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Research Article

# Phenotyping of Tomato RILs for Resistance to *Alternaria Solani* under Poly House and Field Conditions

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## Abstract

A trial was conducted during Rabi season 2012-2013 both under poly house and field conditions for phenotyping of RILs (Recombinant Inbreed Lines) that have been developed for resistance against early blight of tomato caused by *Alternaria solani*. Field and green house studies showed significant variation among all tested RILs with respect to early blight assessment parameters. In poly house 177 tomato RILs along with parent lines (Punjab Chhuhara and H-88-78-1) were inoculated with spore suspension containing $10^4$ spores/ml obtained from 30 days old culture of *Alternaria solani* grown on sorghum grains. Field condition the natural disease severity was scored on a ten-point scale (0-9). The mean AUDPC value of tomato RILs under both trials (poly house and field) ranged from 46.67 to 1232.78. Mean AUDPC value in susceptible parent (Punjab Chhuhara) and resistant parent (H-88-78-1) were recorded 1174.44 and 89.44, respectively. The Percent Disease Index (PDI) and Area Under Disease Progress Curve (AUDPC) value were calculated on the basis of data recorded. The frequency distribution curve for Area Under Disease Progress Curve value showed presence of major Quantitative Trait Loci.

**Keywords:** *Alternaria solani*, Phenotyping, Resistance, RILs, AUDPC, PDI

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## Introduction

Vegetable crops have an important place in the agricultural economy of India. Tomato (*Lycopersicon esculentum* Mill, n = 12) belongs to the family solanaceae and is one of the most remunerable and widely grown vegetables in the world. Tomato cultivation has become more popular since mid-nineteenth century because of its varied climatic adaptability and high nutritive value. Tomato is being exported in the form of whole fruits, paste and in canned form to West Asian countries, U.K., Canada and USA. Tomato ranks third in priority after potato and onion in India but ranks second after potato in the world. India ranks second in the area (865000 thousand ha) as well as in production (16826000 thousand tons) and has productivity of 19.5 tons/ha. The major tomato growing countries are China, USA, Italy, Turkey, India and Egypt. Total area under tomato is 4582438 thousand ha with production of 150513813 thousand tons and with productivity of 32.8 tons/ha in world [1].

Among the vegetables tomato ranks next to potato in world acreage and ranks first among the processing crops. There are several diseases on tomato caused by fungi, bacteria, viruses, nematodes and abiotic factors [2]. Among the fungal diseases, early blight also known as target spot disease incited by *Alternaria solani* (Ellis and Martin) Jones and Grout is one of the world's most catastrophic disease. It is very difficult to manage, due to its broad host range, extreme variability in pathogenic isolates and prolonged active phase of the disease cycle. A coefficient of disease index (CODEX) of 71.66 % and 78.51 % loss in fruit yield has been reported under severe epidemic [3]. The disease appears on leaves, stems, petiole, twig and fruits under favorable conditions resulting in defoliation, drying off of twigs and premature fruit drop and thus causing loss from 50 to 86 percent in fruit yield [4].

The control measures include 3 to 5 years crop rotation, routine applications of fungicides, and the use of disease free transplants [5, 6]. The development of resistant variety is an important component of integrated disease management (IDM) strategies. Resistant cultivars are potentially the most economical control measure as they can extend the fungicide spray intervals while maintaining control of the disease [5, 7, 8]. Classical quantitative genetic analyses have provided estimates of the number of quantitative trait loci (QTLs) for Early Blight resistance, average gene action and heritability which provided the prospects for progress in breeding programs based on phenotypic selection [9-11].

Most genetic studies on the inheritance of EB resistance using different sources of resistance (*S. lycopersicum*, *S. habrochaites* and *S. pimpinellifolium*) arrived at the same conclusions that the resistance is a quantitative trait that is controlled polygenically. The estimated minimum number of controlling factors is two [12] or three [9]. Analysis using quantitative genetic methods (generation mean analysis and scaling tests) and several sources of resistance (C1943, NCEBR-2, IHR 1939 and IHR 1816) revealed additive and dominant genetic control with the presence of epistatic effects [9, 10, 13]. The EB resistance genes in C1943 and 71B2 are recessive and not allelic [10, 12]. However, in crosses of these two resistance sources with another susceptible genotype, the F1 hybrids were intermediate, indicating additive genetic control or partial dominance [10]. Recessive genes have been reported in *S. lycopersicum* 83602029 [14], in IHR1939 and IHR1816 by [13]. Partially dominant inheritance has been found in *S. pimpinellifolium* and *S. habrochaites* [15]. The line 87B187, derived from *S. habrochaites* PI 390662, shared common resistance genes with NCEBR-2, although this line was developed via C1943 from a *S. lycopersicum* source [10].

Given the low to moderate heritability estimates, a marker-aided selection approach is potentially useful to accelerate the transfer of EB resistance genes into new tomato cultivars [16] was the first to map QTLs for EB resistance. They used backcross progenies of a cross between *S. habrochaites* PI 126445 and a susceptible tomato line. Mapping was done in the BC1 and validated in the BC1S generation. Fourteen QTLs were identified which together explained 57% of the total phenotypic variation. For all QTLs the positive allele originated from the resistant parent. In a subsequent study [17] used a selective genotyping approach on a different part of the same BC1 population. Seven QTLs were detected, including one previously mapped major and three minor QTLs. One of the QTLs in this study inherited the resistance allele from the susceptible parent. [18] Identified six QTLs for EB resistance in F2 and F3 populations from a cross between the resistant *S. arcanum* LA2157 and a susceptible tomato. Different environments and phenotypic scoring methods were used in this study, in contrast to the previous mapping studies which used one type of environment and disease measure. In addition, resistance to stem lesions was also assessed in the F3 population. Interestingly, EB QTLs detected in the F2 population were not always detected in the F3 population, and vice versa. This indicates the presence of environment specific or plant age-specific QTLs. Three QTL regions for stem lesion resistance coincided with EB resistance QTLs, which allows simultaneous selection for resistance to both types of disease symptoms. The explained phenotypic variation per EB resistance QTL, 7 to 16%, was in the same range [16]. One QTL for stem lesion resistance, however, had a large effect, explaining 31% of the total variation. For two of the six QTLs, the susceptible parent contributed the resistance alleles. Several of the QTLs found in the cross of *S. habrochaites* PI 126445 [16, 17] overlapped with those found in the *S. arcanum* LA1257. Although many EB resistance QTLs have been identified, many of them have relatively small effects. Not all QTLs need to be incorporated in order to achieve a significant increase in resistance. [16] and [17] recommended combination of four to six QTLs, which explained more than 40% of total phenotypic variation for use in marker-assisted breeding [18] suggested two QTL, which had prominent effects under different environments and gave both EB and stem lesion resistance.

Most of the available resistance sources are not in practical use owing to several unacceptable qualitative and quantitative attributes. It is also not easy to transfer resistant characteristics to a cultivated variety. However, a few commercial cultivars with a moderate but useful degree of resistance have been released like Manapal [19], Meltine and Nemato [20].

Therefore, the present investigation was undertaken with the objective of phenotyping already available RILs (Recombinant Inbred Lines) that have been developed for resistance against early blight of tomato caused by *Alternaria solani*.

## Materials and Methods

The seeds of tomato Recombinant Inbred Lines in $F_7$ generation were collected from IIVR, Varanasi. RILs have been developed from the cross between a susceptible parent (Punjab Chhuhara) and resistant parent (H-88-78-1) by single seed descent method. Punjab Chhuhara has determinate growth habit, flowering time is 32 DAP, fruit long and medium in size. H-88-78-1 has indeterminate growth habit, flowering time is 45 DAP, fruit round and small sized.

### *Details of Poly house experiment*

The details of layout plan are given as follows: Total 177 tomato RILs were taken with parent lines. Repetition of treatments was used five times.

***Raising of nursery***

Seed of 177 tomato RILs were taken with parent lines for growing in nursery field. The mixture of soil, sand and FYM were taken in nursery field and seeds of tomato RILs were sown. After sowing the beds were covered with a thin film of water thereafter light and frequent irrigation were given at a regular interval in order to maintain sufficient moisture in nursery plots for good growth of seedlings. The tomato seedlings were ready for transplanting after 57 days of seeding. The tomato seedlings were transplanted after 57 days of seeding. Seedling were uprooted carefully from the beds and transplanted in the pots.

***Plant Inoculation***

The 30 days old culture (mycelia mat and spores) were grown in sorghum grains medium was harvested. Then the plants were inoculated with $10^4$ spore concentration by the help of automizer.

After inoculation the temperature (25-$30^0$ C) and humidity (80 – 100 %) were maintained in poly house with the help of irrigation and cooler. Plants were examined for appearance of symptoms. The symptoms appeared 3-7 days after inoculation.

***Disease assesment***

The inoculated plants were regularly examined for appearance of symptoms starting from 24 hours after inoculation. The data on PDI were recorded on six different dates at 10 days intervals i.e. $7^{th}$, $14^{th}$, $21^{th}$, $28^{th}$, and $35^{th}$ days after inoculation (DAI). Disease severity was scored on a ten-point scale (0-9) and phenotyping of RILs has been done according [21].

***Details of field experiment***

The 177 tomato RILs with parents were shown in field and evaluated for disease resistance to early blight on the stage of fruit maturity with natural inoculums. And three observations were taken at 10 days intervals.

***Disease assessment***

The plants were regularly examined for appearance of symptoms starting. The data on PDI were recorded on three different dates at 10 days intervals after $I^{st}$ symptoms appearance. Disease severity was scored on a ten-point scale (0-9) and phenotyping of RILs has been done according to [21] (**Table 1**).

**Table 1** Description of disease scale (0-9)

| Sr. No. | 0-9 Scale | Per cent leaf area infected |
|---|---|---|
| **1** | 0 | No infection |
| **2** | 1 | 0-10 |
| **3** | 2 | 10-20 |
| **4** | 3 | 20-30 |
| **5** | 4 | 30-40 |
| **6** | 5 | 40-50 |
| **7** | 6 | 50-60 |
| **8** | 7 | 60-70 |
| **9** | 8 | 70-80 |
| **10** | 9 | 80-100 |

$$PDI = \frac{\text{Sum of all ratings x 100}}{\text{Total no. of observations x Maximum rating scale}}$$

Percent Disease Index (PDI) was worked out by using formula given by [22]. The host plant reaction was classified based on area under disease progress curve. Area under disease progress curve (AUDPC) will be calculated as per [23, 24].

$$AUDPC = \sum_{i=1}^{n-1} \{[(X_{i+1} + X_i)/2] * (t_{i+1} - t_i)\}$$

Where, $X_i$ is the disease index expressed as a proportion at the $i^{th}$ observation; $t_i$ is the time (days after planting) at the $i^{th}$ observations; And n is the total number of observations.

### *Statistical analysis*

The experiment was laid out in Completely Randomize Block Design (CRBD) with five replication in poly house and field trial. The values of data obtained from the field and poly house were subjected to following statistical analysis.

- Analysis of variance (ANOVA)
- DNMRT analysis by SAS

## Results and Discussion

Screening of 177 RILs with parents have been done for resistance to early blight of tomato caused by *A. solani*. After inoculation of 177 RILs with parents using one highly virulent isolate of *A. solani* the phenotypic reactions in poly house were obtained with wide variation. A field trial also has conducted with natural inoculums for disease development.

### *Percent disease index (PDI)*

Total 177 RILs with parents were screened for resistance to early blight in field condition with natural inoculums in the year of 2012-2013. The maximum PDI 100 per cent was recorded in RILs No. 91, 102, 131, 134, 135, 143, 145, 152, 162, 167, 168, 170, 171 and 178 and minimum PDI 4.44 per cent were recorded in RILs No. 59 and 115 (**Table 2**).

Same 177 RILs with parents screened for resistance to early blight under artificial conditions (poly house) in the year of 2012-2013. The maximum PDI 88.89 per cent was recorded in RILs No. 170 per cent and minimum PDI 4.44 percent was recorded in RILs No. 115 (Table 2).

The mean PDI (poly house + field trial) was given maximum 94.45 per cent in RILs No. 170 and minimum 4.44 per cent in RILs No. 115. Susceptible parent Punjab Chhuhara was given 88.89 per cent less than maximum PDI value 94.45 per cent in RILs and resistance H-88-78-1 was given 7.78 per cent more than minimum PDI value 4.44 per cent in RILs.

### *Area under Disease Progress Curve (AUPDC)*

In field conditions with natural inoculums the AUPDC value of the eleven highly resistant RILs ranged from 38.89 to 93.34, thirty eight resistance RILs ranged from 116.67 to 287.78, fifty nine moderately resistance RILs ranged from 295.55 to 474.45, twenty four moderately susceptible RILs ranged from 482.22 to 653.33, twenty nine susceptible RILs ranged from 668.89 to 855.56 and eighteen highly susceptible RILs ranged from 871.11 to 1034.44 were recorded in the year of 2012-2013.

Under poly house conditions with artificial inoculums the AUPDC value of the eight highly resistant RILs ranged from 54.40 to 116.70, twenty six resistance RILs ranged from 140.0 to 334.40, fifty nine moderately resistance RILs ranged from 342.20 to 637.80, thirty nine moderately susceptible RILs ranged from 653.30 to 972.20, twenty four susceptible RILs ranged from 987.80 to 1190.00 and twenty one highly susceptible RILs ranged from 1228.90 to 1446.70 were recorded in the year of 2012-2013.

The mean AUDPC value of both trials (poly house + field trial) was maximum 1232.78 in RILs No. 167 and minimum 46.67 in RILs No. 59. And mean AUDPC value of susceptible parent (1174.44) and resistance parent H-88-78-1 (89.44) were recorded.

Main difficulty in breeding tomatoes for early blight resistance has been the screening process. Results from poly house experiments were highly similar to those from the field, as judged by the significant correlations between poly house and field data. Various methods have been used to evaluate tomato RILs for disease resistance under field conditions [25]. In the present study, both final PDI and AUDPC were used to evaluate and compare tomato RILs (Table 2). When screening large-size populations, it may be sufficient to conduct only a single evaluation [26].

**Table 2** Final PDI Value, AUDPC and Host Reaction of Recombinant Inbred Lines (Punjab Chhuhara X H-88-78-1) of Tomato

| Final PDI Value & AUDPC (Year 2012-2013) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **RILs** | **Name of** | **Field trial** | | | **poly house trial** | | | **Mean** | |
| **No.** | **RILs** | **PDI** | **HR** | **AUDPC** | **PDI** | **HR** | **AUDPC** | **Mean PDI** | **AUDPC** |
| **1** | PR-90-II-2 | 73.33 | S | 770.00 | 66.67 | S | 1096.67 | 70.00 | 933.34 |
| **2** | PR-56-2 | 33.33 | MR | 318.89 | 33.33 | MR | 505.56 | 33.33 | 412.23 |
| **3** | PR-52-2 | 40.00 | MR | 420.00 | 37.78 | MS | 661.11 | 38.89 | 540.56 |
| **4** | PR-69-1 | 57.78 | S | 723.33 | 53.33 | S | 1073.33 | 55.56 | 898.33 |
| **5** | PR-66-1 | 71.11 | S | 770.00 | 57.78 | S | 1096.67 | 64.45 | 933.34 |
| **6** | PR-64 | 42.22 | MR | 396.67 | 42.22 | MR | 567.78 | 42.22 | 482.23 |
| **7** | PR-51-2 | 35.56 | MR | 318.89 | 35.56 | MR | 451.11 | 35.56 | 385.00 |
| **8** | PR-50-1 | 48.89 | MR | 435.56 | 48.89 | MS | 630.00 | 48.89 | 532.78 |
| **9** | PR-54-2 | 44.44 | MR | 427.78 | 44.44 | MR | 614.44 | 44.44 | 521.11 |
| **10** | PR-41-1 | 44.44 | MR | 342.22 | 44.44 | MR | 513.33 | 44.44 | 427.78 |
| **11** | PR-71-2 | 33.33 | MR | 357.78 | 33.33 | MR | 560.00 | 33.33 | 458.89 |
| **12** | PR-44-2 | 40.00 | MR | 443.33 | 40.00 | MR | 637.78 | 40.00 | 540.56 |
| **13** | PR-43-1 | 84.44 | S | 847.78 | 71.11 | S | 1190.00 | 77.78 | 1018.89 |
| **14** | PR-42 | 31.11 | MR | 326.67 | 35.56 | MR | 552.22 | 33.34 | 439.45 |
| **15** | PR-48-3 | 75.56 | S | 840.00 | 71.11 | HS | 1267.78 | 73.34 | 1053.89 |
| **16** | PR-84-1 | 26.67 | R | 272.22 | 28.89 | MR | 420.00 | 27.78 | 346.11 |
| **17** | PR-80-1 | 53.33 | MR | 466.67 | 53.33 | MS | 676.67 | 53.33 | 571.67 |
| **18** | PR-83 | 40.00 | MR | 466.67 | 37.78 | MS | 684.44 | 38.89 | 575.56 |
| **19** | PR-89-2 | 44.44 | MR | 443.33 | 44.44 | MS | 700.00 | 44.44 | 571.67 |
| **20** | PR-58-II | 28.89 | R | 287.78 | 28.89 | MR | 396.67 | 28.89 | 342.23 |
| **21** | PR-61-1 | 35.56 | MR | 350.00 | 37.78 | MR | 497.78 | 36.67 | 423.89 |
| **22** | PR-81-2 | 24.44 | R | 256.67 | 26.67 | MR | 381.11 | 25.56 | 318.89 |
| **23** | PR-82-2 | 55.56 | S | 723.33 | 51.11 | S | 1065.56 | 53.34 | 894.45 |
| **24** | PR-68-3 | 44.44 | MR | 404.44 | 44.44 | MR | 575.56 | 44.44 | 490.00 |
| **25** | PR-77-1 | 57.78 | S | 746.67 | 51.11 | S | 1088.89 | 54.45 | 917.78 |
| **26** | PR-72 | 44.44 | MR | 420.00 | 42.22 | MR | 552.22 | 43.33 | 486.11 |
| **27** | PR-76-1 | 33.33 | MR | 396.67 | 31.11 | MR | 591.11 | 32.22 | 493.89 |
| **28** | PR-40 | 71.11 | S | 668.89 | 68.89 | MS | 948.89 | 70.00 | 808.89 |
| **29** | PR-56 | 33.33 | S | 762.22 | 35.56 | HS | 1252.22 | 34.45 | 1007.22 |
| **30** | PR-73-1 | 33.33 | MR | 326.67 | 35.56 | MR | 474.44 | 34.45 | 400.56 |
| **31** | PR-75-1 | 20.00 | R | 155.56 | 24.44 | R | 210.00 | 22.22 | 182.78 |
| **32** | PR-78-1 | 24.44 | R | 264.44 | 26.67 | MR | 412.22 | 25.56 | 338.33 |
| **33** | PR-79-II-1 | 44.44 | MS | 513.33 | 44.44 | MS | 816.67 | 44.44 | 665.00 |
| **34** | PR-76-II-1 | 75.56 | S | 700.00 | 68.89 | MS | 972.22 | 72.23 | 836.11 |
| **35** | PR-79-3 | 46.67 | MR | 443.33 | 46.67 | MR | 622.22 | 46.67 | 532.78 |
| **36** | PR-79-2 | 42.22 | MR | 365.56 | 42.22 | MR | 528.89 | 42.22 | 447.23 |
| **37** | PR-80-1 | 35.56 | MR | 350.00 | 37.78 | MR | 513.33 | 36.67 | 431.67 |
| **38** | PR-16-II-3 | 24.44 | R | 264.44 | 26.67 | R | 451.11 | 25.56 | 357.78 |
| **39** | PR-112-1 | 11.11 | R | 124.44 | 13.33 | R | 202.22 | 12.22 | 163.33 |
| **40** | PR-118 | 8.89 | HR | 93.33 | 11.11 | R | 140.00 | 10.00 | 116.67 |
| **41** | PR-133-3 | 15.56 | R | 186.67 | 17.78 | R | 295.56 | 16.67 | 241.12 |
| **42** | PR-188-1 | 26.67 | R | 241.11 | 26.67 | MR | 365.56 | 26.67 | 303.34 |
| **43** | PR-136-2011 | 48.89 | MS | 497.78 | 46.67 | MS | 754.44 | 47.78 | 626.11 |
| **44** | PR-129-1 | 53.33 | MS | 653.33 | 51.11 | S | 987.78 | 52.22 | 820.56 |
| **45** | PR-133-II-1 | 75.56 | HS | 886.67 | 60.00 | HS | 1306.67 | 67.78 | 1096.67 |
| **46** | PR-90-2 | 53.33 | MS | 567.78 | 53.33 | MS | 878.89 | 53.33 | 723.34 |
| **47** | PR-114-2 | 24.44 | R | 287.78 | 24.44 | MR | 420.00 | 24.44 | 353.89 |
| **48** | PR-124-2 | 24.44 | R | 272.22 | 24.44 | MR | 404.44 | 24.44 | 338.33 |
| **49** | PR-118-II-1 | 28.89 | MR | 303.33 | 28.89 | MR | 443.33 | 28.89 | 373.33 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **50** | PR-91-1 | 48.89 | MS | 567.78 | 48.89 | MS | 832.22 | 48.89 | 700.00 |
| **51** | PR-113 | 46.67 | MS | 583.33 | 46.67 | MS | 886.67 | 46.67 | 735.00 |
| **52** | PR-104-1 | 88.89 | HS | 948.89 | 64.44 | HS | 1330.00 | 76.67 | 1139.45 |
| **53** | PR-108-1 | 31.11 | R | 233.33 | 31.11 | R | 326.67 | 31.11 | 280.00 |
| **54** | PR-109-II-1 | 60.00 | MS | 575.56 | 60.00 | MS | 863.33 | 60.00 | 719.45 |
| **55** | PR-138 | 40.00 | MR | 365.56 | 40.00 | MR | 560.00 | 40.00 | 462.78 |
| **56** | PR-37 | 80.00 | HS | 910.00 | 77.78 | HS | 1314.44 | 78.89 | 1112.22 |
| **57** | PR-23 | 46.67 | MR | 474.44 | 44.44 | MS | 684.44 | 45.56 | 579.44 |
| **58** | PR-93-3 | 6.67 | HR | 70.00 | 8.89 | HR | 116.67 | 7.78 | 93.34 |
| **59** | PR-71 | 4.44 | HR | 38.89 | 6.67 | HR | 54.44 | 5.56 | 46.67 |
| **60** | PR-139-1 | 66.67 | S | 855.56 | 60.00 | HS | 1275.56 | 63.34 | 1065.56 |
| **61** | PR-106-1 | 17.78 | R | 202.22 | 20.00 | R | 303.33 | 18.89 | 252.78 |
| **62** | PR-91 | 44.44 | MS | 630.00 | 40.00 | S | 995.56 | 42.22 | 812.78 |
| **63** | PR-326-1 | 8.89 | R | 124.44 | 11.11 | R | 171.11 | 10.00 | 147.78 |
| **64** | PR-142-1 | 57.78 | S | 723.33 | 55.56 | S | 1073.33 | 56.67 | 898.33 |
| **65** | PR-151-1 | 20.00 | R | 233.33 | 17.78 | R | 326.67 | 18.89 | 280.00 |
| **66** | PR-148-2 | 24.44 | MR | 334.44 | 22.22 | MR | 521.11 | 23.33 | 427.78 |
| **67** | PR-147-1 | 35.56 | MR | 396.67 | 33.33 | MR | 598.89 | 34.45 | 497.78 |
| **68** | PR-145-1 | 68.89 | S | 816.67 | 66.67 | HS | 1236.67 | 67.78 | 1026.67 |
| **69** | PR-158-2 | 71.11 | HS | 894.44 | 64.44 | HS | 1275.56 | 67.78 | 1085.00 |
| **70** | PR-157-2 | 68.89 | S | 832.22 | 64.44 | HS | 1252.22 | 66.67 | 1042.22 |
| **71** | PR-153-2 | 60.00 | S | 668.89 | 64.44 | S | 1011.11 | 62.22 | 840.00 |
| **72** | PR-152-1 | 44.44 | MS | 482.22 | 46.67 | MS | 723.33 | 45.56 | 602.78 |
| **73** | PR-140-2 | 31.11 | MR | 381.11 | 35.56 | MR | 583.33 | 33.34 | 482.22 |
| **74** | PR-154-II-2 | 62.22 | S | 770.00 | 57.78 | S | 1135.56 | 60.00 | 952.78 |
| **75** | PR-158-1 | 71.11 | HS | 871.11 | 68.89 | HS | 1298.89 | 70.00 | 1085.00 |
| **76** | PR-159-3 | 48.89 | MR | 458.89 | 51.11 | MS | 668.89 | 50.00 | 563.89 |
| **77** | PR-161-2 | 64.44 | S | 754.44 | 66.67 | S | 1158.89 | 65.56 | 956.67 |
| **78** | PR-160-2 | 22.22 | R | 256.67 | 24.44 | MR | 404.44 | 23.33 | 330.56 |
| **79** | PR-162-1 | 13.33 | R | 132.22 | 15.56 | R | 178.89 | 14.45 | 155.56 |
| **80** | PR-161-1 | 42.22 | MR | 427.78 | 44.44 | MS | 653.33 | 43.33 | 540.56 |
| **81** | PR-158 | 37.78 | MR | 451.11 | 40.00 | MS | 707.78 | 38.89 | 579.45 |
| **82** | PR-159-II-1 | 31.11 | MR | 318.89 | 33.33 | MR | 497.78 | 32.22 | 408.34 |
| **83** | PR-139-3 | 77.78 | S | 801.11 | 75.56 | S | 1174.44 | 76.67 | 987.78 |
| **84** | PR-217-II-1 | 71.11 | S | 770.00 | 68.89 | S | 1120.00 | 70.00 | 945.00 |
| **85** | PR-209-II-2 | 71.11 | S | 715.56 | 68.89 | S | 1112.22 | 70.00 | 913.89 |
| **86** | PR-214-1 | 46.67 | MR | 412.22 | 44.44 | MR | 544.44 | 45.56 | 478.33 |
| **87** | PR-212-II-1 | 55.56 | MS | 567.78 | 53.33 | MS | 824.44 | 54.45 | 696.11 |
| **88** | PR-118-1 | 71.11 | S | 793.33 | 68.89 | S | 1174.44 | 70.00 | 983.89 |
| **89** | PR-195-2 | 73.33 | HS | 871.11 | 68.89 | HS | 1283.33 | 71.11 | 1077.22 |
| **90** | PR-32-2011 | 40.00 | MR | 334.44 | 37.78 | MR | 443.33 | 38.89 | 388.89 |
| **91** | PR-114-1 | 100.00 | HS | 1003.33 | 77.78 | HS | 1376.67 | 88.89 | 1190.00 |
| **92** | PR-166-II-2 | 97.78 | HS | 933.33 | 84.44 | HS | 1306.67 | 91.11 | 1120.00 |
| **93** | PR-169-II-2 | 60.00 | MS | 490.00 | 57.78 | MS | 661.11 | 58.89 | 575.56 |
| **94** | PR-170 | 62.22 | MS | 614.44 | 60.00 | MS | 855.56 | 61.11 | 735.00 |
| **95** | PR-177-1 | 35.56 | MR | 295.56 | 33.33 | MR | 396.67 | 34.45 | 346.12 |
| **96** | PR-164-2 | 33.33 | MR | 311.11 | 35.56 | MR | 451.11 | 34.45 | 381.11 |
| **97** | PR-167-1 | 35.56 | MR | 350.00 | 37.78 | MR | 490.00 | 36.67 | 420.00 |
| **98** | PR-149-2011 | 62.22 | MS | 606.67 | 55.56 | MS | 871.11 | 58.89 | 738.89 |
| **99** | PR-209-1 | 35.56 | MR | 303.33 | 33.33 | MR | 435.56 | 34.45 | 369.45 |
| **100** | PR-203-1 | 86.67 | S | 824.44 | 80.00 | S | 1096.67 | 83.34 | 960.56 |
| **101** | PR-184-1 | 80.00 | S | 738.89 | 71.11 | S | 1042.22 | 75.56 | 890.56 |
| **102** | PR-180-3 | 100.00 | HS | 871.11 | 75.56 | S | 1120.00 | 87.78 | 995.56 |
| **103** | PR-182-1 | 44.44 | MR | 451.11 | 40.00 | MR | 583.33 | 42.22 | 517.22 |

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| **104** | PR-200-3 | 28.89 | R | 280.00 | 26.67 | MR | 388.89 | 27.78 | 334.45 |
| **105** | PR-193-2 | 35.56 | MR | 373.33 | 37.78 | MR | 560.00 | 36.67 | 466.67 |
| **106** | PR-184-II-2 | 37.78 | MR | 334.44 | 37.78 | MR | 482.22 | 37.78 | 408.33 |
| **107** | PR-198-II-2 | 35.56 | MR | 334.44 | 33.33 | MR | 490.00 | 34.45 | 412.22 |
| **108** | PR-188-A | 35.56 | MR | 427.78 | 33.33 | MS | 676.67 | 34.45 | 552.23 |
| **109** | PR-188-2 | 44.44 | MS | 497.78 | 42.22 | MS | 777.78 | 43.33 | 637.78 |
| **110** | PR-209-2 | 40.00 | MR | 458.89 | 37.78 | MS | 692.22 | 38.89 | 575.56 |
| **111** | PR-177 | 28.89 | R | 264.44 | 26.67 | MR | 342.22 | 27.78 | 303.33 |
| **112** | PR-178 | 57.78 | MS | 521.11 | 53.33 | MS | 723.33 | 55.56 | 622.22 |
| **113** | PR-196-1 | 44.44 | MR | 381.11 | 42.22 | MR | 451.11 | 43.33 | 416.11 |
| **114** | PR-198-2 | 11.11 | R | 116.67 | 8.89 | R | 140.00 | 10.00 | 128.34 |
| **115** | PR-167 | 4.44 | HR | 54.44 | 4.44 | HR | 62.22 | 4.44 | 58.33 |
| **116** | PR-257-1 | 66.67 | S | 723.33 | 60.00 | MS | 972.22 | 63.34 | 847.78 |
| **117** | PR-195-1 | 6.67 | HR | 77.78 | 6.67 | HR | 108.89 | 6.67 | 93.34 |
| **118** | PR-160 | 22.22 | R | 241.11 | 20.00 | MR | 357.78 | 21.11 | 299.45 |
| **119** | PR-242-1 | 51.11 | MS | 521.11 | 46.67 | MS | 832.22 | 48.89 | 676.67 |
| **120** | PR-246 | 57.78 | MS | 544.44 | 53.33 | MS | 723.33 | 55.56 | 633.89 |
| **121** | PR-47-1 | 51.11 | MS | 490.00 | 53.33 | MS | 676.67 | 52.22 | 583.34 |
| **122** | PR-219-II-1 | 40.00 | MR | 373.33 | 42.22 | MR | 544.44 | 41.11 | 458.89 |
| **123** | PR-247-II-1 | 51.11 | MS | 591.11 | 53.33 | MS | 840.00 | 52.22 | 715.56 |
| **124** | PR-220-3 | 48.89 | MR | 427.78 | 51.11 | MS | 653.33 | 50.00 | 540.56 |
| **125** | PR-221-3 | 55.56 | MS | 598.89 | 57.78 | MS | 933.33 | 56.67 | 766.11 |
| **126** | PR-219 | 13.33 | R | 132.22 | 15.56 | R | 233.33 | 14.45 | 182.78 |
| **127** | PR-320-1 | 17.78 | R | 171.11 | 20.00 | R | 280.00 | 18.89 | 225.56 |
| **128** | PR-221-1 | 11.11 | R | 171.11 | 13.33 | R | 303.33 | 12.22 | 237.22 |
| **129** | PR-323-1 | 15.56 | R | 171.11 | 17.78 | R | 217.78 | 16.67 | 194.45 |
| **130** | PR-291-II-1 | 13.33 | R | 163.33 | 15.56 | R | 272.22 | 14.45 | 217.78 |
| **131** | PR-225-1 | 100.00 | HS | 1034.44 | 82.22 | HS | 1400.00 | 91.11 | 1217.22 |
| **132** | PR-233-2 | 64.44 | MS | 552.22 | 57.78 | MS | 707.78 | 61.11 | 630.00 |
| **133** | PR-242-II-1 | 51.11 | MS | 560.00 | 46.67 | MS | 801.11 | 48.89 | 680.56 |
| **134** | PR-229-2 | 100.00 | HS | 995.56 | 77.78 | HS | 1368.89 | 88.89 | 1182.23 |
| **135** | PR-219-1 | 100.00 | HS | 941.11 | 75.56 | HS | 1228.89 | 87.78 | 1085.00 |
| **136** | PR-227-II-1 | 51.11 | MS | 536.67 | 53.33 | MS | 770.00 | 52.22 | 653.34 |
| **137** | PR-227-2 | 13.33 | R | 132.22 | 15.56 | R | 202.22 | 14.45 | 167.22 |
| **138** | PR-229-II-3 | 40.00 | MR | 427.78 | 37.78 | MS | 653.33 | 38.89 | 540.56 |
| **139** | PR-16-II-1 | 17.78 | R | 171.11 | 20.00 | R | 248.89 | 18.89 | 210.00 |
| **140** | PR-225-2 | 68.89 | S | 692.22 | 60.00 | S | 987.78 | 64.45 | 840.00 |
| **141** | PR-250-3 | 11.11 | R | 132.22 | 13.33 | R | 171.11 | 12.22 | 151.67 |
| **142** | PR-246-1 | 13.33 | R | 140.00 | 15.56 | R | 186.67 | 14.45 | 163.34 |
| **143** | PR-244-1 | 100.00 | HS | 917.78 | 82.22 | HS | 1244.44 | 91.11 | 1081.11 |
| **144** | PR-136 | 26.67 | R | 256.67 | 24.44 | MR | 350.00 | 25.56 | 303.34 |
| **145** | PR-251-3 | 100.00 | S | 855.56 | 77.78 | S | 1104.44 | 88.89 | 980.00 |
| **146** | PR-258-1 | 6.67 | HR | 70.00 | 8.89 | HR | 116.67 | 7.78 | 93.34 |
| **147** | PR-262-1 | 11.11 | HR | 77.78 | 13.33 | HR | 108.89 | 12.22 | 93.34 |
| **148** | PR-260-1 | 15.56 | R | 140.00 | 17.78 | R | 210.00 | 16.67 | 175.00 |
| **149** | PR-266-1 | 22.22 | R | 163.33 | 24.44 | R | 256.67 | 23.33 | 210.00 |
| **150** | PR-274-2 | 26.67 | R | 210.00 | 26.67 | R | 334.44 | 26.67 | 272.22 |
| **151** | PR-269-2 | 22.22 | R | 163.33 | 17.78 | R | 233.33 | 20.00 | 198.33 |
| **152** | PR-257-2 | 100.00 | HS | 956.67 | 77.78 | HS | 1314.44 | 88.89 | 1135.56 |
| **153** | PR-271-1 | 91.11 | S | 801.11 | 77.78 | S | 1104.44 | 84.45 | 952.78 |
| **154** | PR-270-3 | 48.89 | MR | 427.78 | 51.11 | MR | 630.00 | 50.00 | 528.89 |
| **155** | PR-282-1 | 40.00 | MR | 357.78 | 35.56 | MR | 505.56 | 37.78 | 431.67 |
| **156** | PR-294-II-1 | 42.22 | MR | 311.11 | 40.00 | MR | 420.00 | 41.11 | 365.56 |
| **157** | PR-284-1 | 37.78 | MR | 435.56 | 40.00 | MR | 637.78 | 38.89 | 536.67 |

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| **158** | PR-274-3 | 8.89 | HR | 93.33 | 11.11 | R | 140.00 | 10.00 | 116.67 |
| **159** | PR-281-2 | 11.11 | R | 124.44 | 11.11 | R | 194.44 | 11.11 | 159.44 |
| **160** | PR-273-3 | 8.89 | HR | 70.00 | 8.89 | HR | 101.11 | 8.89 | 85.56 |
| **161** | PR-297-II-3 | 24.44 | R | 280.00 | 22.22 | MR | 412.22 | 23.33 | 346.11 |
| **162** | PR-315-2 | 100.00 | S | 855.56 | 71.11 | S | 1088.89 | 85.56 | 972.23 |
| **163** | PR-215-II-3 | 53.33 | MR | 458.89 | 48.89 | MS | 684.44 | 51.11 | 571.67 |
| **164** | PR-326-1 | 44.44 | MR | 466.67 | 42.22 | MR | 637.78 | 43.33 | 552.23 |
| **165** | PR-222-1 | 48.89 | MR | 451.11 | 44.44 | MR | 614.44 | 46.67 | 532.78 |
| **166** | PR-220-6 | 46.67 | MR | 451.11 | 51.11 | MS | 692.22 | 48.89 | 571.67 |
| **167** | PR-324-1 | 100.00 | HS | 1018.89 | 82.22 | HS | 1446.67 | 91.11 | 1232.78 |
| **168** | PR-309-2 | 100.00 | HS | 910.00 | 82.22 | HS | 1236.67 | 91.11 | 1073.34 |
| **169** | PR-295-3 | 51.11 | MS | 536.67 | 57.78 | MS | 847.78 | 54.45 | 692.23 |
| **170** | PR-304-1 | 100.00 | HS | 972.22 | 88.89 | HS | 1423.33 | 94.45 | 1197.78 |
| **171** | PR-327-2 | 100.00 | S | 832.22 | 82.22 | S | 1112.22 | 91.11 | 972.22 |
| **172** | PR-264-2 | 48.89 | MR | 412.22 | 46.67 | MR | 606.67 | 47.78 | 509.45 |
| **173** | PR-308-2-1 | 13.33 | R | 132.22 | 11.11 | R | 186.67 | 12.22 | 159.45 |
| **174** | PR-299-II-1 | 48.89 | MR | 427.78 | 48.89 | MR | 583.33 | 48.89 | 505.56 |
| **175** | PR-338-II-1 | 26.67 | MR | 303.33 | 28.89 | MR | 451.11 | 27.78 | 377.22 |
| **176** | PR-159-1 | 8.89 | HR | 70.00 | 11.11 | HR | 85.56 | 10.00 | 77.78 |
| **177** | PR-341-2 | 33.33 | MR | 365.56 | 28.89 | MR | 544.44 | 31.11 | 455.00 |
| **178** | Pb. Chhuhara | 100 | HS | 972.22 | 77.78 | HS | 1376.67 | 88.89 | 1174.44 |
| **179** | H-88-78-1 | 6.67 | HR | 77.78 | 8.89 | HR | 101.11 | 7.78 | 89.44 |
| **Max.** | | 100.00 | HS | 1034.44 | 88.89 | HS | 1446.67 | 94.45 | 1232.78 |
| **Min.** | | 4.44 | HR | 38.89 | 4.44 | HR | 54.44 | 4.44 | 46.67 |
| **CV %** | | 24.293 | | | 24.507 | | | | |
| **LSD** | | 141.25 | | | 206.24 | | | | |

## Conclusions

Similarity was observed between poly house and field screenings of tomato recombinant inbreed lines for early blight resistance. Field and poly house evaluation was found to be useful for screening tomatoes for EB resistance, so it may be employed to facilitate EB resistance breeding. The AUDPC value of RILs in poly house condition was observed less than the field study. Limited early blight resistance was found in the recombinant inbreed lines of tomato in $F_6$ generation.

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## References

[1] Anonymous (2012). APEDA, Agriculture Data Base, http://agriexchange.apeda.gov.in.
[2] Balanchard, D. (1992). A colour atlas of tomato diseases. Wolfe Pub. Ltd., Brook House, London, P.298.
[3] Datar, V. V. and Mayee, C. D. (1981). Assessment of losses in tomato yields due to early blight. Indian Phytopathol, 34:191–195.
[4] Mathur, K. and Shekhawat, K.S. (1986). Chemical control of early blight in Kharif sown tomato. Indian Journal of Mycology Plant Pathology, 16: 235-238.
[5] Madden, L.; Pennypacker, S.P.; Mac Nab. (1978). FAST a forecast system for Alternaria solani on tomato. Phytopathology, 68: 1354-1358.
[6] Sherf A.F., MacNab A.A. (1986). Vegetable diseases and their control. John Wiley and Sons, New York, pp 634-640
[7] Shtienberg, D., Blachinsky, D., Kremer, Y., Ben-Hador, G., Dinoor, A. (1995). Integration of genotype and age-related resistance to reduce fungicide use in management of Alternaria diseases of cotton and potato. Phytopathology, 85: 995-1002.

[8] Keinath, A.; DuBose, V.B. and Rathwell, P.J. (1996). Efficacy and economics of three fungicide application schedules for early blight control and yield of fresh market tomato. Plant Disease. 80: 1277-1282.

[9] Nash, A.F. and Gardner, R.G. (1988a). Heritability of tomato early blight resistance derived from Lycopersicon hirsutum PI 126445. J Am Soc Hort Sci., 113: 264-268.

[10] Maiero, M.; Ng, T.J. and Barksdale, T.H. (1990a). Genetic resistance to early blight in tomato breeding lines. Hort. Science, 25: 344-346.

[11] Maiero, M.; Ng, T.J. and Barksdale, T.H. (1990b). Inheritance of collar rot resistance in the tomato breeding lines C1943 and NC EBR-2. Phytopathology, 80: 1365-1368.

[12] Barksdale, T.H. and Stoner, A.K. (1977). A study of the inheritance of tomato early blight resistance. Plant Dis Rep, 61: 63-65.

[13] Thirthamalappa and Lohithaswa, H.C. (2000). Genetics of resistance to early blight (Alternaria solani Sorauer) in tomato (Lycopersicum esculentum L.) Euphytica, 113: 187-193.

[14] Stancheva, I. (1991). Inheritance of the resistance to injuries on the growth mass caused by Alternaria solani in the tomato. Genetika-i-Selektsiya, 24:232-236.

[15] Martin, F.W. and Hepperly, P. (1987). Sources of resistance to early blight, Alternaria solani, and transfer to tomato, Lycopersicon esculentum. J Agric Univ Puerto Rico, 71: 85-95.

[16] Foolad, M.R.; Zhang, L.P.; Khan, A.A.; Niño-Liu, D. and Lin, G.Y. (2002). Identification of QTLs for early blight (Alternaria solani) resistance in tomato using backcross populations of a Lycopersicon esculentum × Lycopersion hirsutum cross. Theor Appl Genet, 104: 945-958.

[17] Zhang, L.P.; Lin, G.Y.; Niño-Liu and Foolad, M.R. (2003). Mapping QTLs conferring early blight (Alernaria solani) resistance in a Lycopersicon esculentum × L. hirsutum cross by selective genotyping. Mol Breed, 12: 3-19.

[18] Chaerani, R.; Stam, P. and Voorrips, R. E. (2006). Early blight resistance in tomato: screening and genetic study, Ph.D. thesis, Wageningen University, the Netherlands with summaries in English, Dutch and Bahasa Indonesia.

[19] Walter, J.M., Kelbert, D.G.A., Hayslip, N.C. (1961). Manapal, a disease resistance tomato with the desirable traits of Rutgars. Florida University Agricultural Experimental Station, Gainesville Circ S–131.

[20] Vakalounakis, D.J. (1983). Evaluation of tomato cultivars for resistance to Alternaria blight. Ann Appl Biol, 102: 138-139.

[21] Ghosh, P. P.; Mandal, D.; Laha, S. and Dasgupta, M. K. (2009). Dynamics and severity model in managing fungal diseases. The Journal of Plant Protection Sciences, 1(1): 55-59.

[22] Wheeler, B. E. J. (1969). An Introduction to Plant Diseases. John Wiley and Sons Limited, London, P.301.

[23] Shaner, G. and Finney, R. E. (1977). The effect of nitrogen fertilization on the expression of slow-mildewing resistance in ‘Knox’ wheat. Phytopathology. 67:1051–1056.

[24] Johnson, D. A. and Wilcoxson, R. D. (1982). A talbe of areas under disease progress curve. In: Technical Bulletin. Texas Agricultural Experiment Station Texas.

[25] Barksdale, T. H. (1971). Field evaluation for tomato early blight resistance. Plant Dis. Rep. 55:807-809.

[26] Foolad, M.R.; Ntahimpera, N.; Christ, B.J. and Lin, G.Y. (2000). Comparison of field, greenhouse, and detached leaflet evaluations of tomato germ plasm for early blight resistance. Plant Dis, 84: 967-972.




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