International Journal of Agricultural Research

ISSN 1816-4897

Academic Journals Inc.

www.academicjournals.com

OPEN ACCESS International Journal of Agricultural Research

ISSN 1816-4897
DOI: 10.3923/ijar.2023.17.27

Research Article
Control of Postharvest Anthracnose of Mango Caused by *Colletotrichum gloeosporioides* Penz by the Use of Bio-Pesticides

[1,4]N'Dri Séverin N'Goran, [1,2]Brahima Camara, [1,2]Seydou Tuo, [1,2]Koffi Fernand Jean-Martial Kassi, [3]Koffi Gaston Kouame, [2,3]Toafic Abdel Fabrice Alabi, [1,2]Ler-N'Ogn Dadé Georges Elisée Amari and [1,2]Daouda Kone

[1]Pedagogical and Research Unit of Plant Physiology and Pathology, Laboratory of Biotechnology, Agriculture and Valorization of Biological Resources, UFR Biosciences, Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire
[2]African Center of Excellence for Climate Change, Biodiversity and Sustainable Agriculture, Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire
[3]Faculty of Biological Sciences, Université Peleforo Gon Coulibaly, P.O. BOX 1328, Korhogo, Côte d'Ivoire
[4]Doctoral School of Science Technology and Sustainable Agriculture, Université Felix Houphouet-Boigny, Abidjan, Côte d'Ivoire

Abstract

Background and Objective: Anthracnose caused by the pathogen *Colletotrichum gloeosporioides* penz is one of the major causes of post-harvest losses of mango in Côte d'Ivoire. Chemical control is a common method and has several side-effects. It is in this perspective that the present study was initiated with the general objective of evaluating the *in vitro* and *in vivo* antifungal efficacy of the biopesticides NECO 50 EC, ASTOUN 50 EC and PRORALY 50 EC based on plant extracts against the development of post-harvest anthracnose in mango. **Materials and Methods:** Five concentrations (100, 500, 1000, 1500 and 2000 ppm) of each bio-pesticide were evaluated *in vitro* on the mycelial growth of *C. gloeosporioides*. For the *in vivo* study, 250 mangoes of the Kent variety from the Poro Region, an anthracnose endemic area of Northern Côte d'Ivoire, were used. They were dipped in batches of 25 fruits (10 batches) in different bio-pesticides solutions at doses of 0.15 and 0.20% for 60 and 180 sec for the reference product (prochloraz) at the recommended dose of 0.025%. Treated fruits were stored in a cold room at 10°C for 15 days and at room temperature for 09 days. **Results:** The bio-pesticides NECO 50 EC and ASTOUN 50 EC completely inhibited the radial mycelial growth of *C. gloeosporioides* at concentrations of 1000, 1500 and 2000 ppm. Fruits treated with the biopesticide NECO 50 EC at concentrations of 0.15 and 0.20%, respectively showed no symptoms of anthracnose. In contrast, the negative control and the reference product had incidences above 10%. **Conclusion:** The present study showed the antifungal potential of the biopesticides NECO 50 EC and ASTOUN 50 EC in the control of post-harvest anthracnose of mango. They may constitute an alternative to the abusive use of synthetic fungicides.

Key words: Mango, diseases, anthracnose, *Colletotrichum gloeosporioides*, biopesticides, antifungal activity

Citation: N'Goran, N.S., B. Camara, S. Tuo, K.F.J.M. Kassi and K.G. Kouame *et al.*, 2023. Control of postharvest anthracnose of mango caused by *Colletotrichum gloeosporioides* penz by the use of bio-pesticides. Int. J. Agric. Res., 18: 17-27.

Corresponding Author: Brahima Camara, Pedagogical and Research Unit of Plant Physiology and Pathology, Laboratory of Biotechnology, Agriculture and Valorization of Biological Resources, UFR Biosciences, Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Mango (*Mangifera indica* L.) is a fruit with high added value traded on national, regional and, increasingly, international markets[1]. With an estimated annual production of 180,000 tons and an export of 34,154.25 tons in 2021. Côte d'Ivoire is the leading African exporter and the third largest supplier to the European market after Brazil and Peru[2]. This production generates around CFAF 7 billion in the northern areas where, it is grown[3]. Despite its commercial and economic importance, its production is faced with numerous abiotic and biotic constraints. Among the biotic constraints, post-harvest alterations due to the resurgence of fungal pathogens such as *Colletotrichum gloeosporioides*, *Lasiodiplodia theobromae* and *Alternaria alternata* constitute the major constraints in mango cultivation[4-6]. Of all these fungal diseases, anthracnose, caused by the pathogen *C. gloeosporioides* is the most constraining[7,8]. It attacks the fruit before and after harvest, resulting in interceptions of shipments to European markets and the reduction of the season's time from the onset of the first rains[9]. This situation leads to huge losses in earnings for producers and exporters. Post-harvest losses are estimated at around 30-35% or even 100% of total production if no treatment is carried out. This is equivalent to economic losses of nearly CFAF 3.3 billion per year[10,11]. To reduce the impact of anthracnose on post-harvest losses, many control methods have been advocated and the most widely used method is the use of synthetic fungicides such as prochloraz, fludioxonil, benomyl, maneb, chlorothalonil and mancozeb[12,13]. However, although relatively effective, the use of these synthetic products very often poses the problem of pesticide residues in fruits and are responsible for long-term toxicity on plant organs and consumers[14,15]. In addition, the gradual withdrawal of several chemical molecules for post-harvest treatments of mango raises many concerns for stakeholders in the mango sector. The competitiveness of the production systems is conditioned by the compliance of the mango with the standards and regulations of the importing countries relating to sanitary quality, with a view to safeguarding the health of consumers and the environment. These observations require a redefinition of control methods and new production approaches. The objective of this study was therefore to evaluate the *in vitro* and *in vivo* antifungal efficacy of the biopesticides NECO 50 EC, ASTOUN 50 EC and PRORALY 50 EC based on plant extracts against the development of post-harvest anthracnose in mango.

MATERIALS AND METHODS

Study area: The Poro Region covers a total area of 13,400 km^2. It is located in the extreme north of Côte d'Ivoire. The region is bordered to the north by the Republic of Mali, to the south by the Béré Region, to the east by the Tchologo and Hambol Regions and to the west by the Bagoué Region. It is located between latitudes 5°16 and 6°16 N and western longitudes 8°32 and 10°20. The vegetation of the region is that of the tree Savannah or Western Sudanian Savannah, according to the classification of ecoregions defined by the Worldwide Fund for Nature[16]. The climate of the Poro Region is tropical, with a very hot and dry period from November to April and a rainy period from May to October[16]. During the dry period, the harmattan, the dusty wind from the Sahara Desert, can blow. In the Poro Region, annual rainfall varies between 1200 and 1400 mm and the average annual temperature varies between 25.5 and 30.1°C. The population of the Poro Region is 1040,461 inhabitants in 2021 according to estimates by the national institute of statistics (INS). The population remains essentially agro-pastoral and thus combines agriculture with livestock. Agriculture, mainly rain-fed and extensive livestock farming are the main activities in the region.

The study *in vitro* and *in vivo* was carried out in June, 2022 at the Laboratory of Biotechnology, Agriculture and Valorization of Biological Resources of the Félix Houphouët Boigny University (Cote d'Ivoire).

Materials

Plant material: The plant material used in this study was exportable mangoes of the Kent variety, apparently healthy in sizes 9 and 10 (Fig. 1). They come from the Poro Region, an area endemic to anthracnose in the north of Côte d'Ivoire, precisely in the Korhogo department.

Fungal material: The fungal strain AN4 of *Colletotrichum gloeosporioides* Penz, isolated from a sample of mangoes collected in the Poro Region and showing the characteristic symptoms of anthracnose, was used Fig. 2(a-b). This strain of *C. gloeosporioides* was characterized morphologically and phenotypically. The *C. gloeosporioides* strain AN4 has a greyish-white colour above the Petri dish showing an aerial, cottony mycelial colony with a greyish underside. The conidia have a cylindrical appearance with average lengths of 12.72 µm and average widths of 5.16 µm. A sample of the AN4 strain is kept at the mycotheque of the Pedagogical and Research Unit of Plant Physiology and Pathology of the Felix Houphouet-Boigny University of Cocody (Côte d'Ivoire).

Fig. 1: Size cardboard mangoes

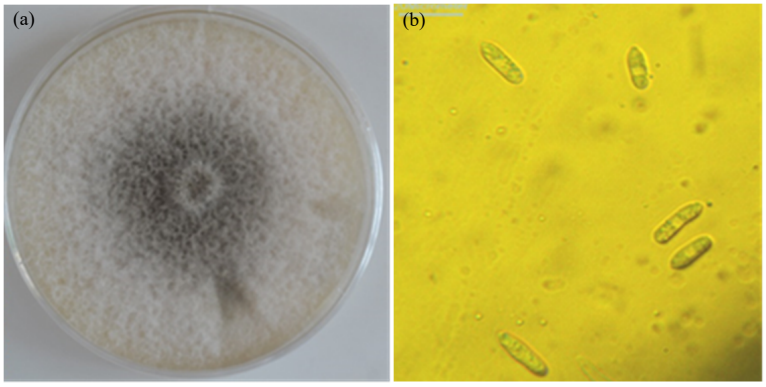

Fig. 2(a-b): Morphological characteristics of the fungal strain AN4 of *Colletotrichum gloeosporioides* used (a) Macroscopic appearance and (b) Microscopic appearance

Table 1: Characteristics of the fungicides tested

Active ingredient	Trade name	Chemical family	Type of formulation
Thymol, gamma terpinene and eugenol	NECO®	Biopesticide	50 EC
Geranial et neral	ASTOUN®	Biopesticide	50 EC
Thymol, eugenol, citronellal, citronellol	PRORALY®	Biopesticide	50 EC
Prochloraze	MIRAGE	Imidazole	450 EC

Bio-pesticides tested: Three bio-pesticides were tested in this study, namely NECO 50 EC, ASTOUN 50 EC and PRORALY 50 EC (Table 1). These bio-pesticides based on plant extracts were provided by the Industrial Research Unit (URI) on bio-pesticides of Felix Houphouet-Boigny University of Cocody (Côte d'Ivoire). These bio-pesticides evaluated *in vitro* and *in vivo* were compared to the synthetic fungicide MIRAGE 450 EC, which is a synthetic fungicide registered on mango in Côte d'Ivoire whose active ingredient is prochloraz.

Methods

Effect of bio-pesticides on mycelial radial growth of *Colletotrichum gloeosporioides*: To evaluate the *in vitro* effect of bio-pesticides on the radial mycelial growth of *C. gloeosporioides*, preliminary tests were carried out to determine the minimum and maximum concentrations to be used in this work. Thus, five concentrations (100, 500, 1000, 1500 and 2000 ppm) corresponding, respectively to (100, 500, 1000, 1500 and 2000 µL L^{-1}) were retained. The culture medium used was potato dextrose agar (PDA). This medium was prepared by adding 20 g of potato puree, 20 g of D-glucose and 20 g of Agar-agar to an Erlenmeyer flask. The volume of the mixture was adjusted with sterile distilled water to 1 L and autoclaved at 121°C under a pressure of 1 bar for 30 min. The medium was then cooled to 45°C and the bio-pesticides were incorporated at concentrations of 100, 500, 1000, 1500 and 2000 ppm. The synthetic fungicide MIRAGE 450 EC used is in concentrated form. From this

Table 2: Level of susceptibility or resistance of *Colletotrichum gloeosporioides* strain AN4 and fungicide efficacy according to the Kumar *et al.*[18]

Class of mycelial inhibition rates Ic (%)	Level of sensitivity/resistance of the fungus	Fungicide efficacy level
Ic>90	Highly sensitive	Very good efficacy
75<Ic≤90	Sensible	Good efficacy
60< Ic≤75	Moderately resistant	Average efficacy
40≤Ic≤60	Resistant	Low efficacy
Ic<40	Highly resistant	Very low efficacy

concentrated form, a 100 mL stock solution of 1000 ppm was prepared by solubilising it in sterilised distilled water. The synthetic fungicide MIRAGE 450 EC, from the 1000 ppm stock solution, was incorporated into the PDA culture medium to obtain concentrations of 10, 50, 100, 150 and 200 ppm. All of the incorporated products were homogenised under agitation and then distributed under a laminar flow hood (STERIL-BIO BAN Compact brand) in 90 mm diameter petri dishes at a rate of 20 mL per dish. Using a cookie cutter, 5 mm diameter mycelial slices were taken from a 7-day old culture of *C. gloeosporioides* strain AN4 and placed in the center of 90 mm Petri dishes containing PDA medium amended with fungicides. The inoculated Petri dishes were sealed with stretch film and incubated at room temperature in the laboratory at 25±2°C, under a 12 hrs photoperiod. A total of five Petri dishes were used for each concentration and for each fungicide (bio-pesticide and synthetic fungicide) and the experiment was repeated 3 times in time. An unfungicide-treated control was carried out under the same culture conditions as before. The radial growth of the mycelium of the fungal colony was assessed every two days according to two perpendicular lines drawn on the reverse side of the Petri dishes and passing through the center, until the surface of the culture medium in the control Petri dish was completely covered, i.e. 10 days after culturing. The effect of fungicides on the radial mycelial growth of *C. gloeosporioides* strain AN4 was determined from the inhibition rate (Ic) calculated according to the formula of Lima *et al.*[17]:

$$\text{Ic } (\%) = \frac{D_0 - D_c}{D_0} \times 100$$

With, D_0 is diameter of the control without fungicide and D_c is growth diameter of the fungus at a concentration (c) of fungicide.

The level of sensitivity or resistance of the fungal strain used was determined according to the scale adapted from Kumar *et al.*[18] (Table 2).

Mycelial pellet recovery test of *Colletotrichum gloeosporioides*: For each bio-pesticide, when mycelial growth was not observed for a given concentration, then the Petri dishes are opened and the mycelial disc is transplanted into a new Petri dish containing PDA medium alone. All of these dishes are kept under the same conditions as before. At the end of the seventh day, the bio-pesticide is evaluated as a fungicide if there is no mycelial regrowth, otherwise, it is declared fungistatic[19,20].

Effect of bio-pesticide application on the development of mango anthracnose: To evaluate the *in vivo* effect of bio-pesticides on the development of mango anthracnose, two slurries at different doses were prepared for each bio-pesticide. For the first dose (0.15%) a volume of 75 mL was taken and poured into a tank already containing 5 L of sterile distilled water. After homogenization, the volume was made up to 50 L with sterile distilled water. For the second dose (0.20%), the volume taken from each bio-pesticide was 100 mL. The synthetic fungicide dip was prepared at the recommended rate (0.45 mL L^{-1}).

The 250 mangoes of the Kent variety were washed thoroughly with tap water and soap and rinsed 3 times with tap water. After rinsing, the fruits were exposed to room temperature for drying on a sterile surface for 1 hr. The fruits were then dipped in batches of 25 fruits/product/concentration for 60 sec for the bio-pesticides and 3 min for the reference product. The negative control was soaked in tap water for 3 min. After soaking, the mangoes were dried on shelves at room temperature and then placed in the packaging boxes. The boxes are marked with the name of the product tested and its dose. The treated fruit was stored in a cold room at 10°C for 15 days to simulate shipping conditions to Europe and at room temperature for 09 days.

Measured parameters and monitoring of the test: The ability of bio-pesticides to reduce or limit *Colletotrichum gloeosporioides* infections was evaluated. This evaluation focused on two phytopathological parameters which are: Incidence, severity and average number of disease spots on fruits. These parameters were evaluated at the exit of the cold room every 03 days for 09 days (i.e., 3 observations) at room temperature.

Impact assessment: The disease infection rate was determined by the ratio of the number of fruits with anthracnose symptoms to the total number of fruits treated with the bio-pesticide or synthetic fungicide.

Severity assessment: The average severity of anthracnose in treated fruit was assessed using a visual rating scale of Coronel *et al.*[20] ranging from 0 to 4 with:

- 0: No disease
- 1: 1-5% of the fruit surface shows mild symptoms
- 2: 6-9% of the fruit surface shows moderate symptoms
- 3: 10-49% of the fruit surface shows severe symptoms
- 4: 50-100% of the fruit surface shows very severe symptoms

From these scores the anthracnose severity index was calculated according to the following formula of Corkidi *et al.*[21]:

$$IS = \sum \frac{n_i}{x_t \times 4} \times 100$$

With IS is severity index, n_i is individual disease symptom score on each fruit, x_t is total number of fruits observed and 4 is highest score on the scale.

Average number of disease spots on fruit: The average number of disease spots on the fruit was determined by counting the characteristic anthracnose symptom spots on the assessed fruit.

Statistical analysis: Data collected on the rates of mycelial radial growth inhibition of *C. gloeosporioides* were subjected to a One-way Analysis of Variance (ANOVA I) using statistical version 12.5 software. When a significant difference was observed, the Newman-Keuls statistical test at the 5% level was used to separate the means.

RESULTS

Effect of different concentrations of bio-pesticides on mycelial radial growth of *Colletotrichum gloeosporioides*: All three bio-pesticides (NECO 50 EC, ASTOUN 50 EC and PRORALY 50 EC) and the synthetic fungicide (MIRAGE 450 EC) tested this study showed antifungal activity against the AN4 strain of *Colletotrichum gloeosporioides* used. Their effects on the radial mycelial growth of *C. gloeosporioides* varied with time and concentration. Concentrations of 1000, 1500 and 2000 ppm of the bio-pesticides NECO 50 EC and ASTOUN 50 EC completely inhibited (Ic = 100%) the radial mycelial growth of the AN4 strain (Fig. 3 and 4). At the same concentrations, the bio-pesticide PRORALY 50 EC recorded inhibition rates between 50.14 and 88.31% for the first 6 days of the experiment (Fig. 5). At the 500 ppm concentration, only the bio-pesticide ASTOUN 50 EC was able to maintain the inhibition rate of radial mycelial growth of the AN4 strain at more than 50% for the entire test period (Fig. 4). The 100 ppm concentration of all three bio-pesticides had the lowest inhibition rates. These inhibition rates are below 50% for all bio-pesticides. For the synthetic fungicide MIRAGE 450 EC,

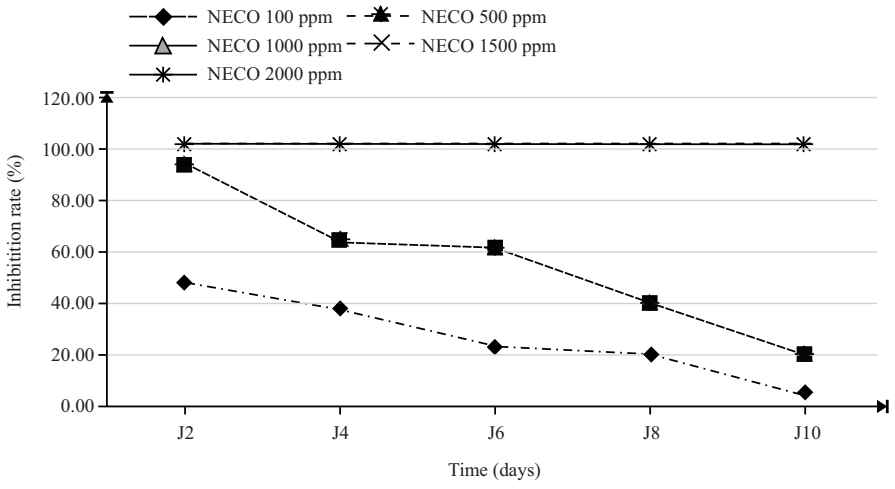

Fig. 3: Evolution of the inhibition rate of mycelial growth of *Colletotrichum gloeosporioides* as a function of time and concentrations of NECO 50 EC

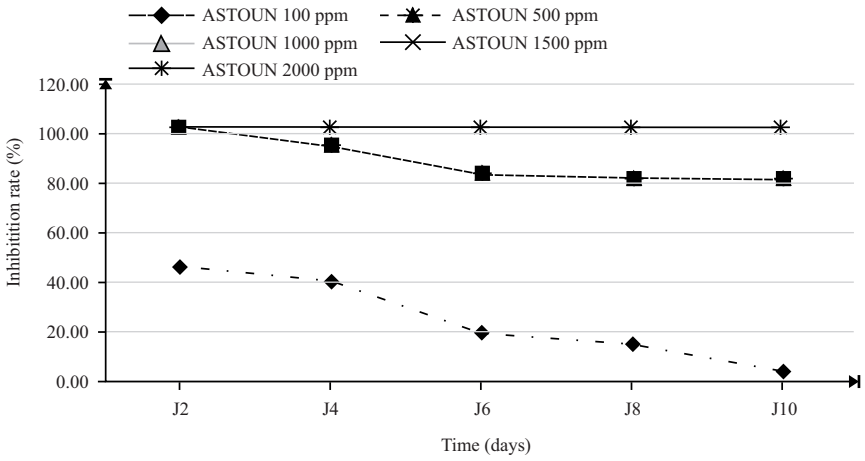

Fig. 4: Evolution of the inhibition rate of mycelial growth of *Colletotrichum gloeosporioides* as a function of time and concentrations of ASTOUN 50 EC

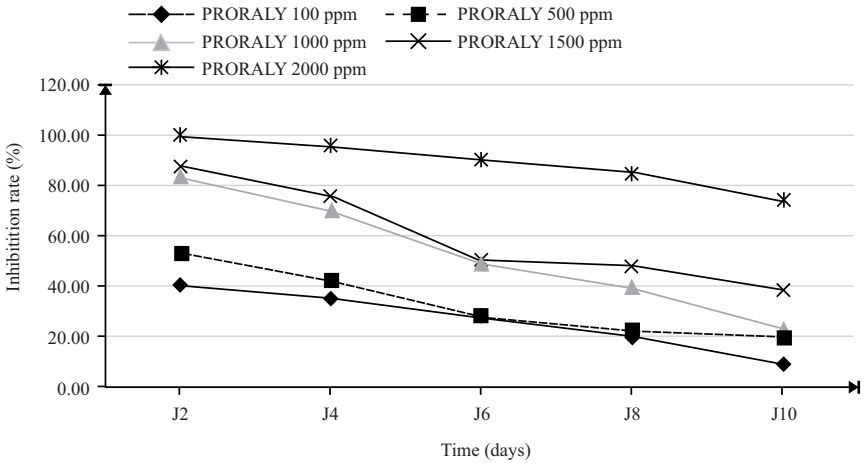

Fig. 5: Evolution of mycelial growth inhibition rate of *Colletotrichum gloeosporioides* as a function of time and concentrations of PRORALY 50 EC

the 100 and 200 ppm concentrations completely inhibited radial mycelial growth of the pathogen *C. gloeosporioides*. Concentrations of 10 and 50 ppm of the synthetic fungicide 450 EC reduced mycelial radial growth to an average inhibition rate of over 50% (Fig. 6). According to the Kumar *et al.*[18] scale, the bio-pesticides and synthetic fungicide tested on *C. gloeosporioides* can be classified into four classes according to their inhibition rates (Table 2):

- *Colletotrichum gloeosporioides* strain AN4 is highly susceptible to the 1000, 1500 and 2000 ppm concentrations of the bio-pesticides NECO 50 EC and 3ASTOUN 50 EC (Ic>90%). This is equivalent to a very good efficacy of the bio-pesticides NECO 50 EC and ASTOUN 50 EC at these concentrations (Fig. 3 and 4)
- At concentrations of 100 and 500 ppm, the AN4 strain is highly resistant to NECO 50 EC bio-pesticides (Ic<40). At these concentrations, NECO 50 EC bio-pesticide has a very low efficacy (Fig. 3 and 7)
- With ASTOUN 50 EC bio-pesticide, the AN4 strain is sensitive at 500 ppm (75<Ic<90) and moderately resistant at 100 ppm (60<Ic<75). The bio-pesticide ASTOUN 50 EC has therefore a good efficacy at the 500 ppm concentration and a medium efficacy at the 100 ppm concentration (Fig. 4 and 7)

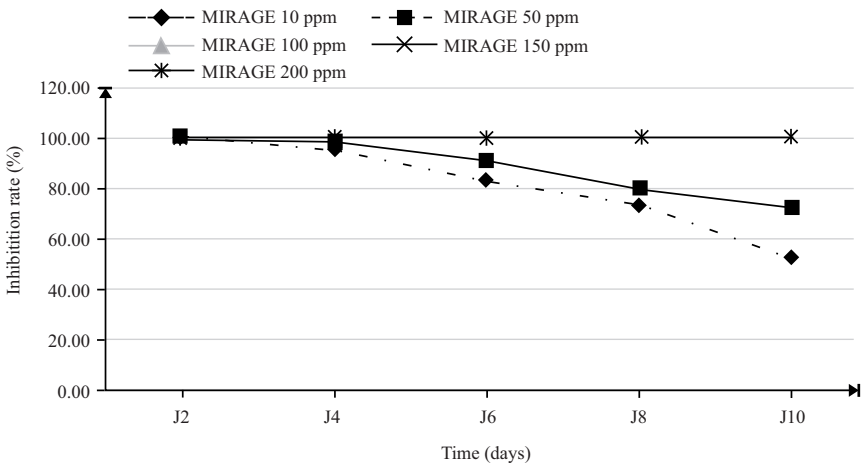

Fig. 6: Evolution of the inhibition rate of mycelial growth of *Colletotrichum gloeosporioides* as a function of time and MIRAGE 450 EC concentrations

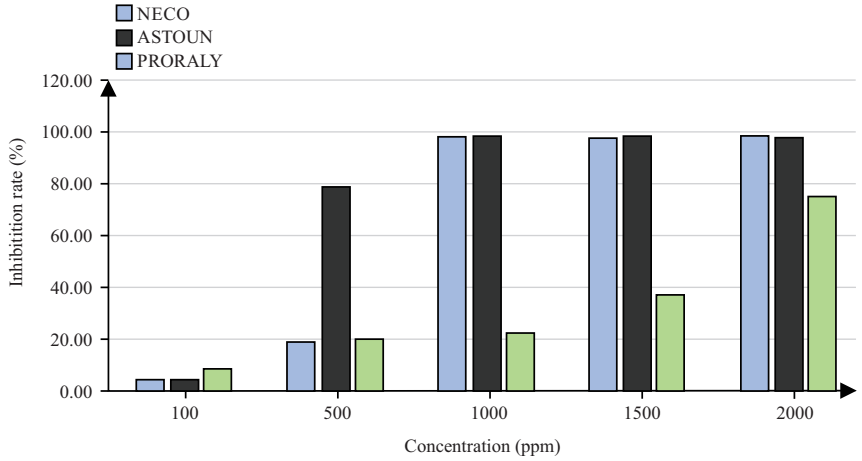

Fig. 7: Reduction in mycelial growth of *Colletotrichum gloeosporioides* as a function of bio-pesticide concentrations at day 9

- The bio-pesticide PRORALY 50 EC had very low efficacy at 100, 500, 1000 and 1500 ppm on strain AN4 (CI<40%). The AN4 strain is therefore highly resistant to these concentrations of PRORALY 50 EC bio-pesticide. At 2000 ppm of the bio-pesticide PRORALY 50 EC, *C. gloeosporioides* strain AN4 is moderately resistant, thus conferring a moderate efficacy to this bio-pesticide (Fig. 5 and 7)

Effect of bio-pesticides on the recovery of the mycelial pellet of *Colletotrichum gloeosporioides*: The evaluation of the toxicity of the bio-pesticides and the synthetic fungicide revealed the fungistatic or fungitoxic effect of these fungicides which completely inhibited the radial growth of the mycelium. The bio-pesticides that completely inhibited the radial mycelial growth of *C. gloeosporioides* were the bio-pesticides NECO 50 EC and ASTOUN 50 EC at concentrations of 1000, 1500 and 2000 ppm and the synthetic fungicide (MIRAGE 450 EC) at concentrations of 100, 150 and 200 ppm.

Mycelial pellets from the PDA medium amended with the bio-pesticide NECO 50 EC at concentrations of 1000, 1500 and 2000 ppm were not able to re-grow after transplanting onto the new unamended PDA medium. This bio-pesticide therefore had a fungitoxic effect on the radial mycelial growth of *C. gloeosporioides* (Table 3). In contrast, with mycelium slices from media amended at concentrations of 1000, 1500 and 2000 ppm with the bio-pesticide ASTOUN 50 EC, the recovery of mycelial growth was 100% on the new PDA medium without amendment. The effect of the bio-pesticide ASTOUN 50 EC is therefore said to be fungistatic on the radial mycelial growth of the *C. gloeosporioides* strain used (Table 3).

Effect of different doses of bio-pesticides on the development of post-harvest anthracnose *in vivo*: During cold storage, the bio-pesticides NECO 50 EC, ASTOUN 50 EC and PRORALY 50 EC, proved to be the most effective products under the trial conditions, with an efficacy of almost 100% in cold storage for the 0.15 and 0.20% doses of the three products. However, 4% of fruit treated with MIRAGE 450 EC synthetic fungicide and 10% of control fruit (fruit soaked in tap water) showed symptoms characteristic of anthracnose.

Effect of products 09 days after removal from cold storage: The incidence of anthracnose varied according to fungicide and concentration. It was less than 22% for all treatments. Fruit treated with the biopesticide NECO 50 EC at concentrations of 0.15 and 0.20%, respectively, showed no symptoms typical of anthracnose in mango. However, untreated fruits (controls) and fruits treated with the biopesticide PRORALY 50 EC at 0.15% had the highest incidence (19% respectively) of anthracnose (Fig. 8).

The values of the histograms followed by the same letter are not significantly different according to the Newman-Keuls test at the 5% threshold.

Evolution of disease symptoms: After removal from cold storage, the fruits were kept at room temperature at the Laboratory of the Pedagogical and Research Unit of Plant Physiology and Pathology of the Felix HOUPHOUET-BOIGNY University, Abidjan (Côte d'Ivoire). The disease then developed significantly on all fruits, except those treated with NECO at the 0.2% dose (Fig. 9).

Table 3: Mycelial growth of *Colletotrichum gloeosporioides* on unfungicide-treated PDA after total inhibition tests on treated PDA

Products	Concentrations (ppm)	Behavior of the washer (growth or not growth)
NECO 50 EC	1000, 1500 and 2000	-
ASTOUN EC	1000, 1500 and 2000	+
MIRAGE	100, 150 and 200	+

NB: +Resumption of mycelial growth of the fungal strain of *Colletotrichum gloeosporioides* and -: No resumption of mycelial growth of the fungal strain of *Colletotrichum gloeosporioides*

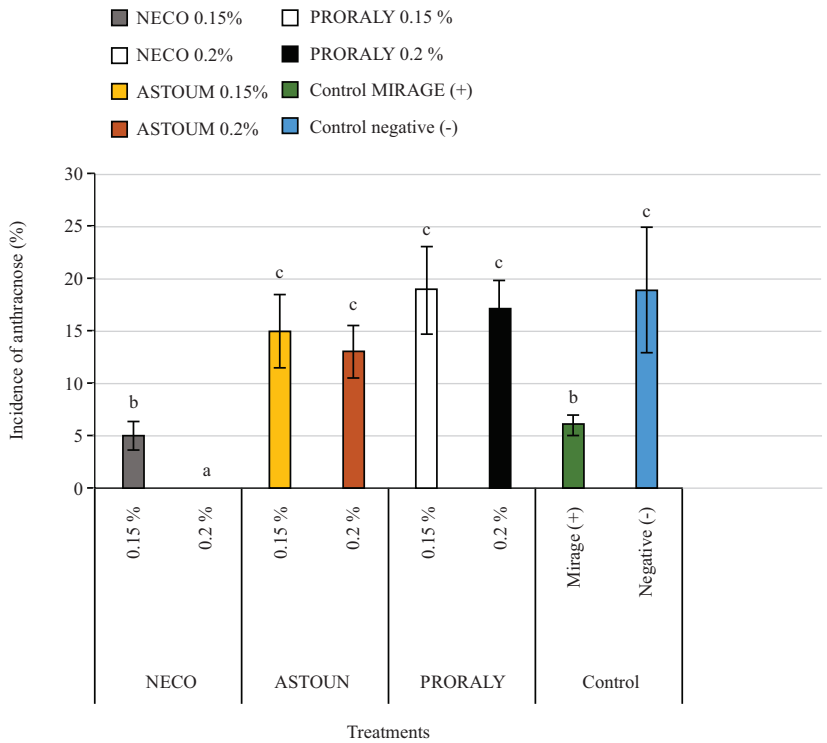

Fig. 8: Incidence of anthracnose according to the treatments during nine days after removal from cold storage

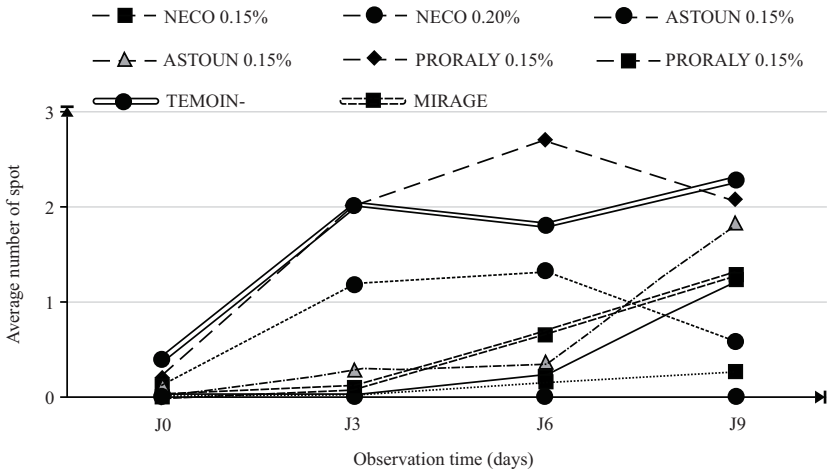

Fig. 9: Evolution of characteristic anthracnose spots during exposure to room temperature

DISCUSSION

This study evaluated the *in vitro* and *in vivo* antifungal activity of the three bio-pesticides NECO 50 EC, ASTOUN 50 EC and PRORALY 50 EC based on plant extracts and the synthetic fungicide MIRAGE 450 EC (prochloraz). The efficacy of these bio-pesticides was tested *in vitro* on the AN4 strain of *Colletotrichum gloeosporioides* isolated from a mango sample showing the characteristic symptoms of anthracnose. Analysis of the effect of varying bio-pesticide concentrations on mycelial radial growth of *C. gloeosporioides* strain AN4 showed that the antifungal activity exhibited was greater at higher concentrations. This shows that the demonstrated antifungal activities are dose-dependent of the biopesticides[22,23]. These three bio-pesticides also showed strong antifungal activity in the concentration range tested. The efficacy of these bio-pesticides on *Colletotrichum gloeosporioides* would be attributed to the presence of chemical molecules that constitute the materials of these bio-pesticides. Indeed, several authors have shown the efficacy of some plant extract-based bio-pesticides on different species of fungal crop pathogens. Thus, Seydou *et al.*[24], in his research on alternative management strategies to chemical control against *Mycosphaerella fijiensis* Morlet was able to demonstrate the antifungal activity of a range of plant extract-based bio-pesticides. Balakissa *et al.*[25] and N'Goran *et al.*[26] tested the antifungal activity of the bio-pesticides NECO 50 EC and ASTOUN 50 EC against *Phytophthora katsurae* and *Phytophthora palmivora*, the agents responsible for brown rot of cocoa pods.

Dipping mangoes of the Kent variety in slurries prepared at different concentrations with the bio-pesticides NECO 50 EC, ASTOUN 50 EC and PRORALY 50 EC and the synthetic fungicide MIRAGE 450 EC showed that both types of fungicides are able to inhibit the development of anthracnose symptoms.

Fruit dipped in the 0.15% NECO 50 EC slurry showed no symptoms. This antifungal activity would be due to the action of the chemical compositions of the bio-pesticides which would inhibit the development of the anthracnose pathogen[27]. The antifungal activity of the bio-pesticide NECO 50 EC on the mycelial and spore growth of *Colletotrichum gloeosporioides*, the causal agent of anthracnose of cashew was demonstrated by Nakpalo *et al.*[28] The authors showed that this bio-pesticide inhibits the growth of the pathogen's propagation organs. Moreover, the work of Ouedraogo *et al.*[15], showed the insecticidal activity of the essential oil of *Cymbopogon nardus*, giving a mortality rate of 99.5±0.50 at 100 µL of *Sitophilus zeamais* adults after 72 hrs of oil application. However, the majority of the compounds in this essential oil are citronellal (30.58%) and geraniol (23.93%). These same compounds constitute the majority of the active ingredients of the bio-pesticide ASTOUN 50 EC. Similarly, Jin *et al.*[14] also showed, after chemical analysis of the essential oil extracted from *Cymbopogon citratus* that cis-citral, trans-citral and geraniol were the dominant compounds in proportions of 36.51, 31.42 and 8.78%, respectively.

The three bio-pesticides were evaluated *in vitro* on a single strain of *Colletotrichum gloeosporioides* from a single mango growing area in Côte d'Ivoire. Also, the mangoes used for the *in vivo* tests came from the same area as the pathogen. This study should be extended to other strains of *C. gloeosporioides* from other mango growing areas. The bio-pesticides tested must be evaluated under natural conditions of infestation of *C. gloeosporioides*.

This study needs to be continued to determine the physico-chemical parameters after fruits in bio-pesticide slurries. Post-harvest treatments of mango and other tropical fruits with bio-pesticides will reduce the use of chemical molecules. The use of bio-pesticides for post-harvest disease control of mango and other tropical fruits is a viable option for a sustainable alternative to the use of synthetic molecules.

CONCLUSION

All the products used in this study showed a varied inhibitory power depending on the concentrations tested. *In vitro*, *C. gloeosporioides* was sensitive to the different biopesticides. Among the three biopesticides, the biopesticides ASTOUN 50 EC and NECO 50 EC had a more pronounced effect than the biopesticide PRORALY 50 EC. The synthetic fungicide showed a strong antifungal activity *in vivo*, the respective doses of 0.15 and 0.20% NECO 50 EC completely prevented the development of anthracnose in mangoes from these different treatments. This biopesticide could be used as an alternative to the withdrawal of synthesized active ingredients.

SIGNIFICANCE STATEMENT

The need for this study lies in the possibility of finding a viable and sustainable alternative to synthetic products for the control of post-harvest diseases of mango, which present risks to the environment, biodiversity and consumers. The results of this study showed a strong potential of bio pesticides to inhibit the anthracnose pathogen in the laboratory and to prevent the development of this disease on fruits treated with these bio pesticides. These results are important in that they give the possibility of using bio pesticides for disease control.

ACKNOWLEDGMENTS

We sincerely thank the Interprofessional Fund for Agricultural Research and Advice (FIRCA) for funding the project "Sustainable and innovative mango production in Côte d'Ivoire through pest control, contract N°1932/FIRCA/UFHB/FADCI-FCIAD/2019". We would like to thank all the producers in the northern part of Côte d'Ivoire who agreed to make their mango plots available to us for our research activities.

REFERENCES

1. Wangithi, C.M., B.W. Muriithi and R. Belmin, 2021. Adoption and dis-adoption of sustainable agriculture: A case of farmers' innovations and integrated fruit fly management in Kenya. Agriculture, Vol. 11. 10.3390/agriculture11040338.
2. Guy, B.K., D. Mohamed, O.Z. Franck, D. Dabé, Y.N. Patrick, K.K.I.I. Nazaire and D.D. Odette, 2021. Distribution of bacterial disease in the main mango production areas of Côte d'Ivoire. Asian J. Agric. Hortic. Res., 8: 26-36.
3. Fofana, S., M. Cissé and K. Soro, 2022. Constraints related to the mango (*Mangifera indica* L.) sector in the Tchologo and Poro Regions (Northern Côte d'Ivoire). Int. J. Agric. Environ. Biores., 7: 165-180.
4. Gaston, K.K., K.K.I.I. Nazaire, K.F. Martial, B.B.B. Antoine, T. Seydou, K. Coffi and K. Daouda, 2015. Antifungal activity of essential oils extracted from *Monodora myristica* (Gaertn), *Ocimum gratissimum* L. and *Zingiber officinalis* roscoe on post-harvest anthracnose of mango fruit (*Mangifera indica* L.) variety kent in Côte d'Ivoire. Int. J. Sci., 4: 8-18.
5. Konsue, W., T. Dethoup and S. Limtong, 2020. Biological control of fruit rot and anthracnose of postharvest mango by antagonistic yeasts from economic crops leaves. Microorganisms, Vol. 8. 10.3390/microorganisms8030317.
6. Reyes-Perez, J.J., L.G. Hernandez-Montiel, S. Vero, J.C. Noa-Carrazana, E.E. Quiñones-Aguilar and G. Rincón-Enríquez, 2019. Postharvest biocontrol of *Colletotrichum gloeosporioides* on mango using the marine bacterium *Stenotrophomonas rhizophila* and its possible mechanisms of action. J. Food Sci. Technol., 56: 4992-4999.
7. Mo, J., G. Zhao, Q. Li, G.S. Solangi and L. Tang *et al*., 2018. Identification and characterization of *Colletotrichum* species associated with mango anthracnose in Guangxi, China. Plant Dis., 102: 1283-1289.
8. Dembele, D.D., L.N. n Dadé Georges Elisée Amari, B. Camara, I. Grechi, J.Y. Rey and D. Kone, 2019. Pre and postharvest assessment of mango anthracnose incidence and severity in the north of Côte d'Ivoire. Int. J. Biol. Chem. Sci., 13: 2726-2738.
9. Akem, C.N., 2006. Mango anthracnose disease: Present status and future research priorities. Plant Pathol. J., 5: 266-273.
10. Arauz, L.F., 2000. Mango anthracnose: Economic impact and current options for integrated management. Plant Dis., 84: 600-611.

11. Ciofini, A., F. Negrini, R. Baroncelli and E. Baraldi, 2022. Management of post-harvest anthracnose: Current approaches and future perspectives. Plants, Vol. 11. 10.3390/plants11141856.
12. Ntui, V.O., E.A. Uyoh, E.E. Ita, A.A.A. Markson and J.N. Tripathi *et al*., 2021. Strategies to combat the problem of yam anthracnose disease: Status and prospects. Mol. Plant Pathol., 22: 1302-1314.
13. Palaniyandi, S.A., S.H. Yang, J.H. Cheng, L. Meng and J.W. Suh, 2011. Biological control of anthracnose (*Colletotrichum gloeosporioides*) in yam by *Streptomyces* sp.MJM5763. J. Appl. Microbiol., 111: 443-455.
14. Jin, C., H. Han, Y. Xie, B. Li, Z. Zhang and D. Zhang, 2022. Toxicity, behavioral effects, and chitin structural chemistry of *Reticulitermes flaviceps* exposed to *Cymbopogon citratus* EO and its major constituent citral. Insects, Vol. 13. 10.3390/insects13090812.
15. Ouedraogo, I., A. Sawadogo, R.C.H. Nebie and D. Dakouo, 2016. Evaluation of the toxicity of essential oils of *Cymbopogon nardus* (L) and *Ocimum gratissimum* (L) against maize insects *Sitophilius zeamais* Motsch and *Rhyzopertha dominica* F, the major insect pests in maize storage in Burkina Faso. Int. J. Biol. Chem. Sci., 10: 695-705.
16. Zadjéhi, K.E.B., D. Nafan, Y.S.D. Martial and S.R. Sylvère, 2021. Effect of seeding rates and nursery management method on the morphological characteristics of seedlings of five varieties of onion (*Allium cepa* L.) in Côte d'Ivoire [In French]. Eur. Sci. J., 17: 208-222.
17. Lima, T.S., K.R. da Silva França, J.L. da Silva, A.B. Santos, J.F. de Oliveira Costa and T.A.L. Cardoso, 2022. Essential oil form clove (*Syzygium aromaticum*) to control *Sclerotium rolfsii in vitro*. Rev. Agro@mbiente On-line, Vol. 16. 10.18227/1982-8470ragro.v16i0.7200.
18. Kumar, R., D.N. Kamra, N. Agarwal and L.C. Chaudhary, 2007. *In vitro* methanogenesis and fermentation of feeds containing oil seed cakes with rumen liquor of buffalo. Asian Australas. J. Anim. Sci., 20: 1196-1200.
19. Ganemtore, S., B. Camara, F.J.M.K. Kassi, A. Kamara and D. Kone, 2022. *In vitro* biological control of four fungi responsible for leaf diseases of yam (*Dioscorea* spp) in Côte d'Ivoire. Int. J. Biol. Chem. Sci., 16: 1929-1940.
20. Coronel, A.C., C.P. Lezama, Y.P. Hernández, O.S. Trinidad, A.R. Tapia and O. Romero-Arenas, 2022. Efficacy of four *in vitro* fungicides for control of wilting of strawberry crops in Puebla-Mexico. Appl. Sci., Vol. 12. 10.3390/app12073213.
21. Corkidi, G., K.A. Balderas-Ruiz, B. Taboada, L. Serrano-Carreon and E. Galindo, 2006. Assessing mango anthracnose using a new three-dimensional image-analysis technique to quantify lesions on fruit. Plant Pathol., 55: 250-257.
22. Chillet, M., J. Minier, M. Ducroq and J.C. Meile, 2018. Postharvest treatment of mango: Potential use of essential oil with thymol to control anthracnose development. Fruits: Int. J. Trop. Subtropical Hortic., 73: 153-157.
23. Seydou, T., A.L.N.D.G. Elisee, K.K.F. Jean-Martial, S. Souleymane and Y. Gnenakan *et al*., 2022. Alternative strategy to the chemical control of *Mycosphaerella fijiensis* morelet, causative agent of banana trees black sigatoka by the use of biopesticides. Am. J. BioSci., 10: 106-117.
24. Seydou, T., K.K.F. Jean-Martial, C. Brahima, O.S. Léonard and K. Daouda, 2021. Biocontrol of *Mycosphaerella fijiensis* morelet, the causal agent of black sigatoka of banana tree (*Musa* spp.) using biopesticides in Côte d'Ivoire. Adv. Biosci. Bioeng., 9: 111-123.
25. Balakissa, F., S. Sibirina, K. Fernand, S. Nakpalo, Z. Michel and K. Daouda, 2020. Valorisation of plant-based biofungicides for eco-efficient management of brown pod rot of cocoa caused by *Phytophthora palmivora* [In French]. J. Anim. Plant Sci., 44: 7664-7676.
26. N'Goran, K.S.B., B. Camara, A.C. N'Guessan, N. Kone, M.S. Tiebre, D. Ouattara and S. Ake, 2021. *In vitro* activities of fungicides based of plants essentials oils (NECO, ASTOUN and FERCA) and phosphorous acid on *Phytophthora katsurae* (Pythiaceae), causal agent of the premature nut fall and the heart rot of the coconut tree, in Côte d'Ivoire. Int. J. Biol. Chem. Sci., 15: 1968-1978.
27. Kassi, J.M.F.K., H.P. N'Guessan, S. Tuo, B. Camara and D. Koné, 2021. Fungitoxic potentialities of NECO 50 EC in an integrated black sigatoka management strategy in industrial dessert banana plantation. Eur. J. Biol. Biotechnol., 2: 47-54.
28. Nakpalo, S., A. Kouabenan, C. Brahima, S. Sibirina and O.G. Mariam *et al*., 2017. Effect of some synthetic fungicides on the *in vitro* growth of *Colletotrichum gloeosporioides*, causative agent of cashew tree anthracnose in Côte d'Ivoire. Asian J. Crop Sci., 9: 149-158.