

# Characterization of Swollen Shoot Disease and Evaluation of the Effectiveness of Rehabilitation Technology in Cocoa Farms in Gbazona, Amaragui, and Liliyo (Côte d'Ivoire )

Original research article

## Abstract

*Objectives:* The study carried out on swollen shoot disease in the Nawa region in Côte d'Ivoire aimed to monitor the early progression of this disease in cocoa plantations rehabilitated using three innovative technologies. The goal was to reduce the damage caused by swollen shoot disease in cocoa production systems.

*Methodology and Results:* Quarterly data collection in each plot, using **GPS** and visual observations, were made to determine the prevalence, incidence, and severity of the cocoa swollen shoot disease within the rehabilitated plots. The rehabilitated plots were found in close proximity to plots already affected by the disease, and virus host plants were identified within the rehabilitated cocoa plots. Newly infected cocoa trees were found in the immediate vicinity of the disease foci. The number of newly infected cocoa trees was found to be proportional to the size of the disease focus. The highest prevalence and severity of the disease were recorded in grafted trees on old cocoa farms (GVV), with 1.28 % and 1.55 %, respectively. The highest incidence of 1.26 % was observed among young grafted cocoa trees (RPG).

*Conclusion and Application of Results:* This study revealed the presence of the cocoa swollen shoot disease in the plots through its characteristic symptoms. The progression and severity of the symptoms were found to depend on the technology used. The presence of virus infected plants within and around the plots indicates either a lack of strict adherence to disease control methods or insufficient knowledge about these host plants during the establishment of the plots. These results will enable producers to better manage the disease, starting with the identification of cocoa swollen shoot virus (CSSV) host plants and the precautions to be taken when using maintenance and grafting tools between infected and non-infected cocoa trees. The implementation of early virus detection tools accessible to producers would be an asset in the fight control of the swollen shoot disease in cocoa.

**Keywords:** cocoa disease, rehabilitated plots, epidemiology, incidence, prevalence, severity

## 1. Introduction

The economy of Côte d'Ivoire is primarily based on agriculture. Cocoa cultivation constitutes a key pillar of the national economy, contributing about 15 % to the national Gross Domestic Product and accounting for nearly 30 % of export revenues (CIRAD, 2025). Côte d'Ivoire is the world's leading producer and exporter of cocoa beans. The annual production was estimated at 2,300,000 tons during the 2022/2023 season (BCEAO, 2014; Isaac *et al.*, 2025). Despite its high production levels, cocoa cultivation in Côte d'Ivoire remains constrained by several biotic stresses, notably the occurrence of insect pests as well as fungal, bacterial, and viral diseases. Among the viral pathogens, the Cocoa Swollen Shoot Virus Disease (CSSVD) stands out as the most devastating, affecting cocoa production in Côte d'Ivoire and other West African producing countries since its first report in the 1930s. The characteristic symptoms of swollen shoot disease include red streaks along the veins of young leaves, mosaic patterns on mature leaves, small rounded pods, and swelling of stems (Kouakou *et al.*, 2011). The disease can cause significant yield losses and even the death of cocoa trees within five years after the first symptoms appear (Kébé, 2013). The recommended control method consists of cutting down infected trees and replanting in healthy environments using good agricultural practices (CNRA, 2016). However, the disease continues to spread from mealybugs and from harvesting and pruning activities carried out by the farmers, reaching new production areas and even rehabilitated plots (Aka *et al.*, 2021). Understanding the epidemiological factors driving this spread is therefore crucial. The objective of this study is to characterize the study plots, assess the prevalence, severity, and incidence of swollen shoot disease, and determine its spatio-temporal evolution in rehabilitated cocoa farms.

## 2. Materials and methods

### 2.1. Material

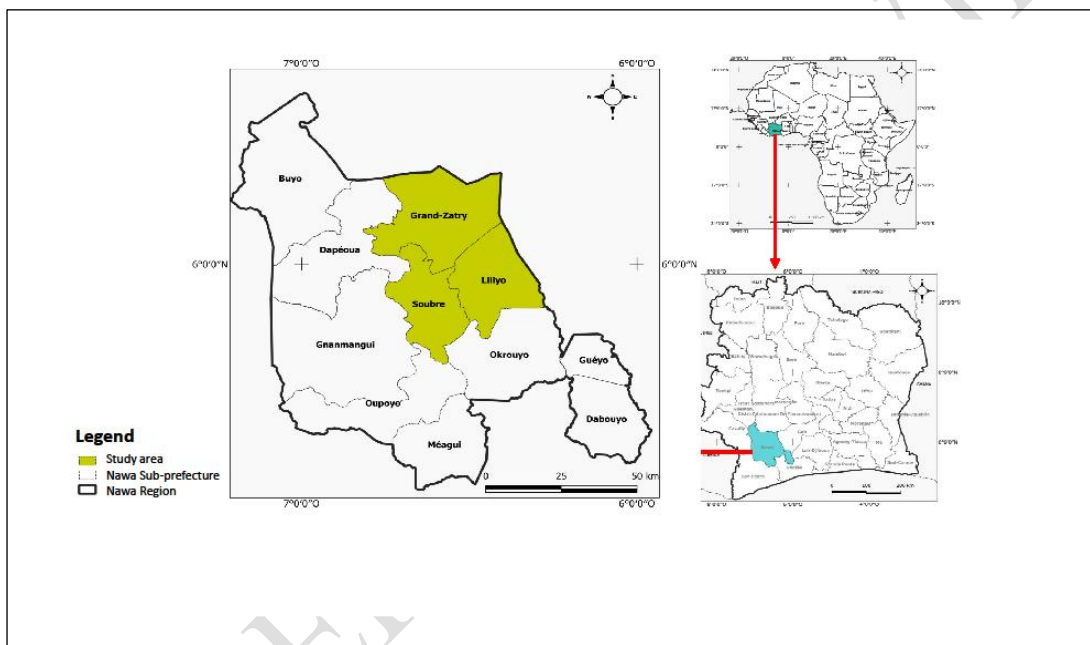
The materials used in this study consisted of plant material and technical equipment. The plant material consisted of cocoa trees of uniform age (six years old), originating from different rehabilitation technologies, namely: Grafting on old plantations (GVV): this technique involved grafting performed on mature cocoa trees in the field using selected cocoa clones (C1, C9, C15, and C16), each representing a distinct genetic variety. Complete replanting with grafted cocoa trees (RPG): this system was established using nursery-grafted cocoa seedlings produced with clones C1, C9, C15, and C16, each of which can be considered a separate cultivar. Replanting with hybrid cocoa seedlings (RPH): this approach involved the use of young hybrid cocoa plants

resulting from the controlled crossing of two pure-line parental varieties. The technical equipment comprised a Garmin **GPS** device for locating the sites and cocoa trees, as well as paint spray cans used for marking trees in the field.

## 2.2.Methods

### 2.2.1. Study area

The study was conducted during year 2022 ~~to may~~ at December in the Nawa region, located in the south-western part of Côte d'Ivoire. Activities were carried out specifically in 3 plots established in the localities of Gbazoa, Amaragui, and Diakitékro, which are situated respectively in the sub-prefectures of Grand-Zatry, Soubré, and Liliyo (Figure 1).



**Figure 1:** Study area

### 2.2.2. Characterization of the Study Plots and Disease Symptoms

Each plot was characterized by determining the type of crops in neighboring plots, and by recording associated crops and shade trees grown alongside cocoa. Diseased cocoa trees were examined from the leaves down to the trunk to describe the characteristic symptoms of swollen shoot disease observed in the field.

### 2.2.3. Assessment of infection level and disease distribution in rehabilitated plots

The infection level of swollen shoot disease in the rehabilitated plots was determined based on

prevalence, incidence, and the severity index. Prevalence was defined as the proportion of diseased trees relative to the total number of trees in the plot:

$$P = \frac{nCi}{NC} \times 100 \quad (1)$$

where : nCi : Number of infected cocoa trees; NC : Total number of cocoa trees in the plot

Incidence represented the proportion of newly infected trees during a given period relative to the total number of trees in the plot:

$$I = \frac{Ci(tx) - Ci(t_0)}{NC} \times 100 \quad (2)$$

Where:  $Ci ( tx )$  : Number of infected cocoa trees at tx ;  $Ci ( t_0 )$  : Number of infected cocoa trees at  $t_0$ ; NC : Total number of cocoa trees in the trial.

Severity assessed the intensity of the disease within the plot. It was evaluated using a symptom severity scale ranging from 0 to 6, as defined by Padi *et al.* (2013) and later modified:

0 = No symptom

1 = Red streaks on young leaves

2 = Reticulated mosaic

3 = Fern-like mosaic

4 = Stem swelling

5 = Die-back

6 = Death of the cocoa tree

The disease severity index ( $I_s$ ) in each experimental plot was calculated according to Kranz (1988):

$$I_s = \frac{\sum(Xi.ni)}{N.Z} \times 100 \quad (3)$$

Where:  $I_s$  : Disease severity index;  $x_i$  : Severity  $i$  of the disease on the tree;  $n_i$  : Number of trees of severity  $i$  ;  $N$  : Total number of trees observed;  $Z$  : Highest note on the scale, i.e. 6.

The geographical coordinates recorded in the field using GPS made it possible to produce distribution maps of swollen shoot disease within the rehabilitated plots.

### 2.2.3. Spatio-temporal distribution of the disease

Diseased cocoa trees were marked with spray paint and located using a Garmin-type GPS device within each plot; this constituted the first trial (Trial 1). A follow-up visit was conducted three months later to mark and locate newly infected cocoa trees, which constituted the second trial (Trial 2). The geographical coordinates collected in the field using the GPS were used to produce maps showing the distribution of the swollen shoot disease within the rehabilitated plots.

### 2.2.4. Data Analysis

The collected data were subjected to analysis of variance (ANOVA 1 factor) using Excel and Statistica 7.1. The geographic coordinates obtained made it possible to produce disease distribution maps using the geographic information system software QGIS 3.28.

## 3. Results

### 3.1.Characterization of study plots

The study plots were located in areas already affected with swollen shoot disease. They bordered infected cocoa farms, and in most cases, there were no sanitary barriers such as buffer plants or safety distances separating them from infected neighboring plots. Within the plots, various associated crops and shade trees were present some of which were potential hosts of the Cocoa Swollen Shoot Virus (CSSV) (Table 1).

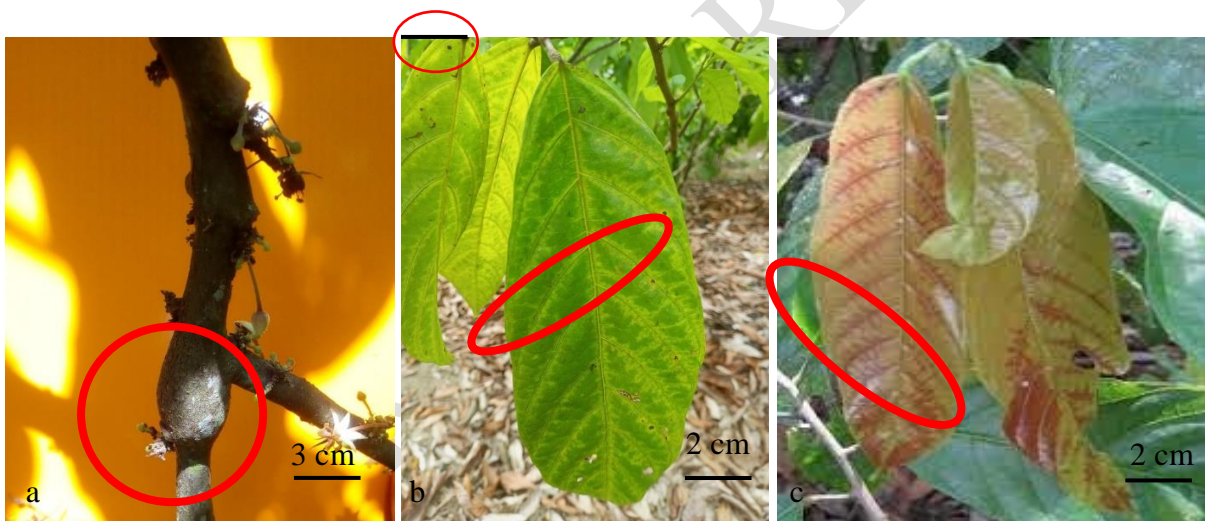
**Table 1:** Characteristics of the study plots

Technologies	Locations	Trees in the plot	Types of Neighboring Plots
GVV	Amaragui 1	<i>Elaeis guineensis</i> , <i>Persea americana</i> , <i>Cola nitida</i> , <i>Citrus sinensis</i>	Infected cocoa plantation

RPG	Grand- Zattry	<i>Terminalia superba</i> <i>Mangifera indica</i>	Infected cocoa plantation, <i>Hevea brasiliensis</i> :
RPH	N' driagui	<i>Tectona grandis</i> , <i>musa Manihot esculenta</i> <i>paradisiaca, Elaeis guineensis</i>	

### 3.2. Characteristic symptoms of swollen shoot disease in different localities

In each observed plot, one dominant symptom of swollen shoot disease was identified. In Amaragui (Soubré) plots, the most common symptoms were reticulated and fern-like mosaics on mature leaves. In Diakit  Camp (Liliyo), red veins on young leaves were predominant. In Grand-Zattry, reticulated mosaics and red veins on young leaves were most frequent, while in N'driagui and Petit Bondoukou, stem swelling was dominant (Figure 3).



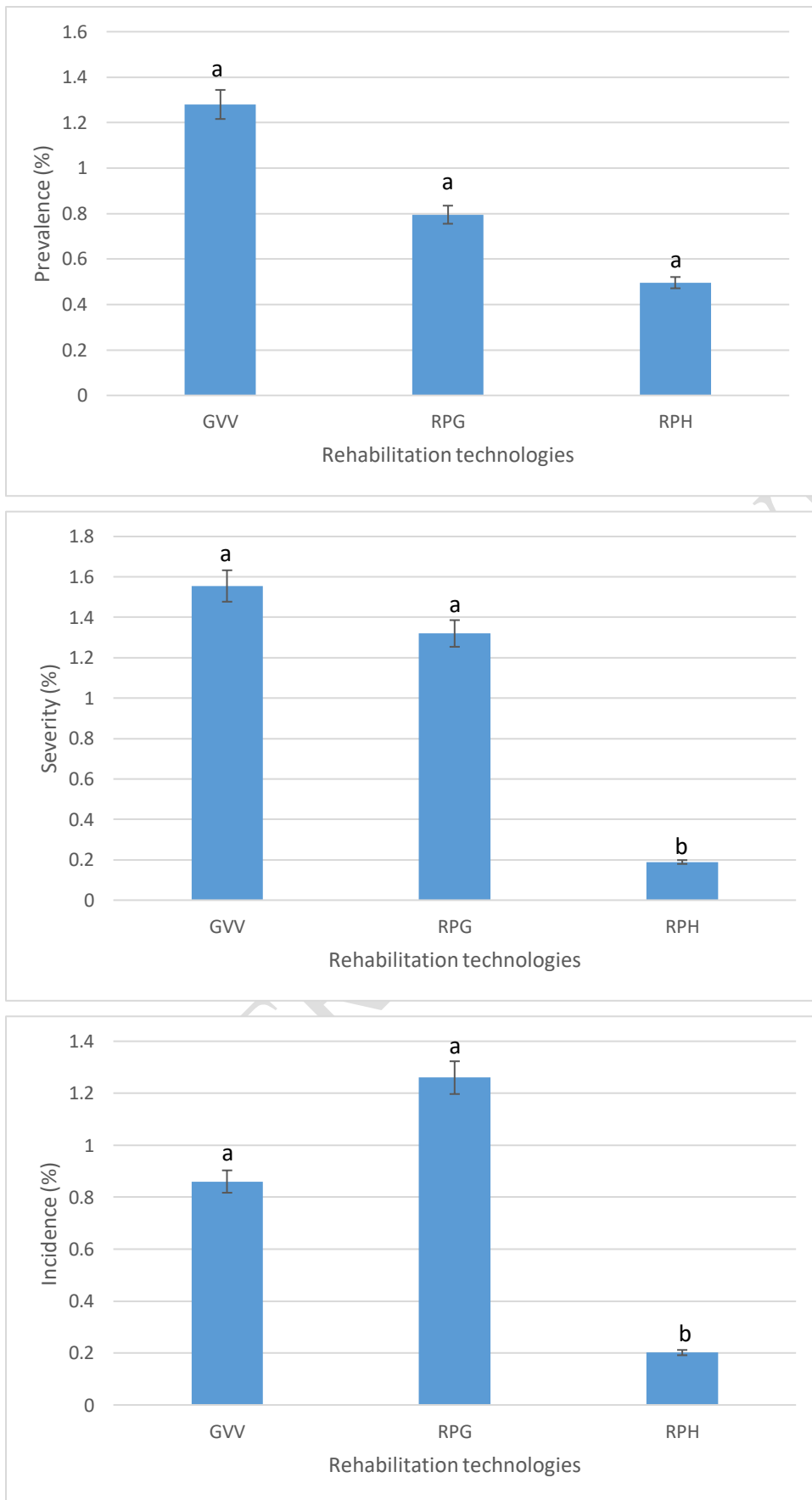
**Figure 2:** Symptoms of swollen shoot in rehabilitated plots A: Stem swelling; B: Fern mosaic; C: Red bands on young leaves

### 3.3. Level of Infection of Swollen Shoot Disease in Rehabilitated Plots

Figure 3 illustrates the prevalence, incidence and severity rate according to the three technologies adopted for replanting. The highest prevalence was recorded in GVV plots (1.28 %) and the lowest in RPH plots (0.50 %). The highest incidence occurred in RPG plots (1.26 %), followed by GVV, while RPH recorded the lowest incidence (0.20 %). ANOVA tests indicated that prevalence was not significantly affected by the technology ( $p > 0.05$ ), whereas incidence differences were significant ( $p < 0.05$ ). Severity ranged from 0.18% to 1.55%,

influenced significantly by the technology ( $p < 0.05$ ). The severity index was highest in GVV and lowest in RPH plots.

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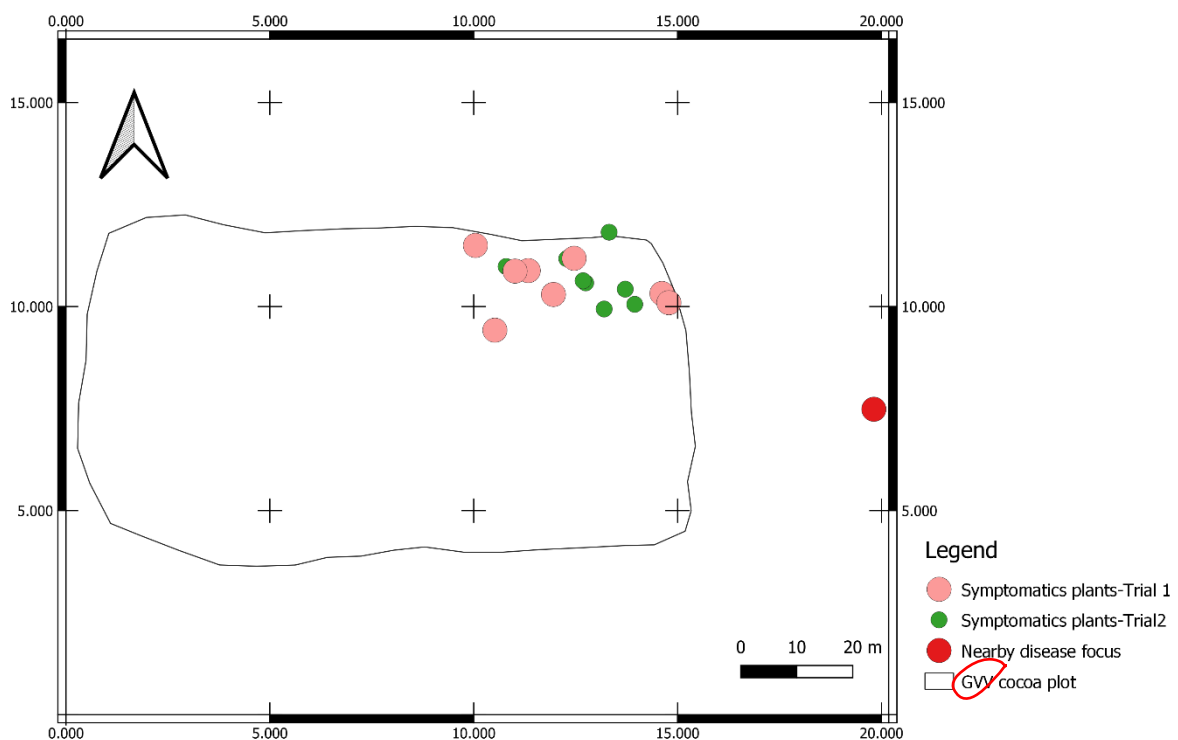


**Figure 2;** Prevalence, incidence and severity of swollen shoot according to technologies

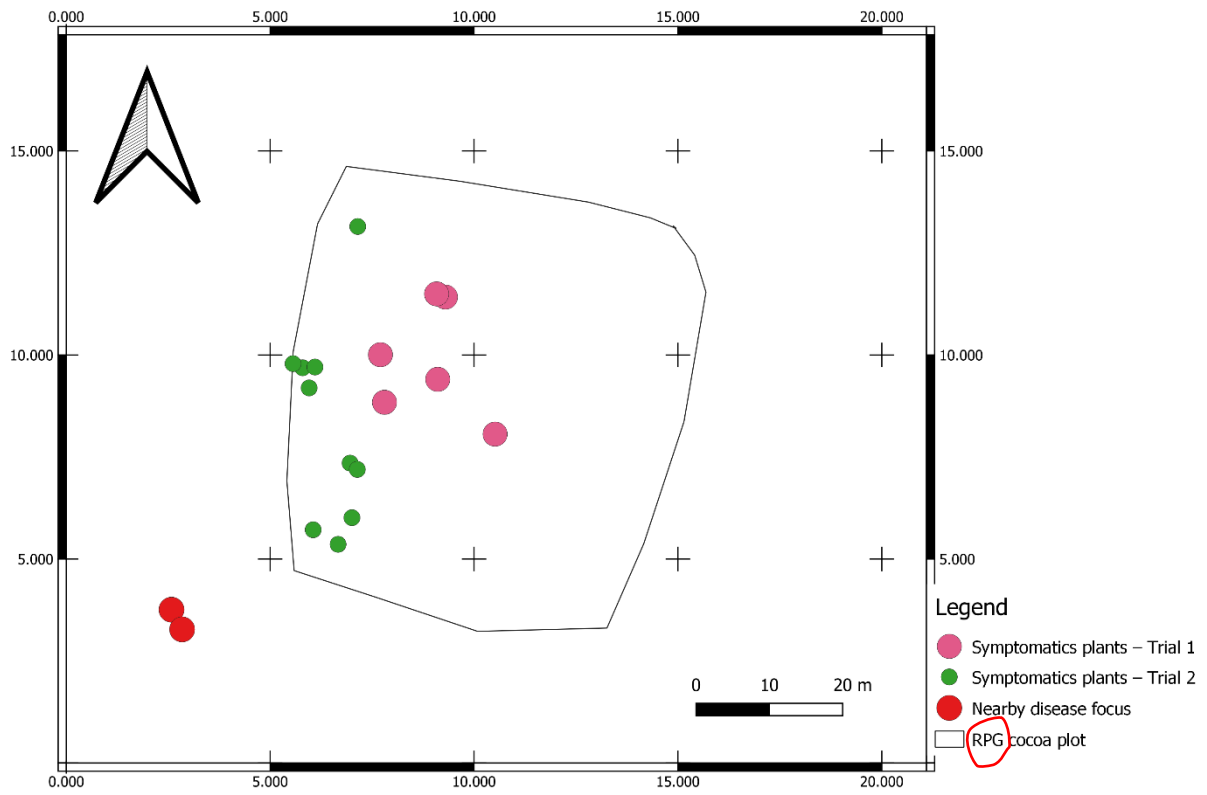
The different letters above the histograms indicate the grouping classes according to the Newman–Keuls test at the 5% significance level. Classes topped with the same letters are not significantly different.

### 3.4. Spatial distribution of swollen shoot disease in rehabilitated Plots

Swollen shoot disease was found to be widespread across all rehabilitated plots, regardless of the technology applied. Field observations indicated that the progression of the disease was closely associated with the number of infected cocoa trees recorded during the initial assessment. Plots with a higher number of infected trees at the **first evaluation** subsequently exhibited a greater number of new infections. Conversely, plots with fewer initial infections showed a lower rate of new cases during the second assessment (Figure 5). Newly infected cocoa trees were predominantly located in the immediate vicinity of previously infected individuals, suggesting a localized spread pattern around primary infection foci (Figures 4-6).

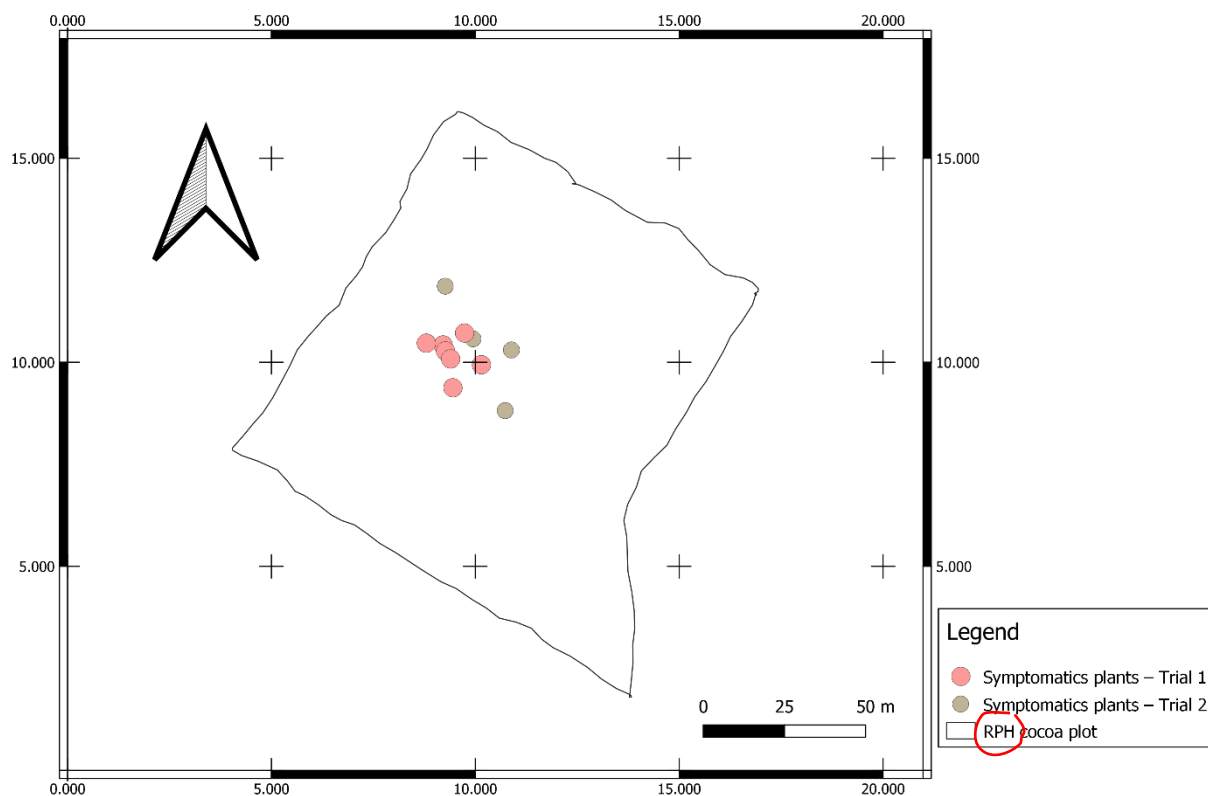


**Figure 4:** Geographic distribution map of swollen shoot in grafting on old cocoa trees plots



**Figure 5:** Geographic distribution map of swollen shoot in replanting with grafted seedlings lots

UNDER REVIEW



**Figure 6:** Geographic distribution map of swollen shoot in replanting with hybrid seedlings plots

#### 4. Discussion

The results of the plots characterization revealed that most of the studied plots were located around infected cocoa farms. They were contiguous, with no barrier plants (*Hevea brasiliensis*, *Coffea Sp.,...*) recommended for the required safety distance. This layout of the rehabilitated plots could explain their reinfection by CSSD. It was strongly recommended to use barrier crops at a distance of 10 to 15 meters around the new plot. This barrier line helps to slow down the spread of mealybugs, which are vectors of the virus. (Kebe *et al.*, 2011). These barrier crops act as traps to keep mealybugs away from cocoa plantations and thus prevent disease outbreak (Kébé *et al.*, 2016).

Furthermore, the presence of various crops and trees associated with cocoa trees was observed in the rehabilitated plots. Among these crops are natural hosts of the CSSV (*Manihot esculenta*, *Cola nitida*, *Citrus sinensis*). The presence of these plants both within and around the fields could therefore serve as new sources of reinfection for the plots. Several crop species and shade trees are known to naturally harbor the swollen shoot virus (Posnette *et al.*, 1950; Kebe *et al.*,

2011). *Cola clamydantha* is believed to be the original source of the CSSV outbreak in West Africa (Todd, 1951). Based on the studies of Aka (2013) on the alternative hosts of CSSV in Côte d'Ivoire, **cassava, orange, kola, and papaya** plants occurring near and within the plots act as potential alternative hosts of the virus. This could therefore partly explain the persistence of the swollen shoot disease in the rehabilitated cocoa plots.

The high levels of prevalence, incidence and severity observed in the RPG and GVV plots compared to the RPH plots can be explained at two levels: first, at the level of grafting, and second, at the level of the resistance of cocoa trees developed through different technologies. Indeed, during field grafting (GVV) and nursery grafting (RPG), some cocoa trees were likely already infected with the CSSV, and the tools used for grafting may have facilitated the transmission of the virus to healthy trees both in the field and in the nursery. Later, after a certain latency period, disease symptoms ~~began to~~ appear on the grafted cocoa trees. These findings confirm existing recommendations for managing the swollen shoot disease, which emphasize avoiding grafting operations in areas ~~already contaminated by the virus~~ and refraining from using the same maintenance tools in infected cocoa plots. Kébé *et al.* (2011) based on previous studies conducted in Tafo, Ghana, suggested that the ~~virus~~ can be transmitted to cocoa trees ~~through~~ grafting, similar to other viral pathogens affecting fruit trees. During the grafting process, virus transmission may occur either from the scion to the rootstock or vice versa, or through contaminated grafting tools if they are not properly sanitized. This situation highlights the importance of early detection with PCR (polymerase chain reaction) of the CSSV before the appearance of visible disease symptoms, in order to prevent the contamination of grafted cocoa trees both in the field and in nurseries.

**Such preventive measures** are essential to avoid the distribution of already infected cocoa plants to ~~producers~~.

Regarding tolerance, some cocoa trees ~~appear to be~~ more tolerant to the ~~disease~~ than others, which could explain the observed differences between the prevalence and incidence rates of hybrids and grafted plants. The tolerance of cocoa trees to the swollen shoot disease has been confirmed by several authors, including Wegbe *et al.* (2012). These researchers initiated a breeding program in Togo aimed at developing CSSV-tolerant hybrids. Various combinations were tested by crossing different ~~clones~~ from the living collection. From these trials, six hybrids emerged as both high-yielding and tolerant to the swollen shoot disease. This varietal selection was based on prevalence and incidence criteria. The parent plants of these hybrids have been used to establish seed gardens, and since 2005, the seeds of these hybrids have been distributed for replanting and for increasing the density of old plantations in areas devastated by swollen

shoot in Togo. Similarly, Padi *et al.* (2013) also demonstrated varying levels of tolerance to CSSV among different cocoa varieties, focusing primarily on the severity of the disease as the main evaluation criterion.

The results of this study revealed that the newly infected cocoa trees were located in the immediate vicinity of those that had been infected during the first observation period. The size of the trees infected during the second assessment was proportional to that of the trees infected during the first. The proximity of these newly infected cocoa trees to the initial infection focus could be explained by the mode of transmission of the swollen shoot disease. According to the study by Oro *et al.* (2012) on the epidemiology of swollen shoot disease in Togo, the virus spreads within plantations either radially or in leaps. This pattern of spread is likely due to the movement of mealybugs the vectors of the CSSV within the plots. The proportional relationship between previously infected cocoa trees and newly infected ones helps to explain the current control strategy against swollen shoot disease, which recommends cutting down both the visibly infected cocoa trees at the center of the infection and their asymptomatic neighbours, depending on the size of the infection focus. The larger the infection focus, the greater the number of asymptomatic trees that must also be removed (CNRA, 2016).

## **Conclusion**

This study revealed the presence of the cocoa swollen shoot disease in the plots through its characteristic symptoms. The progression and severity of the symptoms were found to depend on the technology used. The presence of virus host plants within and around the plots indicates either a lack of strict compliance with disease control methods or insufficient knowledge about these host plants during the establishment of the plots.

A detailed study could be conducted to understand the mechanism of virus transmission through plot maintenance tools and cocoa tree grafting equipment.

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1. chat GTP and google translate: I used them to translate some sentences into English.

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