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RESEARCH ARTICLE

Epidemiology, screening of isabgol (*Plantago ovata* Forsk.) genetic material for resistance sources to downy mildew disease and management strategies

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Abstract

Downy mildew caused by *Peronospora plantaginis* is one of the major threats to isabgol production, resulting in substantial yield losses of crop. The disease incidence varied from 50 to 100% and disease severity index (DSI) level ranged from 40 to 75% on isabgol. Despite of its economic impact, there has been a paucity of information available on epidemiology and resistance sources of isabgol. The research has unveiled critical role of weather factors in development of downy mildew, where, dew precipitation being a pivotal factor for sporangiospores germination showed positive correlation with disease severity. The prevailed minimum temperature 10 °C to maximum temperature 25–30 °C when coincided with night dew precipitation, high relative humidity (> 85%) and less bright sunshine hours (6 to 8 h), favored downy mildew severity. In the present study, 213 breeding lines, 160 recombinant inbred lines (RILs), 75 germplasm of isabgol and 6 *Plantago* species were screened for resistance against downy mildew disease. The lowest disease severity among the breeding lines was 0.47 ± 0.09 on DPO-185 and the highest 8.10 ± 0.06 recorded on DPO-183; in RILs the lowest was 0.66 ± 0.05 on RIL-4 and the highest was 7.99 ± 0.09 on RIL-32, and in germplasm lowest DSI 0.8 ± 0.24 recorded on PB-80. Additionally, the efficacy of nine fungicides was evaluated by applying three consecutive spray and the mixed ψ Metalaxyl 4% + Mancozeb 64% was found to the best in suppressing the disease severity (84.9%) over the check. The identified resistant lines hold promise for the development of resistance varieties. The findings of epidemiological investigation and fungicides evaluation will offer the valuable insights for devising management strategies to mitigate the losses caused by downy mildew disease in isabgol.

Keywords *Peronospora plantaginis* · Severity · Temperature · Dew precipitation · Fungicides

Introduction

Isabgol (*Plantago ovata* Forsk.) belongs to herb family *Plantaginaceae*, is an important medicinal crop, commercially grown in India. The external seed coat 'husk' is an excellent source of dietary fibre, possessing several medicinal properties and is used worldwide for constipation and irritation of digestive tract (Dhar et al. 2005). India is the leading country in area and production as well as the largest exporter of isabgol in the world. Commercially, isabgol is grown during the Rabi season in Rajasthan, Gujarat, Madhya Pradesh and some parts of Haryana in India. The crop is also grown in some parts of Pakistan, Iran, Afghanistan and Egypt (Janakiram et al. 2019). Arid climatic zones are the best-suited ecology for commercial cultivation of this crop, which does not receive summer rain, especially after anthesis (Rathore and Pathak 2002a, b; Patel et al. 2014). Increasing demand for the crop products in the international market gradually pushed up the cultivated acreage in India (Maiti and Mandal 2000; Janakiram et al. 2019). In the dry tracts of India, isabgol cultivation provides an excellent opportunity with good returns to the growers, under minimal fertilizer application.

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Isabgol production is highly influenced by biotic and abiotic factors. Among the abiotic factors, the crop is highly sensitive to unseasonal rainfall (during summer), particularly after flowering which causes complete failure of the crop. On the other hand, wilt, downy mildew diseases and aphid (pests) are the major biotic factors that affect the production of the crop (Mandal and Geetha 2001; Shivakumara et al. 2019; Meena and Roy 2020). Downy mildew (DM) of isabgol caused by *Peronospora plantaginis* (Underwood), belongs to the class *Oomycetes* and is an obligate (biotrophic) fungus. The pathogen survives on seeds and plant debris, and is disseminated by the airborne sporangiospores (Mandal and Geetha 2001). The DM imposes a major threat to production and causes enormous yield losses. The pathogen invades the leaf as well as inflorescence and produce a variety of symptoms. The infected leaves showed a significant reduction in the net photosynthetic rate as a result of the degradation of primary photosynthetic pigments (chlorophyll), while the respiration rate was increased, which ultimately caused serious yield reduction (Mandal et al. 2009). To mitigate the yield losses by fungal diseases, fungicides are indispensable components, particularly against biotrophic pathogens (Carmona et al. 2020). However, control of phytopathogens using chemical fungicides is neither economically nor ecologically suitable, and could adversely affect human health (Houeto et al. 1995). Fungicidal resistance, limits the long-term viability, observed in the management of downy mildew diseases (Keinath et al. 2008; Hausbeck and Cortright 2009). Application of fungicides has been discouraged, particularly in medicinal crops, as raw material is directly used in food commodities, drugs and traditional formulations.

Since, host resistance is one of the best strategies for economical and eco-friendly management of downy mildew diseases, irrespective of the crops. Identification of resistance sources from the genetic resources provided durable and stable resistance against diseases. Several identified resistance sources have been utilized in breeding programs to develop resistance lines and hybrids (Thakur and Mathur 2002). Since downy mildew is one of the most destructive diseases of isabgol, prompted us to explore and identify the resistance sources. Therefore, in the present study, available genetic material of isabgol including 213 breeding lines, 160 recombinant inbred lines (RILs), 75 germplasm and 6 *Plantago* species, which were showing significant phenotypic variation, were screened for DM resistance under natural infections as well as artificially inoculated conditions. This information will significantly help the breeders in isabgol research, where conventional breeding is of paramount importance and to develop management strategies for downy mildew. Besides that, some of the commercially available fungicides were tested for their efficacy in management and the influence of the weather factors , which play a crucial role in the development of downy mildew disease was established.

Methods and materials

Experimental site and cultivation measures

The total evaluated material of isabgol comprised breeding lines, recombinant inbred lines (RILs) and accessions, collected from different parts of India and maintained at ICAR-Directorate of Medicinal and Aromatic Plants Research (ICAR-DMAPR), Anand in Gujarat were screened against DM disease. The soil texture was sandy loam to loamy with 7.62 pH, EC was 0.27 dSm-1, organic carbon 0.30–0.40% (medium), whereas available N_2 250–280, P_2O_5 40–50 and K_2O_5 250–300 kg ha^{-1} was medium in soil. Seeds were sown in lines following the statistically randomized block design and each replicated thrice at Research Farm, ICAR-DMAPR (located at 22°35' N and 72°55' E) at an altitude of about 45.1 m above mean sea level. The experimental seeds were sown during the first or second fortnight of November in 2015, 2016 and 2017 and data were recorded followed by the first appearance of disease symptoms. The standard agronomical practices were followed for cultivation and the recommended dose of fertilizers were applied in crop during the experiments.

Influence of weather factors on downy mildew

In this study, the impact of weather factors including maximum and minimum temperature (MAX T & MIN T), relative humidity (RH1& RH2), rainfall (RF) and bright sunshine (BSS) hours were considered. Along with the weather data, cumulative daily dew precipitation was also recorded. The weekly cumulative values of weather data were calculated by adding everyday values. The disease severity of downy mildew was evaluated based on the data recorded during 2015–16, 2016–17 and 2017–18 for consecutive three years. The weather data was obtained from the Meteorology department at Anand Agriculture University (AAU), Gujarat, India.

Inoculum production and application

Downy mildew of isabgol caused by *Peronospora plantaginis,* is an obligate fungal pathogen. The fresh spores of *P. plantaginis* collected from substrata of naturally infected leaves of infector rows of highly susceptible line, (DPO-14). The spores (sporangiospores) of fungus washed off in normal tap water for inoculation, the spore concentration was adjusted to $1 \times 10^{3-4}$ spores/ml of the inoculum, measured with a hemocytometer. To test, the experimental material

was inoculated by spraying the inoculums during the evening hours. The first inoculation was applied at the anthesis stage, during the second fortnight of December to the first fortnight of January when the conducive environmental condition coincided with pathogenesis and disease development. Three consecutive inoculation sprays of the spores were applied at 15 days interval after the first appearance of disease symptoms in the field.

Screening of isabgol genetic resources for disease resistance

The genetic material of isabgol included 213 breeding lines, 160 recombinant inbred lines (RILs), 75 germplasm of isabgol and 6 *Plantago* species were screened against downy mildew disease. The whole plant was considered as a single unit. The measure of disease viz., per cent disease incidence (DI), were recorded in 100 plants and to evaluate the disease severity index (DSI), data were recorded followed by 15 days after 3rd inoculation spray, which fell around 80–85 days after sowing, on 10 plants from each replication of each accession/ germplasm. DSI was calculated by assigning the 0–9 scoring scale as described by Saari and Prescott (Saari and Prescott 1975) with some modifications, based on the visual symptoms on host in response to infection (Fig. 1). The degree of either resistance or susceptible were classified as: 0–1 scale; highly resistant, 2–3; resistant, 3–5; moderately resistant, 5–7; susceptible and 8–9; highly susceptible to downy mildew of isabgol, as described (Suppl. table 1). Within an accession/ germplasm/ line, even a single leaf sowing the disease rating of 8–9 was considered highly susceptible. The disease severity index (DSI) was calculated based on the assigned values of disease scoring scale (0–9) to the infected areas of leaves.

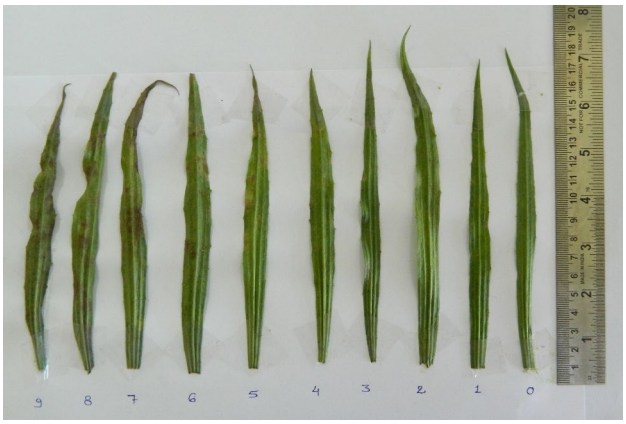

Fig. 1 Downy mildew of isabgol disease severity index (DSI) scoring scale on isabgol developed based on the relative values of leaf portion infected, where: 0- immune, 1–2 Resistant, 3–4 Moderately resistant, 5–6 Moderately susceptible, 7–8 Susceptible and 8–9 Highly susceptible

The disease incidence (DI) was calculated using the following formula:

$$\text{Disease incidence (DI)} = \frac{\text{Total infected plants number}}{\text{Total number of plants observed}} \times 100$$

where the disease severity index (DSI) was calculated using the formula (Wheeler, 1969).

$$\text{Disease severity index (DSI)} = \frac{\sum(\text{Class frequency} \times \text{Score of rating class}}{(\text{Total no of observations}) \times (\text{Maximum disease index})} \times 100$$

Evaluation of fungicides efficacy

The efficacy of seven commercially available fungicides and two salts (salicylic acid (SA) and potassium permanganate (KMno4)) were tested against *P. plantaginis* causing downy mildew of isabgol as described in Table 4, under the field conditions. Three foliar sprays of the tested fungicides were applied using knapsack sprayer. The first spray was applied followed by the appearance of downy mildew symptoms for the first time and 2nd and 3rdsprays were given at two weeks intervals. Followed by 10 days of 3rd spray application, the disease severity was recorded on a minimum of 10 plants of each replication from every treatment. The control plot received three sprays of distilled water similar to fungicides application.

Statistical analysis

The analysis of variance was calculated for various observations recorded form randomized block design during the experiment by using statistical software. The Least significant difference was calculated at 5% ($P = 0.05$). The critical difference (CD) values were calculated to compare the various treatment means. The relative influence of the weather factors on downy mildew disease was analyzed through correlation.

Results and discussion

Symptoms and disease incidence

The downy mildew pathogen of isabgol infected the foliage and caused a variety of symptoms on leaves and inflorescences. Under conducive environmental conditions, furry downy growth appeared on the abaxial (lower) side and

Fig. 2 Symptoms of isabgol downy mildew (**A**) Symptoms of downy mildew developed under typical congenial conditions for disease (**B**) Systemic infection on inflorescences induced male and female sterility and reduced the size of floral parts (**C**) compare to the healthy (**D**) Necrosis on severely infected leaves of isabgol

yellowing on the adaxial (upper) surface of leaves in initial stages (Fig. 2a). In the advancement of the disease, the characteristic grey furry growth of sporangiophores was evident and pathogen growth was observed on both surface of the leaves. Similar symptoms were observed by the earlier workers on isabgol (Mandal and Geetha 2001; Molekar et al. 2017). The systemic infection on inflorescences induced male and female sterility and reduced the size of floral parts compared to the healthy (Fig. 2b and c). Downy mildew pathogen developed profuse sporangiospores and covered the reproductive organs, stem and other aerial parts of the plantains. At a later stage, due to higher disease severity, necrosis started and eventually leaves dried up (Fig. 2d). The disease incidence in the experimental field varied from 50 to 80% during the experimentation, whereas screened lines showed wide variability in resistance and the disease incidence recorded up to 100%, significantly influenced by the prevailing weather conditions. It also induced long spike bearing sterile floret, turning to blackish and adversely affecting the seed yield around 70% of the isabgol (Fig. 3a and b) as earlier workers observed (Mandal et al. 2010; Molekar et al. 2017). Similar results were observed in other crops where the floral infection affect the reproductive parts resulting in yield reduction and also aids in long distance dissemination of the pathogen.

Epidemiology of the disease

It has been well established from previous studies, that the development of downy mildew diseases is significantly influenced by weather factors such as temperature, relative humidity, prolong leaf wetness, etc. (Pugliese et al. 2011; Mandal et al. 2010). The data revealed that downy mildew disease symptoms appeared in first and second week of January on the isabgol leaves, therefore, weather data of two months i.e., December, (no disease

Fig. 3 Downy mildew infected inflorescences (spike) turned into blackish and reduced the economic yield

symptoms) and January (disease symptoms appeared) considered for further analysis (Table 1). At the initial stage of visible symptom appearance, the weekly Max T was varying between 26.2 and 31.8 °C and the prevailing Min T was 9.3 to 10.4 °C. Relative humidity, RH1 was between 87 and 94% whereas RH2 ranged from 36.4 to 40%. Similarly, the bright sunshine (BSS) hours varied between 6.4 to 8.7 and the dew precipitation 10.5 to 12.5 h. The analysis also revealed that high relative humidity and less BSS hours favored the disease development (data not shown). The correlation index was analyzed between disease severity and weather parameters, indicated that the development of downy mildew and the severity of disease was highly influenced by the minimum temperature and dew perception hours as presented (Table 2). The correlation study revealed impact of weather factors showed that the disease severity and the Min T are negatively correlated (− 0.216), whereas dew precipitation was found to be significant and positively correlated (0.694). There was no significant effect of RH2

Table 1 Weekly weather parameters at the time of downy mildew initiation and previous week during 2016, 2017 and 2018

Weather Parameters	2015–16		2016–17		2017–18		Mean	
	Previous week	Disease initiation week	Previous week	Disease initiation week	Previous week	Disease initiation week	Previous week	Disease initiation week
Max. Temp. (°C)	27.5	28.2	30.0	26.2	31.6	29.1	29.70	27.83
Min. Temp. (°C)	10.7	6.6	10.4	9.3	10.6	12.2	10.56	9.36
RH-1(%)	90.3	93.9	96	90	92	90	92.76	91.10
RH-II (%)	44.0	33.4	41.0	38.0	35.0	38.0	40.0	36.46
BSS (hrs)	7.4	6.8	8.7	8.5	9.6	7.0	8.56	7.43
RF (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Dew precipitation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 2 Impact of different weather parameters on downy mildew of isabgol

Month	Std. week	DSI	Rainfall (mm)	Max T (°C)	Min T (°C)	RH 1	RH2	BSS (Hrs.)	Dew Precipitation
Dec., 2015	49	0.00	0	33.0	11.7	86	32	9.5	7.5
	50	0.00	0	28.6	10.5	85	32	9.4	8.5
	51	0.00	0	27.7	8.1	78.1	30.4	9.4	8.6
	52	0.00	0	25.3	8.3	68.6	28.3	7.8	8.8
Jan., 2016	1	7.78	4.4	31.9	10.7	94.1	36.4	6.4	10.5
	2	16.67	0	30.0	10.4	92.3	39.4	8.1	12.8
	3	50.00	0	27.5	10.2	90.3	44.0	7.3	12.5
	4	74.44	0	28.2	6.6	93.9	33.4	6.7	12.6
Dec., 2016	49	0.00	0	30.8	12.8	87.4	37.7	8.0	8.6
	50	0.00	0	31.3	11.5	92.6	36.1	7.0	8.7
	51	0.00	0	30.0	10.9	94.6	36.4	9.5	8.9
	52	0.00	0	30.0	10.4	93.1	33.9	9.1	10.2
Jan., 2017	1	0.00	0	28.5	10.2	96	41	8.7	10.5
	2	11.11	0	26.2	9.3	90	38	8.5	11.8
	3	45.56	0	26.8	12.0	81	45	8.0	12.7
	4	57.78	0	31.1	13.5	93	39	8.9	12.9
Dec., 2017	49	0.00	5.4	24.9	16.1	86	65	2.7	9.0
	50	0.00	0.0	28.7	13.9	87	45	6.7	10.0
	51	0.00	0.0	27.2	14.3	71	42	4.4	9.0
	52	0.00	0.0	25.2	8.5	78	31	8.0	11.0
Jan., 2018	1	7.78	0	27.2	9.4	87	40	8.7	12.5
	2	11.11	0	27.5	13.2	77	40	6.2	13.5
	3	16.67	0	31.2	12.3	85	37	9.3	11.6
	4	34.44	0	29	8.8	92	35	9.4	13.6

and BSS hours but showed weak positive correlation with disease severity (Table 3). In earlier studies, the impact of different weather factors was analyzed under controlled conditions where continuous leaf wetness, around 20 °C temperature and 100% relative humidity were found to be optimum for spore germination (Sain and Sharma 1999). Besides, occurrence of humid and cold weather coinciding with flower development stages may also play an important role in production of different symptoms (Spring 2001).

Table 3 Correlation of different weather parameters and downy mildew incidence

Sr. no	Weather factors	Correlation coefficient (r)
		Disease severity Index
1	Temp. (max.)	0.01
2	Temp. (min.)	− 0.20
3	RH 1	0.26
4	RH2	0.05
5	BSS (Hrs.)	0.05
6	Dew precipitation	0.67

Screening of isabgol accessions for disease resistance

Since, seed and husk of isabgol are often consumed raw, therefore resistant varieties would be the better option to combat and minimize the losses. The genus *Plantago* consists of more than 270 species, which includes out breeding and inbreeding system (Sharma et al. 1999; Lal et al. 1999). Considering the variability observed in the isabgol genetic resources available at the ICAR-DMAPR, Anand, India, to explore the potential source of resistance to downy mildew 213 breeding lines, 160 RILs and 75 germplasm of isabgol (*Plantago ovata*) showed variable measure on disease scoring scale from 0.2 to 8.1 (Table 4). Within the screened breeding lines based on the three years of pooled data, the lowest disease score was at 0.47 ± 0.09 of DPO-185 followed by 1.23 ± 0.09 of DPO-155 and highest scoring was recorded at 8.10 ± 0.06 of DPO-183 followed by 8.07 ± 0.09 on DPO-14 and DPO-210. Among the 160 RILs, lowest was at 0.66 ± 0.05 on RIL-4 followed by 0.90 ± 0.09 on RIL-3 and highest was recorded at 7.99 ± 0.09 on RIL-32. Further, among the screened 75 germplasm lowest disease score 0.8 ± 0.24 recorded on PB-80 and the highest was 8.1 ± 0.27 on DM-11. Additionally, all the other six species viz., *Plantago lanceolate, P. serrana, P. arinaria, P. indica, P. carnopus* and *P. psyllium* were highly resistant against downy mildew under the field conditions. Moreover, the 6 *Plantago* spp. entries found virtually free from disease symptoms. Based on the three-year pooled relative values assigned (0–9 disease scoring scale) to the genetic resources, either resistant or susceptible were categorized in ten classes. Earlier workers also attempted to identify the resistance sources for downy mildew (Patel and Desai 1987; Patel et al. 2014) by screening the germplasm following the 0–5 disease rating scale and with the limited genetic resources of isabgol and ashwagandha (Meena et al. 2019) . Moreover, the present study confirmed the resistance of earlier screened entries. The germplasm EC-124345, Sel 10 and RI 130 were earlier identified as resistant or moderately resistant against downy mildew at Udaipur, Rajasthan (Sain and Sharma 1999). However, Sel-10 was found to be susceptible in the present experiment.

Evaluation of fungicidal efficacy

Downy mildew pathogen is a biotrophic fungus having host-specific tendency in nature and sometime under favorable weather conditions causes immense economic losses to the crop as observed in the previous studies (Rathore and Pathak 2002b). Under such circumstances, chemical fungicides are indispensable assets for disease control and fetching remunerable prices. The highest disease severity 82–87% was recorded under the epiphytotic conditions in the control (untreated) plot. Similarly, disease severity of 57% and 15% were recorded by earlier workers in the control plots using 0–5 disease scoring scale (Sain and Sharma 1999; Mandal et al. 2007). This may be due to different environmental conditions and agronomic practices such as date of sowing, application of nitrogenous fertilizers etc. (Rathore and Pathak 2001; Mandal et al. 2008). Earlier in the 70 s Desai and Desai found aureofungin effectively controlling downy mildew of isabgol (Desai and Desai 1969). In the present study, fungicides were applied at two-week intervals and disease severity was recorded followed by 3rd spray. The results presented (Table 5) showed that the combined fungicide Metalaxyl 4% + Mancozeb 64% was found to be best in suppressing the disease severity (84.9%) over the check. The disease severity in the Metalaxyl 4% + Mancozeb 64% treated plot recorded 12.8% followed by 33.17% in azoxystrobin treated plot. Based on two years data 42% and 48% disease severities were recorded in the mixed fungicide i.e., trifloxystrobin 25% and tebuconazole 50% and tebuconazole treatments, respectively. Besides, two salts; salicylic acid (SA) and potassium permanganate ($KMNO_4$) were also tested for the management of the disease but not found effective in suppressing the disease. The effectiveness of metalaxyl-based fungicides in the management of downy mildew diseases in other crops, such as on onion (Develash and Sugha 1997) cucumber (Bhat et al. 2018), sweet basil, etc. (McGrath 2020) were reported. In isabgol, three sprays of Metalaxyl 4% + Mancozeb 64% at 0.20% were found to be most effective with minimum disease intensity (Sain and Sharma 1999). In another study (Mandal et al. 2007) seed treatment and three foliar sprays of Metalaxyl 4% + Mancozeb 64% were found best in suppressing the downy mildew disease.

Table 4 Screening of isabgol genetic material against downy mildew under field conditions

Scoring	Rating	Description of leaf portion infected (%)
0–2.0	*Highly Resistance*	**BL:** DPO-185, DPO-155, DPO-101, DPO-22, DPO-145, DPO-148
		RILs: RIL-4, RIL-3, RIL-8, RIL-111, RIL-107, RIL-30, RIL-36, RIL-6, RIL-9, RIL-22, RIL-115, RIL-24, RIL-5, RIL-137, RIL-103, RIL-108, RIL-14, RIL-7, RIL-116, RIL-26, RIL-70, RIL-119, RIL-117, RIL-1, RIL-105, RIL-72, RIL-21, RIL-19, RIL-109, RIL-112, RIL-69, RIL-106, RIL-25, RIL-61, RIL-31, RIL-143, RIL-18, RIL-2, RIL-38, RIL-99, RIL-133, RIL-113, RIL-62, RIL-97, RIL-135, RIL-114, RIL-94, RIL-120, RIL-98, RIL-110, RIL-60, RIL-71, RIL-134, RIL-104, RIL-10
		GP: PB-80, EC-124345, MIB-4, Palampur-2, DM-4, DM-3, MIB-122, A-24, PB-62, RI-9808, EC-52095
2.1–4	*Resistance to Moderately resistance*	**BL:** DPO-75, DPO-129, DPO-65, DPO-100, DPO-135, DPO-107, DPO-201, DPO-40, DPO-114, DPO-204, DPO-19, DPO-195, DPO-102, DPO-150, DPO-91, DPO-93, DPO-45, DPO-51, DPO-23, DPO-191, DPO-50, DPO-154, DPO-9, DPO-113, DPO-152, DPO-25, DPO-213, DPO-7, DPO-26, DPO-24, DPO-10, DPO-81, DPO-103, DPO-127, DPO-134, DPO-48, DPO-68, DPO-70, DPO-86, DPO-3, DPO-64, DPO-46, DPO-128, DPO-194, DPO-54, DPO-133, DPO-8, DPO-95, DPO-39, DPO-77, DPO-99, DPO-89, DPO-1, DPO-71, DPO-90, DPO-5, DPO-144, DPO-94, DPO-85, DPO-146, DPO-186, DPO-203, DPO-104, DPO-58, DPO-49, DPO-147, DPO-116, DPO-87, DPO-18, DPO-69, DPO-57, DPO-78, DPO-92, DPO-4, DPO-28, DPO-63, DPO-98, DPO-43, DPO-111, DPO-80,
		RILs: RIL-11, RIL-128, RIL-87, RIL-12, RIL-20, RIL-95, RIL-35, RIL-139, RIL-138, RIL-136, RIL-37, RIL-96, RIL-81, RIL-67, RIL-101, RIL-131, RIL-141, RIL-34, RIL-33, RIL-102, RIL-17, RIL-68, RIL-85, RIL-82, RIL-118, RIL-92, RIL-13, RIL-130, RIL-16, RIL-15, RIL-148, RIL-132, RIL-76,RIL-159, RIL-158, RIL-65, RIL-91, RIL-43, RIL-66, RIL-123, RIL-122, RIL-150, RIL-93, RIL-28, RIL-78, RIL-44, RIL-90, RIL-146, RIL-23, RIL-129, RIL-88, RIL-147, RIL-140, RIL-127, RIL-145, RIL-155, RIL-54
		GP: DM-3, HI-9, UR-188, PB-10–4, MIB-125, MIB-2, RI-130, PB-81, HI-8, MSB-8, RI-153, AM-6, PB-3–1, GI-3, AMD-29, AMB-2, RI-89, Palampur-3, EC-427062
4.1–7	*Moderately susceptible to susceptible*	**BL:** DPO-55, DPO-121, DPO-97, DPO-115, DPO-137, DPO-106, DPO-96, DPO-139, DPO-200, DPO-143, DPO-60, DPO-172, DPO-59, DPO-88, DPO-110, DPO-212, DPO-41, DPO-117, DPO-178, DPO-13, DPO-142, DPO-187, DPO-130, DPO-157, DPO-136, DPO-171, DPO-173, DPO-140, DPO-11, DPO-122, DPO-118, DPO-31, DPO-131, DPO-138, DPO-119, DPO-53, DPO-61, DPO-108, DPO-141, DPO-17, DPO-74, DPO-38, DPO-225, DPO-6, DPO-15, DPO-73, DPO-205, DPO-174, DPO-27, DPO-149, DPO-211, DPO-125, DPO-16, DPO-214, DPO-12, DPO-82, DPO-34, DPO-123, DPO-224, DPO-21, DPO-199, DPO-216, DPO-30, DPO-52, DPO-109, DPO-175, DPO-188, DPO-181, DPO-221, DPO-196, DPO-206, DPO-222, DPO-20, DPO-197, DPO-189, DPO-192
		RILs: RIL-75, RIL-89, RIL-154, RIL-77, RIL-142, RIL-126, RIL-83, RIL-121, RIL-84, RIL-55, RIL-144, RIL-86, RIL-80, RIL-160, RIL-56, RIL-74, RIL-64, RIL-157, RIL-149, RIL-153, RIL-53, RIL-125, RIL-51, RIL-42, RIL-52, RIL-156, RIL-57, RIL-73, RIL-59, RIL-151, RIL-152, RIL-63, RIL-46, RIL-100, RIL-124, RIL-50, RIL-79, RIL-29, RIL-40
		GP: RI-129, MI-4, DM-5, RI-157, Mutant, PB-31, RI-49, PS-19, RI-88, HI-6, P-6, P-33, MS, DM-1, P8-6–3, HI-29, PB-6–1, DM-10, RI-158, MIB-121, P-1, JI-9, MIB-2, RI-149, P-79, SEL-10, DM-4, J-16, MIB-124, Niharika, HI-34, DM-8, RI-156, PS-17, RI-9809, PB-96, GI-1
7.1–9	*Highly susceptible*	**BL:** DPO-33, DPO-208, DPO-218, DPO-112, DPO-124, DPO-120, DPO-198, DPO-47, DPO-72, DPO-37, DPO-62, DPO-190, DPO-193, DPO-29, DPO-182, DPO-66, DPO-76, DPO-210, DPO-14, DPO-183
		RILs: RIL-58, RIL-41, RIL-27, RIL-48, RIL-39, RIL-47, RIL-49, RIL-45, RIL-32
		GP: DM-6, MIB-123, HI-5, P-43, DM-2, DM-7, P-44, DM-11

BL = breeding lines, RILs = recombinant inbred lines and GP = germplasm

Conclusion

In conclusion, the study suggested that downy mildew (*P. plantaginis*) is a destructive disease and a major production constraint in isabgol crop. The min temp of around 10 °C, max temp of 25–30 °C and > 10 h of dew precipitation on leaves with high relative humidity and less bright sunshine hours favor infection and severity of downy mildew disease. The isabgol lines DPO 185, DPO-155, RIL-4 and PB-80 may further be used in breeding programs for developing resistant varieties , which will help to mitigate the losses. The combined fungicide Metalaxyl 4% + Mancozeb

Table 5 Efficacy of fungicides tested against downy mildew of isabgol under field conditions

Sr. No	Treatment	a.i. ha^{-1}	DI in 2016	DI in 2017	Pooled data	Disease suppression (%) over check
T_1	Mancozeb	938 g	52.00 ± 1.16 (46.13)	50.66 ± 1.76 (45.36)	51.33	39.49
T_2	Copper oxychloride (COC)	625 g	66.67 ± 1.76 (54.73)	68.67 ± 1.76 (55.96)	67.68	20.22
T_3	Copper Hydroxide (COH)	670 g	37.67 ± 1.45 (37.84)	35.67 ± 1.20 (36.65)	36.67	56.77
T_4	Metalaxyl 4% + Mancozeb 64%	50 g and 800 g	13.67 ± 0.88 (21.67)	12.00 ± 1.16 (20.22)	12.83	84.87
T_5	Azoxystrobin	115 g	34.33 ± 1.20 (35.85)	32.00 ± 1.16 (34.43)	33.17	60.89
T_6	Trifloxystrobin 25% and tebuconazole 50%	125 g and 250 g	42.33 ± 1.45 (40.57)	41.67 ± 2.03 (40.18)	42.00	50.48
T_7	Tebuconazole	130 g	50.00 ± 1.16 (44.98)	46.00 ± 1.16 (42.69)	48.00	43.41
T_8	Salicylic acid (SA)	150 g	72.33 ± 2.19 (58.27)	69.00 ± 1.73 (56.16)	70.67	16.69
T_9	Potassium permanganate (KMno4)	100 g	72.67 ± 1.76 (58.48)	68.00 ± 2.31 (55.56)	70.33	17.09
T_{10}	Control (Distilled water)	–	87.00 ± 1.16 (68.88)	82.66 ± 1.76 (65.43)	84.83	–
	SE(m)		*1.464*	*1.909*		
	C.D		*4.35*	*5.671*		

*DI = disease incidence; Figures in the parentheses indicate angular transformed values

64% showed the maximum suppression of disease severity and can be used in crop protection against downy mildew of isabgol.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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