

# Alternative Strategy to the Chemical Control of *Mycosphaerella fijiensis* Morelet, Causative Agent of Banana Trees Black Sigatoka by the Use of Biopesticides

Tuo Seydou<sup>1,2,\*</sup>, Amari Ler-N'Ogn Dade Georges Elisee<sup>1,2</sup>, Kassi Koffi Fernand Jean-Martial<sup>1,2</sup>, Sanogo Souleymane<sup>1,2</sup>, Yeo Gnenakan<sup>3</sup>, Camara Brahim<sup>1,2</sup>, Ouedraogo Somnognodin Leonard<sup>4</sup>, Kone Daouda<sup>1,2</sup>

<sup>1</sup>Laboratory of Biotechnology, Agriculture and Valorization of Biological Resources, Pedagogical and Research Unit of Plant Physiology and Pathology, Faculty of Biosciences, University Felix HOUPOUET-BOIGNY, Abidjan, Cote d'Ivoire

<sup>2</sup>African Center of Excellence on Climate Change, Biodiversity and Sustainable Agriculture, Abidjan, Cote d'Ivoire

<sup>3</sup>National Center for Agronomic Research, Ferkessedougou Research Station, Ferkessedougou, Cote d'Ivoire

<sup>4</sup>Institute of Environment and Agricultural Research, Bobo Dioulasso, Burkina Faso

## Email address:

tuoseydou4@yahoo.fr (T. Seydou), amariler@yahoo.fr (A. Ler-N'Ogn D. G. E.), fernand2kassi@yahoo.fr (K. K. F. Jean-Martial), sanogosousa@yahoo.fr (S. Souleymane), yeognenakan@gmail.com (Y. Gnenakan), camara\_ib@yahoo.fr (C. Brahim), tinkoglega@gmail.com (O. S. Leonard), daoudakone2013@gmail.com (K. Daouda)

\*Corresponding author

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**Abstract:** The control of black leaf streak disease (BLSD), caused by *Mycosphaerella fijiensis* Morelet, through the abusive use of synthetic fungicides, most often poses environmental pollution problems and harms consumers' health. In order to overcome this situation, this study was initiated with a view to comparing the impact of eight (8) essential-oil based biopesticides and two synthetic fungicides of the Triazole family, on BLSD progression on-farm with the aim of using them in an integrated and sustainable management. To this end, a trial was conducted in Azaguié, in southeastern Côte d'Ivoire, under natural infestation conditions. The trial was set up in May 2014 and repeated in June 2015. The data collected during these two years of study were combined. An assessment of the effectiveness of biopesticides on phytopathological parameters during the vegetative stage of banana trees, namely the youngest leaf affected (YLA), the youngest necrotic leaf (YNL), the number of living leaves (NLL) and the severity index (SI) then at flowering and at harvest (NFLF, NFLH) was carried out. In addition to these aforementioned parameters, disease progression status (DPS) was assessed. The agronomic parameters assessed during the vegetative stage were the number of emerged leaves (NEL), pseudostem height (pH) and pseudostem girth at 10 cm above ground (C10) and at harvest, bunch weight (BW), the number of hands in the bunch (NHB) and the number of fingers in the bunch (NFB). The assessment of banana tree response to the application of biopesticides on-farm as part of black leaf streak disease control showed significant differences. These differences were observed between the parameters characterizing the foliar symptoms of the disease (YLA, YNL and SI) in the control and treated plots. The results of this study are a contribution to reducing the massive use of synthetic fungicides, particularly in industrial dessert banana plantations.

**Keywords:** Banana Trees, Sigatoka, *Mycosphaerella fijiensis*, Biopesticides, Synthetic Fungicides

## 1. Introduction

Plantain (*Musa paradisiaca*), consumed in several forms, is an important food source for millions of people in intertropical regions [1, 2]. Worldwide, and especially in rural areas, plantain ranks between first and fourth in terms of dietary importance [3]. However, plantain is less available on international markets, unlike dessert banana which is the subject of a well-organized world trade [3].

In Côte d'Ivoire, the annual yield of plantain in 2020, which was estimated at more than 1,800,000 tons [4], is subject to numerous fungal constraints [5, 6]. Among these biotic constraints, black leaf streak disease (BLSD) caused by the ascomycete fungus *Mycosphaerella fijiensis* Morelet, appears to be the main leaf pathology of banana trees due to its virulence and its impact on a larger number of cultivars [6-8]. This pathology is found in all banana production areas around the world where it is responsible for an estimated yield loss ranging between 20 and 50% depending on the cultivar and cropping system [9, 10]. The pathogen, *Mycosphaerella fijiensis* is ubiquitous in all dessert banana and plantain production areas of Côte d'Ivoire [6, 7, 11]. It attacks banana tree leaves and causes the deterioration of the photosynthetic surface, thus reducing their ability to carry out photosynthesis. This results in plant growth delay, poor fruit filling and early fruit ripening, thus affecting yields [11, 12]. In order to deal with this disease, several control methods have been proposed (genetic control, agronomic control, biological control and chemical control). But among all these control methods, chemical control is the most used. However, this practice has many disadvantages in terms of environment and consumers' health. The abusive use of chemical

molecules alone or alternately, among other things, has caused the appearance of strains resistant to triazoles [13] and azoxystrobin [14]. In Côte d'Ivoire, benzimidazole-resistant foci have been observed in many production areas [15]. Faced with this problem and the narrow range of active ingredients effective against *M. fijiensis*, it is currently necessary to develop new strategies that respect the environment and human health. It is in this light that this study was initiated in order to compare the impact of eight (8) essential oil-based biopesticides and two synthetic fungicides of the Triazoles family on the evolution of black leaf streak disease on-farm with a view to their use in an integrated and sustainable management of this disease.

## 2. Materials and Methods

### 2.1. Material

#### 2.1.1. Plant Material

The plant material used was made up of bayonet suckers of the local cultivar "Orishele" (AAB), highly susceptible to black Sigatoka [16]. These bayonet suckers were selected and taken from the experimental plots of the research station of the National Center for Agronomic Research (CNRA) in Bimbresso, pilot branch of Azaguie-Abbe.

#### 2.1.2. Biopesticides Used for Biological Control

Eight (08) biopesticides formulated by the Industrial Research Unit (IRU) on biopesticides of the University Félix HOUPHOUËT-BOIGNY of Cocody (Cote d'Ivoire) were used. These biopesticides were formulated from essential oils extracted from aromatic plants of the Ivorian flora (Table 1). The biopesticide NECO 50 EC was used as reference.

Table 1. Biopesticides formulated and tested.

Major active ingredients (V/V)	Name of the formulation
Thymol and Eugenol (100)	NECO® (Reference)
Carvacrol and 1,8-Cineole (100)	NORDINE 50 EC
β-Caryophyllene and Sabinene (100)	DOCUS 50 EC
Citronellal and Citronellol (100)	FERCA 50 EC
1,8-Cineole and Terpineol (100)	TUSEL 50 EC
β-Caryophyllene and Sabinene / Thymol and Eugenol (50 / 50)	RINEVES 50 EC
Thymol and Eugenol / Citronellal and Citronellol (50 / 50)	WACHET 50 EC
β-Caryophyllene and Sabinene / 1,8-Cineole and Terpineol (25 / 75)	SECARI 50 EC

#### 2.1.3. Synthetic Fungicides Used

The two synthetic fungicides used at the approved doses (Tilt 250 EC and Opal 75 EC) were unisite fungicides belonging to the Triazole family whose respective active ingredients are Propiconazole (250 g/l) and Epoxiconazole (75 g/l).

### 2.2. Methods

#### 2.2.1. Experimental Design for BLSD Control Using Biopesticides

A trial was conducted under natural *Mycosphaerella fijiensis* infestation conditions. The trial was set up in Azaguié, a small town in the southeastern Côte d'Ivoire in May 2014 and repeated in June 2015. A pure plot (monovarietal) comprising 3

completely randomized blocks was set up place in this experiment. All the bayonet suckers of banana trees used belong to the local cultivar "Orishele" (AAB) which is highly susceptible to black Sigatoka. In each plot, banana tree suckers were planted in rows spaced 2.5 m apart. In the same row, the spacing was 2.5 m between suckers, that is, an average density of 1600 suckers per hectare. The different treatments (Table 2) within the same block were bordered by 3 rows of the same "Orishele" cultivar. The main factor studied was the product (treatment) with twelve (12) modalities (Control, two synthetic fungicides, one mineral oil and eight biopesticides). The experimental unit was the banana plant. The experimental design adopted was the split-plot with 3 repetitions (Figure 1). Each block included 12 plots to which the treatments were

assigned. The block was represented by the modalities. The trial therefore comprised 12 plots per block.

Each plot had the "Orishele" cultivar represented by twelve (12) plants (12 repetitions of the experimental unit on two rows at a rate of 6 feet per row). In total, the trial included 144 banana plants per block (at a rate of 12 plants for each treatment). In order to compare the effect of biopesticides (T4, T5, T6, T7 and T8), their combination (T9, T10 and T11) with that of synthetic fungicides (T2 and T3) on black leaf streak disease control, four (4) applications were made. The threshold of 2500 units per treatment has been set to trigger an application. The biopesticides were applied at a concentration of 5 ml/l and the synthetic fungicides at the recommended doses. The effect of each of the treatments was compared to a treatment with Banole mineral oil (T1) which served as a solvent for the biopesticides as well as for Propiconazole and Epoxiconazole. The products were applied from the fifth month after planting on the leaves using a backpack sprayer with a capacity of 16 liters, Solo brand with adjustable nozzle, long reach. All of these treatments were compared to a control treatment which had no biopesticide, synthetic fungicide and Banole mineral oil application (T0). Applications were made before 9 a.m., or after 5 p.m., to avoid wind and the risk of leaf scorch. The observations were spread over a crop cycle.

### 2.2.2. Maintenance of Plots and Banana Plants

The experimental plots were plowed manually using hoes and machetes. On each plot, the banana trees were planted on the same day. These plots were each weeded with a hoe 4 to 5 times throughout the study period.

Fertilization management was carried out by using organic fertilizers on all the plots in a homogeneous way. The organic fertilizer used was chicken manure, dry and well decomposed, taken from the farms. It was used at doses of 2 kg per plant at the time of sucker planting. Subsequently, five other applications of 2 kg each were made monthly, until a total of 12 kg per plant at flowering.

### 2.2.3. BLSD Control Trial Data Collection

Observations began in the fourth month after planting the suckers so as to assess the effectiveness of biopesticides in controlling BLSD development. Each plant was observed during vegetative stage over six months, before the first flowerings. At flowering and harvesting other observations were also made.

Concerning BLSD biological control using biopesticides, additional observations were carried out weekly in order to follow the disease progression status (DPS) after application of the products.

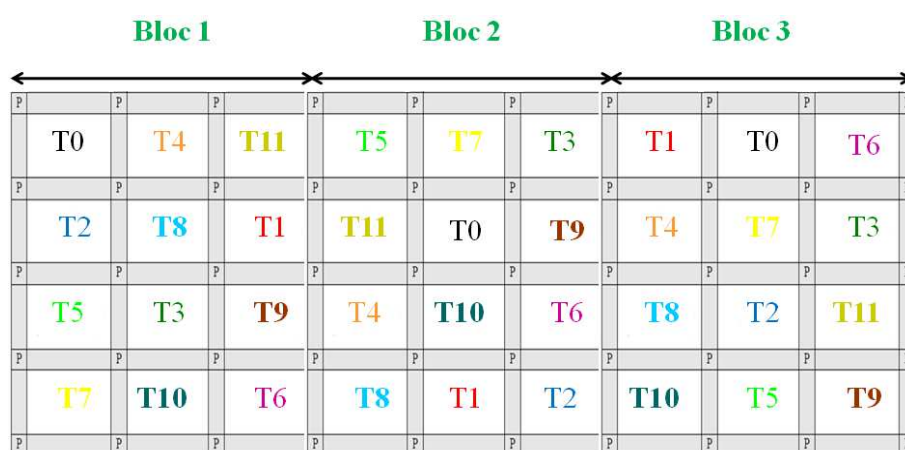


Figure 1. Experimental design for assessing BLSD control products.

P = 3 rows of border plants made up of plants of the "Orishele" cultivar (untreated and used as a source of inoculum); T0 to T11 = Treatment codes for elementary plots (Table 2). Each elementary plot contains 2 rows of 6 plants (that is, 12 plants) of the "Orishele" cultivar.

Table 2. Different treatments carried out for BLSD control.

Products	Treatments	Treatment codes
Control	No treatment	T0
Mineral oil	Banole	T1
Synthetic fungicides	Propiconazole	T2
	Epoxiconazole	T3
	DOCUS 50 EC	T4
	NECO 50 EC	T5
Pure biopesticides	FERCA 50 EC	T6
	TUSEL 50 EC	T7
	NORDINE 50 EC	T8
	WACHET 50 EC	T9
Combined biopesticides	SECARI 50 EC	T10
	RINEVES 50 EC	T11

### (i). Agronomic Observations

#### (a) Plantain tree growth and development parameters

The growth and development parameters of the plants assessed were the number of emerged leaves (NEL), pseudostem height and girth. Pseudostem height (pH) was measured from the collar to the top of the plant, at the level of the V formed by the last two functional leaves. Pseudostem girth was assessed at 10 cm above ground (C10).

#### (b) Agronomic parameters at flowering and harvest

Agronomic descriptors were used during the two production cycles to assess the plants. The intervals expressed in days (d) were calculated: between planting and flowering (PFI) or time elapsed between planting and emergence of the

flower at the top of the pseudostem; then between flowering and harvest (FHI) or time separating the appearance of the flower and the coppicing and between planting and harvest (PCI) or duration of the development cycle. Bunch cutting was performed when the distal end of the fruits turned black, fingers visibly full, without wrinkles and/or at the first finger turning stage.

At harvest, the assessment of the physical characteristics of bunches and fruits focused on the following parameters:

1. the average bunch weight (BW) in kg of each cultivar was determined by weighing each bunch on a scale (Compact Baxtran DSN30 precision  $\pm 1$  g) and the yield per hectare was calculated from the average bunch weight multiplied by plant density;
2. the number of hands (NHB) and fingers (NFB) per bunch were counted.

### (ii). Phytopathological Observations

- (a) Phytopathological parameters during the vegetative stage

The phytopathological parameters assessed for black Sigatoka were: the youngest leaf affected (YLA), the youngest leaf necrotic (YNL), the number of living leaves (NLL) and the disease severity index (SI).

In addition to these above-mentioned parameters, disease progression status (DPS) parameters were also assessed.

Disease progression status (DPS): It provides information on the disease progression speed in relation to the climatic conditions and the intensity of the infection and thus determines the decision-making for treatment. It was determined using the calculation method of Ganry *et al.* [17] adapted to black Sigatoka by Fouré [18].

- (b) Phytopathological observations at flowering and harvest

Phytopathological descriptors were used to assess the plants of each cultivar, during the two production cycles, and to

select the performing prototypes and the effective products. At flowering and at harvest, the pathological descriptors of black leaf streak disease were the following: the number of functional leaves (NFL) and the ratio (NFLH/NFLF) between the number of leaves at flowering and at harvest [19, 20].

### 2.3. Data Analysis

The statistical analyses of the data obtained were carried out with the software STATISTICA version 7.1. Analyses of variance were carried out to assess the agronomic parameters of banana trees and phytopathological parameters of BLSD.

In the event of significant differences, the Newman-Keuls test made it possible to classify the average values at the  $\alpha$  risk of 5% and to compare them.

## 3. Results

### 3.1. Influence of Biopesticides on the Agronomic and Phytopathological Characteristics of Banana Trees

#### 3.1.1. Effect on Plant Growth and Development Parameters

##### (i). Effect on Plantain Plant Height

The average height of banana plants varied between 190.18 and 250.80 cm (Table 3). Overall, plants treated with NORDINE 50 EC had significantly greater pseudostem height than plants treated with other treatments. This was especially observed in the seventh, eighth and ninth month after planting. All plants were less than 3m tall from planting to flowering. Indeed, in the ninth month which marked the end of our observations, the average height of the pseudostems varied from 231.35 to 280.21 cm. Analysis of variance indicated that the treatments had a significant effect on the expression of pseudostem height over time (Table 3). Statistical differences were observed between the treatments at the seventh, eighth and ninth month after planting the suckers.

**Table 3.** Effect of biopesticides on plant height (pH) and pseudostem girth diameter (C10).

Treatments	Pseudostem height (cm)			Pseudostem girth (cm)		
	Period after planting					
	7 months	8 months	9 months	7 months	8 months	9 months
No treatment	188.30 $\pm$ 8.72 b	227.63 $\pm$ 7.55 ab	266.27 $\pm$ 8.44 a	37.90 $\pm$ 0.55 a	47.64 $\pm$ 1.99 a	68.87 $\pm$ 2.08 a
Banole	198.90 $\pm$ 8.24 b	225.93 $\pm$ 7.67 ab	245.60 $\pm$ 6.94 b	37.83 $\pm$ 0.47 a	46.76 $\pm$ 1.71 a	62.67 $\pm$ 1.92 ab
Propiconazole	191.57 $\pm$ 10.35 b	225.67 $\pm$ 10.37 ab	242.00 $\pm$ 11.14 b	36.67 $\pm$ 0.74 a	46.41 $\pm$ 2.43 a	68.63 $\pm$ 2.21 a
Epoxiconazole	175.38 $\pm$ 10.70 b	212.48 $\pm$ 11.25 ab	247.27 $\pm$ 7.18 b	37.63 $\pm$ 0.67 a	44.17 $\pm$ 2.48 a	65.71 $\pm$ 1.90 b
DOCUS 50 EC	181.47 $\pm$ 9.28 b	221.53 $\pm$ 8.91 ab	255.33 $\pm$ 8.39 ab	37.33 $\pm$ 0.65 a	46.56 $\pm$ 2.00 a	60.23 $\pm$ 1.74 ab
NECO 50 EC	186.37 $\pm$ 9.24 b	217.67 $\pm$ 9.33 ab	243.53 $\pm$ 12.46 b	37.77 $\pm$ 0.60 a	45.02 $\pm$ 2.16 a	69.76 $\pm$ 2.79 a
FERCA 50 EC	204.20 $\pm$ 8.97 b	239.53 $\pm$ 8.80 ab	260.60 $\pm$ 9.62 a	38.60 $\pm$ 0.51 a	49.74 $\pm$ 1.84 a	64.12 $\pm$ 1.85 b
TUSEL 50 EC	188.48 $\pm$ 8.92 b	224.50 $\pm$ 9.14 ab	248.67 $\pm$ 15.59 b	36.83 $\pm$ 0.53 a	45.99 $\pm$ 1.94 a	62.10 $\pm$ 2.98 ab
NORDINE 50 EC	232.67 $\pm$ 7.82 a	256.93 $\pm$ 10.96 a	280.21 $\pm$ 12.17 a	39.73 $\pm$ 0.57 a	51.37 $\pm$ 2.50 a	68.43 $\pm$ 1.85 a
WACHET 50 EC	196.10 $\pm$ 10.13 b	233.60 $\pm$ 9.69 ab	254.47 $\pm$ 12.51 ab	37.50 $\pm$ 0.69 a	48.48 $\pm$ 2.11 a	62.89 $\pm$ 2.61 ab
SECARI 50 EC	177.40 $\pm$ 8.03 b	208.80 $\pm$ 8.19 b	234.07 $\pm$ 11.37 b	36.33 $\pm$ 0.60 a	43.07 $\pm$ 1.90 a	69.74 $\pm$ 2.74 a
RINEVES 50 EC	182.60 $\pm$ 10.20 b	218.77 $\pm$ 9.25 b	231.53 $\pm$ 10.24 b	37.63 $\pm$ 0.67 a	45.82 $\pm$ 1.87 a	69.65 $\pm$ 2.74 a
Overall average	190.18 $\pm$ 2.77	224.75 $\pm$ 2.71	250.80 $\pm$ 3.60	37.55 $\pm$ 0.11	46.55 $\pm$ 0.60	61.90 $\pm$ 0.88
CV (%)	32.07	27.20	21.15	12.17	24.03	18.21
P	0.0442	0.0147	0.0381	0.1747	0.4080	0.0272

NB: In the same column, the values followed by the same letter are not significantly different at threshold  $\alpha = 5\%$  according to the Newman-Keuls test.

**(ii). Effect on Plant Pseudostem Girth Diameter**

The results relating to plant pseudostem girth diameter are recorded in Table 3. The analysis of this table highlights an effect of the treatments on plant pseudostem girth diameter. The overall average of this diameter varied between 37.55 and 61.90 cm from the seventh to the ninth month. The analysis of variance shows that there is no significant difference between the treatments during the 7th and 8th month after planting ( $p > 0.05$ ). However, at the ninth month after planting, significant differences ( $p = 0.0272$ ) were observed between the treatments. At this level, the pseudostem girth diameter of the plants varied between 60.23 and 69.76 cm for an overall average of 61.90 cm.

**(iii). Effect on Number of Emerged Leaves**

The number of emerged leaves in the plant between planting and flowering is recorded in Table 4. During the growth and development of the plants, this parameter varied from 11 to 39 emerged leaves for all the treatments during all the observation period.

The average was around 12.46 leaves in the fourth month (start of observations) and 36.50 leaves in the ninth month (end of observations). Significant differences were noted between the treatments except at the fifth and sixth months after planting.

**Table 4.** Effect of biopesticides on the number of emerged leaves in plants (NEL).

Treatments	Number of emerged leaves (NEL)					
	Period after planting					
	4 months	5 months	6 months	7 months	8 months	9 mois
No treatment	13.00 ± 0.36 ab	17.27 ± 0.44 a	20.33 ± 0.46 a	27.90 ± 0.55 ab	32.63 ± 0.43 ab	38.26 ± 0.67 a
Banole	12.27 ± 0.37 b	16.87 ± 0.46 a	19.90 ± 0.31 a	27.83 ± 0.47 ab	32.53 ± 0.49 ab	37.00 ± 0.37 a
Propiconazole	12.47 ± 0.45 b	15.93 ± 0.69 a	18.87 ± 0.42 a	26.67 ± 0.74 b	30.87 ± 0.76 b	34.33 ± 0.74 b
Epoxiconazole	12.40 ± 0.45 b	16.70 ± 0.54 a	19.80 ± 0.36 a	27.63 ± 0.67 ab	31.87 ± 0.56 b	36.80 ± 0.62 ab
DOCUS 50 EC	12.43 ± 0.48 b	16.73 ± 0.60 a	19.43 ± 0.42 a	27.33 ± 0.65 ab	31.73 ± 0.57 b	35.80 ± 0.63 ab
NECO 50 EC	12.33 ± 0.40 b	16.83 ± 0.58 a	19.87 ± 0.39 a	27.77 ± 0.60 ab	31.80 ± 0.61 b	36.06 ± 0.90 ab
FERCA 50 EC	13.13 ± 0.37 ab	17.70 ± 0.50 a	20.47 ± 0.42 a	28.60 ± 0.51 ab	33.23 ± 0.59 ab	37.93 ± 0.64 a
TUSEL 50 EC	11.90 ± 0.46 b	15.97 ± 0.61 a	19.07 ± 0.46 a	26.83 ± 0.53 b	30.73 ± 0.42 b	35.60 ± 0.42 ab
NORDINE 50 EC	14.40 ± 0.39 a	17.30 ± 0.47 a	19.33 ± 0.47 a	29.73 ± 0.58 a	34.27 ± 0.42 a	38.94 ± 0.75 a
WACHET 50 EC	12.13 ± 0.52 b	16.45 ± 0.67 a	19.59 ± 0.32 a	27.50 ± 0.69 ab	31.13 ± 0.64 b	35.26 ± 0.61 ab
SECARI 50 EC	11.70 ± 0.34 b	16.17 ± 0.54 a	18.97 ± 0.41 a	26.33 ± 0.59 b	31.20 ± 0.55 b	35.93 ± 0.75 ab
RINEVES 50 EC	12.30 ± 0.46 b	16.73 ± 0.61 a	19.77 ± 0.44 a	27.63 ± 0.67 ab	31.90 ± 0.64 b	36.06 ± 0.84 ab
Overall average	12.46 ± 0.13	16.72 ± 0.17	19.63 ± 0.11	27.55 ± 0.18	31.89 ± 0.17	36.50 ± 0.23
CV (%)	18.81	18.65	11.31	12.17	9.99	8.79
P	0.0392	0.0573	0.1043	0.0457	0.0040	0.0022

NB: In the same column, the values followed by the same letter are not significantly different at threshold  $\alpha = 5\%$  according to the Newman-Keuls test.

**3.1.2. Effect on Phytopathological Parameters of Plants**

The results relating to the effect of the different treatments on the pathological parameters, namely the youngest leaf affected (YLA), the youngest necrotic leaf (YNL), the

number of living leaves (NLL), the severity index (SI) of the disease, are noted respectively from Table 5 to Table 7 and the disease progression status (DPS).

**Table 5.** Effect of biopesticides on the rank of the youngest leaf affected (YLA).

Treatments	Rank of the youngest leaf affected (YLA)					
	Period after planting					
	4 months	5 months	6 months	7 months	8 months	9 months
No treatment	2.43 ± 0.17 b	2.30 ± 0.10 a	2.73 ± 0.11 b	2.00 ± 0.17 c	1.83 ± 0.17 c	2.00 ± 0.14 b
Banole	2.50 ± 0.14 b	2.43 ± 0.12 a	3.20 ± 0.12 a	2.40 ± 0.15 b	2.13 ± 0.12 b	3.07 ± 0.18 a
Propiconazole	2.20 ± 0.19 b	2.47 ± 0.12 a	3.30 ± 0.15 a	2.93 ± 0.12 ab	2.80 ± 0.10 a	3.40 ± 0.19 a
Epoxiconazole	2.43 ± 0.18 b	2.50 ± 0.10 a	3.10 ± 0.12 a	2.47 ± 0.15 ab	2.43 ± 0.10 ab	3.00 ± 0.24 a
DOCUS 50 EC	2.40 ± 0.18 b	2.43 ± 0.10 a	2.87 ± 0.14 b	2.77 ± 0.08 ab	2.90 ± 0.09 a	2.93 ± 0.18 a
NECO 50 EC	2.33 ± 0.17 b	2.70 ± 0.12 a	3.17 ± 0.10 a	2.97 ± 0.09 a	2.63 ± 0.11 a	3.40 ± 0.21 a
FERCA 50 EC	2.67 ± 0.17 b	2.73 ± 0.13 a	3.23 ± 0.09 a	2.90 ± 0.09 ab	2.80 ± 0.07 a	3.53 ± 0.13 a
TUSEL 50 EC	2.17 ± 0.17 b	2.60 ± 0.12 a	3.07 ± 0.13 a	2.80 ± 0.11 ab	2.50 ± 0.09 ab	2.73 ± 0.15 a
NORDINE 50 EC	3.20 ± 0.20 a	2.80 ± 0.17 a	2.80 ± 0.17 b	2.00 ± 0.10 c	2.80 ± 0.11 a	3.27 ± 0.23 a
WACHET 50 EC	2.33 ± 0.19 b	2.62 ± 0.14 a	3.14 ± 0.12 a	2.97 ± 0.10 a	2.47 ± 0.11 ab	2.73 ± 0.21 a
SECARI 50 EC	2.30 ± 0.17 b	2.57 ± 0.09 a	3.17 ± 0.12 a	2.77 ± 0.11 ab	2.73 ± 0.10 a	2.80 ± 0.28 a
RINEVES 50 EC	2.30 ± 0.16 b	2.47 ± 0.11 a	3.20 ± 0.13 a	2.70 ± 0.14 ab	2.83 ± 0.10 a	3.27 ± 0.18 a
Overall average	2.41 ± 0.05	2.57 ± 0.03	3.09 ± 0.04	2.67 ± 0.04	2.56 ± 0.04	3.01 ± 0.05
CV (%)	39.66	25.75	21.74	27.03	25.68	28.14
P	0.0451	0.5124	0.0270	< 0.0001	< 0.0001	< 0.0001

NB: In the same column, the values followed by the same letter are not significantly different at threshold  $\alpha = 5\%$  according to the Newman-Keuls test.

**Table 6.** Effect of biopesticides on the rank of the youngest necrotic leaf (YNL).

Treatments	Rank of the youngest necrotic leaf (YNL)					
	Period after planting					
	4 months	5 months	6 months	7 months	8 months	9 months
No treatment	4.67 ± 0.21 bc	5.33 ± 0.17 a	5.40 ± 0.16 b	3.03 ± 0.30 e	3.10 ± 0.30 c	4.67 ± 0.13 ab
Banole	4.47 ± 0.18 bc	5.07 ± 0.12 a	5.17 ± 0.12 b	4.83 ± 0.43 d	3.27 ± 0.20 c	4.87 ± 0.22 ab
Propiconazole	4.43 ± 0.33 bc	4.87 ± 0.25 a	6.63 ± 0.32 a	6.90 ± 0.28 a	4.37 ± 0.15 ab	5.13 ± 0.27 ab
Epoxiconazole	4.53 ± 0.25 bc	5.07 ± 0.16 a	5.33 ± 0.15 b	5.20 ± 0.13 cd	4.03 ± 0.12 b	4.80 ± 0.20 ab
DOCUS 50 EC	4.17 ± 0.20 c	5.03 ± 0.13 a	5.17 ± 0.12 b	5.80 ± 0.19 bc	4.50 ± 0.09 ab	4.73 ± 0.15 ab
NECO 50 EC	4.47 ± 0.28 bc	5.20 ± 0.18 a	5.47 ± 0.15 b	6.13 ± 0.15 c	4.33 ± 0.15 ab	4.80 ± 0.22 ab
FERCA 50 EC	4.97 ± 0.17 b	5.50 ± 0.17 a	5.63 ± 0.13 b	6.10 ± 0.18 c	4.53 ± 0.12 ab	5.00 ± 0.22 ab
TUSEL 50 EC	3.77 ± 0.22 d	4.97 ± 0.23 a	5.37 ± 0.18 b	5.90 ± 0.22 bc	4.00 ± 0.12 b	4.27 ± 0.18 b
NORDINE 50 EC	5.40 ± 0.31 a	5.53 ± 0.34 a	5.56 ± 0.34 b	5.67 ± 0.13 bc	4.80 ± 0.14 a	5.02 ± 0.23 ab
WACHET 50 EC	4.23 ± 0.23 c	5.28 ± 0.23 a	5.66 ± 0.17 b	5.90 ± 0.17 bc	4.07 ± 0.13 b	4.40 ± 0.24 ab
SECARI 50 EC	4.20 ± 0.18 c	5.07 ± 0.14 a	5.20 ± 0.14 b	5.73 ± 0.18 bc	4.23 ± 0.11 ab	5.33 ± 0.23 a
RINEVES 50 EC	4.47 ± 0.18 bc	5.30 ± 0.17 a	5.53 ± 0.11 b	6.40 ± 0.19 b	4.50 ± 0.12 ab	4.93 ± 0.21 ab
Overall average	4.44 ± 0.07	5.17 ± 0.05	5.31 ± 0.05	5.63 ± 0.08	4.12 ± 0.05	4.83 ± 0.07
CV (%)	28.55	19.38	18.24	27.71	23.48	17.71
P	0.0042	0.3363	< 0.0001	< 0.0001	< 0.0001	0.0344

NB: In the same column, the values followed by the same letter are not significantly different at threshold  $\alpha = 5\%$  according to the Newman-Keuls test.

**Table 7.** Effect of biopesticides on the number of living leaves (NLL).

Treatments	Number of living leaves (NLL)					
	Period after planting					
	4 months	5 months	6 months	7 months	8 months	9 months
No treatment	6.63 ± 0.25 ab	7.67 ± 0.26 ab	7.60 ± 0.22 a	6.70 ± 0.33 e	5.57 ± 0.18 c	6.27 ± 0.27 c
Banole	6.20 ± 0.25 ab	7.60 ± 0.22 ab	7.43 ± 0.22 a	7.77 ± 0.28 de	8.90 ± 0.36 b	8.68 ± 0.33 b
Propiconazole	5.83 ± 0.44 ab	6.53 ± 0.34 b	8.40 ± 0.34 a	10.70 ± 0.23 a	11.07 ± 0.34 a	11.30 ± 0.35 a
Epoxiconazole	6.17 ± 0.31 ab	7.23 ± 0.26 ab	7.23 ± 0.28 a	8.70 ± 0.46 d	10.60 ± 0.25 a	11.13 ± 0.24 a
DOCUS 50 EC	6.17 ± 0.31 ab	7.20 ± 0.26 ab	7.37 ± 0.25 a	9.33 ± 0.25 c	10.83 ± 0.16 a	11.07 ± 0.18 a
NECO 50 EC	5.93 ± 0.38 ab	7.43 ± 0.27 ab	7.73 ± 0.22 a	10.03 ± 0.25 ab	10.57 ± 0.23 a	10.47 ± 0.39 a
FERCA 50 EC	6.57 ± 0.29 ab	8.17 ± 0.27 a	7.90 ± 0.26 a	10.00 ± 0.22 ab	10.77 ± 0.15 a	11.13 ± 0.22 a
TUSEL 50 EC	5.50 ± 0.32 b	7.07 ± 0.37 ab	7.63 ± 0.31 a	9.57 ± 0.16 b	10.10 ± 0.23 a	10.47 ± 0.36 a
NORDINE 50 EC	7.27 ± 0.42 a	7.80 ± 0.44 ab	7.80 ± 0.45 a	10.40 ± 0.25 ab	10.40 ± 0.21 a	11.27 ± 0.23 a
WACHET 50 EC	6.27 ± 0.34 ab	7.48 ± 0.37 ab	7.83 ± 0.29 a	9.97 ± 0.21 ab	10.17 ± 0.19 a	10.73 ± 0.27 a
SECARI 50 EC	5.76 ± 0.27 ab	6.97 ± 0.26 ab	7.13 ± 0.22 a	9.43 ± 0.18 c	10.43 ± 0.25 a	11.33 ± 0.29 a
RINEVES 50 EC	6.20 ± 0.33 ab	7.70 ± 0.31 ab	7.70 ± 0.24 a	9.67 ± 0.26 b	10.87 ± 0.28 a	10.93 ± 0.30 a
Overall average	6.16 ± 0.10	7.39 ± 0.09	7.64 ± 0.08	9.31 ± 0.10	10.01 ± 0.11	10.40 ± 0.15
CV (%)	28.87	22.09	19.11	19.22	19.74	16.77
P	0.0133	0.0191	0.0902	< 0.0001	< 0.0001	< 0.0001

NB: In the same column, the values followed by the same letter are not significantly different at threshold  $\alpha = 5\%$  according to the Newman-Keuls test.

### (i). Rank of the Youngest Leaf Affected (YLA)

The rank of the youngest leaf affected (YLA) varied between 1 and 4 leaves during the vegetative stage of the plants (Table 5). The first symptoms of the disease were observed on average on the leaves of this rank interval during the entire observation period. The rank of the youngest leaf affected was generally lowest in control plants with no treatment. The application of biopesticides and synthetic fungicides on the plants favored a rank of youngest leaf affected significantly higher than that of the control plants. (Table 5). There were statistically significant differences between treatments from the sixth to the ninth month ( $p < 0.0001$ ).

### (ii). Rank of the Youngest Necrotic Leaf (YNL)

As regards the rank of the youngest necrotic leaf (YNL), the results are recorded in Table 6. The first necroses were observed on average on the leaves of the rank ranging from 3 to 7 during all the observations. However, the overall averages for this rank varied between 4.12 and 5.63 from one

month to another. The averages of the treated plants were significantly higher than those of the untreated plants (Table 6). Thus, the rank of the YNL was lower in the control plants. Analysis of this table shows significant statistical differences between the treatments during the different observations except at the fifth month after planting.

### (iii). Number of Living Leaves (NLL)

The incidence of black leaf streak disease on the number of living leaves (NLL) is presented in Table 7. The number of living leaves on the plants at the time of the observations varied from 6.16 to 10.40 and showed very significant differences depending on the treatments. Treated plants stand out with a higher average than untreated plants (Table 7).

### (iv). Disease Severity Index (SI)

From the fourth month after planting banana tree suckers until the ninth month, the calculation of black leaf streak disease severity index made it possible to observe different infection rates of the banana trees. The untreated plants

(controls) had average indices greater than or equal to 30% from the sixth to the ninth month after planting and therefore showed the highest average values of leaf area affected. Banana trees treated with biopesticides and synthetic fungicides had severity indices that were always lower than those observed in untreated banana trees, with a particularly marked difference from the sixth to the ninth month. The average black leaf streak disease severity index in treated banana plants varied between 12% and 25% (Figure 2). This figure shows that the value of this index was significantly different from one month to another and from one treatment to another. The application of the different products significantly reduced disease severity index. The analysis of variance therefore showed a highly significant effect of the products on the severity index (Figure 2). The comparison of the averages did not show a significant difference between the effect of the biopesticides and that of the synthetic fungicides tested.

#### (v). Disease Progression Status (DPS)

Disease progression status (DPS) of black leaf streaks of

the banana trees of the cultivar "Orishele" in monoculture monitored each week from the 19th week after planting suckers until the 41st week before the first flowerings is represented in Figure 3 in the form of curves. This sawtooth figure shows that all treatments overall influenced DPS. The progression status of black leaf streak disease in banana trees resulting from the different treatments was almost similar. Untreated banana plants (controls) had the highest DPS values compared to banana plants that received applications of biopesticides or synthetic fungicides (Figure 3). Their DPS was faster with a significant progression from one week to another.

Average DPS values varied between 632 and 1213 units for all treatments during the entire observation period. Banana trees treated with Banole mineral oil occupied an intermediate position between untreated plants (controls) and banana trees treated with biopesticides and synthetic fungicides. The lowest DPS values were obtained with biopesticides as well as synthetic fungicides. DPS peaks were reached at weeks 20, 26, 31 and 36 (Figure 3).

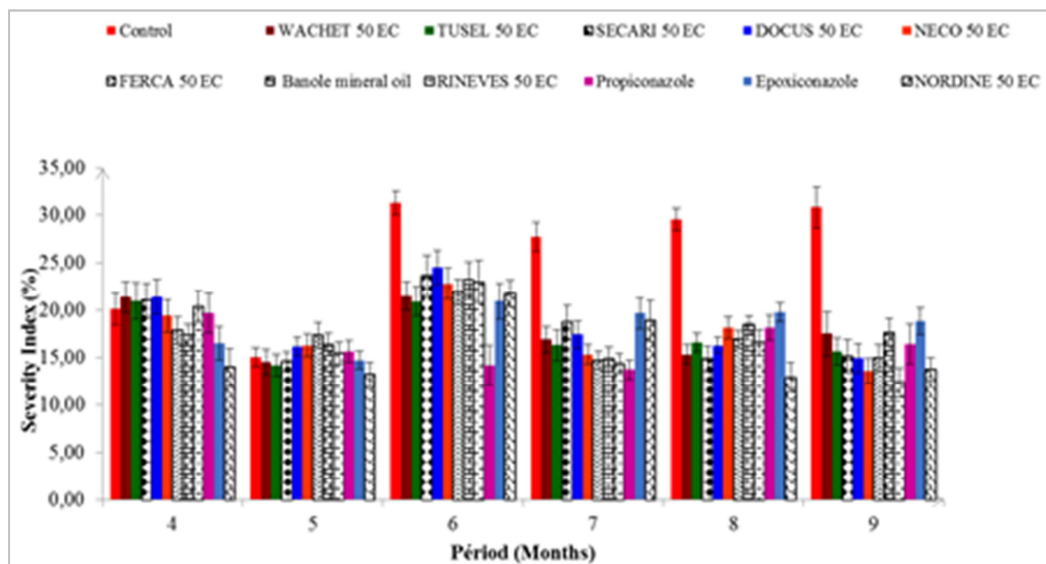


Figure 2. Effect of biopesticides on black leaf streak disease severity.

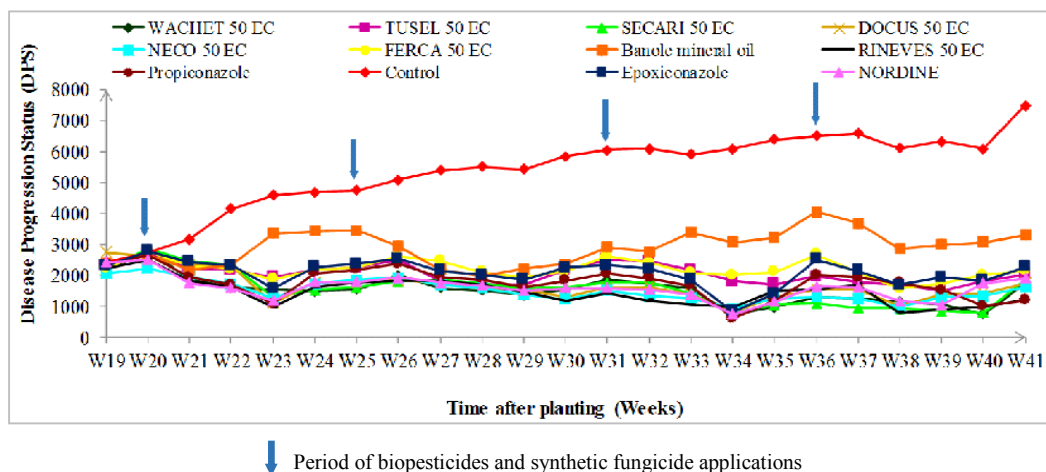


Figure 3. Disease progression state in the cultivar "Orishele" depending on biopesticide applications.



### 3.2. Influence of Biopesticides on Production and Yield Parameters

#### 3.2.1. Effect on the Number of Functional Leaves at Flowering and Harvest

The incidence of leaf streak disease on the number of functional leaves (NFL) at flowering (F) and at harvest (R) is recorded in Table 8.

At flowering, the number of functional leaves (NFLF) varied from 6 to 15 leaves for all treatments. The overall average of functional leaves at flowering was 13.14 leaves. It could be noted that the plants that did not receive any applications arrived at flowering with less than 7 functional leaves (Table 8). On the other hand, the plants which received an application of biopesticides or synthetic fungicides had a number of functional leaves greater than or equal to 12 leaves. No difference was observed between banana trees treated with biopesticides and those treated with synthetic fungicides for this parameter at this phenological stage.

At harvest, the number of functional leaves (NFLH) varied from 1 to 3 leaves for all the treatments. The number of functional leaves was 0.40 (Control) and 2.60 leaves (DOCUS 50 EC), with an overall average of 1.73 leaves (Table 8). Banana trees that received the different treatments retained less than 3 leaves at harvest. Statistically significant differences were observed between the treatments at this stage. Untreated banana trees retained less than one functional leaf at harvest compared to treated banana trees. Banana trees that received DOCUS 50 EC or NORDINE 50 EC biopesticide treatments were able to maintain a number of functional leaves that was clearly greater than 2.

The NFLH/NFLF ratio reflects the speed of leaf disappearance due to black leaf streak disease. It expresses the rate of leaves having survived after the production phase. The NFLH/NFLF ratio of all the different treatments ranged from 0.07 to 0.19 with an average of 0.13 (Table 8). This ratio was less than 0.5 with all treatments. This implies that less than half of the leaves found at flowering were also found at harvest. Banana trees that received no application (controls) had the lowest NFLH/NFLF value (0.07) and banana trees treated with the biopesticide DOCUS 50 EC had the highest value (0.19). In the other treated banana trees, the disappearance of the leaves was slower compared to the controls.

#### 3.2.2. Effect on Banana Tree Production Cycle

The effect of biopesticides and synthetic fungicides on banana tree production cycle is recorded in Table 9.

The planting to flowering interval (PFI) varied from 378.73 to 388.67 days whatever the treatment with an average of 383.78 days (Table 9). The control banana trees and the banana trees treated with biopesticides and synthetic fungicides therefore flowered at the same time. The average planting to flowering interval (PFI) was identical for all treatments ( $p = 0.1995$ ).

Regarding the flowering to harvest interval (FHI), the overall average was 93.24 days or about 3 months for fruit filling. It varied from 91.73 to 95.60 days (Table 9). No

significant difference was also observed between treatments ( $p = 0.9269$ ).

The planting to harvest interval (PHI) oscillated between 473.27 and 484.27 days (Table 9). The average was 477.16 days. The cutting of bunches took place practically between the twelfth and thirteenth month after sucker planting. No significant difference was observed between the treatments ( $p = 0.6472$ ).

The product applications did not influence the length of banana tree production cycle. The analysis of variance showed no difference between the treatments for all the parameters assessed (PFI, FHI and PHI).

#### 3.2.3. Effect on Bunch Characteristics

The bunch was harvested as soon as it reached physiological maturity and the results are given in Table 10. Bunch weight varied from 5.81 (Control) to 8.35 kg (banana trees treated with Propiconazole). The analysis of the production of banana trees showed that the average weight of their bunches was lower in control banana trees than in banana trees treated with biopesticides and synthetic fungicides. Significant differences ( $p < 0.0001$ ) were observed between the weights of the bunches of untreated and treated banana trees (Table 10).

The average number of hands per bunch was between 5 and 7, for an average of 5.95 hands per bunch (Table 10). Statistically, there was no significant difference between treated banana trees and untreated banana trees ( $p = 0.9221$ ).

Regarding the number of fingers per bunch, it was between 26 and 33. No difference ( $p = 0.6125$ ) between the treatments was observed for this parameter (Table 10).

Figure 4 represents the average potential yield per hectare, deducted from the average weight of bunches for each treatment. This yield was higher when the banana trees received applications of biopesticides and synthetic fungicides compared to the control.

**Table 8.** Effect of biopesticides on the number of functional leaves at flowering and at harvest.

Treatments	NFLF	NFLH	NFLH/NFLF
No treatment	6.60 ± 0.36 c	0.40 ± 0.13 c	0.07 ± 0.02 d
Banole	12.00 ± 0.26 b	1.33 ± 0.21 b	0.11 ± 0.02 c
Propiconazole	14.13 ± 0.40 a	1.80 ± 0.14 b	0.13 ± 0.01 bc
Epoxiconazole	13.87 ± 0.36 a	2.13 ± 0.27 ab	0.15 ± 0.02 b
DOCUS 50 EC	14.13 ± 0.19 a	2.60 ± 0.24 a	0.19 ± 0.02 a
NECO 50 EC	13.73 ± 0.41 a	2.07 ± 0.27 ab	0.15 ± 0.02 b
FERCA 50 EC	13.87 ± 0.22 a	1.33 ± 0.21 b	0.10 ± 0.02 c
TUSEL 50 EC	13.33 ± 0.29 a	1.53 ± 0.19 b	0.12 ± 0.01 bc
NORDINE 50 EC	14.46 ± 0.22 a	2.47 ± 0.17 a	0.17 ± 0.02 ab
WACHET 50 EC	13.47 ± 0.34 a	2.13 ± 0.19 ab	0.16 ± 0.01 ab
SECARI 50 EC	14.33 ± 0.27 a	1.60 ± 0.16 b	0.11 ± 0.01 c
RINEVES 50 EC	13.80 ± 0.26 a	1.73 ± 0.18 b	0.13 ± 0.01 bc
Overall average	13.14 ± 0.11	1.73 ± 0.07	0.13 ± 0.07
CV (%)	18.59	55.76	54.08
P	< 0.0001	< 0.0001	0.0001

NB: In the same column, the values followed by the same letter are not significantly different at 5% threshold according to the Newman-Keuls test. NFLF = Number of functional leaves at flowering; NFLH = Number of functional leaves at harvest; NFLH/NFLF = Ratio of the number of functional leaves at harvest to the number of functional leaves at flowering.



**Table 9.** Effect of biopesticides on banana tree production cycle.

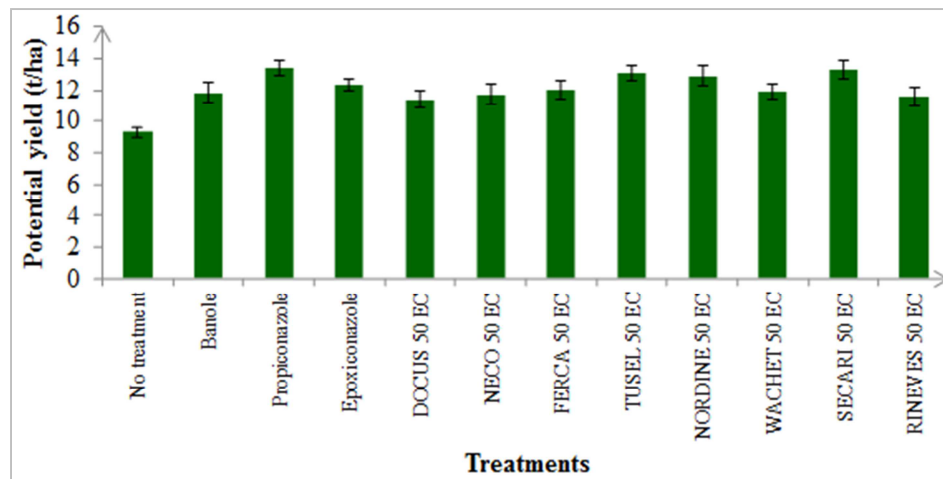
Treatments	Time intervals (d)		
	PFI	FHI	PHI
No treatment	378.73 ± 2.20 a	94.53 ± 2.11 a	473.27 ± 3.23 a
Banole	383.07 ± 1.30 a	91.73 ± 1.57 a	474.80 ± 1.82 a
Propiconazole	382.33 ± 1.39 a	94.60 ± 2.52 a	476.93 ± 3.05 a
Epoxiconazole	386.40 ± 2.75 a	93.80 ± 2.20 a	480.20 ± 3.44 a
DOCUS 50 EC	384.33 ± 2.98 a	92.07 ± 2.34 a	476.40 ± 4.70 a
NECO 50 EC	382.33 ± 1.39 a	93.13 ± 2.33 a	475.47 ± 2.59 a
FERCA 50 EC	388.67 ± 1.68 a	95.60 ± 2.27 a	484.27 ± 2.47 a
TUSEL 50 EC	384.00 ± 2.29 a	93.27 ± 3.06 a	477.27 ± 4.35 a
NORDINE 50 EC	385.33 ± 2.18 a	92.45 ± 2.14 a	477.78 ± 3.13 a
WACHET 50 EC	385.07 ± 2.90 a	90.60 ± 2.79 a	475.67 ± 4.30 a
SECARI 50 EC	383.40 ± 2.52 a	95.27 ± 2.82 a	478.67 ± 3.84 a
RINEVES 50 EC	383.27 ± 1.13 a	91.87 ± 2.51 a	475.13 ± 2.91 a
Overall average	383.78 ± 0.66	93.24 ± 0.72	477.16 ± 1.03
CV (%)	2.19	9.95	2.78
P	0.1995	0.9269	0.6472

NB: In the same column, the values followed by the same letter are not significantly different at 5% threshold according to the Newman-Keuls test. PFI = Planting to flowering interval; FHI = Flowering to harvest interval; PHI = Planting to harvest interval.

**Table 10.** Effect of biopesticides on bunch characteristics.

Treatments	Average bunch weight (kg)	Average number	
		Hands per bunch	Fruits per bunch
No treatment	5.81 ± 0.22 b	5.87 ± 0.24 a	28.33 ± 1.62 a
Banole	7.40 ± 0.37 a	6.07 ± 0.25 a	32.20 ± 3.07 a
Propiconazole	8.35 ± 0.31 a	6.00 ± 0.17 a	27.13 ± 1.33 a
Epoxiconazole	7.71 ± 0.22 a	5.80 ± 0.31 a	29.67 ± 2.29 a
DOCUS 50 EC	7.13 ± 0.33 a	6.13 ± 0.26 a	26.93 ± 1.65 a
NECO 50 EC	7.32 ± 0.39 a	5.80 ± 0.26 a	28.20 ± 2.45 a
FERCA 50 EC	7.50 ± 0.37 a	6.07 ± 0.18 a	27.80 ± 1.61 a
TUSEL 50 EC	8.17 ± 0.29 a	5.93 ± 0.21 a	30.73 ± 1.51 a
NORDINE 50 EC	8.05 ± 0.41 a	6.27 ± 0.33 a	29.75 ± 1.54 a
WACHET 50 EC	7.45 ± 0.30 a	6.09 ± 0.32 a	26.00 ± 1.99 a
SECARI 50 EC	8.30 ± 0.38 a	5.87 ± 0.17 a	26.80 ± 1.80 a
RINEVES 50 EC	7.23 ± 0.38 a	5.60 ± 0.21 a	26.93 ± 2.89 a
Overall average	7.54 ± 0.11	5.95 ± 0.07	28.37 ± 0.63
CV (%)	19.06	15.31	28.56
P	< 0.0001	0.9221	0.6125

NB: In the same column, the values followed by the same letter are not significantly different at 5% threshold according to the Newman-Keuls test.

**Figure 4.** Potential yield per hectare depending on the treatments.

## 4. Discussion

The assessment of the response of banana trees to the application of biopesticides on-farm as part of Black Leaf Streak Disease (BLSD) or Black Sigatoka control showed significant differences. These differences were observed between the parameters characterizing the foliar symptoms of the disease (YLA, YNL and SI) in the control and treated plots. The banana trees in the control plots showed the greatest susceptibility to the disease. During this assessment of the effect of biopesticides on the progression status of black leaf streak disease, four applications were carried out. Product applications (biopesticides and synthetic fungicides) were spaced 5 weeks apart. Comparison of control treatments to mineral oil treatments (Banole) showed a significant effect of the latter on disease severity compared to control treatments alone. These results corroborate those

of Carlier *et al.* [21] and Sadia *et al.* [22], according to which Banole mineral oil might delay the development of the first stages of the disease by prolonging the incubation period of the parasite. Indeed, Banole mineral oil has a fungistatic effect and acts inside the tissues by blocking the germination of ascospores. The inhibitory effect of this mineral oil might be combined with that of the different products assessed. Biopesticides might have exerted an indirect effect on *Mycosphaerella fijiensis* through the induction of secondary metabolites regulating defense reactions in banana trees [12]. Concerning the sanitary status of the leaves (YLA), the first symptoms of the disease were mainly observed overall on the leaves of rank 2 in the control plots and of rank higher than 2, in the treated plots. These YLA ranks thus reflect strong parasitic pressure on the experimental site [23]. In such banana trees that are highly susceptible to BLSD (Orishele, Grande Naine), rank 2 YLA were often observed in Azaguié (Côte d'Ivoire), an area of high pest pressure [19]. However,

on the plots treated with the biopesticides, the banana trees generated an additional healthy leaf compared to the untreated plots. Overall, with a foliar emergence time of about one leaf per week, in plantain tree, the foliar application of biopesticides on banana plants might delay the development of symptoms by one week. Thus, four new untreated leaves were produced after four weeks. The disease might therefore progress more slowly in the treated plots because its dispersion is constrained by a larger functional leaf area than in the plants of the control plots [12]. According to these authors, the control plants might simply express their genetic characteristics vis-à-vis the pathogen. The analysis of the pathological parameters assessed confirms the very high susceptibility of the "Orishele" cultivar to BLSD. This sensitivity is linked to the very high stomatal density of the leaves [24]. The foliar applications of biopesticides in the treated plots lead to a drop in the disease progression status (DPS) and the maintenance of the infection index at a low level; thus suggesting an active participation of its molecules in the direct inhibition of the pathogen. The continuous decline in the progress status of black leaf streak disease beyond four weeks, and despite favorable humidity for the development of the disease, would suggest that the biopesticides applied to the leaves of the banana trees in the treated plots might have, in addition to a direct effect, an indirect effect which faded after 5 weeks. The close relationship between an accumulation of conjugated compounds and the resistance induced in certain plants has already been well established in other pathosystems and is evoked to be a necessary component of the host's defensive response [25, 20]. The applications of the different biopesticides and synthetic fungicides enabled the banana trees to reach flowering with more than 12 functional leaves, unlike the controls with less than 7 leaves. The control plants, which showed the lowest values of the number of functional erect leaves at flowering and the highest measures of disease severity index, would express the susceptibility of the banana cultivar used and this would reflect the positive impact of our different treatments on the incidence of *M. fijiensis*. According to the work of González *et al.* [26], for good productivity, the banana tree must have a minimum of eight functional leaves at flowering. This leaf area is a determining parameter for crop productivity [27]. These foliar treatments given to the plants would be favorable to a good productivity of the banana trees. The analysis of the agronomic parameters at flowering and at harvest showed that the production cycle of banana trees was not influenced by the applications of biopesticides and synthetic fungicides. The control banana trees (untreated) and the banana trees having received the applications of biopesticides or synthetic fungicides reached flowering almost at the same time and the harvest was carried out at the same period. Indeed, the planting to flowering interval (PFI) varied from 378.73 and 388.67 days. While the flowering to harvest interval (FHI) fluctuated between 91.73 and 95.24 days. As for the planting to harvest interval (PHI), it varied between 473.27 and 484.27 days. These results are contrary

to those of N'Guetta *et al.* [28] which showed that the PHI of the cultivar Orishele at different planting densities varied between 349 and 350 days while the PFI oscillated between 277 and 278 days. This difference in days might probably be linked to the application of biopesticides and synthetic fungicides which might have lengthened the vegetative phase, thus delaying the flowering of banana trees. The results of this study also showed that the bunch weight of banana trees treated with biopesticides or synthetic fungicides was greater than that of untreated ones. The average bunch weight varied between 5.81 kg, the lowest value obtained on the untreated banana trees and 8.35 kg, the highest value obtained on the banana trees treated with the synthetic Propiconazole-based fungicide. The low bunch weight of the control banana trees could be explained by the fact that these banana trees reached flowering with less than 7 functional leaves. Indeed, according to the work of Kassi *et al.* [29], when the number of functional leaves is less than 8 leaves, there is poor fruit filling thus affecting bunch weight.

## 5. Conclusion

The biopesticides DOCUS 50 EC and NORDINE 50 EC were effective like the reference biopesticide NECO 50 EC. Biopesticides offer better protection against black leaf streak disease (BLSD) and can be used in integrated pest management with synthetic fungicides in areas with high pest pressure.

There is no doubt that the use of biopesticides formulated with essential oils in phytosanitary control represents a strategy particularly suited to the current concerns of dessert banana and plantain banana producers. Most aromatic plants grow spontaneously in various agro-ecological zones and can be domesticated, thus justifying their availability.

The results of this study are a contribution to reducing the massive use of synthetic fungicides, particularly in industrial banana plantations.

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## References

- [1] Arias, P., Dankers, C., Liu, P., & Pilkauskas, P. (2003). The world banana economy: 1985-2002. FAO Commodity studies 1. Food and Agriculture Organization of the United Nations (FAO), 102 p.
- [2] Falk, A. (2018). Plantain banana market: Self-consumption predominant on this still non globalised market. *FruiTrop*, 256: 50-55.
- [3] Idumah, F. O., Owombo, P. T., Ighodaro, U. B., & Mangodo, C. (2016). Economic analysis of plantain production under agroforestry system Inedo SDtate, Nigeria. *Applied Tropical Agriculture*, 21 (1): 138-144.

- [4] FAO, (2022). FAOSTAT database. Food and Agriculture Organization of the United Nations, Genena, <https://www.fao.org/faostat/fr/#data/QCL>
- [5] Jones, D. R. (2000). Diseases of Banana, Abaca and Enset. CAB International, Wallingford, UK, 544 p.
- [6] Kone, D., Camara, B., Badou, O. J., Doumbouya, M., Soro, S., N'Guessan, A. C., & Bomisso E. L. (2010). Fungicides and biological products activities towards fungi causing diseases on banana and vegetable in Côte d'Ivoire. In *Ebook Fungicides*, 39-68. DOI: 10.5772/13976.
- [7] Tuo, S., Camara, B., Kassi, K. F. J.-M., Kamate, K., Ouédraogo S. L., & Kone, D. (2021). Update of the geographical distribution of Sigatoka of banana in Cote d'Ivoire: diversity and incidence of the pathogen. *Journal of Applied Biosciences*, 166: 17188-17211. <https://doi.org/10.35759/JABs.166.4>
- [8] Bodjona, B. P. T., Odah, K., Kpemoua, K. E., Pitekelaou, R., Bokobana, A., & Gbogbo, K. A. (2021). Epidemiology of black Sigatoka of banana (*Musa* spp.) in ecological zone IV of Togo. *Revue Marocaine des Sciences Agronomiques et Vétérinaires*, 9 (1): 123-129.
- [9] Burt, P., Rutter, J., & Gonzalez, H, 1997. Short distance wind dispersal of the fungal pathogens causing Sigatoka diseases in banana and plantain. *Plant pathology*, 46 (4): 451-458.
- [10] Chillet, M., Abadie, C., Hubert, O., Chilin-Charles, Y., & de Lapeyre de Bellaire, L. (2009). Sigatoka disease reduces the greenlife of bananas. *Crop Protection*, 28 (1): 41-45. doi: 10.1016/j.cropro.2008.08.008.
- [11] Soares, J. M. S., Rocha, A. J., Nascimento, F. S., Santos, A. S., Miller, R. N. G., Ferreira, C. F., Haddad, F., Amorim, V. B. O., & Amorim, E. P. (2021). Genetic improvement for resistance to Black Sigatoka in Bananas: A Systematic Review. *Frontiers in Plant Science*, 12: 1-15. doi.org/10.3389/fpls.2021.657916.
- [12] Kassi, K. F. J.-M., Kouame, K. G., Kouame, K. D., Yao, K. J.-E., Silue, T., Obin, R. M., & Kone, D. (2021). Management of banana Black Sigatoka in industrial dessert Banana cultivation through the reasoned use of synthetic fungicide Vondozeb 62 OD. *Scholars Academic Journal of Biosciences*, 9 (11): 346-353. DOI: 10.36347/sajb.2021.v09i11.004.
- [13] Kassi, K. F. J.-M., Kouame, K. D., N'Guessan, P. H., Kouame, K. G., & Kone, D. (2021). Black leaf streak disease assessment during production of dessert banana basin in South-Eastern Cote d'Ivoire. *International Journal of Plant Pathology*, 12 (1): 1-11. DOI: 10.3923/ijpp.2021.1.11.
- [14] Sierotzki, H., Parisi, S., Steinfeld, U., Tenzer, I., Poirey, S. & Gisi, U. (2000). Mode of resistance to respiratory inhibitors at the cytochrome Bc1 enzyme complex of *Mycosphaerella fijiensis* field isolates. En: *Pest Management Science*, 56 (10): 833-841. DOI: 10.1002/1526-4998(200010)56:10<833: AID-PS200>3.0.CO;2-Q.
- [15] Kone, D., Badou, O. J., Bomisso, E. L., Camara, B., & Ake, S. (2009). [In vitro activity of different fungicides on the growth in *Mycosphaerella fijiensis* var. *difformis* Stover and Dickson, *Cladosporium musae* Morelet et *Deightonella torulosa* (Syd.) Ellis, isolated parasites of the banana phyllosphere in the Ivory Coast]. *Comptes Rendus Biologies*, 332: 448-455. Doi: 10.1016/j.crv.2008.03.013.
- [16] Tuo, S., Amari, L.-N. D. G. E., Camara, B., Soro, S., Sorho, F., Abo, K., Ouedraogo, S. L., & Kone, D. (2016). Assessment of banana and plantain behavior under natural infestation by *Mycosphaerella fijiensis*, Morelet in Southern Côte d'Ivoire. *Journal of Agronomy*, 15 (4): 151-164. DOI: 10.3923/ja.2016.151.164.
- [17] Ganry, J., Foure, E., De Lapeyre de Bellaire, L., & Lescot T. (2012) An integrated approach to control the Black Leaf Streak disease (BLSD) of bananas, while reducing fungicide use and environmental impact. In book: *Fungicides for Plant and Animal Diseases*, 193-225. DOI: 10.5772/29794.
- [18] Foure, E. (1988). Cercospora leaf spot diseases of bananas and their treatments. Comparative efficiency of different fungicide molecules against *Mycosphaerella fijiensis* Morelet, Black Leaf Streak disease in Cameroon (I). *Fruits*, 43 (1): 15-19.
- [19] Ewane, C., Chillet, M., Castelan, F., Brostaux, Y., Lassois, L., Ngando, J. E., Hubert, O., Chilin-Charles, Y., Lepoivre, P., & De Lapeyre de Bellaire, L. (2013). Impact of the extension of black leaf streak disease on banana susceptibility to post-harvest diseases. *Fruits*, 68 (5): 351-365. DOI: 10.1051/fruits/2013081.
- [20] Silue, T., Amari, L.-N'. D. G. E., Tuo, S., Kassi, K. F. J.-M., Silue, N., Camara, B. & Kone, D. (2022). Comparative efficacy of four formulations based on aromatic plant extracts and a synthetic fungicide against *Mycosphaerella fijiensis* Morelet causal agent of Black Leaf Streak Disease (BLSD), in industrial dessert banana production. *International Journal of Advanced Research*, 10 (2): 1339-1348. <http://dx.doi.org/10.21474/IJAR01/14347>.
- [21] Carlier, J., Zapater, M. F., Lapeyere, F., Jones, D. R., & Mourichon, X. (2000). Septoria leaf Spot of Banana: A newly Discovered Disease Caused by *Mycosphaerella eumusae* (anamorph: Septoria eumusae). *Phytopathology*, 90: 884-890. DOI: 10.1094/PHYTO.2000.90.8.884.
- [22] Sadia; G. H., Kouadio, K. T., Pohe, J., & Tienebo E. O. (2017). Contribution to the management of *Mycosphaerella* leaf spot diseases of bananas by using Fluopyram associated with mineral oil in Ivory Coast. *Journal of Applied Biosciences*, 113: 11158-11173. <https://dx.doi.org/10.4314/jab.v11i13.5>
- [23] Ewane, C., Tatsegouock, R., Meshuneke, A., & Niemenak, N. (2020). Field Efficacy of a Biopesticide Based on *Tithonia diversifolia* against Black Sigatoka Disease of Plantain (*Musa* spp., AAB). *Agricultural Sciences*, 11, 730-743. doi: 10.4236/as.2020.118048.
- [24] Vasquez, N., Tapia, A. C., & Galindo J. J. (1989). Ultrastructural studies of the infection process of *Mycosphaerella fijiensis* on *Musa* cultivars. In: R. A. Fullerton & R. H. Stover (Editors), Sigatoka leaf spot diseases of bananas: Proceedings of an international workshop held at San José Costa Rica, March 28- April 1, 1989. International Network for the Improvement of Banana and Plantain, Montpellier, France, 191-200.
- [25] Ongena, M., Daayf, F., Jacques, P., Thonart, P., & Benhamou, N. (2000). Systemic induction of phytoalexins in cucumber in response to treatments with fluorescent *Pseudomonas*. *Plant Pathology*, 49: 523-530.
- [26] Gonzalez, C. R.; Salinas, D. G. C., & Castillo, J. J. M. (2012). Effect of Number of Functional Leaves at Flowering on Yield of Banana Grand Naine (*Musa* AAA Simmonds). *Revista Facultad Nacional de Agronomía Medellín*, 65 (2): 6591-6597.

- [27] Torres-Bazurto, J., Magnitskiy, S., & Sánchez, J. D. (2019). Effect of fertilization with N on height, number of leaves, and leaf area in banana (*Musa* AAA Simmonds, cv. Williams). *Revista Colombiana de Ciencias Hortícolas*, 13 (1): 9-17. Doi: <http://doi.org/10.17584/rcch.2019v13i1.8440>.
- [28] N'Guetta, A., Traore, S., Yao, N'. T., Aby, N., Koffi, Y. D., Atsin, G. O., Otro, S. T. V., Kobenan, K., Gnonhouiri, P., & Yao-Kouame, A. (2016). Effect of planting density on growth and yield of plantain in Cote d'Ivoire: case of two hybrids (PITA 3 and FHIA 21) and two local varieties (Corne 1 and Orishele). *Agronomie Africaine*, 27 (3): 213-222.
- [29] Kassi, F. K. J.-M., N'Guessan, P. H., Tuo, S., Camara, B. & Kone, D. (2021). Fungitoxic potentialities of NECO 50 EC in an integrated Black Sigatoka management strategy in industrial dessert banana plantation. *European Journal of Biology and Biotechnology*, 2 (4): 47-54. DOI: 10.24018/ejbio.2021.2.4.232.