i.e. mixture (78S84, 110S84, 110S119, 46S119, 47S103 & 238S119), 110S119 and 46S119 and *P. triticina* mixture (77-5, 77-9, 104-2 and 12-5) in isolations along with NILs carrying known APR genes and susceptible checks for comparison purpose under the field conditions. The results of the present experiment revealed that fifty two lines were resistant and eighty eight lines were susceptible to most prevalent pathotypes of stripe rust and remaining lines showed different reaction to different combination of pathotypes of stripe rust. Reaction of NILs showed that *Yr1, Yr5, Yr10, Yr15, Yr24, Yr26, YrSP, Yr31, Yr51, Yr47, Yr57, Yr63* are effective against most prevalent pathotypes of stripe rust in Punjab and *Lr2a, Lr2b, Lr8, Lr19, Lr22a, Lr23, Lr(27+31), Lr45, Lr51, Lr53, Lr57, Lr58, Lr76* are effective against leaf rust.

In the third experiment, disease assessment of the populations derived from the crosses between resistant lines with recipient parent (PBW621 for stripe rust and HD3086 for leaf rust). Eleven lines (IC530005, IC530119, IC539090, IC445316, IC530087, IC530086, IC530078, IC529902, IC553914, IC529907, IC529094) resistant to stripe rust and twenty nine lines (IC321853, IC401979, IC531790, IC549520, IC574475, EC570328, IC524017, IC252609, IC252742, IC539316, IC542051, IC547648, IC445527, EC576651, IC401976, EC415866, EC445366, IC278687 IC531201, IC252542, IC416142) resistant to leaf rust were selected on the basis of their performance in the polyhouse and field for the genetic analysis of resistance. In total eleven lines showing resistance to stripe rust were crossed with PBW621. Similarly, twenty nine lines showing resistance to leaf rust were crossed with HD 3086. F1 plants were tested separately for stripe rust and leaf rust reaction. F1 raised and harvested at Kellong during off-season (June-September 2017) in the field. The majority of F1 populations showed resistant reaction to stripe rust and leaf rust. For the inheritance of resistance study, F2 seed was planted in the field and inoculated separately with mixture of stripe rust and leaf rust pathotypes. Resistant and susceptible plants were counted separately and analyzed by Chi-square test.

REFERENCES

Ainsworth G C (1975) *The fungi, An Advanced Treatise*. Academic Press, New York, London.

Ali S, Rodriguez-Algaba J, Thach T, Sorensen C K, Hansen J G, Lassen P, Nazari K, Hodson D P, Justesen A F and Hovmoller M S (2017) Yellow rust epidemics worldwide were caused by pathogen races from divergent genetic lineages. *Front Plant Sci* **8**: 1057-71.

Ali S, Shah S J A and Maqbool K (2008) Field-based assessment of partial resistance to stripe rust in wheat germplasm. *J Agric Rural Dev* **6**: 99-106.

Ali S, Shah S J A, Khalil I H, Raman H, Maqbool K and Ullah W (2009) Partial resistance to yellow rust in introduced winter wheat germplasm at the north of Pakistan. *Aust J crop Sci* **3**: 37-43.

Anonymous (2018a) Directors report of AICRP on wheat and barley 2017-18. Ed: ICAR-IIWBR, Pp 1. Karnal, Haryana.

Anonymous (2018b) *Package of Practices for Rabi crops*. Pp 1-18. Punjab Agricultural University, Ludhiana.

Asthana R P (1948) Wheat rusts and their control, Mag Agric Collage, Nagpur **22**: 136-42.

Bansal U K, Forrest K L, Hayden M J, Miah H, Singh D and Bariana H S (2011) Characterization of a new stripe rust resistance gene *Yr47* and its genetic association with the leaf rust resistance gene *Lr52*. *Theor Appl Genet* **122**: 1461-66.

Barcellos A S, Roelfs A P and De Moraes-Fernandes M I B (2000) Inheritance of adult plant leaf rust resistance in the Brazilian wheat cultivars Toropi. *Plant Dis* **84**: 90-93.

Basandrai A K, Sharma B K and Basandrai D (2013) Efficacy of triazole fungicide for the integrated management of yellow rust, leaf rust and powdery mildew of wheat. *Pl Dis Res* **28**: 135-39.

Basnet B R, Singh R P, Ibrahim A M H, Herrena - Foessel S A, Huerta Espino J, Lan C and Rudd J (2013) Characterization of *Yr54* and other genes associate with adult plant resistance to yellow rust and leaf rust in common wheat Quain3. *Mol Breed* **33**: 385-99.

Bhardwaj S C, Prashar M, Jain S K, Kumar S, Sharma Y P, Sivasamy M and Kalappanavar I K (2010b) Virulence of *Puccinia triticina* on *Lr*28 in wheat and its evolutionary relation to prevent pathotypes in India. *Cereal Res Commun* **38**: 83-89.

Bhardwaj S C, Prashar M, Kumar S, Jain S K and Datta D (2005) *Lr*19 resistance gene in wheat becomes susceptible to *Puccinia triticina* Eriks in India. *Plant Dis* **89**: 1360.

Bhardwaj S C, Prasher M, Jain S K and Datta D (2010a) Adult plant resistance in some Indian wheat genotypes and postulating of leaf rust resistance genes. *Indian Phytopath* **63**: 174-80.

Biffen R H (1905) Mendel's laws of inheritance and wheat breeding. *J Agri Sci* **1**: 4-48.

Bolton M D, Kolmer J A and Garvin D F (2008) Wheat leaf rust caused by *Puccinia triticina. Mol Plant Pathol* **9**: 563-75.

Boroujeni F R, Arzoni A, Afshari F and Torabi M (2011) Postulation of leaf rust resistance genes in Iranian wheat cultivars and breeding lines. *Can J Plant Pathol* **33**: 550-58.

Brahma R N, Asir R and Saikia A (1991) The efficiency of tilt (propiconazol) on different wheat cultivars. *Indian Phytopath* **44**: 116-18.

Bux H, Ashraf M, Chen X and Mumtaz A S (2011) Effective genes for resistance to stripe rust and virulence of *Puccinia striiformis* f. sp. *tritici* in Pakistan. *Afr J Biotechnol* **10**: 5489-95.

Bux H, Muhammad A, Fida H, Muhammad F and Atiq-Ur-Rahman Rattu (2012) Characterization of wheat germplasm for stripe rust (*Puccinia striiformis* f. sp. *tritici*) resistance. *Aust J Crop Sci* **6**: 116-20.

Chaves M S, Wesp C L, Barcellos A L and Scheeren P L (2009) Breakdown of qualitative leaf rust resistance in the wheat cultivar 'BRS 194' by a new race of *Puccinia triticina. Phytopathology* **39**: 228-31.

Chen X M (2005) Epidemiology and control of stripe rust (*P. striiformis* f.sp. *tritici*) on wheat. *Can J Plant Pathol* **27**: 314-37.

Chen X M and Line R F (1992) Inheritance of stripe rust resistance in wheat cultivars used to differentiate races of *Puccinia striformis* in North America. *Phytopathology* **82**: 633-37.

Chen X M and Line R F (1995) Gene action in wheat cultivars with durable, high temperature, adult plant resistance and inter action with race specific, seedling resistance to *Puccinia striiformis*. *Phytopathology* **85**: 556-72.

Chen X M, Evans C K and Garner J P (2012) Control of stripe rust of spring wheat with foliar fungicides. *Plant Disease Management Report* **6**: 31-35.

Chen X M, Evans C K and Liu Y M (2016) Control of stripe rust of winter wheat with various foliar fungicides. *Plant Disease Management Report* **10**: 140-147.

Chen X M, Welling C, Kang Z and Liu T (2014) Wheat stripe rust caused by *Puccinia striiformis* f .sp. *tritici*. *Mol Plant Path* **15**: 433-46.

Chhuneja P, Vikal Y, Kaur R, Singh R, Juneja S, Bains N S, Berry O, Sharma A, Gupta S K, Charpe A, Prabhu K V and Dhaliwal H S (2011) Marker-assisted pyramiding of leaf rust resistance genes *Lr24* and *Lr28* in wheat (*Triticum aestivum*). *Indian J Agr Sci* **81**: 214-18.

Cloutier S, McCallum B D, Loutre C, Banks T W, Wicker T, Feuillet C, Keller B and Jordan M C (2007) Leaf rust resistance gene *Lr1*, isolated from bread wheat (*Triticum aestivum* L.) is a member of the large *psr567* gene family. *Plant Mol Biol* **65**: 93-106.

Dakouri A, McCallum B D, Radovanovic N and Cloutier S (2013) Molecular and phenotypic characterization of seedling and plant leaf rust resistance in a world wheat collection. *Mol Breed* **32**: 663-77.

Dawit W, Flath K, Weber W E, Schumann E, Roder M S and Chin X (2012) Postulating and mapping of seedling stripe rust resistance genes in Ethiopian bread wheat cultivars. *Plant Pathol* **94**: 403-07.

Dyck P L and Johnson R (1983) Temperature sensitivity of genes for resistance in wheat to *Puccinia recondita. Can J Plant Pathol* **5**: 229–34.

Dyck P L and Kerber E R (1971) Chromosome location of three genes for leaf rust resistance in common wheat. *Can J Genet Cytol* **13**: 480-83.

Dyck P L and Kerber E R (1985) Resistance of race specific type, In the cereal rust, Roelfs A P and Bushnell W R, eds; Acedemic Press: Orlands, FL, USA, **2**: 469-500.

Dyck P L and Kerber E R. (1970) Inheritance in hexaploid wheat of adult-plant leaf rust resistance derived from *Aegilops squarrosa. Can J Genet Cytol* **12**: 175–80.

Dyck P L and Samborski D J (1979) Adult-plant leaf rust resistance in PI250413 and introduction of common wheat. *Can J Plant Sci* **59**: 329–32.

Erikkson J and Henning E (1896) "Die Getreideroste." Norstedt and Soner, Stockholm. *Disease, Distribution, Epidemiology, and Control* (Original not seen. Cited by- Roelfs A P and Bushnell W R eds. *Cereal Rusts.* Vol. II. Academic Press, New York.

Eversmeyer M G and Kramer L C (1995) Survival of *Puccinia recondita* and *P. graminis* urediniospores exposed to temperatures from subfreezing to 35 ºC. *Phytopathology* **85**: 161-64.

Farid M, Mohamadi M, Khadarahmi M and Afshari F (2013) Analysis of wheat (*Triticum aestivum* L.) Brown rust disease factor and identification of resistance genes in wheat germplasm. *Arch Phytopathology Plant Protect* **46**: 1417-29.

Flor H H (1955) Host-parasite interaction in flax rust- its genetics and other implications. *Phytopathology* **45**: 680-85.

Forsyth F R and Peturson B (1958) Control of stem and leaf rust of wheat with fungicides. *Can J Plant Sci* **38**: 173-80.

Gangwar O P, Kumar S, Prasad P, Bhardwaj S C, Khan H and Verma H (2016) Virulence pattern and emergence of new pathotypes in *Puccinia striiformis* f. sp. *tritici* during 2011-15 in India. *Indian Phytopath* **69**: 178-85.

Gangwar O P, Kumar S, Prasad P, Bhardwaj S C, Khan H, Savadi S and Sharma S K (2017) Detection of new *Yr1*-virulences in *Puccinia striiformis* f. sp. *tritici* population and its sources of resistance in advance wheat lines and released cultivars. *Indian Phytopath* **70**: 307-14

German S, Barcellos A, Chaves M and kohli M (2007) The situation of common wheat rusts in the southern cone of America and perspective for control. *Aust J Agric Res* **58**: 620-30.

Grewal J S and Dharmvir (1959) Efficacy of different fungicides, field trial in relation to wheat rusts. *Indian Phytopath* **12**: 168-70.

Gupta N, Bhardwaj S C, Sharma T R, Prasad P, Gangwar O P and Kumar S (2018) Population behavior of predominant and virulent pathotypes of *Puccinia triticina* causing wheat brown rust in India. *Indian Phytopath* **71**: 59-64.

Gupta V, Mahajan S, Razdan VK, Fatima K and Sharma S (2018) Characterisation of wheat germplasm for slow rust resistance against *Puccinia striiformis. Arch Phytopathology Plant Prot* **51**: 207-16.

Hasson S F, Hussain M and Rizvi S A (1979) Wheat disease situation in Pakistan, Paper presented at national seminar on wheat research and production August 6-9, Islamabad.

Hawthorn W M (1984) *Genetic Analyses of Leaf Rust Resistance in Wheat.* Ph.D. thesis, University of Sydney.

Hei N B (2017) Evaluation of wheat cultivars for slow rusting resistance to leaf rust (*Puccinia trticina* Eriks) in Ethiopia. *Afr J Plant Sci* **11**: 23-29

Herrera-Foessal S A, Singh R P, Lan C X, Huerta-Espino J, Bansal U K, Bariana H S and Lagudah E S (2015) *Yr60*, a gene conforming moderate resistance to stripe rust in Wheat. *Plant Dis* **99**: 508-11.

Herrera-Foessel S A, Lagudah E S, Huerta-Espino J, Hayden M J, Bariana H S, Singh D and Singh R P (2011) New slow-rusting leaf rust and stripe rust resistance genes *Lr67* and *Yr46* in wheat are pleiotropic or closely linked. *Theor Appl Genet* **122**: 239-49.

Herrera-Foessel S A, Singh R P, Huerta-Espino J, Crossa J, Djurle A and Yuen J (2007) Evaluation of slow rusting resistance components to leaf rust in CIMMYT durum wheats. *Euphytica* **155**: 361–69.

Hiebert C W, Thomas J B, Somers D J, Brent D. McCallum B D and Stephen L F (2007) Microsatellite mapping of adult-plant leaf rust resistance gene *Lr22a* in wheat. *Theor Appl Genet* **115**: 877-84.

Huerta-Espino J, Singh R P, German S, McCallum B D, Park R F, Chen W, S Bhardwaj S C, and Goyeau H (2011) Global status of leaf rust caused by *Puccinia triticina. Euphytica* **179**: 143-60.

Hussein S and Pretorius Z A (2005) leaf and stripe rust resistance among Ethiopian grown wheat varieties and lines. *Ethiop J Sci* **28**: 23-32.

Jain S K, Bhardwaj S C, Prashad M, Kumar S and Sharma Y P (2008) Two new pathotypes 5S45 and 29R7 of *Puccinia triticina* from India. *J Mycol Pl Pathol* **38**: 123-25.

Jankuloski L, Chao S, Chen X, See D and Dubcovsky J (2011) Mapping and validation of QTL which confers partial resistance to broadly virulent post 2000 North American race of stripe rust in bread wheat. *Theor Appl Genet* **123**: 147-57.

Jindal M M, Mohan C and Pannu P P S (2012) Status of stripe rust of wheat in Punjab during 2011-12 season. *Proceedings of Brain Storming Session,* Department of Plant Pathology PAU Ludhiana, Pp-56.

Joshi L M and Pathak K D (1975) Loss in yield due to brown rust (*Puccinia recondita* Rob. ex. Desm.) on late sown wheat crop. *Ind J Agronomy* **20**: 79-81.

Joshi L M Singh D V and Srivastawa K D (1984) Fluctuations in incidence of rust and other wheat diseases during past decade and strategies for their, containment. Proc. 23rd All India wheat research worker's workshop CSAU, Kanpur.

Kaur H, Kaur J, Bala R, Sharma A, Pannu P P S, Chhuneja P, and Bains N S (2017) Virulence and genetic diversity of *Puccinia striiformis* f. sp. *tritici* isolates in Punjab, India. *Indian Phytopath* **70**: 416-25.

Kaur J, Bala R, Kaur H, Pannu P P S, Kumar A and Bhardwaj S C (2018) Current status of wheat diseases in Punjab. *Agric Res J* **55**: 113-16.

Kaur L and Singh J (2004) Performance of elite wheat genotypes to wheat stripe rust (*Puccini striiformis*) races 46S103 and 46S119. *Pl Dis Res* **20**: 119-21.

Kerber E R and Dyck P L (1990) Transfer of hexaploid wheat of linked genes for adult plant leaf rust and seedling stem rust resistance from an amphiploid of *Aegiolops speltoides* X *Triticum monococcum*. *Genome* **33**: 530-37.

Kirk P M, Cannonan J C, David J C and Stalpere J A (2008) *Ainsworth and Bisby's Dictionary of the fungi.* CAB International, Oxon, UK.

Knott D R (1989) Introduction In: Knot D R (ed) *The wheat rusts – Breeding for Resistance*. Monograph on Theoretical and Applied Genetics Pp 1-3, Springer-Verlag, Berlin.

Kokhmetova A, Sharma R C, Rsaliyev S, Galymbek K, Baymagambetova K, Ziyaev Z and Morgounov A (2017) Evaluation of Central Asian wheat germplasm for stripe rust resistance. *Plant Genet Resour* **16**: 178-84.

Kolmer J A (2013) Leaf rust of wheat: pathogen biology, variation and host resistance. *Forests* **4**: 70-84.

Kolmer J A, Chen X and Jin Y (2009) Diseases which challenges global wheat production the rusts, In: Carver B F (ed) *Wheat science and trade*. Wiley Ames, Pp 89-124.

Kolmer J A, Garvin D F, Hayden M and Spielmeye W (2018a) Adult plant leaf rust resistance derived from the wheat landrace cultivar Americano 44d is conditioned by interaction of three QTL. *Euphytica* **214**: 59-63.

Kolmer J A, Jin Y and Dong D L (2007) Wheat leaf and Stem rust of in the United States. *Aust J Agric Res* **58**: 631-38.

Kolmer J A, Mert Z, Akan K, Demir L, Unsal R, Sermet C, Keser M, Akin B and Morgounov A (2013) Virulance of *Puccinia triticina* in Turkey and leaf rust resistance in Turkish wheat cultivars. *Eur J Plant Pathol* **135**: 703-16.

Kolmer J A, Su Z, Bernardo A, Bai G and Chao S (2018b) Mapping and characterization of the new adult plant leaf rust resistance gene *Lr77* derived from Santa Fe winter wheat. *Theor Appl Genet* **131**: 1553-60.

Kumari B, Deepshikha and Devi E P (2015) Confirmation of resistance in wheat germplasms aganist brown/leaf rust through seedling resistance test and plant reaction. *Indian Phytopath* **68**: 386-89.

Kumari M, Singh D V and Srivastava K D (1992) Estimation of yield losses in wheat cultivars to leaf rust at different stages under artificial inoculation. *Indian Phytopath* **42**: 266-68.

Kumer S, Awasthi R P and Kumar G (2014) Adult plant resistance in some Indian wheat cultivars and postulating of yellow rust resistance genes. *Indian Phytopath* **67**: 134-37.

Li J, Shi L, Wang X, Zhang N, Wei X, Zhang L, Yang W and Liu D (2018) Leaf rust resistant of 35 cultivars (lines) *J Plant Pathol Microbiol* **9**: 429-36.

Li Y, Niu Y C and Chen X M (2009) Mapping a stripe rust resistance gene *YrC591* in wheat variety C591 with SSR and AFLP markers. *Theor Appl Genet* **118**: 339-46.

Li Z F, Xia X C and Zhou X C (2006) Seedling and slow rusting resistance to stripe rust in Chinese common wheat. *Plant Dis* **90**: 1302-12.

Li Z F, Xia X C, He Z H, Li X, Zhang L J, Wang H Y, Meng Q F, Yang W X, Li G Q and Liu D Q (2010) Seedling and slow rusting resistance to leaf rust in Chinese wheat cultivars. *Plant Dis* **94**: 45-53.

Lin F and Chen X M (2007) Genetics and molecular mapping of genes for race-specific all stage resistance and non-race specific high-temperature adult plant resistance to stripe rust in spring wheat cultivar Alpowa. *Theor Appl Genet* **114**: 1277-87.

Line R F (2002) Stripe rust of wheat and barley in North America: a retrospective historical review. *Annu Rev Phytopathol* **40**: 75–118.

Line R F and Qayoum A (1992) *Virulance, Aggressiveness, evaluation and distribution of races of Puccinia striiformis (the cause of stripe rust of wheat) in North America 1968-87*. Bull 1788 Pp 1-44, United states department of agricultural, North America.

Liu-sha H, Zai-feng1 L, Jia-zhen W, Ling-zhi S , Lin Z, Xing L, Da-qun L and Shah S J A (2015) Molecular mapping of leaf rust resistance genes in the wheat line Yu 356-9 *J Integr Agr* **14**: 1223–28.

Luo P G, Ren Z L, Zhang H Q and Zhang H Y (2005) Identification, Chromosome Location, and Diagnostic' Markers for a New Gene (*YrCNI9*) for Resistance to Wheat Stripe Rust. *Euphytica* **56**: 412-15.

Martin G B, Bogdanove A J and Sessa G (2003) Understanding the function of plant disease resistance proteins. *Annu Rev Plant Biol* **54**: 23-61.

Mateen A and Khan M A (2014) Identification of Yellow Rust Virulence Pattern on Wheat Germplasm in Relation to Environmental Conditions in Faisalabad. *J Biol Agric Healthc* **4**: 62-83.

McCallum B D, Fetch T and Chong J (2007) Cereal rust control in Canada. *Aust J Agric Res* **58**: 639-47.

McIntosh R A, Dubcovsky J, Rogers W J, Morris C, Appels R and Xia X C (2009) Catalogue of gene symbols for wheat. *11th International Wheat Genetics Symp*. Pp 1-10. The University of Sydney, Australia.

McIntosh R A, Wellings C R and Park R F (1995) *Wheat Rusts, an Atlas of Resistance Genes*. Pp 1-200, CSIRO Publication, Melbourne, Australia.

Mehta K K (1940) Further studies on cereal rusts in India. Part–I, Indian Council of Agricultural Research. *Scientific Monograph* **14**: 224.

Muhammad S, Khan A I and Aziz-ur-Rehman A (2015) Screening for leaf rust resistance and association of leaf rust with epidemiology factor in wheat. *Pak J Agri Sci* **52**: 691-700.

Mutari B, Udupa S M, Mavindidze P and Mutengwa C S (2018) Detection of rust resistance in selected Zimbabwean and ICARDA bread wheat (*Triticum aestivum*) germplasm using conventional and molecular techniques *S Afr J Plant Soil* **35**: 101–10.

Nagarajan S (1993) Plant diseases in India and their control. *Ciba Foundation Symposia* **177**: 208-27.

Nayar S K (1996) Variation in wheat rusts and their management through resistance. *Indian Phytopath* **49**: 132-33.

Nayar S K, Bhardwaj S C and Prashar M (2003) Slow rusting in wheat. *Ann Rev Plant Pathol* **2**: 271-86.

Nayar S K, Bhardwaj S C and Jain S K (2002) Fungal diseases of wheat- rusts, In: Gupta V K and Paul Y S *Diseases of field crops*. Pp 17-39. New Delhi, India.

Nayar S K, Prashar M and Bhardwaj (1997) Mannual of Current Techniques in wheat rusts. Directorate of wheat research, Research Bulletin no. 2 Pp 1-32 Flowerdale Shimla.

Pal B P (1966) Wheat, ICAR Monograph, pp. 370

Pannu P P S, Kumar S, Mohan C, Meeta M, Bhardwaz S C, Kaur H and Singh G (2014) Present scenario of yellow rust of wheat in Punjab and its management. *J Res Punjab Agric Univ* **51**: 278-83.

Peterson R F, Campbell A B and Hannah A E (1948) A diagrammatic scale for estimating rust intensity of leaves and stem of cereals. *Can J Res* **26**: 496–500.

Pink D A C (2002) Strategies using genes for non- durable disease resistance. *Euphytica* **124**: 227-36.

Prashar M, Bhardwaj S C, Jain S K and Datta D (2007) Pathotypic evolution in *Puccinia striiformis* in India during 1995-2004. *Aus J Agric Res* **58**: 602-04.

Prashar M, Bhardwaj S C, Jain S K and Gangwar O P (2015) Virulence diversity in *Puccinia striiformis* f. sp. *tritici* causing yellow rust on wheat (*Triticum aestivum*) in India. *Indian Phytopath* **68**: 129-33.

Qi A, Li X, Shi L, Liu D and Li Z (2015): Identification of a leaf rust resistance gene in the Chinese wheat line LB0288. *Czech J Genet Plant Breed* **51**: 43-49.

Rabaninasab H A, Okhovat M, Torabi M, Abbasi M and Mozafari J (2008) Virulance and molecular diversity in *Puccinia striiformis* f. sp. *tritici* from Iran. *J Plant Prot* **22**: 47-60.

Ren Y Z, He X and Liu D C (2012) Major quantitative trait loci for seminal root morphology of wheat seedlings. *Mol Breed* **30**: 139-48.

Riaz A, Athiyannan A K, Periyannan S K, Afanasenko O, Mitrofanova O P, Platz G J, Aitken E A B, Snowdon R J, Lagudah E S, Hickey L T and Voss‑Fels K P (2018) Unlocking new alleles for leaf rust resistance in the Vavilov wheat collection. *Theor Appl Genet* **131**: 127-44

Rizwani S, Ahmad I, Ashraf M, Sahi GM, Mirza JI, Ratto AUR and Mujeeb-kazi A (2007) New source of wheat yellow rust (*Puccinia striiformis* f. sp. *tritici*) seedling resistance. *Pak J Bot* **39**: 595-602.

Roelfs A P and Bushnell W R (1985) *The Cereal Rusts*, Academic Press, Orlando.

Roelfs A P, Singh R P and Saari E. E (1992) Rust Diseases of Wheat: Concepts and Methods of Disease Management. Pp. 7-14. D. F. CIMMYT, Mexico.

Rubiales D and R E Niks (1995) Characterization of *Lr34,* a major gene conferring non-hypersensitive resistance to wheat leaf rust. *Plant Dis* **79**: 1208-212.

Safavi S A, Ahari A B, Afshari F and Arzanlou M (2010) Slow rusting resistance in 19 promising wheat lines to stripe rust in Ardabil. *Pak J Bio Sci* **3**: 240–244.

Saha L R (2002) *Hand book of plant diseases.* Pp 44-45 Kalayan Publisher, New Delhi.

Saini R G, Kaur M, Singh B, Sharma S, Nanda G S, Nayar S K, Gupta A K and Nagarajan S (2002) Genes *Lr*48 and *Lr*49 for hypersensitive adult plant leaf rust resistance in wheat (*Triticum aestivum* L.). *Euphytica* **124**: 365–70.

Sener Kurt (2002) Screening of wheat cultivars for resistance to stripe rust and leaf blotch in Turkey. *Crop Prot* **21**: 495–500.

Shah A S J, Hussain S, Ahmad M, Farhatullah and Ibrahim M (2014) Pathogenicity variations of *Puccinia striiformis* f. sp. *tritici* (westend.) in wheat growing areas of Nepal. *Int J Dev Res* **4**: 2615-19.

Shahin A A (2014) Resistance to stripe rust in some Egyptian wheat germplasm. *J Plant Prot Path* **5**: 983-93.

Shahin S I and El-Orabey W M (2015) Relationship between Partial Resistance and Inheritance of Adult Plant Resistance Gene *Lr46* of Leaf Rust in Six Bread Wheat Varieties *Int J Sci Res* **4**: 1511-17.

Sharma D L, Guleria S, Kaur L and Saini R G (2002) Diversity for stripe rust resistance in wheat germplasm nurseries. *Pl Dis Res* **10**: 145-48.

Singh B, Bansal U K, Muhammad H M, Gill B and Bariana H S (2014) Postulation of resistance genes and assessment of adult plant response variation for stripe rust in three international wheat nurseries. *Indian J Genet Pl Br* **74**: 134-37.

Singh P, Kang B S and Singh D P (2010) Status of yellow rust caused by *Puccinia striiformis* in district Shaheed Bhagat Singh Nagar during epidemic year 2008-09. *Pl Dis Res* **25**: 84.

Singh R P (1993) Resistance to leaf rust in 26 Mexican wheat cultivars. *Crop Sci* **33**: 633-37.

Singh R P and Huerta E J (1995) Inheritance of seedling and adult plant resistance to leaf rust in wheat cultivars Ciano79 and Papago86. *Plant Dis* **79**: 35-38.

Singh R P and McIntosh R A (1984) Complementary genes for resistance to *Puccinia recondita tritici* in *Triticum aestivum*. *Canadian J Genet Cytol* **26**: 723-35.

Singh R P, Herrera-Foessel S, Huerta-Espino J, Singh S, Bhavani S, Lan C X and Basnet B R (2012) Progress towards genetics and breeding for minor genes based resistance to

Ug99 and other rusts in CIMMYT high yielding spring wheat. *Proc 13th International Cereal Rusts and Powdery Mildews Conference*. Pp 107, Beijing, China.

Singh R P, Huerta Espino J and Rajaram S (2001) Achieving near immunity to leaf rust and stripe rusts in wheat by combining slow rusting resistance genes. *Acta Phytopathol Entomol Hung* **35**: 133-39.

Singh R P, Huerta-Espino J, Pfeiffer W and Figueroa-Lopez P (2004) Occurrence and impact of a new leaf rust race on durum wheat in northwestern Mexico from 2001 to 2003. *Plant Dis* **88**: 703-08.

Singh R S (1990) Plant Diseases. pp 619. Oxford and IBH Publishing Co., New Delhi.

Singh V K, Mathuria R C, Singh G P, Singh P K, Singh S, Gogoi R and Aggarwal R (2015) Characterisation of yellow rust resistance genes by using gene postulation and assessment of adult plant resistance in some Indian wheat genotypes. *Research on Crops* **16**: 741-50.

Singla J, Luthi linda, Wicker T, Bansal U, Krattinger S G and Keller (2017) Characterization of *Lr75*: a partial, broad-spectrum leaf rust resistance gene in wheat. *Theor Appl Genet* **130**: 1-12.

Spielmeyer W, Mago R, Simkova H, Dolezel J, Krattinger S, Keller B, Paux E, Feuillet C, Breen J, Appels R, McIntosh R, Kota R, Wellings C and Lagudah E (2010) Durable rust resistance in wheat is effective against multiple pathogens. *Plant and Animal Genomes XVII Conference.* Town and Country Convention Center San Diego, CA.

Stubbs R W (1985) Stripe rust. In *The Cereal Rusts.* Vol II Pp: 61-101 Academic Press, New York.

Sumikova T and Hanzalova A (2010) Multiplex PCR assay to detect rust resistance genes *Lr26* and *Lr37* in wheat. *Czech J Genet Plant* **46**: 85-89.

Tomar S M S and Menon M K (1998) Adult plant response of near isogenic lines and stocks of wheat carrying specific *Lr* genes against leaf rust. *Indian Phytopath* **51**: 61-67.

Tomar S M S, Singh S K, Sivasamy M and Vinod (2014) Wheat rusts in India: Resistance breeding and Gene deployment- A review. *Indian J Genet Pl Br* **74**: 129-56.

Uauy C, Brevis J C, Chen X, Khan I, Jackson L and Chicaiza O (2005) High temperature adult plant (HTAP) stripe rust resistance gene *Yr*36 from *Triticum turgidum* ssp *dicoccoides* is closely linked to the grain protein content locus Gpc-B1. *Theor Appl Genet* **112**: 97-105.

Vallavieielle-pope D, Huber L, Leconte M and Goyau H (1995) Comparative effect of temperature and interrupted wet period of germination, penetration and infection of *Puccinia recondite* f. sp. *tritici* and *Puccinia striiformis* on wheat seedlings. *Phytopathology* **85**: 409-15.

Vander Plank J E (1963) Plant diseases, epidemics and control. *Academic Press*. Pp349. New York.

Viljanen Rollinson S L H, Cromey M G and Callagham M (1998) The effectiveness of stripe rust resistance gene *Yr18* in wheat cultivars. *Arable crops* **12**: 71-75**.**

Wan A, Chen X M, Zhao Z, He Z, Jin Q, Yau G, Yang J, Wang B, Li G, Bi Y and Yuan Z (2004) Wheat stripe rust epidemic and virulence of *Puccinia striformis* f. sp. *tritici* in China in 2002. *Plant Dis* **88**: 896-04.

Wang M and Chen X (2017) Stripe rust resistance. In: Chin X and Kang Z (ed) *Stripe rust.* Pp 353-78, Springer nature, Dordrecht, Netherland.

Xia X C, Ll Z F, Li G Q and Singh R P (2007) Stripe rust resistance in Chinese bread wheat cultivars and lines. In: Buck H T, Nisi J S and Salmon N (eds) *Wheat Production in Stressed Environments*. Pp 77-82 Springer Amsterdam, Neteherlands.

Zakeri A, Afshari F, Yasaie M, Nikzad A R and Rajaei S (2016) Genetic analysis of resistance to stripe rust in some Iranian bread wheat cultivars and elite lines. *Crop Breed J* **4**: 1-8.

Zaman MA, Khatun MT, Hanafi MM and Sahebi M (2017) Genetic analysis of resistance genes in global wheat cultivars: an overview. *Biotechnol Biotec Eq* **31**: 431-45.

Zeng Q D, Han D J, Wang Q L, Yuan F P, Wu J H, Zhang L, Wang X J, Huang L L, Chen X M and Kang Z S (2014) Stripe rust resistance and genes in Chinese wheat cultivars and breeding lines. *Euphytica* **196**: 271-84

Zhao J, Wang M, Chen X and Kang Z (2016) Role of alternate hosts in epidemiology and pathogen variation of cereal rusts. *Ann Rev Phytopathol* **54**: 207-28.

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