Influence of surrounding flora, vegetation, and altitude on infection of rubber leaves caused by fungi in village plantations in Côte d'Ivoire.

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1 SUMMARY

***Hevea brasiliensis* is a plant cultivated in Africa and Southeast Asia, for its rubber-rich latex. In Côte d'Ivoire, foliar fungal diseases of rubber trees are increasingly identified in village plots, but epidemiological factors other than climate remain unknown to date. They hinder the mechanism of photosynthesis of trees and greatly reduce latex production. To remedy this, a study was conducted to assess the incidence of pathogenic fungi present in the rubber orchard and to understand the relationship between it, the surrounding flora and the altitude of the plots. The study was conducted in 24 villages with rubber plantations at the sites of Tabou, Nouamou, Man, Daoukro, Zoukougbeu, and Gagnoa. It examined the presence of the pathogens *Corynespora cassiicola*, *Colletotrichum gloesporoïdes*, and *Helminthosporium heveae* in the plots, the surrounding vegetation, the flora, and the altitude of the plots. The results of the study showed that isolated plant species do not influence disease incidence. However, the types of surrounding vegetation: ripicole forests, shallows, forest patches, and fallows could influence the presence of these fungi in rubber plantations of the six localities studied. The model implemented, based on data, and predicts that the probability that a rubber plot is infested by these pathogens near these biotopes is 0.4 or 40%. In addition, this study shows that altitude is negatively correlated with disease incidence. For altitudes above 353 meters, Diseases are practically non-existent. These results could be considered indicators in the management of foliar fungal diseases of rubber trees in Côte d'Ivoire.**

2 INTRODUCTION

The rubber tree with its scientific name *Hevea brasiliensis* (Euphorbiaceae) is a tropical tree native to the Amazon rainforest of South America (Noordin *et al*., 2012). Rubber is one of the most important agricultural products in the world, heavily cultivated in Southeast Asia and Africa for its natural rubber. Côte d'Ivoire is the world's third-largest producer of natural rubber and the first African country with a production of 1 387 738 tonnes (APROMAC, 2022). This important national production comes from 650,000 ha of rubber plantations, including 6, 00,000 ha of village plantations, or 92.3% of the planted area. Rubber trees are widely cultivated due to soil and climate adequacy, and are mainly concentrated in forest areas (Kouassi, 2018). Natural rubber production faces many challenges, including price fluctuations, scarcity of favourable production areas, and the risk of destructive epidemics (Heng and Joo, 2017). Among these epidemics, risks are the increasing attacks of leaf fungi that cause considerable damage to cultivated clones in the world in general and in sub-Saharan Africa in particular (Gill and Onybe, 1990; Hévécam, 1995). Today, while crisscrossing the Ivorian countryside, these fungi, which invade the rubber orchard, are perceptible by the characteristic foliar symptoms (Manju *et al*., 2011; Thomson, 2017; Liyanage *et al*., 2016; MRB, 2018). Many factors have favoured the emergence of foliar fungal diseases in rubber trees: uncontrolled transfer of plant material, increase in agricultural area Antoine *et al*., (2021), the introduction of invasive pathogens, and climate change. Since the appearance of significant fungi in the rubber tree plots, various methods of preventive and curative control have been employed. However, foliar fungal diseases of perennial crops, including rubber, are more difficult to control because the cost of managing them is high (Aliya *et al*., 2022).

Rubber, vectors, and fungi are interdependent components of a complex pathosystem. The effect of surrounding flora on the ability of fungi to infect rubber plantations and cause disease is a major central issue in plant pathology to understand the emergence of foliar diseases and to develop strategies for their management. Pagán *et al*., (2012) and Keesing *et al*., (2006) postulated that reduced flora may increase disease incidence due to an increased abundance of susceptible major hosts, thereby facilitating disease spread. The spread of foliar diseases is inherently a spatial process often embedded in physically complex landscapes (Biek and Real 2010). However, little is known about the relationship between spatial processes at the flora level, and the rate of primary or secondary inoculum infection in the epidemiological process of leaf disease (Manju *et al*., 2014). This study, therefore, aims to evaluate the incidence of pathogenic fungi *Corynespora Cassiicola*, *Colletotrichum gloesporoïdes*, *Helminthosporium heveae*, *Oidium heveae*, and *Phytophthora palmivora* associated with the surrounding rubber tree flora and altitude in plantations village women study sites.

3 MATERIALS AND METHODS

3.1 Study settings: The study was conducted in Côte d'Ivoire in village rubber plantations in six localities namely Tabou, Nouamou, Man, Daoukro, Zoukougbeu, and Gagnoa (Figure 1). These localities are rubber disease observation posts, chosen as part of a national rubber tree health-monitoring project. This choice took into account the diversity of ecological zoning covered by the rubber-growing sectors of Côte d'Ivoire. In total, twenty-four (24) plots, four (4) per locality, aged 7 to 14 years have been prospected. The choice of the sites of Tabou and Nouamou, located respectively in the west of the country at 9°32'00" north latitude and 6°29'00" west longitude and in the south at 5°11'00" north latitude and 2°54'00". These localities border Liberia and Ghana respectively. This is justified by the fact that Côte d'Ivoire and these two countries share the cultivation of rubber. The site of Man, to the west and with geographical coordinates 7°24'00" N, 7°33'00" W, is justified by the fact that this locality enjoys a special mountain microclimate that is characterized by high annual rainfall, from about 1400 to 1600 mm and dry cold in periods of drought. The locality of Daoukro, in the center-west, at 7°15'00" north and 3°52'00"west, is a marginal area. The localities of Gagnoa and Zoukougbeu, located in west-central Côte d'Ivoire, are considered areas of development of rubber cultivation. The geographic coordinates of these localities are 6°08'00" north latitude and 5°56'00" west longitude and 6°45'00" north latitude and 6°53'00" west longitude, respectively. These six (6) localities have vegetation composed of dense semi-deciduous humid forests, cleared forests, and mesophilic savannahs.

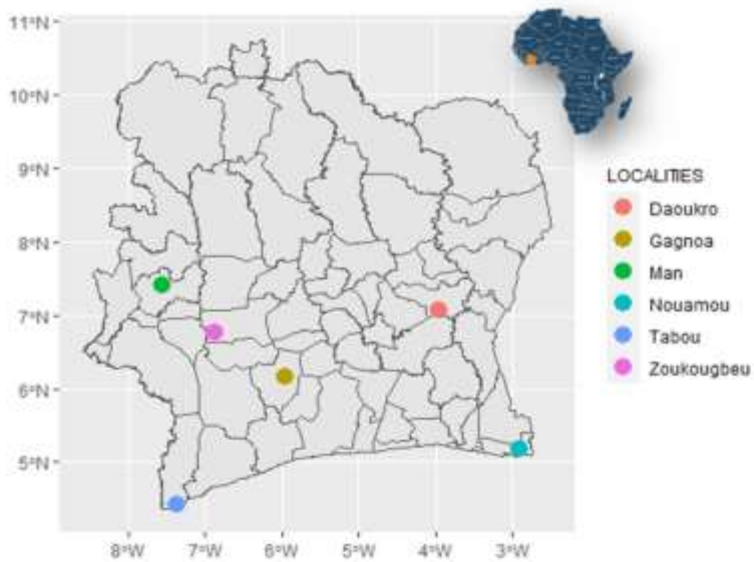

Figure 1: Location of study sites

3.2 Study material

3.2.1 Plant material: The study was carried out in 2021 in village plots before the defoliation of rubber trees and in polyclonal plantations. These are the main clones GT 1, PB 217, IRCA 41, and seedling, i.e., genetically indeterminate rubber trees. These clones are popularized for their agronomic performance and disease tolerance (Okoma *et al.*, 2016).

3.2.2 Technical equipment: It consisted of Binoculars of visions (VISIONING- 7X50V) for the observation of diseases on rubber trees and a GPS (Garmin) for geo-referencing plots.

3.3 Study methods: Three types of data were collected. First, it was the data on the occurrence of the various foliar diseases due to fungi that are *Corynespora Cassiicola, Colletotrichum gloesporoïdes*, *Helminthosporium heveae*, *Oidium heveae*, and *Phytophthora palmivora*. Then, the incidence and severity of the diseases were measured. Thirdly, those of the inventory of the floristic environment in the vicinity of plantations. The plantations prospected had a maximum area of two (2) hectares. The choice of plots was made according to the orientation of these according to the locality, it is a choice based on the four cardinal points.

3.3.1 Occurrence of disease-causing fungi: Field observation was conducted to determine the presence or absence of pathogens in rubber plantations. This included the detection of browning of skate veins, the appearance of "fishbones" a diagnostic symptom of *Corynespora cassiicola*, and very white spots in their center bordered with brown leading to the presence of *Helminthosporium heveae*. Necrosis reliefs at the base of the deformation of the blade and leaves are covered with a fine white mycelium caused respectively by *Colletotrichum gloesporoïdes* and *Oidium heveae*. Finally, typical symptoms of *Phytophthora palmivora* are characterized by brown lesions on petioles with white droplets of coagulated latex.

3.3.2 Study of the incidence and severity of diseases: This study consisted of two phases. First, in each plantation, 12 trees were chosen according to a diagonal experimental set-up, i.e., five (5) pulses of observations per plot. The sampled trees were then physically counted and tagged from 1 to 12 using coloured labels. Finally, observations on the defoliation status of trees were made. The incidence or attack rate of disease represented the proportion of sick rubber trees out of the 60 trees in the sample, it was evaluated according to the following formula:

$$AR = \frac{Nx}{Nt} \times 100$$

AR: Attack rate or disease incidence (%)
Nx: Number of diseased trees
Nt: Total number of trees observed (60 trees/plot).
The evaluation of parasitic attacks or the disease severity index (ISM) was carried out, from the 12 trees of each elementary plot, according to the scale of values from 0 to 5 of Manju *et al.*, (2002) described as follows:

- 0: Absence of infection (no leaf lesion),
- 1: very low attack (less than 5 lesions per sheet),
- 2: low attack (5 – 10 lesions and 10 – 25% defoliation),
- 3: medium attack (more than 10 lesions and 26 to 50% defoliation),
- 4: severe attack (large lesions and 51 – 75% defoliation),
- 5: very severe attack (large lesions and more than 75% defoliation).

The disease severity index was calculated using the following formula, Jayasinghe *et al.* (2003).

$$ADS = \frac{\sum(Ni \times I)}{Nt}$$

ADS: Average Disease Severity Index
I: Disease severity index (I ranging from 0 to 5)
N_i: Number of trees with index I
Nt: Total number of trees examined.

3.3.3 Study of the surrounding flora and vegetation of the plantations: The inventory of species and the description of the characteristics of the surrounding flora and vegetation have been carried out. For a better knowledge of the flora around the plots, a buffer zone 100 m long and 50 m wide representing the surface survey was created around each stand, and itinerant floristic surveys were carried out (Figure 2). This botanical survey method is the one used by Aké-Assi (2002) and Konan (2015). The species collected were used to make a herbarium.

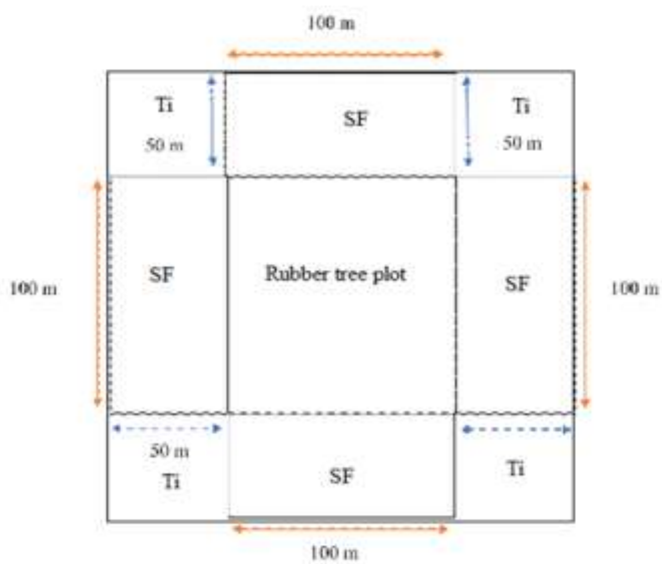

Figure 2: Data Collection System
SF = Surrounding flora and Ti = Travelling inventory

3.3.4 Determination of Specific Richness: The specific richness of a plot is the number of species recorded within its boundaries. The sites investigated were established using the method recommended by Aké-Assi (1984). This method consists of counting all the species recorded on the site without taking into account their abundance. This is also the case for the families of inventoried species. The floristic list of each plot was thus drawn up. Subsequently, the specific richness of each site was determined.

3.3.5 Measurement of plot altitude: The altitude in meters above sea level was recorded using the Ground Positioning System (GPS) at a central point in the sub-plots of each plot studied.

3.3.6 Statistical approach: Multinomial logistic regression is an extension of logistic regression to qualitative variables with three or more modalities. In this case, each modality of the variable of interest will be compared to the reference modality (No pathogen). The model described, beyond the simple prediction of the existence of the disease (binary yes/no or 1/0 approach), to give an estimate of the incidence of the disease. Therefore, multinomial logistic regression is the most suitable for our modelling. The variable Y to be explained is the incidence of a target disease and the variables Xi distribute between the two types of data. Much of the data collected (80%) was used to develop our multinomial logistic regression model.

3.3.5 Data analysis: The inventory and completed severity scores were entered on Microsoft Excel spreadsheets where codes for certain variables were assigned. The results of the statistical analysis were performed using the R 4.2.0 programming language (Rstudio, 2022). The various statistical data were analysed using a parametric approach. Analysis of variance (ANOVA) was used to generate averages for incidence, disease severity, and floristic richness at different sites. In the event of significant differences, the comparison test of means at the 5% level was carried out to identify homogeneous groups. A multinomial modelling approach was used to understand the relationship between species, biotopes, and diseases. Correlation and linear regression analysis were used to test the magnitude and nature of relationships (association) between disease incidence and farm altitude.

4 RESULTS

4.1 Presence of fungi in the localities studied: Typical symptoms consistent with infections of three fungi were observed in all twenty-four (24) plots of localities studied. These are *Corynespora cassiicola*, *Helminthosporium heveae*, and *Colletotrichum gloesporoïdes* (Table 1). Specifically, the disease most present in the plots was that caused by *Helminthosporium heveae* followed by *Corynespora cassiicola* and *Colletotrichum gloesporoïdes*. The localities of Tabou and Nouamou observed the presence of the three diseases in the orchards. However, no fungal disease has been observed in Man.

Table 1: Occurrence of fungi in plantations of different localities

Locality	*Corynespora cassiicola*	*Helminthosporium heveae*	*Colletotrichum gloesporoïdes*
Tabou	+	+	+
Nouamou	+	+	+
Man	-	-	-
Zoukougbeu	-	+	-
Gagnoa	+	+	-
Daoukro	-	+	+

(+) Presence of disease in the locality and (-) absence of disease

4.2 Effect of spatial context on the incidence and severity of diseases caused by the three fungi: The results of the survey indicate a wide distribution of fungal foliar diseases due to *Corynespora cassiicola*, *Helminthosporium heveae* and *Colletotrichum gloesporoïdes* in all plantations in the different localities studied. With *Corynespora cassiicola*, the highest severity indices were recorded at 2.800 and 1.143 in the localities of Tabou and Nouamou. These severity indices are statistically different from each other and from those obtained in other localities according to the Newman-Keuls test at the 5% level. The severity index of *Corynespora cassiicola* was zero in the localities of Man, Daoukro, and Zoukougbeu. For *Helminthosporium heveae*, the highest severity indices obtained were 2.09 and 1.94 respectively in Nouamou and Gagnoa. These values are statistically identical and different from those of other localities ($p < 0.05$). All the localities studied have a considerable number of rubber trees with the highest incidences of 44.97% and 28.02%. These incidences are due to *Corynespora cassiicola* and *Helminthosporium heveae*, respectively. For *Corynespora cassiicola*, the highest incidence (44.97%) was observed in the locality of Tabou, and the lowest incidence (4.24%) in Gagnoa. *Colletotrichum gloesporoïdes* is the pathogen with a low incidence with values ranging from 2.57 to 7.83 for the localities of Daoukro, Tabou, and Nouamou. The results reveal a generally low distribution of the incidence of fungal foliar diseases in the rubber plantations of the study localities. The highest incidence and severity index of leaf disease due to *Corynespora cassicola* was observed in Tabou (44.97% and 2.8 respectively) followed by the locality of Nouamou (14.44% and 1.14 respectively). Leaf disease due to *Helminthosporium heveae* was strongly expressed in the locality of Nouamou with an incidence of 28.02% and a severity of 2.08 followed by the locality of Gagnoa (24.63% and 1.94) (Table 2).

Table 2: Severity and average annual incidence (2021) of major fungal foliar diseases of rubber trees in different localities

Locations	Average severity			Average incidence		
	Cc	***Hh***	***Cg***	***Cc***	***Hh***	***Cg***
Daoukro	0.00±0.00 b	1.52±0.50 ab	0.84±0.249 a	0.00±0.000 b	20.81±14.59 a	2,57 ± 0,78 b
Gagnoa	0.47±0.51 b	1.94±0.69 a	0.00±0.00 b	4.24±2.5 b	24.63±8.79 a	0.00±0.00 c
Man	0.00±0.00 b	0.00±0.00 b	0.00±0.00 b	0.00±0.0 b	0.00±0.00 b	0.00±0.00 c
Naouamou	1.14±0.69 ab	2.08±0.65 a	1±0.04 a	14.4±9.1 ab	28.02±11.56 a	7,83 ± 4,05 a
Tabou	2.80±0.97 a	1.24±0.54 ab	1.05±0.04 a	44.97±20 a	24.14±10.67 a	6,77 ± 2,45 a
Zoukougbeu	0.00±0.00 b	0.88±0.91 ab	0.00±0.00 b	0.00±0.00 b	8.14±8.69 ab	0.00±0.00 c

In the same column, the mean values followed by the same letter are not statistically different according to the Newman and Keuls test at the 5% probability threshold.

Cc = *Corynespora cassicola*; **Hh** = *Helminthosporium heveae*; Cg = *Colletotrichum gloesporoïdes*

4.3 Influence of flora and vegetation on the presence of pathogens in plantations

4.3.1 . Floristic richness around rubber plots: In all (6) six forest fragments were inventoried, and 369 species individuals were counted. They are distributed between 95 species and 39 families. According to the APG IV classification, the individuals recorded belong mainly to three families: Euphorbiaceae (14%), Rubiaceae (10%), and Asteraceae (8%) (Table 3). At the specific level, the average plot richness varies from 13.3 ± 1.5 species to 43.5 ± 11.25 species with an overall average of 27.01 ± 5.3. Average specific wealth is statistically different ($p < 0.05$) from one locality to another.

Table 3: Floristic richness of different environments according to localities

Locality	Number of individuals	Number of species	Number of families	Average specific wealth
Tabou	101	79	34	43,5 ± 11,25 a
Zoukougbeu	43	33	21	20,8 ± 2,25 b
Gagnoa	56	47	24	23,5 ± 4 b
Daoukro	51	38	17	22,5 ± 5,2 b
Man	31	21	8	13,3 ± 1,5 c
Nouamou	87	76	32	38,5 ± 7,5 a
Total	369	95	39	27,01 ± 5,3

In one column the means followed by the same letter are not significantly different according to Tukey's HSD mean comparison test at α = 0.05.

4.3.2 Relationship between plant species, biotopes and impacts of the 3 fungi: Floristic species do not affect the presence or absence of diseases and their incidence. The results of the ANOVA test of the multinomial logistic regression model show that there is no relationship between plant species and the presence or absence of diseases, as well as their incidence (p-value = 0.73). On the other hand, the results show that there is a significant relationship between the type of biotope and the incidence of diseases (p-value = 5.174e-13***).

4.3.3 Relationship between the presence of diseases and the biotope variable using the multinomial logistic model approach: The multinomial logistic model was used to understand the relationship between the different modalities of the biotope variable (vegetation) on the presence of fungi in plantations (Figure 3). This validated model shows that the incidence of diseases is related to vegetation (Biotope). Model data were used to make an advanced heat map to infer the relationship between the presence of the three fungi in rubber patches and their vicinity. This analysis confirmed that the non-infected ted rubber plots have cocoa, cashew, oil palm, and rubber plantations in their vicinity. The plots infected by *Helminthosporium heveae* have in the vicinity a fallow (Jache). The presence of ripicole forest, forest patches, and lowlands (ForriIlofoBasfo) around the plots was much more characterized by the presence of leaf disease due to *Corynespora cassiicola*. Finally, the presence of *Colletotrichum gloesporoïdes* in a rubber patch was associated with a forest patch around it.

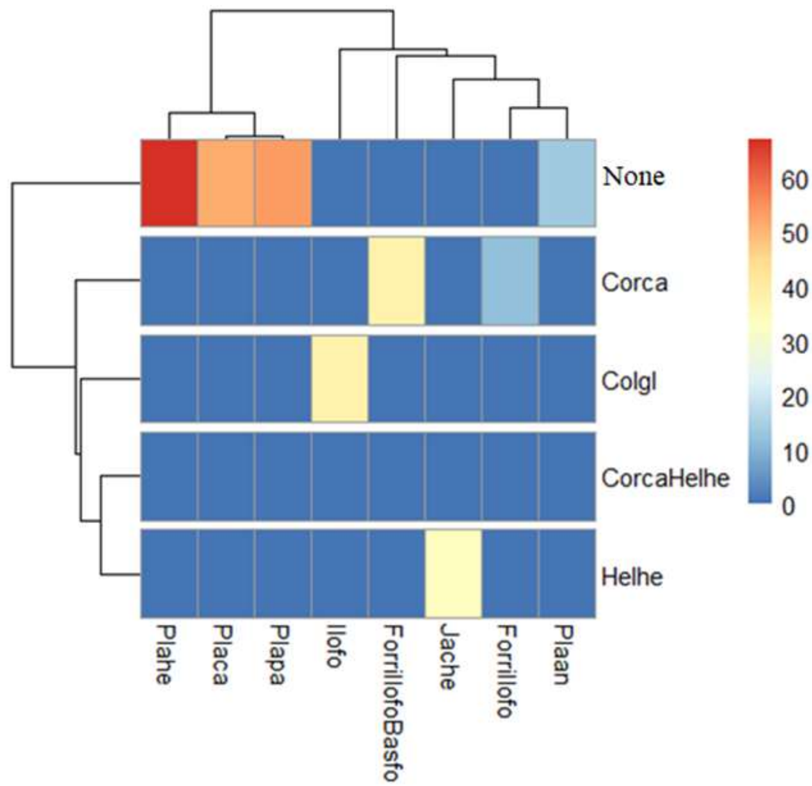

Figure 3: Thermal map showing the effect of the biotope variable on the presence of fungi

4.3.4 Probability of the presence of fungi according to each biotope: The probability of the presence of each phenomenon (disease-biotope) is compared to that of the phenomenon quite present in the study ("no pathogen-disease" relationship) whose probability is equal to 1. Orchards near fallow, ripicole forests, forest patches, and lowlands have a probability (p = 0.4) of being infected by *Helminthosporium heveae* and *Corynespora cassiicola* respectively. For adult patches, infected by both *Corynespora cassicola* and *Helminthosporium heveae*, the probability of infestation (p= 0.4) is due to the presence of ripicole forests and forest patches in the vicinity of these. The probability of a rubber patch being infested with *Colletotrichum gloesporoïdes* with a forest patch as its vicinity is less than 0.4 (Figure 4).

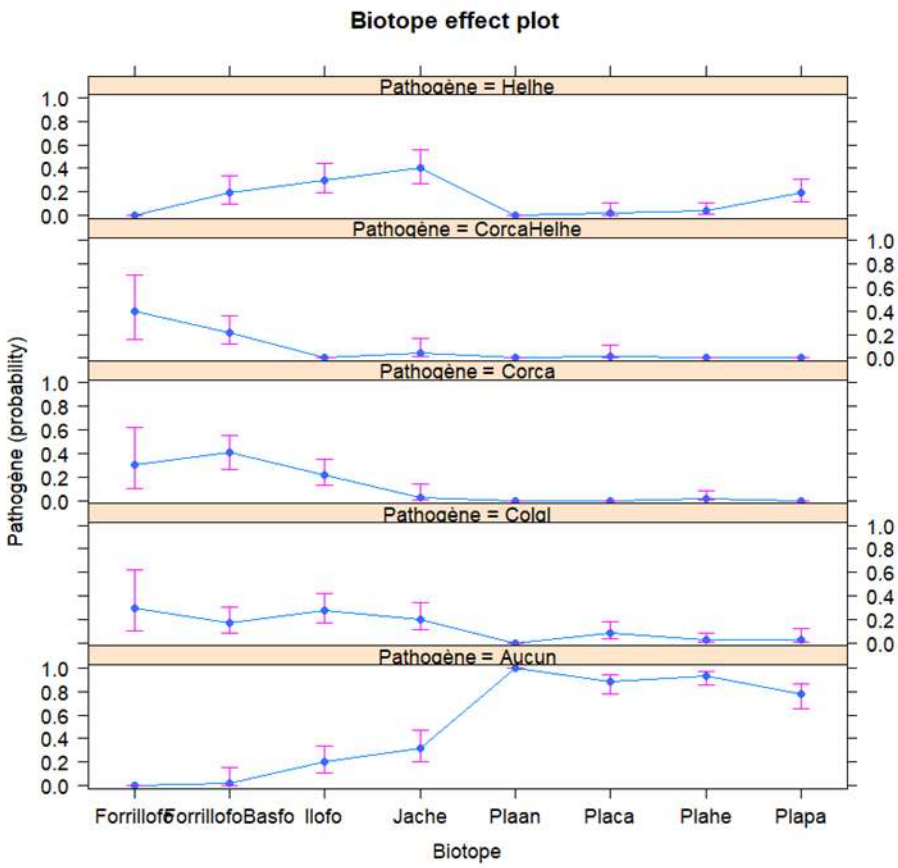

Figure 4: Probability of disease occurrence according to biotopes
Forri= Ripicole forest, Ilofo= forest island, Basfo= Lowland, Jache= Fallow, Plaan= Cashew plantation, Placa=Cocoa plantation, Plahe=Rubber plantation, Plapa=Oil palm plantation

4.3.5 Model validation: The confounding matrix for a multinomial logistic regression model shows the number of correct and incorrect predictions for each class category (No pathogen, *Colletotrichum gloesporiodes, Corynespora cassiicola, Corynespora cassiicola, a*nd *Helminthosporium heveae, and Helminthosporium heveae)* (Table 4). Depending on whether a pathogen is present, the columns in the matrix represent predictions and the rows represent the actual values. Diagonal cells give the number of correct predictors, that is, the cases where the actual values and the predictions of the model are identical. The other cells indicate the number of incorrect classifications. Confusion matrices using calibrated and validated data (Table 4. A and 4. B) were used to evaluate model performance. Thus, in calibration, the number of correct predictors for the different classes was 159 for "no pathogen", 11 for "*Colletotrichum gloesporoïdes*", 22 for "*Corynespora cassiciola* ", 0 for the simultaneous presence of "*Corynespora cassiciola*" and "*Helminthosporium heveae*" and 13 for "*Helminthosporium heveae*". In validation, the number of correct predictors for the same classes is 38, 3, 1, 0, and 7, respectively. The accuracy of the model in calibration was 0.67 or 67% and in validation, it was 0.65 or 65%.

Table 4: Matrices of confusion, A. From the calibration of the model, B. From model validation data

A	None	Colgl	Corca	CorcaHelhe	Helhe
None	159	8	0	1	17
Colgl	10	11	6	0	11
Corca	1	8	22	11	8
CorcaHelhe	0	0	0	0	0
Helhe	8	9	1	2	13
B	**None**	**colgl**	**corca**	**corcahelhe**	**helhe**
None	38	2	1	1	0
colgl	0	3	5	0	4
corca	0	3	1	2	1
corcahelhe	0	0	0	0	0
helhe	6	1	0	0	7

4.4 Effect of plot elevation on the incidence of *Corynespora cassiicola, Helminthosporium heveae* and *Colletotrichum gloesporoïdes*

- **Effect of plot elevation on the incidence of *Corynespora cassiicola:*** The results indicate a mean and negatively significant relationship (P < 0.001) between the incidence of *Corynespora cassiicola* and altitude (r = -0.58). This implies that the incidence of *Corynespora cassiicola* in rubber plots increases with each unit of decrease in farm altitude (Figure 5). This association is more detailed in the following linear regression equation:

$$\boldsymbol{Y = -0.08X + 24.6}$$

Where Y= percentage incidence of *Corynespora cassiicola* and X= altitude in meters. The equation further predicts that the probability of a patch of susceptible rubber tree being infested with *Corynespora cassiicola* is low above 121 meters altitude. While the probability of infection is high below 121 meters.

- **Effect of plot elevation on the incidence of *Helminthosporium heveae:*** The incidence of disease due to *Helminthosporium heveae* also shows a mean and negatively significant relationship (P < 0.001) with altitude (r = -0.56). The incidence of this disease is inversely related to altitude (Figure 5). The linear regression equation describing this relationship is:

$$\boldsymbol{Y = -0.06X + 31.95}$$

Where Y= percentage of the characteristic disease of *Helminthosporium heveae* and X= altitude. The equation indicates that the probability of a sensitive rubber tree plantation being infested with *Helminthosporium heveae* is high at low altitudes between 5.34 and 237 meters above sea level.

- **Effect of plot elevation on the incidence of *Colletotrichum gloesporiodes:*** The relationship between the incidence of rubber *Colletotrichum gloesporoïdes* disease and plot elevation is mean and negatively correlated (r=-0.75, P < 0.001). This result means that increases in altitude levels promote a sharp decrease in the disease (Figure 5). The linear regression equation describing this relationship is:

$$\boldsymbol{Y = -0.02X + 6.82}$$

Where Y= percentage of the characteristic disease due to *Colletotrichum gloesporoïdes* and X= altitude. The equation indicates that the probability of a susceptible rubber tree plantation being infested with *Colletotrichum gloesporoïdes* is high at low altitudes.

The results of the linear regression model estimation show an adjustment of the determination coefficients R^2= 0.34 for *Corynespora cassiicola* disease, R^2 = 0.32 for *Helminthosporium heveae* disease, and R^2 = 0.55 for *Colletotrichum gloesporoïdes* disease. Equations showing the relationship between disease incidence and plantation elevation predict these relationships on average and significantly (Figure 6).

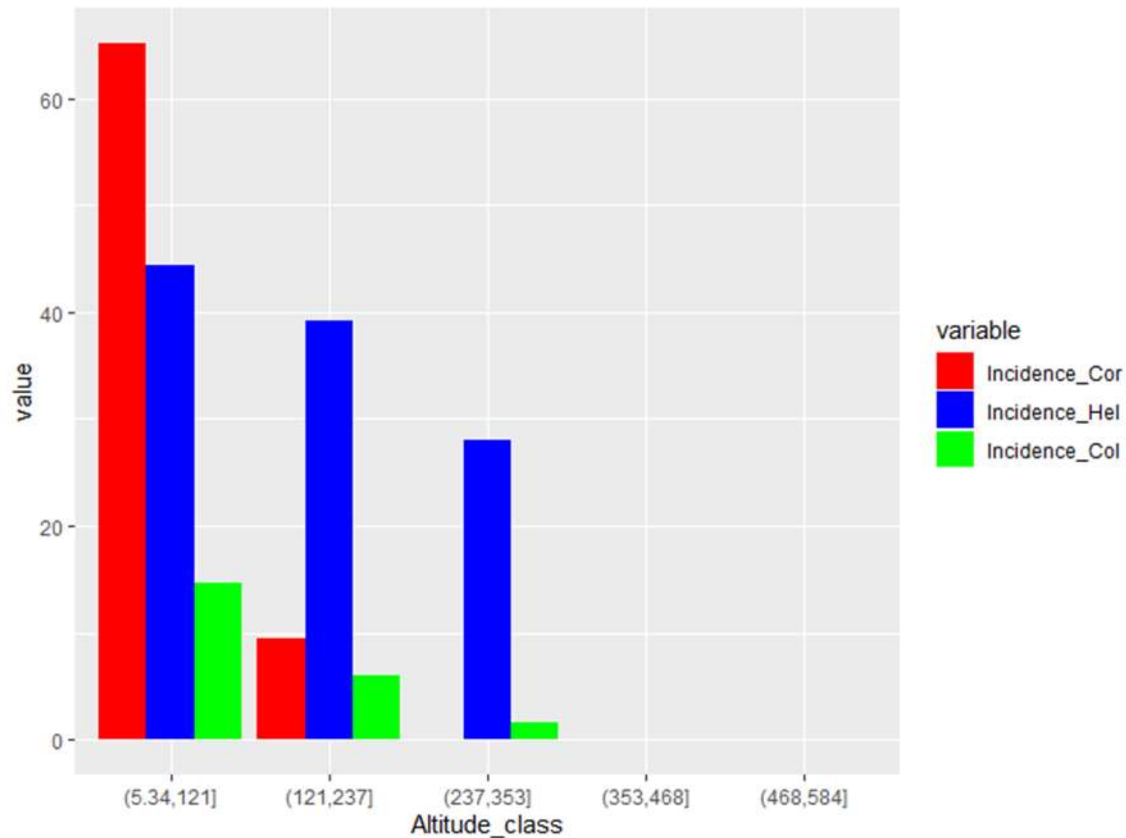

Figure 5: A. Relationship between altitude and incidence of fungal foliar diseases caused by *Corynespora cassiicola*, *Helminthosporium heveae* and *Colletotrichum gloesporoïdes* in rubber farms sampled in producing regions of Côte d'Ivoire.

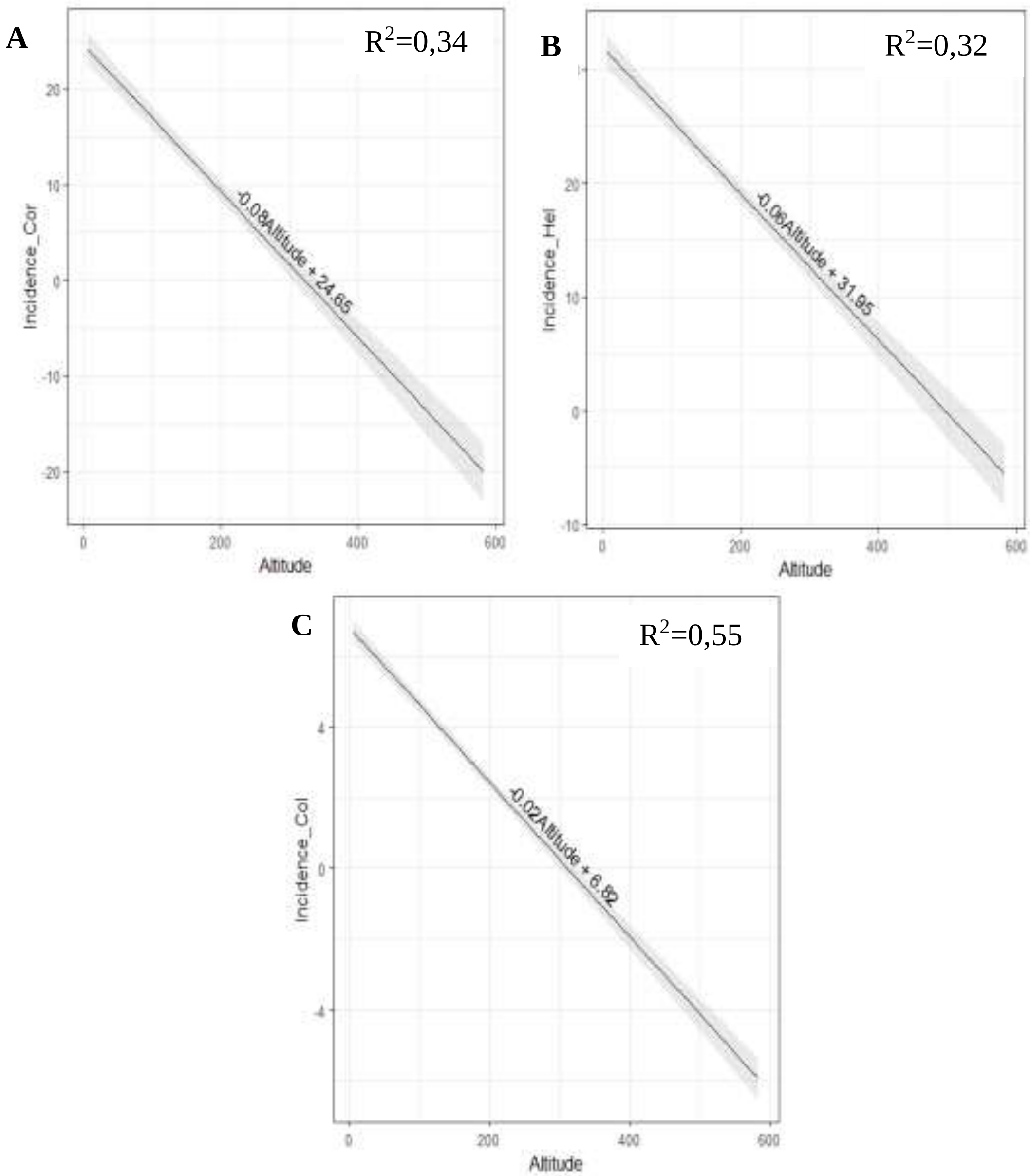

Figure 6: Linear regression model equations, A. *Corynespora cassiicola* disease B. disease due to *Helminthosporium heveae*, C. Disease due to *Colletotrichum gloesporoïdes*

5 DISCUSSION

Foliar fungal diseases of rubber trees induced by *Corynespora cassiicola*, *Helminthosporium heveae*, and Colletotrichum *gloesporoïdes* affect the yields of Ivorian rubber plantations. In addition, these diseases have received little attention at the scale of the composition of the surrounding flora and vegetation of the plots, despite the key role of landscape features in the development and spread of these diseases. The development and development of efficient control methods that integrate environmental concerns requires a thorough knowledge of these pathogens and their habitats. The objective of this work was to identify the vegetation associated with the presence of the main fungal pathogens responsible for foliar diseases in the plots.

5.1 Effect of spatial context on fungal foliar diseases identified in study localities: During this study, certain fungi such as *Corynespora cassiicola*, *Helminthosporium heveae*, and *Colletotrichum gloesporoïdes* were identified in the orchards of Côte d'Ivoire. Except for Man (West of the country), three (3) fungi were observed in the other five localities. These diseases have already been reported elsewhere in other producing countries such as Malaysia (Aliya *et al*., 2022), India (Thakurdas *et al*., 2002; Xiaoyu *et al*., 2019), China (Xueren *et al*., 2017) and some African countries (Déon, 2012). Our results are consistent with those of Omorusi et al. (2013) which showed during a diagnostic and phytosanitary treatment study of fungal foliar diseases of rubber trees *Corynespora cassiicola*, *Colletotrichum gloesporoïdes*, and *Helminthosporium heveae* were the main rubber diseases in Nigeria, a West African country. *Corynespora cassiicola*, *Colletotrichum gloesporoïdes*, and *Helminthosporium heveae* can be considered the main rubber diseases in Côte d'Ivoire. "Corynespora leaf fall" one of the diseases that cause significant production losses in rubber trees has been more inventory in the two border areas of Tabou (western Côte d'Ivoire) and Naoumou (south-east of Côte d'Ivoire). The presence of this pathology is explained by the fact that these localities share the cultivation of rubber trees with Liberia and Ghana respectively for neighbouring countries. In a personal communication by Clément-Demange, this disease was initiated in Nigeria in 2000 the disease then appeared on the Araromi plantation, then on the Grel plantation in Ghana (2003), then in Côte d'Ivoire (2008-2009), then in Liberia (2010). This unequal distribution of diseases is explained by climatic conditions (temperature, humidity) which differ from one growing area to another and which are favourable or not to the development of each pathogen. Indeed, the humid tropical climate with high rainfall frequencies, and areas of the prevalence of the disease, would favour the sporulation and germination of *Corynespora* spp spores and rubber cultivation. Similar observations were made by Pawirosoemardjo *et al*., (2009), who reported that annual rainfall greater than 2500 mm was the cause of an outbreak of *Corynespora* leaf fall disease caused by *Corynespora* spp west of Kalimantan, Indonesia. Unlike the localities of Tabou and Nouamou, the incidence of the disease was low in the other localities of the study. This low incidence in other localities could be explained by the fact that these regions belong to the new rubber growing area where pest pressure is still low, coupled with a relatively less favourable climatic context. In addition, the disease is present in relatively low and medium proportions. Indeed, the incidence rates of *Corynespora* leaf fall disease in the surveyed areas were less than 50%. This would indicate a decrease in parasite pressure, compared to that observed in 2010 by Wahounou *et al*., (2011). Unlike the locality of Man, *Helminthosporium heveae* has been identified in the other localities prospected. The presence of a pathogen would be due to the alternation of humidity and high temperatures, that is to say, immediately after a rain, the sudden temperature rise would favour the development of the pathogen. It had already been reported in rubber nurseries in Côte d'Ivoire in the 1950s, the largest comprising 21 hectares (Merny, 1956). This pathogen has not been the subject of specific studies on rubber trees since the diagnostic work in Merny's nursery. *Colletotrichum gloesporoïdes* is the fungus weakly represented in the adult rubber plots of the localities studied, with an incidence of 7.83% and a high mean severity of 1 observed in Nouamou. Firmino *et al*., (2022), justified the presence of this pathogen in adult rubber plots in Brazil by a mild temperature that would promote the development of the pathogen. This low presence in adult plots is explained by the characteristic symptoms of the disease that are more visible on young leaves in graft gardens and nurseries. However, this pathogen has been present in adult cashew plantations according to the work of Silué N. *et al*., (2017).

5.2 Flora and vegetation surrounding adult rubber plots: The study of the floristic richness near the rubber plots shows that it is rich in 369 individuals, and 95 plant species, arranged in 39 families based on the 4zones s delimited around the plots. The most dominant families were Euphorbiaceae (14%), Rubiaceae (10%), and Asteraceae (8%). Indeed, the presence of Rubiaceae generally represented by wood species is a common feature of all tropical rainforests as noted by Adnan *et al.* (2022) and Lan *et al.* (2017) in a study conducted respectively in Indonesia and China on the plant diversity of small rubber plantations in Segamat and Johor. There were 28 common species around the 24 pilot rubber plots in the six (6) localities. Common species refer to plants, and trees that are always present, found, or widespread in that particular area based on their overall presence in the environment. Common species are also designations used in ecology to describe the population status of a species. However, the presence of these species around the rubber plots did not have an impact on the presence or incidence of the three fungi observed in the plots. This result would be explained by the local diversity of the flora close to rubber trees, the richness of fungal species in this flora, the fungal infestation on host trees, and the infestation by individual fungal species. Using a landscape-level epidemiological approach, Haas *et al.* (2011) found that the risk of infection with the plant pathogen *Phytophthora ramorum* was lower at sites with a greater diversity of species. In addition, Hantsch *et al.* (2014) were able to show that some non-host species near the target species can hinder or facilitate infestation by fungal pathogens, depending on the identity of the species as well as their proportion in the local neighbourhood. For the study of the relationship between individual species and the impact of the three (3) pathogens studied, the relationship between the biotope (vegetation) and disease incidence was significant using the multinomial logistic model approach. The choice of multinomial logistic regression is justified by its ability to estimate the probabilities of the appearance of a pathogen according to explanatory variables, including biotopes. This statistical method is also used in human epidemiology. Nicole *et al.* (2001) used it in a study of spatial vegetation dynamics in Germany and Nguyen *et al.* (2012) also used it in a study to raise awareness among cardiologists about the impact of air pollution on cardiovascular disease in Vietnam and the Philippines. The model results showed that biotopes such as ripicole forests, forest patches, fallow land, and lowland in combination or individually in the vicinity of plots could influence the presence and incidence of *Corynespora cassiicola*, *Colletotrichum gloesporoïdes* and *Helminthosporium heveae* in rubber tree. In addition, the probability that a patch of the susceptible rubber tree is infested by one of these pathogens with these biotopes as a neighbourhood is 0.4. Ripicole forests, forest areas bordering rivers, shallows, forest patches, and fallow land can play a role in regulating ecosystems. Although the literature does not mention the relationship between the biotope and susceptible fungal-infested rubber patches, these biotopes may be a habitat for plant pathogenic fungi. In addition, in these high-humidity biotopes, spores could easily germinate in a short period, which could lead to the further spread of the disease among stands (Kpu *et al.*, 2022). These biotopes are thought to be reservoirs for fungi. There was not much literature and research regarding the relationship between flora and vegetation around infested rubber plantations in Africa, particularly in Côte d'Ivoire, so the data collected in this study were compared with studies conducted in Indonesia, China, and Germany.

5.3 Impacts of the three altitude-influenced pathogens: During this study, the evaluation of the influence of attitude on the impact of the three fungi in rubber plots was determined. The relationship between elevation and disease incidence was inversely correlated (negative). Indeed, it has been observed that as the altitude gradient increases, the incidence of diseases due to each pathogen decreases. The estimated probability of infestation increased as the elevation of the rubber production areas sampled decreased. At altitudes above 353 m, no incidence is observed regardless of the pathogen. This would explain the high incidence of diseases due to *Corynespora cassiicola* and

Helminthosporium heveae in the localities of Tabou and Nouamou, two lowland production areas. Our results are consistent with those of Manuel *et al.* (2023); Asfaw *et al.* (2019) and Zambolim *et al.* (2005); Matovu e*t al.* (2013) which showed the inverse correlation between berry borer infestation and coffee leaf rust and altitude. This negative correlation would be strongly related to temperature, knowing that, if we go higher in the altitudinal gradient, the temperature will tend to decrease and vice versa (Mariño *et al.*, 2017). The optimal conditions for the germination of conidia of these rubber mushrooms are a relative humidity of 97 to 100% and temperatures between 25 and 28 °C. Therefore, on sites with lower temperatures, the development time of pathogens is longer compared to sites with high temperatures. However, our results do not corroborate this of Camara (2011). Indeed, the author working on the distribution and characterization of banana leaf fungi in Côte d'Ivoire found that the pressure of Banana black stripe disease was greater at high altitudes where temperatures, rainfall, and humidity are very high than at low altitudes

6 CONCLUSION

This study shows that fungi such as *Corynespora cassiicola*, *Colletotrichum gloesporoïdes*, and *Helminthosporium heveae* are present in rubber orchards in localities except for Man. The highest incidence and severity were observed in the two border localities of Tabou and Nouamou. Vegetation and altitude at the spatial scale influence the behaviour of fungi observed in the agroecosystems of adult rubber plantations in Côte d'Ivoire. The multinomial logistic regression model indicates that plant species around plots have no relationship to disease presence and incidence. Biotopes such as ripicole forests, shallows, forest patches, and fallow land play a role in the fungal infestation of rubber trees. With this study, it is demonstrated that in future plantation creation projects or management of existing plantations, these epidemiological factors should be considered. Linear regression has indicated that for altitudes above 353 meters, disease incidences are very low or non-existent. These results are very encouraging for the study areas since they are tropical forest ecosystems. The ecological factors studied such as altitude and vegetation around the plots have influenced in one way or another the incidence of each disease due to the three pathogens, which offers a first opportunity for integrated pest management, a decision-making tool in the management of fungal foliar diseases of rubber.

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