Colegio de Postgraduados

Climatic variables that favor the Black Sigatoka (*Mycosphaerella fijiensis* Morelet) [anamorph: *Pseudocercospora fijiensis* (Morelet) Deighton] infestation in a banana-growing zone

Aceves-Navarro, Lorenzo A.[1]; **Rivera-Hernández, Benigno**[2*]; **Arrieta-Rivera, A.**[3]; **Juárez-López, J. Francisco**[1]

[1] Colegio de Postgraduados-Campus Tabasco, Carretera Cárdenas-Huimanguillo, Km. 3.5, C. P. 86500, Cárdenas, Tabasco, México.
[2] Universidad Popular de la Chontalpa, Carretera Cárdenas-Huimanguillo, Km. 2.0, r/a Pazo y Playa, Cárdenas, Tabasco, México.
[3] Tecnológico Nacional de México/IT Zona Olmeca, Prol. Ignacio Zaragoza s/n, Villa Ocuiltzapotlán, Centro, Tabasco, México.
* Correspondence: benigno.rivera@upch.mx

ABSTRACT

Objective: To establish the favorable or unfavorable climatic conditions for the emergence and development of Black Sigatoka in a banana-growing area within the influence zone of the Teapa weather station (27004) in Tabasco, Mexico.

Design/Methodology/Approach: We analyzed temperature data for n=59 years (1961-2019) at the Teapa weather station (27044) in Tabasco, as reported by IMTA (2009) and the Servicio Meteorológico Nacional (until 2019). Relative humidity was calculated using the equation developed by Allen *et al.* (2006). We also established the favorable or unfavorable climatic conditions for the development of Black Sigatoka in Teapa by resorting to the favorability typology posited by Júnior *et al.* (2008).

Results: There are no highly favorable climatic conditions for the incidence and development of this disease. Overall, spring and summer are the less favorable months, while fall and winter offer more favorable conditions.

Study Limitations/Implications: This study should be replicated in other banana-growing areas of Tabasco, since both temperature and relative humidity may differ and, consequently, the frequency of the disease may vary.

Findings/Conclusions: October and March are the most favorable months for Black Sigatoka occurrence. Therefore, comprehensive management and control programs should be designed for this period.

Keywords: Temperature, Relative Humidity, Banana, Yields, Probability, Prediction Models.

Citation: Aceves-Navarro, L. A., Rivera-Hernández, B., Arrieta-Rivera, A., & Juárez-López, J. F. (2023). Climatic variables that favor the Black Sigatoka (*Mycosphaerella fijiensis* Morelet) [anamorph: *Pseudocercospora fijiensis* (Morelet) Deighton] infestation in a banana-growing zone. *Agro Productividad*. https://doi.org/10.32854/agrop.v16i12.2500

Academic Editors: Jorge Cadena Iñiguez and Lucero del Mar Ruiz Posadas

Received: February 02, 2023.
Accepted: September 25, 2023.
Published on-line: December 27, 2023.

Agro Productividad, 16(12). December. 2023. pp: 41-48.

INTRODUCTION

Black Sigatoka (*Mycosphaerella fijiensis* Morelet [anamorph: *Pseudocercospora fijiensis* (Morelet) Deighton]) is an infectious disease that attacks banana and plantain leaves worldwide. The reproduction of this ascomycete fungus can be sexual or asexual (Soares *et al.*, 2021). Black Sigatoka is considered the most harmful and costly of banana diseases, with its control taking up nearly 27% of production costs (Júnior *et al.*, 2008). This disease can cause a 25-100% yield reduction, if no methods and appropriate agronomic practices are in place to control its effects (Nfor *et al.*, 2011).

The climatic variables that favor the emergence, incidence, and severity of the Black Sigatoka attack are mainly temperature, relative air humidity, precipitation, and the time that leaves remain wet; the maximum effect has been recorded during the first symptoms (Álvarez *et al.*, 2013; Khan *et al.*, 2015). The optimal temperature range for the development of the disease is 25 °C to 28 °C (Bebber, 2019; Orozco *et al.*, 2008). Relative humidity levels of 92% or higher are a predictor of disease outbreaks (Khan *et al.*, 2015). Jacome and Schuh (1992) report that ≥92% relative humidity favors conidia infection, whether the leaves are wet or not. However, ascospore infections do require wet leaves (Júnior *et al.*, 2008).

To categorize the climatic conditions that favor the incidence and development of Black Sigatoka in any given locality or region, Júnior *et al.* (2008) proposed a classification based on temperature and relative humidity. Based on the abovementioned background, the occurrence of Black Sigatoka in the state of Tabasco must be researched. Consequently, the duration of climatic conditions (*i.e.*, temperature and relative humidity) that favor the occurrence of the Black Sigatoka infection was estimated. The most crucial variables for the disease model are precipitation, relative humidity, and temperature (Bombelli *et al.*, 2013). Improving the quality of weather and climate forecasting can help to estimate the probability of disease occurrence in plants and to predict the emergence or absence of severe epidemics.

MATERIALS AND METHODS

Climatological information and data management

The daily average maximum and minimum temperature data (T_{max} and T_{min}) were retrieved from the ERIC III database developed in 2009 by the Instituto Mexicano de Tecnología del Agua (IMTA). The information covered n=59 years (1961-2019) of data gathered at the Teapa weather station (27044), Tabasco, Mexico. We complemented this information with data up to 2019 recorded by the Servicio Meteorológico Nacional (SMN, 2021). The Teapa weather station is located at 92° 57' 12" W and 17° 32' 56" N. The average annual temperature in the zone ranges from 24 °C to 26 °C, while the total annual precipitation fluctuates between 2,000 and 4,000 mm (Zavala-Cruz *et al.*, 2016). The resulting data were transcribed into an Excel sheet for accessibility. The average daily temperature (T_{med}) was obtained using the following equation (1):

$$T_{med} = \frac{T_{\max} + T_{\min}}{2} \quad (1)$$

The average monthly temperature was subsequently estimated. Consequently, we had 12 average monthly values (T_{med}) for each one of the 59 registered years (708 month data). Finally, an annual average was determined for all 59 years. The same procedure was followed for the relative humidity data.

Estimating relative humidity (HR)

Since neither Eric III nor the Servicio Meteorológico Nacional provide HR data, its percentage was estimated based on the ratio of the actual partial pressure of water vapor to the partial pressure of water vapor at saturation, using the equation proposed by Allen *et al.* (2006):

$$HR = \left(\frac{e_a}{e_s}\right) * 100 \quad (2)$$

Where HR is the relative humidity (%) and "e_a" is the actual partial pressure of water vapor (kPa). We used 348,192 data captured every 10 minutes in 13 automatic weather stations distributed throughout the Tabasco Plain. The following equation (3) was used to carry out these calculations:

$$e_a = \left(\frac{HR}{100}\right) * e_s \quad (3)$$

Where "e_s" is the partial pressure of water vapor at saturation (kPa), obtained from temperature data using the equation proposed by Allen *et al.* (2006):

$$e_s = 0.61078 * \exp\left[\frac{(17.269 * T_{med})}{(T_{med} + 237.3)}\right] \quad (4)$$

A daily average was obtained with the values of "e_a". Subsequently, a regression analysis was carried out between these values and the daily average temperature to find an equation or functional relation to estimate "e_a" based only on temperature data for all existing weather stations in Tabasco. The result was equation (5), which had a coefficient of determination in the validation phase (R^2) of 0.852.

$$e_a = 4.646 - \left(\frac{45.15}{T_{med}}\right) \quad (5)$$

Once "e_a" and "e_s" were established, the daily, monthly, and annual average relative humidity (HR) was calculated using equation (2).

Typology of climatic favorability for Black Sigatoka

The different types of climatic favorability for the development of Black Sigatoka were determined for each month of the year using monthly average temperature and relative humidity data. This categorization draws on the climatic favorability types proposed by Júnior *et al.* (2008) (Table 1).

Determining favorability types

Based on the monthly average temperature and relative humidity data recorded each year at the Teapa weather station, a typology of climatic favorability was developed for each

Table 1. Types of favorability for Black Sigatoka development, according to temperature and relative humidity intervals (Júnior *et al*., 2008).

Favoring class	Description	Temperature ranges (°C)	Relative humidity ranges (%)
1	Highly Favorable	25 a 28	>90
2	Favorable	25 a 28	80 a 90
3	Relatively Favorable	20 a 25 o 28 a 35	>80
4	Poor	20 a 35	70 a 80
5*	Unfavorable	<20 a >35	<70

(*) Favorability type 5 occurs with a <70% relative humidity in any temperature interval.

of the 708 months of the 1961-2019 period, as well as the monthly average (59 data per month) and the total annual average. The typology of favorability (based on temperature and relative humidity) was determined using the limits shown in Table 1. Subsequently, the relative frequency for each month was determined to estimate the probability of each of the five favorability types and their corresponding return period.

Relative frequency analysis

The division of the number of occurrences in a specific period (Table 1) by the historical record was the basis of the analysis of the relative frequencies of temperature and relative humidity (separately or combined). This is how we determined the relative frequency for each of the five types of favorability and each month of the 59 years recorded.

RESULTS AND DISCUSSION

Isolated effect of temperature on the development of Black Sigatoka

None of the 708 monthly average temperature values analyzed met the criteria for the Unfavorable category. In 72.3% of the period under observation, the temperature ranged from Relatively Favorable to Highly Favorable for the development of Black Sigatoka. Temperatures in September and October were Highly Favorable for the manifestation of Black Sigatoka disease, since the values in these months fluctuate between 25 °C and 28 °C. Only 27.7% of the months analyzed were classified as Slightly Unfavorable. In conclusion, the thermal conditions in three out of every four years are conducive to the development of the disease in the influence zone of the Teapa weather station in Tabasco.

Isolated effect of relative humidity on the development of Black Sigatoka

The average relative humidity during the 59 years studied was high (78.8%). No ≥90% HR values were recorded in any month of the analyzed period. Therefore, the Highly Favorable conditions did not occur at the monthly average level. However, 98% of the analyzed months recorded relative humidity values greater than 70%. Consequently, <70% relative humidity occurred only in 2% of the period under observation. Therefore, Unfavorable conditions for the development of Black Sigatoka would take place once every 50 to 51 years. This is a very unlikely phenomenon. Slightly Unfavorable conditions were recorded 58.2% of the time (HR between 70% to 80%). In contrast, Relatively Favorable to Favorable conditions occurred only 39.8% of the time (HR >80%). If we consider HR alone, Slightly Unfavorable to Unfavorable conditions predominate at the Teapa weather station (27044) in Tabasco, Mexico, most of the time. Hence, these conditions will be present in six out of every ten years.

Combined effect of total average temperature and relative humidity

Using a single average temperature and relative humidity value for the 59 years of recorded data (Table 1), the overall climatic conditions were determined to be Relatively Favorable for the emergence of the Black Sigatoka disease in bananas, in the influence zone of the Teapa weather station (27044).

Combined effect of monthly average temperature and relative humidity on the development of Black Sigatoka for the whole analyzed period

Table 2 shows the relative time of each type of climatic favorability, during each of the 708 months of the 1961-2019 period. This Table shows that there were no Highly Favorable conditions for the development of Black Sigatoka during the whole period. On the one hand, the Table also shows that, most of the time (56.9%), the conditions were Slightly Unfavorable for the development of the disease, with a 2-year return period. On the other hand, Relatively Favorable conditions prevailed during 28% of the time analyzed (*i.e.*, a 4-year return period). Meanwhile, Favorable conditions have an 8-year return period (13.1 %). Finally, Unfavorable conditions had a 50- to 51-year return period (2%).

Table 2 shows the relative frequency and return period for the various climatic conditions recorded in the 708 months under study. It also indicates the frequency with which they can occur in any of the 12 months of the year. In nearly 60% of the period under analysis, the climatic conditions ranged from Slightly Unfavorable to Unfavorable for the development of Black Sigatoka. Based on a monthly analysis, Highly Favorable conditions do not occur, while Unfavorable ones occur once every 51 years.

Figure 1 contains the results of temperature and relative humidity analyses for each of the 708 months; these results determine the type of climatic favorability and its relative frequency. On the one hand, the climatic conditions in January are 100% Relatively Favorable (Type 3, the prevailing type), although they do not reach 100% conditions during November, December, and February. On the other hand, July, August, and September show 100% Slightly Unfavorable climatic conditions (Type 4), with a certain reduction

Table 2. Relative time of occurrence for different types of climatic favorability and their corresponding return periods, from 1961 to 2019, in the influence zone of the Teapa weather station (27044) in Tabasco, Mexico.

Climatic condition	Time analyzed (%) (1961 - 2019)	Return period (years)
Favorable	13.1	8
Relatively Favorable	28.0	4
Poor	56.9	2
Unfavorable	2.0	51

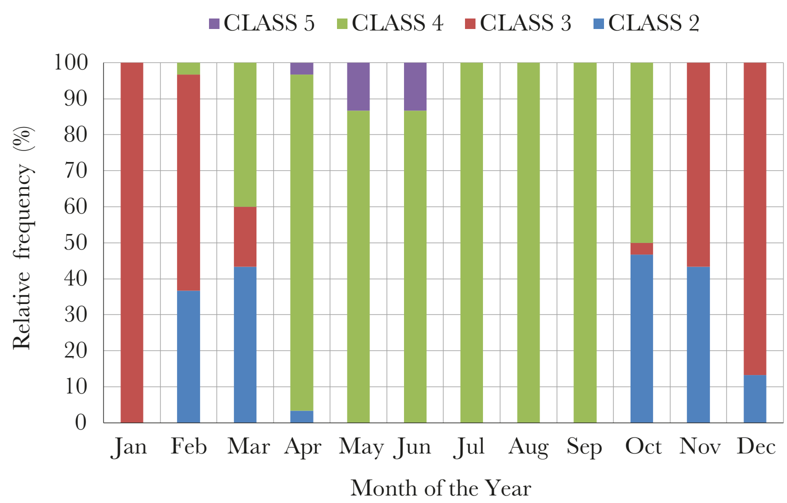

Figure 1. Relative frequency of climatic favorability types for the development of Black Sigatoka for all months of the year in the influence zone of the Teapa weather station (27044) in Tabasco, Mexico.

during April, May, June, and October, while still remaining prevalent. Likewise, Favorable conditions are not fully met (100%) in any month of the year, with >40% values only in October, November, and March.

Figure 2 shows the four types of favorability for Black Sigatoka development in the Teapa banana-growing area, divided into favorable and unfavorable conditions. From April to September (spring-summer), Slightly Unfavorable to Unfavorable conditions for the development of Black Sigatoka prevailed —with values that fluctuate between 96.6% and 100%. Meanwhile, from November to March (autumn-winter), the prevailing conditions range from Relatively Favorable to Favorable (100% in November, December, and January). During these three months, continuous sampling must be conducted to gain a more effective control over Black Sigatoka in the influence zone of the Teapa weather station (27044) in Tabasco, Mexico.

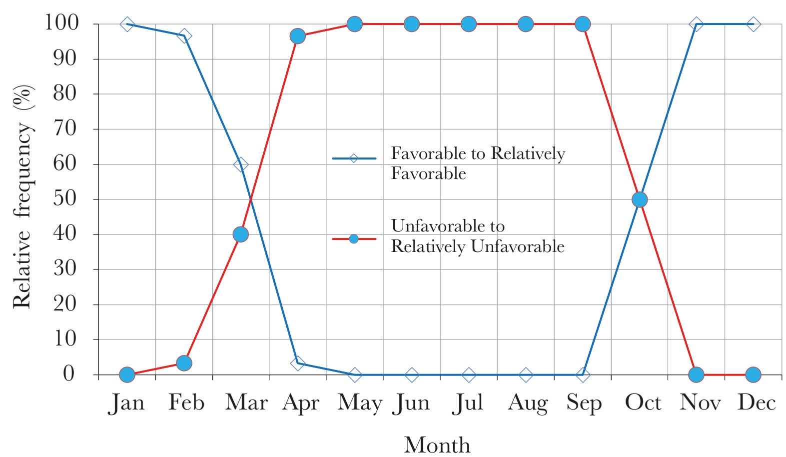

Figure 2. Favorable climatic conditions for the development of Black Sigatoka, for all months of the year, in the influence zone of the Teapa weather station (27044) in Tabasco, Mexico.

Combined effect of monthly average temperature and relative humidity on the development of Black Sigatoka

Table 3 shows the monthly average favorability types for the influence zone of the Teapa weather station (27044) in Tabasco, Mexico.

The monthly average values in Table 3 do not include Highly Favorable and Unfavorable types for the development of Black Sigatoka. From April to September, climatic conditions are Slightly Unfavorable for the development of the disease. These results match those obtained in the analysis of the whole period (708 months). Favorable climatic conditions occur in October, November, and March. Khan *et al.* (2015) reported similar results in four banana-growing areas in Bangladesh, where the highest incidence and severity of Black Sigatoka are recorded in October. These authors found a high correlation between the incidence and severity of the disease and the precipitation and temperature which are influenced by relative humidity.

Table 3. Monthly average temperature and relative humidity values defining the types of climatic favorability for Black Sigatoka infestation in the influence zone of the Teapa weather station (27044) in Tabasco, Mexico, from 1961 to 2019.

Month	T_{max}	T_{min}	T_{med}	*RH*	Favoring class	Description
January	26.6	18.0	22.3	86.9	3	Relatively Favorable
February	28.2	18.5	23.4	85.3	3	Relatively Favorable
March	31.3	20.0	25.7	81.2	2	Favorable
April	33.7	21.8	27.8	76.8	4	Poor
May	34.9	23.0	29.0	74.0	4	Poor
June	34.0	23.0	28.5	75.1	4	Poor
July	33.5	22.4	28.0	76.4	4	Poor
August	33.3	22.5	27.9	76.5	4	Poor
September	32.2	22.6	27.4	77.6	4	Poor
October	30.3	21.7	26.0	80.5	2	Favorable
November	28.8	20.1	24.5	83.4	2	Favorable
December	27.1	18.6	22.9	86.1	3	Relatively Favorable

T_{max}: maximum temperature; T_{min}: minimum temperature; T_{med}: average temperature; *RH*: relative humidity.

CONCLUSIONS

In the analyzed period (1961-2019), the climatic conditions were Relatively Favorable for the manifestation of the Black Sigatoka disease. No Highly Favorable climatic conditions for the emergence of Black Sigatoka occurred in the zone of influence of the Teapa weather station. The methodology and results of this work should be incorporated into a web system, using hourly or daily data to issue an early real-time warning about the risk of Black Sigatoka in the banana-growing region of Teapa, Tabasco.

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