



RESEARCH ARTICLE

Epidemiological studies and comprehensive screening of cercospora leaf spot of pigeonpea (*Cajanus cajan* L.) caused by *Cercospora cajani* Henn.

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Abstract

Pigeonpea (*Cajanus cajan* L.) is a vital pulse crop in India, but its productivity is severely impacted by various pests and diseases. Among these, Cercospora leaf spot (CLS) disease, caused by *Cercospora cajani* Henn., has emerged as a significant challenge to pigeonpea cultivation. A field study was conducted during the kharif season of 2023–24 at the experimental research farm of Tirhut College of Agriculture, Dholi, Muzaffarpur to evaluate the resistance of 114 pigeonpea genotypes, including a susceptible check, under artificial field conditions using an infector row technique. Based on percent disease index (PDI), 11 genotypes were moderately resistant, while 7 genotypes were moderately susceptible. On the basis of the area under disease progress curve (AUDPC), the same 11 genotypes were classified as resistance, whereas the 7 moderately susceptible genotypes were classified as moderately resistant. Significant differences in disease severity and AUDPC values were observed, suggesting varying levels of resistance among the genotypes. Furthermore, disease progression of CLS in pigeonpea was significantly influenced by weather conditions, with early-sown crops showing lower severity than late-sown crops. Maximum disease progression occurred from the first to second week of December under moderate temperatures (25.6–27.8 °C maximum and 14.0–18.5 °C minimum), high relative humidity, low wind velocity, light rainfall and limited sunshine. The regression models explained 77–91 % of the variation in disease severity. These findings contribute to identifying resistant pigeonpea genotypes and understanding environmental influences on CLS disease, thereby aiding future breeding programs for the development of disease-resistant varieties.

Keywords: cercospora leaf spot; disease severity; infector row; pigeonpea; weather correlation

Introduction

Pigeonpea (*Cajanus cajan* L. Millsp.) is one of the most versatile legume crops globally cultivated. India accounts for 79 % of the global output with current production of 42.20 lakh tonnes from an area of 49 lakh hectares recording an average yield of 861 kg ha⁻¹ (1). It is the second most important pulse crop in India after chickpea (2). In Bihar, pigeonpea is cultivated over an area of 0.21 lakh hectares, yielding a total production of 0.13 lakh tonnes, with an average productivity of 1607 kg ha⁻¹. In India, pigeonpea is cultivated under diverse cropping systems, either as a sole crop, mixed crop, or intercropping systems. It is

predominantly grown in the states of Maharashtra, Uttar Pradesh, Karnataka, Madhya Pradesh, Gujarat, Andhra Pradesh, Odisha, Bihar and Tamil Nadu. The introduction and implementation of short duration early maturing pigeonpea genotypes have significantly promoted its cultivation in Punjab, Haryana and Rajasthan under pigeonpea-wheat sequential cropping systems (3).

Diseases are a major constraint for the successful and economical cultivation of pigeonpea. Pigeonpea is affected by more than 200 diseases which are mainly caused by fungi, bacteria, viruses, phytoplasma-like organisms and nematode

from numerous parts of the country (4). The diseases of major economic importance in pigeon including wilt, sterility mosaic, *Phytophthora* blight, CLS and *Alternaria* blight are widespread and hold greater economic importance during the main kharif season (5). However, yield losses due to CLS range from 23–96 % under natural epiphytic conditions (6–8). Previous researcher reported an outbreak of CLS disease in Uttar Pradesh, Bihar and numerous southern Indian states (9). The disease incited yield losses of up to 85 % and was severe during the podding stage, resulting in defoliation of the leaves (10, 11).

Cercospora cajani Henn. infects the crop, producing symptoms on the leaves in the form of water-soaked spot with greyish borders. As the spots coalesce, they lead to leaf blight and defoliation. Under wet conditions, young leaves and tender branches are also infected, leading to tip drying and dieback. Under favourable environmental conditions, the lesions enlarge and, during the flowering and pod formation stages, cause severe defoliation (9). Significant efforts have been made to manage this disease using chemicals, but several sprays are needed to achieve effective disease control. Furthermore, fungicidal control is neither economical nor practicable for farmers with limited resources and small holdings. To enhance the feasibility of chemical control, it is crucial to develop an effective chemical spray schedule for better disease management for which the epidemiological studies are of great significance and the disease can be effectively and economically managed by utilising resistant varieties. The objectives of the present study were to evaluate pigeonpea entries for resistance against CLS and to examine the influence of epidemiological factors, such as date of sowing and weather variables on disease progression, with the aim of developing a prediction equation for effective disease management.

Materials and Methods

Field experiments were conducted during the kharif season 2023–24 at the experimental farm of Tirhut College of Agriculture (TCA), Dholi situated at a latitude of 25.9956° N and a longitude of 85.5941° E, while laboratory studies were carried out in the Department of Plant Pathology, TCA, Dholi. A total of 114 pigeonpea genotypes obtained from All India Coordinated Research Project (AICRP) on Pulses and TCA, Dholi were planted in an augmented design with 2 replications (row length: 4 m, row spacing: 60 cm). The susceptible variety Bahar was used as a check and artificial inoculation was performed to ensure high disease pressure. To study CLS disease progression, a field experiment was conducted using the susceptible variety Bahar on 5 sowing dates (15-day intervals) with 3 replications (5 × 5 m plots) in a randomised block design (Supplementary Fig. 1), followed by spore suspension inoculation.

Inoculation technique

Infected leaves were collected from the experimental field at TCA, Dholi and a spore suspension was prepared by soaking them in water for 2–4 hr, followed by maceration. The suspension was further incubated for 2–4 hr, then filtered through muslin cloth to remove debris. Spore concentration was determined using a haemocytometer. The prepared suspension was uniformly sprayed on both leaf surfaces using a hand sprayer during the evening hours to ensure effective dissemination.

Isolation of pathogen

Cercospora-infected leaf samples from the cultivar Bahar were collected from the experimental field at TCA, Dholi (RPCAU, Pusa). Leaves were surface sterilised with 70 % ethanol (30 sec), followed by 1 % sodium hypochlorite (2–3 min) and rinsed with sterile distilled water. Small sections (5–10 mm) including healthy and infected portions were placed on potato dextrose agar (PDA) plates under sterile conditions and incubated at 25 °C in the dark for 5–7 days. Fungal colonies with characteristic *C. cajani* morphology were observed and pure cultures were obtained through hyphal tip or spore transfers. Microscopic examination confirmed the pathogen as *Cercospora cajani* based on conidial morphology. Isolates were preserved on PDA slants at 4 °C (Supplementary Fig. 2A, B and C).

Weather parameters (temperature, relative humidity (RH), wind speed, sunshine hours and precipitation) were recorded weekly from the meteorological observatory at TCA, Dholi. Pigeonpea entries were evaluated using percent disease index (PDI) and Area Under Disease Progress Curve (AUDPC).

Percent Disease Index (PDI)

Screening of pigeonpea entries against CLS was done by a formula proposed by McKinney as given below (12):

$$\text{PDI} = \frac{\text{The sum of all numerical ratings}}{\text{Number of leaves observed} \times \text{Maximum ratings}} \times 100 \quad (\text{Eqn. 1})$$

Disease severity was calculated and the entries were later categorised using a 0–9 disease rating scale developed by C D Mayee and V V Datar as depicted below in Table 1 and supplementary Fig. 3 (13).

Area under disease progress curve (AUDPC)

To quantify the extent of disease over time, AUDPC was calculated using a formula proposed by Wilcoxon et al (14).

$$A = \sum_{i=1}^k \frac{1}{2} (S_i + S_{i-1}) \times d \quad (\text{Eqn. 2})$$

Where, A = AUDPC value; S_i = disease severity at the end of the week; S_{i-1} = disease severity on the first day of evaluation; d = interval between two evaluations; k = number of consecutive evaluations of disease.

Table 1. Disease rating scale of *Cercospora* leaf spot disease of pigeonpea

Scale	Description	Category
0	No symptoms.	Immune
1	Small, pinhead-sized spots on the leaves, affecting less than 1 % of its area.	R
3	Small lesions on the leaves, measuring 1–2mm in diameter, that cover 1–10 % of its area.	MR
5	11–25 % area of the leaves covered by lesions without coalescing.	MS
7	The lesions coalescing and covering 26–50 % area of the leaves.	S
9	Large coalescing lesions covering 51 % or more area of the leaf surface.	HS

The genotypes were categorised according to the following disease rating scale (15). The disease reaction resistant (AUPDC value < 350), moderately resistant (AUPDC value 351–360) and susceptible (AUPDC value 651 and above).

Statistical analysis

To assess the progress of CLS disease in 5 different sowing dates a statistical analysis of the data (correlation coefficients and regression) was conducted using KAU grapes and OPSTAT software, regression analysis was performed according to the methodology suggested by Gomez and Gomez (16).

$$Y = b_0 + b_1X_1 + b_2X_2 + \dots + b_nX_n \quad (\text{Eqn. 3})$$

Where, Y = Predicted disease severity; b_0 = Intercept; $b_1, b_2, \dots, b_n$ = Regression coefficient; $X_1, X_2, \dots, X_n$ = Independent variables. The goodness of fit for multiple regression models was assessed using the coefficient of determination (R^2) and correlation coefficient. Critical differences were determined at a significance level of 5 % to assess treatment comparisons while correlation coefficients were computed at significance level of both 5 % and 1 %.

Results and Discussion

It has been observed that changes in cultivation patterns, the use of different susceptible varieties and shifting climatic conditions have contributed to the transformation of previously minor diseases into major threats. This is evident in the case of CLS of pigeonpea, caused by *C. cajani*, which has recently emerged as a significant concern, particularly during the rainy season, resulting in substantial yield losses. Even though many efforts, have been made over the last couple of decades for crop improvement due to its significant importance in the agricultural economy, crop yield has remained limited when compared to the high yielding varieties of many countries across the world. Therefore, to increase the production of this crop, extensive research is needed to manage diseases through appropriate plant protection measures and to achieve greater productivity. Since CLS disease of pigeonpea caused by *C. cajani* has caused serious damage in recent years in Bihar, about which limited information is available; so far a

detailed study was undertaken up on the different aspects pertaining to prevalence and incidence of this disease and to develop suitable strategies in order to manage this disease more effectively.

Cercospora leaf spot of pigeonpea appears as small, circular and light brown or dark brown necrotic spots on the leaves. As the disease progresses, these spots become irregular in shape. As infection advances the spots coalesce and cause blighting of the infected leaves (Supplementary Fig. 4). The disease becomes more severe during flowering and pod formation stages. In severe cases, affected leaves dry up and drop prematurely, causing significant defoliation. The present findings support earlier reports that as infection progresses, affected leaves dry, curl and eventually fall off. Lesions were more frequent on leaves and petioles than on stems, appearing grey to black in colour and elongated along the longitudinal axis of the petiole (9–11, 17).

A total of 114 released and promising pigeonpea genotypes were evaluated under artificial conditions against CLS disease incited by *C. cajani* during the crop season 2023–24 and the results are presented in Table 2 and Fig. 1. Out of 114 genotypes screened, none of the genotypes showed highly resistant and resistant reaction to the disease whereas 11 genotypes (LRG-133-33, SKNPCH-2008, BDNPH-13 01, WRGE-171, AL-2324, UPAS-120, PAU-881, NAAM-88, BDN-2019-28, RKVP-1152, PUSA ARHAR-21-60) were moderately resistant to CLS disease. Seven genotypes (SKNP-2127, LRG-489, AL-2481, WRGE-178, PA-740, AKTE-21-02 and PT 2108) showed a moderately susceptible reaction. The remaining 96 genotypes showed a susceptible or highly susceptible reaction for CLS disease. The present findings are supported by earlier studies reporting variable responses of mungbean genotypes to CLS, with only a limited number exhibiting resistance or disease-free reactions and most showing varying levels of susceptibility (18, 19).

Based on AUDPC, out of 114 genotypes screened (Table 3 and Fig. 2), 11 genotypes (LRG-133-33, SKNPCH 2008, BDNPH-13-01, WRGE-171, AL-2324, UPAS-120, PAU-881, NAAM-88, BDN 2019 -28, RKVP-1152, PUSA ARHAR-21-60) were resistant, whereas 7 genotypes (SKNP-2127, LRG-489, AL-2481, WRGE-178, PA-740,

Table 2. Reaction of pigeonpea genotypes to Cercospora leaf spot disease under artificial inoculation field condition

Disease Reaction	Genotypes on PDI basis	Genotypes on AUDPC basis
Resistant	-	LRG-133-33, SKNPCH-2008, BDNPH-13-01, WRGE-171, AL-2324, UPAS-120, PAU-881, NAAM-88, BDN-2019-28, RKVP-1152, PUSA ARHAR-21-60
Moderately resistant	LRG-133-33, SKNPCH-2008, BDNPH-13-01, WRGE-171, AL-2324, UPAS-120, PAU-881, NAAM-88, BDN-2019-28, RKVP-1152, PUSA ARHAR-21-60	LRG-489, AKTE-21-02, AL-2481, PT-2108, PA-740, SKNP-2127, WRGE-178
Susceptible	LRG-489, AKTE-21-02, AL-2481, PT-2108, PA-740, SKNP-2127, WRGE-178, WRG-447, WRG-93, WRG-97, BDNPH-23-03, BDNPH-23-04, BDNPH-23-05, K-118, BDNPH-21-01, BDNPH-18-05, IPAL-22-10, IPAL-22-4, DA-23-2, PUSA-216, PUSA-214, PA-686, IPAE-22-1, IPAE-22-2, NUPPC-7A, BP-16-184, AL-2371, SKNP-2122, LRG-504, IPAM-22-2, K-82, IPAM-22-1, BAUPP-19-11, RKVP-1147, GJP-2209, PT-19105, AL-2362, NUPPC-6A, PA-703, MA-6, PUSA ARHAR-23-4, BDN-716, Co-Rg7, Co-9, WRG-443, BDN-2019-29, AKTM-2123, ICAKTM-19424, RPS-2014-21, PT-13-3, CRG-18004, AKTE-19-04, RKVP-1165, RKVP-1149, PA-714, SKNP-2107, AKTE-21-01, RPS-2014-34, K-15, WRGE-155, BDNPH-19-05, K-108, AKTM-1916, K-105, MAL-68, DA-23-1, RP-1, CRG-19-007, K-15, NAM-329, BAUPP-19-7, IPAB-5, LRG-454, GJP-2206, K-25, NUPPC-6B, RKVP-1156, PA-739, MAL-13, MAL-60, PUSA ARHAR-23-5, BDN-711, PT-11-16, PT-0012, PA-6, Mira, K-62, TDRG-272, RPS-2014-19, PT-12-8, PT-12-19-2, IPAME-22-1, K-1, K-52, NTL-1127, SKNP-2105, BDN-2019-2, RPS-2014-6, PT-167-1, WRGE-150, ICP-8863 and Bahar	WRG-447, WRG-93, WRG-97, BDNPH-23-03, BDNPH-23-04, BDNPH-23-05, K-118, BDNPH-21-01, BDNPH-18-05, IPAL-22-10, IPAL-22-4, DA-23-2, PUSA-216, PUSA-214, PA-686, IPAE-22-1, IPAE-22-2, NUPPC-7A, BP-16-184, AL-2371, SKNP-2122, LRG-504, IPAM-22-2, K-82, IPAM-22-1, BAUPP-19-11, RKVP-1147, GJP-2209, PT-19105, AL-2362, NUPPC-6A, PA-703, MA-6, PUSA ARHAR-23-4, BDN-716, Co-Rg7, Co-9, WRG-443, BDN-2019-29, AKTM-2123, ICAKTM-19424, RPS-2014-21, PT-13-3, CRG-18004, AKTE-19-04, RKVP-1165, RKVP-1149, PA-714, SKNP-2107, AKTE-21-01, RPS-2014-34, K-15, WRGE-155, BDNPH-19-05, K-108, AKTM-1916, K-105, MAL-68, DA-23-1, RP-1, CRG-19-007, K-15, NAM-329, BAUPP-19-7, IPAB-5, LRG-454, GJP-2206, K-25, NUPPC-6B, RKVP-1156, PA-739, MAL-13, MAL-60, PUSA ARHAR-23-5, BDN-711, PT-11-16, PT-0012, PA-6, Mira, K-62, TDRG-272, RPS-2014-19, PT-12-8, PT-12-19-2, IPAME-22-1, K-1, K-52, NTL-1127, SKNP-2105, BDN-2019-2, RPS-2014-6, PT-167-1, WRGE-150, ICP-8863 and Bahar

Note: PDI: Percent disease index; AUDPC: Area under disease progress curve.

Table 3. Reaction of pigeonpea genotypes to *Cercospora* leaf spot disease on percent disease index (PDI) and area under disease progress curve (AUDPC) basis

S. No.	Name of entry	PDI (%)	AUDPC-Value	Disease reaction	
				PDI basis	AUDPC basis
1.	WRG-447	49.48	1038.8	S	S
2.	LRG-133-33	8.06	163.4	MS	R
3.	WRG-93	41.80	878.8	S	S
4.	WRG-255	69.23	1457.9	HS	S
5.	WRG-97	48.32	1017.8	S	S
6.	IPAL-21-26	67.63	1424	HS	S
7.	BDNPH 19-05	63.27	1332.5	HS	S
8.	BDNPH 23-03	42.49	890.5	S	S
9.	K108	57.77	1213	HS	S
10.	SKNPCH 2008	9.30	190.6	MS	R
11.	BDNPH 22-04	46.10	970	S	S
12.	BDNPH 23-05	46.94	991.5	S	S
13.	K118	43.05	906	S	S
14.	BDNPH 21-01	48.87	1029.4	S	S
15.	BDNPH 18-05	47.77	1003	S	S
16.	BDNPH 13-01	9.05	185	MS	R
17.	AKTM 1916	61.13	1283.6	HS	S
18.	K105	57.07	1195.7	HS	S
19.	IPAL 22-10	38.75	806.9	S	S
20.	IPAL 22-4	40.55	851.6	S	S
21.	MAL-68	59.28	1242	HS	S
22.	DA 23-2	44.99	956.5	S	S
23.	DA 23-1	56.66	1197.7	HS	S
24.	PUSA-216	49.90	1055.6	S	S
25.	PUSA-214	48.83	967	S	S
26.	LRG 489	20.94	435.2	S	MR
27.	RP-1	63.33	1337.7	HS	S
28.	CRG 19-007	59.44	1252	HS	S
29.	PA 686	38.01	793.8	S	S
30.	AL 2481	24.58	517.2	S	MR
31.	IPAE 22-1	44.74	937	S	S
32.	IPAE 22-2	39.16	815.5	S	S
33.	NUPPC-7A	40.55	847.6	S	S
34.	BP 16-184	42.39	894	S	S
35.	AL 2371	49.90	1055.6	S	S
36.	WRGE-171	6.27	132.9	MR	R
37.	K15	60.13	1261.3	HS	S
38.	WRGE-178	21.25	449	MS	MR
39.	NAM 329	64.16	1367.8	HS	S
40.	BAUPP 19-7	60.55	1260	HS	S
41.	SKNP-2122	35.27	741.7	S	S
42.	SKNP-2127	19.54	415.6	MS	MR
43.	LRG 504	44.16	925.5	S	S
44.	IPAB 5	71.66	1508.8	HS	S
45.	IPAM 22-2	38.32	804.9	S	S
46.	RKPV 1152	7.80	162	MR	R
47.	LRG 454	72.49	1528	HS	S
48.	K82	42.03	885	S	S
49.	IPAM 22-1	46.29	974.8	S	S
50.	BAUPP 19-11	44.71	948.7	S	S
51.	RKPV 1147	34.16	719.3	S	S
52.	GJP 2206	65.64	1377.8	HS	S
53.	GJP 2209	39.81	835.5	S	S
54.	PT 19105	31.66	668.8	S	S
55.	AL 2324	8.89	182.8	MR	R
56.	Pusa Arhar 21-60	5.83	127.4	MR	R
57.	AL 2362	40.55	847.7	S	S
58.	K25	65.73	1394.6	HS	S
59.	NAAM 88	9.86	212	MR	R
60.	NUPPC-6B	67.40	1670	HS	S
61.	NUPPC-6A	45.36	946	S	S
62.	RKPV 1156	61.66	1296.9	HS	S
63.	PA-739	57.95	1208	HS	S
64.	PA-703	49.71	1047	S	S
65.	MAL-13	69.72	1473.8	HS	S
66.	MAL-60	70.55	1485.4	HS	S
67.	MA-6	34.71	737	S	S
68.	PUSA ARHAR 23-5	65.55	1375.5	HS	S
69.	PUSA ARHAR 23-4	50.00	1050.8	S	S
70.	BDN-716	49.02	1039	S	S

71.	BDN-711	62.46	1317.8	HS	S
72.	PT-11-16	61.66	1291	HS	S
73.	PT-0012	65.69	1378.5	HS	S
74.	UPAS-120	7.92	161.5	MR	R
75.	PA-6	63.19	1334.9	HS	S
76.	PAU-881	4.17	89.5	MR	R
77.	Co-Rg7	38.88	808.8	S	S
78.	Co-9	36.10	762	S	S
79.	Mira	53.88	1134.4	HS	S
80.	WRG-443	43.88	919.6	S	S
81.	K-62	58.60	1232.7	HS	S
82.	BDN 2019-29	47.21	987.4	S	S
83.	TDRG 272	61.10	1287	HS	S
84.	AKTM 2123	39.44	824.3	S	S
85.	ICAKTM 19424	41.10	864	S	S
86.	RPS 2014-19	54.44	1143	HS	S
87.	RPS 2014-21	44.44	933	S	S
88.	PT 13-3	43.88	922.8	S	S
89.	PT 12-8	58.88	1233	HS	S
90.	CRG 18004	40.73	852.8	S	S
91.	AKTE 19-04	41.66	873.6	S	S
92.	PT 12-19-2	62.19	1305.7	HS	S
93.	IPAME 22-1	55.80	1163	HS	S
94.	K52	68.88	1445.5	HS	S
95.	NTL-1127	55.83	1174.3	HS	S
96.	RKVP 1165	42.77	894.3	S	S
97.	RKVP 1149	41.38	858.4	S	S
98.	PA-740	21.64	454.6	MS	MR
99.	PA-714	39.71	828	S	S
100.	SKNP-2107	40.82	846	S	S
101.	SKNP-2105	60.49	1264	HS	S
102.	BDN 2019-2	57.35	1201.5	HS	S
103.	BDN 2019-28	9.98	213.7	MR	R
104.	AKTE 21-01	45.52	953.5	S	S
105.	AKTE 21-02	23.40	490	MS	MR
106.	RPS 2014-6	55.97	1170.5	HS	S
107.	RPS 2014-34	48.32	1011.3	S	S
108.	PT 2108	24.72	518	MS	MR
109.	PT-167-1	58.33	1221	HS	S
110.	K51	46.66	983.8	S	S
111.	WRGE-150	62.22	1306.6	HS	S
112.	WRGE-155	34.72	723	S	S
113.	ICP-8863	76.24	1603	HS	S
114.	Bahar (Check)	84.10	1780.6	HS	S

HR: highly resistant; R: resistant; MR: moderately resistant; MS: moderately susceptible; S: susceptible; HS: highly susceptible.

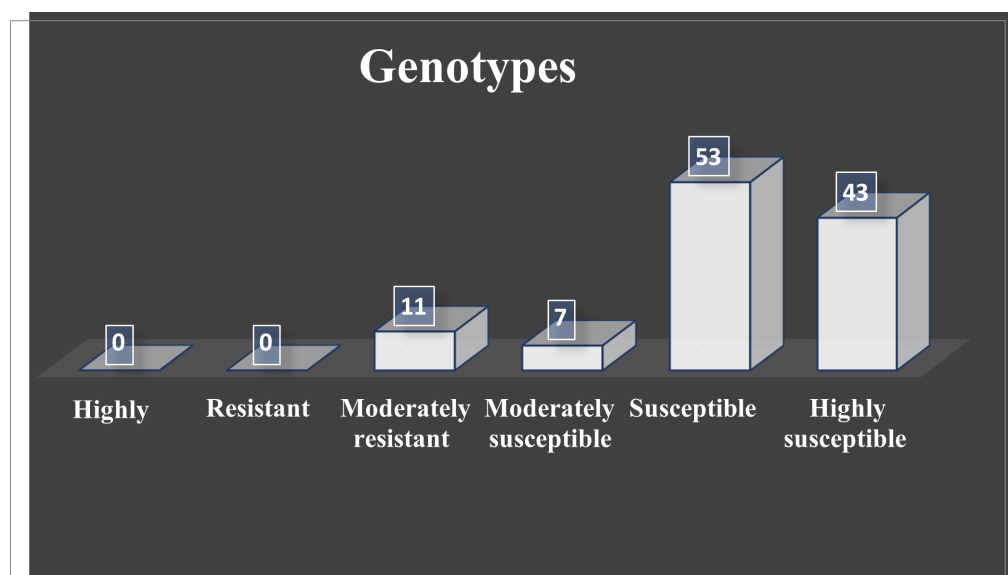


Fig. 1. Evaluation of pigeonpea genotypes for resistance to cercospora leaf spot disease based on percent disease index (PDI).

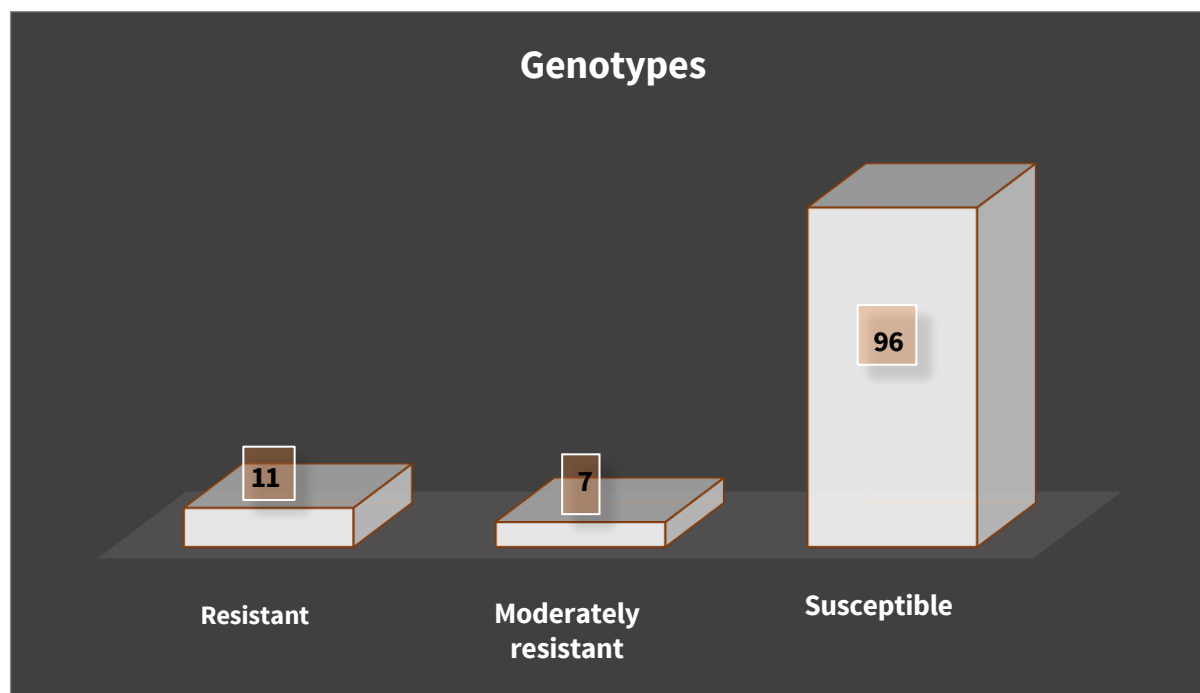


Fig. 2. Evaluation of pigeonpea genotypes for resistance to cercospora leaf spot disease on the basis of area under disease progress curve (AUDPC).

AKTE-21-02 and PT-2108) were moderately resistant against CLS. The remaining 96 genotypes showed a susceptible or highly susceptible reaction for CLS disease. Similar results were found in which 14 groundnut genotypes for AUDPC were evaluated in response to late leaf spot disease (20). The genotype AVT-1666, demonstrating moderate resistance to late leaf spot, exhibited the lowest AUDPC value (1480.67). Conversely, the susceptible genotype K-6 recorded the highest AUDPC value (2812.95). Mahapatra assessed disease progression in 261 mungbean germplasm by calculating the AUDPC (21). Field screening for CLS revealed that 88 genotypes were resistant, 89 were moderately resistant, 51 were moderately susceptible and 33 were susceptible. The present findings are supported by previous researchers who used AUDPC to assess disease progression among genotypes and observed considerable variation in disease development, with lower AUDPC values indicating relatively better resistance,

although the differences among genotypes were not statistically significant (22). Later, similar findings were previously reported (23,24).

The data presented in Table 3 revealed that minimum disease severity and AUDPC value were recorded in PAU-881 (PDI 4.17 % and AUDPC 89.5) followed by Pusa Arhar 21-60 (PDI 5.83 % and AUDPC 127.4), WRGE-171 (PDI 6.27 % and AUDPC 132.9), RKPV 1152 (7.80 % and AUDPC 162) respectively, while the maximum were recorded in ICP-8863 (PDI 76.24 % and AUDPC 1603) followed by LRG-454 (PDI 72.49 % and AUDPC 1528), IPAB-5 (PDI 71.66 % and AUDPC 1508.8), MAL-60 (PDI 70.55 % and AUDPC 1485.4) respectively.

Epidemiology

The present research was carried out to determine optimum sowing time for higher yield and to study the impact of sowing

Table 4. Progress of cercospora leaf spot disease in relation to weather parameters

Date of observations	30-06-2023	15-07-2023	30-07-2023	15-08-2023	30-08-2023	Weather parameters						
	PDI	PDI	PDI	PDI	PDI	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
07-10-2023	0.0	2.2	0.0	0.0	0.0	25.1	29.7	90	89.2	22.5	2.5	4.0
14-10-2023	0.0	5.0	5.0	2.7	0.0	24.3	34.0	91.2	65.4	14.5	0.8	7.6
21-10-2023	0.0	8.3	12.2	10.5	0.0	20.5	31.1	80.8	76.4	8.0	1.6	7.9
28-10-2023	0.0	13.8	20.5	16.6	4.5	30.7	19.0	80.8	69.8	0.0	1.1	9.1
04-11-2023	3.5	17.7	27.2	23.8	11.6	18.8	31.2	91.1	69.5	0.0	0.9	7.9
11-11-2023	4.0	19.4	31.1	28.3	20.5	17	29.6	88.1	68.4	0.0	1.3	1.6
18-11-2023	5.3	22.6	36.6	32.2	27.7	15.8	29.5	85.1	69.8	0.0	0.4	8.0
25-11-2023	7.2	27.2	42.1	38.8	31.9	13.8	29.0	83.0	66.5	0.0	1.7	4.9
02-12-2023	9.4	39.4	50.5	49.4	44.1	14	27.8	88.4	74.0	0.0	3.9	4.0
09-12-2023	15.0	46.2	62.2	53.8	59.1	18.5	25.6	87.4	83.7	9.0	2.9	2.9
16-12-2023	17.7	47.5	68.6	56.6	61.6	7.2	24.7	81.4	62.5	0.0	1.2	5.4
23-12-2023	18.8	48.3	72.2	58.3	64.4	7.1	24.3	79.2	67.2	0.0	2.4	6.0
30-12-2023	20.5	49.5	73.8	61.6	67.7	9.6	27.58	84.7	79.8	0.0	3.1	3.0
06-01-2024	21.1	50.0	74.4	63.3	70.0	6.5	21.3	88.5	82.2	0.0	6.0	1.2
13-01-2024	21.6	51.2	75.0	64.4	72.7	7.7	19.4	88.0	84.5	0.0	7.4	0.5
20-01-2024	22.2	51.2	75.5	65.0	74.4	6.2	14.8	86.7	87.4	0.0	4.1	0.5
27-01-2024	22.7	51.2	75.5	65.5	75.0	5.4	14.4	86.7	89.0	0.0	6	0.4
03-02-2024	23.5	51.2	75.5	66.1	75.5	6.0	21.0	88.1	78.5	0.0	7.7	4.15
10-02-2024	24.2	51.2	75.5	66.1	76.1	9.8	21.1	85.0	90.8	0.1	12.4	5.6
17-02-2024	25.0	51.2	75.5	66.1	76.1	11.4	24.4	98.2	61.2	0.1	8.2	4.9

X₁: minimum temperature(°C); X₂: maximum temperature(°C); X₃: morning relative humidity (%); X₄: evening relative humidity (%); X₅: rainfall (mm); X₆: wind speed (km/hr); X₇: sunshine (hr).

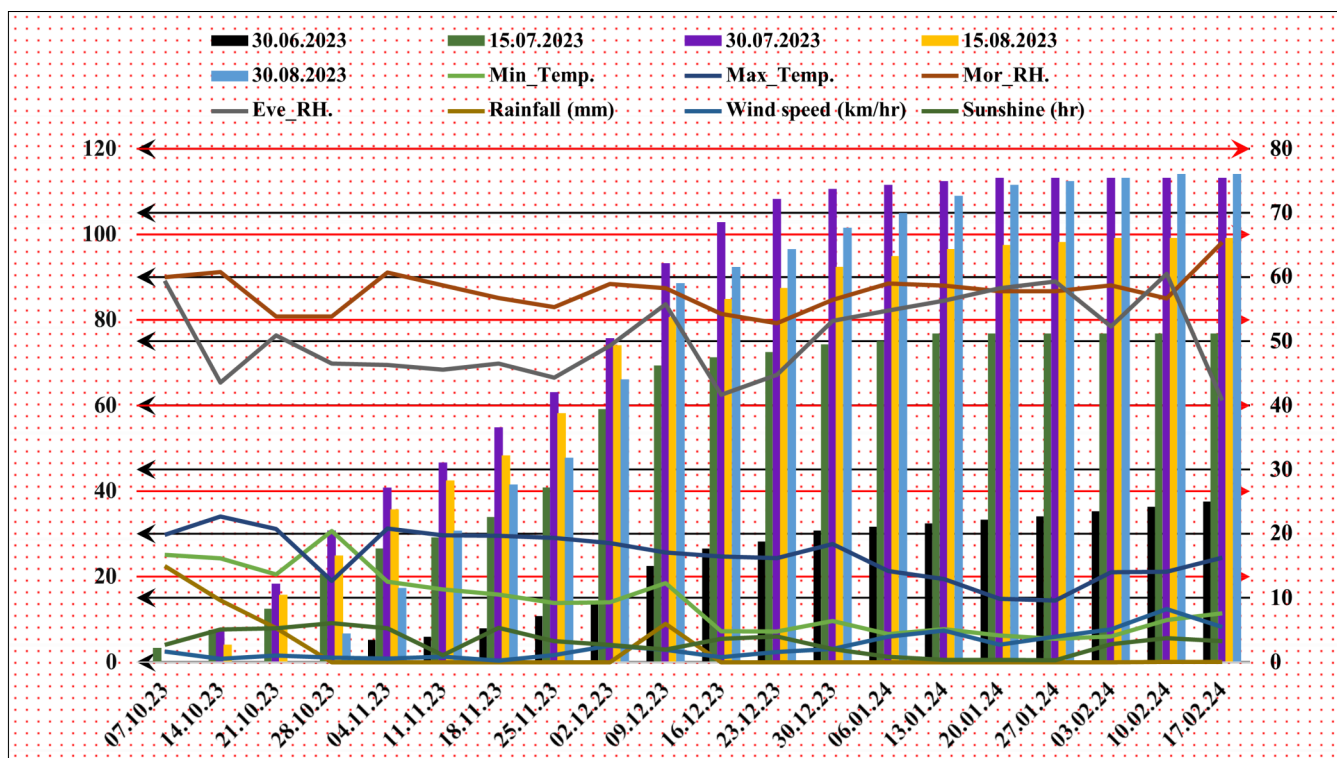


Fig. 3. Cumulative progress of cercospora leaf spot disease in relation to weather parameters.

time on disease severity in pigeonpea during the kharif season 2023–24 (Table 4 and Fig. 3). The study on the role of various weather parameters in the disease progression across 5 different sown dates (30th June 2023, 15th July 2023, 30th July 2023, 15th August 2023 and 30th August 2023) revealed that in the early sown crop (30th June 2023), disease incidence was reported up to 25 % by the 59th meteorological week. In contrast, the crop sown on the August 30, 2023, exhibited the highest disease incidence (76.1 %). The results of this study revealed that late-sown crops experience significantly higher disease incidence compared to early and normally sown crops. The peak period of disease progress was noted between 2nd December to 15th December 2023 (48th and 49th meteorological week). During this period maximum temperature ranged between 25.6–27.8 °C, while the minimum temperature 14–18.5 °C, morning relative humidity varied between 87.4–88.4 % and evening relative humidity between 74.0–83.7 %. Wind velocity ranged from 2.9–3.9 km/hr, total rainfall was 9.0 mm and sunshine duration varied between 2.9–4.0 hr. Similar findings have been reported by earlier workers (25–27), who observed that groundnut crops sown early in the season experienced lower severity of CLS compared to those planted later.

The effects of different planting dates on disease were examined caused by *Cercospora* sp. and found that the ideal temperature for germination and infection was 25–30 °C and relative humidity was 90–100 % (28). Conidia formation was inhibited below 10 °C temperature. Previous works reported that ideal environmental conditions for disease development include daytime temperatures between 25–35 °C, night time temperatures around 16 °C and extended periods of 90–95 % relative humidity or the presence of free moisture on leaves (29). The ideal temperature range for CLS of corn is 22–30 °C, with no germination happening at 36 °C (30). Similar types of findings were also reported by previous researchers (31–35).

Weather parameters, viz., maximum and minimum temperature, morning and evening relative humidity, rainfall, wind

speed and sunshine hours were recorded in correspondence to disease observations and correlated with disease development. Stepwise linear multiple regression analysis was done to derive disease prediction equations (Table 5). During the 2023–24 crop season, a comprehensive analysis was undertaken to establish the correlation between weather variables and disease progression across five different sowing dates. The study meticulously analysed each variable independently and in combination, revealed that each variables play a critical role in influencing disease development, along with other unidentified factors. Notably, a highly significant and negative correlation was found between minimum temperature (-0.894^{**}) and disease progression. Similarly, maximum temperature (-0.686^{**}), rainfall (-0.606^{**}) and sunshine (-0.595^{**}) were significantly and negatively correlated with the development of CLS disease whereas, wind speed (0.684^{**}) was significantly and positively correlated with the disease progression in all five dates of sowing. Morning (0.048) and evening (0.282) relative humidity were positively correlated with disease development. Similar types of findings were also reported (32, 35, 36). Later works showed that temperature is negatively correlated with disease development in groundnut (26).

The multiple linear regression equation was developed using disease progression as dependent variable and all the weather parameters as independent variables. The analysis revealed that minimum temperature and wind speed were particularly influential, accounting for 77 % and 91 % of the variability in disease progression across all five sowing dates. These findings are consistent with those earlier reports who reported that weather variables could explain 81.2 % of the variability in the development of CLS disease in green gram (37). Analysis was also done by using the average data of all the dates of sowing. The following equations were developed. The minimum temperature along with maximum temperature, morning relative humidity and evening relative humidity could explain the variability between 80–87 % in all five dates of sowing (Table 6). These equations can serve as reliable tools for

Table 5. Correlation matrix for cumulative progression of Cercospora leaf spot disease in relation to weather parameters

	Per cent disease index	X ₂ -Minimum temperature (°C)	Maximum temperature (°C)	Morning relative humidity (%)	Evening relative humidity (%)	Rainfall (mm)	Wind speed (km/hr)	Sunshine (hr)
Percent disease index	1.000	-0.894**	-0.686**	0.048	0.282	-0.606**	0.684**	-0.595**
X ₂ -Minimum temperature (°C)		1.000	0.537*	0.021	-0.224	0.585**	-0.545*	0.609**
Maximum temperature (°C)			1.000	0.117	-0.496*	0.452*	-0.566**	0.525*
Morning relative humidity (%)				1.000	-0.003	0.202	0.31	-0.237
Evening relative humidity (%)					1.000	0.203	0.506*	-0.555*
Rainfall (mm)						1.000	-0.258	0.149
Wind speed (km/hr)							1.000	-0.405
Sunshine (hr)								1.000

(**) significant at 0.01 level; (*) significant at 0.05 level.

Table 6. Regression equation for cumulative progression of cercospora leaf spot disease in relation to weather parameters

Regression equation	R ²
Y = 369.78 – 130.6 (Min. Temp.)	0.80
Y = 479.35 – 10.80 (Min. Temp.) – 5.63 (Max. Temp.)	0.85
Y = 319.04 – 10.67 (Min. Temp.) – 6.36 (Max. Temp.) + 2.47 (Morn. RH) – 0.49 (Even. RH)	0.87

predicting CLS disease in pigeonpea under field conditions if these factors are known.

AT, RK and AAL helped summarise and revise the manuscript. All authors read and approved the final manuscript.

Conclusion

Accurate weather information is essential for understanding the development of favourable conditions for disease occurrence and for predicting disease outbreaks. In pigeonpea, rainfall-induced leaf wetness, along with suitable temperature and high relative humidity, plays a major role in the development of CLS. The highest disease progression was observed from the first to the second week of December under moderate temperatures, high humidity, light rainfall, low wind speed and limited sunshine. These favourable weather conditions resulted in increased disease severity, severe defoliation and peak infection at the pod formation stage. The findings emphasise the critical influence of weather on disease progression and suggest that understanding the relationship between weather parameters and disease development can aid in developing reliable disease forecasting models. Future studies should focus on validating these models across different locations and seasons, integrating real-time weather data and combining epidemiological insights with resistant cultivars and need-based fungicide applications to improve sustainable disease management strategies.

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Authors' contributions

SK performed the experiments. BK designed the research. PK and DKC wrote the manuscript. SS and PP revised and corrected the manuscript. AS, DK and DD assisted in conducting the experiments.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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