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Article

Efficacy of ginger (*Zingiber officinale*) in controlling fungi causing postharvest deterioration in yam tuber

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Abstract: Yam (*Dioscorea* sp.) is a popular tuber in Cameroon, where it is grown for both food and income. One of the most challenging aspects of the long-term storage of yam tubers is post-harvest spoilage, often caused by fungi. The use of post-harvest chemicals on yam tubers is not a matter of course. The present study evaluated the efficacy of aqueous extract and powder of Zingiber officinale against fungi associated with the storage rot of yam. The fungi were isolated from two yam cultivars, "Calabar" and "Ghana", from three localities in Cameroon. The antifungal activity of the aqueous extract and ginger powder was studied in vivo on slices of yam tubers. The results obtained showed that eight fungi were associated with yam tubers and exhibited typical rotting symptoms. The most prevalent and virulent fungus was *Penicillium* sp., which caused decay volumes of 12.76 cm^3 and 8.74 cm^3 for "Calabar" and "Ghana" cultivars, respectively. Fungal spoilage was greatly reduced by the application of aqueous extract and ginger powder. The aqueous extract tested at the 30% dose was more effective with up to 80% inhibition. However, the ginger powder was more effective against *Penicillium* sp., *Aspergillus niger*, and *Colletotrichum* sp. associated with rot in the variety "Ghana" with total inhibition (100%). Therefore, the aqueous extracts and powder of *Zingiber officinale* can be used as a bio fungicide to improve the shelf life of yam tubers.

Keywords: ginger efficacy; aqueous extract; powder; rotting; fungi; *Dioscorea* sp.

1. Introduction

Yams are monocotyledonous plants that belong to the genus *Dioscorea* to the family *Dioscoreaceae*. They are multispecies of crops used for food, sociocultural activities, and income. Their high starch content meets the fundamental energy needs of 500 million people particularly in Africa [1]. Yams are also a good source of minerals, including calcium, phosphorus, iron, and vitamins such as B and C [2]. The most important areas for yam cultivation and consumption extend from Ivory Coast to Ghana, Nigeria, Togo, Gabon, the Central African Republic, the Democratic Republic of the Congo, and Cameroon [3]. In Cameroon, yams are the third most produced root plant after cassava and cocoyam, with 610, 136 tons [4]. The regions of Adamawa, South-west, Littoral, Center, West, and East produce the majority of yams, with outputs of 47%, 15%, 5%, 3%, 2.5%, and 1%, respectively [4]. Yam cultivation plays a crucial role in both the local economy and food security in Cameroon, making it an

essential crop for the country's agricultural sector and the well-being of its population [5].

It is widely recognized that the current national yams output is insufficient to meet the increasing local population. Inadequate cultural techniques, along with pests and diseases, are factors limiting yam production. Diseases have been identified as the most significant threat to production [6]. Pathogenic microorganisms related for yam deterioration are mainly fungi, including *Botryodiplodia* spp., *Penicillium* spp., *Aspergillus* spp., Fusarium spp., *Rhizopus* spp. [3,7–9]. Yam rots typically begin in the soil and continue during storage, often without visible external symptoms on infected tubers. Without effective control strategies, the disease can reduce yield output by 80%, alter the taste and nutritional value of yam tubers, and decrease food self-sufficiency [10]. Some fungi that cause spoilage in yam tubers have been reported to produce mycotoxins, which can be harmful to human health if consumed [7–10].

Chemical fungicides are commonly used to manage postharvest rot disease; however, they can cause the development of fungal resistance [11]. Additionally, the continuous and inadequate use of chemical fungicides to prevent or treat yam infections is not considered a long-term solution, as it increases investment costs, the risk of toxic residues, and poses health and environmental concerns [6]. To meet the demands of our growing economies and achieve food security, adequate food production must be effectively matched with protection from spoilage and rot inducing organisms [12]. Several studies have highlighted the use of plant extracts and derivatives as alternative techniques for reducing postharvest fungal rot of crops [13–15]. Natural products are considered as a good alternative to synthetic fungicides for treating fungal infections in plants, as they have little or no detrimental impact on the environment [16,17].

Ginger (*Zingiber officinale*) is a popular culinary spice known among African people for many years due to its economic, pharmaceutical, and antimicrobial benefits [18]. The plant is widely cultivated in Cameroon, where it is utilized in many households as a spice to enhance the taste of cooking and as a potent medication for its medicinal properties. It contains a diverse range of active constituents, including anthocyanins, tannins, and pungent phenolic compounds known as gingerols, zingerone, shogaols, and sesquiterpenes [19,20]. These constituents give ginger the potential to be used to increase production and food preservation [21–23]. However, there has been limited conducted in Cameroon to find a suitable alternative and low-cost method to preserve yam tubers against fungi that cause postharvest losses. The aim of this study was to identify the fungi that cause tuber rot of yams during storage in three different locations and to evaluate the antifungal activity of ginger aqueous extract and powder against most pathogenic molds.

2. Materials and methods

2.1. Study area

The collection of yams varieties was carried out in three different localities, namely Mbe, Penda-Mboko and Dschang. Mbe is located in agroecological zone 2 characterized by a high guinean savannahs which lies between 5°42″ to 8°36″ N latitude and 11°24″ to 14°36″ East longitude. It is largely made up of a vast plateau of

altitudes between 900 and 1500 m, with peaks reaching 1800 m. The climate is Sudanian, tropical humid with two seasons a year. The average annual rainfall is about 1500 mm, with about 150 days of rain. Penda-Mboko is located in agroecological zone 4 characterized by a monomodal rainforest zone. The area is between 2°6″ and 6°12″ North latitude, and 8°48″ and 10°30″ East longitude. The climate is of the "Cameroonian" type, very humid and warm, a variation of the equatorial climate. Rainfall is abundant, averaging 2500 to 4000 mm. Dschang is located in agroecological zone 3 characterized by western highlands. This area is between 4°54″ to 6°36″ North latitude and 9°18″ to 11°24″ East longitude. The climate is the "Cameroonian altitude" type, marked by two seasons of unequal length: a dry season more marked than in the bimodal zone and which runs from mid-November to mid-March, and a rainy season which lasts from mid-March to mid- November. Average temperatures are low (19 ℃), and heavy rains (1500–2000 mm) fall in a single mode configuration.

2.2. Collection of samples

Tubers of two varieties of yams, "Calabar" and "Ghana", displaying symptoms of rot, were collected from open markets in three separate localities: Mbe, Penda-Mboko, and Dschang in March 2021. A total of 90 yam tubers, with 30 samples from each location, were gathered, placed in sterile plastic bags, labeled, and transported to the Phytopathology Laboratory of the University of Dschang, for analysis.

2.3. Isolation and identification of fungal pathogens

Tubers with rots were carefully cleaned with running tap water to remove soil and debris that had adhered to the tubers. Fragments of the tubers about 5 mm in diameter were taken from the boundary between the healthy and rotten parts using a sterile kitchen knife, surface-sterilized for 3 min in 1% sodium hypochlorite solution, and rinsed three times successively with sterile distilled water for 5 min each. After spinning, the fragments were seeded into Petri dishes containing PDA culture medium, then labeled and incubated at 25 ℃ for 5 days [24]. To obtain pure culture, the fungal colonies that emerged from the fragments were carefully subcultured on fresh sterile PDA plates. The identification of fungal isolates was performed using the standard identification keys of Larone [25], Howard [26], Watanabe [27], Pitt and Hocking [28] based on the macroscopic and microscopic distinctive patterns of fungi. Cultural and morphological characteristics by which the isolates were identified included mycelia colour, growth pattern, nature of mycelia and growth rate in the Petri dish.

2.4. Frequency of occurrence of fungi

The frequency of isolates occurrence was determined using the method described by Walder [29]. The record of isolated fungi was kept on a regular basis, and the time a specific fungus emerged was calculated as a percentage of all fungal organisms isolated. The occurrences number of each isolate was recorded and computed as a ratio of the total number of occurrences using the formula:

$$F(\%) = \frac{n}{N} \times 100 \quad (1)$$

where:

F is the frequency of occurrence,
n is the total time a specific organism occurred,
N is the total number of all fungal isolates in the samples screened.

2.5. Pathogenicity test

The method described by Assiri et al. [30] was used to assess the pathogenicity of fungi isolated from yam tubers. For this purpose, yam tubers of "Calabar" and "Ghana", apparently healthy were washed with tap water and disinfected with 90° alcohol. Then they were cut into slices of about 4 cm thickness. Using a 0.5 cm diameter cookie cutter, a 1 cm deep hole was made in the center of each yam slice. A fungal inoculum in the form of a disc taken from a 7-day-old mycelial colony was introduced into the opening made in the discs. For controls, the slices were inoculated with PDA disks without fungus. The hole was closed with the yam cylinder previously removed. The treated yams were stored for 14 days in sterile plastic bins containing blotting paper soaked in sterile distilled water to maintain a high relative humidity. The trial was done with three replicates and the experiment was repeated twice. **Figure 1** shows a disc of fungal inoculum introduced into the centre of a yam disc.

The rot volume of the yam discs was determined according to the following formula.

$$\text{Rot volume } (\text{cm}^3) = \pi r^2 \times h \quad (2)$$

where *r* is the radius (cm) and *h* is the height of the rot (cm).

Figure 1. Fungal inoculum disc inserted in the center of the hole **(A)**; Hole closed with a cylinder of yam **(B)**.

2.6. Preparation of plant powder and crude extract

Fresh ginger rhizomes (*Zingiber officinale* Rosc) were acquired from a marketplace in Dschang (West Cameroon region). The ginger rhizomes were washed three times with tap water, disinfected for 15 minutes with 10% sodium hypochlorite, and then rinsed with tap water before drying at room temperature for 15 minutes. These were cut into small pieces, dried in an oven at 55 °C for two days, and then crushed in a crusher (moulinex) to obtain a fine powder. The extracts were prepared according to the modified method of Andersen [31]. The extract was obtained by macerating 100 g of ginger powder in 500 mL of sterile distilled water for 48 hours

under constant stirring. After successive filtering on two layers of muslin, then on Whatman No. 1 paper, the filtrate is obtained and stored.

2.7. Antifungal activity of aqueous extract and plant powder

The method of Amadioha and Obi [32] was used to evaluate the effect of aqueous ginger extracts on fungi causing postharvest rotting. Yam slices of about 9 cm in diameter and 4 cm thick, obtained from whole tubers, were washed thoroughly with tap water and then disinfected with 90° alcohol. After drying on hydrophilic paper, two perpendicular lines were drawn on one of the two faces of each disc. Then, they were soaked in a suspension of aqueous ginger extract at concentrations of 5%, 10%, 15%, 20%, and 25% for 3 min. As for the negative controls, they were soaked in sterilized distilled water. The positive control was treated with thiabendazole fungicide at the manufacturer's recommended concentration. A 0.5 cm diameter disc of a 7-day culture of fungus was placed in the center of the yam slices. The treated yam slices were stored in sterile plastic trays containing blotting paper soaked in sterile distilled water to maintain high relative humidity. The trays were kept at room temperature.

For powder activity, yam slices were sprinkled with the ginger powders at amounts of 50, 100, 150, 200 and 250 g per 500 g of yam slices, i.e. at concentrations of 0.1; 0.2; 0.3; 0.4 and 0.5% (g/g).

At 10 days after incubation, the volume of decay was calculated in both trials using the formula of Mascher and Défago [33]. Each trial was repeated three times.

$$\text{Decay Volume } (cm^3) = \pi r^2 \times h \quad (3)$$

with r = radius (in cm) and h = height of the rot (in cm).

2.8. Statistical analysis

The data obtained on the pathogenicity test, frequency of isolation, and rot volumes were entered and submitted to Fisher's test to see if there is a difference between the ranks, and the separation of ranks at the 5% probability level was done using the statistical analysis software R version 3.5.1.

3. Results

3.1. Fungi associated with yam rot and their frequency of occurrence

A total of 8 different filamentous fungi were obtained from rotted yam tubers of the "Calabar" and "Ghana" varieties. These fungi were: *Colletotrichum* sp., *Penicillium* sp., *Fusarium solani*, *Aspergillus parasiticus*, *Aspergillus niger*, *Cercospora* sp., *Rhizoctonia* sp. and *Trichoderma* sp. **Figure 2** illustrates the macroscopic and microscopic aspects of isolated fungi on a PDA medium, 7 days old.

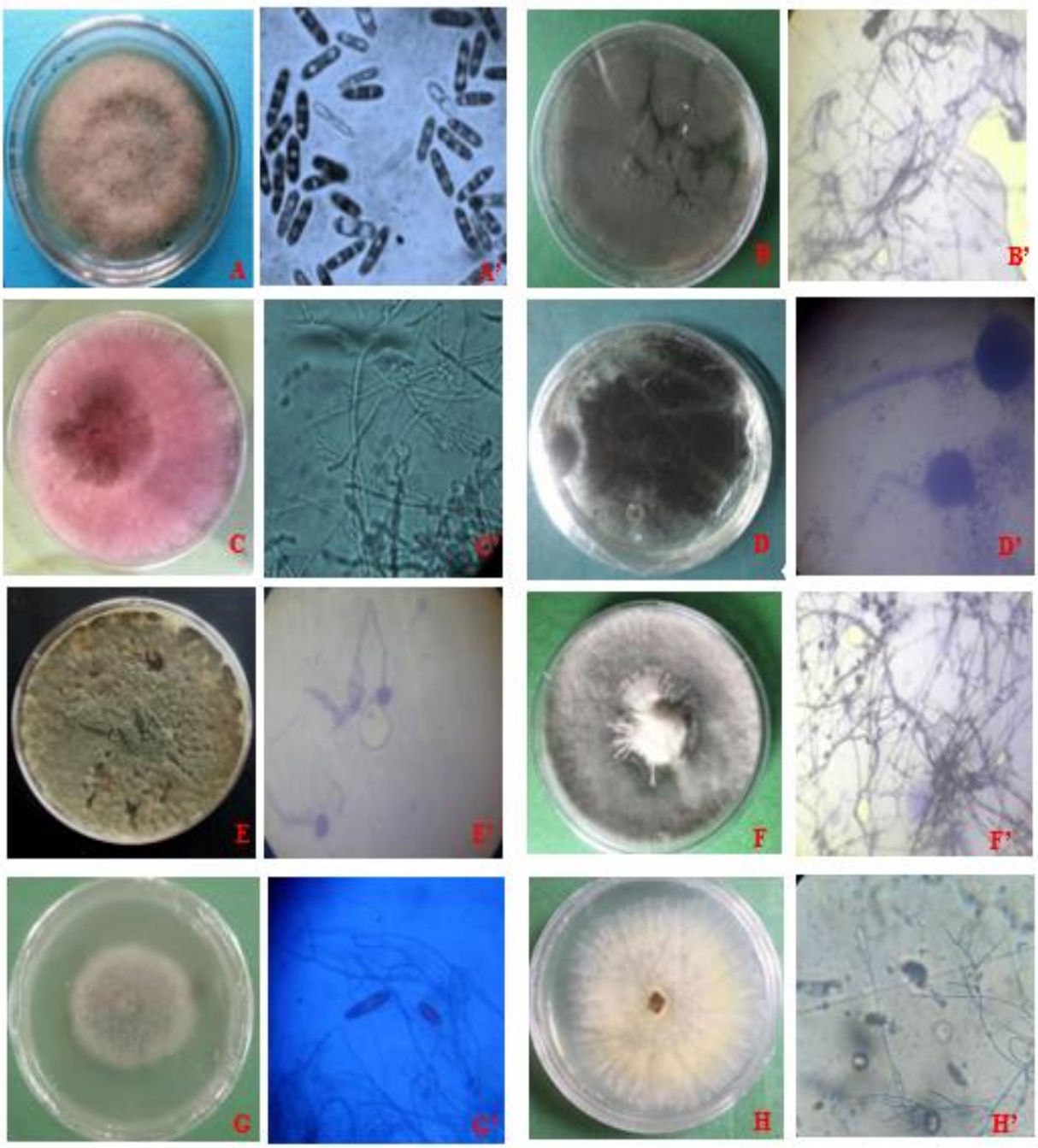

Figure 2. Macroscopic and microscopic (×40 magnification) cultural features of isolated fungi associated with yam rot tuber on PDA medium. **A** and **A'** indicate *Colletotrichum* sp., **B** and **B'** indicate *Penicillium* sp., **C** and **C'** indicates *Fusarium* sp., **D** and **D'** indicate *Aspergillus niger*; **E** and **E'** indicate *Aspergillus parasiticus*; **F** and **F'** indicates *Cercospora* sp.; **G** and **G'** indicate *Rhizoctonia* sp.; **H** and **H'** indicate *Trichoderma* sp.

Table 1 shows the frequency of isolation of fungi based on the varieties of yam. It appears that a significant difference in the frequencies of the fungi according to the yam varieties is observed. *Penicillium* sp., *Fusarium* sp., and *Aspergillus niger* were the most commonly isolated in both yam cultivars. Concerning the "Calabar" cultivar, these fungi emerged at rates of 39.8%, 22.75%, and 20.55%, respectively. However, the same fungi occurred at rates of 26.13%, 21.47%, and 18.40% in the "Ghana"

cultivar, respectively. In contrast, *Aspergillus parasiticus* was the least present species at 0.57% to 1.31% respectively on the "Calabar" and "Ghana" varieties.

Table 1. Isolation frequencies (%) of fungi according to yam's varieties.

Fungi	Yam varieties and fungal frequency (%)	
	"Calabar"	**"Ghana"**
Penicillium sp.	39.81 ± 3.84^{a}	26.13 ± 2.7^{a}
Fusarium sp.	22.75 ± 3.84^{b}	21.47 ± 1.09^{b}
Aspergillus niger	20.55 ± 0.00^{bc}	18.40 ± 2.14^{c}
Cercospora sp.	7.81 ± 3.84^{c}	13.33 ± 1.20^{d}
Rhizoctonia sp.	7.19 ± 0.84^{c}	8.11 ± 3.80^{e}
Colletotrichum sp.	5.25 ± 2.12^{d}	6.89 ± 1.38^{e}
Trichoderma sp.	2.33 ± 2.12^{de}	5.4 ± 0.77^{de}
Aspergillus parasiticus	1.31 ± 3.84^{de}	0.57 ± 0.17^{e}

Numbers assigned the same superscript letter on the same column are not significantly different by Fischer's test at $p \geq 0.05$.

Depending on the locality of sample collection, a significant influence was observed between the frequencies of the fungi. The locality of Penda-Mboko recorded the highest frequencies followed by Dschang and Mbe. *Penicillium* was the most frequent genus in all localities with frequencies of 25.19%, 27.45% and 25.45% in Mbe, Penda-Mboko and Dschang respectively. *Aspergillus niger* was the second most frequent species with a frequency of 24.55%, 24.11% and 23.11% in the same localities respectively. *Cercospora* sp., *Rhizoctonia* sp. and *Colletotrichum* sp. were absent from the samples collected in Mbe (**Table 2**).

Table 2. Frequency (%) of fungal strains by collection site.

Fungi	Location and frequency of occurrence (%)		
	Mbe	**Penda-Mboko**	**Dschang**
Penicillium sp.	35.39 ± 2.25^{a}	27.45 ± 2.74^{a}	25.45 ± 0.71^{a}
Fusarium sp.	26.67 ± 2.88^{b}	19.68 ± 2.19^{c}	20.11 ± 1.78^{c}
Aspergillus niger	37.71 ± 0.00^{a}	24.11 ± 2.34^{b}	23.01 ± 3.44^{b}
Cercospora sp.	$0{,}00 \pm 0.00^{c}$	18.03 ± 1.79^{c}	18.00 ± 2.12^{d}
Rhizoctonia sp.	0.00 ± 0.00^{c}	2.01 ± 1.20^{e}	7.34 ± 1.35^{e}
Colletotrichum sp.	0.00 ± 0.00^{c}	6.58 ± 0.78^{d}	6.01 ± 1.70^{e}
Trichoderma sp.	0.12 ± 0.21^{d}	1.02 ± 0.04^{f}	0.03 ± 1.00^{f}
Aspergillus parasiticus	0.11 ± 0.08^{d}	1.12 ± 0.09^{f}	0.05 ± 0.20^{f}

Numbers assigned the same superscript letter on the same column are not significantly different by the Fischer test at $p \geq 0.05$.

3.2. Pathogenicity of the fungi

Healthy yam slices inoculated with the previously isolated fungi showed rot symptoms that varied with the type of fungus. Significant differences were observed between the ability of each fungus to cause rot. Four fungi, namely *Colletotrichum*

sp., *Penicillium* sp., *Fusarium* sp. and *Aspergillus niger*, were found to be responsible for rotting yam tubers with lesion areas of 12.76, 10.13, 7.22 and 7.34 cm^3, respectively, on the Kalaba variety. On the slices of the Ghana variety, the areas of decay caused by these fungi are 8.74; 5.67; 5.12 and 6.15 cm^3 respectively (**Table 3**). It is also noted that the variety "Kalaba" recorded the highest volume of rot compared to the variety "Ghana" (**Figure 3**). In contrast, *Aspergillus parasiticus*, *Rhizoctonia* sp., *Cercospora* sp. and *Trichoderma* sp. were non-aggressive with very low decay areas comparable to the control.

Table 3. Decay volumes (cm^3) caused by fungi according to yam's cultivars.

Fungi	**Decay volume (cm^3) and varieties**	
	"Calabar"	**"Ghana"**
Penicillium sp.	12.76 ± 0.33^{a}	8.74 ± 0.15^{a}
Aspergillus niger	10.13 ± 1.21^{b}	5.67 ± 0.54^{b}
Fusarium sp.	7.22 ± 1.33^{c}	5.12 ± 2.22^{c}
Colletotrichum sp.	7.34 ± 0.68^{c}	6.15 ± 1.20^{c}
Aspergillus parasiticus	1.17 ± 0.44^{d}	0.59 ± 0.40^{d}
Cercospora sp.	0.67 ± 0.01^{d}	$0{,}30 \pm 0.05^{e}$
Rhizoctonia sp.	0.38 ± 0.02^{e}	0.25 ± 0.01^{f}
Trichoderma sp.	0.00 ± 0.01^{f}	0.00 ± 0.03^{g}
Control	0.00 ± 0.00^{f}	0.00 ± 0.00^{g}

Means assigned with the same superscript letter on the same column are not significantly different by Fischer's test at $p \geq 0.05$.

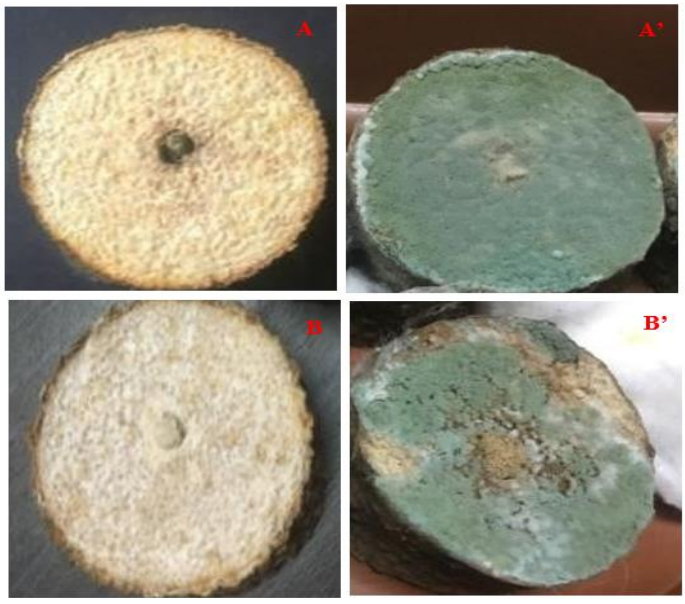

Figure 3. Colonization of the surface of yam slices by *Penicillium* sp. on the "Calabar" and "Ghana" varieties after 10 days of incubation. **A** and **B** indicate uninoculated yam slices of "Calabar" and "Ghana" varieties, respectively. **A** and **B'** indicate symptoms caused by *Penicillium* sp. on the "Calabar" and "Ghana" varieties, respectively.

3.3. In vivo antifungal effect of ginger aqueous extract

Table 4 shows the efficiency of ginger aqueous extract in controlling yam tuber rot. According to these, the activity of the ginger aqueous extract was influenced by the type of fungal pathogen tested, the extract's concentration, and the yam's variety. The percentage of decay inhibition increased significantly with the dose.

Globaly at the 30% aqueous extract dose, high inhibition rates were recorded and ranged from 65.73% to 80%. At this dose, *Aspergillus niger* and *Colletotrichum* sp. were less susceptible with an inhibition rate of 65% on "Calabar" variety. The variety "Ghana" was found to be more susceptible to aqueous extracts. The chemical was more effective than the plant extracts and showed significant differences from the plant extracts at all concentrations. The effect of the *Fusarium* sp. on the variety "Calabar" was totally inhibited by the synthetic fungicide (thiabendazole), applied at the manufacturer's rate (0.4%).

Table 4. Inhibition percentage of fungal growth on yam tubers treated with ginger aqueous extracts.

Doses (%)	***Penicillium* sp.**		***Aspergillus niger***		***Fusarium* sp.**		***Colletotrichum* sp.**	
	"Calabar"	**"Ghana"**	**"Calabar"**	**"Ghana"**	**"Calabar"**	**"Ghana"**	**"Calabar"**	**"Ghana"**
T$^-$	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}
10	13.43 ± 0.49^{f}	16.99 ± 1.60^{f}	3.57 ± 0.31^{f}	18.03 ± 0.16^{e}	14.87 ± 0.74^{f}	16.04 ± 1.01^{f}	9.57 ± 1.35^{f}	12.84 ± 0.07^{e}
15	25.57 ± 0.31^{e}	19.27 ± 2.74^{e}	16.50 ± 2.10^{e}	19.38 ± 2.66^{e}	21.27 ± 1.80^{e}	24.11 ± 2.97^{e}	25.30 ± 0.70^{e}	37.08 ± 1.59^{d}
20	38.86 ± 2.15^{d}	33.17 ± 0.91^{d}	27.01 ± 0.46^{d}	34.32 ± 1.34^{d}	32.23 ± 2.68^{d}	40.87 ± 2.49^{d}	38.77 ± 2.75^{d}	39.99 ± 2.67^{d}
25	55.80 ± 1.29^{c}	75.77 ± 2.50^{c}	51.67 ± 2.67^{c}	69.50 ± 1.56^{c}	49.17 ± 0.05^{c}	57.95 ± 1.43^{c}	50.23 ± 1.62^{c}	52.99 ± 0.48^{c}
30	77.40 ± 0.10^{b}	79.97 ± 1.45^{b}	65.86 ± 1.70^{b}	76.38 ± 1.82^{b}	72.23 ± 0.91^{b}	73.41 ± 2.93^{b}	65.73 ± 1.45^{b}	79.00 ± 0.05^{b}
T+	81.21 ± 1.37^{a}	85.91 ± 0.44^{a}	83.39 ± 4.32^{a}	86.67 ± 0.45^{a}	100.00 ± 0.00^{a}	93.65 ± 1.59^{a}	98.61 ± 2.24^{a}	91.55 ± 1.50^{a}

Means assigned the same superscript letter on the same column are not significantly different by Fischer's test at $p \geq 0.05$. T+: Thiabendazole

3.4. In vivo antifungal effect of ginger powder

Table 5 shows the percentages of fungal growth inhibition on yam tubers treated with ginger powder. The activity of the ginger powder was influenced by the fungal species, the amount of powder, and the yam variety. There were significant differences between the effects of the powder and the untreated control.

At the 0.5% doses, ginger powder showed the highest inhibition percentages compared to the negative control. These inhibition percentages ranged from 57.3% to 100%. The lowest reduction was recorded for *Aspergillus niger* on the "Calabar" yam tubers of the variety while 100% inhibition was obtained for *Penicillium* sp., *Aspergillus niger*, and *Colletotrichum* sp. on yam tubers of the variety "Ghana".

No significant difference between the inhibition rates recorded for tubers treated with ginger powder (0.5 g/g) and those of tubers treated with synthetic fungicide. With regard to the results of the aqueous extracts and the ginger powder, it appears that the application of the powder showed the highest inhibition rates of fungal development on yam tubers.

Table 5. Inhibition percentage (%) of fungal growth on yam tubers treated with ginger powder.

Doses (g/g)	*Penicillium* sp.		*Aspergillus niger*		*Fusarium* sp.		*Colletotrichum* sp.	
	"Calabar"	**"Ghana"**	**"Calabar"**	**"Ghana"**	**"Calabar"**	**"Ghana"**	**"Calabar"**	**"Ghana"**
T-	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	10.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}	0.00 ± 0.00^{g}
0.1	12.80 ± 1.94^{f}	24.99 ± 1.06^{f}	19.49 ± 0.66^{d}	21.39 ± 0.62^{e}	17.76 ± 0.41^{f}	21.04 ± 2.78^{e}	15.99 ± 1.51^{f}	21.06 ± 1.88^{e}
0.2	26.74 ± 0.15^{e}	37.72 ± 2.45^{e}	21.50 ± 3.44^{d}	38.84 ± 2.22^{d}	27.73 ± 1.05^{e}	42.70 ± 3.56^{d}	38.5 ± 1.03^{e}	43.19 ± 2.43^{d}
0.3	39.96 ± 3.23^{d}	42.17 ± 0.19^{d}	37.01 ± 0.55^{c}	39.56 ± 2.45^{d}	39.54 ± 2.87^{d}	54.12 ± 0.29^{c}	49.725 ± 3.96^{d}	59.33 ± 3.11^{d}
0.4	51.44 ± 1.90^{c}	65.81 ± 2.95^{c}	51.68 ± 2.93^{b}	61.60 ± 1.68^{c}	46.72 ± 1.51^{c}	63.43 ± 1.21^{b}	81.93 ± 1.24^{c}	62.90 ± 1.37^{c}
0.5	62.23 ± 1.18^{b}	100.00 ± 0.00^{a}	79.69 ± 1.88^{a}	100.00 ± 0.00^{a}	67.35 ± 0.29^{b}	93.21 ± 1.38^{a}	89.73 ± 2.15^{b}	100.00 ± 0.00^{a}
T+	80.62 ± 1.22^{a}	85.91 ± 0.44^{b}	83.39 ± 4.32^{a}	86.67 ± 0.45^{b}	100.00 ± 0.00^{a}	93.65 ± 1.59^{a}	98.61 ± 2.24^{a}	91.55 ± 1.50^{b}

Means assigned the same superscript letter on the same column are not significantly different by Fischer's test at $p \geq 0.05$. T+: Thiabendazole.

4. Discussion

Eight distinct fungi were isolated and identified from yam tubers exhibiting typical dry rot symptoms. These fungi have previously been isolated from decaying yam tubers by various authors [9,11,34]. It was observed that among these eight fungi, *Penicillium* sp., *Aspergillus niger*, and *Fusarium* sp. were more abundant and consistent across locations and yam varieties. The high relative percentage of incidence of these fungi on yam tubers could be attributed to their ubiquitous nature in the soil, natural occurrence, and the warm and humid conditions commonly found in yam-growing regions where yam tubers were collected. Previous studies have linked the presence of the fungi isolated from the samples analyzed to dry rot disease of yam [6,35–37], implying that these fungi may be responsible for post-harvest yam deterioration. *Colletotrichum* sp., *Cercoscopora* sp. and *Rhizoctonia* sp. were not isolated from yam varieties collected in the Mbe locality, due to the low prevalence of anthracnose, cercosporiose and *Rhizoctonia* sp. in the yam fields, where the tubers were grown. Indeed, the work of Egesi et al. [38] demonstrated that the occurrence and severity of fungal diseases differed according to agroecological zones and sampling sites. In this study, the differences in climatic conditions amongst agroecological zones surveyed could explain the variations in fungal frequencies. In fact, the climatic conditions in the localities of Mbe, Dschang, and Penda-Mboko in Cameroon differ due to their geographical locations and elevation.

The results of the pathogenicity test showed that the fungal isolates are capable of inducing decay at varying degrees depending on the fungus and the yam variety tested. Several previous works have also shown the involvement of some fungi including *Penicillium* sp. and *Aspergillus niger* in the development of rot on inoculated healthy yam tubers [39,40].

The two varieties, Calabar and Ghana used in this study, exhibited the highest volumes of rot caused by *Penicillium* sp. and *Aspergillus niger*. Assiri et al. [30], Gwa and Ekefan [2] and Gwa et al. [41] also made similar findings in their work. According to these authors, *Penicillium* and *Aspergillus* genera are the pathogens that cause severe post-harvest damage to yam tubers overall. The ability of these pathogens to induce a high degree of decay in yam tissue could be attributed to their *aggressiveness due to genetic differences linked to* their ability to produce a high level of cellulose

and pectin lytic enzymes, which degrade the medial lamina of the cell wall to provide essential nutrients for fungal development and growth.

Trichoderma sp. did not cause decay on healthy yam slices. This could be explained by the fact that some *Trichoderma* species are endophytic fungi known to possess harmless effects on plants. The cultivar "Calabar" is more susceptible to rot than the cultivar "Ghana". This result is similar to that obtained by Tschannen [42], who demonstrated that it is mainly the varieties of the *D. cayenensis-rotundata* complex type that present a high risk of rot, due to the high water content of the cultivar as well as by its richness in sugars and nutrients, which favor the development of phytopathogenic fungi.

Several studies have been conducted and reported on using of plants extracts and powder to manage the fungal pathogens associated with yam rotting tubers [9,11,43,44]. According to the results of this work, the aqueous extract and ginger powder significantly reduced decay volumes compared to the negative control. The inhibitory activities of the extract and powder increased as the dose increased. The aqueous extract tested at the 30% dose was more active with inhibition percentages ranging from 65.73% to 80%. However, the chemical was more effective than the plant extracts and showed significant differences from the plant extracts at all concentrations. At the 0.5% doses, ginger powder showed the highest inhibition percentages compared to the negative control with inhibition percentages ranging from 57.3% to 100%. No significant difference between the inhibition rates recorded for tubers treated with ginger powder (0.5%) and those of tubers treated with synthetic fungicide.

These results show that the ginger extract and powder possess antifungal components capable of inhibiting or suppressing the growth of the tested fungi and minimizing the occurrence of rot on yam slices. This confirms the findings of Yeni [45], who studied the antifungal effect of *Z. officinale* against *A. flavus, A. niger, F. solani,* and *F. oxysporum* on postharvest rot of yam (*D. alata*). He found that the extract was effective in reducing necrosis caused by all pathogens tested. According to Banso et al. [46], the antifungal compounds found in plant extracts are fungistatic at low doses but fungicidal at high concentrations. This could explain why, in this study, the activity of the extract and powder increased with concentration. *The significance of dose-dependent relationship observe in the inhibition percentages for both ginger extract and powder indicates that the effectiveness of extracts in inhibiting yam decay caused by fungi is directly related to the concentration of ginger extract and powder. This mean that the higher the concentration of ginger extract and powder, the greater the inhibition of fungal growth or yam decay.* Sesquiterpenes, sesquiphellandrene, caryophyllene, zingiberene, farnesene, bisabolene, and geraniol are among the fungicidal chemicals found in *Z. officinale*. The presence of these fungicidal compounds in *Z. officinale* has been reported to inhibit the growth of pathogenic microorganisms in vitro [47]. The ginger-derived powder was found to be more active than the aqueous extract. This could be due to the fact that the active components of the aqueous extract are diluted in water, which decreases their final concentration. In the case of the powder, the active components are more concentrated. The use of ginger aqueous extract and powder as bio fungicides for farmers and local communities is feasible and holds several potential benefits. In fact, ginger is a widely

cultivated and easily accessible plant in many regions of Cameroon, making its aqueous extract and powder relatively easy for farmers and local communities to obtain. Beside this, Compared to synthetic fungicides, ginger aqueous extract and powder may offer a cost-effective alternative for disease management in yam and other crops.

5. Conclusion

This study demonstrated that both the aqueous extract and powder derived from ginger rhizome exhibited antifungal properties against fungi responsible for rotting in white yam tubers of "Ghana" and "Calabar" cultivars. These ginger-based products were able to significantly reduce the spoilage caused by the fungi, with the powder showing greater effectiveness compared to the aqueous extract. Given these findings, ginger powder could be developed and utilized as an alternative to chemical products for managing pathogenic fungi in yam tubers, particularly during post-harvest periods. Based on the findings of this study, further research should focus on identification of active compounds and investigating the persistence and formulation of this powder.

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