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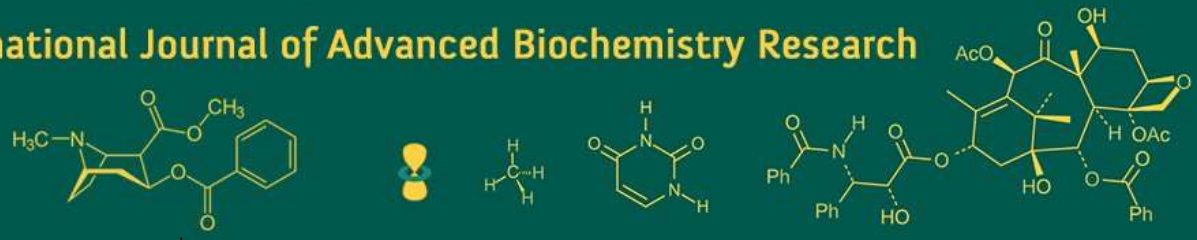

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Effect of environmental factors on an emerging disease: Black banded disease of mango

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Abstract
Black banded disease is an emerging disease of mango occurs with cool and moist weather conditions during the growing season. Since, environmental factors play crucial role on growth, dissemination and infection of pathogen as well as influence the expression of susceptibility/resistance of the host plant after infection. Therefore, an experiment was carried out during 2019-2020, at, UAS, Dharwad to study the effect of weather factors on disease development. Present study revealed that that length of black band progressively increased during July to October, 2019 and during remaining period of the year no growth or negligible increase in black band was noticed. Among the various weather parameters studied, high rainfall, number of rainy days, and minimum temperature seem to have pronounced effect on the spread of black banded disease. More number of rainy days with high rainfall of 150-300 mm, more than 80 per cent relative humidity and temperature of 27 to 30˚C were observed to be favourable for the development and spread of black band. It was confirmed from this study that development and spread of black banded disease occurred mainly during part of monsoon season from July to October.

Keywords: Black banded disease, weather factors, spread pattern, evening relative humidity

Introduction
Mango (*Mangifera indica* L.) is one of the world's most important and esteemed fruits. By the virtue of its wide range of adaptability, delicious taste, superb flavour, very high nutritive and medicinal value as well as great religio-historical significance, it is rightly titled as "King of the fruits" (Hayes, 1953) [6]. Diseases are one of the major constraints in the profitable mango production as they inflict heavy losses every year. Black banded disease is one among the many fungal diseases of mango, earlier it was considered as disease of minor importance, but in recent years it is spreading widely and coming up as a serious malady in some parts of the country including Karnataka. The disease was first time recorded by Massee (1901) [9] from Poona, India. He described *Rhinocladium corticolum* Massee as a causal agent of black banded disease of mango (Saccardo, 1906) [15]. Later Subramanian (1956) [16] renamed the pathogen as *Peziotrichum corticolum* (Massee) Subram. Presently both names are used as synonyms, but now a days *Peziotrichum corticolum* is most commonly used as causal organism of black banded disease of mango (Patil and Dangat, 2011a & 2012) [10, 11]. As far as occurrence of the disease is concerned, it was noticed on the mid-ribs, veins of the leaves, twigs and branches of mango trees as black velvety fungal growth (Prakash and Srivastava, 1987; Masood *et al.*, 2010; Chirag *et al.*, 2017a) [12, 8, 3].

Although some information about the control measure of the above-mentioned diseases are available but influence of environmental factors on disease development are not known and comprehensive attempts on epidemiology of the diseases have not been made so far. Environmental factors decide the spread of black banded disease of mango. The environmental factors like temperature, relative humidity, rainfall and number of rainy days are important for disease development and these environmental factors are being used to forecast disease severity. Further, the knowledge of weather conditions for the development and spread of disease are important to organize agro advisory services for the farmers to take up timely management practices.

Therefore, an experiment was undertaken to study the influence of temperature, relative humidity (RH), rainfall and number of rainy days on the development of the black banded disease of mango under Dharwad (Karnataka) conditions, first of it's kind in the Karnataka.

Material and Methods

Field Experiments

Effect of weather factors such as maximum and minimum temperature, morning and evening relative humidity, rainfall and number of rainy days on the development of disease was studied under natural condition in Silver Jubilee Orchard, UAS, Dharwad using susceptible cultivar Alphonso (>15 years age) during May-2019 to April-2020. Plot size was about 20 m × 20 m block and spacing between trees was about 2.5 m × 2.5 m.

Since, the pathogen is slow growing we made observation for the increase in length of black band (cm) on mango branches at monthly interval for about one year period. The disease spread on branches was recorded on any of the randomly selected trees in a plot and subsequently, the difference in length of the black band was calculated at monthly intervals.

Weather Data

Data on weather factors like maximum and minimum temperature (°C) and morning and evening relative humidity (%), total rainfall (mm) and number of rainy days were collected from Meteorological Observatory of University of Agricultural Sciences, Dharwad. Dharwad is situated in northern transitional zone (Zone-8) of Karnataka state at 15˚ 15' N latitude, 75˚ 07' E longitude and at an altitude of 774.0 m above mean sea level. The meteorological observatory is located 1 km away from the experimental site.

Relationships between meteorological parameters and length of black band

Correlation coefficients were calculated between length of black band disease and different weather parameters like temperature, relative humidity, rainfall and number of rainy days. Regression analysis was done between weather parameters and length of black band disease and multiple linear regression equation was developed by using SPSS 16.0 as well as R software and the results obtained were same by both of these software.

Results

Influence of weather factors on spread pattern of black band during 2019-20 *(One year)* In the present investigation, disease development in relation to weather parameters was studied as described in "Material and Methods". This study, would give some idea about possible relationship between the weather factors like temperature, relative humidity and cumulative rainfall with the spread of black band in a year (May-2019 to April-2020).

Disease progress in relation to weather parameters revealed that, initially in the month of May-2019, length of black band was low (9.70 cm) which increased gradually to 11.39 cm till April-2020. The length of black band progressively increased from July-2019 to October-2020, which was coincided with minimum temperature and maximum relative humidity, rainfall and rainfall of previous months. However, from November to June there was negligible growth or no growth recorded.

Correlation, multiple and simple linear regression analysis between spread of black band in relation to weather parameters

The analysis was made to establish relationship between weather parameters *viz.*, maximum and minimum temperature, morning and evening relative humidity, rainfall, number of rainy days with increase in length of black band on susceptible genotype Alphonso through correlation, multiple and simple linear regression.

The increase in length of black band was correlated with weather parameters recorded during May-2019 to April-2020. The increase in length of black band was correlated positively and was highly significant with evening relative humidity (r = 0.891), morning relative humidity (r = 0.755) and negatively correlated and was highly significant with maximum temperature (r = -0.778). For other weather parameters correlation was positive but non-significant (Table 1). The data were subjected to multiple linear regression analysis and the equation obtained was like this, $Y= - 0.34 - 0.003 X_1 + 0.018 X_2 - 0.002 X_3 + 0.008 X_4 + 0.003 X_5 - 0.04 X_6$ with efficiency of about 84.4 percent (R^2). Here (Y - Increase in length of black band, X_1 - Maximum temperature (°C), X_2 - Minimum temperature (°C), X_3 - Relative humidity (morning) (%), X_4 - Relative humidity (evening) (%), X_5 - Rainfall (mm) and X_6 - No. of rainy days), (Table 3).

Later the data were further subjected to step-wise regression analysis to find the variable which is contributing more on increase in length of the black band. Stepwise regression analysis revealed that evening relative humidity was the parameter which is contributing more on length of black band. Therefore, simple linear regression equation was developed between increase in length of black band and evening relative humidity. The simple regression equation developed is $Y = -0.207 + 0.006 X_4$. Where, Y = increase in length of black band and X_4 = Evening relative humidity. The simple regression equation was significant for the data with $R^2 = 0.79$ (Table.3) for the increase in length of black band. There was variation in the disease development progression which was accounted by the independent variable evening relative humidity. This equation revealed that higher the evening relative humidity higher is the spread of black band. For every unit increase in evening relative humidity, length of black band increased by 0.006 cm. The obtained increase in length of black band was almost similar to predicted increase in length of black band except in two situations (Table 2).

Our studies on influence of weather parameters on spread pattern of black banded disease revealed that length of black band progressively increased during July to October, 2019 and during remaining period of the year no growth or negligible increase in black band was noticed. Among the various weather parameters studied, high rainfall, more number of rainy days, high relative humidity and minimum temperature seem to have pronounced effect on the spread of black banded disease. More number of rainy days with high rainfall of 150-300 mm, more than 80 per cent relative humidity and temperature of 27 to 30 ˚C were observed to be favourable for the development and spread of black band. It was confirmed from this study that development and spread of black banded disease occurred mainly during part

of monsoon season from July to October. It is clearly indicated from this study that the spread and development of this disease is taking place during monsoon.

The correlation and regression studies also clearly indicated that maximum temperature, morning and evening relative humidity were highly correlated with increase in length of black band. Morning relative humidity and evening relative humidity correlated positively and were highly significant whereas, maximum temperature was negatively correlated but significant. Further, stepwise regression analysis revealed that evening relative humidity was the parameter which is contributing more on length of black band. Therefore, simple linear regression equation was developed between increase in length of black band and evening relative humidity.

Table 1: Correlation between increase in length of black band in relation to weather parameters

Parameters	Y	X1	X2	X3	X4	X5	X6
Y - Increase in length of black band	1.000	-0.778**	0.125	0.755**	0.891**	0.438	0.529
X_1 - Maximum temperature (ºC)	-0.778**	1.000	0.219	-0.584*	-0.872	-0.073	-0.196
X_2 - Minimum temperature (ºC)	0.125	0.219	1.000	0.398	0.131	0.621*	0.760**
X_3 - Relative humidity (morning) (%)	0.755**	-0.584*	0.398	1.000	0.868**	0.424	0.593*
X_4 - Relative humidity (evening) (%)	0.891**	-0.872**	0.131	0.868**	1.000	0.345	0.510
X_5 - Rainfall (mm)	0.438	-0.073	0.621*	0.424	0.345	1.000	0.940**
X_6 - No. of rainy days (days)	0.529	-0.196	0.760**	0.593*	0.510	0.940**	1.000

**Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed)

Table 2: Influence of weather factors on spread pattern of black banded disease of mango during 2019-20 (One year)

Year	Month	Weather factors								Spread pattern of black band (cm)	Observed increase in length of black band (cm)	Predicted increase in length of black band (cm)
		T_{max} (˚C)	T_{min} (˚C)	RH-1 (%)	RH-2 (%)	Rain fall (mm)	Total rain falls during successive months (mm)	Rainy days	Rainy days during successive months			
2019	May	35.4	21.9	76.23	48.74	101.8	---	8	---	9.70	---	0.085
	June	29.5	21.5	85.90	72.03	31.4	133.2	5	13	9.77	0.07	0.22
	July	27.6	21	88.13	78.71	117.8	149.2	10	15	9.99	0.22	0.26
	August	28.6	20.8	90.13	80.61	32.4	150.2	5	15	10.29	0.31	0.27
	September	28.7	20.7	93.40	88.27	197.6	230	13	18	10.64	0.35	0.32
	October	29.5	19.9	93.16	84.16	72.6	270.2	7	20	10.93	0.29	0.29
	November	29.8	15.8	83.20	68.67	16.2	88.8	1	8	11.10	0.17	0.20
	December	28.7	14.1	82.97	71.10	0.4	16.6	0	1	11.23	0.13	0.21
2020	January	29.84	13.91	74.81	57.71	0	0.4	0	0	11.33	0.10	0.13
	February	32.11	15.67	54.11	38.50	1	1	0	0	11.37	0.04	0.02
	March	34.90	19.30	65.00	28.00	72.4	73.4	3	3	11.39	0.01	-0.039
	April	36.20	21.10	79	36	32.8	105.8	3	6	11.39	0.00	0.009
Average		30.90	18.81	80.50	62.71	Total 676.40		Total 55.00			Total = 1.69	

Tmax = Maximum temperature, Tmin = Minimum temperature, RH-1 = Morning relative humidity, RH-2 = Evening relative humidity

Table 3: Regression between increase in length of black band in relation to weather parameters

Multiple linear regression equation	R^2
Y= - 0.34 - 0.003 X_1 + 0.018 X_2- 0.002 X_3+ 0.008 X_4+ 0.003 X_5- 0.04 X_6	0.84*
Stepwise linear regression equation	**R^2**
Y= - 0.202 + 0.005 X_4	0.79

*Significant at 0.05 level

Discussion

The results of this study underscore the profound influence of weather parameters on the spread of black band disease, with a particular emphasis on the role of relative humidity and temperature. The disease exhibited a marked progression from July to October 2019, coinciding with the monsoon season. This finding aligns with previous studies, notably by Reddy *et al.* (1961) [14] and Venkateswarlu (1989) [17], which have similarly documented a pronounced spread of black band disease during the rainy season and limited growth during drier months.

Relative humidity, especially during the evening, emerged as a critical factor influencing disease spread. The high correlation coefficient (r = 0.891) between evening relative humidity and black band length suggests that high moisture levels in the atmosphere during the evening provide conducive conditions for disease proliferation. This is consistent with studies by Fernandes *et al.* (2005) [5], who reported that high relative humidity fosters fungal spore germination and subsequent infection in various plant diseases. The study's stepwise regression analysis further emphasized this, with evening relative humidity being identified as the most influential factor. The regression equation (Y = -0.207 + 0.006 X4) suggests that for every unit increase in evening relative humidity, the length of the black band increases by 0.006 cm. This finding highlights the necessity of monitoring and managing humidity levels as a part of integrated disease management strategies, especially during susceptible periods.

The role of temperature was also significant, though inversely related to disease spread. Maximum temperature exhibited a negative correlation (r = -0.778) with black band length, indicating that higher temperatures may suppress the disease's progression. This is supported by studies such as those by Cook and Papendick (1972) [4], which indicate that elevated temperatures can inhibit the growth and spread of

many plant pathogens by creating unfavourable conditions for their survival and reproduction. Minimum temperature, however, contributed positively to disease spread, although its impact was less pronounced compared to relative humidity. The findings of the present study are in agreement with Reddy *et al.* (1961) [14] who reported that the black banded disease was spreading appreciably during October to November, while growth was negligible from February to September. Venkateswarlu (1989) [17] also reported that rainfall of 414-426 mm, maximum and minimum temperature of 31.8 and 22.3˚C supported maximum disease incidence of black banded disease in Chittoor districts of Andhra Pradesh.

Rainfall and the number of rainy days were also positively correlated with black band progression, albeit non-significantly. The observed pattern suggests that high rainfall during the monsoon months of July to October provides a favourable environment for disease spread. These findings are consistent with the work of Chakraborty *et al.* (2000) [2], who noted that prolonged wet conditions can enhance the incidence and severity of foliar diseases in crops. Although the correlation between rainfall and black band length was not statistically significant, the trend observed supports the notion that moisture availability is a critical component of disease dynamics.

The negligible growth of black band disease from November to June further reinforces the seasonal dependency of the disease. The dry conditions and higher temperatures during these months likely limit the disease's spread, a pattern observed in other pathosystems as well. For instance, Magarey *et al.* (2005) [7] reported that drought conditions can reduce disease severity in grapevines by limiting the availability of free water required for pathogen infection and development.

The findings of this study have important implications for the management of black band disease, particularly in regions where weather conditions mirror those observed in this investigation. The high sensitivity of the disease to relative humidity and temperature suggests that predictive models incorporating these variables could be developed to forecast disease outbreaks and guide timely interventions. Moreover, the results highlight the importance of adopting integrated management practices that account for weather patterns, such as adjusting irrigation schedules or deploying protective measures during periods of high humidity and moderate temperatures.

In conclusion, this study reinforces the critical role of weather parameters, particularly evening relative humidity, in driving the spread of black band disease. The findings provide valuable insights for developing targeted disease management strategies that could be implemented during critical periods of disease risk. Further research is needed to refine predictive models and explore the potential of integrating weather forecasting with disease management practices in affected regions.

Conclusion

From the above findings, it can be concluded that the spread and development of this disease is taking place during monsoon. This provides new and useful information about the environmental factors favourable for development and spread of black banded disease. The study on the influence of weather factors on the spread of black band disease during 2019-20 demonstrated a clear relationship between disease progression and specific climatic conditions. The length of the black band increased significantly from July to October 2019, coinciding with high evening and morning relative humidity, moderate temperatures (27-30°C), and substantial rainfall. Among these, evening relative humidity was identified as the most influential factor through stepwise regression analysis, contributing significantly to the spread of the disease. The developed regression model indicated that for every unit increase in evening relative humidity, the length of the black band increased by 0.006 cm. This study emphasizes that the monsoon season, characterized by these specific weather conditions, plays a crucial role in the development and spread of black band disease.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have approved to influence the work reported in this paper.

Ethical Statement

All the experimental procedures involving only on plant species were conducted following the University of Agricultural Science, Dharwad-580005, Karnataka, India institutional guidelines. There are no human and animal subjects/trials conducted in this article and informed consent is not applicable.

Disclosure Statement

The authors declare that there are no financial/commercial conflicts of interest.

Author Contributions

A. Jayashree (Conceptualization [supporting], Data curation [lead], Formal analysis [lead], Investigation [lead], Visualization [lead], Writing-original draft [lead]), Divya shree (Supervision [supporting], Validation [equal], Writing -review & editing [equal]), Ravikumar Vaniya (Supervision [supporting], Validation [supporting]), V. Rathna (Supervision [supporting], Validation [lead]) Padsala jaykumar jagdishbhai (conceptualization [supporting], Formal analysis [supporting]).

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