



Identification of novel source of resistance to powdery mildew in bottle gourd (*Lagenaria siceraria*)

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ABSTRACT

Powdery mildew caused by *Podosphaera xanthii* is one of the prevalent fungal diseases causing significant economic loss in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. The present study was carried out during 2021 to 2023 at ICAR-Indian Agricultural Research Institute, New Delhi to identify the novel source of resistance to powdery mildew in bottle gourd. About 82 diverse genotypes of bottle gourd were screened under controlled conditions and experiment was conducted in three replications with five seedlings in each germplasm. The seedlings were artificially inoculated with powdery mildew spores using dusting method at cotyledonary leaf stage. Disease severity on 0–9 scale was recorded from 7–28 days post inoculation. The mean per cent disease index (PDI) value at 4 weeks post inoculation (WPI) ranged from 0.00–98.52% (2021), 0.74–93.33% (2022), and 0.00–97.04% (2023) across the years of screening. Disease pressure was high over the years as indicated by higher PDI shown by susceptible genotypes. A rapid increase in PDI was recorded during 1–2 WPI, reaching highest at 4 WPI. This suggests that preventive measures to control powdery mildew should be implemented as soon as symptoms appear in the field. Three genotypes, viz. EC800996, EC800998 and IC337078 were identified as resistant having low pooled mean PDI value ranging from 0.00–8.89%. Moderate resistant reaction was reported in Pusa Santusthi, IC296733, EC1085257, EC1085231, IC567545, and IC567534. Additionally, low values of AUDPC and rAUDPC further indicates slow progression of disease after inoculation in resistant and moderately resistant genotypes. The resistant genotypes identified may serve as potential source for resistance breeding against powdery mildew in bottle gourd.

Keywords: AUDPC, Bottle gourd, PDI, Powdery mildew, rAUDPC,

Bottle gourd [*Lagenaria siceraria* (Mol.) Standl.], popularly known as Calabash, white flowered gourd (Jeffrey 1967), lauki, ghiya or dhodh. It is monoecious, annual vine herb belongs to the cucurbitaceae family and cultivated in tropical and subtropical regions of the world. It is native of African region, and domesticated independently in Africa and Asia (Whitaker 1971, Heiser 1979, Chakravarty 1982, Walters *et al.* 2001). Bottle gourd is very popular vegetable of India, cultivated in about 0.20 million ha with an annual production of 3.36 million MT (Anonymous 2022–23). Among the various biotic and abiotic factors affecting its successful cultivation, powdery mildew (PM) caused by *Podosphaera xanthii* (Castagne) Braun and Shishkoff (syn. *Sphaerotheca fuliginea* auct. p.p.) is one of the most prevalent foliar diseases. It has ability to infect various plant parts, viz. hypocotyls, cotyledons, stem, leaves, fruits (Jahn *et al.* 2002, Cohen *et al.* 2004, Kousik *et al.* 2008

and 2011, McGrath 2017), and also reduces seedling vigour in bottle gourd (Kousik *et al.* 2008, McGrath 2017). The characteristic symptoms include the development of whitish, talcum-like powdery fungal growth on leaves, petioles and stems (Sitterly 1978, Zitter *et al.* 1996). Further, severe infestation leads to premature defoliation, undersized and deformed fruits and death of vines. It not only affects the yield but also reduces the fruit quality due to powdery growth on them. Bottle gourd remains susceptible to powdery mildew throughout its growth stages, leading to significant yield loss. Consequently, it has emerged as the primary foliar disease affecting bottle gourd production globally in recent times (Perez-Garcia *et al.* 2009, McGrath 2017, Zhang *et al.* 2023).

The application of fungicides is the most common method to manage powdery mildew and its success rate depends on the frequency of spraying. However, the use of excessive fungicides poses financial burdens to growers and causes risks to human health and environment. Moreover, it also leads to the development of fungicide resistance in powdery mildew strains (Lebeda *et al.* 2010, McGrath 2017). Hence, cultivation of resistant varieties/hybrids is one of the most practical, simple, economical, environment friendly

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and sustainable approach to manage powdery mildew (Kousik *et al.* 2008 and 2018a, McGrath, 2017). However, the concept of developing resistant/tolerant varieties/hybrids is still not fully implemented in bottle gourd. This is further corroborated by the fact that only few attempts were made by researchers at national and international level to identify stable resistance sources against powdery mildew (Kousik *et al.* 2008 and 2018a). Keeping this in view, the present investigation was carried out to identify stable resistant/tolerant source.

MATERIALS AND METHODS

Plant materials: The present study was carried out during 2021 to 2023 at ICAR-Indian Agricultural Research Institute (28.08°N and 77.12°E, 228.61 m amsl), New Delhi. The experimental material consisted of 82 diverse bottle gourd genotypes, comprising released varieties, indigenous and exotic germplasm collected from various sources and maintained at ICAR-Indian Agricultural Research Institute, New Delhi. The experiment was conducted in three replications with five seedlings in each germplasm and test genotypes were screened using artificial inoculation during the year of 2021, 2022 and 2023 in growth chamber maintained at the temperature range of 20–25°C, with relative humidity 60–70% and a photoperiod of 12 h. Seedlings were raised in 50-cell pro-trays filled with artificial media (coco-peat: vermiculite: perlite in the ratio of 3:1:1 on volume basis).

Powdery mildew isolate and inoculation: The pathogen was isolated from the naturally infected bottle gourd cv. Pusa Naveen leaf samples during Feb–March month of 2021. It was then continuously maintained throughout the years in growth chamber on ‘Pusa Naveen’. The identity of pathogen was confirmed based on sequence similarities of the internal transcribed spacer (ITS) region of rDNA from conidia (Takamatsu and Kano 2001, Hirose *et al.* 2005). For artificial screening, 2-week old seedlings were dusted with conidia from heavily sporulating host leaves for two days (Thomas *et al.* 2005, Davis *et al.* 2006 and 2007, Koushik *et al.* 2008). Screening was carried out in growth chamber for optimal infection and good sporulation of powdery mildew.

Disease scoring and percent disease index (PDI) estimation: Individual seedlings were scored after 7th day of inoculation to 28 days post inoculation at 7 days interval. Scoring was conducted using modified Horsfall-Barrett ten point severity scale (0–9 scale) as per powdery mildew symptoms (Koushik *et al.* 2018b). The scoring criteria were as follows, 0, No disease (0% disease); 1, Very sparse mycelial growth on leaves with few to no visible conidia; 2, 3–6% of area covered with PM and Sparse development of conidia; 3, 6–12% of area covered with PM; 4, 12–25% of area covered with PM; 5, 25–50% of area covered with PM; 6, 50–75% of area covered with PM; 7, 75–87% of area covered with PM and abundant conidia; 8, 87–97% of area covered with PM and abundant conidia; 9, 97–100% of area covered with abundant conidia and leaf/plant dead.

The percent disease index (PDI) for each genotype

were calculated following Wheeler (1969):

$$PDI = \frac{\text{Sum of all disease rating}}{\text{Total number of observations} \times \text{Maximum disease grade}} \times 100$$

Genotypes were classified into five categories based on PDI value at seedling stage, viz. PDI, 0–10% (resistant); PDI, 10–20% (Moderately resistant); PDI, 20–40% (Moderately susceptible); PDI, 40–60% (Susceptible); PDI, >60% (Highly susceptible).

Area under disease progress curve (AUDPC) and relative AUDPC (rAUDPC) estimation: The progression of the disease over time was assessed by determining the AUDPC using formula as given below (Madden *et al.* 2007).

$$AUDPC = \sum_{i=1}^{(n-1)} \frac{y_i + y_{(i+1)}}{2} \times (t_{(i+1)} - t_i)$$

where y_i is an assessment of a disease (percentage) at the i^{th} observation; t_i is time (in weeks) at the i^{th} observation and n is the total number of observations.

The rAUDPC of each genotype was calculated as a percentage of the mean of theoretical maximum AUDPC value (Feng *et al.* 2018). AUDPC and rAUDPC values were determined using excel based calculator, as outlined by Simko (2021).

Data Analysis: Analysis of the variance of the data generated on PDI values, AUDPC values and rAUDPC values were analyzed using SPAR-2.0.

RESULTS AND DISCUSSION

In order to ensure the effectiveness of screening in the study, genotypes were inoculated with pure culture of powdery mildew from susceptible genotype maintained in growth chamber continuously. We confirmed the pathogen through BLAST homology search of 585 bp sequence against GenBank database, which revealed 100% similarity with *P. xanthii* (data not presented). The genotypic variations with respect to PDI became significant from one-week post-inoculation (WPI). The mean PDI values of 82 bottle gourd genotypes at different time points screened over the three years is represented in circular stacked bar plots (Fig. 1). The perusal of data revealed that in the year 2021, average PDI at 4 WPI was 63.84%, ranging from 0.00% (EC800996) to 98.52% (IC-0332281). Similarly, it ranged from 0.74% (EC800996) to 93.33% (Co-1) with average PDI value of 61.66% at 4WPI in year 2022. Further, the average PDI at 4WPI in the year 2023 was 62.85%, with a range from 0.00% (EC800996) to 97.04% (IC-0418265). The PDI value above 90% in susceptible genotype across the years of screening indicates high disease pressure during the experiment. Additionally, it is also reported that pooled PDI (%) value across the years in bottle gourd genotypes ranged from 2.96–87.16% at 3 WPI, which increased to 0.00–94.81% at 4 WPI (Table 1). The average pooled PDI were 55.63% and 63.14%, respectively at 3 and 4 WPI indicating highly susceptible reactions of genotypes against powdery mildew incidence across the years. Three genotypes EC800996, EC800998, and IC337078 were consistently exhibited

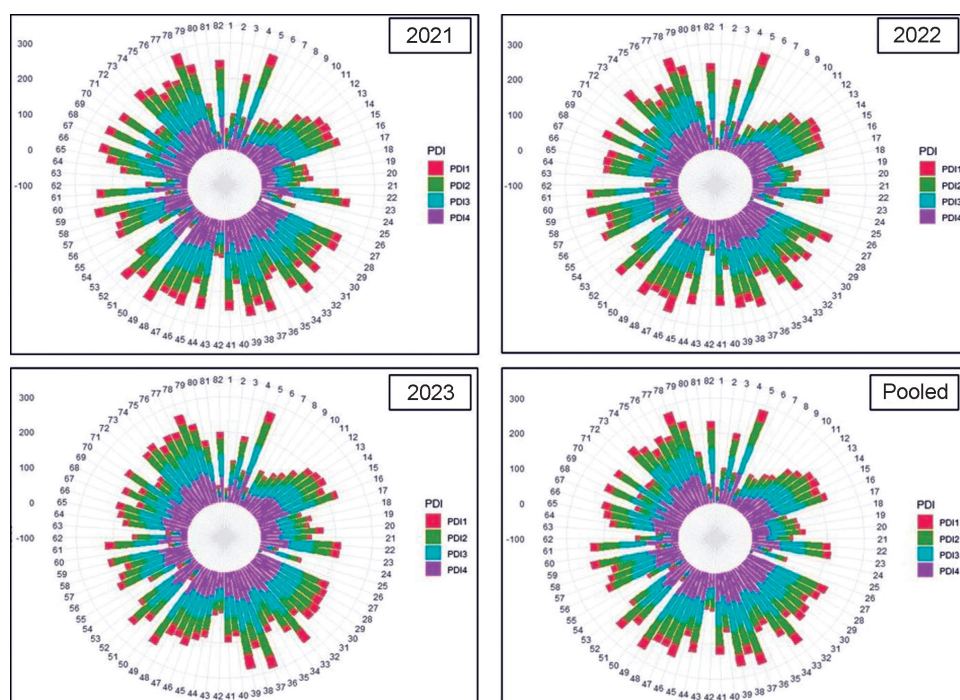


Fig. 1 The average PDI (%) value of 82 bottle gourd genotypes against powdery mildew.

*Genotypes number is as per the number in Table 1; PDI1, Percent disease index at 1 WPI; PDI2, Percent disease index at 2 WPI; PDI3, Percent disease index at 3 WPI; PDI4, Percent disease index at 4 WPI.

low pooled PDI values at 4 WPI ranged from 0.00–8.89% across the years of screening, hence categorized as resistant genotypes. Among the resistant genotypes, lowest pooled PDI value at 4 WPI was recorded in EC800996 (0.00%) collected from USDA as USLV351-PMR followed by EC800998 (5.68%) which is statistically at par. Genotypes, Pusa Santusthi, IC296733, EC1085257, EC1085231, IC567545, and IC567534 were identified as moderately resistant with pooled PDI value ranged from 15.8–19.01% at 4 WPI. However, majority of the released varieties were found susceptible across the years of screening with high pooled PDI value (>40%) against powdery mildew. It has also been reported that several genotypes, including Arka Bahar, EC1085239, EC1085248, EC1085238 and others, exhibited low PDI values at 7 days after inoculation as compared to few resistant and moderately resistant lines. However, these genotypes showed a sudden increase in PDI values at 2 WPI, followed by steady increase at later time points. This variation may be attributed to genetic factors, differences in plant defense mechanisms, gene-environment interactions, and instances where the pathogen overcomes the plant's defenses. A similar pattern was observed by previous researchers in their evaluations against powdery mildew in bottle gourd germplasm (Kousik *et al.* 2008), watermelon (Thomas *et al.* 2005, Davis *et al.* 2006 and 2007, Tetteh *et al.* 2010, Yadav *et al.* 2021) and bitter gourd (Prasanth *et al.* 2019).

The classification of genotypes according to their PDI values at different time points after inoculation with powdery mildew across the years is depicted in Fig. 2. The analysis of

PDI over time revealed that at 1 WPI, most of the genotypes exhibited moderately resistant and moderately susceptible reaction followed by resistant reaction across all three years of screening. However, very few genotypes showed susceptible and none showed highly susceptible reaction. With the advancement to 2 WPI, symptoms development progressed at faster rate as indicated by shifting of majority of the genotypes to moderately susceptible and susceptible category. By 3 and 4 WPI, most of the genotypes exhibits highly susceptible reaction, with very few remains in the other four categories, viz. resistant, moderately resistant, moderately susceptible and susceptible. These findings were further supported with circular stacked bar plots,

which showed that across the years, genotypes exhibited low PDI 1 values (1 WPI). However, PDI 4 (4 WPI) contributed more significantly in stacked bars thus, suggesting that by the 4 WPI majority of the genotypes fall under susceptible category.

The weekly disease growth progress for nine selected bottle gourd genotypes categorized by resistance level, viz. highly susceptible, susceptible, moderately susceptible, moderately resistant, and resistant based on pooled PDI values against powdery mildew (Fig. 3). The graph revealed that in highly susceptible genotypes IC0418265 and Pusa Naveen, disease severity exceeded 60% in second week after inoculation, reached above 80% in 3 WPI, and with its peak during 4 WPI (>90%). In the case of the susceptible genotype Pusa Sandesh and moderately susceptible genotypes IC256043, disease development progressed rapidly in 2 weeks after inoculation, followed by steady growth at subsequent time points. In contrast, moderately resistant genotypes IC567534 and Pusa Santusthi exhibited slower disease progression over the time points studied. The resistant genotypes, viz. EC800996, EC800998, and IC337078, showed mild disease incidence between 1–2 WPI, with symptoms recovery between 2–4 WPI. Thus, at the end of 4 weeks after inoculation, a resistant genotype EC800996 reported completely disease-free and remaining two resistant genotypes (EC 800998 and IC 337078) showed low PDI values (<10%). Therefore, effective management strategies for disease control should be implemented within the identified period based on the observed rate of disease progression. The slower and reduced progression

Table 1 Pooled average PDI (%), AUDPC and rAUDPC of the 82 bottle gourd genotypes screened against powdery mildew for three years (2021–23)

Genotype	Percent disease index				AUDPC	rAUDPC	Category
	PDI1	PDI2	PDI3	PDI4			
EC800998	11.85	16.79	10.62	5.68	253.20	0.12	R
IC0331025	8.89	24.94	30.62	37.78	552.22	0.26	MS
ABG-1	20.49	46.67	64.69	72.59	1105.31	0.53	HS
Arka Bahar	6.42	21.73	28.64	38.02	508.15	0.24	MS
Co-1	35.06	70.37	87.16	94.32	1555.56	0.74	HS
EC 1085231	7.16	12.59	18.02	18.02	302.47	0.14	MR
EC 1085238	8.40	28.15	31.36	38.27	579.88	0.28	MS
EC 1085239	8.15	26.17	30.12	38.02	555.68	0.26	MS
EC 1085240	13.83	27.90	38.77	46.91	679.26	0.32	S
EC 1085241	12.35	29.14	43.70	52.10	735.43	0.35	S
EC 1085242	14.32	38.02	58.27	67.90	961.85	0.46	HS
EC 1085243	16.05	43.21	62.47	72.84	1050.86	0.50	HS
EC 1085244	19.75	54.81	67.41	74.57	1185.68	0.56	HS
EC 1085245	25.43	52.59	66.91	75.06	1188.27	0.57	HS
EC 1085246	22.47	45.43	66.17	75.80	1125.19	0.54	HS
EC 1085247	16.05	44.94	75.06	86.67	1199.51	0.57	HS
EC 1085248	8.40	20.74	33.83	38.77	547.04	0.26	MS
EC 1085249	8.89	32.35	39.51	45.68	693.95	0.33	S
EC 1085250	12.59	26.67	41.98	48.40	693.95	0.33	S
EC 1085251	16.30	34.57	42.22	49.63	768.27	0.37	S
EC 1085252	10.12	27.90	33.33	38.02	597.16	0.28	MS
EC 1085253	20.49	47.90	67.16	74.32	1137.28	0.54	HS
EC 1085254	20.74	47.90	67.41	77.78	1151.98	0.55	HS
EC 1085257	6.91	13.83	17.53	16.79	302.47	0.14	MR
EC800995	8.40	20.74	33.83	38.77	547.04	0.26	MS
EC800996	0.74	4.20	2.96	0.00	52.70	0.03	R
GH-22	28.40	53.33	70.37	81.23	1249.63	0.60	HS
IC-0092336	21.98	52.59	69.38	79.26	1208.15	0.58	HS
IC-0092447	16.05	47.65	63.95	71.60	1088.02	0.52	HS
IC-0092455	20.74	53.33	68.89	77.53	1199.51	0.57	HS
IC-0264909	24.69	51.36	69.88	80.74	1217.65	0.58	HS
IC-0330987	19.26	42.47	63.95	69.88	1056.91	0.50	HS
IC-0332281	30.37	63.46	83.95	92.84	1463.09	0.70	HS
IC-0339206	21.48	55.80	72.10	80.00	1250.49	0.60	HS
IC-0418249	17.78	41.48	54.81	63.70	959.26	0.46	HS
IC-0418258	17.78	40.25	61.73	68.89	1017.16	0.48	HS
IC-0418265	31.36	64.94	86.42	94.81	1501.11	0.71	HS
IC-0418354	25.68	56.79	73.58	83.46	1294.57	0.62	HS
IC-0505648	36.79	60.99	82.72	88.89	1445.80	0.69	HS
IC146391-X	12.35	36.79	55.56	63.70	912.59	0.43	HS
IC204890	26.91	53.83	70.12	80.74	1244.44	0.59	HS
IC256043	8.89	26.67	32.84	40.00	587.65	0.28	MS
IC256043-1	8.89	20.00	33.09	41.98	549.63	0.26	S

Contd.

Table 1 (Concluded)

Genotype	Percent disease index				AUDPC	rAUDPC	Category
	PDI1	PDI2	PDI3	PDI4			
IC256051	28.64	52.35	68.40	79.26	1222.84	0.58	HS
IC260998	19.01	36.05	61.73	70.62	998.15	0.48	HS
IC262313	37.28	61.73	72.35	83.46	1361.11	0.65	HS
IC262957	21.98	58.77	71.11	81.48	1271.23	0.61	HS
IC279630	24.69	58.02	70.86	79.26	1266.05	0.60	HS
IC279634	32.59	61.48	84.20	90.86	1451.85	0.69	HS
IC296733	8.15	12.35	16.54	16.05	286.91	0.14	MR
IC297489	22.72	47.90	70.12	81.98	1192.59	0.57	HS
IC297583	25.93	56.05	85.68	92.84	1407.78	0.67	HS
IC321414	11.85	45.93	61.98	73.09	1052.59	0.50	HS
IC337078	12.59	15.31	15.80	8.89	292.96	0.14	R
IC36240	10.86	24.44	34.81	42.22	600.62	0.29	S
IC385814	18.02	55.56	71.36	80.00	1231.48	0.59	HS
IC415716	17.28	50.12	67.16	74.32	1141.60	0.54	HS
IC538142	18.02	46.42	59.26	68.89	1043.95	0.50	HS
IC548546	23.21	58.27	75.80	85.43	1318.77	0.63	HS
IC567534	10.12	16.05	18.02	19.01	340.49	0.16	MR
IC567534	22.72	55.31	72.84	85.93	1277.28	0.61	HS
IC567545	7.65	15.06	18.77	19.01	330.12	0.16	MR
IC567546	17.78	43.95	59.26	66.17	1016.30	0.48	HS
IC567549	14.07	27.65	34.07	40.00	621.36	0.30	MS
IC567567	22.47	49.14	64.44	71.85	1125.19	0.54	HS
IC570505	24.69	46.91	67.41	79.75	1165.80	0.56	HS
IC-588084	15.56	26.67	41.98	49.88	709.51	0.34	S
Kalyanpur Long Green	23.46	53.83	71.60	80.49	1241.85	0.59	HS
Kashi Ganga	13.33	31.85	43.46	53.58	761.36	0.36	S
Narendra Dharidar	18.77	53.83	72.35	81.48	1234.07	0.59	HS
Narendra Jyoti	14.07	30.62	43.21	53.33	752.72	0.36	S
Narendra Rashmi	10.86	28.15	43.70	55.31	734.57	0.35	S
NDBG-132	28.15	56.05	74.57	82.96	1303.21	0.62	HS
Pant Lauki-3	18.02	45.43	74.07	86.17	1201.23	0.57	HS
Punjab Komal	23.46	45.93	61.48	68.64	1074.20	0.51	HS
Punjab Long	21.23	50.12	73.58	81.73	1226.30	0.58	HS
Punjab Samrat	15.31	48.15	72.10	80.99	1178.77	0.56	HS
Pusa Naveen	38.02	65.93	83.95	91.85	1503.70	0.72	HS
Pusa Samridhi	25.19	56.79	75.31	86.42	1315.31	0.63	HS
Pusa Sandesh	15.31	36.79	45.43	54.07	818.40	0.39	S
Pusa Santusthi	9.63	14.32	17.53	15.80	311.98	0.15	MR
VRBG-6	23.21	53.83	72.35	82.96	1254.81	0.60	HS
Average	18.24	41.16	55.63	63.15	962.38	0.46	-
CD _{0.05}	6.97	7.50	6.55	9.56	128.92	0.061	-
Range	0.74-38.02	4.2-70.37	2.96-87.16	0.0-94.81	52.7-1555.56	0.03-0.74	-

WPI; *Week post inoculation; PDI1, Percent disease index at 1; PDI2, Percent disease index at 2 WPI; PDI3, Percent disease index at 3 WPI; PDI4, Percent disease index at 4 WPI; HS, Highly susceptible; S, Susceptible; MS, Moderately susceptible; MR, Moderately resistant; R, Resistant.

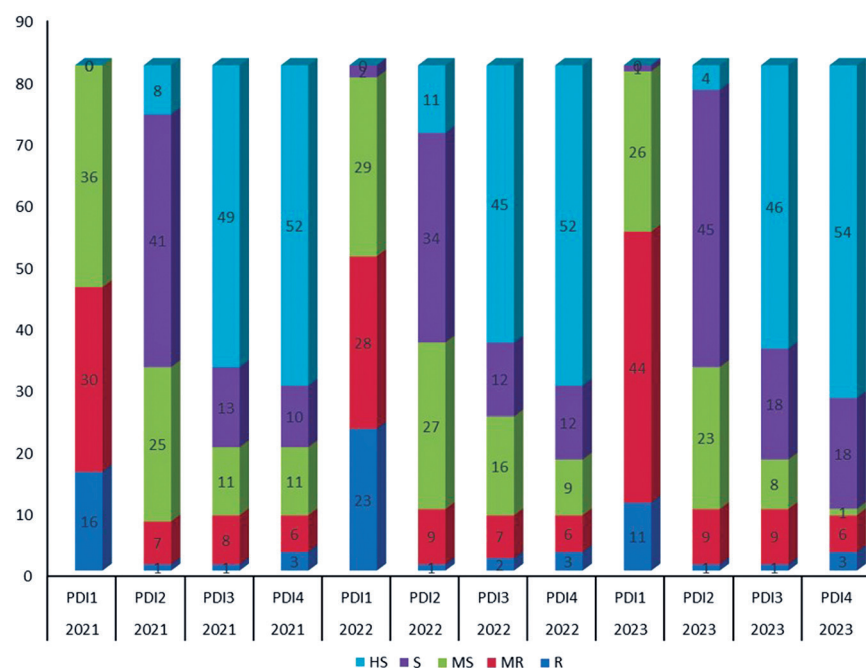


Fig. 2 Categorization of bottle gourd genotypes based on PDI value over the years of screening.

WPI; *Week post inoculation; PDI1, Percent disease index at 1; PDI2, Percent disease index at 2 WPI; PDI3, Percent disease index at 3 WPI; PDI4, Percent disease index at 4 WPI; HS, Highly susceptible; S, Susceptible; MS, Moderately susceptible; MR, Moderately resistant; R, Resistant.

of symptoms after their initial appearance at 1–2 WPI in resistant and moderately resistant genotypes may be attributed to structural barriers and immune responses, such as adult plant resistance, activation of systemic acquired resistance, effector-triggered immunity, hypersensitive reactions, production of antifungal compounds, and activation of resistance genes. These mechanisms collectively limit pathogen growth by restricting nutrient availability, delaying development, and generating reactive oxygen species (Liu *et al.* 2022, Sulima and Zhukov 2022, Xu *et al.* 2022).

The area under disease progress curve (AUDPC) was used to quantify the temporal increase of powdery mildew in bottle gourd genotypes (Table 1). The AUDPC ranged from 52.7–1555.56 with a mean value of 960.12. The lowest value of AUDPC was recorded in the resistant genotype EC800996 while highest in Co-1. Among the resistant genotypes, EC800996 had lowest AUDPC value along with low PDI value followed by EC800998. Thus, indicating the low disease incidence and slow progress

of the disease in resistant genotypes, which can be utilized in powdery mildew resistance breeding. In case of six identified moderately resistant genotypes, IC296733 had the lowest disease progression followed by EC 1085257. Additionally, it is also reported that in genotype IC296733 had low AUPDC value as compared to resistant genotypes, viz. IC337078. Therefore, suggesting that though the disease incidence in this genotype is more as compared to the resistant ones but had slow disease development. The majority of the released varieties recorded high AUPDC values along with more than 40% PDI value suggesting their higher susceptibility rate against powdery mildew. The relative area under disease progress curve (rAUDPC) values of genotypes ranged from 0.03–0.74. The rAUDPC ranged from 0.03–0.17 in resistant and moderately resistant genotypes indicating their fold superiority over the susceptible genotypes. The identified resistant lines were further confirmed

based on low rAUDPC values and lowest value were recorded in EC800996 (0.03) followed by EC800998 (0.12).

Out of the 82 genotypes screened, 64 genotypes (>78%) tended to be susceptible with pooled PDI value more than 40% after 28 days of inoculation. Nine genotypes showed resistant to moderately resistant disease reaction. Majority of the released varieties showed susceptible and highly susceptible category except Pusa Santusthi and Arka Bahar which showed moderately resistant and moderately susceptible disease reaction, respectively. It was also observed that few small disease symptoms appear

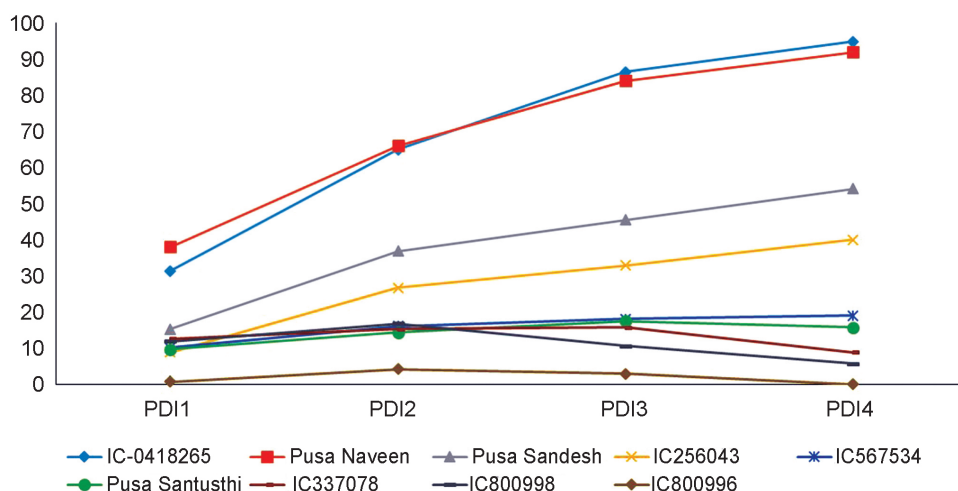


Fig. 3 Disease progress curve in nine selected bottle gourd genotypes against powdery mildew. PDI1, Percent disease index at 1 WPI; PDI2, Percent disease index at 2 WPI; PDI3, Percent disease index at 3 WPI; PDI4, Percent disease index at 4 WPI.

between 7–14 days after inoculation in resistant lines. This may be due to challenge inoculation with pure culture of powdery mildew, ambient climatic conditions for pathogen growth under controlled growth chamber, and high inoculum level in dusting method of inoculation. Therefore, resulting in the development of symptoms in all tested genotypes over the years of screening. The plant defence system was activated and symptoms recovery was recorded in resistant and moderately resistant genotypes between 2–4 WPI. It was further confirmed by the low PDI value at 4 WPI, low AUDPC and rAUDPC which indicates slow disease progression in these genotypes over the years. However, in case of susceptible and highly susceptible genotypes pathogen overpowered the defence mechanism and symptom development progressed at faster rate between 2–4 WPI. The slow disease progression in various host pathogen system in case of powdery mildew were reported by various researchers, viz. Kousik *et al.* (2008), Chaudhary and Banyal (2016), Hong *et al.* (2018), Prasanth *et al.* (2019), Yadav *et al.* (2021). Similar findings have also been reported by various researchers in different crops, such as bottle gourd against Zucchini yellow vein mosaic virus (Ling and Levi 2007), onion for purple blotch (Chauhan *et al.* 2023), and sponge gourd for resistance to *ToLCNDV* (Singh *et al.* 2024).

Powdery mildew has become a significant threat to the cultivation of various cucurbits including bottle gourd which have wide host range and spread rapidly thus causes substantial yield losses. Host plant resistance is the most effective and sustainable approach for reducing economic loss. Therefore, extensive screening of the diverse germplasm is needed to identify novel resistant sources which can be used in resistant breeding programme of bottle gourd against powdery mildew. In our study we screened diverse bottle gourd genotypes including released varieties, accessions from NBPGR and exotic lines from USDA thus representing various geographical regions of world. We identified genotypes EC800996, EC800998, and IC337078 as resistant with low PDI consistently for three years of evaluation. Additionally, low AUDPC values and lack of symptoms on 3rd true leaves and stem further confirming lower disease progression in these genotypes. Thus, the resistant genotypes identified can be utilized for powdery mildew resistance breeding programme in bottle gourd.

REFERENCES

- Anonymous. 2023. Horticultural statistics at a glance. Department of Agriculture & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, GoI.
- Chakravarty H L. 1982. Fascicles of Flora of India Fascicle 11. *Cucurbitaceae*, pp. 136. Botanical Survey of India, Howrah, India.
- Chaudhary J and Banyal D K. 2016. Study of slow mildewing components of powdery mildew of pea caused by *Erysiphe pisi*. *Plant Disease Research* **31**: 138–14.
- Chauhan S S A, Islam S, Prasad L, Singh S, Ellur R K and Tomar B S. 2023. Screening of onion (*Allium cepa*) genotypes to find out novel resistant source against purple blotch (*Alternaria porri*). *The Indian Journal of Agricultural Sciences* **93**(11): 1208–13.
- Cohen R, Burger Y and Katzir N. 2004. Monitoring physiological races of *Podosphaera xanthii* (syn. *Sphaerotheca fuliginea*), the causal agent of powdery mildew in cucurbits: Factors affecting race identification and the importance for research and commerce. *Phytoparasitica* **32**: 174–83.
- Davis A R, Levi A, Tetteh A, Wehner T C and Pitrat M. 2006. Watermelon resistance to powdery mildew race 1 and race 2. *Proceeding of Cucurbitaceae*, pp. 412–20. Holmes G J (Ed.). Universal Press, Raleigh, NC.
- Davis A R, Levi A, Tetteh A, Wehner T C and Pitrat M. 2007. Evaluation of watermelon and related species for resistance to race 1W powdery mildew. *Journal of the American Society for Horticultural Science* **132**: 790–95.
- Decker-Walters D S, Staub J E, Lopez-Sese A and Nakata E. 2001. Diversity in landraces and cultivars of bottle gourd (*Lagenaria siceraria*; Cucurbitaceae) as assessed by random amplified polymorphic DNA. *Genetic Resource and Crop Evolution* **48**: 369–80.
- Feng J, Wang M, See D R, Chao S, Zheng Y and Chen X. 2018. Characterization of novel gene Yr79 and four additional quantitative trait loci for all-stage and high-temperature adult-plant resistance to stripe rust in spring wheat PI 182103. *Phytopathology* **108**(6): 737–47. <https://doi.org/10.1094/PHYTO-11-17-0375-R>
- Heiser C B. 1979. *The gourd book*. University of Oklahoma Press, Norman, Oklahoma, USA.
- Hirose S, Tanda S, Kiss L, Grigaliunaite B, Havrylenko M and Takamatsu S. 2005. Molecular phylogeny and evolution of the maple powdery mildew (*Sawadaea*, *Erysiphaceae*) inferred from nuclear rDNA sequences. *Mycological Research* **109**: 912–22.
- Hong Y J, Hossain M R, Kim H T, Park J I and Nou I S. 2018. Identification of two new races of *Podosphaera xanthii* causing powdery mildew in melon in south Korea. *Plant Pathology Journal* **34**: 182–90.
- Jahn M, Munger H M and Mc Creight J D. 2002. Breeding cucurbit crops for powdery mildew resistance. *The Powdery Mildews: A Comprehensive Treatise*, pp. 239–48. Belanger R R, Bushnell W R, Dik A J and Carver T L W (Eds.). APS Press, St. Paul, Minnesota.
- Jeffrey C. 1967. Cucurbitaceae. *Flora of Tropical East Africa*, pp. 47–53. Milnep-Redlead E and Polhill R M (Eds.). Crown Agents, London, UK.
- Kousik C S, Levi A, Ling K S and Wechter W P. 2008. Potential sources of resistance to cucurbit powdery mildew in U.S. plant introductions of bottle gourd. *HortScience* **43**: 1359–64.
- Kousik C S, Donahoo R S, Webster C G, Turechek W W, Adkins S T and Roberts P D. 2011. Outbreak of cucurbit powdery mildew on watermelon fruit caused by *Podosphaera xanthii* in southwest Florida. *Plant Disease* **95**: 1586.
- Kousik C S, Ikerd J L, Mandal M K, Adkins S, Webster C G and Turechek W W. 2018a. Powdery mildew-resistant bottle gourd germplasm lines: USVL351-PMR and USVL482-PMR. *HortScience* **53**: 1224–7. <https://doi.org/10.21273/HORTSCI13067-18>
- Kousik C S, Mandal M and Hassell R. 2018b. Powdery mildew resistant rootstocks that impart tolerance to grafted susceptible watermelon scion seedlings. *Plant Disease* **102**: 1290–98.
- Lebeda A, McGrath M T and Sedlakova B. 2010. Fungicide resistance in cucurbit powdery mildew fungi. *Fungicides*, pp. 221–46. Carisse O (Eds.). InTech Publishers, Rijeka, Croatia.
- Ling K S and Levi A. 2007. Sources of resistance to Zucchini yellow

- mosaic virus in *Lagenaria siceraria* germplasm. *HortScience* **42**: 1124–26.
- Liu H, Han G, Gu T, Jin Y, Shi Z, Xing L, Yan H, Wang J, Hao C, Zhao M and An D. 2022. Identification of the major QTL QPm.cas-7D for adult plant resistance to wheat powdery mildew. *Frontiers in Plant Science* **13**: 1042399. <https://doi.org/10.3389/fpls.2022.1042399>
- Madden L V, Hughes G and Van den Bosch F. 2007. *The Study of Plant Disease Epidemics*. APS Press St. Paul, Minnesota.
- McGrath M T. 2017. Powdery mildew. *Compendium of Cucurbit Diseases and Pests*, 2nd edn, pp. 62–64. Keinath A P, Wintermantel W M and Zitter T A (Eds.). APS Press, St. Paul, Minnesota.
- Perez-Garcia A, Romero D, Fernandez-Ortuno D, Lopez-Ruiz F, De Vicente A and Tores J A. 2009. The powdery mildew fungus *Podosphaera fusca* (synonym *Podosphaera xanthii*), a constant threat to cucurbits. *Molecular Plant Pathology* **10**: 153–60.
- Prasanth K, Varalakshmi B, Venugopalan R and Sriram S. 2019. Screening of bitter melon germplasm and advanced breeding lines against powdery mildew. *Indian Phytopathology* **72**: 15–22. <https://doi.org/10.1007/s42360-018-0070-7>
- Simko I. 2021. IdeTo: Spreadsheets for calculation and analysis of area under the disease progress over time data. *PhytoFrontiers™* **1**(3): 244–7. <https://doi.org/10.1094/PHYTOFR-11-20-0033-A>
- Singh J, Munshi A D, Singh D, Meena B R, Singh A K, Nagar A, Lyngdoh Y A, Tomar B S, Dey S S, Ranjan J K, Singh N, Kumar N and Mahajani K. 2024. Identification of new stable resistant sources and assessing agro-morphological performance of sponge gourd germplasm against Tomato Leaf curl New Delhi Virus incidence. *Frontiers in Plant Science* **15**: 1373352. <https://doi.org/10.3389/fpls.2024.1373352>
- Sitterly W P. 1978. Powdery mildew of cucurbits. *The Powdery Mildews*, pp. 359–79. Spencer D M (Eds). Academic Press, London.
- Sulima A S and Zhukov V A. 2022. War and peas: Molecular bases of resistance to powdery mildew in pea (*Pisum sativum* L.) and other legumes. *Plants* **11**(3): 339. <https://doi.org/10.3390/plants11030339>
- Takamatsu S and Kano Y. 2001. PCR primers useful for nucleotide sequencing of rDNA of the powdery mildew fungi. *Mycoscience* **42**: 135–39.
- Thomas C E, Levi A and Caniglia E. 2005. Evaluation of U.S. plant introductions of watermelon for resistance to powdery mildew. *HortScience* **40**:154–6.
- Tetteh A Y, Wehner T C and Davis A R. 2010. Identifying Resistance to Powdery Mildew Race 2W in the USDA-ARS Watermelon Germplasm Collection. *Crop Science* **50**:933-9.
- Wheeler B E J. 1969. *An Introduction to Plant Diseases*, pp. 254. John Wiley and Sons Ltd; London, UK.
- Whitaker T W. 1971. Endemism and Pre-Columbian Migration of Bottle Gourd, *Lagenaria siceraria* (Mol.) Standl. *Man across the Sea: Problems of Pre-Columbian Migration*, University of Texas Press, 64–9.
- Xu X, Chen Y, Li B, Zhang Z, Qin G, Chen T and Tian S. 2022. Molecular mechanisms underlying multi-level defense responses of horticultural crops to fungal pathogens. *Horticulture Research* **14**: 9. uhac066. <https://doi.org/10.1093/hr/uhac066>
- Yadav V, Wang Z, Lu G, Sikdar A, Yang X and Zhang X. 2021. Evaluation of watermelon germplasm and advance breeding lines against powdery mildew race ‘2F’. *Pakistan Journal of Agricultural Sciences* **58**(1): 321–30.
- Zhang Z, Wang K, Chen C, Tian S, Wu J, Li J, Kong L, Yang X, Zhang C, Li Y, Zhu H and Xiao D. 2023. Transcriptome sequence analysis of defense response of resistant and susceptible bottle gourd to powdery mildew. *Agronomy* **13**: 1406. <https://doi.org/10.3390/agronomy13051406>
- Zitter T A, Hopkins D L and Thomas C E. 1996. *Compendium of Cucurbits Diseases*. APS Press, Saint Paul, Minnesota.