Journal of Agricultural Chemistry and Environment, 2023, 12, 51-64
https://www.scirp.org/journal/jacen
ISSN Online: 2325-744X
ISSN Print: 2325-7458

Inventory and Management of Fungi Associated with Banana Plant through the Use of *Allium ampeloprasum* and *Cymbopogon citratus* Extracts

Agyingi Lucy Ambang[1], Keuete Kamdoum Elie[2*], Maah Romanus Nyamjua[1,2]

[1]Department of Plant Biology, Faculty of Science, University of Dschang, Dschang, Cameroon
[2]Department of Plant Science, Faculty of Science, University of Buea, Buea, Cameroon
Email: *keuete.elie@ubuea.cm

How to cite this paper: Agyingi *et al.* (2023) Inventory and Management of Fungi Associated with Banana Plant through the Use of *Allium ampeloprasum* and *Cymbopogon citratus* Extracts. *Journal of Agricultural Chemistry and Environment*, **12**, 51-64.
https://doi.org/10.4236/jacen.2023.122005

Received: February 1, 2023
Accepted: April 7, 2023
Published: April 10, 2023

Abstract

Despite the nutritional, economic and medicinal values of banana plant, independent of the region and production system is confronted with some diseases such as the fungi disease. These fungal diseases are responsible for the low yields. The objective of this study was to improve the sanitary state of banana plant. To achieve this objective, fungi associated with banana leaves were isolated on Potato Dextrose Agar (PDA) culture medium and their identification was done on the basis of morphological and microscopic characteristics using reference documents. Antifungal activity of *Allium ampeloprasum* and *Cymbopogon citratus* extracts were evaluated *in vitro* on agar medium on the development of *Pseudocercospora fijiensis*, *P. musicola* and *Pestalopsis* sp. The results showed that banana plant harbours a diversity of fungal species, the most frequent being *P. fijiensis* (51.58%), *Pestalopsis* sp. (15.47%) and *P. musicola* (12.03%). Aqueous extracts of *C. citratus* at the concentration of 15 mg/ml, inhibited 100% of the radial growth of *P. fijiensis* and *Pestalopsis* sp with a fungitoxic activity. Similarly, ethanolic extract *A. ampeloprasum* inhibited at 100% the radial growth of *Pestalopsis* sp. This antifungal activity was fungistatic. These results suggest that the aqueous and ethanol extracts of the tested plants could be used as alternatives to chemical products in the fight against banana diseases especially Sigatoka. Hence further studies need to be undertaken to isolate the active compounds from these extracts with fungicidal potential.

Keywords

Banana, Fungi, *Cymbopogon citratus*, *Allium ampeloprasum*, Plant Extracts

1. Introduction

Banana plant (*Musa acuminata*) is a perennial herbaceous plant of the family of Musaceae, originated from South-East Asia specifically in the region of the Malasia Peninsula, Indonesia, the Philippines and New Guinea [1], which are largely cultivated in many tropical and subtropical regions for their fruit rich in carbohydrates, mineral salts (potassium, zinc, magnesium), vitamins such as B6, A, C, K [2]. It is therefore the most traded fresh fruit in the world and the banana sector also serves as an essential source of employment and is cultivated in over 120 countries on about 10 million hectares particularly in the tropical and subtropical regions in the world for its nutritional, economic and medicinal values [3]. Banana is the world's most important fruit crop in terms of production volume and trade. The global production in 2020 was estimated at 117 million tons. India is the highest producer with a production of 30.5 million tons and Cameroon on the 20th position globally and number 6 in Africa with a production volume of 1.2 million tons [4].

Bananas are essential to food security and livelihoods of about 400 million people in the world [5]. Banana cultivation is a source of income for producing countries. Bananas produced in Cameroon are sold in local and international (CEMAC and EU) markets. In 2020, Cameroonian banana exports generated 136 billion CFA francs [6]. Despite the socio-economic importance of banana, their cultivation is still confronted with several abiotic and biotic constraints. Among the biotic constraints, diseases of fungal origin cause the most serious damages. The fungal diseases of the banana plants are responsible for yield losses and low productivity of bananas [1]. Fungal diseases such as sigatoka are of two types: black and yellow. *Pseudocercospora fijiensis* formally called *Mycosphaerella fijiensis* responsible for black sigatoka [7] and *P. musicola* or *M. musicola* which is responsible for yellow sigatoka [8]. These diseases are responsible for yield losses estimated at about 80% [9]. Panama disease occurs in almost all production areas. It is caused by a soil and root fungus *Fusarium oxysporum*, which causes the plant to suffocate and become unable to take up nutrients and water from the soil [10].

Confronted with these diseases, management is often done through the usage of chemical fungicides. Nonetheless, not only is there a continuous increase in the cost of these chemical fungicides, they induce a certain number of problems like environmental pollution, development of resistance by the fungi and the presence of chemical residues in the fruits which are potentially detrimental to the health of the consumers and workers [11]. Hence, it is important to develop other alternative methods of control other than the use of chemical fungicides. Among these alternative methods, the control method through the usage of natural products is the most recommended. The utilization of natural products, especially plant extracts, has been shown to be effective against many plant pathogens and considered to be safe for consumers and the environment [11]. The works of [12] are reported that aqueous and ethanol extracts of *Cymbopogon citratus* inhibit the development of *Colletotrichum kahawae*, causal agent of anth-

racnose berry coffee. Extract of *Allium ampeloprasum* possess antifungal potential against *Aspergillus niger*, *Penicillium italicum*, *Botrytis cinerea*, and *Trichoderma harzianum* [13]. The aim of this study is to ameliorate banana production through the control of banana plant diseases by the use of plant extracts.

2. Materials and Methods

2.1. Collection of Samples

Symptomise leaves of banana plant were collected from the BOH Plantation Limited in Tiko subdivision of the South-West Region of Cameroon. Samples were put in appropriate bags, labelled and transported to the Research Unit of Phytopathology and Agricultural Zoology of the Faculty of Agronomy and Agricultural Sciences of the University of Dschang for fungi isolation.

2.2. Isolation of Fungi Associated with Banana Leaves

The symptomized leaves collected from the field were washed thoroughly in tap water and cut into small fragments of about 2 mm^2. These fragments were then disinfected in a sodium hypochlorite solution at 2% for 2 minutes and rinsed three times with sterile distilled water. The fragments were plated in Petri dishes containing 20 ml of Potato Dextrose Agar (PDA) medium amended with chloramphenicol (1 g/l) to prevent bacterial contamination and incubated at 24˚C ± 2˚C [14].

After 2 to 3 days of incubation, the growing mycelium was sub-cultured on fresh PDA medium until pure cultures were obtained and maintained in the refrigerator at 4˚C. Morphological identification of fungal isolates was carried out based on the cultural characteristics and with the help of identification key of mycology [15].

Frequency occurrence of isolation of each fungus was calculated using the following formula:

$$F = \frac{NF}{NT} \times 100$$

where F represent the frequency of occurrence (%) of a fungus, NT is the total number of all fungi isolated and NF is the specific number of fungus isolated.

2.3. Preparation of Plant Extracts

Fresh leaves of *Cymbopogon citratus* and *Allium ampeloprasum* were collected in Dschang locality. These leaves were disinfected separately with a sodium hypochlorite solution at 2%, rinsed with sterile distilled water to remove any impurities, chopped into small fragments using a sterilized knife and dried in darkness for one week. When fully dried, the samples were grinded to powder using an electric grinding machine (trade of machine). Thereafter, using cold solvent extraction method [12], 100 g of each processed samples of *A. ampeloprasum* and *C. citratus* were macerated in 500 ml of each solvent (sterile distilled water and ethanol) in a bottle for 48 hours at room temperature. After 48 hours, the mixture

was filtered using cheese cloth followed by Whatmann filter paper N˚. 1.

The different filtrates (aqueous and ethanol) of the two plants were poured into sterilized stainless steel trays (plates) and dried in an electric oven at temperatures of 40˚C. The plant extracts were transferred into labeled sterile bottles and stored at 4˚C in a refrigerator pending utilization for the antifungal activity tests [16].

2.4. *In Vitro* Evaluation of Antifungal Activities of Plant Extracts on the Growth of Different Fungi

Three fungi; *Pseudocercospora fijiensis*, *Pseudocercospora musicola* and *Pestalosis* sp. were selected for this test. The choice of these three fungi was related to high frequencies during the inventory of fungi associated with banana leaves. The evaluation of the inhibition of radial growth of the different fungi was done using the agar dilution method on Potato Dextrose Agar medium. The ethanol extracts were dissolved in Dimethyl Sulphoxide (DMSO). The effect of DMSO was pre-tested to ensure it zero influence on the growth of the selected fungi [12]. For both extracts the concentrations used were 5, 10 and 15 mg/ml. 1 ml of each extracts at different concentrations were incorporated into 19 ml of PDA and poured into sterilised Petri dishes of 90 mm diameter and allowed to solidify in a fume hood which was lighted by flame from a Bunsen burner.

After solidification, mycelia discs (5 mm) of 10-days old growing in pure cultures of each fungus were transferred to the Petri dishes with the help of a cork borer of 5 mm in diameter [11]. PDA plates mixed with fungicide (Dithane) at the recommended dosage of the producer (1 mg/ml) served as the positive control while distilled water served as the negative control. The Petri dishes were incubated at 24˚C ± 2˚C until there was a 100% growth of negative control. This test for *In vitro* evaluation of plant extracts was done in a complete randomized design with 3 replicates and the following parameters were evaluated:

- **Percentage of inhibition**

The effectiveness of the extract was recorded in terms of percentage inhibition (PI), which was calculated according to the following formula:

$$PI = \frac{(DT - D)}{DT} \times 100$$

where DT is the growth diameter of the negative control Petri dish and D is the growth diameter of the supplementary Petri dish of plant extracts. The EC_{50} and EC_{90} were obtained by transforming percentage inhibitions in probity.

- **Nature of toxicity of plant extracts**

The evaluation of the toxicity of plant extracts consisted of seeing if the mycelia growth, where complete inhibition was observed, was accompanied by a fungistatic or fungitoxic activity. In this case, the explants of the mycelium where complete inhibition was observed on the supplementary PDA medium on plant extracts were retaken and placed aseptically on a none fungicide or plant extract containing PDA medium in a sterilized hood lighted by a Bunsen flame. After 10 days of re-incubation, at a temperature of 24˚C ± 2˚C, the activity of plant ex-

tracts was considered as fungistatic if there was mycelia regrowth of the fungal pathogen and fungitoxic if there was no mycelia growth of the pathogen.

2.5. Statistical Analysis of Data

Data collected on the percentage inhibition, EC_{50} and EC_{90} were subjected to the analysis of variance (ANOVA) using SPSS software version 22.0 and the mean values were separated using Duncan Multiple Range Test (DMRT) at 5% probability.

3. Results

3.1. Frequency of Occurrence of Different Fungi Associated with Banana Leaves

Nine fungal species identified were associated with banana leaves (**Figure 1**). Amomg these species, the most frequent fungus was *Pseudocercospora fijiensis* with an isolation frequency of 51.58%. This was followed by *Pestalopsis* sp. and *Pseudoscercospora musicola* with isolation frequencies of 15.47% and 12.03% respectively. The least common fungal species were *Verticillium theobromae*, *Deightoniella torulosa* and *Trichoderma harzianum* with isolation frequencies of 0.29%, 1.72% and 2.29% respectively.

The morphological and microscopic aspects varied with respect to the different fungi (**Figure 2**). *Pseudocercospora musicola* showed faint pink coloured mycelia which became faint purple as it grew to a 10 days old pure culture. *P. fijiensis* showed whitish mycelia which became darkish as it grew to a 10 days old pure culture. Both species under the light microscope, showed elongated conidiophores which are greyish with septate hyphae. *Fusarium oxysporium* was characterised by abundant aerial mycelium which were whitish and hyaline in colour. Microscopically, macro and micro conidia were observed with macro conidia slightly curved with tapering ends. *Trichoderma harzianum*, showed numerous mycelia that were initially whitish which later as the conidia grows, formed scattered blue-green, dark green to yellow green patches. Microscopically, its conidiophores are numerous, branched, ovoid in shape and occurred in clusters. *Verticillium theobromae* showed cream white mycelia with smooth and septate hyphae conidiophores under the microscope with some ramified, some simple and straight.

3.2. Effects of Plants Extract on the Growth of Fungi

3.2.1. Effect of Aqueous Extracts on the Percentage of Inhibition

Table 1 shows the effect of aqueous extracts of *Cymbopogon citratus* and *Allium ampeloprasum* on the percentage inhibition of radial growth of *Pseudocercospora fijiensis*, *Pseudocercospora musicola* and *Pestalosis* sp. The different plant extracts inhibited the growth of each of the fungal species to varying degrees with respect to the plant, type of extract and applied concentration. Petri dishes enriched with *C. citratus* extracts at concentrations of 5 mg/ml and 10 mg/ml showed significantly higher percentages of inhibition of radial growth of *P. fijiensis*, *P. musicola* and *Pestalosis* sp. than those enriched with *A. ameloprasum*

extract at the same concentrations of 5 mg/ml and 10 mg/ml respectively. At 15 mg/ml, *C. citratus* extract showed a 100% inhibition on the radial growth of *Pestalopsis* sp*. and P. fijiensis.* These percentages of inhibitions were significantly identical ($P < 0.05$) to the positive control. However, the Petri dishes that contained only PDA media and the inoculum (negative control) had a 0% inhibition for all the pathogens.

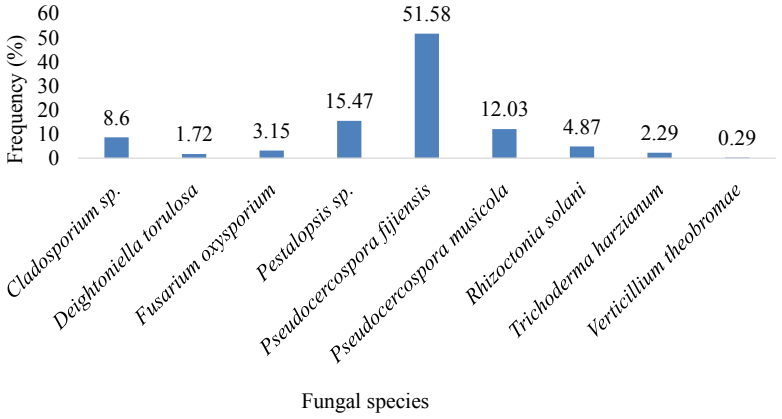

Figure 1. Isolation frequency (%) of fungi associated with banana leaves.

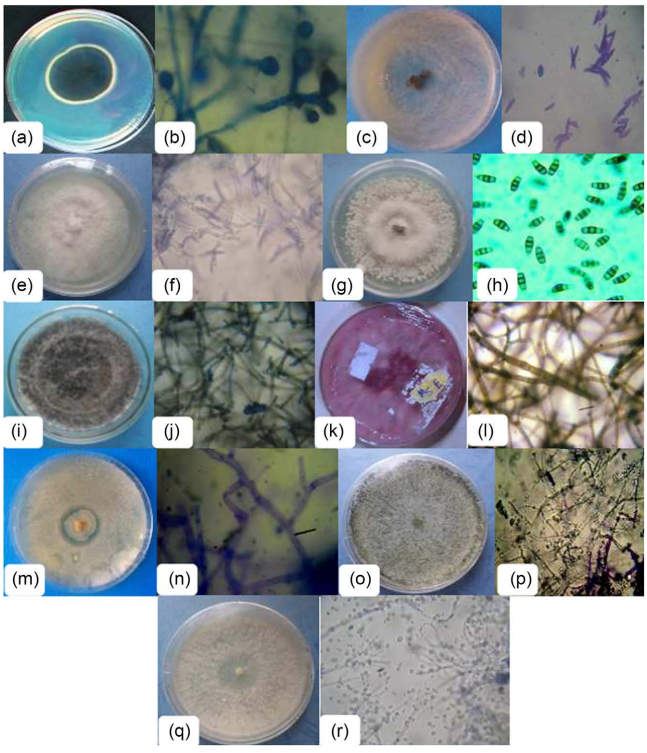

Figure 2. 10 days old of pure culture and microscopic morphology character of some fungi associated with *Musa acuminata* leaves. (a) and (b): *Cladosporium* sp., (c) and (d): *Deightoniella torulosa*, (e) and (f): *Fusarium oxysporium*, (g) and (h): *Pestalopsis* sp., (i) and (j): *Pseudocercospora fijiensis*, (k) and (l): *P. musicola*, (m) and (n): *Rhizoctonia solani*, (o) and (p): *Trichoderma harzianum*, (q) and (r): *Verticillium theobromae*.

Table 1. Effect of aqueous extract on percentage inhibition (%).

Concentrations	*Pseudocercospora fijiensis*	*Pseudocercospora musicola*	*Pestalopsis sp*
	Cymbopogon citratus		
T- (0 mg/ml)	$0.00 \pm 0.00^{d*}$	0.00 ± 0.00^{e}	0.00 ± 0.00^{d}
5 mg/ml	88.82 ± 1.56^{c}	77.84 ± 1.22^{d}	87.06 ± 1.56^{c}
10 mg/ml	94.71 ± 2.56^{b}	83.92 ± 1.2^{c}	90.00 ± 2.56^{b}
15 mg/ml	$100.00 \pm 0.00^{a*}$	93.14 ± 2.07^{b}	$100.00 \pm 0.00_{a}$
T+ (1 mg/ml)	100.00 ± 0.00^{a}	$100.00 \pm 0.00^{a*}$	99.61 ± 0.68^{a}
	Allium ampeloprasum		
T- (0 mg/ml)	0.00 ± 0.00^{d}	0.00 ± 0.00^{e}	0.00 ± 0.00^{d}
5 mg/ml	60.39 ± 6.01^{c}	77.25 ± 1.48^{d}	71.57 ± 4.49^{c}
10 mg/ml	71.96 ± 1.2^{b}	81.96 ± 1.48^{c}	83.53 ± 3.11^{b}
15 mg/ml	76.67 ± 1.22^{b}	95.29 ± 1.18^{b}	98.04 ± 0.34^{a}
T+ (1 mg/ml)	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	99.61 ± 0.68^{a}

*Means affected by the same letter in the same column are not significantly different according to the Duncan test at 5%. T- = negative control (distilled water) and T+ = positive control (Dithane).

3.2.2. Effect of Ethanol Extracts on the Percentage of Inhibition of Fungal Pathogens

The antifungal activity of ethanol extracts of *Cymbopogon citratus* and *Allium ampeloprasum* on the percentage inhibition of the growth of *Pseudocercospora fijiensis*, *Pseudocercospora musicola* and *Pestalopsis sp* as presented in **Table 2**, showed that the degree of inhibition of growth of each pathogen was strictly dependent on the plant type, concentration of the extract and the pathogen in question. The Petri dishes enriched with *A. ampeloprasum* extracts at concentrations 5 mg/ml, 10 mg/ml and 15 mg/ml showed a higher percentage of inhibition more than Petri dishes enriched with *C. citratus* at the same concentrations. *A. ampeloprasum* completely inhibited the growth of *Pestalopsis* sp. at 15 mg/ml. Hence the positive control showed a 100% inhibition on *P. fijiensis* and *P. musicola* and a 99.61% inhibition on *Pestalopsis* sp.

3.3. EC_{50} and EC_{90} Values of Aqueous and Ethanol Extracts

3.3.1. EC_{50} and EC_{90} Values of Ethanol Extracts

EC_{50} and EC_{90} varied depending on the plant or the fungal species (**Table 3** shows). The extract of *Cymbopogon citratus* shows higher values of Equivalent Concentrations (EC) of 50 and 90 compared to the extract of *A. ampeloprasum* which showed the lowest values of $EC_{50\ and}$ EC_{90}. At $EC_{50\ and}$ EC_{90}, *C. citratus* had a significantly higher value on the growth of *Pseudocercospora fijiensis* (12.44 mg/ml and 17.24 mg/ml respectively) compared to *Pseudocercospora musicola and Pestalopsis* sp. *A. ampeloprasum* showed that EC_{50} was not significantly different on the growth of *Pseudocercospora fijiensis* (2.77 mg/ml) and *P. musicola* (2.71 mg/ml).

Table 2. Effect of ethanol extract on percentage inhibition (%).

Concentration	*Pseudocercospora fijiensis*	*Pseudocercospora musicola*	*Pestalopsis sp*
	Cymbopogon citratus		
T- (0 mg/ml)	0.00 ± 0.00^{e*}	0.00 ± 0.00^{d}	0.00 ± 0.00^{d}
5 mg/ml	11.76 ± 1.18^{d}	74.90 ± 2.96^{c}	68.43 ± 4.26^{c}
10 mg/ml	48.63 ± 8.01^{c}	88.04 ± 4.00^{b}	76.47 ± 3.11^{b}
15 mg/ml	66.27 ± 8.26^{b}	90.59 ± 2.34^{b}	97.45 ± 1.89^{a}
T+ (1 mg/ml)	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	99.61 ± 0.68^{a}
	Allium ampeloprasum		
T- (0 mg/ml)	0.00 ± 0.00^{d}	0.00 ± 0.00^{e}	0.00 ± 0.00^{d}
5 mg/ml	83.14 ± 6.56^{c}	84.12 ± 2.56^{d}	95.1 ± 1.36^{c}
10 mg/ml	89.61 ± 3.34^{b}	90.59 ± 1.18^{c}	97.65 ± 1.02^{b}
15 mg/ml	98.43 ± 2.72^{a}	96.86 ± 1.2^{b}	100.00 ± 0.00^{a}
T+ (1 mg/ml)	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	99.610 ± 0.68^{a}

*Means affected by the same letter in the same column are not significantly different according to the Duncan test at 5%. T- = negative control (distilled water) and T+ = positive control (Dithane).

Table 3. EC_{50} and EC_{90} values (mg/ml) of ethanol extract of tested plants.

Fungi	EC_{50}	EC_{90}
	Cymbopogon citratus	
Pseudocercospora fijiensis	12.44 ± 1.13^{a*}	17.24 ± 0.43^{a}
Pseudocercospora musicola	3.17 ± 0.22^{c}	14.95 ± 0.06^{b}
Pestalopsis sp	3.95 ± 0.09^{b}	12.62 ± 0.33^{c}
	Allium ampeloprasum	
Pseudocercospora fijiensis	2.77 ± 0.28^{a*}	11.17 ± 0.17^{a}
Pseudocercospora musicola	2.71 ± 0.08^{a}	9.95 ± 0.29^{b}
Pestalopsis sp	1.64 ± 0.23^{b}	4.55 ± 0.1^{c}

*Means affected by the same letter in the same column are not significantly different according to the Duncan test at 5%.

3.3.2. EC_{50} and EC_{90} Values of Aqueous Extracts

The EC_{50} and EC_{90} values depended on the plant used and the fungus (Table 4). *Cymbopogon citratus* at EC_{50} shows no significant difference between the pathogens with EC_{50} values ranging from 2.09 to 2.53 mg/ml. With *Pseudocercospora musicola*, the higher value of EC_{90} obtained was 12.99 mg/ml. This value was significantly higher than the values of EC_{90} obtained on the growth of *P. fijiensis* (8.71 mg/ml) and *Pestalopsis* sp. (8.52 mg/ml). *Allium ampeloprasum*, on the growth of *P. fijiensis*, shows an EC_{50} (3.91 mg/ml) and EC_{90} (16.81 mg/ml) significantly higher ($P < 0.05$) than the values obtained with the growth of *P. musicola* and *Pestalopsis* sp.

Table 4. EC_{50} and EC_{90} values (in mg/ml) of aqueous extracts.

Fungi	EC_{50}	EC_{90}
Cymbopogon citratus		
Pseudocercospora fijiensis	2.53 ± 0.47[a*]	8.71 ± 0.27[b]
Pseudocercospora musicola	2.53 ± 0.12[a]	12.99 ± 0.35[a]
Pestalopsis sp.	2.09 ± 0.11[a]	8.52 ± 0.49[b]
Allium ampeloprasum		
Pseudocercospora fijiensis	3.91 ± 0.20[a]	16.81 ± 0.18[a]
Pseudocercospora musicola	2.69 ± 0.14[c]	13.70 ± 0.29[b]
Pestalopsis sp.	3.51 ± 0.09[b]	13.35 ± 0.71[b*]

*Means affected by the same letter in the same column are not significantly different according to the Duncan test at 5%.

3.4. Fungistatic and Fungitoxicity Activities of Plant Extracts

The nature of activities of the plant extracts depended on the plant and the fungus (Table 5). The aqueous extract of *C. citratus* showed a fongitoxic effect at 15 mg/ml on the growth of *Pseudocercospora fijiensis* and *Pestalopsis*. Meanwhile the ethanol extract of *A. ampeloprasum* had a fungistatic effect on the development of *Pestalopsis* sp. at 15 mg/ml.

4. Discussion

4.1. Inventory of the Different Fungi Associated with Banana Leaf

This study identified 9 fungal species associated with *Musa acuminata* leaves such as *Pseudocercospora fijiensis*, *P. musicola*, *Fusarium oxysporum*, *Pestalopsis* sp., *Cladosporium* sp., *Rhizoctonia solani.* The presence of this diversity of fungi could be due to the fact that *Musa acuminata* leaves constitute an important source of carbohydrate for these fungi. Species like *P. fijiensis* (51.58%), *P. musicola* (12.03%), and *Pestalosis* sp. (15.47%) had the highest frequency compared to the other fungal species isolated. These three species are generally reported to cause significant damage to the leaves, pseudostems, fruits and of course to the entire banana plant. These results are similar to those of [7], who reported that *Pseudocercospora fijiensis* is a very formidable species for a wide range of hosts, attacking the foliage, stems and fruits of its hosts. *Cladosporium* sp., *R. solani*, *D. torulosa*, *T. harzianum* and *V. dahlia* were relatively less important with respect to their low isolation frequencies. These fungi are however harmful to the banana plant and have also been reported as pathogenic in some fruits including mango, apple, citrus and grape in other parts in the tropics [9] [17]. Several reports showed the implication of the genus *Pseudocercospora* and *Fusarium* as being responsible for the major economic losses in the production of banana [18]. The origin of banana plant infection especially on the leaves by fungi is difficult to determine as it is difficult to predict the potential spread of the pathogens to and from neighboring areas. These results are also similar to

Table 5. Nature of toxicity of plant extracts on the growth of the different fungi at 15 mg/ml.

		Pseudocercospora fijiensis	*Pseudocercospora musicola*	*Pestalopsis* sp.
Aqueous extracts	*Cymbopogon citratus*	F*	/	F
	Allium ampeloprasum	/	/	/
Ethanol extract	*Cymbopogon citratus*	/	/	/
	Allium ampeloprasum	/	/	f

*F: fungitoxic, f: fungistatic and /: none 100% of inhibition on the radial growth of fungus.

those reported by [19], on isolation and pathogenicity evaluation of postharvest fungal of some fruits in Cameroon.

4.2. Effect of Plant Extracts on the Radial Growth Fungal Pathogens

In this study, we investigated the antifungal activities of *Cymbopogon citratus* and *Allium ampeloprasum* extracts against *Pseudocercospora fijiensis*, *P. musicola*, *and Pestalopsis* sp. Our results demonstrated that *C. citratus* and *A. ampeloprasum* extract at all tested concentrations had greater overall depressive effect on the radial growth of these three fungi strains than the negative control. The plants used could have contained inhibiting compounds or substances that could have influenced the growth of the fungal species tested. Indeed, the work of [20] have shown, some plants contain compounds with antifungal properties (alkaloids, sterols, terpenoids, flavonoids, anthraquinone phenols, saponins or tannins), hence their use sometimes in traditional medicine. These results are also similar to those of [21] who showed that *Moringa oleifera* L. seed extract had antifungal activities against fungi associated with banana plant which included; *Fusarium oxysporum*, *F. solani*, *Alternaria solani A. alternate*, *Rhizoctonia solani*, *Sclerotium rolfsii* and *Macrophomina phaseolina*.

Radial growth of the fungi species tested was influenced by the concentration applied as well as by the type of extract. The radial growth of the different test pathogens decreased with increasing concentrations, which may suggest that high concentration of extracts is more fungicidal than low concentrations Similar results of the antifungal activity of some plant extracts against post-harvest fungi in avocado fruit have already been reported by [22]. Different radial growths were observed at the same concentrations. These differences in the activity of plant extracts towards these fungi could be attributed to their active ingredients. On the other hand, according to [23], it should be mentioned that the antifungal activity of plant extracts is often very much linked to simultaneous actions of their constituents.

The results obtained with *Cynbopogon citratus* extracts were in accordance with those obtained by [12] [24] who showed that these extracts had antifungal

activities on the development of *Colletotrichum kahawae* responsible for anthracnose of coffee berry and *Colletotrichum musae* and *Aspergillus niger* responsible for banana fruit rot respectively. Similarly, those obtained with *Allium ampeloprasum* extract are similar to the results obtained by [25] who showed that the *A. sativum* and *A. ampeloprasum* extracts inhibited the development of *Alternaria triticina*, causal agent of leaf blight in wheat and *Magnaporthe oryzae*, causal agent of blast disease in rice.

The EC_{50} and EC_{90} values were heterogeneous. Ethanol extracts were significantly more effective than aqueous extracts. The difference in efficacy between ethanol extracts and aqueous extracts from the tested plants could be due to the fact that ethanol may have extracted compounds with more effective antifungal properties than distill water that may have extracted the majority of compounds with less effective antifungal properties. This hypothesis is similar to the hypothesis of [26] [27] who reported that organic solvent extraction is more effective on antimicrobial activity than water.

Explants on Petri dishes with 100% inhibition were transplanted onto extract-free PDA medium to demonstrate fungistatic or fungitoxic activity. The fungistatic activity observed with *Allium ampeloprasum* extracts are similar to that reported by [11] who showed that *Erigeron floribundus* and *Euphorbia hirta* extracts had fungistatic activity on the fungi associated with avocado. In addition, the results are also similar to those of [28], reported that *Cupressus lusitanica* extracts had fungistatic activity on the growth of *Phytophtora colocasiae*, the agent responsible for taro blight. The fungitoxicity of *Cymbopogon citratus* extract on the growth of the pathogens was in accordance with that of [25], who showed the fungitoxicity activity of these extracts on the development of *Alternaria triticina*, causal agent of leaf blight in wheat.

5. Conclusion

This study revealed that *Musa acuminata* leaves are affected by a diverse range of fungi of which the most common are those belonging to the genus *Pseudocercospora* and *Pestalopsis* sp. The extracts of *A. ampeloprasum* and *C. citratus* can be used for the control of these fungi. Hence, it can be inferred from the results obtained in this study that both ethanol and aqueous extracts of *C. citratus* and *A. ampeloprasum* plants could be developed as natural fungicides in the control of fungi that affects banana plant.

Author's Contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Funding Statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Jones, D.R. (2018) Handbook of Diseases of Banana, Abaca and Enset. CABI, Wallingford. https://doi.org/10.1079/9781780647197.0000

[2] Zebaze, N.R. (2018) Stop AVC et les maladies silencieuses. POSAFA, Yaoundé, 49 p.

[3] FAO (2019) The State of Food and Agriculture: Innovation in Family Farming. 161 p.

[4] FAOSTAT (2021) Production mondiale de la Banae.

[5] FAO (2020) Technical Manual Prevention and Diagnostic of *Fusarium* Wilt (Panama Disease) of Banana Caused by *Fusarium oxysporum* f. sp. cubense Tropical Race 4 (TR4). 74 p.

[6] Czislowski, E., Fraser-Smith, S., Zander, M., O'Neill, W.T., Meldrum, R.A., Tran-Nguyen, L.T.T., Batley, J. and Aitken, E.A.B. (2017) Investigating the Diversity of Effector Genes in the Banana Pathogen, *Fusarium oxysporum* f. sp. cubense, Reveals Evidence of Horizontal Gene Transfer. *Molecular Plant Pathology*, **19**, 1155-1171. https://doi.org/10.1111/mpp.12594

[7] Yonow, T., Ramirez-Villegas, J., Abadie C., Darnell, R.E., Ota, N. and Kriticos D.J. (2019) Black Sigatoka in Bananas: Ecoclimatic Suitability and Disease Pressure Assessments. *PLOS ONE*, **14**, e0220601. https://doi.org/10.1371/journal.pone.0220601

[8] Churchill, A.C.L. (2011) *Mycosphaerella fijiensis*, the Black Leaf Streak Pathogen of Banana: Progress towards Understanding Pathogen Biology and Detection, Disease Development and Changes of Control. *Molecular Plant Pathology*, **12**, 307-328. https://doi.org/10.1111/j.1364-3703.2010.00672.x

[9] Kwon-Ndung, E.H., Terna, T.P., Goler, E.E. and Obande, G. (2022) Post-Harvest Assessment of Infectious Fruit Rot on Selected Fruits in Lafia, Nasarawa State Nigeria. *Journal of Plant Science and Phytopathology*, **6**, 154-160. https://doi.org/10.29328/journal.jpsp.1001090

[10] Hung, T.N., Hung, N.Q., Mostert, D., Viljoen, A., Chao, C.P. and Molina, A.B. (2017) First Report of Fusarium Wilt of Cavendish Bananas, Caused by *Fusarium oxysporum* f. sp. Cubense Tropical Race 4 (VCG 01213/16), in Vietnam. *Plant Diseas*, **21**, 102-448. https://doi.org/10.1094/PDIS-08-17-1140-PDN

[11] Keuete, K.E., Fomen, Y.M.B. and Tsopmbeng, N.G.R. (2022) Antifungal Potential of Three Plant Extracts in the Control of Some Major Fungi Associated with Cashew Seeds (*Anacardium occidentale* L.). *Journal of Experimental Agriculture International*, **44**, 168-179. https://doi.org/10.9734/jeai/2022/v44i930863

[12] Yemo, N.Y., Tsopmbeng, N.G.R., Keuete, K.E. and Nchongboh, C.G. (2017) Antifungal Activities of Plant Extracts against Coffee Berry Disease Caused by *Colletotrichum kahawae* L. *International Journal of Current Research in Biosciences and Plant Biology*, **4**, 60-66. https://doi.org/10.20546/ijcrbp.2017.407.007

[13] Nyaka, A.I.C.N., Fadimatou, S.N.M.Z., Dzokouo, C.U.D., Bourou, S. and Yaouba, A. (2021) Effet antifongique de deux extraits de plantes sur les agents pathogènes identifiés sur des fruits de l'anacardier (*Anacardium occidentale* L.) au Nord Cameroun. *International Journal of Biological and Chemical Science*, **15**, 1121-1139.

https://doi.org/10.4314/ijbcs.v15i3.21

[14] Keuete, K.E., Tsopmbeng, N.G.R. and Kuiate, J.R. (2018) Cross-Infectivity of Colletotrichum Isolates, Causal Agent of Anthracnose on Fruits in Three Regions of Cameroon. *International Journal of Pure and Applied Bioscience*, **6**, 1-10. https://doi.org/10.18782/2320-7051.6795

[15] Barnett, H.L. and Hunter, B.B. (1987) Illustrated General of Imperfect Fungi. 4th Edition, Burgess Publishing Company, Minneapolis, 218 p.

[16] Amala, S.E., Nweke, S.N., Nwalozie, R. and Monsi, T.P. (2021) Antimicrobial Properties and Phytochemical Composition of *Garcinia kola*, *Bryophyllum pinnatum*, and *Allium sativum* Juices on Some Clinical Pathogens. *Advances in Bioscience and Biotechnology*, **12**, 388-406. https://doi.org/10.4236/abb.2021.1211025

[17] Bashar, M.A., Shamsi, S. and Hossain, M. (2012) Fungi Associated with Rotten Fruits in Dhaka Metropolis. *Bangladesh Journal of Botany*, **41**, 115-117. https://doi.org/10.3329/bjb.v41i1.11090

[18] Blomme, G., Dita, M., Jacobsen, K.S., Pérez, V.L., Molina, A., Ocimati, W., Poussier, S. and Prior, P. (2017) Bacterial Diseases of Bananas and Enset: Current State of Knowledge and Integrated Approaches toward Sustainable Management. *Frontiers in Plant Science*, **8**, 1290. https://doi.org/10.3389/fpls.2017.01290

[19] Aoudou, Y. and Essoua, M.G.P. (2017) Isolation and Pathogenicity Evaluation of Postharvest Fungal of Some Fruits in Cameroon. *International Journal of Environment, Agriculture and Biotechnology*, **2**, 56-60. https://doi.org/10.22161/ijeab/2.1.9

[20] Sobolewska, D., Michalska, K., Podolak, I. and Grabowska, K. (2016) Steroidal Saponins from the Genus Allium. *Phytochemistry Review*, **15**, 1-35. https://doi.org/10.1007/s11101-014-9381-1

[21] El-Mohamedy, R.S.R. and Abdallah, A.M. (2014) Antifungal Activity of *Moringa oleifera* Oil and Seed Extract against Some Plant Pathogenic Fungi. *Middle East Journal of Agriculture Research*, **3**, 242-249.

[22] Keuete, K.E., Tsompbeng, N.G.R., Yaouba, A., Djeugap F.J. and Signaboubo, A. (2015) Antifungal Potential of Some Plant Extracts against Three Post-Harvest Fungal Pathogens of Avocado (*Persea americana* Mill.) Fruits. *International Journals of Multidisciplinary Research and development*, **2**, 148-152.

[23] Boulenouar, N., Marouf, A. and Cheriti, A. (2009) Effect of Some Poisonous Plants Extracts on *Fusarium oxysporum f. sp. albedinis*. *Journal of Biological Sciences*, **9**, 594-600. https://doi.org/10.3923/jbs.2009.594.600

[24] Nyamath, S. and Karthikeyan, B. (2018) *In Vitro* Antifungal Activity of Lemongrass (*Cymbopogon citratus*) Leaf Extracts. *Journal of Pharmacognosy and Phytochemistry*, **7**, 1148-1151.

[25] Khan, S., Kaur, A. and Sharma, N.R. (2018) Evaluation of Antifungal Potential of *Allium ampeloprasum* against Fungal Phytopathogens. *Asian Journal of Pharmaceutical and Clinical Research*, **11**, 129-133. https://doi.org/10.22159/ajpcr.2018.v11i11.27463

[26] Akhilesh, D., Neeraj, M. and Neha, S. (2010) Antimicrobial Activity of Some Selected Vegetables. *International Journal of Applied Biology and Pharmaceutical Technology*, **1**, 994-999.

[27] Achraf, K., Boumediene, M., Abdellah, M., Houcine, B. and Saif G. (2012) Screening phytochimique et effet antifongique de certains extraits de plantes sur le développement *in Vitro* des moisissures. *European Journal of Scientific Research*, **80**, 311-321.

[28] Megatche, C. (2011) Efficacité *in Vitro* des extraits de plantes sur la croissance et le développement de *Phytophthora colocasiae*, agent causal de la flétrissure des feuilles de taro (*Colocasia esculenta*) Mémoire de Master II en phytopathologie. Université de Dschang, Dschang, 164 p.