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Research Article

Epidemiological Investigation of Witches' Broom Disease in *Cola nitida* [(Vent.) Schott et Endl] Plantations in Selected Regions of Côte D'Ivoire

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ABSTRACT

The *Cola nitida* tree represents a significant source of income for thousands of people. However, this crop is severely threatened by witches' broom disease. The present study aimed to assess the phytosanitary condition of kola orchards by evaluating key epidemiological parameters across various localities. Specifically, correlations between the phenological stage of the orchards, relative humidity, and disease severity were investigated. In addition, the impact of disease severity on trunk and crown girth was analyzed. The highest prevalence (70.12%) and severity index (78.27%) were recorded in Aboisso. Overall, prevalence rates were relatively consistent across the surveyed localities. Pearson correlation analysis revealed no significant relationship between symptom prevalence and orchard relative humidity ($r = 0.044$, $P = 0.893$). However, a strong positive correlation was observed between symptom severity and relative humidity ($r = 0.843$, $P < 0.001$). A weak negative correlation was found between orchard age and disease severity ($r = -0.280$, $P = 0.127$). No significant correlation was detected between disease severity and kola tree trunk girth ($r = 0.025$, $P = 0.66$). Interestingly, trees exhibiting witches' broom symptoms but lower severity indices had the largest crown sizes ($r = -0.287$, $P < 0.001$). Witches' broom disease was found to be widespread in all surveyed areas, with consistently high severity indices. A comprehensive understanding of the epidemiology of witches' broom disease is essential for the development of more targeted and effective management strategies.

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Introduction

Witches' broom is a stem branching anomaly characterized by the excessive proliferation of twigs with shortened internodes and small, often deformed leaves. These symptoms result from abnormal bud excitation, which may be triggered by trauma or parasitic organisms

(Lepoivre, 2007). This exogenous disease is currently widespread in South America, particularly in Ecuador, Brazil, and Colombia, where it causes significant yield losses in cocoa orchards (Griffith et al., 2003). In regions where it becomes endemic, yield losses may range from 30% to 100%, making it a potentially devastating threat if introduced into new cocoa-producing areas. In Brazil, for example, the disease has significantly reduced cocoa yields, transforming the country from a major exporter to an importer of cocoa (Andrade et al., 2008; Meinhardt et al., 2008; Sousa et al., 2021).

The causal organism of witches' broom disease in cocoa is the hemibiotrophic fungus *Moniliophthora perniciosa* (Andrade et al., 2008; Mondego et al., 2008; Ferreira et al., 2012). Although this pathogen affects various plant parts including vegetative shoots, flowers, flower cushions, and pods, the most characteristic symptom is the hypertrophy and abnormal growth of vegetative meristems, forming 'brooms' (Mondego et al., 2008; Zaparoli et al., 2009). The disease manifests through symptoms such as stem swellings, axillary shoot outgrowth, and necrotic pods (Alves da Silva et al., 2022; Paschoal et al., 2025). The life cycle of M. perniciosa comprises two distinct phases. In the biotrophic phase, the fungus colonizes living tissue, particularly the apoplast of meristematic regions, where it can persist for approximately 60 days (Mondego et al., 2008; de Oliveira et al., 2024). This phase is marked by the formation of monokaryotic hyphae and the induction of hypertrophic growth in the host plant (Zaparoli et al., 2009). Following this, the fungus enters the necrotrophic phase, during which it colonizes and degrades dead tissue. This stage involves the development of dikaryotic mycelia and the formation of basidiocarps, which produce basidiospores responsible for initiating new infections (Mondego et al., 2008; Pires et al., 2009; Zaparoli et al., 2009).

Interestingly, while witches' broom-like symptoms are also observed in *Cola nitida*) trees, they may not be caused by *M. perniciosa*. Recent investigations in Côte d'Ivoire by Eba et al. (2025) identified four fungal genera, *Lasiodiplodia*, *Pestalotiopsis*, *Fusarium*, and *Trichoderma*, on kola trees exhibiting witches' broom symptoms. This suggests that other pathogens may be involved, indicating a potentially different etiology in kola compared to cocoa (Scarpari et al., 2005; Sousa et al., 2021; Carvajal-Rivera et al., 2022).

The discovery of different fungal genera associated with witches' broom symptoms in kola trees highlights the need for further research to understand the etiology of the disease and develop effective management strategies. This distinction from the well-studied witches' broom in cocoa emphasizes the complexity and diversity of plant-pathogen interactions in different species.

The present study, therefore, was conducted to evaluate the health status of kola tree orchards and to gain a better understanding of the epidemiology of witches' broom disease. The objectives included assessing the epidemiological parameters of the disease across different localities, analyzing the correlation between climatic variables and the intensity of these parameters, and investigating the relationship between disease severity and key agromorphological traits of kola trees.

Materials and Methods

Assessment of the phytosanitary status of kola tree plantations

Symptom description

A diagnostic survey was conducted across six localities: Aboisso, Agboville, Bongouanou, Daloa, Duékoué, and Gagnoa. Witches' broom symptoms were described based on the appearance of affected plant organs and the progression stage of the disease. Observations were made on various organs of both juvenile and mature kola trees. In nurseries and plantations, leaves, flower buds, and internodes were carefully examined for characteristic symptoms.

Assessment of disease prevalence

Disease prevalence in the six localities was estimated by recording the number of broom clumps observed on kola trees. For this purpose, five plots were surveyed per locality. In monoculture orchards, a rectangular subplot measuring 30 m × 15 m was demarcated, and 10 kola trees per plot were assessed using a Z-shaped sampling method. In intercropped systems, 10 kola trees were randomly selected.

Disease prevalence was calculated as the percentage of trees showing witches' broom clumps relative to the total number of trees observed, using the formula adapted from Koffi (2015):

$$\mathrm{Pm}(\%) = \frac{Pi}{\mathrm{Pti}} \times 100$$

Where:

P_m = Mean disease prevalence (%)

P_i = Number of diseased trees

P_{ti} = Total number of trees assessed

Assessment of disease severity

Symptom severity was scored according to the scale proposed by Ouattara et al. (2018), using a 0 to 4 rating based on the number and size of witches' broom clumps on the 10 selected kola trees:

0 = No clumps present on branches

1 = <25% of branches with clumps

2 = 26–50% of branches with clumps

3 = 51–75% of branches with clumps

4 = >75% of branches with clumps

These severity scores were then used to compute the Disease Severity Index (DSI) following the method of Rempel and Hall (1996):

$$\mathrm{IS} = \frac{\sum(\mathrm{Xi} \times \mathrm{Ni} \times 100)}{4 \times \mathrm{Nt}}$$

Where:

IS = Disease Severity Index

X_i = Severity score

N_i = Number of trees with score X_i

N_t = Total number of trees evaluated

Correlation between disease severity, plot age, and relative humidity

Two Pearson correlation analyses were performed. The first analysis aimed to evaluate the relationship between plot age and the severity of disease symptoms, with the age of the surveyed plots ranging from 6 to 40 years. The second analysis examined the potential correlation between epidemiological parameters, specifically disease prevalence and severity, and orchard relative humidity. Phytosanitary status and relative humidity were recorded monthly across the different agroecological zones throughout the study period. Relative humidity data for the study sites were obtained from the website https://www.historiquemeteo.net.

Correlation between disease severity and agromorphological parameters

A Pearson correlation analysis was also conducted to examine the relationship between disease severity and kola tree stem girth. Stem girth was measured at 1.30 meters above ground level using a standard measuring tape.

In addition, the mean plumb radius of kola trees was determined using a Trotec BD21 rangefinder and calculated using the formula:

$$\mathrm{Rm} = \frac{(\mathrm{R1} + \mathrm{R2})}{2}$$

Where: R_m = Mean plumb radius

R_1, R_2 = Measured radii from two perpendicular directions

Another Pearson correlation analysis was conducted to determine the potential relationship between witches' broom disease severity and the mean plumb radius of kola trees.

Results

Phytosanitary status of kola tree plantations Observed symptoms

Broom formation was observed on both fresh and dry branches. Deformation was the predominant symptom recorded across all surveyed localities. This was characterized by profuse proliferation of twigs (Figure 1A), blistered or distorted leaves (Figure 1B), and shortened internodes (Figure 1C). Hypertrophic growth of flower buds (Figure 1D) was also noted, likely resulting from hormonal imbalances induced by pathogen activity.

At the seedling stage, broom formation can lead to hypertrophy below the cotyledonary node. Vegetative brooms may arise from buds located at this node, with cotyledons sometimes remaining attached for an extended duration. Affected flowers often exhibit a star-shaped appearance and persistent necrosis of the sepals. These abnormalities significantly reduce fruit set and overall yield due to the detrimental effects of the pathogen during the flowering phase.

Figure 1. Symptoms of witches' broom disease in *Cola nitida*. A: Profuse twig proliferation on an affected tree; B: Blistered leaves; C: Shortened internodes; D: Hypertrophy of flower buds.

Mean disease prevalence

Across the six surveyed localities, disease prevalence ranged from 70.12 ± 4.10% to 81.48 ± 5.31%. Although variations were observed among the localities, these differences were not statistically significant ($p > 0.05$) (Figure 2).

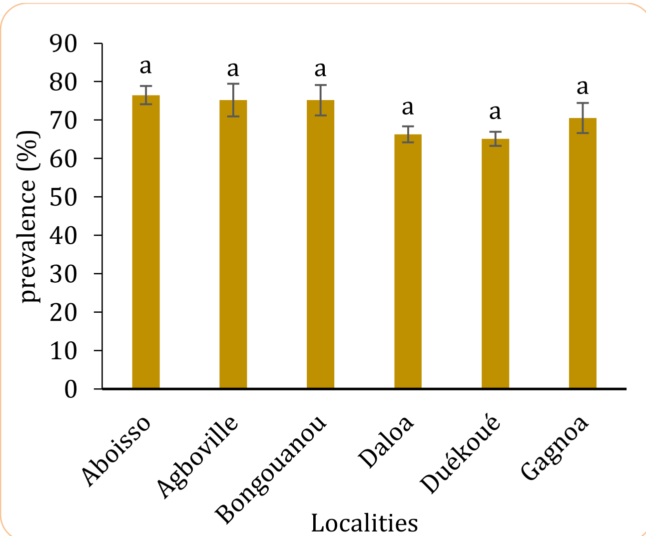

Figure 2. Prevalence of witches' broom disease in different localities.

Disease severity index

The mean disease severity index of witches' broom symptoms across the six surveyed localities ranged from 78.27 ± 11.37% to 80.78 ± 14.30%. Statistical analysis indicated no significant differences ($p > 0.05$) in severity indices among the six localities examined (Figure 3).

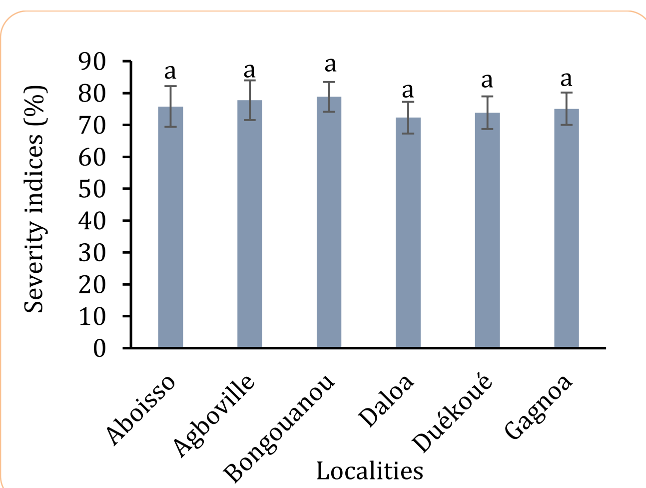

Figure 3. Severity index of witches' broom disease across different localities.

Disease prevalence and severity index in relation to relative humidity

Pearson correlation analysis revealed no significant positive relationship between disease symptom prevalence and orchard relative humidity ($r = 0.044$, $p = 0.893$). The corresponding scatterplot showed widely dispersed data points with no clear trend along the line of best fit (Figure 4), indicating that fluctuations in relative humidity did not influence the number of kola trees exhibiting witches' broom symptoms.

In contrast, a strong and statistically significant positive correlation was found between disease symptom severity and orchard relative humidity ($r = 0.843$, $p < 0.001$). In this case, the data points closely followed the line of best fit (Figure 5), suggesting that increasing relative humidity was associated with higher symptom severity. Notably, a profuse development of broom-like flower buds was observed on kola trees during periods of elevated humidity.

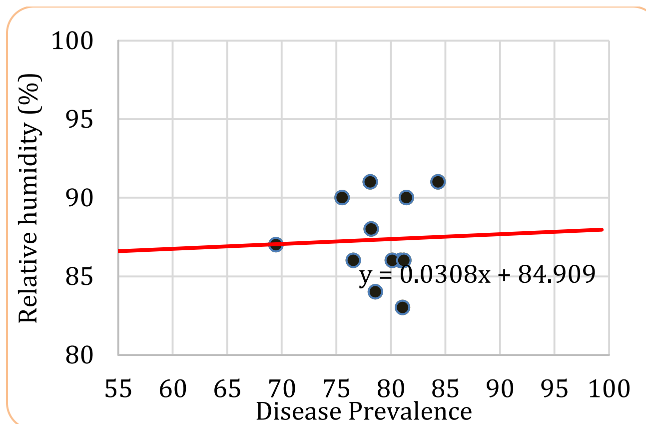

Figure 4. Relationship between relative humidity and disease prevalence.

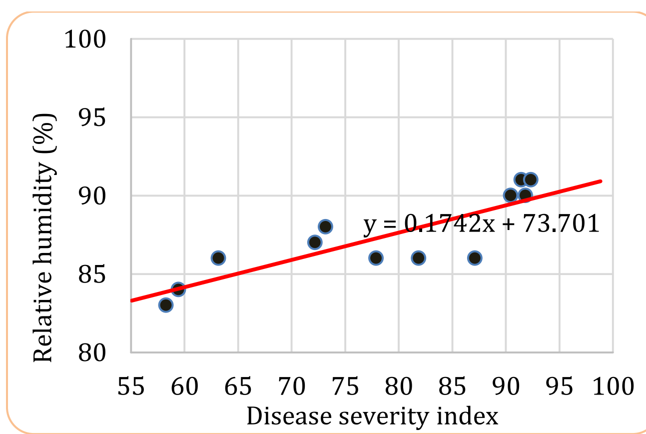

Figure 5. Relationship between disease severity index and relative humidity.

Correlation between disease severity index and plot age

Pearson correlation analysis revealed a weak negative correlation between plot age and disease severity index (r = -0.280), indicating a tendency for disease severity to decrease with increasing plot age. However, this correlation was not statistically significant (p = 0.127 > 0.05), suggesting that disease severity was not significantly associated with plot age and appeared to be independent of it (Figure 6).

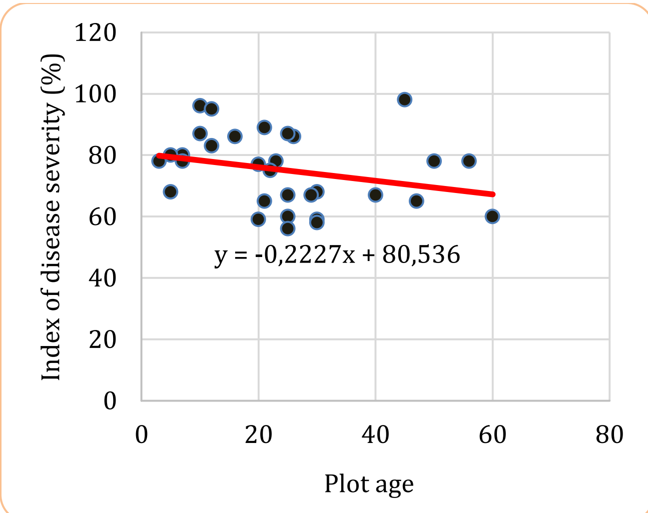

Figure 6. Relationship between plot age and disease severity index.

Correlation between disease severity index and agromorphological parameters of kola trees

No significant correlation was observed between the disease severity index and kola tree girth (r = 0.025; p = 0.66), indicating that disease severity had no measurable impact on trunk girth (Figure 7).

In contrast, a statistically significant negative correlation was found between disease severity index and crown diameter (r = −0.287; p < 0.001). This suggests that kola trees with lower disease severity tended to have larger crowns, whereas increased disease severity was associated with a reduction in crown diameter (Figure 8).

Discussion

Symptoms of organ deformation, such as profuse shoot proliferation and shortened internodes, were observed in kola trees. The presence of witches' broom represents a physiological response of the plant to parasitic attack. The biotic agent interferes with host metabolism by secreting lytic enzymes including chitinases, glucanases, and lipases. These enzymes compromise the integrity of plant tissues and promote pathogen colonization. The findings of this study align with those of Agrios (2005), who reported that fungal pathogens facilitate host invasion through the production of such lytic enzymes. Similarly, Vidhyasekaran (2010) documented morphological alterations in *Oryza sativa*, such as tissue hyperplasia, dwarfism, and witches' broom, induced by pathogenic fungi via enzymatic and toxic secretions.

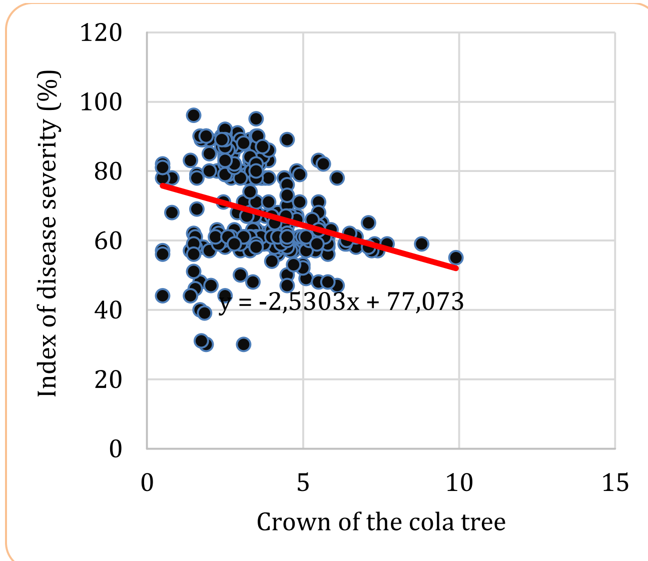

Figure 7. Disease severity index and crown symptoms of infected kola trees.

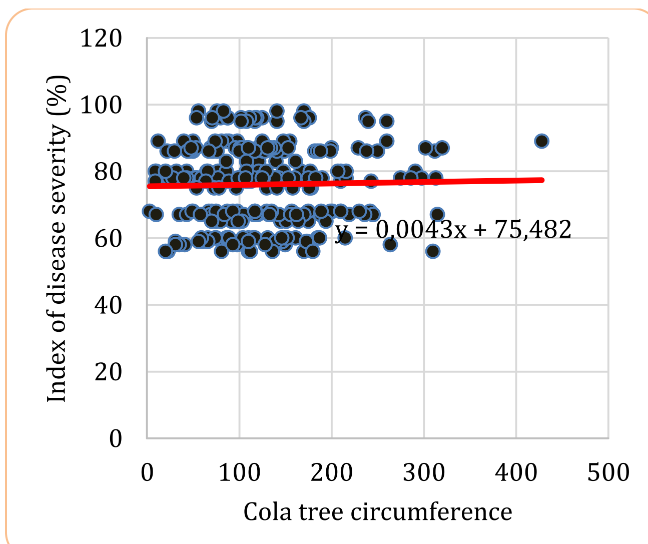

Figure 8. Disease severity index and girth of infected kola trees.

Relative humidity did not influence the prevalence of witches' broom disease across any of the surveyed localities. The consistently high prevalence observed may instead be attributed to conducive climatic and agronomic conditions across these agroecological zones. Statistical analyses revealed no significant differences in disease prevalence among the six localities, suggesting a uniform and widespread distribution of the disease. The mean severity index was high (79.52%) across all sites, further indicating a robust establishment of the pathogen irrespective of site-specific conditions. The virulence of the causal agents appears independent of plot location or agroecological variability, likely due to long-term adaptation of the pathogens to local environments. This observation is consistent with the work of Dumartinet (2021), who demonstrated adaptive evolution of *Pseudocercospora fijiensis*, the causal agent of black Sigatoka in bananas, to resistant cultivars across diverse ecological zones. Likewise, Gbedié et al. (2019) reported the development of improved varieties exhibiting substantial resistance to this disease.

Although relative humidity did not influence the prevalence of witches' broom, it appears to significantly affect symptom severity. This discrepancy may be due to the primary dissemination of the disease via wind and insect vectors, combined with tree spacing that limits horizontal transmission. These findings corroborate those of Bastos and Evans (2015), who reported minimal influence of relative humidity on disease spread. However, relative humidity can enhance disease severity by promoting fungal sporulation and the production of pathogenic structures. High humidity creates a favorable microenvironment for fungal growth and symptom expression. This is in agreement with Magarey et al. (2005), who demonstrated a positive correlation between relative humidity and disease severity in foliar fungal infections of nursery plants under controlled temperature conditions.

No significant correlation was found between disease severity and trunk diameter growth in kola trees. However, increased disease severity was associated with a marked reduction in canopy development. This may be due to the disruption of meristematic tissues by the pathogen, which limits vegetative growth. A weak negative correlation (r = -0.280) was observed between the age of kola plots and the severity index, suggesting that disease severity may decline as plantations mature. This may reflect age-related tolerance or physiological adaptation of older trees. Similar findings were reported by Agrios (2005), who noted that the susceptibility of plants to certain diseases may vary with age.

Conclusion

The present study assessed the phytosanitary status of kola tree orchards in selected agroecological zones. Witches' broom disease was detected in all surveyed areas, with an average prevalence of 75.8% and a mean severity index of 76%. Relative humidity did not significantly affect disease prevalence but was positively associated with symptom severity, likely due to its role in enhancing fungal sporulation. Although disease severity declined with increasing orchard age, the correlation was weak and not statistically significant. Trunk diameter growth showed no association with disease severity, whereas canopy development was significantly reduced under high disease pressure. These findings underscore the need for integrated disease management strategies and the development of resistant kola varieties adapted to local agroecological conditions.

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Authors' Contributions

EM, SK, KKT, and AK conceptualized the study and designed the methodology; EM collected and compiled the data; YWJ and NADC assisted with data collection; EM, KKT, SK, AK, and NAJ analyzed the data and drafted the manuscript; All authors have read and approved the final version of the manuscript.

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Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger

SDG 8: Decent Work and Economic Growth

SDG 12: Responsible Consumption and Production

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