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RESEARCH ARTICLE

PREVENTIVE AND CURATIVE EFFECTS OF SYNTHETIC FUNGICIDES AND ESSENTIAL OILS AGAINST *MYCOSPHAERELLA FIJIENSIS* IN BANANA

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ABSTRACT

Bananas are the most consumed fruit worldwide, especially in West Africa. However, banana plantations are often infected by the ascomycete fungus *Mycosphaerella fijiensis* M., the agent of black sigatoka disease (BSD), also called black leaf streak, which can lead to yield losses exceeding 50%. This fungal disease is widely reported in banana plantations in Burkina Faso, causing significant reductions in fruit yield and quality. This study aims to improve banana productivity in Burkina Faso through integrated and sustainable management. The experiment was conducted using a factorial block design with two factors: the first factor involved treatment products (Copper Hydroxide, Mancozeb, *Ocimum gratissimum*, and *Lippia multiflora*), and the second factor involved application doses at three levels, including an untreated control. The experimental material consisted of *vivo*-plants of the Grande Naine banana variety and the BH isolate of *M. fijiensis*. The in *vivo* results showed that all plants exhibited a 100% incidence. In preventive treatment, the disease index increased from 29.16 % to 97.22 % in the control, while *Ocimum gratissimum* (15.27 % to 22.22 %) and Mancozeb (15.27 % to 20.83 %) significantly limited its progression, compared to *Lippia multiflora* (18.05 % to 54.16 %) and copper hydroxide (16.66 % to 62.33 %). In curative treatment, the control increased from 29.16 to 97.22, *O. gratissimum* from 12.5 % to 19.33 %, and Mancozeb from 16.66 % to 30.55 %, while *L. multiflora* (18.05 % to 66.66 %) and copper hydroxide (18.05 % to 70.66 %) were less effective. The AUDPC confirms the high effectiveness of *O. gratissimum* and Mancozeb, suggesting their use alone or in combination as part of an integrated black sigatoka disease management strategy.

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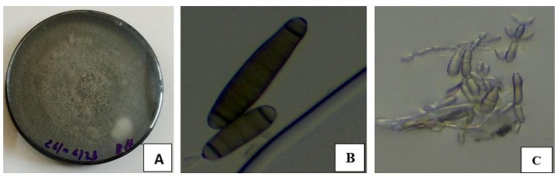
INTRODUCTION

The banana plant is one of the main staple crops for human nutrition (Ondh-Obame, 2021). This crop ranks first in fruit production, with just over 170.3 million tons produced worldwide, of which 85% are consumed locally (FAO, 2022). In Africa, banana production is an important source of employment and income for households (Onautshu et al., 2013). Indeed, profits from banana marketing are estimated at over 5.6 billion US dollars in 2021 (FAOSTAT, 2022). In Burkina Faso, bananas are among the most consumed fruit products and are the third most produced fruit, after mangoes and citrus fruits (MAAH, 2016). Between 2009 and 2021, banana production nearly tripled, increasing from 18,606 to 46,033 tons (FAOSTAT, 2022). Although banana production has increased over the past ten (10) years, the supply only partially meets local demand, leading to imports estimated at over 5,410 tons, valued at approximately 93.8 million CFA francs per year (FAO, 2021). To reduce, on one hand, these increasing imports, and on the other hand, to improve productivity in this sector, the government and its partners have developed strategies to support the industry. These include promoting banana varieties and modern cultivation techniques, as well as subsidizing inputs and agricultural equipment (Ariste and Kamboule, 2002; Nanema, 2004). However, it is clear that many challenges remain to invigorate and ensure effective participation of the banana sector in the country's economy. The development of the banana industry is limited by numerous parasitic threats, the most significant of which are fungi, viruses, bacteria, or insects (Mourichon, 2003). Black Sigatoka, or the black streak disease (BSD), caused by the fungus *Mycosphaerella fijiensis* Morelet, is the main foliar disease of banana plants due to its virulence and its impact on a wide range of cultivars (Carlier et al., 2003). Without control, direct yield losses are estimated at 50% (Tuo et al., 2021) and can reach 100% from the second crop cycle (Chillet et al., 2009). Indirect losses are also recorded, affecting the fruit's conservation potential, with a high risk of premature ripening (De Lapeyre de Bellaire et al., 2014). The most common control methods mainly rely on synthetic chemical products (Jones and Stover, 2019). Given the limitations of traditional methods for controlling phytopathogenic fungi, the search for effective and sustainable alternatives remains a major issue in crop protection. Therefore, it is necessary to evaluate, under controlled conditions, the effectiveness of synthetic fungicides (Mancozeb, copper hydroxide) and essential oils from *Ocimum gratissimum* and *Lippia multiflora*.

MATERIALS AND METHODS

Study Area: The research was conducted in controlled and semi-controlled environments at the Institute of Environment and Agricultural Research (INERA) research station in Farako-Bâ. It is located 10 km southwest of Bobo-Dioulasso along the Bobo-Banfora axis. Its geographic coordinates are 04°20' west longitude, 11°60' north latitude, with an altitude of 405 meters.

Plant Material, Fungal Material, and Essential Oils: This study was carried out on in *vivo* plants of the Grande Naine banana variety, which belongs to the Cavendish subgroup and is susceptible to black Sigatoka (Koné et al., 2009). The technique of plant-derived stem fragment pieces (PIF) was used to obtain banana vivo-plants. The replanting was then done in buckets previously filled with cultivation soil and sterilized potting soil. The plants were maintained throughout the data collection period. The culture medium based on rice flour and potato dextrose agar (PDA), according to Kassankogno et al. (2022), was used to promote good development and sporulation of the fungus. The isolate BF5Mf of *Mycosphaerella fijiensis*, obtained following the method described by Koné (1998) at the phytopathology laboratory of the Farako-Bâ research station of the Institute of Environment and Agricultural Research (INERA), was used for inoculations (Figure 1). Two fungicides based on copper hydroxide (65.5% copper hydroxide, dispersible powder) and Mancozeb (800 g/kg Mancozeb, dispersible powder) were used. The essential oils (EOs) used in the study were extracted from the plant species *Ocimum gratissimum* (thymol: 29.5%; γ-terpinene: 20.5%; p-cymene: 12.9%) and *Lippia multiflora* (30.8% thymol, 20.8% acetate, and 3.1% γ-terpinene), by the Natural Substances Laboratory of the Institute of Applied Sciences and Technologies (IRSAT).



Legend: Fungal mycelium in a Petri dish (A); Conidia viewed under the microscope (40x) (B); Ascospores viewed under the microscope (40x) (C)

Figure 1. Morphology of the BF5Mf isolate of Mycosphaerellafijiensis

Table I. Characteristics of the treatments used in the study

Facteur 1		Facteur 2 (Doses)		
Fongicides/HE	Composition	Lower dose	Recommended dose	Higher dose
Control	Sterile distilled water	0	0	0
HE of *L.multiflora*	Thymol (30,8%) et acétate (20,8%), γ-Terpinène (3,1%)	500 ppm	1000 ppm	4000 ppm
HE of *O. gratissimum*	Thymol (29,5%), γ-terpinene (20,5%) et p-cymene (12,9%)	500 ppm	1000 ppm	4000 ppm
Copper hydroxide	65,5% d'Hydroxyde de cuivre, WP	7500 ppm	10000 ppm	12500 ppm
Mancozeb	Mancozèbe, 800g/Kg, WP	5000 ppm	6700 ppm	8400 ppm

Experimental device: A factorial block design with three repetitions was used in this study. The first factor consists of the treatment products. The secondary factor includes three levels of product dose (essential oils, synthetic fungicides) and an untreated control. The different product doses were expressed in ppm and recorded in Table I.

Preparation and application of synthetic fungicides and essential oils: Synthetic fungicides and essential oils were prepared by measuring the desired amount of each product for each treatment and adding it to 40 mL of distilled water. For essential oils, their preparation was carried out using Tween 20 at a ratio of 95% essential oil to 5% Tween 20 (Belhouan, 2017), to facilitate their miscibility in the liquid medium. Tween acts as a dispersant for the oils in water. It is both miscible with oil and water. The quantities used for Lippia multiflora and *Ocimum gratissimum* were 0.02 mL, 0.04 mL, and 0.16 mL, respectively. Regarding the studied synthetic fungicides, the quantities used were 0.3 g, 0.4 g, and 0.5 g for copper hydroxide, and 0.2 g, 0.27 g, and 0.34 g for mancozeb. Their application in a semi-controlled environment was performed using a laboratory micro-sprayer. The different applications were carried out preventively 72 hours before inoculation and curatively 72 hours after inoculation. Each pot received 40 mL of the mixture corresponding to one dose. The control plants were sprayed with sterile distilled water.

Preparation of the inoculum and inoculation of banana vivoplants: The inoculum was prepared from 14-day-old cultures of Mycosphaerellafijiensis that had sporulated. Thus, ten (10) Petri dishes containing spores were scraped with a brush, and ten (10) milliliters of sterile distilled water were added to each dish. These suspensions were vortexed for 30 minutes to ensure homogenization. Then, the number of spores in the prepared concentrations was determined using a Malassez cell. For plant inoculation, the obtained spore suspension was adjusted to 10^5 spores/mL with sterile distilled water.

A few drops of a 5% gelatin solution were added to this suspension to promote adhesion of the inoculum to the leaf area. The spore solutions were sprayed onto 60-day-old vivoplants using a micro-sprayer. The inoculation was performed on the underside of the leaves, along the midrib, using a micro-sprayer. On each plant, the two youngest leaves after the cigar, labelled 1 and 2, and the two oldest leaves, labelled 3 and 4, were inoculated (Tuo et al., 2021). The inoculations were carried out in the evening to prevent desiccation of the inoculum. The inoculated banana plants were then placed in an incubation chamber for 48 hours. A humidifier was installed beforehand to maintain a relative humidity of 95-100%.

Determination of the effectiveness level of synthetic fungicides and essential oils: The sensitivity or resistance level of the fungus to synthetic fungicides and essential oils was determined according to the scale of Paranagama et al. (2003) as recorded in Table IV. The effectiveness of synthetic fungicides and essential oils was determined based on overall inhibition percentage, with the mean inhibition percentage calculated for each dose.

Table II. Effectiveness level of synthetic fungicides and essential oils according to the scale used by Paranagama et al. (2003)

Scale	Mycelial inhibition rate class I (%)	Fungal sensitivity/resistance level	Fungicide/essential oil effectiveness level
1	75 % < I ≤ 100 %	Very Sensitive	Very effective (TE)
2	50 % < I ≤ 75 %	Sensible	Effective (E)
3	25 % ≤ I ≤ 50 %	Moderately Resistant	Moderately effective (ME
4	0% ≤ I ≤ 25 %	Resistant	Not effective (NE)

Evaluation of the effectiveness of synthetic fungicides and essential oils on the severity and incidence of black Sigatoka in banana plants: The incidence is determined according to the formula used by Kassi et al. (2014). :$I = \frac{n}{N} x100$, with I = Incidence, n = number of infected leaves, and N = number of observed leaves. The severity of the disease is assessed using the rating scale used by Bermúdez et al. (2001) from 0 to 6.

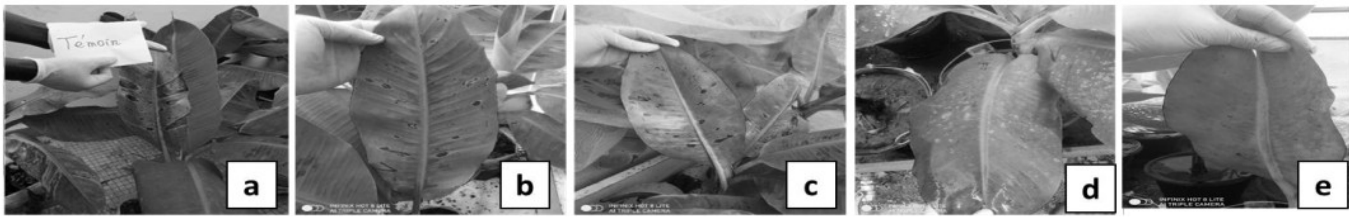
Table III. Modified scale for assessing the severity index and evaluating the effectiveness of synthetic fungicides and essential oils

Scoring	Severity index (%)	Degree of resistance	Fungicide/HE effectiveness level
1	0-10	Strongly resistant (FR)	Very effective (VE)
2	11-20	Resistant (R)	Effective (E)
3	21- 30	Moderately resistant (MR)	Moderately effective (ME)
4	31-40	Moderately sensitive (MS)	
5	41-50	Sensible (S)	Not effective (NE),
6	Plus de 50	Highly sensitive (HS)	

Table IV. Comparison of the average severity indices and incidence of black Cercospora leaf spot of banana in preventive treatment with synthetic fungicides and essential oils

Fongicides/ HE	Lower dose						Recommended dose						Higher dose						NEP
	Im 14eDAI	IS 14eDAI	IS 28eDAI	IS 42eDAI	IS 56eDAI	NE	Im 14eDAI	IS 14eDAI	IS 28eDAI	IS 42eDAI	IS 56eDAI	NE	Im 14eDAI	IS 14eDAI	IS 28eDAI	IS 42eDAI	IS 56eDAI	NE	
Control	100	29,1c	59,72 c	92,88 d	97,22 e	-	100	29,16 b	59,72 c	92,88 c	97,22 d	-	100	29,16 b	59,72 b	92,887 c	97,22 c	-	-
HE of *L.multiflora*	100	19,4ab	38,7b	61,11 c	75 d	PE	100	18,05 a	34,61 b	42,94 b	54,16 b	PE	100	16,66 a	29,16 a	41,49 b	51,38 b	PE	PE
HE of *O. gratissimum*	100	16,6a	29,1ab	40,10 ab	44,27 b	PE	100	15,27 a	18,05 a	20,72 a	22,22 a	ME	100	15,27 a	16,66 a	17,77 a	19,16 a	E	ME
Copper hydroxide	100	16,6a	37,49 b	49,82 bc	59,72 c	PE	100	16,66 a	33,50b	49,82 b	62,33 c	PE	100	16,66 a	29,16 a	42,71 b	54,16 b	PE	PE
Mancozeb	100	16,6a	19,44 a	20,61 a	20,61 a	E	100	15,27a	16,49 a	17,88 a	20,83 a	E	100	16,66 a	18,05 a	17,88 a	17,71 a	E	E
Probability > F	-	< 0,0001	< 0,0001	< 0,0001	< 0,0001	-	-	< 0,0001	< 0,0001	< 0,0001	< 0,0001	-	-	< 0,0001	< 0,0001	< 0,0001	< 0,0001	-	-
Significance	-	THS	THS	THS	THS	-	-	THS	THS	THS	THS	-	-	THS	THS	THS	THS	-	-

Legend: THS: Highly significant; DAI: Day after infection; Im: Average incidence; IS: Severity index; NE: Level of effectiveness; PE: Not effective; ME: Moderately effective; E: Effective; NEP: Product effectiveness level; Control: Untreated control; NB: Means followed by the same letters in the same column are not significantly different according to the Newman-Keuls (SNK) statistical test at the 5% threshold



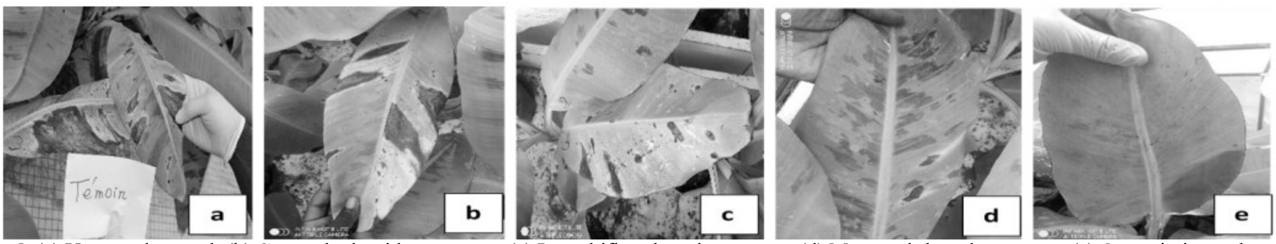
Legend: (a) Untreated control; (b) Treatment with Copper Hydroxide; (c) Treatment with L. multiflora; (d) Treatment with Mancozeb; (e) Treatment with O. gratissimum

Figure 2. Effect of preventive treatment on the severity of black cercospora at the 56th day after inoculation (DAI)

Table V: Comparison of the average severity indices and incidence of black Sigatoka in banana plants under curative treatment with synthetic fungicides and essential oils

Fongicides/HE	Lower dose						Recommended dose						Higher dose						NEP
	Im 14eDAI	IS 14eDAI	IS 28eDAI	IS 42eDAI	IS 56eDAI	NE	Im 14eDAI	IS 14eDAI	IS 28eDAI	IS 42eDAI	IS 56eDAI	NE	Im 14eDAI	IS 14eDAI	IS 28eDAI	IS 42eDAI	IS 56eDAI	NE	
Control	100	29,16b	59,72c	92,88c	97,22d	-	100	29,16b	59,72d	92,88d	97,22d	-	100	29,16b	59,72c	92,88d	97,22d	-	-
HE of *L.multiflora*	100	18,05a	44,44b	70,83b	76,38c	PE	100	18,05a	35,94b	54,16b	66,66c	PE	100	18,05a	34,55b	38,49b	40,09b	ME	PE
HE of *O. gratissimum*	100	16,66a	16,66a	33,33a	50,00b	PE	100	12,5a	12,5 a	16,66a	19,33a	E	100	12,5 a	13,88a	16,66a	16,66a	E	ME
Copper hydroxide	100	18,05a	44,44b	68,05b	80,55c	PE	100	18,05a	45,49c	62,49c	70,66c	PE	100	18,05a	38,55b	54,16c	59,72c	PE	PE
Mancozeb	100	16,66a	20,83a	29,16a	40,10a	ME	100	16,66a	18,05a	23,61a	30,55b	ME	100	16,66a	16,66a	20,83a	22,22a	ME	ME
Probability> F	-	< 0,0001	< 0,0001	< 0,0001	< 0,0001	-	-	< 0,0001	< 0,0001	< 0,0001	< 0,0001	-	-	< 0,0001	< 0,0001	< 0,0001	< 0,0001	-	-
Significance	-	THS	THS	THS	THS	-	-	THS	THS	THS	THS	-	-	THS	THS	THS	THS	-	-

Legend: THS: Very highly significant; DAI: Day after infection; Im: Average incidence; IS: Severity index; NE: Level of effectiveness; PE: Not effective; ME: Moderately effective; E: Effective; NEP: Product effectiveness level; Control: Untreated control.



Legend: (a) Untreated control; (b) Copper hydroxide treatment; (c) L. multiflora-based treatment; (d) Mancozeb-based treatment; (e) O. gratissimum-based treatment

Figure 3. Effect of the curative treatment on the severity of black cercospora at 56 days after inoculation

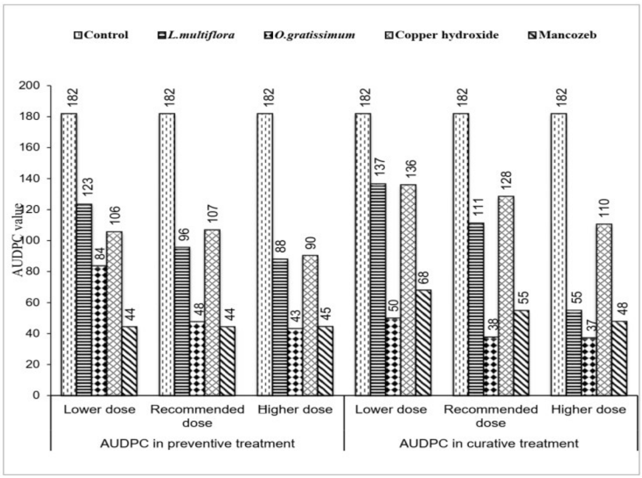


Figure 4. Disease progression area according to doses and products in preventive and curative treatment

According to this scale, 0 = no visible symptoms, 1 = < 1%, 2 = 1-5%, 3 = 6-15%, 4 = 16-33%, 5 = 34-50%, and 6 = 51-100% of the leaf surface covered by symptoms. After recording the severity of black cercospora, the severity index for each evaluated plant was calculated using the formula: $\text{Severity index} = \sum \frac{nb}{(N-1)T} x100$ (Bermúdez et al., 2001) where b = degree of the scale (0-6), with N = number of indices in the leaf lesion rating scale; n = number of leaves for each degree of the scale; T = total number of leaves evaluated. Slight modifications have been made in order to take into account the effectiveness of synthetic fungicides and essential oils (Table III). Severity data are collected on the 14th, 28th, 42nd, and 56th days after inoculation (DAI). As for incidence, it was collected on the 14th DAI.

Evaluation of the evolution of black Cercospora leaf spot on banana plants over time: The effectiveness of synthetic fungicides and essential oils was assessed using the area under the disease progress curve (AUDPC). The severity values of Cercospora at each evaluation date were used to calculate the area under the disease progress curve (AUDPC) according to the following equation (Campbell and Madden, 1990):$\text{AUDPC} = \sum[(X_i + X_i + 1)/2(t_i + 1 - t_i)]$where: Xi is the severity of the disease expressed as a percentage of the diseased leaf surface (SFM) and is observed at time ti; (ti+1 - ti) represents the time interval in days between two observations.

Data processing and analysis: The data were entered and processed using Excel 2016. XLSTAT 2016.02.27444-ANOVA software was used for variance analysis followed by mean comparison using the Newman-Keuls (SNK) statistical test at a 5% significance level.

RESULTS AND DISCUSSION

Effect of Preventive Treatment on the Severity and Incidence of Black Sigatoka in Banana Plants: The severity and incidence of black Cercospora leaf spot on banana plants in preventive treatment were evaluated on the 14th, 28th, 42nd, and 56th days after inoculation **(Table IV).** Variance analysis revealed highly significant results (P<0.0001). The incidence of the disease did not vary from the 14th to the 56th day after inoculation. Indeed, all plants showed symptoms of black Cercospora (100% incidence), regardless of the evaluation date. However, treatments and the timing of evaluation significantly influenced the severity of black Cercospora (Figure 2). Severity indices ranged from 29.16% to 97.22% for the control treatment from the 14th to the 56th day post-infection. For essential oils, they varied from 16.66% to 75% in the Lippia multiflora treatment, compared to 15.27% to 44.27% in the *Ocimum gratissimum* treatment. As for synthetic fungicides, severity indices ranged from 16.66% to 59.72% in the Copper Hydroxide treatment, versus 16.66% to 23.61% in the Mancozeb treatment. The treatments with the lowest severity indices on the 56th day after inoculation were those with Mancozeb, with respective values of 20.61%, 20.83%, and 17.71% at the lower dose, the recommended dose, and the higher dose, and *Ocimum gratissimum* at the medium dose (22.22%) and the high dose (19.16%). Additionally, the effect of different products in preventive treatment depended on the dose, except for synthetic fungicides. In this regard, the Mancozeb treatment was effective at all doses in reducing disease severity, unlike Copper Hydroxide, which showed no effectiveness. Regarding essential oils, *Ocimum gratissimum* was moderately effective at the medium and high doses but ineffective at the low dose in reducing infection rate, while *Lippia multiflora* was ineffective at all doses. The overall ranking of product effectiveness highlights three groups of fungicides/essential oils: the effective group (Mancozeb), the moderately effective group (*Ocimum gratissimum*), and the ineffective group (Copper Hydroxide, *Lippia multiflora*).

Effect of curative treatment on the severity and incidence of black Sigatoka in banana plants: The evaluation of the effect of synthetic fungicides and essential oils in curative treatment is presented in Table V and Figure 3. The statistical analysis of these results was highly significant (P<0.0001). As with preventive treatment, the incidence was 100% on the 14th day after inoculation (DAI), while the severity indices varied with the evaluation time. The control treatment showed the highest rates of affected leaf surface, ranging from 29.16% to 97.22%. It was followed by treatment with *Lippia multiflora* essential oil, with severity indices ranging from 18.05% to 76.38%, and with copper hydroxide, with values ranging from 18.05% to 80.55%. Considering the dose, notable differences were observed between the products. Indeed, the lowest severity indices on the 56th day after inoculation were observed with the *O. gratissimum* essential oil treatment at the medium and high doses, with values of 19.33% and 16.66%, respectively. It was followed by the Mancozeb treatment, which showed values of 30.55% and 22.22% at the recommended and higher doses, respectively. Conversely, severity was more pronounced in the copper hydroxide treatment at the lower dose (80.55%), the recommended dose (70.66%), and the higher dose (59.72%). Similarly, *Lippia multiflora* essential oil very weakly reduced disease severity at the low dose (66.66%) and the medium dose (53.99%). Comparing the products' effectiveness by dose, the medium and high doses of *O. gratissimum* essential oil were effective. In contrast, *Lippia multiflora* oil was moderately effective at the high dose and ineffective at the low and medium doses. Two groups of fungicides and essential oils can be formed based on their effectiveness levels: the moderately effective group (*O. gratissimum*, Mancozeb) and the weakly effective group (*Lippia multiflora*, copper hydroxide).

Assessment of the disease progression area in preventive and curative treatments: The effects of the products on black cercospora in preventive and curative treatments were evaluated using the disease progression area (AUDPC) and are illustrated in Figure 4. In preventive treatment, disease progression depended on the type of product and the dose. The highest AUDPC value was observed in the control (AUDPC=182), followed by *Lippia multiflora* at the low dose (AUDPC=123), the medium dose (AUDPC=96), and the high dose (AUDPC=88). In addition to these treatments, Copper Hydroxide showed the highest AUDPC values at all doses. The lowest disease progression values were observed with Mancozeb at the lower and recommended doses (AUDPC=44) and the higher dose (AUDPC=45), as well as with O. gratissimum at the high dose (AUDPC=43) and the recommended dose (AUDPC=48). Overall, the disease progression area was reduced more with Mancozeb treatments at all doses, and with *O. gratissimum* at the medium and high doses. In curative treatment, the lowest AUDPC values were recorded with *O. gratissimum* at the high dose (AUDPC=37), the medium dose (AUDPC=38), and the low dose (AUDPC=50), and with Mancozeb at the higher dose (AUDPC=48). On the other hand, treatments with Copper Hydroxide and *Lippia multiflora* very minimally reduced disease progression, as evidenced by their high AUDPC values. The overall trend of the disease progression curve in curative treatment shows that the essential oil of *O. gratissimum* was the most effective against black cercospora.

DISCUSSION

Effectiveness of essential oils and synthetic fungicides on the severity and incidence of black Sigatoka in banana plants in preventive and curative treatments in a semi-controlled environment: In both preventive and curative treatments, the disease incidence on the GraindeNaine cultivar was 100% across all evaluation periods. Overall, a regression effect was observed with treatments based on synthetic fungicides and essential oils on the severity and the area under the disease progression curve (AUDPC). Indeed, in preventive treatment, the control plants showed the highest AUDPC values and the highest severity index measures.

They were followed by the treatment based on Copper Hydroxide and Lippia multiflora essential oil, which also exhibited high severity indices at all doses. The lowest severity index values were induced by the treatment based on Mancozeb, with respective values of 20.61%, 20.83%, and 17.71% at the lower, recommended, and higher doses, and by *Ocimum gratissimum* at the medium dose (22.22%) and high dose (19.16%) 56 days after incubation. According to Koné et al. (2009), the Grande Naine variety is highly susceptible to black cercospora; therefore, a study conducted in a semi-controlled environment, excluding the varietal resistance factor, shows that resistance to the disease is probably due solely to the effect of Mancozeb used in preventive control.

Our results agree with those of Ngoh et al. (2021b), who demonstrated the effectiveness of Mancozeb 80 WP in reducing infections caused by *Pestalotia heterocornis*, the agent responsible for leaf browning in cashew trees, during preventive treatment. Similar preventive work on tomato septoria caused by *Septoria lycopersici*, using Mancozeb, chlorothalonil, and fluazinam, reduced disease severity by more than 70%, according to Monteiro et al. (2021). In curative treatment, the severity and AUDPC of black cercospora were significantly reduced on leaves treated with *O. gratissimum* essential oil and Mancozeb compared to Copper Hydroxide and Lippia multiflora essential oil. Thus, *O. gratissimum* may act directly on the vegetative organs of the pathogen, especially on the propagation organs, according to Camara et al. (2010). In a similar study, Kouamé et al. (2015) reported that *O. gratissimum* essential oil was as effective as Azoxystrobin in curative treatment of mango anthracnose.

CONCLUSION

The main goal of this study was to improve banana productivity in Burkina Faso. It evaluated the effectiveness of various synthetic fungicides and essential oils, determining their optimal doses. Under in vivo conditions, Mancozeb and *O. gratissimum* essential oil better controlled disease spread than other treatments. However, their effectiveness depends on the application method.

For prevention, Mancozeb was effective at all doses, whereas *O. gratissimum* essential oil showed better curative performance. Its medium and high doses were effective, whereas the low dose was moderately effective. *L. multiflora* was moderately effective at the high dose in a curative treatment.

Based on these results, Mancozeb and *O. gratissimum* essential oil were the most effective. These findings are promising because they highlight the potential of *O. gratissimum* essential oil as an alternative for biological control or as part of an integrated pest management system, in combination with Mancozeb. However, further field research is necessary to confirm its effectiveness against black Sigatoka disease of banana.

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