Revista Facultad Nacional de Agronomía Medellín
ISSN: 0304-2847
ISSN: 2248-7026
Facultad de Ciencias Agrarias - Universidad Nacional de Colombia

Restrepo-Leal, Julián D.; Rada-González, Deimys F.; Páez-Redondo, Alberto R.
Epidemiological study of *Colletotrichum* spp. associated with *Enterolobium cyclocarpum* (Jacq.) Griseb. and *Platymiscium pinnatum* (Jacq.) Dugand in the Colombian Caribbean Region
Revista Facultad Nacional de Agronomía Medellín,
vol. 75, no. 1, 2022, January-April, pp. 9773-9789
Facultad de Ciencias Agrarias - Universidad Nacional de Colombia

DOI: https://doi.org/10.15446/rfnam.v75n1.94723

Research article

https://revistas.unal.edu.co/index.php/refame

Revista Facultad Nacional de Agronomía

Epidemiological study of *Colletotrichum* spp. associated with *Enterolobium cyclocarpum* (Jacq.) Griseb. and *Platymiscium pinnatum* (Jacq.) Dugand in the Colombian Caribbean Region

UNIVERSIDAD NACIONAL DE COLOMBIA

Estudio epidemiológico de *Colletotrichum* spp. asociado a *Enterolobium cyclocarpum* (Jacq.) Griseb. y *Platymiscium pinnatum* (Jacq.) Dugand en la region caribe colombiana

https://doi.org/10.15446/rfnam.v75n1.94723

Julián D. Restrepo-Leal[1]*, Deimys F. Rada-González[1] and Alberto R. Páez-Redondo[1]

ABSTRACT

Epidemiological analyzes of foliar diseases associated with *Colletotrichum* spp. in *Enterolobium cyclocarpum* and *Platymiscium pinnatum* were performed under field conditions and without any type of intervention. At the Universidad del Magdalena (Santa Marta, Colombia), four trees for each species and four equidistant monitoring sites per tree were established. The incidence and severity were recorded for 33 weeks (March to November 2016), including two follow-up periods: dry and rainy season. Disease development curves were elaborated. Moreover, the development rate (*r*) and the area under the disease progress curve (*AUDPC*) were calculated for each follow-up period. The effect of the meteorological variables was statistically analyzed by correlation and multiple regression. In *E. cyclocarpum*, the highest incidence and severity were recorded between September and November with 100 and 19.6%, respectively, showing a positive correlation with relative humidity and negative with average temperature, solar radiation and wind speed. In *P. pinnatum*, the maximum values of incidence and severity were observed between March and April with 68.9 and 1.3%, respectively. However, correlation analyzes did not support their relationship with the environmental factors. The *r* values during the dry months were 0.136 and 0.107 units week^{-1} and the *AUDPCs* were calculated at 51 and 4 units week^{-1} for *E. cyclocarpum* and *P. pinnatum*, respectively. In the rainy months, the *r* values were 0.187 and 0.016 units week^{-1} and the *AUDPCs* were 186 and 2 units week^{-1}, respectively. In conclusion, the development of the disease varies according to the forest species, time of year and some meteorological variables.

Keywords:
Development curves
Disease development rate
Foliar diseases
Incidence
Severity

RESUMEN

Se realizó un análisis epidemiológico de enfermedades foliares asociadas a *Colletotrichum* spp. en *Enterolobium cyclocarpum* y *Platymiscium pinnatum* bajo condiciones de campo y sin ningún tipo de intervención. En el campus de la Universidad del Magdalena (Santa Marta, Colombia), se seleccionaron cuatro árboles de cada especie forestal y cuatro sitios equidistantes de seguimiento por árbol. La incidencia y severidad fueron registradas durante 33 semanas (de marzo a noviembre, 2016), incluyendo dos periodos de seguimiento: seco y lluvioso. Se elaboraron curvas de desarrollo de la enfermedad. Además, la tasa de desarrollo (*r*) y el área bajo la curva del progreso de la enfermedad (*AUDPC*) fueron calculadas para cada periodo de seguimiento. El efecto de las variables meteorológicas fue estadísticamente analizado mediante correlación y regresión múltiple. En *E. cyclocarpum*, el valor más alto de incidencia y severidad fueron registrados entre septiembre y noviembre con 100 y 19,6%, respectivamente, mostrando una correlación positiva con la humedad relativa y negativa con la temperatura promedio, la radiación solar y la velocidad del viento. En *P. pinnatum*, los valores máximos de incidencia y severidad fueron observados entre marzo y abril con 68,9 y 1,3%, respectivamente. Sin embargo, los análisis de correlación no confirmaron su relación con los factores ambientales. Los valores de *r* durante los meses secos fueron de 0,136 y 0,107 unidades semana^{-1} y las *AUDPCs* fueron calculadas en 51 y 4 unidades semana^{-1} para *E. cyclocarpum* y *P. pinnatum*, respectivamente. En los meses lluviosos, los valores *r* fueron de 0,187 y 0,016 unidades semana^{-1} y las *AUDPCs* fueron 186 y 2 unidades semana^{-1}, respectivamente. Se concluyó que el desarrollo de la enfermedad varía según la especie forestal, la época del año y algunas variables meteorológicas.

Palabras clave:
Curvas de desarrollo
Tasa de desarrollo de la enfermedad
Enfermedades foliares
Incidencia
Severidad

[1] Fitotecnia del Trópico. Facultad de Ingeniería. Universidad del Magdalena, Santa Marta, Colombia. julianrestrepoleal@gmail.com, deimysrada@gmail.com, apaez@unimagdalena.edu.co

* Corresponding author

Received: September 22, 2021; Accepted: October 25, 2021
Rev. Fac. Nac. Agron. Medellín 75(1): 9773-9789. 2022

ISSN 0304-2847 / e-ISSN 2248-7026

Enterolobium cyclocarpum (Jacq.) Griseb. and *Platymiscium pinnatum* (Jacq.) Dugand (Fabaceae family) are common trees of the Colombian Caribbean region, with a high presence in the city of Santa Marta (department of Magdalena). *E. cyclocarpum* (subfamily: Mimosoideae) is distributed throughout the dry forests of Central America and northern South America (Rocha *et al*., 2018). This fabaceous is a species widely known for its uses in different human activities and, in forestry systems, its wood is used for construction, production of household utensils, furniture, musical instruments, among others (Pacheco *et al*., 2012). Its wide canopy provides shade appreciated in silvopastoral systems, as well as in urban centers, where it is planted as an ornamental tree along with parks and roads (Cordero and Boshier, 2003). Additionally, its fruits and seeds are suitable for human and animal consumption, making it possible to produce flours (Cordero and Boshier, 2003). On the other hand, extracts from different parts of the tree have been used to alleviate various ailments in humans and animals (Pacheco *et al*., 2012).

Platymiscium pinnatum (subfamily: Faboideae) is a neotropical tree distributed from Mexico to Brazil, preferably occupying dry habitats; however, its growth is common in humid ecosystems (Saslis-Lagoudakis *et al*., 2008). *P. pinnatum* is highly valued in forestry for its wood, which is used for multiple purposes, such as construction, fine wood carvings, furniture making, and musical instruments (Cordero and Boshier, 2003). This species has been described as a nitrogen fixer, being ideal for agroforestry systems and enrichment of degraded forests (Cordero and Boshier, 2003). In Central America, for example, *P. pinnatum* has been associated with organic and conventional agroforestry systems of shade coffee (Haggar *et al*., 2015). On the other hand, the use of leaf infusions has been reported for the treatment of infectious diseases in the skin and eyes (Pabón *et al*., 2017).

In a survey of pathogens in the urban trees of Santa Marta, Colombia, *Colletotrichum* spp. were associated with foliar diseases in *E. cyclocarpum* and *P. pinnatum* (Cantillo, 2014). The symptoms associated with *Colletotrichum* in *E. cyclocarpum* consist of whitish rounded spots at the leaflet base on the leaf underside, while in *P. pinnatum*, the symptom corresponds to a light or dark brown anthracnose surrounded by a chlorotic halo (Cantillo, 2014; Restrepo-Leal and Rada-González, 2017). Furthermore, in previous tests, the fungal pathogenicity was verified in both developing and mature foliar tissues of these forest species with the expression of characteristic symptoms in each plant (Restrepo-Leal and Rada-González, 2017). Due to these symptoms, the name “foliar Anthracnose” was defined to refer to this disorder or pathology.

Colletotrichum is one of the most important phytopathogenic fungi in the world because it affects a large number of plant species, causing huge economical losses (Dean *et al*., 2012). Moreover, this pathogen has a regular occurrence in different forest species, where it mainly has a causal relationship with foliar diseases that are expressed as spots, blights or anthracnose (Arguedas-Gamboa and Cots-Ibiza, 2012). In general, *Colletotrichum* spp. cause the disease called Anthracnose and, in aerial organs, these fungi cause sunken necrotic lesions, subcircular or angular, where the acervuli are formed (Dean *et al*., 2012; Arguedas-Gamboa and Cots-Ibiza, 2012).

To develop efficient control strategies, it is necessary: *i*) to carry out epidemiological studies of the disease that allow understanding its behavior, including aspects related to the infective period (Miles *et al*., 2013), and *ii*) to know the effect of the environmental variables on the disease development (Moral *et al*., 2012). In this regard, some research indicate that *Colletotrichum* species can be inactive during dry periods and change to infective when temperatures oscillate between 25 and 30 °C, and the relative humidity is greater than 80% (Miles *et al*., 2013; Lima *et al*., 2015). The severity of the disease is conditioned by the intensity and duration of precipitation, duration of humidity on the leaf surface, luminosity, among others (Huertas-Palacios *et al*., 2009; Moral *et al*., 2012).

Plant health studies in forest species have been limited to describing the pathogens associated with the crops; similarly, the phytosanitary regulatory bodies in each country have focused on keeping the phytosanitary status updated and, with some exceptions, on designing dispersal models or indicating the distribution of pests that threat forest production (Cordero and Boshier, 2003; Arguedas-Gamboa and Cots-Ibiza, 2012). In Colombia and Latin America, there are few investigations related to the epidemiology of pathologies in forest species, and

Anthracnose caused by *Colletotrichum* species is not an exception.

Information on the development of *Colletotrichum* spp. in *E. cyclocarpum* and *P. pinnatum* is non-existent. Additionally, in Santa Marta and the Caribbean region, there are few studies on forest health, which makes it difficult to develop phytosanitary management strategies for trees. The previous situation has motivated the beginning of an investigative process on the interaction *Colletotrichum* spp. – forest species, raising the hypothesis that the epidemiological behavior of foliar anthracnose associated with *Colletotrichum* spp. varies between forest tree species. This study aimed to analyze the behavior of "foliar Anthracnose" associated with *Colletotrichum* spp. in *E. cyclocarpum* and *P. pinnatum* under field conditions.

MATERIALS AND METHODS

Area of study

The research was carried out in trees at the Universidad del Magdalena Campus, located in the city of Santa Marta (Colombia), in an area between 11°13'43" and 11°13'22" North latitude, and 74°11'00" and 74°11'16" West longitude, at an altitude of approximately 20 m. Santa Marta city presents an average temperature of 28.3 °C, average relative humidity of 76% and an average annual rainfall of 545 mm (IDEAM, 2014).

Four individuals of *E. cyclocarpum* and *P. pinnatum* were selected from a population of 97 and 40 trees, respectively. In each tree, four monitoring sites were marked, corresponding to the four cardinal points. Every monitoring site corresponded to five leaves located in the terminal part of a branch and positioned in the under-canopy layer.

Epidemiological variables

The epidemiological parameters were evaluated during 33 weeks, from March 26, 2016, to November 6, 2016, obtaining 29 measurements for each monitoring site. The number of leaflets with symptoms and the number of total leaflets were recorded; in this way, the incidence of *Colletotrichum* spp. at each monitored time was calculated. The severity of the disease was estimated according to scale diagrams designed for each forest species (Figure 1), following the severity scale described by Páez *et al.* (2003), with modifications. This scale involved six levels of affectation, as indicated in Table 1. Additionally, defoliation was determined for each monitoring site, based on the differences in the total records of leaves from one measurement with respect to the previous one. Based on weekly data, disease development curves were constructed for each forest species and Spearman correlations were made between these variables (incidence, severity and defoliation).

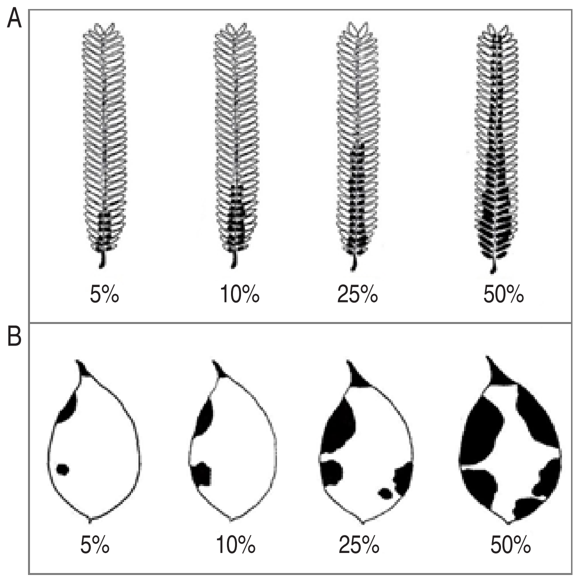

Figure 1. Scale diagrams to measure the severity of foliar Anthracnose (*Colletotrichum* spp.). A. Leaflets of *E. cyclocarpum.* B**.** Leaflets of *P. pinnatum.*

The disease development rate (r) was determined, according to Equation (1) proposed by Van der Plank (1963):

$$r = \frac{1}{\Delta_t}\left(\ln\frac{x_f}{1-x_f} - \ln\frac{x_i}{1-x_i}\right) \quad (1)$$

where r is the rate of disease development, Δt is the time difference, x_f is the final value of the disease and x_i the initial value of the disease.

Table 1. Scale to quantify the anthracnose severity (*Colletotrichum* spp.).

Rank	%Affectation	Severity classification
0	0	Healthy
1	Up to 5	Very slight
2	6-10	Slight
3	11-25	Mild
4	26-50	Strong
5	>50	Very strong

Likewise, the area under the disease progress curve (*AUDPC*) was calculated, according to Equation (2) indicated by López-Vásquez *et al.* (2013):

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

where *AUDPC* is the area under the disease progress curve, y_i is the final severity, y_{i-1} is the initial severity, t_i is the final time and t_{i-1} the initial time.

Both the development rate and the *AUDPC* were determined based on the severity values recorded for two follow-up periods: the first one, considered dry or with less rainfall, corresponding to March to June (first semester of the year); and the second one, considered rainy or with higher rainfall, between July and November (Table 2).

Effect of meteorological variables on the disease development

In order to know the effect of the meteorological variables on the behavior of foliar Anthracnose, a Spearman correlation analysis and a multiple regression analysis by ordinary least squares were performed between both incidence and severity with rainfall (mm), relative humidity (%), average temperature (°C), solar radiation (W m^{-2}) and wind speed (m s^{-1}). The meteorological data were provided by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM, 2014), according to the readings of the Meteorological Station of the Universidad del Magdalena. The measurements were analyzed weekly, averaging the values of each meteorological variable, except for rainfall, which was calculated cumulatively. All statistical analyzes were performed in Statgraphics® Centurion XVI program.

During the 33 weeks of field follow-up, the total rainfall was 402.2 mm. In the dry period (March-June) the accumulated rainfall was 82.7 mm, while in the rainy period (July-November), it was 319.5 mm, being October the rainiest month with 17.8 mm (Table 2).

From March to June, the highest values of temperature (average of 30 °C), solar radiation (average of 5961.0 W m^{-2}), and wind speed (average of 4.21 m s^{-1}) were recorded, while relative humidity (average of 68.1%) presented the lowest values during this follow-up period. In the second period, average temperature, solar radiation, and wind speed were 29 °C, 5298.0 W m^{-2} and 3.02 m s^{-1}, respectively. The average relative humidity was higher than the first semester with a value of 72.1% (Table 2).

This meteorological behavior is typical of the Colombian Caribbean region, where there is a unimodal rain distribution, with a short rainy period accentuated in the second semester of the year, and a long dry period that covers almost the entire first semester and some of the second. The temperature and relative humidity present fluctuating values throughout the year, with a slight increase in temperature in the first two months of the year and an increase of humidity in September to November, due to the effect of the rains. Wind speed is generally higher between December to March (IDEAM, 2014).

RESULTS AND DISCUSSION

Incidence and severity of foliar anthracnose and their relationship with tree defoliation

The mean of incidence and severity, for both follow-up periods (*i.e.* dry and rainy), are shown in Table 3. *E. cyclocarpum* presented higher values of the disease

Table 2. Meteorological data from 26-03-2016 to 06-11-2016 (33 weeks) at the Universidad del Magdalena, Santa Marta, Colombia. Rain: Rainfall. R.H: Relative humidity. Temp: Average temperature. Rad: Solar radiation. Wind: Wind speed.

Month	Day	Rain (mm)	R.H (%)	Temp (°C)	Rad (W m^{-2})	Wind (m s^{-1})
March	86	0.4	64.3	30.3	(no data)	(no data)
	93	0.0	65.3	29.7	6446.1	7.44
April	100	0.0	59.8	29.8	6962.2	5.35
	107	0.6	61.3	30.0	6759.7	4.12
	114	10.6	70.7	30.1	5586.1	5.56
	121	0.0	73.0	29.9	5574.0	2.02
May	128	5.4	73.0	29.9	5291.9	3.22
	135	13.8	69.1	30.3	5757.8	3.37
	143	0.0	64.3	31.8	6789.6	5.23
	150	0.8	70.9	29.9	5800.9	3.13
	156	7.6	75.1	29.5	5289.9	4.44
June	163	7.6	72.4	30.0	5630.4	3.58
	170	5.6	67.4	29.7	6032.7	4.66
	177	30.3	71.1	29.1	5510.4	2.97
	184	0.0	64.3	30.2	6022.3	3.88
Average*		**82.7**	**68.1**	**30.0**	**5961.0**	**4.21**
July	191	0.0	63.0	29.9	6322.6	4.66
	198	2.2	65.7	29.5	5175.2	3.50
	205	26.6	70.1	28.7	5665.4	3.57
	212	0.6	62.6	29.9	5298.1	4.52
August	219	5.9	72.8	28.2	5410.3	2.85
	227	0.0	67.3	29.7	6305.0	2.99
	234	0.1	62.1	30.9	6401.9	3.42
	242	0.0	67.7	29.6	5803.0	4.12
September	248	10.4	73.5	29.1	5109.6	2.44
	255	11.9	73.4	28.6	5089.0	3.07
	263	64.1	77.0	28.3	4526.8	2.60
	269	2.6	74.9	29.7	5061.4	1.77
	277	93.1	73.4	28.6	3972.0	3.22
October	284	6.1	76.3	29.0	5288.7	2.59
	290	4.6	80.0	28.3	4709.9	1.85
	297	39.1	79.7	28.4	5520.0	2.68
	304	38.3	79.3	28.2	5028.3	2.57
November	311	13.9	78.6	28.3	4676.7	1.85
Average*		**319.5**	**72.1**	**29.0**	**5298.0**	**3.02**
Total*		**402.2**	**70.3**	**29.5**	**5588.1**	**3.50**

*For rainfall, the shown values correspond to their accumulated. For the other meteorological variables, these values correspond to their average.

than *P. pinnatum* in the two periods. Both incidence and severity in *E. cyclocarpum* increased in the rainy season, registering a mean incidence of 83.9%, in contrast with the mean incidence during the dry period (44.3%). Mean severity in rainy months was 11.3%, while in dry months was 8.2%.

Table 3. Mean of incidence and severity of foliar Anthracnose, and defoliation in *E. cyclocarpum* and *P. pinnatum* in two follow-up periods. Universidad del Magdalena, Santa Marta, Colombia. 2016.

Variables (%)	*E. cyclocarpum*		*P. pinnatum*	
	Dry (March-June)	Rainy (July-November)	Dry (March-June)	Rainy (July-November)
Incidence	44.3	83.9	35.8	19.9
Severity	8.2	11.3	0.6	0.3
Defoliation	32.6	19.8	22.6	17.7

In *E. cyclocarpum*, from 26-03-2016 (day 86) and until 04-06-2016 (day 156), a decrease in the incidence of the disease was observed (from 68.0 to 28.8%). Starting on day 156, a linear growth was evidenced until 04-09-2016 (day 248), when the disease reached 100% and stabilized until the end of monitoring (06-11-2016; Figure 2A). The disease severity had a similar behavior; it decreased in the first six weeks, reaching a minimum percentage on 04-07-2016 (day 191) with 2.0%. Subsequently, from day 198 to the end of monitoring on 06-11-2016 (day 311), a linear increase was recorded, with a maximum value of 19.6%, considered moderate (Figure 2B).

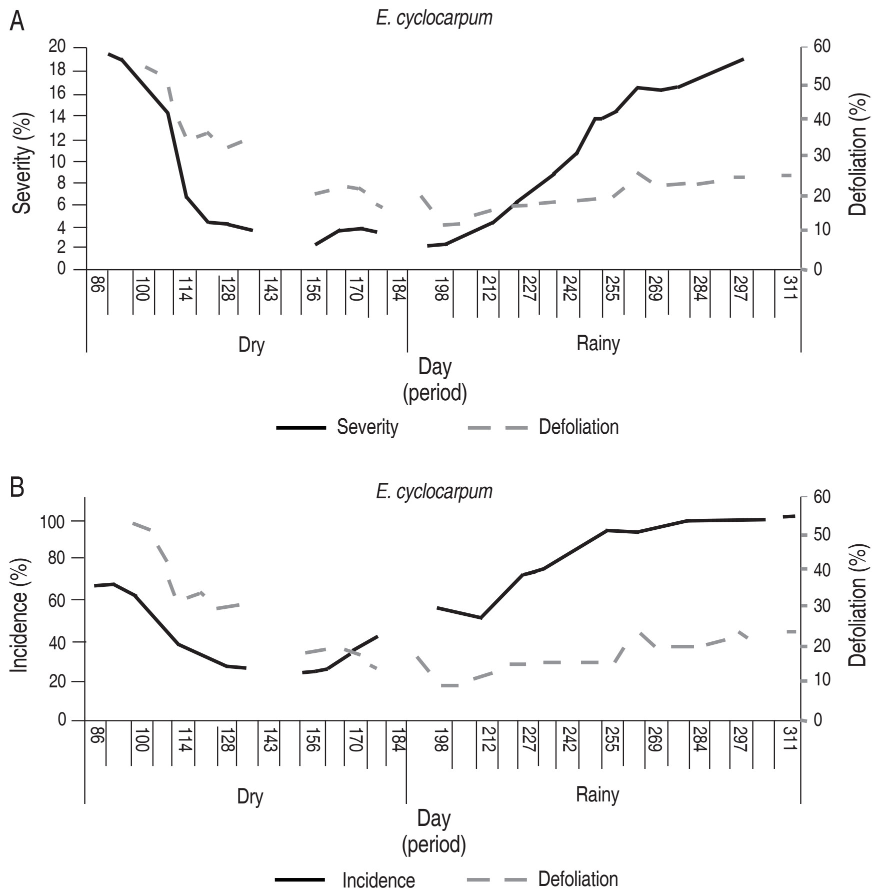

Figure 2. Development curve of foliar Anthracnose associated with *Colletotrichum* spp. in *E. cyclocarpum*. A. Severity and defoliation. B. Incidence and defoliation.

Defoliation in *E. cyclocarpum* was strong in the first weeks, with 54.6% in 09-04-2016 (day 100), and progressively decreased until 16-07-2016 (day 198), with values of 12.3 %. From this date, the defoliation increased until the end of the follow-up period, reaching moderate values of 25.5% (Figure 2).

According to Spearman's correlation analysis (Table 4), the severity of the disease showed a significant relationship with defoliation (correlation=0.431; *P*<0.05) indicating that as the affected leaf area increases, the greater the induction of leaflet defoliations. The high correlation between incidence and severity (correlation=0.807; *P<0.05*) explains that in higher inoculum pressure, new leaflets are infected.

Table 4. Correlation coefficients between epidemiological variables of foliar Anthracnose and defoliation in *E. cyclocarpum*.

	Defoliation	Incidence
Incidence	-0.073	——
Severity	0.431*	0.807*

*Significant correlation (*P<0.05*).

In *P. pinnatum*, the incidence and severity of the disease decreased from 26-03-2016 (day 86) to 14-05-2016 (day 135); the incidence was reduced from 68.9 to 15.0%, while the severity decreased from 1.3 to 0.2%. From day 135, there was a slight increase in the values of both variables, presenting 25.0 and 0.3% of incidence and severity on day 311 (11-06-2016). Defoliation presented

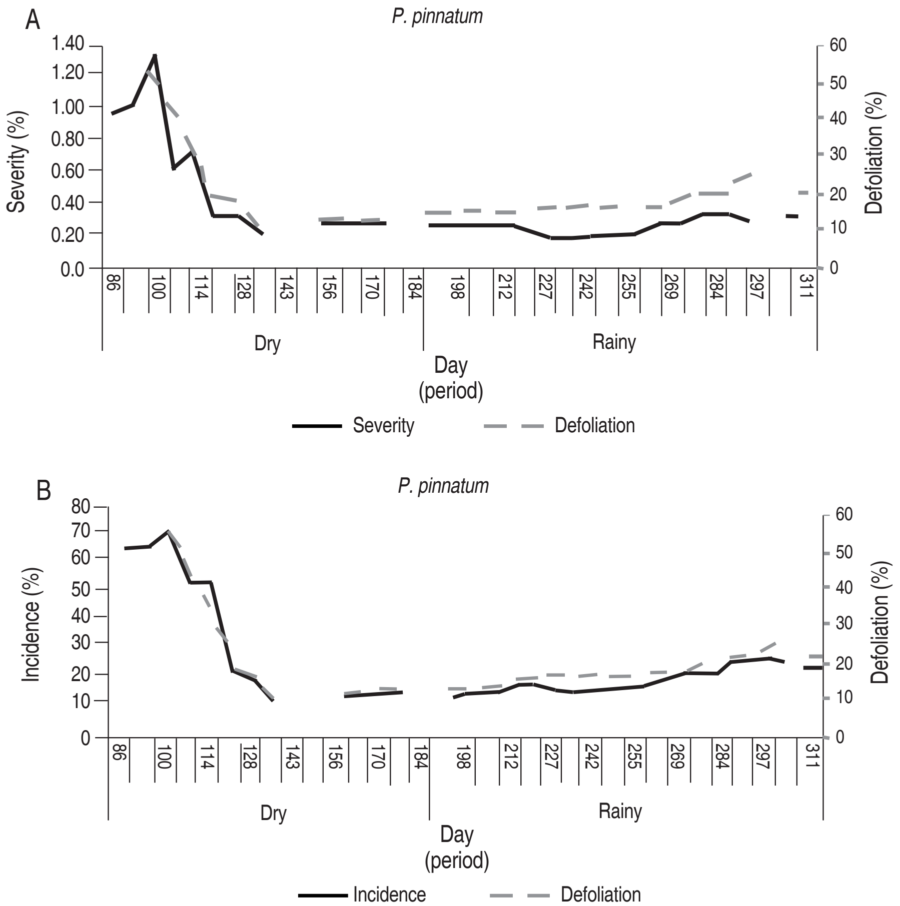

Figure 3. Development curve of the foliar Anthracnose associated with *Colletotrichum* spp. in *P. pinnatum*. A. Severity and defoliation. B. Incidence and defoliation.

a similar behavior to the other two variables, decreasing to 11.6% on day 135 (14-05-2016). From that date, it showed a slight increase, registering 20.7% at the end of the follow-up period (Figure 3).

According to the correlation analysis, there was a significant direct relationship between incidence and severity in *P. pinnatum* with defoliation, and between incidence and severity (Table 5).

Table 5. Correlation between epidemiological variables of foliar Anthracnose and defoliation in *P. pinnatum*.

	Defoliation	Incidence
Incidence	0.867*	——
Severity	0.540*	0.692*

*Significant correlation (*P<0.05*).

The evaluated epidemiological variables indicated that *E. cyclocarpum* has a greater susceptibility to *Colletotrichum* spp., compared to *P. pinnatum*. One explanation for the differences in the amount of disease present in each forest species may be related to the production of secondary metabolites and the anatomy of their leaves. In *Platymisicium* species, the presence of flavonoids, isoflavonoids and other compounds with antifungal and cytotoxic properties has been reported (Cardoso-Lopes *et al*., 2008; Cuellar *et al*., 2020), although plant metabolites produced by *E. cyclocarpum* may also have antifungal activity (Pacheco *et al.,* 2012; Biabiany *et al*., 2013). Arambarri *et al.* (2006) observed the presence of conspicuous epicuticular waxes in *Enterolobium* spp., a common feature of species adapted to dry environments, which can confer resistance to penetrating pathogens. Regarding *P. pinnatum*, de Enrech and Agostini (1987) indicated that the cuticle of this species presents a greater thickness, compared to other *Platymiscium* species. It is known that a greater thickness in the cuticle, as well as the presence of additional waxes, confers greater resistance to the penetration of fungi; however, it is worthy to mention that many pathogens can establish infections in plants with a considerable cuticle thickness (Freeman and Battie, 2008). In this research, the characteristics described for the leaves of both forest species did not prevent the development of the disease. It would be necessary to carry out studies on the physical and chemical composition of the leaves in these forest trees, as well as their relationship with resistance to *Colletotrichum* species.

The development of the disease depended fundamentally on the phenological development of the hosts since this defines successive sprouts and defoliation that, in turn, influence the diseases values over time. Initially, in the available leaf area, the disease values increase, being more evident with the first defoliation; however, as defoliation becomes widespread, the affected tissue is removed and the amount of initial disease decreases. In other words, the reduction in the amount of disease (incidence and severity) is mainly due to the loss of the plant organ (defoliation) and the appearance of new healthy tissue. This behavior has been used to establish management techniques for foliar Anthracnose where, through artificial defoliation, the severity of the disease is reduced (Guyot *et al*., 2005). However, a progressive increase in defoliation is an indicator of disease severity (Guyot *et al*., 2005; Huertas-Palacios *et al*., 2009).

The real effect of the fungus on defoliation is not understood nor if this is a plant defense mechanism against infection. In this research, the highest defoliation values, in both species, were recorded during the driest months. *E. cyclocarpum* is a semi-deciduous species that loses part of its foliage during the driest months, beginning defoliation at the end of the rainy season. On the other hand, the increase in foliage occurs when rainfall increases after the end of the dry season (Rocha *et al*., 2018). *P. pinnatum* is deciduous during the dry season, where trees can lose between 50 and 80% of their foliage, and as rainfall increases, the fall of the foliage decreases (Gómez, 2010). It is recommended to evaluate the effect of foliar Anthracnose in the defoliation of these forest species in future investigations.

Development rate and area under the disease progress curve (*AUDPC*)

In *E. cyclocarpum*, during the dry period (March to June), the foliar Anthracnose presented a development rate of 0.136 units week^{-1}. Starting with the rains of July, and increasing in September and October, *r* reached 0.187 units week^{-1}. The *AUDPC* was lower in the first period (dry), with 51 units week^{-1}, compared to 186 units week^{-1} obtained during the rainy period (Table 6). These results indicated a more rapid development of the disease during the second half of the year.

In *P. pinnatum*, the disease presented a development rate of 0.107 units week^{-1} during the first semester of the year. In the rainiest months, the development rate was lower (0.016 units week^{-1}). The *AUDPC* indicated that foliar Anthracnose was higher in the months with less rainfall, registering a value of 4 units week^{-1}, while in the second period the *AUDPC* was 2 units week^{-1} (Table 6). In this host, different behavior of the disease was registered to that obtained in *E. cyclocarpum*, which makes to consider other factors than the environment.

Table 6. Development rate and area under the progress curve of foliar Anthracnose associated with *Colletotrichum* spp. in *E. cyclocarpum* and *P. pinnatum* for two follow-up periods.

	Dry period (March – June)		Rainy period (July – November)	
	Development rate (*r*) (units week^{-1})	*AUDPC* (units week^{-1})	Development rate (*r*) (units week^{-1})	*AUDPC* (units week^{-1})
E. cyclocarpum	0.136	51	0.187	186
P. pinnatum	0.107	4	0.016	2

In this study, *P. pinnatum* presented lower development of foliar Anthracnose, especially when the climatic conditions were more favorable for the synthesis. In contrast, *E. cyclocarpum* was more susceptible to the action of the pathogen, observing a greater progression of the disease during periods where conditions of high humidity prevail. This greater disease progress during the rainy season agrees with studies in other pathosystems, including *Colletotrichum* species (Huertas-Palacios *et al*., 2009; Moral *et al*., 2012; Miles *et al*., 2013; Lima *et al*., 2015).

Effect of meteorological variables on the development of the disease

In *E. cyclocarpum*, the incidence of foliar Anthracnose was inversely correlated with mean temperature (*P<0.05*). Although the analysis showed a significant negative correlation with solar radiation and wind speed, and a positive correlation with relative humidity, the coefficients were not high. For severity, a significant negative correlation with mean temperature was observed, but with a low coefficient (-0.391; Figure 4-5; Table 7). In *P. pinnatum*, this type of analysis did not allow to identify significant correlations between epidemiological variables of the disease and meteorological variables (Figure 5-7; Table 7).

The multiple regression analysis by ordinary least squares confirmed that mean temperature was the only variable related to the incidence of foliar Anthracnose in *E. cyclocarpum*, explaining the incidence behavior by 39.72% with the whole model (Table 8). In the highest temperature values (between March and June) with an average of 30 °C (Table 2), the incidence remained at values close to 45% (Figure 2B); however, the temperature decreased slightly, except for certain events with maximum peaks, coinciding with the increase in incidence. On the other hand, severity could not be explained from the behavior of any of the analyzed meteorological variables. This raises the hypothesis that there are factors intrinsic to the pathogen or the host that influence a lesser or greater aggressiveness of the disease, under the meteorological conditions of the study area.

The multiple regression analysis by ordinary least squares confirmed that mean temperature was the only variable related to the incidence of foliar Anthracnose in *E. cyclocarpum*, explaining the incidence behavior by 39.72% with the whole model (Table 8). In the highest temperature values (between March and June) with an average of 30 °C (Table 2), the incidence remained at values close to 45% (Figure 2B); however, the temperature decreased slightly, except for certain events with maximum peaks, coinciding with the increase in incidence. On the other hand, severity could not be explained from the behavior of any of the analyzed

meteorological variables. This raises the hypothesis that there are factors intrinsic to the pathogen or the host that influence a lesser or greater aggressiveness of the disease, under the meteorological conditions of the study area.

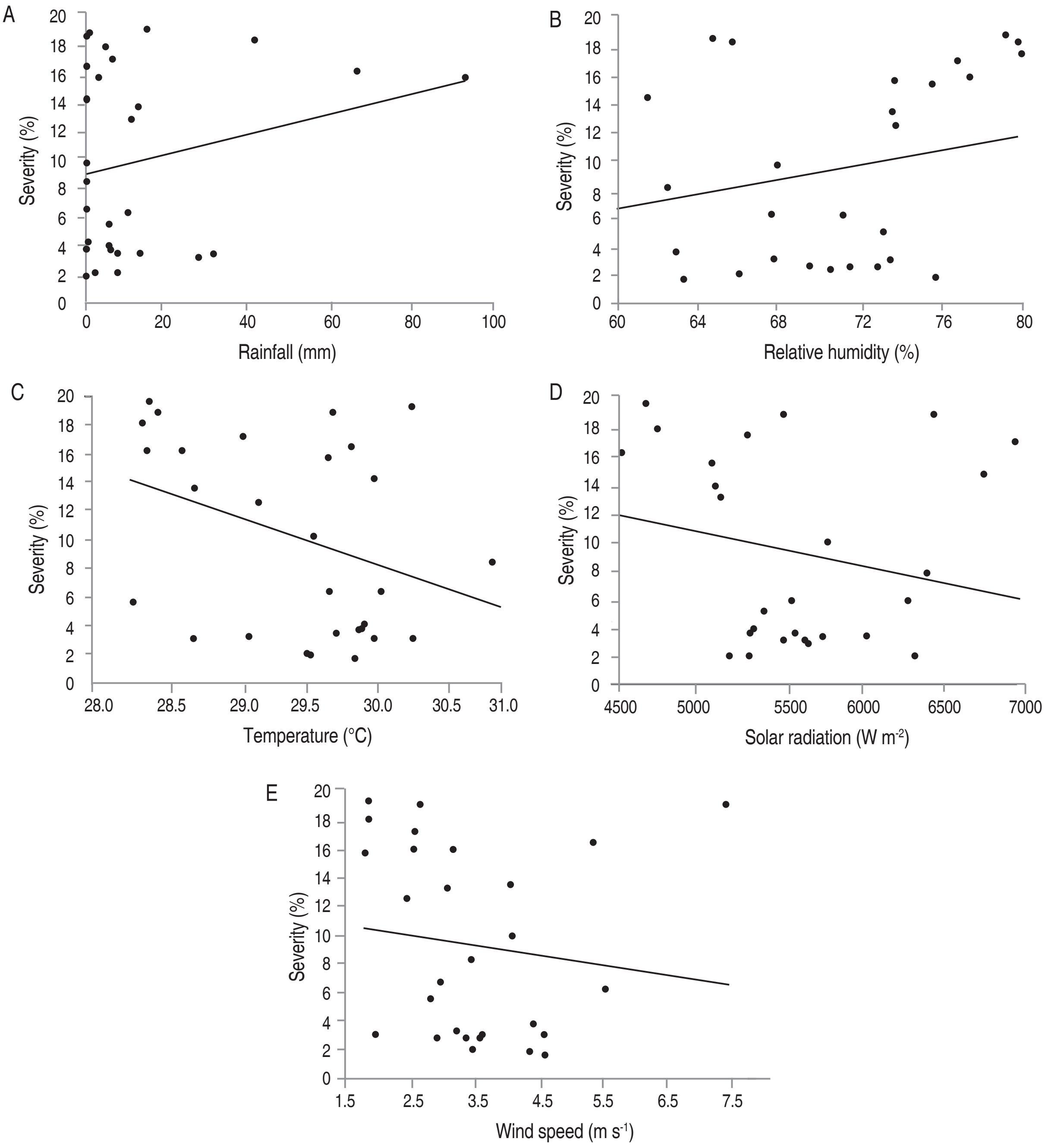

Figure 4. Relationship between the meteorological variables with the severity of foliar Anthracnose in *E. cyclocarpum*. Severity with (A) rainfall, (B) relative humidity, (C) mean temperature, (D) solar radiation, and (E) wind speed.

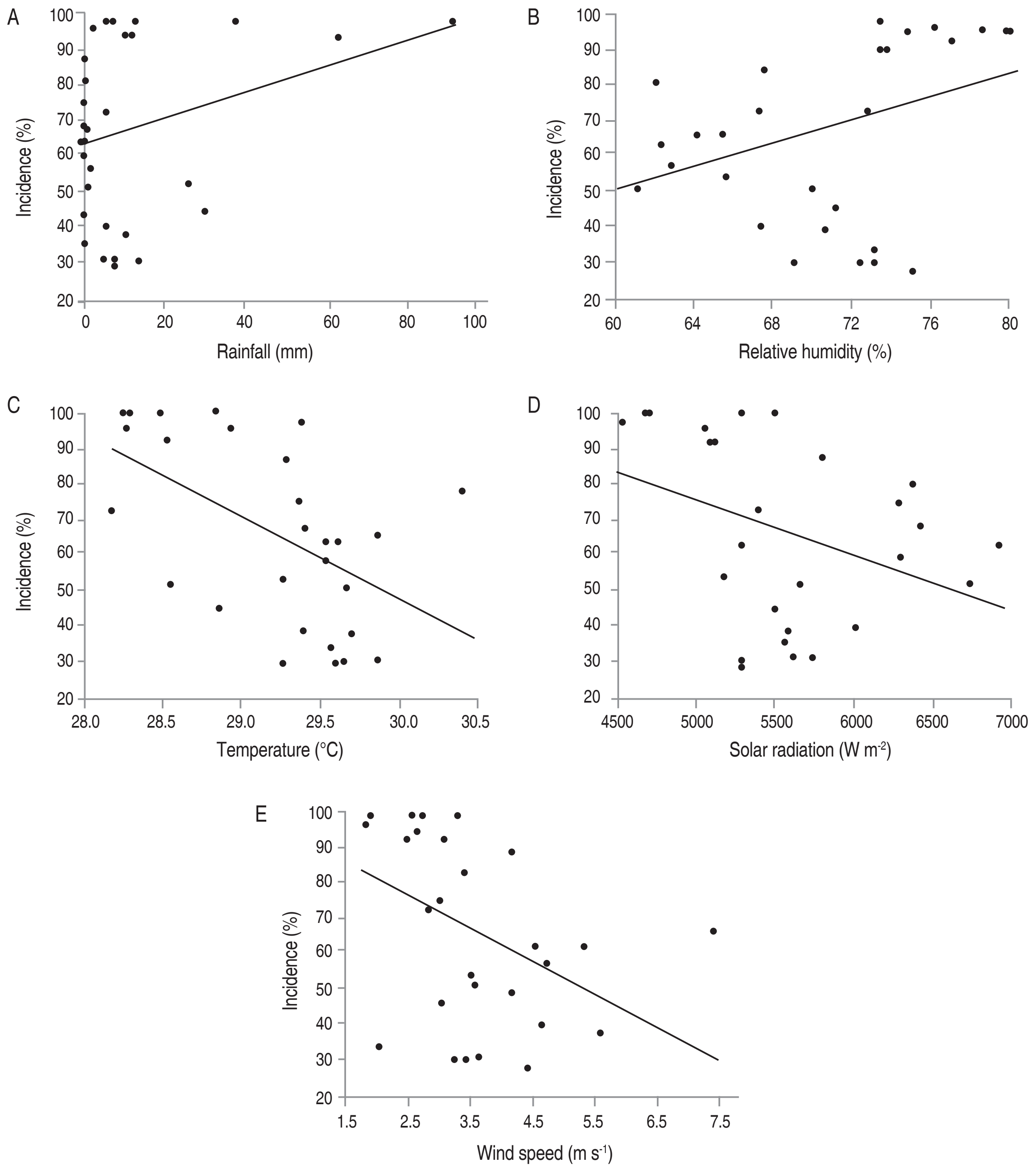

Figure 5. Relationship between the meteorological variables with the incidence of foliar Anthracnose in *E. cyclocarpum.* Incidence with (A) rainfall, (B) relative humidity, (C) average temperature, (D) solar radiation, and (E) wind speed.

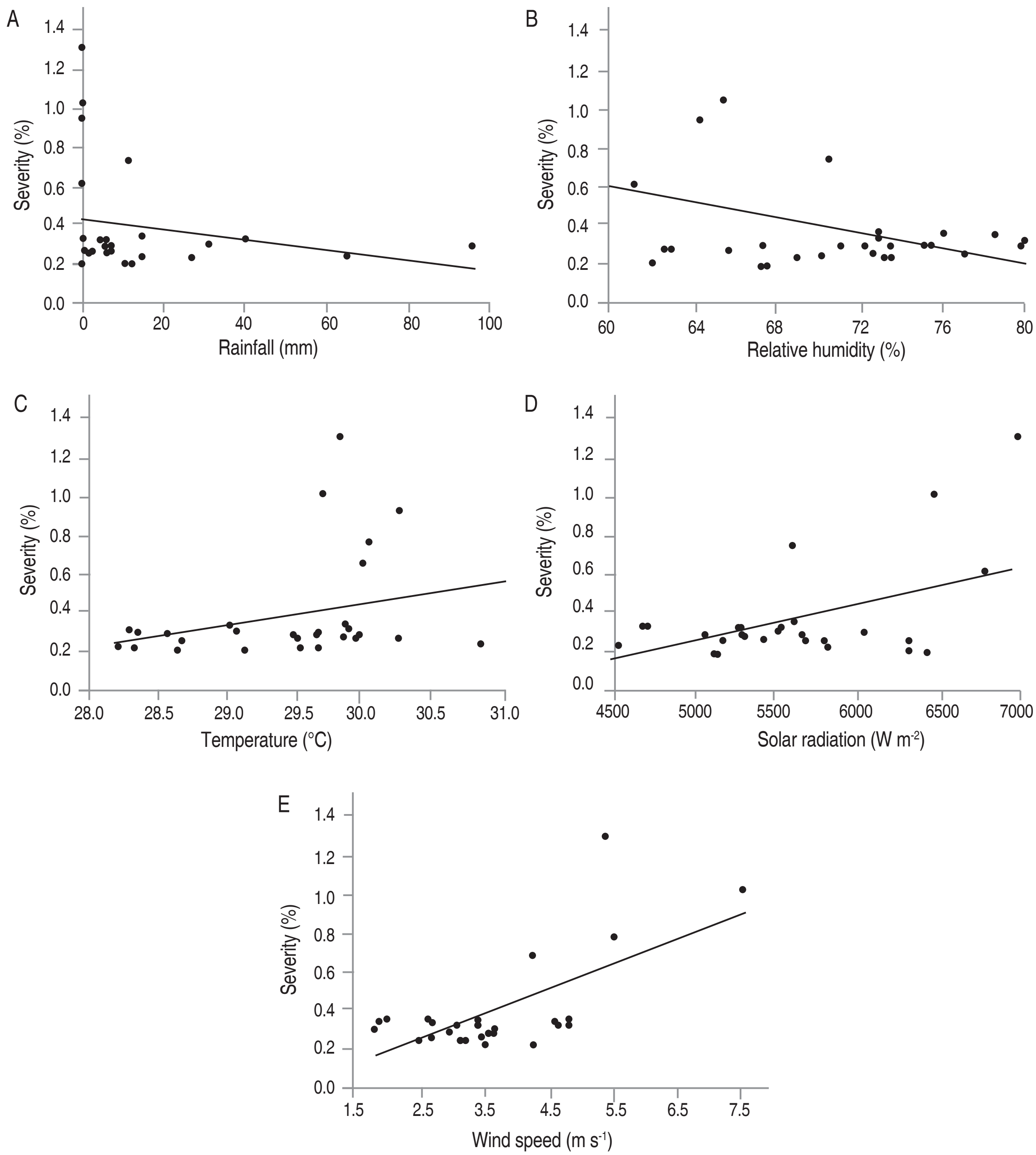

Figure 6. Relationship between the meteorological variables with the severity of foliar Anthracnose in *P. pinnatum*. The severity with (A) rainfall, (B) relative humidity, (C) mean temperature, (D) solar radiation, and (E) wind speed.

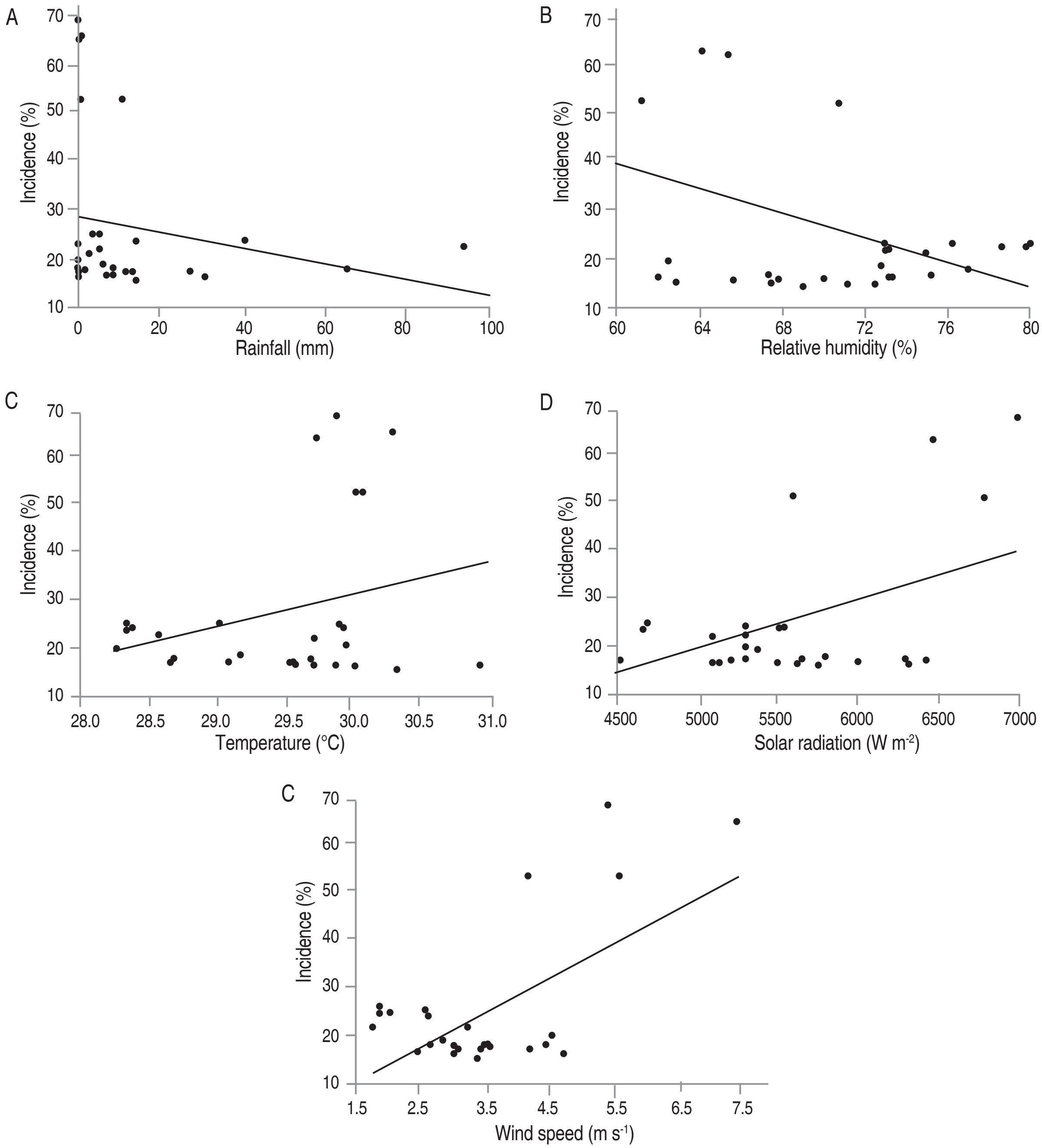

Figure 7. Relationship between the meteorological variables with the incidence of foliar Anthracnose in *P. pinnatum*. Incidence with (A) rainfall, (B) relative humidity, (C) mean temperature, (D) solar radiation, and (E) wind speed.

Table 7. Correlation between the meteorological variables and diseases values (incidence and severity) of foliar Anthracnose in the foliage of *E. cyclocarpum* and *P. pinnatum*, recorded from 26-03-2016 to 06-11-2016. (n = 29).

Meteorological variable	*E. cyclocarpum*		*P. pinnatum*	
	Incidence	Severity	Incidence	Severity
Rainfall	0.1644	0.0836	-0.1670	-0.0819
Relative humidity	0.4399*	0.3668	0.1269	0.0529
Mean temperature	-0.6345*	-0.3907*	-0.1143	0.1111
Solar radiation	-0.4628*	-0.2304	-0.0486	0.1253
Wind speed	-0.5382*	-0.3582	-0.0572	0.1593

*Significant correlation (P<0.05).

Table 8. Multiple regression between meteorological variables and the incidence of *Colletotrichum* spp. in the foliage of *E. cyclocarpum*, registered from 26-03-2016 to 06-11-2016.

Variable		Estimation	*P-value*
Rainfall		0.000214	0.9379
Relative humidity		-0.013140	0.3607
Average temperature		-0.219628	0.0226*
Solar radiation		-0.000023	0.8423
Wind speed		-0.058586	0.2165
Multiple regression	R = 0.6302 R^2 = 0.3972 Adjusted R^2 = 0.2602	8.38838	0.0370*

*Significant variable (P<0.05).

In *P. pinnatum*, the multiple regression analysis indicated a relationship of incidence and severity of foliar Anthracnose with wind speed, explained in 44.59 and 50.29% of its behavior with the whole model, respectively (Tables 9 and 10). Figures 6E and 7E show that the maximum values of wind speed, which correspond to March-April, coincided with the highest values recorded in both incidence and severity. Nevertheless, it is noted that these variables were not correlated (Table 7).

The temperature was the only variable that influenced the development of the disease in *E. cyclocarpum*, showing a negative correlation. Although an optimal temperature range of 25-30 °C is proposed for *Colletotrichum* spp. (Miles *et al.*, 2013), the different fungal species present specific requirements (Lima *et al.*, 2015). In this study, when the temperature was more favorable for the activity of the pathogen, an increase in the disease was evidenced. Nonetheless, to better understand the effect of temperature on the development of the disease, it would be necessary to carry out complementary research on the specific optimum temperature of the *Colletotrichum* species found in the forests of the Caribbean region.

In other interactions, in addition to temperature, relative humidity affects the expression of disease, such as those observed in Anthracnose caused by *Colletotrichum* spp. in avocado (Márquez, 2016), and in mango inflorescences (Páez *et al*., 2003). Likewise, correlations have been described between solar radiation and the number of lesions of *C. gloesporioides* in *Stylosanthes scabra* (Pangga *et al*., 2011), on the survival and production of conidia of *Colletotrichum acutatum* (Fracarolli *et al*., 2016), or the beginning of *Colletotrichum lindemuthianum* infections in beans (Pérez-Vega *et al*., 2010). Nevertheless, in the present study, this variable was not determining for the disease behavior.

Table 9. Multiple regression between meteorological variables and the incidence of *Colletotrichum* spp. in the foliage of *P. pinnatum*, registered from 26-03-2016 to 06-11-2016.

Variable		Estimation	*P-value*
Rainfall		0.000248	0.8681
Relative humidity		0.005172	0.5064
Average temperature		-0.038458	0.4382
Solar radiation		0.000093	0.1541
Wind speed		0.067594	0.0131*
Multiple regression	R = 0.6678 R^2 = 0.4459 Adjusted R^2 = 0.3199	0.259038	0.0169*

*Significant variable (*P*<0.05)

Table 10. Multiple regression between meteorological variables and the severity of *Colletotrichum* spp. in the foliage of *P. pinnatum*, registered from 26-03-2016 to 06-11-2016.

Variable		Estimation	p-value
Rainfall		0.000004	0.8664
Relative humidity		0.000084	0.5177
Average temperature		-0.000698	0.3986
Solar radiation		0.000002	0.1234
Wind speed		0.001245	0.0068*
Multiple regression	R = 0.7091 R^2 = 0.5029 Adjusted R^2 = 0.3899	0.004447	0.0059*

*Significant variable (*P*<0.05)

For *P. pinnatum*, although the regression analysis indicated a relation between wind speed and level of disease (incidence and severity), the correlation was not significant. In contrast, disease incidence in *E. cyclocarpum* was correlated with wind speed. The effect of wind speed on diseases caused by *Colletotrichum* spp. is mainly related as a complementary mechanism of spore dissemination (Siddiqui and Ali, 2014). However, the correlation between disease increase and wind speed is not clear. According to Guyot *et al.* (2005), although strong winds can favor an increase in infections, this phenomenon does not necessarily produce a notable dispersal of spores.

In this study, no relationship was found between rainfall and disease progress under conditions of the Universidad del Magdalena campus. Similar results have been observed in the epidemiology of *Colletotrichum* spp. in mango (Páez *et al.,* 2003) and in *Heliconias* cultivars (López-Vásquez *et al.,* 2013). Some studies show that high rainfall does not necessarily favor the dispersal of *Colletotrichum* spp. spores. (Guyot *et al*., 2005). Even heavy rainfall can have a negative effect on the severity of *Colletotrichum* spp., due to the washing of the inoculum caused by the rains (Huertas-Palacios *et al.,* 2009).

CONCLUSIONS

Foliar Anthracnose associated with *Colletotrichum* spp. in forest species varied with the period of the year and the host. During the months with the highest rainfall, the highest incidence and severity values were presented in *E. cyclocarpum*; however, in *P. pinnatum*, the maximum values were observed during the dry period. Likewise, the values of the development rate and the area under the disease progress curve indicated different behaviors in each pathosystem.

The progress of the disease was related to relative humidity, temperature, solar radiation and wind speed for *E. cyclocarpum*. In *P. pinnatum*, no correlation was found between environmental factors and disease level. It is highlighted that the phenological cycles of the host, which define defoliation and successive regrowth, influenced the initiation and development of multiple infective processes. It would be necessary to clarify the influence of the disease/pathogen presence in the host's defoliation in further investigations.

Finally, the initial hypothesis was confirmed, since the behavior of foliar anthracnose caused by *Colletotrichum* spp. varied according to the forest species. This research provides the first epidemiological studies of *Colletotrichum* spp. associated with forest trees in the Colombian Caribbean region.

REFERENCES

Arambarri A, Freire S, Colares M, Bayón N, Novoa M, Monti C and Stenglein S. 2006. Leaf anatomy of Medicinal Shrubs and Trees from Gallery Forests of the Paranaense Province (Argentina). Part 1. Boletín de la Sociedad Argentina de Botánica 41(3-4): 233-268.

Arguedas-Gamboa M and Cots-Ibiza J. 2012. La "antracnosis" (*Colletotrichum* spp.) en viveros forestales. Revista Forestal Mesoamericana Kurú 9(22): 60-62. https://doi.org/10.18845/rfmk.v9i22.364

Biabiany M, Roumy V, Hennebelle T, François N, Sendid B, Pottier M, Aliouat E.M, Rouaud I, Lohézic-Le Dévéhat F, Joseph H, Bourgeois P, Sahpaz S and Bailleul F. 2013. Antifungal Activity of 10 Guadeloupean Plants. Phytotherapy Research 27: 1640-1645. https://doi.org/10.1002/ptr.4906

Cantillo C. 2014. Reconocimiento de enfermedades en el arbolado del campus de la Universidad del Magdalena (Bachelor's thesis). Universidad del Magdalena. Santa Marta, Colombia. 99 p.

Cardoso-Lopes E, Carreira R, Gomes D, Brandão L, Cordeiro I, da Silva V, de Campos S and Marx M. 2008. Screening for antifungal, DNA-damaging and anticholinesterasic activities of Brazilian plants from the Atlantic Rainforest - Ilha do Cardoso State Park. Revista Brasileira de Farmacognosia 18: 655-660. https://doi.org/10.1590/S0102-695X2008000500002

Cordero J and Boshier D. 2003. Árboles de Centroamérica: un manual para extensionistas. OFI/CATIE, (s.l.). 1079 p.

Cuellar J, Martínez J, Rojano B, Gil J, and Durango, D. 2020. Chemical composition and antioxidant and antibacterial activity of *Platymiscium gracile* Benth.: A species threatened by extinction. Journal of King Saud University 32(1): 702-708. https://doi.org/10.1016/j.jksus.2018.11.006

de Enrech N and Agostini G. 1987. Revisión taxonómica del género *Platymiscium* Vog. (Leguminosae: Faboideae, Dalbergieae) en Venezuela. Acta Botánica 15(2): 99-131.

Dean R, van Kan J, Pretorius Z, Hammond-Kosack K, Di Pietro A, Spanu P, Rudd J, Dickman M, Kahmann R, Ellis J and Foster G. 2012. The Top 10 fungal pathogens in molecular plant pathology. Molecular Plant Pathology 13(4): 414-430. https://doi.org/10.1111/j.1364-3703.2011.00783.x

Fracarolli L, Rodrigues G, Pereira A, Massola N, Silva-Junior G, Bachmann L, Wainwright M, Kenupp J and Braga G. 2016. Inactivation of plant-pathogenic fungus *Colletotrichum acutatum* with natural plant-produced photosensitizers under solar radiation. Journal of Photochemistry and Photobiology B: Biology 162: 402-411. https://doi.org/10.1016/j.jphotobiol.2016.07.009

Freeman B and Beattie G. 2008. An Overview of Plant Defenses against Pathogens and Herbivores. The Plant Health Instructor. https://lib.dr.iastate.edu/plantpath_pubs/94

Gómez, M. 2010. Fenología reproductiva de especies forestales nativas presentes en la jurisdicción de CORANTIOQUIA, un paso hacia su conservación. Volumen I. Corantioquia, Medellín. 224 p.

Guyot J, Omanda E and Pinard F. 2005. Some epidemiological investigations on *Colletotrichum* leaf disease on rubber tree. Crop Protection 24(1): 65-77. https://doi.org/10.1016/j.cropro.2004.06.009

Haggar J, Asigbaase M, Bonilla G, Pico J and Quilo A. 2015. Tree diversity on sustainably certified and conventional coffee farms in Central America. Biodiversity and Conservation 24(5): 1175–1194. https://doi.org/10.1007/s10531-014-0851-y

Huertas-Palacios G, Holguín-Meléndez F, Benítez-Camilo F and Toledo-Arreola J. 2009. Epidemiología de la Antracnosis [*Colletotrichum gloeosporioides* (Penz.) Penz. and Sacc.] en Mango (*Mangifera indica* L.) cv. Ataulfo en el Soconusco, Chiapas, México. Revista Mexicana de Fitopatología 27(2): 93-105.

IDEAM - Instituto de Hidrología, Meteorología y Estudios

Ambientales. 2014. Atlas Climatológico de Colombia. In: http://atlas.ideam.gov.co/cclimatologicas/

Lima N, Lima W, Tovar-Pedraza J, Michereff S and Câmara M. 2015. Comparative epidemiology of *Colletotrichum* species from mango in northeastern Brazil. European Journal of Plant Pathology 141(4): 679-688. https://doi.org/10.1007/s10658-014-0570-y

López-Vásquez J, Marulanda-Ángel M and López-Gutiérrez A. 2013. Factores climáticos y su influencia en la expresión de enfermedades fúngicas en cultivares de Heliconias. Universitas Scientiarum 18(3): 331-344. http://doi.org/10.11144/Javeriana.SC18-3.fcie

Márquez M. 2016. Incidencia atmosférica de *Fusarium* spp. y *Colletotrichum* spp. en el cultivo de aguacate en Ocuituco, Morelos (Master's thesis). Instituto Politécnico Nacional. Yautepec, México. 79 p.

Miles TD, Gillett JM, Jarosz AM and Schilder AMC. 2013. The effect of environmental factors on infection of blueberry fruit by *Colletotrichum acutatum*. Plant Pathology 62(6): 1238-1247. https://doi.org/10.1111/ppa.12061

Moral J, Jurado-Bello J, Isabel M, de Oliveira R and Trapero A. 2012. Effect of Temperature, Wetness Duration, and Planting Density on Olive Anthracnose Caused by *Colletotrichum* spp. Phytopathology 102(10): 974-981. https://doi.org/10.1094/PHYTO-12-11-0343

Pabón L, Rodríguez M and Hernández-Rodríguez P. 2017. Plantas medicinales que se comercializan en Bogotá (Colombia) para el tratamiento de enfermedades infecciosas. Boletín Latinoamericano y del Caribe de Plantas Medicinales y Aromáticas 16(6): 529-546.

Pacheco M, Del Rio R, Flores A, Martinez R, Ron O and Raya D. 2012. *Enterolobium cyclocarpum* (Jacq.) Griseb.: The biotechnological profile of a tropical tree. Boletín Latinoamericano y del Caribe de Plantas Medicinales y Aromáticas 11(5): 385-399.

Páez A, Leal E and Morales R. 2003. Tasa de desarrollo de la Antracnosis (*Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc.) en cinco cultivares de mango (*Mangifera indica* L.) en el municipio de Sevilla (Magdalena). Fitopatología Colombiana 27: 1-6.

Pangga I.B, Hanan J and Chakraborty S. 2011. Pathogen dynamics in a crop canopy and their evolution under changing climate. Plant Pathology 60(1): 70-81. https://doi.org/10.1111/j.1365-3059.2010.02408.x

Pérez-Vega E, Campa A and Ferreria J. 2010. Control de la antracnosis en el cultivo de faba granja asturiana. Tecnología Agroalimentaria 7: 7-11.

Restrepo-Leal J and Rada-Gonzalez D. 2017. Estudio epidemiológico de *Colletotrichum* spp. asociado a tres especies del arbolado del campus de la Universidad del Magdalena (Bachelor's tesis). Universidad del Magdalena. Santa Marta, Colombia. 139 p.

Rocha O, Gómez C, Hamrick J, Trapnell D, Smouse P and Macaya G. 2018. Reproductive consequences of variation in flowering phenology in the dry forest tree *Enterolobium cyclocarpum* in Guanacaste, Costa Rica. American Journal of Botany 105(12): 2037-2050. https://doi.org/10.1002/ajb2.1205

Saslis-Lagoudakis C, Chase M, Robinson D, Russell S and Klitgaard B. 2008. Phylogenetics of neotropical *Platymiscium* (Leguminosae: Dalbergieae): systematics, divergence times, and biogeography inferred from nuclear ribosomal and plastid DNA sequence data. American Journal of Botany 95(10): 1270-1286. https://doi.org/10.3732/ajb.0800101

Siddiqui Y and Ali A. 2014. Chapter 11 - *Colletotrichum gloeosporioides* (Anthracnose). Pp. 337-371. In: Bautista-Baños S. (ed.) Postharvest Decay Control Strategies. First edition. Academic Press. 394 p.

Van der Plank J.E. 1963. Plant diseases: Epidemics and control. Academic Press, New York. 349 p.