



Influence of Weather Variables on the Incidence of Urdbean Leaf Crinkle Disease and Yield of Blackgram under Different Sowing Dates

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ABSTRACT

Background: Viral diseases are the major constraints in blackgram causing significant yield losses. Among the viral diseases, yellow mosaic virus (YMV) and leaf crinkle are the predominant diseases in the major blackgram growing areas of Andhra Pradesh. The weather parameters play a vital role in development and spread of disease. Therefore, understanding of weather factors and their association with disease incidence is required to provide baseline information for developing a disease prediction system which enables the timely management strategies.

Methods: A field experiment in split plot design with three replications evaluated three blackgram varieties (PU-31, TBG-104 and LBG-752) across five sowing dates (October I fortnight to December I fortnight) at Agricultural Research Station, Utukur, YSR Kadapa district of Andhra Pradesh. The standard weekly weather data were correlated with leaf crinkle disease incidence using correlation analysis, multiple linear regression and principal component analysis (PCA) to determine weather-disease relationships.

Result: The significant differences in leaf crinkle disease incidence were observed among the sowing dates and varieties. The lowest disease incidence occurred in October I fortnight sowing (13.4%), while the highest was in December I fortnight sowing (23.0%). Variety PU-31 showed higher incidence (22.42%), whereas TBG-104 recorded lower incidence (16.02%). Highest seed yield was obtained in D2 sowing (1194 kg ha⁻¹). Correlation analysis showed significant negative association of relative humidity with disease incidence. Regression analysis indicated strong influence of weather parameters on disease development (R^2 : 0.52-0.99). PCA identified temperature and humidity as major factors influencing disease incidence and yield.

Key words: Blackgram, Correlation, Leaf crinkle, Principal component analysis, Regression.

INTRODUCTION

Blackgram is the most important short duration pulse crop grown throughout the year in various states of India due to its suitability to fit into various cropping systems and most importantly because of its commercial value. The crop is cultivated in an area of 3.0 million ha in India with a production of 2.11 million tonnes with an average productivity of 702 kg/ha (Ministry of Agriculture and Farmers Welfare, Government of India. 2025). In India, the major blackgram producing states are Andhra Pradesh, Tamil Nadu, Assam and Telangana. Blackgram has a potential yield exceeding 1.5 t/ha, but actual yields remain far lower due to diseases, insect pests and other production constraints. Among the various biotic stresses affecting black gram, the major diseases include powdery mildew, blight, root rot, anthracnose, rust, yellow mosaic disease (YMD) and urdbean leaf crinkle disease (ULCD). Among the various viral diseases, urdbean leaf crinkle disease (ULCD) is an economically significant, widespread and devastating disease. The leaf crinkle disease is characterized by severe crinkling, curling, puckering and rugosity of leaves, along with stunting, floral deformation, reduced pod set and poor seed filling. The etiology of ULCD remains unclear and has been associated either with two distinct viruses or with a complex mixture of viruses

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(Kamaal *et al.*, 2023). However, the causal agent of ULCD has not been fully characterized. The yield losses up to 35 to 81% were reported with ULCD depending on cultivated varieties and their cropping seasons (Bashir *et al.*, 1991). Barathi and Babu (2026) also reported that 62-100% yield loss due to crinkle disease in blackgram depending on

the genotype, location, infection time and cropping season. Transmission of leaf crinkle virus is reported through seed, sap inoculation, grafting and potentially by multiple insect vectors including aphids, whiteflies and certain beetles (Dhingra, 1975; Prasad *et al.*, 1998; Beniwal and Bharathan, 1980). The seed transmission of ULCD ranging from 52.9 to 71.6% was reported under natural conditions (Priyanga *et al.*, 2024).

The disease development is influenced by several factors such as cropping season, sowing date, host genotype and weather parameters. The southern zone of Andhra Pradesh is identified as one of the major endemic zones for the leaf crinkle disease in blackgram, where the disease frequently occurs in severe form. Among the different management factors of the viral disease, sowing time is known to influence yield and optimum date of sowing could be an important strategy to avoid the outbreak of the viral diseases. Favorable weather aggravates further spread and outbreak of the leaf crinkle disease under such favorable weather conditions. Therefore, the present research was planned with an objective to study the effect of sowing dates and weather variables on incidence of ULCD and yield in blackgram grown in southern zone of Rayalaseema Region of Andhra Pradesh.

MATERIALS AND METHODS

A field experiment was conducted at Agricultural Research Station, Utukur, of Acharya N.G Ranga Agricultural University (ANGRAU). The research station is situated at YSR Kadapa district of Andhra Pradesh, where the leaf crinkle disease is more prevalent, because of the congenial weather conditions for the disease development. The experiment was laid out in Split plot design consisting of five dates of sowings *i.e.*, October I FN (D_1), October II FN (D_2), November I FN (D_3), November II FN (D_4) and December I FN (D_5) as main plot treatments and three blackgram varieties *viz.*, *i.e.*, PU-31, TBG-104 and LBG-752 as sub plot treatments during *rabi*, 2021-22 and 2022-23. Each variety was sown in 3.0 m × 3.0 m experimental plots with a spacing of 30 cm × 10 cm and followed all recommended agronomic practices. Each plot was regularly monitored for the initiation and progression of the disease.

Data on leaf crinkle disease incidence was recorded starting from initiation of disease to harvest of the crop during experimental period at weekly interval and per cent disease incidence was calculated:

Per cent disease incidence =

$$\frac{\text{Total number of infected plants}}{\text{Total number of plants observed}} \times 100$$

Development of a regression model

A regression analysis was done for each variety, the most significant weather parameters for the occurrence of the leaf crinkle disease were identified. Daily weather data including maximum temperature ($T_{\max}$), minimum

temperature ($T_{\min}$), relative humidity at morning hours (RH I), relative humidity at evening hours (RH II) and rainfall of this period were recorded. The correlation and regression analysis for leaf crinkle disease with weather parameters and yield attributes was carried out. The principal component analysis (PCA) and related data visualization were carried out using different weather variables across four crop stages to identify key drivers of disease incidence and yield. The PCA analysis was conducted using R software.

RESULTS AND DISCUSSION

An experiment was taken up to study the influence of changing weather on incidence of ULCD on popular varieties in black gram *i.e.*, PU-31, TBG-104 and LBG-752 during 2021-22 and 2022-23 at Agricultural Research Station, Utukur and to find out the most favourable sowing window of black gram during *rabi* season in the southern zone of Andhra Pradesh. The symptoms of ULCD include stunting of plants, crinkling, curling, puckering and rugosity on leaves. The severity of the disease depends on the variety, cropping season and weather conditions prevailing during the season. However, the effect of weather factors on the incidence of the crinkle disease was studied.

Effect of dates of sowing on leaf crinkle incidence and yield of black gram varieties

The incidence of leaf crinkle disease varied significantly with sowing dates and varieties, whereas their interaction was found to be non-significant (Table 1). The early-sowings (D_1 and D_2) had lower incidence, while delayed sowings (D_4 and D_5) experienced higher disease incidence.

Among the five sowing dates studied, D_1 (I fortnight of October) recorded the lowest mean disease incidence (13.4%), followed by D_3 (18.2%) and D_2 (20.3%), whereas the highest incidence was observed in D_5 (23.0%) followed by D_4 (22.4%). Among the varieties, PU-31 recorded comparatively higher mean disease incidence (22.42%), followed by LBG 752 (19.9%), while TBG-104 showed the lowest incidence (16.02%), indicating relative tolerance to leaf crinkle disease. Overall, the results indicated that delayed sowing during December showed higher disease incidence compared to early October sowing. The present findings are in agreement with (Sushma *et al.*, 2022), who reported that TBG-104 as resistant, while LBG-752 and PU-31 are the moderately resistant varieties to ULCD under natural field conditions.

Among the different dates of sowings, D_2 (II fortnight of October) recorded the highest mean seed yield (1194 kg ha⁻¹), followed by D_1 (792 kg ha⁻¹), whereas the lowest mean was observed in D_3 (I fortnight of November) (259 kg ha⁻¹). Early sowings (D_1 and D_2) recorded higher seed yield compared to delayed sowings. Among the varieties, TBG-104 registered the highest overall mean (762 kg ha⁻¹), followed by PU-31 (638 kg ha⁻¹), while LBG-752 recorded the lowest mean (564 kg ha⁻¹). The non-significant

interaction indicated that the performance trend of varieties remained similar across different sowing dates (Table 2). In present study, it was observed that though the disease incidence in D2 sowing was relatively higher than D1, prevailing environmental conditions during reproductive stage were more favourable for crop growth, pod filling and biomass accumulation. Therefore, the negative impact of moderate disease incidence under on yield was compensated by the beneficial effect of favourable environment. Similar influence of sowing time on the disease incidence was reported by Kadian (1989), who observed that environmental conditions prevailing during crop growth significantly affected the development of leaf crinkle disease in blackgram.

Relationship between leaf crinkle disease incidence and weather parameters

The relationship between leaf crinkle disease incidence and prevailing weather conditions also exhibited a distinct variation across sowing windows. The early sowing periods (D1 and D2) were characterized by moderate maximum temperatures (28.8-29.2°C), relatively high minimum temperatures (20-21°C), high relative humidity (RH I: 85-87%, RH II: 63-70%) and substantial rainfall (111-308 mm). Under these weather conditions,

comparatively lower incidence of leaf crinkle was recorded. In contrast, the delayed sowing periods (D4 and D5) experienced higher maximum temperatures (30.8-32.4°C), lower humidity (RH I: 74%, RH II: 44-52%) and very low rainfall (4-6 mm), where disease incidence was significantly higher. These findings indicate that disease development was influenced by complex interactions among weather parameters and sowing environments.

Although higher temperatures coincided with increased disease incidence under certain sowing windows, the correlation was mostly non-significant. Conversely, relative humidity showed a strong negative correlation with leaf crinkle disease occurrence. As humidity decreased, the incidence of leaf crinkle disease increased. High humidity during early sowing periods may have indirectly reduced the disease spread. Similarly, rainfall also played a crucial role, higher rainfall during October may have been less conducive for disease development, while the near absence of rainfall in November and December provided dry conditions appeared conducive for disease incidence. Therefore, early sowing, which coincides with cooler temperatures, higher humidity and occasional rainfall, provides a more favorable environment for healthy crop growth and minimizes the risk of disease.

Table 1: Effect of dates of sowing on leaf crinkle disease in three blackgram varieties.

Dates of sowing	Varieties			Mean
	PU-31	TBG-104	LBG-752	
D ₁ (I FN October)	13.5	11.8	14.9	13.4
D ₂ (II FN October)	23.6	22.0	15.2	20.3
D ₃ (I FN November)	21.8	10.4	22.4	18.2
D ₄ (II FN November)	29.2	14.8	23.1	22.4
D ₅ (I FN December)	24.0	21.1	23.9	23.0
Mean	22.42	16.02	19.9	
Factors	CD	SE (m)		
Dates of sowing (DS)	1.8	0.54		
Varieties (var.)	0.99	0.33		
Interaction (DS × Var.)	NS	0.82		

Table 2: Effect of dates of sowing on yield of three blackgram varieties.

Dates of sowing	Yield (kg ha ⁻¹)			Mean
	PU-31	TBG-104	LBG-752	
D ₁ (I FN October)	763	827	786	792
D ₂ (II FN October)	1305	1361	916	1194
D ₃ (I FN November)	216	306	255	259
D ₄ (II FN November)	608	725	422	585
D ₅ (I FN December)	298	594	444	445
Mean	638	762	564	
Factors	CD	SE (m)		
Dates of sowing (DS)	342.6	103.4		
Varieties (var.)	121.4	40.9		
Interaction (DS × Var.)	NS	127.6		

Among the three varieties, TBG-104 consistently maintained the lowest incidence across all weather conditions, suggesting its better adaptability and tolerance to fluctuating environmental factors. In contrast, PU-31 and LBG-752 were more adversely affected by late sowing and unfavorable weather, showing higher disease incidence under increasing temperature and decreasing humidity. From this study it is suggested that, T_{max} with a range of 29 to 33°C while a range of T_{min} of 22°C and above and a diurnal temperature variation of 9°C or below can create the most favourable microclimate for disease development and possible vector activity. These observations are in agreement with those of Kadian (1989); Ashfaq *et al.* (2008) and Dubey *et al.* (2019). Kadian (1989) reported that maximum disease incidence was observed when the Maximum and Minimum temperatures are 35°C+2°C and 25°C+2°C respectively. Ashfaq *et al.* (2008) found that ULCD disease progress had significant positive correlation with maximum and minimum temperatures and found no correlation with relative humidity, rainfall and wind movement. Dubey *et al.* (2019) also studied on threshold temperatures for crinkle disease symptoms expression through mechanical inoculation of seeds and exposed to a fixed temperature under glasshouse conditions and found that typical ULCD symptoms were observed in the temperature range 25-38°C and they also reported that leaf crinkle incidence was significantly increased between temperature range 30-35°C and reduced at 38°C or above. Over all, the disease symptom expression is highly influenced by temperature. Furthermore, a standardized sap transmission/inoculation technique developed for ULCD can facilitate future studies on disease progression and symptom expression under controlled environmental conditions (Teja *et al.*, 2024).

Correlation and regression analysis

The correlation analysis revealed that most of the weather parameters showed non-significant association with leaf crinkle disease incidence in all the blackgram varieties and sowing dates (Table 3). However, significant negative correlation was observed between RH-I and disease incidence in D3 sowing across all the varieties, indicating reduction in disease incidence with increase in morning relative humidity. Similarly, RH-II exhibited significant negative correlation in D4 sowing, suggesting that higher evening relative humidity reduced disease incidence. Maximum and minimum temperatures and rainfall showed inconsistent and mostly non-significant correlation with leaf crinkle disease.

Multiple regression equations were performed using maximum temperature (T_{Max}), minimum temperature (T_{Min}), morning relative humidity (RH I), evening relative humidity (RH II) and rainfall (RF) as independent variables to quantify their combined influence on disease incidence (Table 4). The coefficient of determination (R^2) values ranged from 0.52 to 0.99, indicating moderate to very high contribution of weather factors towards disease development.

Table 3: Correlation matrix for blackgram Leaf crinkle disease in relation to weather parameters and dates of sowing.

Weather parameters	r' value leaf crinkle disease														
	PU-31					TBG-104					LBG-752				
	D1	D2	D3	D4	D5	D1	D2	D3	D4	D5	D1	D2	D3	D4	D5
T_{Max}	-0.052 ^{NS}	-0.032 ^{NS}	0.754 ^{NS}	0.361 ^{NS}	0.261 ^{NS}	0.017 ^{NS}	-0.176 ^{NS}	0.744 ^{NS}	0.526 ^{NS}	0.220 ^{NS}	-0.067 ^{NS}	-0.176 ^{NS}	0.587 ^{NS}	0.372 ^{NS}	0.513 ^{NS}
T_{Min}	-0.554 ^{NS}	-0.046 ^{NS}	-0.433 ^{NS}	-0.579 ^{NS}	0.484 ^{NS}	0.589 ^{NS}	-0.582 ^{NS}	-0.305 ^{NS}	-0.524 ^{NS}	0.445 ^{NS}	-0.541 ^{NS}	-0.582 ^{NS}	-0.469 ^{NS}	-0.653 ^{NS}	0.339 ^{NS}
RH-I	0.168 ^{NS}	-0.264 ^{NS}	-0.884 [*]	-0.033 ^{NS}	-0.208 ^{NS}	0.095 ^{NS}	0.303 ^{NS}	-0.883 [*]	-0.022 ^{NS}	-0.150 ^{NS}	-0.161 ^{NS}	0.303 ^{NS}	-0.821 [*]	-0.099 ^{NS}	-0.544 ^{NS}
RH-II	-0.012 ^{NS}	0.005 ^{NS}	-0.722 ^{NS}	-0.779 [*]	-0.180 ^{NS}	-0.080 ^{NS}	0.114 ^{NS}	-0.650 ^{NS}	-0.881 [*]	-0.169 ^{NS}	-0.018 ^{NS}	0.114 ^{NS}	-0.640 ^{NS}	-0.774 [*]	-0.508 ^{NS}
Rainfall (RF)	0.303 ^{NS}	-0.288 ^{NS}	-0.588 ^{NS}	-0.614 ^{NS}	0	0.250 ^{NS}	0.397 ^{NS}	-0.591 ^{NS}	-0.605 ^{NS}	0	0.293 ^{NS}	0.397 ^{NS}	-0.520 ^{NS}	-0.611 ^{NS}	0

Higher R^2 values were observed in D2, D3 and D4 sowings, suggesting that weather parameters had greater influence on disease incidence during these sowing periods. Relative humidity generally exhibited negative regression coefficients in most sowing dates, indicating reduction in disease incidence with increased humidity, whereas maximum temperature showed both positive and negative effects depending upon sowing time and variety. Rainfall had comparatively lesser influence on disease incidence across all sowing dates.

Although correlation and regression analysis identified individual relationships between weather variables and

leaf crinkle disease incidence, they are limited in explaining multivariate interactions among meteorological factors. Therefore, principal component analysis (PCA) was performed to identify major weather variables contributing to disease development across crop growth stages and sowing environments.

Principal component analysis

Principal component analysis performed using different weather variables (Maximum temperature: T_{max} , minimum temperature: T_{min} , morning relative humidity: RH I, evening relative humidity: RH II, rainfall-RF, growing degree days:

Table 4: Regression equations between weather parameters and incidence of leaf crinkle in five dates of sowing in blackgram.

Sowing date	Variety	Regression equation	R^2 value
D ₁ (I FN October)	PU-31	$Y = -26.59 + 0.90 T_{Max} + 0.57 T_{Min} + 0.11 RH-I + 0.04 RH-II + 0.07 RF$	0.58
	TBG-104	$Y = -46.04 + 1.51 T_{Max} - 0.88 T_{Min} + 0.13 RH-I + 0.14 RH-II + 0.004 RF$	0.67
	LBG-752	$Y = -15.69 + 0.71 T_{Max} - 0.58 T_{Min} + 0.13 RH-I + 0.06 RH-II + 0.017 RF$	0.52
D ₂ (II FN October)	PU-31	$Y = 70.86 - 0.79 T_{Max} - 0.90 T_{Min} - 0.69 RH-I + 0.46 RH-II - 0.029 RF$	0.93
	TBG-104	$Y = 61.02 - 0.61 T_{Max} - 0.95 T_{Min} - 0.59 RH-I + 0.45 RH-II - 0.03 RF$	0.94
	LBG-752	$Y = 62.07 - 0.21 T_{Max} - 1.37 T_{Min} - 0.83 RH-I - 0.66 RH-II - 0.032 RF$	0.85
D ₃ (I FN November)	PU-31	$Y = 19.78 - 0.104 T_{Max} + 0.015 T_{Min} - 0.179 RH-I + 0.029 RH-II - 0.011 RF$	0.94
	TBG-104	$Y = 17.60 - 0.132 T_{Max} + 0.058 T_{Min} - 0.149 RH-I - 0.03 RH-II + 0.008 RF$	0.89
	LBG-752	$Y = 39.68 - 0.419 T_{Max} - 0.018 T_{Min} - 0.290 RH-I - 0.037 RH-II + 0.017 RF$	0.89
D ₄ (II FN November)	PU-31	$Y = -34.68 + 0.827 T_{Max} - 0.205 T_{Min} + 0.178 RH-I - 0.014 RH-II + 0.059 RF$	0.99
	TBG-104	$Y = -15.72 + 0.389 T_{Max} - 0.049 T_{Min} + 0.097 RH-I - 0.051 RH-II + 0.061 RF$	0.99
	LBG-752	$Y = -42.62 + 1.090 T_{Max} - 0.412 T_{Min} + 0.163 RH-I + 0.073 RH-II + 0.013 RF$	0.98
D ₅ (I FN December)	PU-31	$Y = 47.49 - 1.270 T_{Max} + 0.802 T_{Min} - 0.176 RH-I - 0.124 RH-II + 0 RF$	0.84
	TBG-104	$Y = 29.69 - 0.817 T_{Max} - 0.534 T_{Min} - 0.089 RH-I - 0.107 RH-II + 0 RF$	0.84
	LBG-752	$Y = 48.19 - 1.161 T_{Max} + 0.613 T_{Min} - 0.200 RH-I - 0.109 RH-II + 0 RF$	0.82

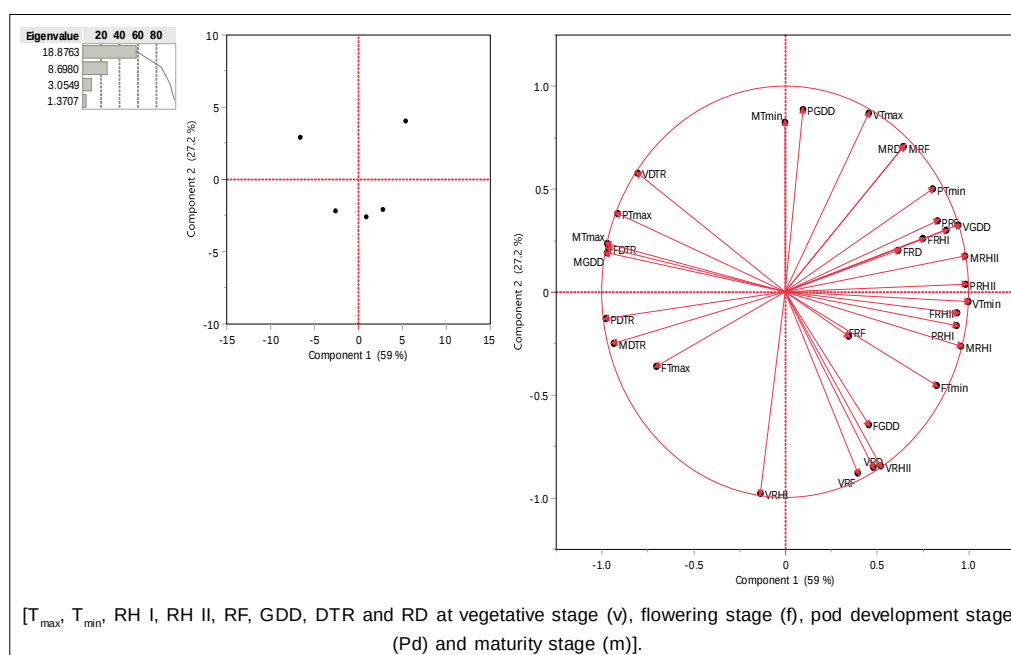


Fig 1: Principal component analysis (PCA) for urdbean leaf crinkle disease incidence and weather parameters during different crop growth stages.

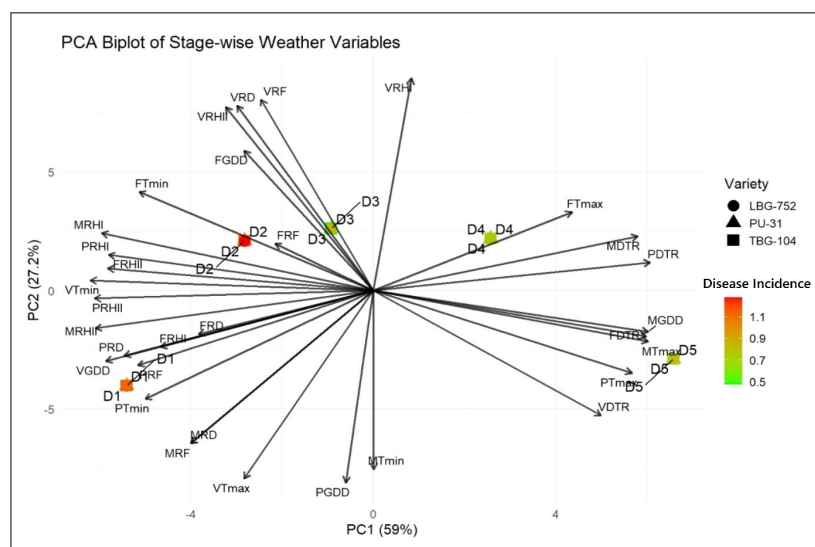


Fig 2: PCA Biplot showing relationships between crop stage-wise weather variables, disease incidence and varieties.

GDD, diurnal temperature ranges: DTR, rainy days: RD) across four growth stages (Vegetative, flowering, pod formation and maturity) explained 86.2% of the total variation in the first two components. PC1 alone captured 59% variation, mainly representing the overall temperature, relative humidity and accumulated heat units across all stages. PC2 explained an additional 27.2% of the variation and primarily separated the flowering and pod-stage humidity and rainfall variables (Fig 1). The PCA correlation circle revealed strong structure among the weather variables across crop growth stages. Variables associated with temperature (T_{max} , T_{min} , GDD and DTR) showed long vectors aligned strongly with PC1, indicating that temperature-related parameters contributed most to the overall variance in the dataset. In contrast, humidity variables (RH I, RH II), rainfall and rainy days loaded predominantly on the positive side of PC2, suggesting that moisture-related factors formed an independent axis of variation. The clear separation of temperature and humidity vectors, combined with their vector lengths, indicates that thermal conditions were the dominant drivers of variability, whereas moisture-related factors explained additional but secondary variation across sowing dates and stages.

The PCA biplot (Fig 2) further revealed clear separation among sowing dates. Early sowings (D1, D2) clustered towards negative PC1, representing cooler and more humid environments, whereas late sowings (D4, D5) shifted toward positive PC1, indicating hotter and drier conditions. Varieties showed partial overlap, but TBG-104 showed lower disease incidence levels across the sowing environments, indicating better tolerance to the leaf crinkle disease. Disease incidence gradients superimposed on the PCA scatter confirmed that higher severity of leaf crinkle disease was associated with late sowing environments characterized by higher T_{max} , lower RH and higher DTR.

Taken together, PCA demonstrated that stage-wise thermal and humidity environments are the primary drivers of disease development and sowing date exerts a major modifying effect by altering exposure to these critical weather factors. However, further multi-location and multi season validation may further strengthen the prediction of disease-weather relationships.

CONCLUSION

The study clearly concluded that early sowing during October significantly reduced leaf crinkle disease incidence and improved productivity of blackgram. Weather factors such as temperature, relative humidity and rainfall significantly influence both disease development and yield formation. Maximum temperature exhibited a positive relationship with disease incidence, whereas humidity and rainfall were inversely related. Further, multiple regression analysis indicated that weather parameters accounted for substantial proportion of variation in disease incidence. Among the varieties, TBG-104 was found as the most adaptable and tolerant and maintaining superior yield performance under a range of environmental conditions. The integration of early sowing and selection of disease-tolerant varieties of black gram provides an effective, eco-friendly approach to manage leaf crinkle disease and enhance black gram productivity under changing climatic conditions.

Conflict of interest

The authors here by declare that there are no conflicts of interest.

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