Plant Genetic Resources: Characterization and Utilization

cambridge.org/pgr

Evaluation of resistance against anthracnose (*Colletotrichum capsici* and *C. gloeosporioides*) in chilli landraces collected from the northeastern region of India

Neeraj Dwivedi[1], Dipti S Tirkey[1], Shabnam Katoch[2] and Lakshman Prasad[2]

[1]TERI–Deakin Nanobiotechnology Centre, TERI Gram, The Energy and Resources Institute (TERI), Gwal Pahari, Gurugram, Haryana, 122002, India and [2]Division of Plant Pathology, ICAR-Indian Agricultural Research Institute, New Delhi, 110012, India

Research Article

Cite this article: Dwivedi N, Tirkey DS, Katoch S, Prasad L (2021). Evaluation of resistance against anthracnose (*Colletotrichum capsici* and *C. gloeosporioides*) in chilli landraces collected from the northeastern region of India. *Plant Genetic Resources: Characterization and Utilization* **19**, 538–544. https://doi.org/10.1017/S1479262121000666

Received: 16 December 2020
Revised: 21 December 2021
Accepted: 21 December 2021
First published online: 25 March 2022

Key words:
Anthracnose; disease resistance; fruit rot; fungal disease; landraces

Author for correspondence:
Neeraj Dwivedi,
E-mail: neeraj.dwivedi@teri.res.in; ndbiotech@gmail.com

Abstract

Anthracnose or fruit rot disease caused by *Colletotrichum* spp. leads to substantial economic losses in chilli (*Capsicum annuum* L.) production worldwide. In the present study, 24 different Bhut Jolokia chilli landraces and seven *Capsicum annuum* cultivars have been collected from the northeastern region of India and subsequently screened under *in vitro* and *in vivo* conditions against *Colletotrichum capsici* and *C. gloeosporiodes* infections. During field evaluation, eight chilli genotypes (CC0164, CC0165, CC0191, CC0192, CC0202, CC0206, CC0209 and CC0218) were highly resistant and 12 genotypes (CC0154, CC0179, CC0181, CC0183, CC0186, CC0189, CC0193, CC0198, CC0205, CC0210, CC0213 and CC0217) were found in resistant category against *C. capsici* infection. During *in-vitro* germplasm evaluation, 11 and 12 landraces were found to be highly resistant to *C. capsici* and *C. gloeosporioides* infections, respectively. According to the findings, the majority of Bhut Jolokia chilli landraces are resistant to anthracnose. Given the difficulties farmers experience as a result of excessive use of fungicides and pesticides, germplasm screening for host resistance has already begun. The resistant lines identified in the current study offers better choices to tackle anthracnose and could be used effectively in breeding programs to develop anthracnose resistant varieties.

Introduction

Anthracnose is a devastating chilli disease caused by *Colletotrichum* spp. that has resulted in up to 50% yield losses owing to pre- and post-harvest fruit rot in India (Pakdeevaraporn *et al.*, 2005). India is the largest exporter of chilli and its products (Geetha and Selvarani, 2017), however, anthracnose disease causes an estimated annual loss of 29.5%, corresponding to 491.67 million US$ (Garg *et al.*, 2014). In India, primarily three important species, namely, *C. capsici*, *C. gleosporoides* and *C. acutatum* have been reported to be linked with the disease as solo or as disease complex (Than *et al.*, 2008*a*; Saxena *et al.*, 2016). Among these, *C. capsici* is causing major damage at the ripening stage of the plant (Ranathunge *et al.*, 2012; Saxena *et al.*, 2014) while, *C. gloeosporioides* have been found to be more abundant in developing infections of young and mature green fruits (Hong and Hwang, 1998; Kim *et al.*, 1999). Anthracnose results in seedling rot during the initial stages of plant growth, while later die back and has fruit rot disease. In severe epidemic conditions, sunken dark necrotic lesions with acervuli are commonly formed on infected chilli fruits (Katoch *et al.*, 2017). Acervuli formed in the lesions can competitively serve as the source of initial infectious inoculum in addition to the asexual fruiting bodies; *Colletotrichum* is also known to be occurring for internally and/or externally seed-borne in nature. To compete with the standards of the global chilli market, the management of anthracnose disease is very important. In this regard, farmers are mainly and unintentionally dependent on chemical fungicides to control anthracnose in the field which can leave accountable pesticide residue in chilli fruit usually harmful/toxic for consumers. However, as people become more aware of the benefits of eating pesticide-free food on a regular basis, demand for organic agri-products has risen, In the case of chilli, this can only be achieved by using anthracnose resistant cultivars. Because of the harmful consequences of chemical pesticides on the environment and human health, an integrated approach has already been adopted around the world. Host resistance is the most reliable and environmentally friendly strategy among the several approaches to integrated disease management. Therefore, the present study is an attempt to screen chilli landraces collected from India's northeastern region for anthracnose resistance. Some genetic resources resistant to anthracnose in chilli have been independently reported from different countries and regions (Park *et al.*, 1987; Kim *et al.*, 1989; Hong and Hwang, 1998; Pae *et al.*, 1998; AVRDC, 1999; Yoon and Park, 2001; Begum *et al.*, 2015; Katediya *et al.*, 2019). In particular, some lines of

C. baccatum and *C. chinense* showed strong resistance to the pathogen, and pathogen inoculation resulted in no or limited lesions on the chilli fruits. 'PBC80' and 'PBC81' reported as resistant resources in *C. baccatum* germplasm (AVRDC 1999; Yoon *et al*., 2004) and 'PBC932' is a resistant resource in *C. chinense* germplasm (AVRDC 2003*a*, 2003*b*; Pakdeevaraporn *et al*., 2005). However, to date, no strong resistance has been found in *Capsicum annuum*, which is the only species grown worldwide. Hence, further research is needed to identify more effective resistance sources that can be used in breeding programs.

Bhut Jolokia (King chilli or Ghost chilli) is a well-known landrace from the northeastern region of India which has been domesticated for a long time by the local communities and is grown for its high pungent fruits. A study done at ICAR-Indian Institute of Vegetable Research, Varanasi, India has shown that Bhut Jolokia has significant resistance against anthracnose (Garg *et al*., 2014). In some other reports also mentioned that Bhut Jolokia chilli lines carry resistant against anthracnose (Garg *et al*., 2013; Mishra *et al*., 2018). Hence keeping in mind the facts of losses caused by anthracnose and the presence of resistance in the lines of Bhut Jolokia, we have collected Bhut Jolokia landraces from different locations of The northeastern region of India and screened for resistance against *C. capsici* and *C. gloeosporioides* through a field and artificial screening.

Material and methods

Plant material

Twenty-four Bhut Jolokia landraces were collected in the month of September 2015 and January 2016 from Assam and Nagaland states of the northeastern region of India (Table S1) and subsequently screened for anthracnose in the next cropping seasons under both *in vitro* and *in vivo* conditions at poly-house facility/experimental field of TERI GRAM, Gwal Pahari, Gurugram, Haryana. Seven different *Capsicum annum* cultivars namely 'Pusa Sadabahar', 'Pusa Jwala', 'Kashi Anmol', 'IC-570408', 'California Wonder', 'R line' and 'Punjab Lal' that have already been reported for possessing resistance against other chilli diseases were also screened against anthracnose.

Inoculum preparation

For the inoculation of chilli germplasm, the cultures of *Colletotrichum capsici* (ITCC No. 6078) and *C. gloeosporiodes* (ITCC No. 6270) were procured from Indian type culture collection (ITCC), Division of Plant Pathology, Indian Agricultural Research Institute, New Delhi and were maintained on potato dextrose agar medium at 25 °C under 12 h fluorescent light/12 h dark in BOD incubation chamber for 15 days. Conidial suspension of *C. capsici and C. gloeosporioides* was prepared separately for each strain in sterilized distilled water by harvesting acervuli/conidia from freshly sporulating cultures (15 days old). Inoculum load was adjusted to 5×10^5 conidia per ml using a haemocytometer under a compound microscope and diluted accordingly. Tween-80 were added @ 2% and mixed with prepared conidial suspension and was further used as standard inoculum for carrying out phenotypic studies on chilli landraces and cultivars.

Artificial inoculation

Artificial screening of chilli landraces and genotypes were done under controlled conditions using *C. capsici* and *C. gloeosporioides* cultures (Fig. 1). Three to five mature fruits of each

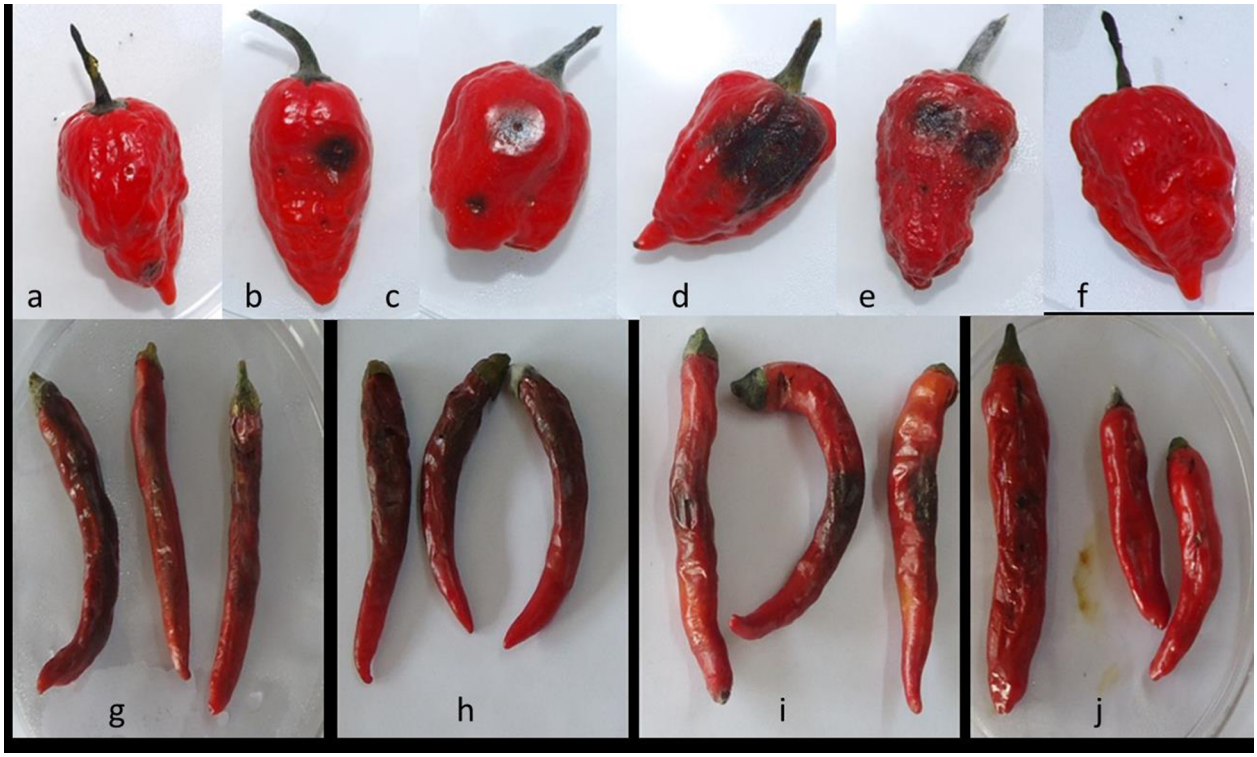

Fig. 1. *In vitro* screening of chilli germplasm against Colletotrichum capsici. (a) CC0165 (b) CC0181 (c) CC0183 (d) CC0191 (e) CC0193 (f) CC0164 (g) Pusa Jawala (h) Punjab Lal (i) Pusa Sadabahar (J) IC- 570408.

https://doi.org/10.1017/S1479262121000666 Published online by Cambridge University Press

genotype were harvested and surface sterilized with 0.1% mercuric chloride ($HgCl_2$) for 2 min. followed by two washings with sterile distilled water. The washed fruits were kept on sterile filter paper for drying. Thereafter fruits were inoculated following a superficial minor injury on fruit at two points with 5 µl conidial suspension of 5×10^5 spore concentration at each point. The inoculated fruits were placed on layers of sterile moistened paper towels and kept in acrylic boxes. The boxes were tightly sealed with plastic bags to maintain more than 90% humidity and kept in dark at 20–25 °C for 48 h. The boxes were then removed from plastic bags and incubated at 25 ± 1 °C with a 12 h dark/light cycle in a small moist chamber [relative humidity (RH) more than 90%]. The lesion length (LL) and/or diameter was recorded 9 days after inoculation and the disease reaction against *C. capsici* and *C. gloeosporioides* was assessed using an empirical scale based on lesion diameter or length (Hartman and Wang, 1992; Garg *et al.*, 2014). According to this scale, accessions were categorized into symptomless (SL, no lesion), highly resistant (HR, 1.0–4.9 mm), moderately resistant (MR, 5.0–9.9 mm), moderately susceptible (MS, 10.0–19.9) and highly susceptible (HS, >20.0 mm).

Field screening

Thirty-one chilli cultivars were grown in the experimental field at TERI GRAM, Gual Pahari, Gurugram, Haryana, in three replications with 10 plants per replication. Conidial suspension of *C. capsici* with the same concentration was evenly sprayed using an atomizer on 70 days old chilli plants bearing green and red fruits. Un-inoculated plants (three) of each germplasm line were kept as control/check. Disease severity was recorded 9 days after inoculation and per cent disease index (PDI) was calculated by dividing the sum of individual scores with the total number of observations, multiplied by the maximum scale and expressed in percentage (Garg *et al.*, 2014). On the basis of PDI values, genotypes were categorized in six disease reactions: symptomless (SL, 0), resistant (R, 0.1–10), moderately resistant (MR, 10.1–25), MS (MS, 25.1–50), susceptible (S, 50.1–75) and HS (HS, 75.1–100) (Garg *et al.*, 2014).

Statistical analysis

Field screening was done by conducting an experiment in randomized block design for two cropping seasons. The obtained data were subjected to a one-way analysis of variance (ANOVA). The comparative analysis of each chilli germplasm was done at 0.05 and 0.01 per cent level of significance using OPSTAT online Agriculture Data Analysis software (Sheoran *et al.*, 1998). Likewise, the data obtained in *in vitro* screening was also statistically analysed with a completely randomized design (CRD).

Results

During *in-vitro* assessment of chilli genotypes against both *Colletotrichum* species (*C. capsici* and *C. gloeosporioides*), 'California wonder' was found to be a HS while, 'Punjab Lal', 'R-line' and CC0182 were MS (Tables 1 and 2). During *in vitro* studies, twenty-six genotypes showed resistant reactions to *C. capsici*, while, twenty-seven genotypes were resistant against *C. gloeosporioides*. The chilli germplasms (CC0164, CC0165, CC0186, CC0189, CC0192, CC0202, CC0206, CC0209, CC0217 and CC0218) were found to be highly resistant against both pathogens (*C. capsici* and *C. gloeosporioides*) under *in vitro* conditions. Along with these lines, CC0210 and IC-570408 chilli germplasms also showed a highly resistant reaction against *C. gloeosporioides* (Tables 1 and 2). Likewise, the disease reaction of 31 chilli indigenous lines have also been screened under field conditions that revealed the majority of the Bhut Jolokia genotypes were resistant to the disease. Eight lines were found to be highly resistant viz.,-CC0164, CC0165, CC0191, CC0192, CC0202, CC0206, CC0209, CC0218; 12 lines were resistant viz.,-CC0154, CC0179, CC0181, CC0183, CC0186, CC0189, CC0193, CC0198, CC0205, CC0210, CC0213, CC0217 and six lines viz. CC0157, CC0161, CC0173, CC0182, 'Kashi Anmol' and 'Punjab Lal' were moderately resistant to *C. capsici* infection (Table 3). The rest of the five genotypes were MS ('IC- 570408', 'California Wonder' and 'R-line'), and susceptible ('Pusa Sadabahar' and 'Pusa Jwala') (Table 3).

The combined analysis of data obtained by experiments conducted under in field and *in vitro* conditions revealed such finding as maximum germplasm that are symptomless during field screening were also found to have a high level of resistance against anthracnose under controlled epiphytotic environmental conditions also. Statistically, the disease severity as per lesion length was significantly different among various genotypes.

Discussion

Among different *Colletotrichum* species *C. capsici* and *C. gloeosporioides* have been reported from Indonesia, Taiwan, Vietnam, Papua New Guinea and India are the major cause of anthracnose disease in chilli (Park and Kim, 1992; Johnston and Jones, 1997; Don *et al.*, 2007; Selvakumar, 2007; Than *et al.*, 2008b). For the management of anthracnose disease two major strategies are used commonly that includes the use of chemical fungicide or developing strong resistant cultivars. Assessment of pesticide residue revealed that 61% of fresh vegetable samples including green chilli showed the presence of pesticide traces above maximum residue limits (MRLs) in chilli samples tested from Pakistan (Latif *et al.*, 2011). Hence, it can be postulated that the chilli landraces having long-lasting resistance could be a great resource for the development of anthracnose resistant cultivar. Bhut Jolokia chilli also contains potent landraces cultivated traditionally since years at Brahmaputra flood plain of Assam, Nagaland, Manipur and other parts of the northeastern region of India (Roy, 2016) considered to be a hybrid of *C. frutescens* and *C. chinense* (Bosland and Baral, 2007), later on traced out as distinct species (*C. assamicum*) (Purkayastha *et al.*, 2012). Earlier reports based on anthracnose screening of different Bhut Jolokia lines have already shown the presence of resistance (Montri *et al.*, 2009; Garg *et al.*, 2013; Mishra *et al.*, 2018). However, the diversity within Bhut Jolokia germplasm regarding anthracnose resistance has not been explored yet by any researchers. In the present study, we have collected twenty-four Bhut Jolokia landraces from different geographical locations of the northeastern region of India and screened against two pathogenic species of *Colletotrichum* (*C. capsici* and *C. gloeosporioides*). Maximum of Bhut Jolokia lines were found to be positive for the existence of resistance genes against anthracnose, however, we have also observed a significant variation in anthracnose resistance among different lines of Bhut Jolokia, it is hypothesized that such effect may arise due to differences in pungency level, as a correlation between pungency and anthracnose resistance has been reported earlier by Azad (1991). Similarly, Tenaya *et al.* (2001) also reported that a higher level of capsaicin content in cultivated

https://doi.org/10.1017/S1479262121000666 Published online by Cambridge University Press

Table 1. *In vitro* screening of chilli germplasm against *Colletotrichum capsici*

Sr. No.	Genotypes	LA[a] (mm) (9 DAI)		Avg. LA (mm)	LL[b] (mm) (9 DAI)		Avg. LL (mm)	Disease rxn[c]
		2017–18	2018–19		2017–18	2018–19		
1	CC0154	76.23 (8.78)	63.95 (8.05)	70.09	10.38(3.37)	8.12 (3.02)	9.25	MR
2	CC0157	40.88 (6.46)	44.26 (6.69)	42.57	5.79 (2.59)	7.16 (2.85)	6.48	MR
3	CC0161	84.42 (9.23)	71.45 (8.51)	77.935	11.80(3.57)	9.73 (3.27)	10.77	MS
4	CC0164	3.00 (1.99)	3.23 (2.04)	3.115	1.84 (1.68)	1.73 (1.65)	1.79	HR
5	CC0165	4.04 (2.24)	3.77 (2.18)	3.905	2.33 (1.82)	2.18 (1.78)	2.26	HR
6	CC0173	63.25 (8.00)	61.29 (7.88)	62.27	8.81 (3.13)	8.74 (3.12)	8.78	MR
7	CC0179	18.60 (4.42)	19.21 (4.48)	18.905	4.98 (2.45)	5.44 (2.54)	5.21	MR
8	CC0181	33.07 (5.83)	33.34 (5.85)	33.205	6.08 (2.66)	6.74 (2.78)	6.41	MR
9	CC0182	135.76(11.62)	92.32 (9.63)	114.04	14.01(3.86)	11.58(3.54)	12.79	MS
10	CC0183	37.38 (6.20)	45.45 (6.80)	41.415	6.52 (2.74)	5.66 (2.58)	6.09	MR
11	CC0186	11.13 (3.48)	12.44 (3.66)	11.785	3.91 (2.22)	3.76 (2.17)	3.84	HR
12	CC0189	12.97 (3.73)	17.33 (4.28)	15.15	3.22 (2.05)	4.11 (2.25)	3.67	HR
13	CC0191	77.49 (8.86)	68.54 (8.30)	73.015	9.28 (3.21)	7.73 (2.95)	8.51	MR
14	CC0192	3.69 (2.16)	3.45 (2.09)	3.57	1.78 (1.67)	1.37 (1.54)	1.58	HR
15	CC0193	50.82 (7.19)	50.82 (7.19)	50.82	8.01 (3.00)	6.83 (2.79)	7.42	HR
16	CC0198	53.51 (7.34)	80.84 (9.05)	67.175	8.66 (3.10)	8.01 (3.00)	8.34	MR
17	CC0202	3.37 (2.09)	4.25 (2.28)	3.81	1.83 (1.68)	1.58 (1.60)	1.71	HR
18	CC0205	31.40 (5.67)	30.85 (5.62)	31.125	6.15 (2.67)	6.67 (2.77)	6.41	MR
19	CC0206	15.70 (4.05)	19.11 (4.46)	17.405	3.93 (2.22)	3.39 (2.09)	3.66	HR
20	CC0209	8.83 (3.12)	13.65 (3.82)	11.24	3.67 (2.16)	3.26 (2.06)	3.47	HR
21	CC0210	25.27 (5.12)	28.00 (5.37)	26.635	5.68 (2.58)	5.27 (2.50)	5.48	MR
22	CC0213	32.41 (5.77)	42.85 (6.62)	37.63	5.85 (2.62)	5.15 (2.48)	5.50	MR
23	CC0217	11.79 (3.56)	11.27 (3.47)	11.53	3.78 (2.18)	2.97 (1.99)	3.38	HR
24	CC0218	7.10 (2.79)	8.31 (3.00)	7.705	2.54 (1.87)	3.12 (2.02)	2.83	HR
25	PusaSadabahar	64.67 (8.09)	65.68 (8.15)	65.175	8.08 (3.01)	9.04 (3.17)	8.56	MR
26	PusaJwala	82.40 (9.13)	89.00 (9.47)	85.7	9.12 (3.18)	10.37(3.37)	9.75	MR
27	Kashi Anmol	64.99 (8.12)	45.25 (6.78)	55.12	8.68 (3.11)	7.29 (2.88)	7.99	MR
28	IC- 570408	29.94 (5.53)	31.51 (5.68)	30.725	6.08 (2.66)	5.93 (2.63)	6.01	MR
29	California Wonder	458.25 (21.38)	362.41 (18.98)	410.33	23.44 (4.94)	22.08 (4.79)	22.76	HS
30	R line	178.21 (13.38)	151.47 (12.34)	164.84	14.09 (3.88)	11.69 (3.56)	12.89	MS
31	Punjab Lal	98.24 (9.94)	112.97 (10.66)	105.605	10.89 (3.45)	9.56 (3.25)	10.23	MS
CD (0.05)		1.042	1.059		0.260	0.244		

HR, Highly resistant; MR, Moderately resistant; MS, Moderately susceptible; HS, Highly susceptible.
[a]Lesion area.
[b]Lesion length.
[c]Disease reaction.

red chilli (*C. annuum*) also linked with a greater level of anthracnose resistance. In addition to this, there are reports present as well in which various anthracnose resistant lines (other than Bhut Jolokia) have also been identified (Prasath and Ponnuswami, 2008; Babu *et al.*, 2011). In the current study, 31 genotypes were screened under *in vitro* and *in vivo* conditions among which 32.0 and 38.71% genotypes screened under controlled conditions showed highly resistant reaction against both *C. capsici* and *C. gloeosporioides*, respectively. Whereas under field conditions, 25.81% lines were found highly resistant, 38.71% lines resistant and 19.35% lines moderately resistant to *C. capsici*. Among 24 Bhut Jolokia lines 11 showed highly resistant, 11 showed moderately resistant and only two in the MS category out of fruit puncture method of *C. capsici*. The most resistant Bhut Jolokia line was CC0192 with 1.58 mm average lesion length followed by CC0202 1.71 mm and CC0164

https://doi.org/10.1017/S1479262121000666 Published online by Cambridge University Press

Table 2. *In vitro* screening of chilli germplasm against *Colletotrichum gloeosporioides*

Sr. No.	Genotypes	LA[a] (mm) (9 DAI)		Avg. LA (mm)	LL[b] (mm) (9 DAI)		Avg. LL (mm)	Disease rxn[c]
		2017–18	2018–19		2017–18	2018–19		
1	CC0154	48.16 (6.99)	37.09 (6.16)	42.625	7.22 (2.87)	6.78 (2.79)	7.00	MR
2	CC0157	81.12 (9.06)	39.36 (6.33)	60.24	10.70(3.41)	6.50 (2.74)	8.60	MR
3	CC0161	71.62 (8.52)	25.10 (5.07)	48.36	10.45(3.38)	5.06 (2.46)	7.76	MR
4	CC0164	2.77 (1.94)	2.78 (1.94)	2.775	1.83 (1.68)	1.71 (1.65)	1.77	HR
5	CC0165	4.17 (2.27)	3.48 (2.12)	3.825	2.28 (1.81)	2.09 (1.76)	2.19	HR
6	CC0173	87.40 (9.39)	41.23 (6.49)	64.315	10.36(3.37)	6.82 (2.80)	8.59	MR
7	CC0179	25.82 (5.18)	15.11 (4.00)	20.465	6.03 (2.65)	3.99 (2.21)	5.01	MR
8	CC0181	33.55 (5.87)	20.87 (4.67)	27.21	6.08 (2.66)	4.47 (2.34)	5.28	MR
9	CC0182	151.29 (12.29)	92.32 (9.63)	121.805	14.20 (3.89)	9.88 (3.29)	12.04	MS
10	CC0183	60.30 (7.82)	31.80 (5.72)	46.05	8.59 (3.10)	5.43 (2.54)	7.01	MR
11	CC0186	23.51 (4.95)	12.79 (3.71)	18.15	5.26 (2.50)	3.79 (2.19)	4.53	HR
12	CC0189	21.70 (4.74)	17.33 (4.28)	19.515	5.00 (2.45)	4.22 (2.28)	4.61	HR
13	CC0191	59.49 (7.77)	38.97 (6.31)	49.23	8.35 (3.06)	6.92 (2.81)	7.64	MR
14	CC0192	3.03 (2.01)	2.14 (1.77)	2.585	1.71 (1.65)	1.06 (1.43)	1.39	HR
15	CC0193	41.42 (6.50)	30.34 (5.59)	35.88	7.30 (2.88)	5.74 (2.59)	6.52	MR
16	CC0198	70.86 (8.47)	28.54 (5.43)	49.7	9.04 (3.17)	5.47 (2.54)	7.26	MR
17	CC0202	2.93 (1.98)	2.18 (1.78)	2.555	1.83 (1.68)	1.27 (1.50)	1.55	HR
18	CC0205	52.43 (7.25)	17.32 (4.26)	34.875	7.37 (2.88)	4.21 (2.28)	5.79	MR
19	CC0206	15.10 (4.01)	9.03 (3.16)	12.065	4.27 (2.30)	3.18 (2.04)	3.73	HR
20	CC0209	13.80 (3.84)	7.01 (2.83)	10.405	4.28 (2.30)	2.83 (1.96)	3.56	HR
21	CC0210	26.16 (5.20)	19.05 (4.47)	22.605	5.31 (2.51)	4.21 (2.28)	4.76	HR
22	CC0213	32.41 (5.77)	32.82 (5.79)	32.615	6.31 (2.70)	6.00 (2.65)	6.16	MR
23	CC0217	11.70 (3.55)	6.64 (2.76)	9.17	3.84 (2.20)	2.96 (1.99)	3.40	HR
24	CC0218	6.33 (2.70)	7.00 (2.82)	6.665	2.79 (1.95)	3.00 (2.00)	2.89	HR
25	Pusa Sadabahar	35.37 (6.03)	37.16 (6.16)	36.265	6.15 (2.67)	6.57 (2.75)	6.36	MR
26	Pusa Jwala	66.72 (8.23)	60.65 (7.81)	63.685	8.66 (3.11)	8.06 (3.01)	8.36	MR
27	Kashi Anmol	56.77 (7.58)	23.79 (4.96)	40.28	8.10 (3.02)	4.90 (2.43)	6.5	MR
28	IC- 570408	23.33 (4.93)	19.82 (4.53)	21.575	5.05 (2.46)	4.74 (2.39)	4.89	HR
29	California Wonder	418.31 (20.47)	309.30 (17.61)	363.805	23.21 (4.92)	18.52 (4.42)	20.87	HS
30	R line	184.77 (13.63)	125.12 (11.22)	154.945	14.64 (3.95)	11.44 (3.53)	13.04	MS
31	Punjab Lal	135.82 (11.70)	86.03 (9.32)	110.925	12.71 (3.70)	9.37 (3.22)	11.04	MS
CD (0.05)		0.809	0.758		0.220	0.178		

HR, Highly resistant; MR, Moderately resistant; MS, Moderately susceptible; HS, Highly susceptible.
[a]Lesion area.
[b]Lesion length.
[c]Disease reaction.

with 1.79 mm. Almost similar results were recorded with *C. gloeosporioides* inoculation where 11 Bhut Jolokia lines showed highly resistant, 11 showed moderately resistant and only two in MS where three most resistant Bhut Jolokia line was CC0192 1.39 mm followed by CC0202 1.55 mm and CC0164 with 1.77 mm of lesion length. None of the Bhut Jolokia lines showed HS reaction only *C. annuum* cultivars displayed HS and MS reactions. California wonder was found as a HS variety with LL 22.76 mm followed by Punjab Lal and R line with 10.23 and 12.89 mm of lesion length, respectively. Infield screening of Bhut Jolokia lines, eight genotypes were found symptomless, 12 resistant and four in moderately resistant categories. Pusa Sadabahar and Pusa Jawala were found susceptible with 64.67, 50.67% PDI, respectively, followed by California Wonder and

https://doi.org/10.1017/S1479262121000666 Published online by Cambridge University Press

Table 3. Field screening of chilli accessions using *Colletotrichum capsici*

Sr. No.	Genotypes	PDI[a]at 65 DAP	Disease reaction[b]
1	CC0154	6.67 (2.75)	R
2	CC0157	11.33 (3.50)	MR
3	CC0161	14.67 (3.95)	MR
4	CC0164	0.00 (1.00)	SL
5	CC0165	0.00 (1.00)	SL
6	CC0173	11.33 (3.50)	MR
7	CC0179	6.67 (2.75)	R
8	CC0181	8.00 (2.99)	R
9	CC0182	22.67 (4.85)	MR
10	CC0183	10.00 (3.31)	R
11	CC0186	0.67 (1.24)	R
12	CC0189	0.67 (1.24)	R
13	CC0191	0.00 (1.00)	SL
14	CC0192	0.00 (1.00)	SL
15	CC0193	4.00 (2.21)	R
16	CC0198	7.33 (2.88)	R
17	CC0202	0.00 (1.00)	SL
18	CC0205	1.33 (1.41)	R
19	CC0206	0.00 (1.00)	SL
20	CC0209	0.00 (1.00)	SL
21	CC0210	2.00 (1.66)	R
22	CC0213	5.33 (2.51)	R
23	CC0217	3.33 (1.96)	R
24	CC0218	0.00 (1.00)	SL
25	Pusa Sadabahar	64.67 (8.08)	S
26	Pusa Jwala	50.67 (7.16)	S
27	Kashi Anmol	24.67 (5.06)	MR
28	IC- 570408	48.67 (7.04)	MS
29	California Wonder	48.67 (7.03)	MS
30	R line	28.67 (5.43)	MS
31	Punjab Lal	18.00 (4.34)	MR
CD (0.05)		0.688	

[a]PDI, Plant disease index.
[b]Disease reaction.
SL, Symptomless; R, Resistant; MR, Moderately resistant; MS, Moderately susceptible; S, Susceptible.

Analysis of variance for chilliaccessions screened against chilli anthracnose

Source of variation		Mean square
Treatment	30	13.71**
Error	60	0.18

$F_{tab.}$ (at 0.05) = 1.65; $F_{tab.}$ (at 0.01) = 2.03; *, **Significance at $P = 0.05$ and $P = 0.01$ respectively.

IC-570408 with 48.67% PDI. A similar finding has also been reported by Garg *et al.*, 2013; Mishra *et al.*, 2018. On the basis of the present findings, it is clear that the Bhut Jolokia lines carry resistant genes against *Colletotrichum* species. Future attempts could be made towards the crossing of Bhut Jolokia lines as donor parents with commercial cultivars of chilli to develop anthracnose resistant varieties. The only contradiction was found with Garg *et al.* (2013) reported 'Punjab Lal' as an anthracnose resistant genotype but in our study, it was found to be MS. Variation in resistance from resistant to the MS reaction of 'Punjab Lal' under *in vitro* conditions, might be because of change in pathogen virulence or diversity or because of different pathogenic strains. Also, 'IC- 570408' line (*C. annuum*) reported as immune to anthracnose caused by *C. capsici* (Singh *et al.*, 2018) was found MS in our field screening against *C. capsici*. The virulence shift and resistance breakdown can be tackled by the utilization of various resistant genotypes in resistance breeding and gene pyramiding programs. These obtained results provided us information on the reaction of a few Bhut Jolokia landraces against anthracnose and also an idea that these identified resistant Bhut Jolokia landraces may be harbouring new R-genes against *C. capsici* and *C. gloeosporioides* which are yet to be identified. Based on the findings of the present study, it could also be concluded that the genotypes collected from states of the northeastern region of India have resistance against anthracnose disease and in future 20 Bhut Jolokia lines (CC0164, CC0165, CC0191, CC0192, CC0202, CC0206, CC0209, CC0218, CC0154, CC0179, CC0181, CC0183, CC0186, CC0189, CC0193, CC0198, CC0205, CC0210, CC0213 and CC0217) would likely to brought under chilli breeding programs for crossing with commercial cultivars. Moreover, Bhut Jolokia landraces are cross-compatible with *C. annuum* genotypes. This generated information can be effectively utilized in chilli breeding programs against anthracnose and various other stress factors.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1479262121000666.

Acknowledgements. The first author is grateful to Science and Engineering Research Board (SERB), India, for providing financial support under the Core Research Grant scheme (File No: CRG/2019/004797) (date 07.02.2020). The authors are also thankful to farmers in India's northeastern region for contributing to the valuable chilli landraces used in this study.

References

AVRDC (1999) Studies on pepper anthracnose. In AVRDC Report 1998.Shanhua, Taiwan: (AVRDC-The World Vegetable Center), pp. 27–30.

AVRDC (2003*a*) AVRDC Progress. Report for 2002, Asian Vegetable Research and Development Centre, AVRDC publication 03-563.

AVRDC (2003*b*) Host resistance to pepper anthracnose. In AVRDC Report 2002. Shanhua, Taiwan: AVRDC-the World Vegetable Center, pp. 27–30.

Azad P (1991) Fate and role of chemical constituents of chilli fruits during infection with *Colletotrichum capsici*. *Indian Phytopathology* **44**, 129–131.

Babu BS, Pandravada SR, Rao RDVJP, Anitha K, Chakrabarty SK and Varaprasad KS (2011) Global sources of pepper genetic resources against arthropods, nematodes and pathogens. *Crop Protection* **30**, 389–400.

Begum S, Narjinary M, Anand YR and Nath PS (2015) Screening of chilli genotypes against anthracnose under field condition. *Environment & Ecology* **33**, 1858–1862.

Bosland PW and Baral JB (2007) 'Bhut Jolokia'- The world's hottest known Chile pepper is a putative naturally occurring interspecific hybrid. *Hortscience* **42**, 222–224.

Don LD, Van TT, Phuong VYTT and Kieu PTM (2007) Colletotrichum spp attacking on chilli pepper growing in Vietnam. Country report. In Oh DG and Kim KT (eds), *Abstracts of the First International Symposium on Pepper Anthracnose*. Korea: Held at Seoul National University, p. 24 (17-19 Sept 2007).

Garg R, Kumar S, Kumar R, Loganathan M, Saha S, Kumar S, Rai AB and Roy BK (2013) Novel source of resistance and differential reactions on chilli fruit infected by *Colletotrichum capsici*. *Australasian Plant Pathology* **42**, 227–233.

Garg R, Loganathan M, Saha S and Roy BK (2014) Chilli anthracnose: a review of causal organism, resistance source and mapping of gene. In Kharwar RN, Upadhyay R, Dubey N and Raguwanshi R (eds), *Microbial Diversity and Biotechnology in Food Security*. New Delhi: Springer, pp. 589–610.

Geetha R and Selvarani K (2017) A study of chilli production and export from India. *International Journal of Advance Research* **3**, 205–210.

Hartman GL and Wang TC (1992) Characteristics of two Colletotrichum species and evaluation of resistance to anthracnose in pepper. Proc. 3rd International Conference on Plant Protection in the Tropics, vol 6. Malaysian Plant Protection Society, Kuala Lumpur, pp. 202–205.

Hong JK and Hwang BK (1998) Influence of inoculum density, wetness duration, plant age, inoculation method, and cultivar resistance on infection of pepper plants by *Colletotrichum cocodes*. *Plant Disease* **82**, 1079–1083.

Johnston PR and Jones D (1997) Relationships among *Colletotrichum* isolates from fruit-rots assessed using rDNA sequences. *Mycologia* **89**, 420–430.

Katediya MA, Jaiman RK and Acharya SK (2019) Survey and screening of germplasm against chilli anthracnose. *International Journal of Chemical Studies* **7**, 543–545.

Katoch A, Sharma P and Sharma PN (2017) Identification of *Colletotrichum* spp. Associated with fruit rot of *Capsicum annuum* in northwestern Himalayan region of India using fungal DNA barcode markers. *Journal of Plant Biochemistry and Biotechnology* **26**, 216–223.

Kim BS, Park HK and Lee WS (1989) Resistance to anthracnose (Colletotrichum spp.) in pepper. In *Tomato and Pepper Production in the Tropics*. Shanhua: AVRDC, pp. 184–188.

Kim KD, Oh BJ and Yang J (1999) Differential interactions of a *Colletotrichum gloeosporioides* isolate with green and red pepper fruits. *Phytoparasitica* **27**, 1–10.

Latif Y, Sherazi ST and Bhanger MI (2011) Assessment of pesticide residues in commonly used vegetables in Hyderabad, Pakistan. *Ecotoxicology and Environmental Safety* **74**, 2299–2303.2011.07.030.

Mishra R, Rout E and Joshi RK (2018) Identification of resistant sources against anthracnose disease caused by *Colletotrichum truncatum* and *Colletotrichum gloeosporioides* in *Capsicum annuum* L. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences* **89**, 517–524.

Montri P, Taylor PWJ and Mongkolporn O (2009) Pathotypes of *Colletotrichum capsici*, the causal agent of chili anthracnose, in Thailand. *Plant Diseases* **93**, 17–20.

Pae DH, Yoon JY and Lee JM (1998) Screening for resistance to *Colletotrichum gloeosporioides* using detached fruits in pepper (*Capsicum annuum*) by high-pressure spray. *Journal of Korean Society and Horticultural Science* **39**, 690–692.

Pakdeevaraporn P, Wasee S, Taylor PWJ and Mongkolporn O (2005) Inheritance of resistance to anthracnose caused by *Colletotrichum capsici* in *Capsicum*. *Plant Breeding* **124**, 206–208.

Park KS and Kim CH (1992) Identification, distribution, and etiological characteristics of anthracnose fungi of red pepper in Korea. *Korean Journal of Plant Pathology* **8**, 61–69.

Park WM, Park SH, Lee YS and Ko YH (1987) Differentiation of *Colletotrichum* spp. Causing anthracnose on *Capsicum annuum* L. by electrophoretic method. *Korean Journal of Plant Pathology* **3**, 85–92.

Prasath D and Ponnuswami V (2008) Screening of chilli (*Capsicum annuum* L.) genotypes against *Colletotrichum capsici* and analysis of biochemical and enzymatic activities in inducing resistance. *Indian Journal of Genetics and Plant Breeding* **68**, 344–346.

Purkayastha J, Alam SI, Gogoi HK and Singh L (2012) *Capsicum assamicum* sp. nov. (Solanaceae), from Assam, northeastern India. *Ozean Journal of Applied Sciences* **5**, 55–66.

Ranathunge NP, Mongkolporn O, Ford R and Taylor PWJ (2012) *Colletotrichum truncatum* pathosystem on *Capsicum* spp.: infection, colonization and defence mechanisms. *Australasian Plant Pathology* **41**, 463–473.

Ridzuan R, Rafii MY, Ismail SI, Yusoff MM, Miah G and Usman M (2018) Breeding for anthracnose disease resistance in chili: progress and prospects. *International Journal of Molecular Sciences* **19**, 31–22.

Roy A (2016) Bhut jolokia A. (*Capsicum chinense* Jaqc): a review. *International Journal of Pharmaceutical Sciences and Research* **7**, 882–889.

Saxena A, Raghuvanshi R and Singh HB (2014) Molecular, phenotypic and pathogenic variability in *Colletotrichum* isolates of subtropical region in North-Eastern India, causing fruit rot of chillies. *Journal of Applied Microbiology* **117**, 1422–1434.

Saxena A, Raghuwanshi R, Gupta VK and Singh HB (2016) Pepper anthracnose: the epidemiology and management. *Frontiers in Microbiology* **7**, 1527.

Selvakumar R (2007) Variability among *Colletotrichum capsici* causing chilli Anthracnose in North Eastern India In first international symposium on pepper Anthracnose held at Seoul National University, Seoul, 17-19 Sept 2007.

Sheoran OP, Tonk DS, Kaushik LS, Hasija RC and Pannu RS (1998) Statistical software package for agricultural research workers. In DS Hooda and Hasija RC (eds), *Recent Advances in Information Theory, Statistics & Computer Applications*. Hisar: Department of Mathematics Statistics, CCS HAU, pp. 139–143.

Singh K, Kumar S, Gupta K, Pradheep K and Rajasekharan PE (2018) Genetic resource management and utilisation of horticultural crops in India – A perspective. *International Journal of Innovative Horticulture* **7**, 71–103.

Tenaya IMN, Setiamihardja R and Natasasmita S (2001) Correlation of capsaicin content, fructose, and peroxidase activity with anthracnose disease in chili pepper × red pepper. *Zuriat* **12**, 73–83.

Than PP, Jeewon R, Hyde KD, Pongsupasamit S, Mongkolporn O and Taylor PWJ (2008*a*) Characterization and pathogenicity of *Colletotrichum* species associated with anthracnose on chilli (*Capsicum* spp.) in Thailand. *Plant Pathology* **57**, 562–572. doi: 10.1111/j.1365-3059.2007.01782.x

Than PP, Shivas RG, Jeewon R, Pongsupasamit S, Marney TS, Taylor PWJ and Hyde KD (2008*b*) Epitypification and phylogeny of *Colletotrichum acutatum* JHSimmonds. *Fungal Diversity* **28**, 97–108.

Yoon JB and Park HG (2001) Screening method for resistance to pepper fruits anthracnose: pathogen sporulation, inoculation methods related to inoculum concentrations, post-inoculation environments. *Journal of Korean Society and Horticultural Science* **42**, 382–393.

Yoon JB, Yang DC, Lee WP, Ahn SY and Park HG (2004) Genetic resources resistant to anthracnose in the genus *Capsicum*. *Journal of Korean Society for Horticultural Science* **45**, 318–323.