Journal of Biology, Agriculture and Healthcare
ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)
Vol.5, No.13, 2015
www.iiste.org

Identification of Leaf Rust Virulence Pattern on Wheat Germplasm In Relation To Environmental Conditions in Faisalabad

Abdul Mateen*, Muhammad Aslam Khan, Abdul Rashid, Muhammad Hussain[1], Shams Ur Rehman[2], Maqsood Ahmed[3]
Department of Plant Pathology, University of Agriculture Faisalabad
1, Wheat Research Institute, Ayub Agricultural Research Institute, Faisalabad
2, Department of Plant Pathology, KPK Agricultural University of Peshawar
3, Pest Warning and Quality Control of Pesticides Sialkot

Abstract
One hundred and fifty varieties/lines were screened against wheat leaf rust. The natural environmental conditions of Ayub Agricultural Research Institute, Faisalabad were favorable for the development of leaf rust disease of wheat. Out of 150lines/cultivars which were screened against brown/leaf rust, 29 lines/cultivars were immune, the resistance was showed by 57 varieties and remaining all was susceptible. Values of area under disease progress curve (AUDPC) of all varieties were calculated. Also from the virulence and avirulence formula studied show that 57 varieties of leaf rust were avirulent and 49 varieties were virulent by leaf rust fungi, respectively. Environmental factors had great effect on the progress of leaf rusts diseases of wheat. Correlation between disease severity and environmental factors was also determined. Maximum varieties/lines showed comprehensible response to environmental factors. Four environmental factors (Temperature, Relative Humidity, Wind Speed and Rainfall) showed significant influence to disease severity. Five varieties/lines V-15, V-45, V-77, V-102, and V-118 showed considerable response to all environmental factors against brown rust. Utilization of this data for wheat improvement coupled with national varietal and gene deployment is discussed. The compiled field results exhibit that although the virulence frequency for some of the leaf rust resistance genes remained low, yet the presence of virulence against them is alarming under the circumstances when genetic base of resistance is stumpy in the presently cultivated varieties. On the basis of data these environmental factors were tested for correlation with leaf rust severities. It was concluded that screening and identifying the virulence pattern of leaf rust on wheat germplasm and utilizing these virulence genes on advanced lines may be helpful to produced for rust resistance in wheat to get maximum production.
Keywords: Leafrust, Virulence Pattern, Resistance source, Epidemiology, Correlation.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most essential cereal crop of the world. It is the most widely grown crop and is staple food its increasing demand due to increase in population of Pakistan, its requirements have become increasing day by day. Of the total area (approximately 215 million hectares) sown to hexaploid and tetraploid wheat (*Triticumaestivum* and *T. turgidumvar. durum*) worldwide, 44% (95 million hectares) is in Asia. Of this, 62 million hectares are located in just three countries: China, India and Pakistan(Singh *et al*., 2004). In Pakistan, wheat is grown under an area of 8.80 million hectare and gives 25.09 million tons of production (Anon., 2011). Despite of its economic importance, wheat is attacked by number of diseases caused by fungi (rusts, smuts, bunts etc), bacteria (bacterial leaf blight, bacterial mosaic, black chaff etc) and virus (wheat dwarf, wheat spot mosaic, wheat streak mosaic etc). Wheat rusts problem has emerged due to attack of fungus not only in Asia but all over the wheat growing areas of the world. However, leaf rust caused by fungi (*Pucciniarecondita*) also called as brown rust, stripe rust caused by fungi (*Pucciniastriiformis*) also called yellow rust and stem rust caused by (*Pucciniagraminis*) called as black rust is stable risk that causes decrease in the yield of wheat (Singh *et al*., 2005). To increase production of wheat one considerable constraint is the fungal attack i.e., different races of rust on the wheat crop.

Leaf rust could affect production on approximately 60 (63%) and 43 (46%) m ha, respectively, in Asia if susceptible cultivars were grown there (Aquino *et al*., 2002). During 1960s, the rusts were conservatively estimated to have reduced North American wheat yield by over 1 million tons (2%) annually (Wiese, 1977). In Western Australia, in 1992 well known rust epidemic occur which affected on yield. In susceptible varieties, losses due to leaf rust were 37% with typical losses of 15% (McIntosh, 1995). Losses due to rust have been estimated Rs. 30-40 million which were very high in the epidemic year i.e., in 1977-78. Reduction in total wheat production due to epidemics of stripe and leaf rusts 2.2 million tons worth US$ 330 million. During 1977-78 in Pakistan, 10.1% yield losses of 0.83 million tons valuing US $86 million (Hafiz, 1986; Hassan *et al*., 1979).

Some general work was performed to recognize the virulence factors of leaf rust to determine the effective genes based on differential lines in Pakistan. In Pakistan, during 1961 to 1975 study on the incidence and distribution of physiological races of leaf rust showed prevalence of 8 different races. Leaf rust disease samples collected from the trap nurseries and affected fields used for the identification of virulence frequencies of leaf rust pathogen from different districts of Baluchistan, Sindh, NWFP and Punjab provinces (Aslam, 1975; Hussain *et al*., 1978-1979).

For rust fungi, living host requires for their survival and rust fungi are obligate parasites. The survival of fungi during offseason is either on other grass species or on other voluntary wheat plants. Furthermore, in different locations of Asia, cool and irrigated agriculture encourage the inoculum. Similarly, during growing season of wheat, temperature and high humidity support development of disease that leads to dew development (Singh *et al.,* 2004b). There are five stages of spore of Wheat rusts where, in the spring and in summer huge quantity of uredospores produce significant epidemic. Wind is also responsible in the dispersal of spore from one plant to other plant where, they generate new infections and secondary uredospores with a low period of seven days (Wiese, 1987). The uredospores are free from nutrient and as soon as they germinate and build a contact with humidity and go through the germ tubes straight in stomata. Thus substomatal vesicles are produced and intercellular hyphae having globose or lobed haustoria which set up physiologic contact with host cell membranes thus starting infection process (Wiese, 1987).Virulence patterns of rust and definite relations between pathogen (rusts) avirulence genes and host (wheat) resistance genes provide valuable marker for description of population of rust (Samborski and Dyck, 1976).

Environmental parameters play vital role in the scattering of rust and cause epidemics. At the right time, blowing wind in the opposite direction may bring spores and vectors far away from the infected plants.

The preferable and most economical method is the utilization of genetic resistance to manage the wheat rusts. Chemical control neither is advocated nor advisable due to health hazards of pesticides in staple food. To screen out each and every variety/advance line is the prime focus of wheat breeders and pathologists. Many new varieties were released after the green revolution, but new races of rust quickly breakup the resistance (Khan, 1987).

So, to enhance farmers' earnings and wheat productivity, appropriate measures and strategies are to be adopted to overcome these serious losses. Various management strategies are used for rust which are sowing of resistant varieties, fungicide application and discussion predictions on the basis of environmental factors conducive for disease development etc. Chemotherapy of leaf rust is not experienced in Pakistan on large scale due to low market price of wheat, health vulnerability concerns and lack of a systematic disease diagnostic pattern.

To avoid rust outbreak in the state is a multifaceted confront, given that less number of cultivars are on hand, that many of them lines/varieties are sheltered by the same immune source at genetic level. The need is to identify those cultivars with resistant sources so as to be suggested as most fit for the cultivation in the more diseased areas of the country keeping in view different ecological zones. The monitoring/screening is considered as the best and the cheapest way to identify these cultivars of wheat which show resistance against leaf rust. This would be helpful for the future studies on the identification of resistant sources in wheat against leaf rust.

For monitoring of leaf rust virulence pattern in relation to environmental factors objectives based on, to identify the resistant lines, monitoring of virulence pattern and correlated with environmental factors with rust response values. In order to accomplish above mentioned objectives the procedure was followed first establishment of wheat germplasm nurseries against leaf rust during two seasons 2010-2012, artificial inoculation of leaf rust through spray method, metrological data was recording, monitoring of leaf rust virulence pattern and correlation of environmental factors with leaf rust response.

MATERIALS AND METHODS

For monitoring of wheat leaf/brown rust virulence/avirulence pattern leaf rust differential set and commercial wheat germplasms/cultivars was obtained from Wheat Research Institute, Ayub Agricultural Research Institute (AARI), Faisalabad. During the years 2010-2012, these host differentials were sown at wheat research area in AARI (Ayub Agricultural Research Institute), Faisalabad. As a single row, each entry was planted while, in nursery every 10 entry Morocco was included and to make artificial epidemic condition Morocco was planted around the trial as a rust spreader. Row to row distance was 2m; line to line distance 30cm with 1m path. Plantation of these lines/cultivars was done during third week of November 2010 and 2011 in the experimental area. These lines were inoculated with the mixture of virulent races of the pathogen.

Inoculation of Wheat germplasm

Inoculum was stored in vacuum and ultra-low refrigeration at -196^{o}C. Organisms that survive cooling, freezing, and subsequent thawing can be stored indefinitely in liquid N_2. Different methods of artificial inoculation were followed. These methods were including spraying with leaf rust inoculums, rubbing, dusting with talcum powder and transplanting of rusted plants (Stubbs *et al.,* 1986). Method of inoculation was repeatedly every 7 days after the emergence of leaves. At booting stage twice in a week, with an aqueous suspension of uredospores @ of

106/ml of water (Rao *et al*., 1989), nursery was inoculated to sustain the rust inoculums pressure (Roelf*et al*., 1992). Preparation of suspension of artificial urediniospores was done in laboratory and sprayed on wheat germplasm.

Recording of Brown Rust Data

On the appearance of symptoms, rust severity (percentage) and response of the plants to disease were assessed for three consecutive observations at 10 day intervals. The severity and the reaction of brown rust were recorded by modified Cobb's scale (Peterson *et al*., 1948). Recording the data of rust was taken upto physiological maturity of wheat crop. When severities of disease became 80-100%, the final disease rating was determined. The final disease severity data for the leaf rust was converted into a coefficient of infection (CI) by multiplying severity with a constant value for field response (Yadav, 1985; Stubbs *et al.,* 1986; and Roelf*et al.,* 1992) given in table-1.

Area under Disease Progress Curve (AUDPC)

Set of 150 germplasms/cultivars was sown to estimate the leaf rust virulence races including 15 Morroco at every 10th position of the nursery. Inoculation of lines was done with the virulent races mixture. Mixture was prepared by adding water in to fungal spores. Data of rust recorded after every one week interval. Area Under Disease Progress Curve (AUDPC) was calculated by using formula developed by CIMMYT

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

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

Monitoring of rusts virulence pattern through avirulence/virulence formula

The trial was consisted of rust differential sets of which consist of near isogenic germplasm for leaf rust as same as Thatcher, wheat cultivars with identified genes planted at different locations in Ayub Agricultural Research Institute (AARI), Faisalabad. Wheat cultivars and reaction of genes was recorded. In an area, data of rust differential and wheat varieties was used to determine the rust virulence pattern.

Environmental data

Environmental data consist of wind velocity, temperature (minimum, maximum), relative humidity (R.H.) and rainfall was recorded by instruments installed in observatory in the field of Ayub Agricultural Research Institute, Faisalabad which are close to wheat experimental area.

Analysis of Data

Simple correlation was determined between the different environmental factors (maximum & minimum temperature, relative humidity, rainfall and wind speed) and leaf rust response value through modified Cobb's scale described by Peterson *et al.,* (1948) for wheat varieties/lines (Steel, *et al*., 1997). The response value/relative resistance index (RRI) was calculated on the basis of following formula;

$$RRI = \frac{(100\text{-}CARPA) \times 9}{100}$$

Whereas the scale used for calculating RRI value ranged from 0 to 9 and CARPA stands for Country Average Relative Percentage Attack.

All the rust severities and environmental data were subjected to correlation and regression analysis to determine the relation of epidemiological factors with wheat rusts.

RESULTS AND DISCUSSION

Wheat lines/cultivars screening against brown/leaf rust

Out of 150 advance lines/cultivars which were screened against brown/leaf rust, 29 lines/cultivars were immune, resistance was shown by 54 varieties and remaining all were susceptible which were given in Table-2.

Data Recorded on the basis of Area Under Disease Progress Curve (AUDPC)

Five lines V-5, V-31, V-107, V-133 and V-134 were resistant to leaf rust and these cultivars showed the AUDPC values as 157.5, 175, 175, 70 and 105, respectively and their response values were 0.2. The response value for susceptible lines V-21, V-65, V-98, V-118 and V-128 were 1.0 and their AUDPC values 717.5, 700, 910, 770 and 780, respectively given in Table-3.

Monitoring of leaf rust virulence pattern through avirulence/virulence formula

To observe the virulence pattern of leaf rust (*Pucciniarecondita*) under field condition a set of trap nursery consisting of 56 near isogenic lines and39 commercial wheat cultivars and few were unknown sources of resistances and 55 were leaf and yellow rust differentials were planted during the cropping season. Monitoring of leaf rust virulence pattern was done on the basis of infection types in a host pathogen system. There were 29 varieties immune which were having zero infection type, 57 varieties were avirulent having infection type moderately resistant (MR) to resistant (R) due to having resistance genes in combination or single *Lr-26, 34, 13, 17, 21, 46, 16, 14A, 3KA, 9, 11, 15, 18, 19, 20, 21, 22a, 24, 25, 28, 32, 33, 34, 35, 27+31, Yr-1, 2, 8, 9, 10, 15, 17, 18, 26, 28, 29, 31, AOC-YRA, AOC+YRA*while, remaining 49 were virulent having infection type moderately susceptible (MS) to susceptible (S) due to having genes *Lr-1, 10, 14, 23,27, 31, 2a, 2b, 2c, 3, 3BG, 12, 14a 14b, 16, 22b, 29, 30, 23, Yr-5, 6, 7, 24, 27, YRCV* were showed in Table-4.

Determination of Correlation of Environmental factors and Leaf Rust Severity

In table 5 given the data shows the correlation of environmental conditions with leaf rust. Ten varieties/lines V-8, V-15, V-18, V-45, V-77, V-79, V-102, V-111, V-117 and V-118show statistically significant relationship with maximum temperature. Ten varieties/linesV-8, V-15, V-18, V-45, V-77, V-79, V-102, V-111, V-117 and V-118 show statistically significant relationship with minimum temperature. These varieties/linesV-8, V-15, V-18, V-45, V-77, V-79, V-102, V-111, V-117 and V-118 having statistically significant relationship with relative humidity and wind speed.

Among 150, 15 lines (Morocco) were used as disease spreaders. Morocco was highly susceptible to leaf rust. However, discussing relationship of environmental factors, 15 lines which are Morocco not included in each case of environmental factors. Now, approaching towards leaf rust and maximum temperature association, on the basis of correlation existing it was accomplished that 95varieties/lines showed significant trend for the leaf rust that is linearity in the relationship of leaf rust and maximum temperature. While, in contrast, 26varieties/lines showed non-significant relationship to maximum temperature that is increase in temperature did not increase the level of disease severity. On the other hand, temperature (maximum, minimum) showed more likely for the spreading of leaf rust pathogen. There were 106varieties/lines which showed significant relationship and 15varieties/lines which showed non-significant relationship with leaf rust. Relative humidity (R.H.) had significant effect on 62 varieties/lines as these all showed an increase in the level of disease severity with an increase in relative humidity (R.H.) however, despite of 59 varieties/lines which showed non-significant relationship with an increase in relative humidity (R.H.). Rainfall on the other hand, had some significant relationship among 41 varieties/lines and 80 varieties/lines showed no significant relationship with rainfall while, wind speed is also effective factor for spreading of leaf rust disease as 91 varieties/lines were showed significant relationship while rest of the 30 varieties/lines showed non-significant relationship with wind speed. It means spores are spreading due to wind from infected plants to healthy plants and causing leaf rust disease.

Minimum temperature Vs Leaf rust severity

There was positive relationship between minimum temperature and leaf rust severities. The varieties V-15, V-45, V-77, V-102, and V-118 showed considerable reaction with an increase in temperature 14-18°C, values of leaf rust also increased. This demonstrates clearly about the response values of leaf rust varieties/lines to minimum temperature showed in Fig-1.

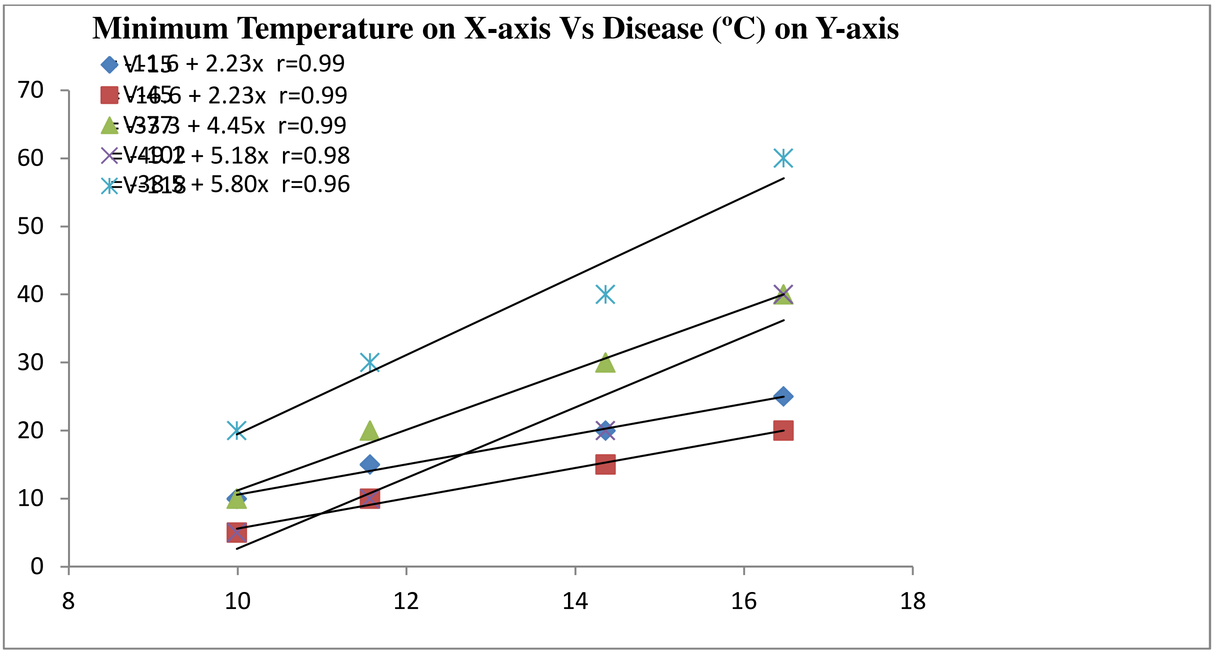

Fig-1.Relationship of minimum temperature with leaf rust disease severity on (V-15, V-45, V-77, V-102, and V-118)

Maximum temperature Vs Leaf rust severity

There was positive relationship between maximum temperature and leaf rust severities. The varieties V-15, V-45, V-77, V-102, and V-118 showed considerable reaction with an increase in temperature 28-32°C, values of leaf rust also increased. This demonstrates clearly about the response values of leaf rust varieties/lines to maximum temperature showed in Fig-2.

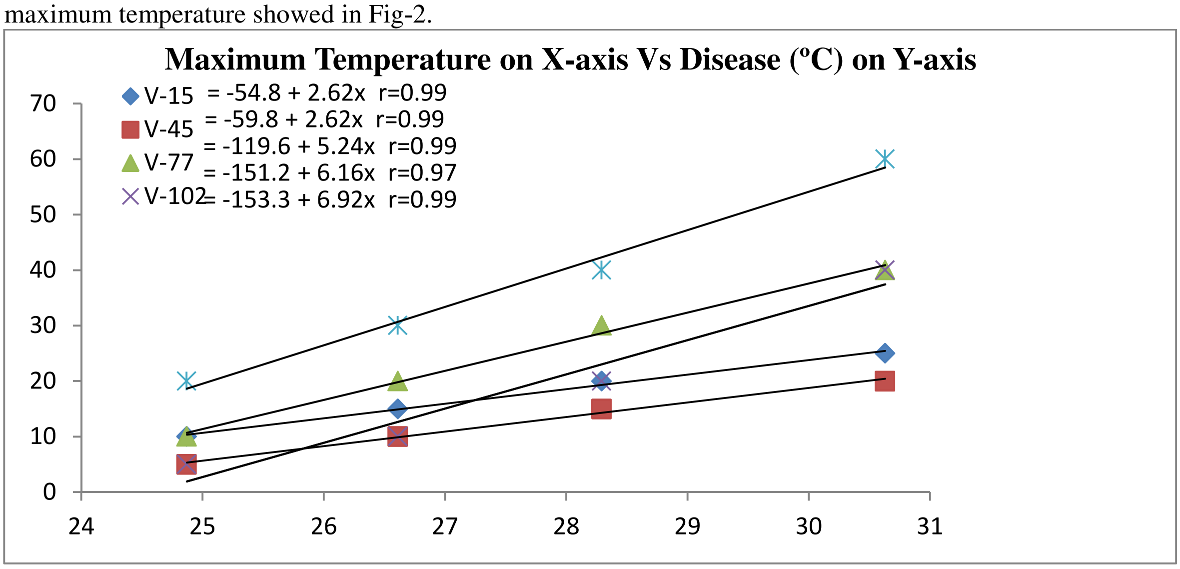

Fig-2. Relationship of maximum temperature with leaf rust disease severity on (V-15, V-45, V-77, V-102, and V-118)

Relative humidity Vs Leaf rust severity

There was positive relationship between relative humidity and leaf rust severities. The varieties V-15, V-45, V-77, V-102, and V-118 showed considerable reaction with an increase in relative humidity 70-74, values of leaf rust also increased. This demonstrates clearly about the response values of leaf rust varieties/lines to relative humidity showed in Fig-3.

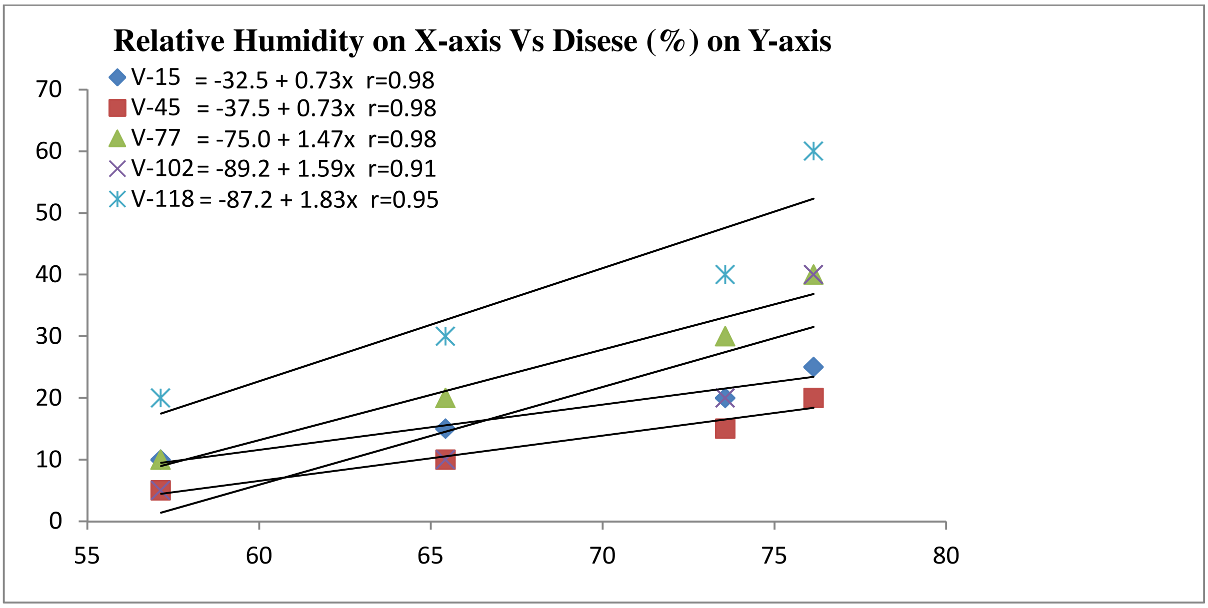

Fig-3. Relationship of relative humidity with leaf rust disease severity on (V-15, V-45, V-77, V-102, and V-118)

Wind speed Vs Leaf rust severity

There was positive relationship between wind speed and leaf rust severities. The varieties V-15, V-45, V-77, V-102, and V-118 showed considerable reaction with an increase in wind speed 2.8-3.3, values of leaf rust also increased. This demonstrates clearly about the response values of leaf rust varieties/lines to wind speed showed in Fig-4.

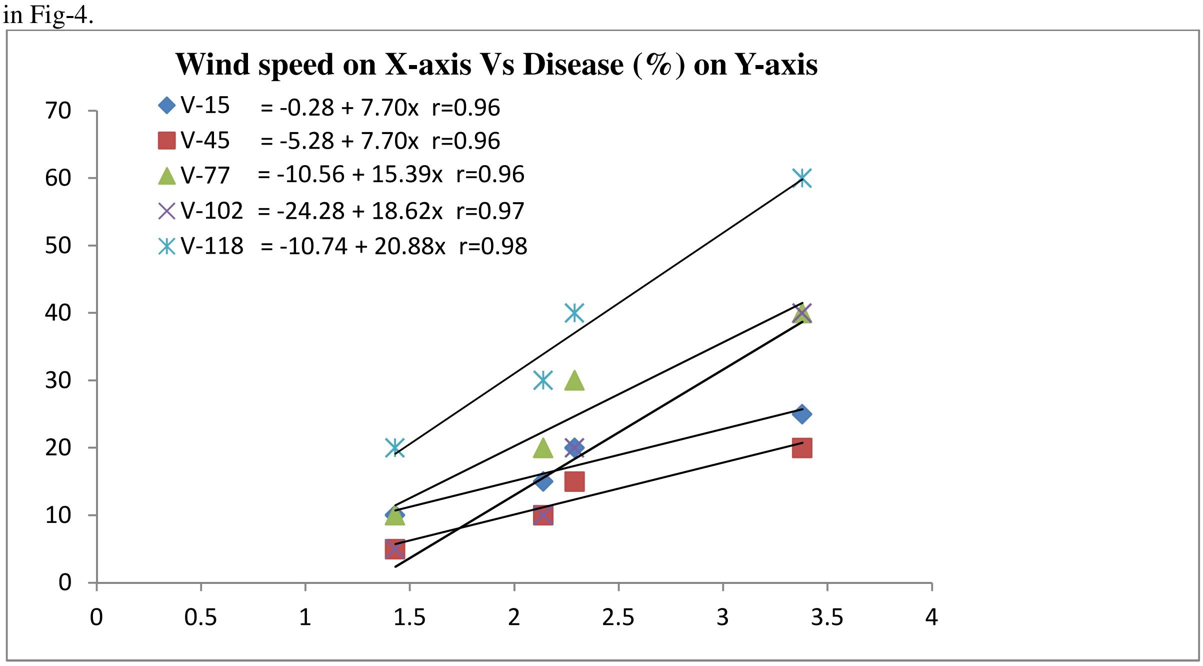

Fig-4. Relationship of wind speed with leaf rust disease severity on (V-15, V-45, V-77, V-102, and V-118)

Rainfall Vs Leaf rust severity

There was positive relationship between rainfall and leaf rust severities. The varieties V-15, V-45, V-77, V-102, and V-118 showed considerable reaction with an increase in rainfall 1.43-2.38, values of leaf rust also increased. This demonstrates clearly about the response values of leaf rust varieties/lines to rainfall showed in Fig-5.

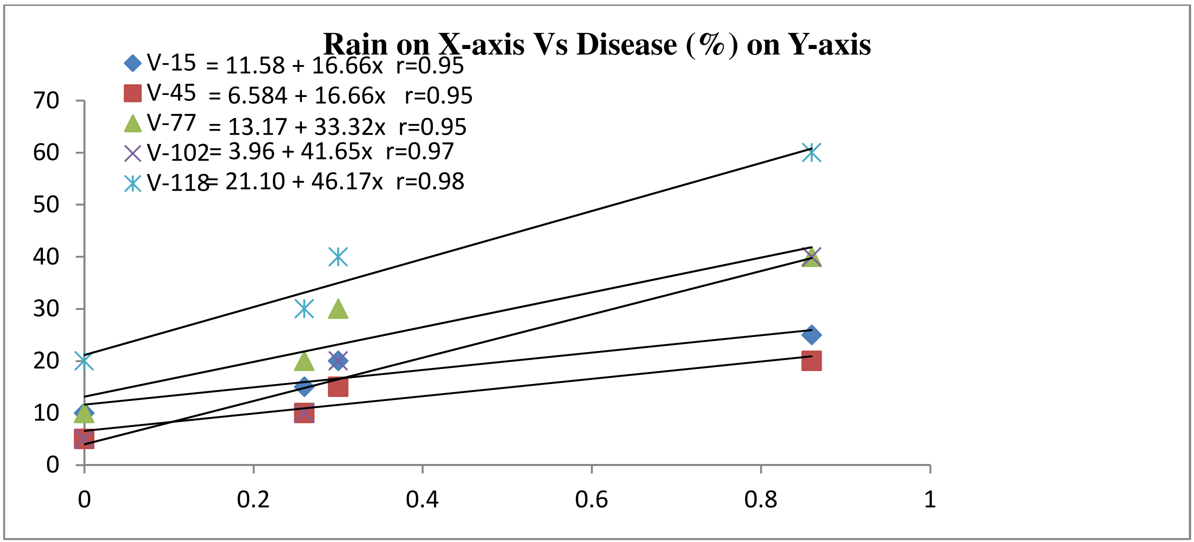

Fig-5. Relationship of rainfall with leaf rust disease severity on(V-15, V-45, V-77, V-102, and V-118)

During the cropping season 2010-2012, studies regarding identification of the virulence pattern of leaf rust on wheat germplasms in relation to environmental conditions werecarried out. Along with natural inoculums, artificial inoculation of leaf rust spores were done on wheat varieties/lines by using various methods like transplanting of rusted plants, rubbing, dusting with talcum powder and spraying. Studies were also carried out in 1992 byRoelfs*et al*., by using one of the same method i.e., fresh spores (uredospores) mixed with talcum powder and then applied at tillering, heading and flag leaf stages of the wheat crop to evaluate the resistance source of wheat germplasm, including a checked (Morocco) after each 9th line/variety, one hundred and fifty varieties/lines were screened against leaf rust disease severities in the present studies and resultantly during 2010-2012, it was found that the leaf rust disease severity on spreader Morocco attained 100S (Susceptible: High values above 600 of AUDPC showed greater incidence of leaf rust on wheat plants, with lower AUDPC values indicating resistance to leaf rust in wheat genotypes) out of all the varieties/lines sown 29 were immune, 57varieties were resistance and 49 were susceptible against leaf rust. In 1987, Arora *et al*., screened 158 durum and aestivum wheat lines and showed that there was only 1 line immune while, 4 were resistant against leaf rust. In 2001, Khan *et al*., screened 145 lines of wheat against leaf rust and followed that 39, 64, 29, 13 lines were immune, resistant, moderately resistant and moderately susceptible, respectively. In 2002, Khan *et al*., carried out the studies of screening 197 lines/varieties and followed that on a leaf rust severity scale 89, 43, 32, 10, 16 and 7 varieties/lines which were immune, resistant, moderately resistant, moderately susceptible and highly susceptible, respectively. To monitor the leaf rust virulence pattern, the present studies were carried out on the basis of reaction types in a host pathogen system. There were 29 varieties which were immune having zero infection type reaction, 57 varieties were avirulentinfection type reaction moderately resistant (MR) to resistant (R) and remaining 49 were virulent having infection type reaction moderately susceptible (MS) to susceptible (S) to leaf rust excluding Morocco. In the present study the lines having genes *Lr-9, 15, 17, 18, 13, 34, 26, 3, 21, 16, 46, 14A, 19. 24, 32, 33, 34, 35, Yr-1, 2, 15, 17, 28, 29, 31, 3KA* were moderately resistant (MR). While, lines having genes *Lr-11, 20, 22a, 25, 27+31, Yr-8, 9, 10, 18, 26, AOC-YRA, AOC+YRA* were resistant (R). In 2003, Khan conducted the studies on leaf rust virulences and found that *Lr-19, 24, 25, 27, 36, 37* genes were resistant. In 2009,Rattu*et al*., reported that genes *Lr-1, 3, 2, 29, 30, 12, 16, 15, 17, 18, 21* and *24* were resistant against leaf rust. From the present study lines having these genes *Lr-1, 10, 14, 23, 27, 31, 2a, 2b, 2c, 3, 3BG, 12, 14a 14b, 16, 22b, 29, 30, 23, Yr-5, 6, 7, 24, 27, YRCV* and *Lr-1, 10, 14, 23, 27, 31, 2a, 2b, 2c, 3, 3BG, 12, 14a 14b, 16, 22b, 29, 30, 23, Yr-5, 6, 7, 24, 27, YRCV* were moderately susceptible (MS) to susceptible. In 2006,Kolmer*et al*., found that *Lr-1, 2c, 10, 14a* genes were virulent on leaf rust and reported that virulence on many of these genes widespread in wheat cultivated area of the world. While, in 2004 Singh *el al*., found that *Yr-18* with other minor genes is known to be resistance source such as Parula, Trap, Yaco and others. In 1976, Samborski and Dyck, studied to identify the virulence patterns of rusts which moreover alter nearby or introduced through movement. The definite relations between pathogen (rusts) avirulence genes and host (wheat) resistance genes provided valuable marker for description of population of rust. In 1993, Wu *et al*., all of sixty seven virulence patterns on the basis of their avirulence/virulence formula on the 17 differentials and the population structures of the pathogen have diverse with the related resistance change in wheat cultivar. Chaudhary *et al*., in 1996 monitored rust virulence and found that varieties Inq-91, Parwaz-94 and Chkwal-86 were resistant to leaf rust. Fsd-85 and Rawal-87 were moderately susceptible to leaf rust. In 2008, Fayyaz*et al*., carried out the virulence studies and found the *Lr* genes having virulence at Nawabshah and Karachi, partial virulence was seen on different *Lr*genes at 3 localities. Majority of the wheat varieties showed susceptibility against brown rust.To predict disease severity, relationship of environmental conditions to disease severity has its importance as well.The study of environmental factors conducive for leaf rust which helped out to prediction of leaf rust epidemics, so that precautionary measures should be taken well in time to minimize the yield losses and to ensure the quality of the wheat. Present study was also focused on the correlation of environmental factors with leaf rust responses. There was positive relationship between maximum temperature and leaf rust severities on all 150 varieties/lines. The varieties 94 showed considerable reaction with an increase in temperature and these findings of the present studies supported according to Psquini*et al*., in 1996, who initiated that climatic condition like mild winter temperature was particularly favored to develop the leaf rust disease severity. It was also observed that there was positive correlation between relative humidity and leaf rust severity. Out of the varieties/lines 62 showed considerable reaction with an increase in relative humidity 75-80 percent, values of leaf rust also increased.Khan 1997, who developed a multiple regression model by utilize leaf rust disease severity as dependant and 24 hour wind speed as independent variable and established a positive correlation between these two variables. Khan in 1998, found that environmental conditions favorable for the development of leaf rust infection at minimum and maximum temperature 8 to 16ºC and 22 to 28 ºC, correspondingly. Hussain, in 1999, examined that Inq-91 was not infected from rust pathogen also had various temperature susceptible genes confer resistance to stripe rust. Singh and Tewari in 2001, described that relative humidity ranged between 42.8% to 88.2 % was favored for the development of severity of leaf rust disease. With the increasing amount of precipitation and in relative humidity leaf rust of wheat were also in increasing trend. Wind speed also an environmental factor which cannot be neglected here. There was positive correlation between wind speed and leaf rust severity. Results are conflicting to that of Khan 1994, there was negative linear relationship between relative humidity, rainfall and leaf rust severities. Singh and Tewari in 2001 showed that the main cause of epidemic may be the favorable environmental conditions. Under suitable environment, the chance of disease incidence increases. Sajjid*et al*., in 2010, created infection artificial inoculation on the crop with leaf rust urediospores and determined the correlation of leaf rust. There was positive correlation between minimum and maximum temperature at 15-25 ºC and 30-35ºC, respectively, while negative correlation in rising relative humidity and rainfall for the development of leaf rust.

REFRENCES

Anonymous, 2011. Pakistan statistical year book, Statistic division, Federal Bureau of Statistcs. Govt. of Pak. Islamabad.

Aquino, P., Carrion F, Calvo R, 2002. Selected wheat statistics. In CIMMYT 2000-2001 World Wheat Overview and Outlook: Developing No-Till Packages for Small-Scale Farmers. (Ed. J. Ekboir) pp. 52-62. (CIMMYT, Mexico DF).

Arora, P. C., G. Anil, R. Basant, S. Singh, A. Gupta and B. Ram, 1987. Screening of wheat germplasms against brown and yellow rusts. *Ind. J. Mycol. Pl. Pathol.*17:60-71.

Aslam, M., 1975. Pathogenic specialization in *Pucciniarecondita* f. sp. *tritici* in NWFP. *Agri. Pak.*, 2281: 171-175.

Chaudhry. M., H.M. Hussain and J.A. Shah, 1996. Wheat rust scenario. 1994-95. *Pak. J. Phytopathol.*, 8: 96-100.

Fayyaz, M., A.R. Rattu, I. Ahmad, M.A. Akhtar, A.A. Hakro and A. Mujeeb-Kazi, 2008. Current status of the occurrence and distribution of (*Pucciniatriticina*) wheat leaf rust virulence in Pakistan. *Pak. J. Bot.*, 40: 887-895.

Hafiz, A., 1986. Plant Diseases. Publisher PARC Islamabad, Pakistan, pp 552.

Hassan, S. F., M. Hussain and S. A. Rizvi, 1979. Wheat diseases situation in Pakistan. National Seminar on Wheat Research and Production, August 6-9, Islamabad.

Hussain, M., M.H. Chaudhry, A.R. Rehman, J. Anwar, S.B. Khan, J.A. Shah and M. Hussain. 1999. Development of durable rust resistance in wheat. *Pak. J. Phytopath.*, 11: 130-139.

Hussain, M., S.F. Hassan and M.S.A. Kirmani. 1980. Virulences in *Puccinia recondita* Rob. Ex Desm. f. sp. *tritici* in Pakistan during 1978 and 1979. Proceedings of the fifth European and Mediterranean cereal rusts conference, Bari, Italy. 179-184.

Hussain, S. F. 1999. Wheat disease situation in Pakistan. *Proc. Nation. Sem. on Wheat Res. and Prod.*, 10: 6-9.

Khan, M. A. 1994. A Decision-support model for the economic chemotherapy of leaf rust on winter wheat in Mississippi State, Ph.D Thesis, Department of Entomology and Plant Pathology Mississippi, USA. pp 38-63.

Khan, M.A. 1987. Wheat Variety Development and Longevity of Rust Resistance. Lahore: Directorate of Agri. Information, Punjab. pp. 9.

Khan, M.A. 2003. Wheat Crop Management for Yield Maximization. 1st Edition Wheat Research Institute, Faisalabad. Agri. Deptt. Government of Punjab, Lahore, Pakistan.

Khan, M.A., 1997. Evaluation of multiple regression models based on epidemiological factors to predict leaf rust on wheat. *Pak. J. Agric. Sci.*, 5: 1-7.

Khan, M.A., M. Yaqub and M.A. Nasir, 1998. Slow rusting response of wheat genotypes against *Pucciniarecondita* f. sp. *tritici* in relation to environmental conditions. *Pak. J. Phytopathol.*, 10: 78-85.

Khan, M.A., Mustafa, A.Y. and M. Hussain, 2001, Determination of minimum leaf rust levels for breeding high yielding wheat varieties. *Pak. J. Phytopathol.*, 13: 18-25.

Khan, M.A., S.M. Khan and M. Hussain, 2002. Evaluation of wheat lines/varieties against artificial and natural inoculums of *Pucciniarecondita* f. sp. *tritici* causing brown rust. *Pak. J. of Agri. Sci.*, 39: 226-231.

Kolmer, J.A., 1996. Genetics of resistance to wheat leaf rust. Annual Review of *Phytopathol.*, 34: 435-455.

McIntosh, R. A., C. R. Wellings and R. F. Park 1995. Wheat Rusts. An Atlas of Resistance Genes. CSIRO Publications, Est Melbourne, Victoria 3002, Australia pp.200.

Peterson, R.F., A.B. Campbell and Hanna, 1948. A diagrammatic scale for estimating rust severity on leaves and stems of cereals. *Can. J. Res. Sci.*, 26: 249-500.

Prescot, J.M., P.A. Burnett, E.E. Sarri, R.P. Singh and G. Bekele, 1986. Wheat diseases and pests; A guide for field identification. CIMMYT. M Mexico, D. F., Mexico.

Rao, S.K.V., J.P. Snow and G.T. Berggren. 1989. Effect of growth stages and initial inoculum level on leaf rust development and yield loss caused by *Pucciniarecondita* f. sp. *tritici*. *J. Phytopath.*, 127: 200-210.

Rattu, A.R., I. Ahmad, M. Fayyaz, M. A. Akhtar, Irfan-Ulhaque, M. Zakria and S.N. Afzal, 2009. Virulence analysis of *Pucciniatriticinia* cause of leaf rust of wheat. *Pak. J. Bot.*, 41: 1957-1964.

Roelf, A.P., R.P. Singh and E.E. Saari. 1992. Rust diseases of wheat: Concept and methods of disease management ‘Mexico’ D.F. CIMMYT. Pp. 81.

Samborski DJ, Dyck PL (1976). Inheritance of virulence in *Pucciniarecondita* on six backcross lines of wheat with single genes for resistance to leaf rust. *Can. J. Bot.* 54:1666-1671.

Shaner, G. and R.E. Finney. 1977. The effect of Nitrogen fertilization on the expression of slow mildewing resistance in known wheat. *Phytopath.*, 67: 1052-1056.

Singh, R.P., H.M. William, J. H. Espino and G. Rosewarne. 2004b. Wheat rust in Asia: Meeting the challenges with old and new technologies. In: Proceedings of the 4th International Crop Science Congress, 26 Sep – 1 Oct 2004, Brisbane, Australia.

Singh, R.P., H.M. William, J.H. Espino and G. Rosewarne, 2005. Wheat rust in Asia: Meeting the challenges with old and new technologies. In: Proceedings of the 4th International Crop Science Congress, 26 Sep – 1 Oct 2004, Brisbane, Australia.

Singh, R.P., J. Huerta-Espino, W. Pfeiffer and P. Figueroa-Lopez, 2004. Occurrence and impact of a new leaf rust race on durum wheat in north western Mexico from 2001 to 2003. *Pl. Dis.,* 88: 703-708.

Singh, S.S., J.B. Sharma and J.B. Singh, 2004. Resistance to leaf rust (*Pucciniarecondita* f. sp. *tritici*) in some cultivars and promising lines of Indian wheat. *Annals of Plant Protect. Sci.*, 12: 448-450.

Singh, T.B. and A.N. Tewari, 2001. The role of weather conditions in the development of foliar diseases of wheat under tarai conditions of north western India. *Plant Dis. Res.*, 16: 173-178.

Steel, R.G.D., J.H. Torri and D.A. Dicky, 1997. Principles and procedures of statistics: A Biometrical Approach. 3rd Ed., McGraw Hill Book Co., New York.

Stubbs, R.W., J.M Prescott, E.E. Suari and H.J. Dubin, 1986. Cereal Disease Methodology Manual. Centro International de Maize by trig (CIMMVT), Mexico.

Wiese, M.V., 1977. Compendium of wheat diseases. (*American phytopathology society*: St Paul, Minnesota, USA).

Wiese, M.V., 1987. Compendium of wheat diseases. 2nd ed. Amer. Phytopath. Soc. St. Paul, Minnesota. Pp 1-124.

Wu, L. R., Yang, H. A., Yuan, W. H., Song, W. Z., Yang, J. X., Li, Y. F., and Bi, Y. Q. 1993. On the physiological specialization of stripe rust of wheat in China during 1985-1990. *Chin. J. Plant Pathol.* 23:269-274.

Yadav, B., 1985. Evaluation of spring wheat lines for slow leaf rusting. *Ann. Biol., India*, 1: 165-170.

Table-1. Rust reaction, infection type for field response and response value

Reaction	Infection type	Field response	Response value
No disease	0	No visible infection	0
Resistant	R	Necrotic areas with or without minute uredia	0.2
Moderately resistant	MR	Small uredia present surrounded by necrotic area	0.4
Moderately resistant, moderately susceptible	MRMS	Small uredia present surrounded by necrotic areas as well as medium uredia with no necrosis but possible some distinct chlorosis	0.6
Moderately susceptible	MS	Medium uredia with no necrosis but possible some distinct chlorosis	0.8
Moderately susceptible-susceptible	MSS	Medium uredia with no necrosis but possible some distinct chlorosis as well as large uredia with little or chlorosis present	0.9
Susceptible	S	Large uredia and little or no chlorosis present	1.0

Cobb's scale (Peterson *et al.,* 1948) was used only to record the rust severity data

Table-2. Area Under Disease Progress Curve and varietal/lines Reaction against Leaf/Brown Rust

Sr. No	Ranges of AUDPC	Varieties /Lines (2010-2011)	Varieties /Lines (2011-2012)	Level of Resistance or Susceptibility
1	1-200	V-3, V-5, V-26, V-31, V-32, V-52, V-107, V-122, V-124, V-133, V-134, V-135, V-141	V-5, V-26, V-31, V-52, V-107, V-124, V-133, V-134, V-135, V-141	R (Resistant)
2	201-400	V-6, V-9, V-11, V-13, V-15, V-27, V-33, V-35, V-41, V-42, V-45, V-46, V-54, V-58, V-61, V-62, V-63, V-66, V-72, V-74, V-75, V-76, V-78, V-81, V-82, V-83, V-86, V-87, V-95, V-96, V-102, V-103, V-104, V-117, V-119, V-127, V-129, V-131, V-132, V-138, V-146, V-147, V-148, V-149	V-3, V-6, V-9, V-11, V-13, V-15, V-25, V-27, V-32, V-33, V-35, V-41, V-42, V-45, V-46, V-48, V-54, V-58, V-62, V-63, V-66, V-72, V-74, V-76, V-78, V-81, V-83, V-86, V-87, V-95, V-96, V-101, V-102, V-103, V-104, V-119, V-122, V-127, V-132, V-136, V-144, V-146, V-147, V-148	MR (Moderately Resistant)
3	401-600	V-4, V-7, V-8, V-16, V-17, V-22, V-25, V-28, V-34, V-38, V-39, V-43, V-48, V-53, V-55, V-56, V-57, V-59, V-64, V-77, V-79, V-88, V-89, V-101, V-108, V-111, V-112, V-115, V-121, V-123, V-125, V-126, V-136, V-137, V-144, V-145	V-4, V-7, V-8, V-16, V-17, V-22, V-28, V-34, V-38, V-39, V-43, V-53, V-55, V-56, V-61, V-64, V-75, V-77, V-79, V-88, V-89, V-82, V-91, V-108, V-111, V-112, V-115, V-117, V-121, V-123, V-125, V-126, V-129, V-131, V-137, V-138, V-149	MS (Moderately Susceptible)
4	601-More	V-18, V-21, V-23, V-47, V-65, V-69, V-91, V-98, V-113, V-114, V-116, V-118, V-128	V-18, V-21, V-23, V-47, V-57, V-59, V-65, V-69, V-79, V-98, V-113, V-114, V-116, V-118, V-128, V-145	S (Susceptible)

R=Resistant, MR=Moderately Resistant, MS=Moderately Susceptible, S=Susceptible.

Table-3. Nearisogenic lines and wheat differentials used for the observation of virulence pattern of leaf rust pathogen under field conditions

Sr. No	Symbols of Varieties/ Differentials	Gene	Reaction Type	Sr. No	Symbols of Varieties/ Differentials	Gene	Reaction Type
1	Morocco	-	S	69	V-75	-	MR
2	V-1	Lr26	0	70	V-76	Lr34,46	MR
3	V-2	Lr34	0	71	V-77	Lr1,23	MS
4	V-3	Lr13,26	R	72	V-78	Lr13,46	MR
5	V-4	Lr1	MS	73	V-79	-	MS
6	V-5	Lr13,34	R	74	V-81	-	MR
7	V-6	Lr34	MR	75	V-82	Lr34	MR
8	V-7	-	MS	76	V-83	Lr34	MR
9	V-8	Lr1,10	MS	77	V-84	AOC-YRA	0
10	V-9	Lr26,34	MR	78	V-85	AOC+YRA	0
11	V-11	Lr13	MR	79	V-86	Yr-I	MR
12	V-12	Lr17	0	80	V-87	Yr-2	MR
13	V-13	Lr3	MR	81	V-88	Yr-5	MS
14	V-14	-	0	82	V-89	Yr-6	MS
15	V-15	Lr21	MR	83	V-91	Yr-7	S
16	V-16	Lr14	MS	84	V-92	Yr-8	0
17	V-17	Lr23	MS	85	V-93	Yr-9	0
18	V-18	Lr23	S	86	V-94	Yr-10	0
19	V-19	Lr13,34	0	87	V-95	Yr-15	MR
20	V-21	Lr23	S	88	V-96	Yr-17	MR
21	V-22	-	MS	89	V-97	Yr-18	0
22	V-23	Lr1	S	90	V-98	Yr-24	S
23	V-24	Lr13,46	0	91	V-99	Yr-26	0
24	V-25	-	MS	92	V-101	Yr-27	MS
25	V-26	-	R	93	V-102	Yr-28	MR
26	V-27	Lr13	MR	94	V-103	Yr-29	MR
27	V-28	Lr1	MS	95	V-104	Yr-31	MR
28	V-29	-	0	96	V-105	Lr34	0
29	V-31	-	R	97	V-106	Lr34	0
30	V-32	-	R	98	V-107	Lr13,26	R
31	V-33	Lr13,26	MR	99	V-108	Lr23	MS
32	V-34	Lr14	MS	100	V-109	Lr34	0
33	V-35	Lr26	MR	101	V-111	YRCV	MS
34	V-36	Lr34	0	102	V-112	Lr-I	MS
35	V-37	Lr27,31	0	103	V-113	Lr-2a	S
36	V-38	-	MS	104	V-114	Lr-2b	S
37	V-39	Lr1	MS	105	V-115	Lr-2c	MS
38	V-41	Lr13	MR	106	V-116	Lr-3	S
39	V-42	Lr34	MR	107	V-117	Lr-3KA	MR
40	V-43	Lr10,23	MS	108	V-118	Lr-3BG	S
41	V-44	Lr34	0	109	V-119	Lr-9	MR
42	V-45	Lr13,34	MR	110	V-121	Lr-10	MS
43	V-46	Lr26	MR	111	V-122	Lr-11	R
44	V-47	-	S	112	V-123	Lr-12	MS
45	V-48	-	MS	113	V-124	Lr-13	R
46	V-49	Lr13,26	0	114	V-125	Lr-14a	MS
47	V-51	Lr13,34	0	115	V-126	Lr-14b	MS
48	V-52	Lr34	R	116	V-127	Lr-15	MR
49	V-53	-	MS	117	V-128	Lr-16	S
50	V-54	-	MR	118	V-129	Lr-17	MR
51	V-55	Lr1	MS	119	V-131	Lr-18	MR
52	V-56	Lr10,23	MS	120	V-132	Lr-19	MR

53	V-57	Lr10	MS	121	V-133	Lr-20	R
54	V-58	Lr13,46	MR	122	V-134	Lr-21	R
55	V-59	Lr10	MS	123	V-135	Lr-22a	R
56	V-61	Lr13,34	MR	124	V-136	Lr-22b	MS
57	V-62	Lr34	MR	125	V-137	Lr-23	MS
58	V-63	Lr13,34	MR	126	V-138	Lr-24	MR
59	V-64	Lr1	MS	127	V-139	Lr-25	0
60	V-65	-	S	128	V-141	Lr-26	R
61	V-66	Lr16	MR	129	V-142	Lr-27+31	0
62	V-67	Lr13,34	0	130	V-143	Lr-28	0
63	V-68	Lr13,34	0	131	V-144	Lr-29	MS
64	V-69	-	S	132	V-145	Lr-30	MS
65	V-71	Lr26	0	133	V-146	Lr-32	MR
66	V-72	-	MR	134	V-147	Lr-33	MR
67	V-73	-	0	135	V-148	Lr-34	MR
68	V-74	Lr14A	MR	136	V-149	Lr-35	MR

Reaction Types-0, R=Resistant, MR=Moderately Resistant, MS=Moderately Susceptible, S=Susceptible.

Table-4. Avirulence/Virulence formula for mixture races of *P. triticina*

Avirulence	Virulence
Lr-26, 34, 13, 17, 21, 46, 16, 14A, 3KA, 9, 11, 15, 18, 19, 20, 21, 22a, 24, 25, 28, 32, 33, 34, 35, 27+31, Yr-1, 2, 8, 9, 10, 15, 17, 18, 26, 28, 29, 31, AOC-YRA, AOC+YRA	*Lr-1, 10, 14, 23, 27, 31, 2a, 2b, 2c, 3, 3BG, 12, 14a 14b, 16, 22b, 29, 30, 23, Yr-5, 6, 7, 24, 27, YRCV*

Formula: Avirulence=R and MR type of reaction, Virulence=S and MS type of reaction.

Table-5. Correlation of Leaf rust with Different Environmental factors

Sr. No.	Varieties/ Lines	Maximum Temperature	Minimum Temperature	Relative Humidity	Rainfall	Wind Speed
1	V-3	0.9943	0.9804**	0.9225	0.9786**	0.9857**
		0.0057	0.0196	0.0775	0.0214	0.0143
2	V-4	0.9860**	0.9806**	0.9876**	0.9174	0.9529*
		0.0140	0.0194	0.0124	0.0826	0.0471
3	V-5	0.9968*	0.9950*	0.9780**	0.9344	0.9611*
		0.0032	0.0050	0.0220	0.0656	0.0389
4	V-6	0.9968*	0.9950*	0.9780**	0.9344	0.9611*
		0.0032	0.0050	0.0220	0.0656	0.0389
5	V-7	0.9968*	0.9950*	0.9780**	0.9344	0.9611*
		0.0032	0.0050	0.0220	0.0656	0.0389
6	V-8	0.9968*	0.9950*	0.9780**	0.9344	0.9611*
		0.0032	0.0050	0.0220	0.0656	0.0389
7	V-9	0.9936	0.9967*	0.9477	0.9406	0.9550*
		0.0064	0.0033	0.0523	0.0594	0.0450
8	Morocco	0.9943	0.9804**	0.9225	0.9786**	0.9857**
		0.0057	0.0196	0.0775	0.0214	0.0143
9	V-11	0.9936	0.9967*	0.9477	0.9406	0.9550*
		0.0064	0.0033	0.0523	0.0594	0.0450

10	V-13	0.9968* 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
11	V-15	0.9968* 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
12	V-16	0.9860** 0.0140	0.9806** 0.0194	0.9876** 0.0124	0.9174 0.0826	0.9529* 0.0471
13	V-17	0.9902 0.0098	0.9986** 0.0014	0.9814** 0.0186	0.9093 0.0907	0.9378 0.0622
14	V-18	0.9968* 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
15	Morocco	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
16	V-21 0.0140	0.9860** 0.0194	0.9806** 0.0124	0.9876** 0.0826	0.9174 0.0471	0.9529*
17	V-22	0.9968* 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
18	V-23	0.9388 0.0612	0.9271 0.0729	0.9768** 0.0232	0.8611 0.1389	0.9113 0.0887
19	V-25	0.9860** 0.0140	0.9806** 0.0194	0.9876** 0.0124	0.9174 0.0826	0.9529* 0.0471
20	V-26	0.9570* 0.0430	0.9666* 0.0334	0.8762 0.1238	0.9185 0.0815	0.9158 0.0842
21	V-27	0.9936 0.0064	0.9967* 0.0033	0.9477 0.0523	0.9406 0.0594	0.9550* 0.0450
22	V-28	0.9968* 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
23	Morocco	0.9570* 0.0430	0.9666* 0.0334	0.8762 0.1238	0.9185 0.0815	0.9158 0.0842
24	V-31	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
25	V-32	0.9968** 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
26	V-33	0.9936 0.0064	0.9967** 0.0033	0.9477 0.0523	0.9406 0.0594	0.9550* 0.0450
27	V-34	0.9725** 0.0275	0.9931 0.0069	0.9545* 0.0455	0.8821 0.1179	0.9038 0.0962
28	V-35	0.9968** 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
29	V-38	0.9943	0.9804**	0.9225	0.9786**	0.9857**

		0.0057	0.0196	0.0775	0.0214	0.0143
30	V-39	0.9968** 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611** 0.0389
31	Morocco	0.9446 0.0554	0.9223 0.0777	0.8129 0.1871	0.9782** 0.0218	0.9603** 0.0397
32	V-41	0.9968** 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611** 0.0389
33	V-42	0.9968** 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
34	V-43	0.9968** 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
35	V-45	0.9968** 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
36	V-46	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
37	V-47	0.9814** 0.0186	0.9970* 0.0030	0.9797** 0.0203	0.8877 0.1123	0.9175 0.0825
38	V-48	0.9725** 0.0275	0.9931 0.0069	0.9545* 0.0455	0.8821 0.1179	0.9038 0.0962
39	Morocco	0.9814** 0.0186	0.9970* 0.0030	0.9797** 0.0203	0.8877 0.1123	0.9175 0.0825
40	V-52	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
41	V-53	0.9968* 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
42	V-54	0.9936 0.0064	0.9967* 0.0033	0.9477 0.0523	0.9406 0.0594	0.9550* 0.0450
43	V-55	0.9705** 0.0295	0.9624* 0.0376	0.9874** 0.0126	0.8978 0.1022	0.9397 0.0603
44	V-56	0.9864** 0.0136	0.9915 0.0085	0.9298 0.0702	0.9377 0.0623	0.9469 0.0531
45	V-57	0.9968** 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
46	V-58	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
47	V-59	0.9968** 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
48	Morocco	0.9547* 0.0453	0.9350 0.0650	0.8317 0.1683	0.9788** 0.0212	0.9644* 0.0356

49	V-61	0.9765** 0.0235	0.9555* 0.0445	0.8741 0.1259	0.9889** 0.0111	0.9841** 0.0159
50	V-62	0.9936 0.0064	0.9967* 0.0033	0.9477 0.0523	0.9406 0.0594	0.9550* 0.0450
51	V-63	0.9936 0.0064	0.9967** 0.0033	0.9477 0.0523	0.9406 0.0594	0.9550* 0.0450
52	V-64	0.9864** 0.0136	0.9915** 0.0085	0.9298 0.0702	0.9377 0.0623	0.9469 0.0531
53	V-65	0.9705** 0.0295	0.9624* 0.0376	0.9874** 0.0126	0.8978 0.1022	0.9397 0.0603
54	V-66	0.9936 0.0064	0.9967** 0.0033	0.9477 0.0523	0.9406 0.0594	0.9550* 0.0450
55	V-69	0.9943 0.0057	0.9804 0.0196	0.9225 0.0775	0.9786 0.0214	0.9857 0.0143
56	Morocco	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
57	V-72	0.9936 0.0064	0.9967* 0.0033	0.9477 0.0523	0.9406* 0.0594	0.9550* 0.0450
58	V-74	0.9774** 0.0226	0.9657* 0.0343	0.8810 0.1190	0.9742** 0.0258	0.9700* 0.0300
59	V-75	0.9705** 0.0295	0.9624* 0.0376	0.9874** 0.0126	0.8978 0.1022	0.9397 0.0603
60	V-76	0.9938 0.0062	0.9768** 0.0232	0.9604* 0.0396	0.9599* 0.0401	0.9835** 0.0165
61	V-77	0.9968* 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611** 0.0389
62	V-78	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
63	V-79	0.9968** 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
64	Morocco	0.9824** 0.0176	0.9808** 0.0192	0.9052 0.0948	0.9544* 0.0456	0.9563* 0.0437
65	V-81	0.9943** 0.0057	0.9804* 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
66	V-82	0.9968** 0.0032	0.9950** 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
67	V-83	0.9834** 0.0166	0.9970** 0.0030	0.9542* 0.0458	0.9079 0.0921	0.9267 0.0733

68	V-86	0.9824** 0.0176	0.9808** 0.0192	0.9052 0.0948	0.9544* 0.0456	0.9563* 0.0437
69	V-87	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
70	V-88	0.9814** 0.0186	0.9970* 0.0030	0.9797** 0.0203	0.8877 0.1123	0.9175 0.0825
71	V-89	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
72	Morocco	0.9936 0.0064	0.9967** 0.0033	0.9477 0.0523	0.9406 0.0594	0.9550* 0.0450
73	V-91	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
74	V-95	0.9585* 0.0415	0.9330 0.0670	0.8369 0.1631	0.9891** 0.0109	0.9766** 0.0234
75	V-96	0.9774** 0.0226	0.9657** 0.0343	0.8810 0.1190	0.9742** 0.0258	0.9700* 0.0300
76	V-98	0.9705** 0.0295	0.9624* 0.0376	0.9874** 0.0126	0.8978 0.1022	0.9397 0.0603
77	Morocco	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
78	V-101	0.9968* 0.0032	0.9950* 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611** 0.0389
79	V-102	0.9774** 0.0226	0.9657* 0.0343	0.8810 0.1190	0.9742** 0.0258	0.9700* 0.0300
80	V-103	0.9936 0.0064	0.9967** 0.0033	0.9477 0.0523	0.9406 0.0594	0.9550* 0.0450
81	V-104	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
82	V-107	0.9943 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
83	V-108	0.9814** 0.0186	0.9970* 0.0030	0.9797** 0.0203	0.8877 0.9175 0.1123	0.0825
84	Morocco	0.9968** 0.0032	0.9950** 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
85	V-111	0.9968** 0.0032	0.9950** 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
86	V-112	0.9979** 0.0021	0.9822** 0.0178	0.9469 0.0531	0.9721** 0.0279	0.9883** 0.0117
87	V-113	0.9857**	0.9678*	0.9669*	0.9453	0.9749**

		0.0143	0.0322	0.0331	0.0547	0.0251
88	V-114	0.9936**	0.9967**	0.9477	0.9406	0.9550*
		0.0064	0.0033	0.0523	0.0594	0.0450
89	V-115	0.9547*	0.9350	0.8317	0.9788**	0.9644*
		0.0453	0.0650	0.1683	0.0212	0.0356
90	V-116	0.9689*	0.9897**	0.9863**	0.8582	0.8944
		0.0311	0.0103	0.0137	0.1418	0.1056
91	V-117	0.9968**	0.9950**	0.9780**	0.9344	0.9611*
		0.0032	0.0050	0.0220	0.0656	0.0389
92	V-118	0.9943**	0.9804**	0.9225	0.9786**	0.9857**
		0.0057	0.0196	0.0775	0.0214	0.0143
93	V-119	0.9936**	0.9967**	0.9477	0.9406	0.9550*
		0.0064	0.0033	0.0523	0.0594	0.0450
94	Morocco	0.9938**	0.9768**	0.9604**	0.9599**	0.9835**
		0.0062	0.0232	0.0396	0.0401	0.0165
95	V-121	0.9968**	0.9950**	0.9780**	0.9344	0.9611*
		0.0032	0.0050	0.0220	0.0656	0.0389
96	V-122	0.9943**	0.9804**	0.9225	0.9786**	0.9857**
		0.0057	0.0196	0.0775	0.0214	0.0143
97	V-123	0.9570*	0.9666*	0.8762	0.9185	0.9158
		0.0430	0.0334	0.1238	0.0815	0.0842
98	V-124	0.9943**	0.9804**	0.9225	0.9786**	0.9857**
		0.0057	0.0196	0.0775	0.0214	0.0143
99	V-125	0.9920**	0.9693*	0.9248	0.9853**	0.9959**
		0.0080	0.0307	0.0752	0.0147	0.0041
100	V-126	0.9585*	0.9330	0.8369	0.9891**	0.9766**
		0.0415	0.0670	0.1631	0.0109	0.0234
101	V-127	0.9705**	0.9624*	0.9874**	0.8978	0.9397
		0.0295	0.0376	0.0126	0.1022	0.0603
102	V-128	0.9943**	0.9804**	0.9225	0.9786**	0.9857**
		0.0057	0.0196	0.0775	0.0214	0.0143
103	V-129	0.9705**	0.9624*	0.9874**	0.8978	0.9397
		0.0295	0.0376	0.0126	0.1022	0.0603
104	Morocco	0.9943**	0.9804**	0.9225	0.9786**	0.9857**
		0.0057	0.0196	0.0775	0.0214	0.0143
105	V-131	0.9705**	0.9624*	0.9874**	0.8978	0.9397
		0.0295	0.0376	0.0126	0.1022	0.0603
106	V-132	0.9705**	0.9624**	0.9874**	0.8978	0.9397
		0.0295	0.0376	0.0126	0.1022	0.0603

107	V-133	0.9570* 0.0430	0.9666* 0.0334	0.8762 0.1238	0.9185 0.0815	0.9158 0.0842
108	V-134	0.9576* 0.0424	0.9172 0.0828	0.9021 0.0979	0.9699* 0.0301	0.9878** 0.0122
109	V-135	0.9968** 0.0032	0.9950** 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
110	V-136	0.9648* 0.0352	0.9897** 0.0103	0.9724** 0.0276	0.8549 0.1451	0.8861 0.1139
111	V-137	0.9943** 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
112	V-138	0.9968** 0.0032	0.9950** 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
113	Morocco	0.9968** 0.0032	0.9950** 0.0050	0.9780** 0.0220	0.9344 0.0656	0.9611* 0.0389
114	V-141	0.9943** 0.0057	0.9804** 0.0196	0.9225 0.0775	0.9786** 0.0214	0.9857** 0.0143
115	V-144	0.9705** 0.0295	0.9624* 0.0376	0.9874** 0.0126	0.8978 0.1022	0.9397 0.0603
116	V-145	0.8811 0.1189	0.8867 0.1133	0.9712** 0.0288	0.7553 0.2447	0.8218 0.1782
117	V-146	0.9570* 0.0430	0.9666** 0.0334	0.8762 0.1238	0.9185 0.0815	0.9158 0.0842
118	V-147	0.9585* 0.0415	0.9330 0.0670	0.8369 0.1631	0.9891** 0.0109	0.9766** 0.0234
119	V-148	0.9576* 0.0424	0.9172 0.0828	0.9021 0.0979	0.9699* 0.0301	0.9878** 0.0122
120	V-149	0.9968** 0.0032	0.9950* 0.0050	0.9780* 0.0220	0.9344 0.0656	0.9611* 0.0389
121	Morocco	0.9765** 0.0235	0.9555* 0.0445	0.8741 0.1259	0.9889** 0.0111	0.9841** 0.0159

*** Significant** **** Highly Significant**

Upper values in a column indicate Pearson‘s Correlation Coefficients
Lower values indicate significance level at P = 0.05.

Appendix: List of varieties/Lines included in the trial conducted at AARI during 2010-2012.

Sr.No	Symbols of Varieties	Varieties/Lines	Sr.No	Symbols of Varieties	Varieties/Lines
1	V-1	Chenab-2000	76	V-76	Parulla
2	V-2	Frontana	77	V-77	Pasban-90
3	V-3	Iqbal-2000	78	V-78	PBW-343
4	V-4	Lu-26	79	V-79	Seher-06
5	V-5	ERA	80	Morocco	Morocco
6	V-6	Nacozari-76	81	V-81	Ufaq-2000
7	V-7	Crow	82	V-82	Fareed-06
8	V-8	Fsd-83	83	V-83	W-462
9	V-9	Fsd-85	84	V-84	AOC-YRA
10	Morocco	Morocco	85	V-85	AOC+YRA
11	V-11	GA-2002	86	V-86	Yr-I
12	V-12	CHK-86	87	V-87	Yr-2
13	V-13	CHK-97	88	V-88	Yr-5
14	V-14	CHRIS	89	V-89	Yr-6
15	V-15	AS-2002	90	Morocco	Morocco
16	V-16	Blue Silver	91	V-91	Yr-7
17	V-17	BWP-97	92	V-92	Yr-8
18	V-18	BHK-02	93	V-93	Yr-9
19	V-19	GPWP 118	94	V-94	Yr-10
20	Morocco	Morocco	95	V-95	Yr-15
21	V-21	Kohisar-95	96	V-96	Yr-17
22	V-22	Local White	97	V-97	Yr-18
23	V-23	LYP-73	98	V-98	Yr-24
24	V-24	MH-97	99	V-99	Yr-26
25	V-25	C-271	100	Morocco	Morocco
26	V-26	C-273	101	V-101	Yr-27
27	V-27	HD-2169	102	V-102	Yr-28
28	V-28	HD-2179	103	V-103	Yr-29
29	V-29	Bou White	104	V-104	Yr-31
30	Morocco	Morocco	105	V-105	Punjab-11
31	V-31	C-518	106	V-106	Millat-11
32	V-32	C-591	107	V-107	AARI-11
33	V-33	Koh-i-Noor-83	108	V-108	PBW-343
34	V-34	Maxipak-65	109	V-109	Super Kauz
35	V-35	Manthar	110	Morocco	Morocco
36	V-36	Bwp-2000	111	V-111	YRCV
37	V-37	Inq-91	112	V-112	Lr-I
38	V-38	Koh	113	V-113	Lr-2a
39	V-39	SA-42	114	V-114	Lr-2b
40	Morocco	Morocco	115	V-115	Lr-2c
41	V-41	SA-75	116	V-116	Lr-3
42	V-42	V-85205	117	V-117	Lr-3KA
43	V-43	V-87094	118	V-118	Lr-3BG
44	V-44	V-02192	119	V-119	Lr-9
45	V-45	Pb-96	120	Morocco	Morocco
46	V-46	Pak-81	121	V-121	Lr-10
47	V-47	Parwaz-94	122	V-122	Lr-11
48	V-48	PND-I	123	V-123	Lr-12
49	V-49	Lasani-08	124	V-124	Lr-13

50	Morocco	Morocco	125	V-125	Lr-14a
51	V-51	HD-29	126	V-126	Lr-14b
52	V-52	Fsd-08	127	V-127	Lr-15
53	V-53	V-04179	128	V-128	Lr-16
54	V-54	Spica	129	V-129	Lr-17
55	V-55	Pb-76	130	Morocco	Morocco
56	V-56	Pb-81	131	V-131	Lr-18
57	V-57	Pb-85	132	V-132	Lr-19
58	V-58	Pavon-76	133	V-133	Lr-20
59	V-59	Shalimar-88	134	V-134	Lr-21
60	Morocco	Morocco	135	V-135	Lr-22a
61	V-61	Borlog-95	136	V-136	Lr-22b
62	V-62	WH-542	137	V-137	Lr-23
63	V-63	V-03079	138	V-138	Lr-24
64	V-64	Yecora	139	V-139	Lr-25
65	V-65	Uqab-2000	140	Morocco	Morocco
66	V-66	Sarsabaz	141	V-141	Lr-26
67	V-67	DR. 07028	142	V-142	Lr-27+31
68	V-68	DR. 07029	143	V-143	Lr-28
69	V-69	WL-711	144	V-144	Lr-29
70	Morocco	Morocco	145	V-145	Lr-30
71	V-71	Rawal-87	146	V-146	Lr-32
72	V-72	Rohtas-90	147	V-147	Lr-33
73	V-73	Shafaq-06	148	V-148	Lr-34
74	V-74	Pothohar-73	149	V-149	Lr-35
75	V-75	Nasir-2k	150	Morocco	Morocco