**Identification of Wheat Genotypes for Leaf Rust Resistance in Pakistan**

**Sabina Asghar, Aziz ur Rehman, M. Makky Javed, Sadia Ajmal, Aneela Ahsan, Saima Gulnaz, Nadeem Ahmad, M. Ijaz Tabassum, M. Zulkifal and Javed Ahmad**

**Wheat Research Institute, AARI, Faisalabad, Pakistan**

**Abstract**

Three forty one entries were tested for Leaf rust (***Puccinia triticina***) at four different locations viz. Faisalabad, Bahawalpur, Khanewal and Kot Naina representing different ecological zones of Punjab, Pakistan during 2016-17 and 2017-18 crop season. Out of three hundred and forty one entries, there were two hundred and fifty genotypes/lines and ninety one were genes/gene differentials. Each entry was planted in one meter long row and Morocco was repeated after an interval of ten rows as check/spreader. Data on leaf rust was recorded by following Modified Cobb Scale during 3rd week of March. At Faisalabad, the data was recorded three times on the following dates i.e. 2nd, 22nd March and 29th during 2018. The disease severity ranged from 0-100S during 2016-17 and from 0-80S during 2017-18. The genotype HYT 60-5 and the genes Lr-19, Lr-26 and Lr 27+31 showed no disease reactions at any location during both the study years. AUDPC ranged from 0-550 while that of Morocco which is a susceptible check has AUDPC value of 600. One hundred and twenty entries have disease progression 0 which shows there may be a major gene based resistance in these entries. AUDPC/DAY was calculated for the rest of one hundred and thirty entries to have a deep understanding of the disease progression, out of which forty three entries have AUDPC/Day value ranging from 1-2 and twenty eighty have AUDPC/Day value ranging from 2-3 which shows that these entries are very useful for use in breeding for durable rust resistance and can be utilized as a parent in back cross and top cross breeding schemes due to slow rusting behavior. The approved variety Ujala-16 and advanced lines V-14154, V-14124 and HYT 60-5 have shown good resistance. These advanced lines are candidate for approval as a commercial variety.

**Introduction**

Wheat is one of the most important cereal in the world. Since green revolution, there is many fold increase in wheat production especially in the developing world (Heisey *et al* 2002). Many factors are responsible for limiting wheat production like heat stress, drought stress, diseases and insect attack etc. Among the diseases, rusts have caused serious yield losses (Brennan and Murry 1988). .

Chemical control of the rust is being practiced in developed countries whereas in the developing world, it is not affordable for the farmers. Hence, they depend upon genetic resistance (Singh and Dubin 1997) and development of resistant cultivars is considered the most effective way to manage the disease (Chen et al 2013, Esmail *et al* 2015). Identification of genetic variability for rust resistance and its use to develop resistant cultivars through schematic breeding is pre requisite to develop rust resistant cultivars. During the post green revolution period, cultivars with different genes have continuously been released across the world and eliminated with the passage of time (Khan *et al* 2013, Negam 2013).

Leaf rust caused by *puccinia triticina* is a serious threat and results in major yield losses to wheat production in warm areas like Pakistan (Hassan 1979, Huesta-Espino *et al.* 2011). Wheat breeders mostly introduced wheat breeding material mostly depending upon varieties containing genes Lr 1, Lr 13 and Lr 26 in combination with the minor genes (Rehman *et al* 2013). These varieties help to boost up wheat production due to higher yield potential and adaptability to rusts especially leaf rust resistance. However due to development of new leaf rust races in a short time period, the breeders periodically deployed new rust resistance genes all over the world ( Akhtar-uz-Zaman *et al* 2017) the cultivars developed with monogenic or vertical résistance could not live long therefore now, the breeders are mainly depending on new sources of resistance to leaf rust based on minor genes which slows down the rust development and significantly reduce the losses due to rusts (Niks and Rubiales 2002). Breeders are looking for the genotypes with slow rusting mechanism for use in the breeding program. In previous years, many accessions with this type of resistance have been selected (Hussain *et al.* 2011, Hussain *et al.,* 2011, Singh et al. 2005) and were used for developing back crosses, top crosses for pyramiding minor genes present in wheat germplasm (Muhammad et al 2015) and many wheat varieties like Seher-06, Shafaq-06, Lasani-08, Faisalabad-08, AARI-11, Pb-11, Galaxy-13 etc have been released which contributed significantly in enhancing wheat production (Hussain *et al*. 2007, Hussain *et al* 2009, Rehman *et al*. 2013,). breeders are now preferring genotypes with slow rusting or horizontal resistance based on minor genes or combination of minor and major genes (Negam *et al* 2017, Wu *et al* 2020). Area Under Disease Progressive Curve (AUDPC) has been used by many scientists to understand disease development pattern and they preferred the genotypes having slow rusting pattern with lower AUDPC values for rust (Pawan et al 2015). The current studies were designed to screen wheat germplasm for identification of leaf rust resistance sources and to sort out slow rusting genotypes for use in the breeding program.

**Material and Methods:**

A set of germplasm comprising of three hundred and forty one entries (two hundred and fifty genotypes/advanced lines and ninety one genes/gene differentials) was sown in the third week of November during the years 2016-17 and 2017-18 at four different locations of Punjab viz. Wheat Research Institute, Faisalabad, Punjab Seed Corporation, Khanewal, Regional Agriculture Research Institute, Bahawalpur and Agriculture Adaptive Research Farm, Kot Naina district Narowal which were located in different agro-ecological zones of the punjab. Each entry was sown in a 2 meter long single row by maintaining 30cm row to row distance. A single line of susceptible cultivar, Morocco was repeatedly sown after every ten lines of experimental material. Two rows of spreader “Morocco” were sown on each side of the experimental material. The fertilizer NPK was applied as a basil dose at the rate of 120, 75 and 60 kg ha-1. Three irrigations were applied at different growth stages i.e. first at tillering stage, second at booting stage and third at grain formation stage. Weeds were controlled by manual hoeing at all four locations. At Faisalabad, the inoculation of material was done three times during first fortnight of Feburary at an interval of five days. The previous years collected inoculums mixture (mixture of pathotypes found from all over Punjab) stored at -80oC was used after proper heat shock and re-hydration process. One gram of inoculum was mixed in 250g of talcum powder and was dusted on experimental material. The leaf rust data was recorded three times on the following dates i.e. 02-03-2018, 15-03-2018 and 29-03-2018. The data was used to calculate Area Under Disease Progressive Curve (AUDPC) by following Pandey *et al*., 1989 and Singh *et al*., 2000.

n

AUDPC = Σ [{(*Yi + Y* (*i* +1)) / 2} x (*t* (*i* +1)- *ti*)]

*i* =1

Where Yi is disease severity at ti time, *t* (*i* +1)- *ti* is time interval between two consecutive data recording events, n is no. of data recordings

AUDPC = AUDPC/Day was calculated by dividing AUDPC with the number of days counted from the first to the last data recording date. At all other three locations, disease appearance was based on natural inoculation. The data was recorded once during fourth week of March. The data was recorded following Modified Cobb’s Scale and the entries were classified as resistant, moderately resistant, moderately susceptible, moderately resistant to moderately susceptible and susceptible described by Peterson *et al*.(1948) given in table 1.

**Table:1**

|  |  |  |
| --- | --- | --- |
| **Reaction** | **Symbol** | **Field Response** |
| No disease | 0 | No visible infection |
| Resistant | R | Necrotic area with or without minute uredia |
| Moderately resistant | MR | Small uredia present surrounded by necrotic area |
| Moderately susceptible | MS | Medium uredia with no necrosis but some distinct chlorosis. |
| Moderately resistant moderately susceptible | MRMS | Small uredia present surrounded by necrotic areas as well as medium uredia with no necrosis but some distinct chlorosis. |
| Susceptible | S | Large uredia and little or no chlorosis present. |

**Results**

Leaf rust is a serious issue in major wheat growing areas of Pakistan. Therefore, there is a continuous work on screening of advanced lines of wheat against leaf rust. Current and old varieties have been have been screened along with differential sets containing different genes to understand changes in virulence pattern. The current study was conducted on a set of three hundred and forty one genotypes (two hundred and fifty genotypes/advanced lines and ninety one were gene differentials). Table 1-5 shows reaction of this set of genotypes to leaf rust at four locations viz. Faisalabad, Bahawalpur, Khanewal and Kot Naina during the study years.

During the year 2016-2017, there was no disease on seventeen entries (Table-2). Out of these, two were the advanced lines i.e V-15235 and HYT 60-5 and remaining were gene differentials comprising of Lr-19, Lr-26, Lr 27+31, Yr-1, Yr-9, Yr-10, Yr-15, Yr-24, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 at Faisalabad. Similarly, there was no disease on thirty entries containing two advanced lines i.e V-15235 and HYT 60-, two approved varieties i.e TATARA and Ujala-16 and gene differentials Lr-9, Lr-18, Lr-19, Lr-22A, Lr-26, Lr-27+31, Lr-36, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1. Similarly at Khanewal, there was no disease on four advanced lines and approved varieties V-15235, HYT 60-5, TATARA and Ujala-16 and twenty eight gene differentials Lr-9, Lr-18,Lr 19, Lr-22A, Lr 26, Lr 27+31, Lr-28, Lr 36, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-26, Yr CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1. At Kot Naina, disease did not appear on fifty eight entries. Out of these, nineteen were advanced lines/varieties i.e. 14124, 14154, 15235, HYT 60-5, 60-57, WL-711, TATARA, PBW-343, SERI, SUPER KAUZ, Ujalla-16, Galaxy-13, Pb-11, AARI-11, Millat-11, Fsd-08, Lasani-08, Seher-06, Inq-91 and thirty nine were gene differentials i.e. Lr-9, Lr-12, Lr-13, Lr-15, Lr-16, Lr-17, Lr-18,Lr 19, Lr-21, Lr-22A, Lr-25, Lr 26, Lr 27+31, Lr 36, Lr23+GAZA, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-26, Lr-27, Lr-28, Yr-29, Yr-31, Yr CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, SRGP, SRAC-1, AOC+YRA.

Two advanced lines V-15235 and HYT 60-5 did not show any disease symptoms on all four locations of Punjab, Pakistan during the year 2016-17 (Table-3) and fifteen gene differentials Lr-19, Lr-26, Lr 27+31, Yr-1, Yr-9, Yr-10, Yr-15, Yr-24, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 whereas Lr-29 was moderately susceptible at all locations. Six gene differentials showed susceptibility i.e. Lr-10, Lr-11, Lr-14B, Lr-24, Lr-30 and Lr-34.

During the year 2017-2018, there was no disease appeared on two genotypes HYT 60-5 and Ujala-16 whereas twenty gene differentials i.e. Lr 19, Lr 26, Lr 27+31, Lr 36, Lr23+GAZA, Yr-1, Yr-5, Yr-7, Yr-10, Yr-24, Yr-26, Yr-29, Yr-31, Yr CV, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1 were free from leaf rust symptoms at Faisalabad (Table-4). At Bahawalpur, fifty eight entries did not show any disease reaction and out of these twelve were advanced lines/varieties i.e. 14124, 14154, 15235, 60-5, 60-57, TATARA, PBW-343, SERI, SUPER KAUZ, Ujalla-16, Pb-11, Millat-11 and rest were the gene differentials i.e. Lr-9, Lr-10, Lr-11, Lr-12, Lr-13, Lr-14A, Lr-14B, Lr-15, Lr-16, Lr-17, Lr-18, Lr 19, Lr-21, Lr-22B, Lr-23, Lr-24, Lr 26, Lr 27+31, Lr-28, Lr-29, Lr 36, Lr23+GAZA, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-26, Lr-27, Lr-28, Yr-29, Yr-31, Yr CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1. At Khanewal, sixty nine entries were disease free. Among these sixty nine entries, seventeen were advanced lines/varieties i.e. 14124, 14154, 15235, 60-5, 60-57, WL-711, TATARA, PBW-343, SERI, SUPER KAUZ, Ujalla-16, Galaxy-13, Pb-11, AARI-11, Millat-11, Lasani-08, Inq-91 and fifty two were gene differentials i.e. Lr-9, Lr-10, Lr-11, Lr-12, Lr-14A, Lr-14B, Lr-15, Lr-16, Lr-17, Lr-18,Lr 19, Lr-21, Lr-22A, Lr-22B, Lr-23, Lr-24, Lr 26, Lr 27+31, Lr-28, Lr-29, Lr-30, Lr-33, Lr-34, Lr-35, Lr 36, Lr-37, Lr B, Lr23+GAZA, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-26, Lr-27, Lr-28, Yr-29, Yr-31, Yr CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1. At Kot Naina, seventy five entries were completely free from leaf rust disease symptoms. Out of these, eighteen were advanced lines/varieties 14124, 14154, 15235, 60-5, 60-57, WL-711, TATARA, PBW-343, SERI, SUPER KAUZ, Ujalla-16, Galaxy-13, Pb-11, AARI-11, Millat-11, Fsd-08, Lasani-08, Seher-06, Inq-91 and remaining ere gene differentials Lr-9, Lr-10, Lr-11, Lr-12, Lr-13, Lr-14A, Lr-14B, Lr-15, Lr-16, Lr-17, Lr-18,Lr 19, Lr-20, Lr-21, Lr-22A, Lr-22B, Lr-23, Lr-24, Lr-25, Lr 26, Lr 27+31, Lr-28, Lr-29, Lr-30, Lr-32, Lr-33, Lr-34, Lr-35, Lr 36, Lr-37, Lr B, Lr23+GAZA, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-26, Lr-27, Lr-28, Yr-29, Yr-31, Yr CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1. A variety Punjab-11 at Faisalabad and gene Lr-20 at Bahawalpur showed moderately resistant behavior. The advanced lines/varieties V-14124, V-14154, V-HYT 60-57, PBW-343 and SUPER KAUZ showed moderately resistant to moderately susceptible reaction at Faisalabad.

During the year 2017-2018, twenty two entries were common in the entries containing one advanced line V-HYT 60-5 and one variety Ujala-16 and gene differentials i.e. Lr 19, Lr26, Lr 27+31, Lr 36, Lr23+GAZA, Yr-1, Yr-5, Yr-7, Yr-10, Yr-24, Yr-26, Yr-29, Yr-31, Yr CV, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1 (Table 5). One advanced line V-HYT 60-5 and one variety Ujala-16 and the gene differentials i.e. Lr 19, Lr 26, Lr 27+31, Lr 36, Lr 23+GAZA, Yr-1, Yr-5, Yr-7, Yr-10, Yr-24, Yr-26, Yr-29, Yr-31, Yr CV, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1 did not show any disease reaction at all four locations of Punjab, Pakistan.

From the two year data at four locations (Table 6), it was concluded that V-HYT 60-5 was the advanced line which did not show any disease symptoms at all the four locations of the Punjab, Pakistan, Therefore, this can be treated as the most promising leaf rust resistant genotype for use in the breeding program. Similarly, the gene differentials containing Lr-19, Lr-26 and Lr-27+31did not show any susceptibility at any target location during the two study years. Therefore, the material containing these three genes may be targeted for improving leaf rust resistance in bread wheat breeding material.

Area under disease progression curve (AUDPC) show disease development in relation to time period and AUDPC per day gives its clear picture. In the present study during the year 2017-18, Area Under Disease Progressive Curve (AUDPC) was calculated to find out disease progression pattern. AUDPC ranged from 0-550 while that of Morocco which is a susceptible check has AUDPC value of 600. The entries 60-5, 15082, 15099, 16005, 15113, 15291, 15166, 15216, 1038, 14058, 14061, 20-6, 20-19, 55-33, NS-76, 15-29, 1432, 1578, 1579, 1581, 15-1711, 15-1713, 15-1725, 15-755, 16CO38, 16CO39, NR 521, NR 523, NR 525, 15 BT 001, NW-2-17, Pb-76, Pavon-76, 16222, 16227, 16233, 16259, 16261, 16266, 16274, 16275, 16276, 16277, 16287, 16289, 16282, 16280, 16265, 16291, 16293, 16294, 16295, 16290, 16221, 16260, 16003, 16004, 16005, 16006, 16018,60 16023, 16024, 16025, 16036, 16049, 16051, 16077, 16079, 16087, 16090, 16124, 16125, 16128, 16129, 16131, 16132, 16134, 16144, 16145, 16146, 16147, 16152, 16153, 16157, 16159, 16160, 17153, 17154, 17155, 17157, 17158, 17159, 17161, 17162, 17163, 17165, 17169, 17170, 17171, 17175, 17176, 17177, 17180, 17182, 17183, 16106, 16108, 16111, 15012, 15009, 5011, 15018, 15035, 15006, 14003, 14011, 14035, BARDC-2-B-17, Ujalla-16 and Chakwal-50 have disease progression 0 which shows there may be a major gene based resistance in these entries. AUDPC/DAY was calculated for the rest of one hundred and thirty entries to have a deep understanding of the disease progression, out of which forty three entries i.e. 14124, 14154, 15070, 15212, 15309, 15327, 55-40, Iqbal-2000, 16230, 16264, 16281, 16284, 16286, 16002, 16007, 16012, 16027, 16050, 16057, 16081, 16119, 16120, 16133, 16141, 16148, 16149, 16150, 16154, 16163, 16164, 17156, 17160, 17164, 17166, 17167, 17168, 17172, 17178, 17179, 17188, 16097, 16098, 16114 have AUDPC/Day value ranging from 1-2 and twenty eighty entries i.e. 15235, 27-11, 60-57, 80-34, 15100, Uqab-2000, 16234, 16270, 16288, 16034, 16052, 16058, 16060, 16063, 16066, 16080, 16136, 16140, 16155, 16158, 16161, 17151, 17152, 17173, 17174, 17187, 16102, 16115 have AUDPC/Day value ranging from 2-3 which shows that these entries are extremely useful for use in breeding for durable rust resistance and can be utilized as a parent in back cross and top cross in breeding scheme.

**Discussion**

In Past, Wheat varieties with different types of rust resistance mechanism have been released all over the world. The varieties having monogenic and varietal resistance generally have short life whereas the varieties with multiple gene resistance and horizontal resistance have long life (Khan *et al* 2015, Niks and Rubales 2002, Singh *et al* 2005). Furthermore, use of monogenic resistance also sometimes create monocentric situation. Material possessing 1B-1R translocation was used all over the world and results in the evolution of new devastating like Yr9, Yr27 and Ug99 (Rehman *et al* 2013, Esmail *et al* 2015, Huerta-Espino *et al* 2011). Current studies revealed that most of the gene studied showed virulence however virulence for Lr 19, Lr 26 and Lr 27+31 was not present in the Punjab, Pakistan. Therefore, the varieties having adult plant resistance based on minor genes were preferred by wheat breeders (Rehman *et al* 2013, Rehman and Ajmal 2011). Among the advanced lines/varieties tested, only one entry HYT 60-5 has not shown any disease symptoms which might be due to the presence of major gene and combination of major/minor gene. Advanced lines V-14124, V-14154, V-15235 and HYT 60-57 have shown no disease development at Bahawalpur, Khanewal and Kot Naina where disease inoculation was not applied. However, The lines V-14124, V-14154 and HYT 60-57 showed moderately resistant reaction whereas V-15235 showed moderately susceptible reaction during 2017-18. In 2016-17, the line V-15235 has not shown any disease symptoms at Faisalabad, Bahawalpur, Kala Shah Kaku and Kot Naina whereas the lines V-14124 and V-14154 showed moderately resistant reaction which shows that these lines have horizontal resistance based on minor genes Presence of minor genes based resistance have been reported in international and Pakistani germplasm by Muhammad *et al* (2015) and Muhammad *et al* (2018). During 2017-18, there was no disease on HYT 60-5. Among approved wheat varieties, Ujala-16 has not shown any disease during 2017-18 whereas at Bahawalpur, Khanewal and Kot Naina it showed MRMS reaction. Variable disease reactions of different wheat genotypes have already been reported in literature and this variation may be due different genetic background of breeding material (Hussain *et al* 2006, 2007, Negam *et al* 2013)

As far as reaction of gene differentials is concerned, leaf rust resistant genes Lr-19, Lr-26, Lr 27+31 have not shown any virulence. Therefore, these genes can be used as a source of leaf rust resistance in wheat breeding program preferably in combination with other major and minor genes. Wheat scientists believe that high and sustainable level of resistance can be achieved by combining major and minor genes (Wu et al 2020)

At Faisalabad during the year 2017-2018, the disease data was recorded three times on the following dates i.e. 02-03-2018, 15-03-2018 and 29-03-2018. The area under disease progressive curve was calculated by using software developed by CIMMYT following the formula developed by developed by Singh *et al*., 2000. AUDPC values ranged from 0 to 690. Maximum AUDPC was recorded in case of susceptible universal check, Morocco. Area under disease progressive curve per day was calculated by dividing AUDPC with the number of days. The range for AUDPC per day ranged from 0-25.56 with the average value of 4.72. There are one hundred and twenty two genotypes which have shown AUDPC/Day value of 0. Ninety two genotypes fall in the AUDPC/Day values range from 1-5. Fourteen genotypes have shown AUDPC/Day value ranging from 6-10. Seven genotypes have AUDPC/Day value in the range of 11-15. There are six genotypes showing AUDPC/Day value ranging from 16-20 and thirty six genotypes having AUDPC/Day value above 20 (Table 7). It was concluded from that the genotypes having AUDPC/Day value less than 10 can be utilized as valuable source in the breeding program and such material with lower AUPDC values can be released for commercial cultivation as use of such material is environment friendly, enhances farmers profitability (Heisy *et al* 2002, Rehman *et al* 2013).

**Conclusion:**

The material screened at different locations all over the Punjab showed that different breeding lines and gene differentials behaved differently with change in environmental conditions due to genotype environment interaction. As the inoculum used was a mixture of races collected from different locations of Punjab during the previous three years. Leaf rust genes Lr-19, Lr-26 and Lr-31 showed resistance against the prevalent inoculum in different agro-ecoloical zones of the Punjab. Hence, these genes can be explode in breeding programs for leaf rust resistance. Among the tested advanced lines, V-14154, V-14124 and HYT 60-5 were very useful advanced lines for release as a commercial variety or use as a parent for leaf rust resistance as they showed resistance against leaf rust all over Punjab. Among the current commercial varieties of the Punjab, Ujala-16 has shown the best resistance for leaf rust

**Table: 2 Leaf rust resistant genotypes during 2016-17 at different locations:**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **REACTION** | **Faisalabad** | | | **Bahawalpur** | | | **Khanewal** | | | **Kot Naina** | | |
| **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** |
| **No disease** | 17 | 15235, 60-5 | Lr-19, Lr -26,  Lr-27+31, Yr-1, Yr-9, Yr-10, Yr-15, Yr-24, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 30 | 15235, 60-5, TATARA, Ujalla-16 | Lr -9, Lr -18, Lr-19, Lr-22A, Lr-26, Lr-27+31, Lr-36, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 32 | 15235, 60-5, TATARA, Ujalla-16 | Lr-9, Lr -18, Lr-19, Lr-22A, Lr-26, Lr-27+31, Lr-28, Lr- 36, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-26, Yr-CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 58 | 14124, 14154, 15235, 60-5, 60-57, WL-711, TATARA, PBW-343, SERI, SUPER KAUZ, Ujalla-16, Galaxy-13, Pb-11, AARI-11, Millat-11, Fsd-08, Lasani-08, Seher-06, Inq-91 | Lr-9, Lr-12, Lr-13, Lr-15, Lr-16, Lr-17, Lr-18, Lr-19, Lr-21, Lr-22A, Lr-25, Lr-26, Lr- 27+31, Lr-36, Lr-23+GAZA, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-26, Lr-27, Lr-28, Yr-29, Yr-31, Yr-CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, SRGP, SRAC-1, AOC+YRA |
| **Resistant** | 6 | - | Lr-18, Lr-22A, Lr-36, Yr-CV, Yr-7, Yr-26 | - | - | - | - | - | - | 2 | - | Lr-22B, Lr-B |
| **Moderately resistant** | 1 | - | Lr-23+GAZA | 3 | - | Lr-23+GAZA, Yr-26, YR-28 | 1 | - | Lr-23+GAZA | - | - | - |
| **Moderately resistant-moderately susceptible** | 15 | 14124, 14154, PBW-343, Ujalla-16, Pb-11, Millat-11, Fsd-08 | Lr-16, Lr-22B, Lr-23, Lr-25, Lr-28, Yr-5, YR-18, Yr-28 | 10 | 14124, 14154, PBW-343, Pb-11, Millat-11, Fsd-08 | Lr-16, Lr-22B, Lr-23, Lr-28 | 9 | 14154, PBW-343, Pb-11, Millat-11, Fsd-08 | Lr-16, Lr-22B, Lr-23, Yr-28 | 1 | - | Lr-35 |
| **Moderately susceptible** | 4 | 60-57, Inq-91 | Lr-29, Lr-33 | 3 | 60-57 | Lr-29, Lr-33 | 3 | 14124 | Lr-29, Lr-33 | 1 | - | Lr-29 |
| **Susceptible** | 32 | WL-711, TATARA, SERI, SUPER KAUZ, Galaxy-13, AARI-11, Lasani-08, Seher-06 | Lr-9, Lr-10, Lr-11, Lr-12, Lr-13, Lr-14A, Lr-14B, Lr-15, Lr-17, Lr-20, Lr-21, Lr-24, Lr-30, Lr-32, Lr-34, Lr-35, Lr-37, Lr-B, Yr-2, Yr-6, Yr-17, Yr-27, Yr-29, Yr-31 | 29 | WL-711, SERI, SUPER KAUZ, Galaxy-13, AARI-11, Lasani-08, Seher-06, Inq-91 | Lr-10, Lr-11, Lr-12, Lr-13, Lr-14A, Lr-14B, Lr-15, Lr-17, Lr-20, Lr-21, Lr-24, Lr-25, Lr-30, Lr-32, Lr-34, Lr-35, Lr-37, Lr-B, Yr-27, Yr-29, Yr-31 | 29 | WL-711, SERI, SUPER KAUZ, Galaxy-13, AARI-11, Lasani-08, Seher-06, Inq-91 | Lr-10, Lr-11, Lr-12, Lr-13, Lr-14A, Lr-14B, Lr-15, Lr-17, Lr-20, Lr-21, Lr-24, Lr-25, Lr-30, Lr-32, Lr-34, Lr-35, Lr-37, Lr-B, Yr-27, Yr-29, Yr-31 | 7 | - | Lr-10, Lr-11, Lr-14B, Lr-24, Lr-30, Lr-34, Yr-6 |

**Table: 3 Genotypes resistant to leaf rust at all locations during 2016-17**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **REACTION** | **Faisalabad** | | | **Bahawalpur** | | | **Khanewal** | | | **Kot Naina** | | |
| **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differential** | **No of genotypes** | **lines/ varieties** | **Gene differentials** |
| **No disease** | 17 | 15235, 60-5 | Lr-19, Lr-26,  Lr-27+31, Yr-1, Yr-9, Yr-10, Yr-15, Yr-24, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 17 | 15235, 60-5 | Lr-19, Lr-26,  Lr-27+31, Yr-1, Yr-9, Yr-10, Yr-15, Yr-24, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 17 | 15235, 60-5 | Lr-19, Lr-26,  Lr-27+31, Yr-1, Yr-9, Yr-10, Yr-15, Yr-24, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 17 | 15235, 60-5 | Lr-19, Lr-26,  Lr-27+31, Yr-1, Yr-9, Yr-10, Yr-15, Yr-24, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 |
| **Resistant** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Moderately resistant** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Moderately resistant-moderately susceptible** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Moderately susceptible** | 1 | - | Lr-29 | 1 | - | Lr-29 | 1 | - | Lr-29 | 1 | - | Lr-29 |
| **Susceptible** | 6 | - | Lr-10, Lr-11, Lr-14B, Lr-24, Lr-30, Lr-34 | 6 | - | Lr-10, Lr-11, Lr-14B, Lr-24, Lr-30, Lr-34 | 6 | - | Lr-10, Lr-11, Lr-14B, Lr-24, Lr-30, Lr-34 | 6 | - | Lr-10, Lr-11, Lr-14B, Lr-24, Lr-30, Lr-34 |

**Table: 4 Leaf rust resistant genotypes during 2017-18 at different locations:**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **REACTION** | **Faisalabad** | | | **Bahawalpur** | | | **Khanewal** | | | **Kot Naina** | | |
| **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** |
| **No disease** | 22 | 60-5, Ujalla-16 | Lr-19, Lr-26, Lr-27+31, Lr- 36, Lr-23+GAZA, Yr-1, Yr-5, Yr-7, Yr-10, Yr-24, Yr-26, Yr-29, Yr-31, Yr-CV, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1, | 58 | 14124, 14154, 15235, 60-5, 60-57, TATARA, PBW-343, SERI, SUPER KAUZ, Ujalla-16, Pb-11, Millat-11 | Lr-9, Lr-10, Lr-11, Lr-12, Lr-13, Lr-14A, Lr-14B, Lr-15, Lr-16, Lr-17, Lr-18, Lr-19, Lr-21, Lr-22B, Lr-23, Lr-24, Lr-26, Lr- 27+31, Lr-28, Lr-29, Lr-36, Lr-23+GAZA, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-26, Lr-27, Lr-28, Yr-29, Yr-31, Yr-CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 69 | 14124, 14154, 15235, 60-5, 60-57, WL-711, TATARA, PBW-343, SERI, SUPER KAUZ, Ujalla-16, Galaxy-13, Pb-11, AARI-11, Millat-11, Lasani-08, Inq-91 | Lr-9, Lr-10, Lr-11, Lr-12, Lr-14A, Lr-14B, Lr-15, Lr-16, Lr-17, Lr-18, Lr-19, Lr-21, Lr-22A, Lr-22B, Lr-23, Lr-24, Lr-26, Lr-27+31, Lr-28, Lr-29, Lr-30, Lr-33, Lr-34, Lr-35, Lr-36, Lr-37, Lr-B, Lr-23+GAZA, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-26, Lr-27, Lr-28, Yr-29, Yr-31, Yr CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 75 | 14124, 14154, 15235, 60-5, 60-57, WL-711, TATARA, PBW-343, SERI, SUPER KAUZ, Ujalla-16, Galaxy-13, Pb-11, AARI-11, Millat-11, Fsd-08, Lasani-08, Seher-06, Inq-91 | Lr-9, Lr-10, Lr-11, Lr-12, Lr-13, Lr-14A, Lr-14B, Lr-15, Lr-16, Lr-17, Lr-18, Lr-19, Lr-20, Lr-21, Lr-22A, Lr-22B, Lr-23, Lr-24, Lr-25, Lr-26, Lr-27+31, Lr-28, Lr-29, Lr-30, Lr-32, Lr-33, Lr-34, Lr-35, Lr-36, Lr-37, Lr- B, Lr-23+GAZA, Yr-1, Yr-2, Yr-5, Yr-6, Yr-7, Yr-9, Yr-10, Yr-15, Yr-17, Yr-18, Yr-24, Yr-26, Lr-27, Lr-28, Yr-29, Yr-31, Yr CV, Sr-5, Sr-6, Sr-7A, AOC-YRA, AOC+YRA, SRGP, SRAC-1, |
| **Resistant** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Moderately resistant** | 1 | Pb-11 | - | 1 | - | Lr-20 | - | - | - | - | - | - |
| **Moderately resistant-moderately susceptibl** | 5 | 14124, 14154, 60-57, PBW-343, SUPER KAUZ | - | - | - | - | - | - | - | - | - | - |
| **Moderately susceptible** | 19 | 15235, SERI, AARI-11, MILLAT-11, FSD-08, LASANI-08 | Lr-10, Lr-11, Yr-18, Yr-27, Yr-28, SR-7A, Lr-24, Lr-29, Lr-30, Yr-18, Yr-27, Yr-28, SR-7A | 10 | AARI-11, FSD-08, LASANI-08 | Lr-25, Lr-30, Lr-33, Lr-34, Lr-35, Lr-37, Lr-B | 6 | FSD-08, SEHER-06 | Lr-13, Lr-22A, Lr-25, Lr-32 | - | - | - |
| **Susceptible** | 31 | TATARA, Galaxy-13, Seher-06, Inq-91 | Lr-9, Lr-12, Lr-13, Lr-14A, Lr-14B, Lr-15, Lr-16, Lr-17, Lr-18, Lr-20, Lr-21, Lr-22A, Lr-22B, Lr-23, Lr-25, Lr-28, Lr-32, Lr-33, Lr-34, Lr-35, Lr-37, Lr-B, Yr-2, Yr-6, Yr-9, Yr-15, Yr-17 | 5 | WL-711, Galaxy-13, Seher-06, Inq-91 | Lr-32 | 1 | - | Lr-20 | - | - | - |

**Table: 5 Genotypes resistant to leaf rust at all locations during 2017-18**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **REACTION** | **Faisalabad** | | | **Bahawalpur** | | | **Khanewal** | | | **Kot Naina** | | |
| **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** |
| **No disease** | 22 | 60-5, Ujalla-16 | Lr-19, Lr-26, Lr-27+31, Lr- 36, Lr-23+GAZA, Yr-1, Yr-5, Yr-7, Yr-10, Yr-24, Yr-26, Yr-29, Yr-31, Yr-CV, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1, | 22 | 60-5, Ujalla-16 | Lr-19, Lr-26, Lr-27+31, Lr- 36, Lr-23+GAZA, Yr-1, Yr-5, Yr-7, Yr-10, Yr-24, Yr-26, Yr-29, Yr-31, Yr- CV, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 22 | 60-5, Ujalla-16 | Lr-19, Lr-26, Lr-27+31, Lr- 36, Lr-23+GAZA, Yr-1, Yr-5, Yr-7, Yr-10, Yr-24, Yr-26, Yr-29, Yr-31, Yr- CV, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 22 | 60-5, Ujalla-16 | Lr-19, Lr-26, Lr- 27+31, Lr-36, Lr-23+GAZA, Yr-1, Yr-5, Yr-7, Yr-10, Yr-24, Yr-26, Yr-29, Yr-31, Yr-CV, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1 |
| **Resistant** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Moderately resistant** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Moderately resistant-moderately susceptible** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Moderately susceptible** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Susceptible** | - | - | - | - | - | - | - | - | - | - | - | - |

**Table: 6 Leaf rust resistant genotypes at all locations during both years 2016-17 and 2017-18**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **REACTION** | **Faisalabad** | | | **Bahawalpur** | | | **Khanewal** | | | **Kot Naina** | | |
| **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** | **No of genotypes** | **lines/ varieties** | **Gene differentials** |
| **No disease** | 13 | 60-5 | Lr--19, Lr-26,  Lr-27+31, Yr-1, Yr-10, Yr-24, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 13 | 60-5 | Lr--19, Lr-26,  Lr-27+31, Yr-1, Yr-10, Yr-24, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 17 | 60-5 | Lr-19, Lr-26,  Lr-27+31, Yr-1, Yr-10, Yr-24, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1 | 17 | 60-5 | Lr-19, Lr-26,  Lr-27+31, Yr-1, Yr-10, Yr-24, Sr-5, Sr-6, AOC-YRA, AOC+YRA, SRGP, SRAC-1 |
| **Resistant** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Moderately resistant** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Moderately resistant-moderately susceptible** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Moderately susceptible** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Susceptible** | - | - | - | - | - | - | - | - | - | - | - | - |

**Table: 7 Classification of advanced lines on the basis of Area Under Disease Progressive Curve**

|  |  |  |
| --- | --- | --- |
| **AUDPC/Day Value** | **No. of genotypes** | **Genotypes** |
| 0 | 120 | 60-5, 15082, 15099, 16005, 15113, 15291, 15166, 15216, 1038, 14058, 14061, 20-6, 20-19, 55-33, NS-76, 15-29, 1432, 1578, 1579, 1581, 15-1711, 15-1713, 15-1725, 15-1755, 16-CO38, 16-CO39, NR-521, NR-523, NR-525, 15 BT 001, NW-2-17, Morocco, Ujala-16, Chak-50, Pb-76, Pavon-76, 16222, 16227, 16233, 16259, 16261, 16266, 16274, 16275, 16276, 16277, 16287, 16289, 16282, 16280, 16265, 16290, 16291, 16293, 16294, 16295, 16221, 16260, 16003, 16004, 16005, 16006, 16018, 16023, 16024, 16025, 16036, 16049, 16051, 16077, 16079, 16087, 16090, 16124, 16125, 16128, 16129, 16131, 16132, 16134, 16144, 16145, 16146, 16147, 16152, 16153, 16157, 16150, 16160, 17153, 17154, 17155, 17157, 17158, 17159, 17161, 17162, 17163, 17165, 17169, 17170, 17171, 17175, 17176, 17177, 17180, 17182, 17183, 16106, 16108, 16111, 15012, 15009, 5011, 15018, 15035, 15006, 14003, 14011, 14035. |
| 1-2 | 43 | 14124, 14154, 15070, 15212, 15309, 15327, 55-40, Iqbal-2000, 16230, 16264, 16281, 16284, 16286, 16002, 16007, 16012, 16027, 16050, 16057, 16081, 16119, 16120, 16133, 16141, 16148, 16149, 16150, 16154, 16163, 16164, 17156, 17160, 17164, 17166, 17167, 17168, 17172, 17178, 17179, 17188, 16097, 16098, 16114 |
| 2-3 | 28 | 15235, 27-11, 60-57, 80-34, 15100, Uqab-2000, 16234, 16270, 16288, 16034, 16052, 16058, 16060, 16063, 16066, 16080, 16136, 16140, 16155, 16158, 16161, 17151, 17152, 17173, 17174, 17187, 16102, 16115 |
| 1-5 | 27 | 15153, 15168, 15174, 9408, 16-1154, 13FJ 20, 13FJ 29, NR 520, NR 529, SUPER KAUZ, Annaj-17, AAS-11, Fsd-08, Lasani-08, Pasban-90, Blue Silver, 16262, 16033, 16061, 16065, 16084, 17185, 17189, 17196, 16094, 16104, 16117. |
| 6-10 | 14 | 12304, 14116, 14BT 016, PBW 343, SERI, Pb-11, AARI-11, Millat-11, SA-75, 16297, 16055, 17184, 16093, 16100. |
| 11-15 | 07 | JOUHAR-16, Shafaq-06, Parwaz-94, SH-88, Pak-81, Lyp-73, 16009. |
| 16-20 | 06 | Morocco, Seher-06, MH-97, Inq-91, 16278, 16056. |
| Above 20 | 02 | Morocco, Galaxy-13. |

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