In *Vitro* Antifungal Activity of Selected Plant Extracts Against *Fusarium Oxysporum* and *Colletotrichum Musae* Causing Banana Disease in Donga, Nigeria

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Abstract
Fungal diseases limit banana (Musa spp.) production in Donga Local Government Area (LGA), Taraba State, Nigeria, but the fungi involved have not been identified and locally available botanical control options remain untested. This study isolated and identified fungi from diseased banana and evaluated the in vitro antifungal activity of leaf extracts of Boswellia dalzielii, Daniellia oliveri and Moringa oleifera against them. Diseased tissues from three farms were plated on potato dextrose agar (PDA); isolates were identified from cultural and microscopic characters, and pathogenicity was tested by artificial inoculation of healthy banana. Aqueous, ethyl acetate and n-hexane extracts were incorporated into PDA at 7.5, 15, 22.5 and 30 mg/mL (poisoned food technique) in a Completely Randomised Design. Fusarium oxysporum was recovered from Dakinsama and Sobbo and Colletotrichum musae was recovered from Dakinsama and Guruza, with both occurring together at Dakinsama. Both isolates were pathogenic to banana, with F. oxysporum causing yellowing and wilting. All extracts inhibited both fungi in a concentration-dependent manner ($p < 0.05$). The ethyl acetate extract of D. oliveri was the most inhibitory, giving 97.93% inhibition of F. oxysporum at 30 mg/mL and 97.60% of C. musae at 22.5 mg/mL; the ethyl acetate extract of M. oleifera reached 85.88% and 97.12%, respectively, and B. dalzielii was generally least inhibitory (maximum 70.47% and 73.96%). Ethyl acetate was generally the most effective solvent and water the least. D. oliveri and M. oleifera are promising candidates for greenhouse and field evaluation, subject to molecular confirmation of the isolates' identity.

Keywords: Banana; *Fusarium oxysporum*; *Colletotrichum musae*; *Daniellia oliveri*; *Moringa oleifera*; *Boswellia dalzielii*.

Introduction

Banana (*Musa spp*.) is a major food and cash crop across the tropics, with global production rising from about 69 million tonnes in 2000–2002 to roughly 115 million tonnes in 2017–2019, valued at approximately US$40 billion (Food and Agriculture Organization of the United Nations [FAO], 2020). In Nigeria, banana is an important source of household income for

smallholders, although national production has not kept pace with its potential, largely because of disease pressure (Olumba and Onunka, 2020).

Among the diseases limiting production, Fusarium wilt (Panama disease) is one of the most destructive (Ploetz, 2015a). It is caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *cubense* (Foc), a member of the *F. oxysporum* species complex (Fourie *et al*., 2011; Ploetz, 2006). The pathogen infects the roots and colonises the xylem, producing progressive yellowing and wilting of leaves, collapse of leaves at the petiole, longitudinal splitting of the pseudostem and internal vascular discolouration, and eventually plant death (Abdullahi *et al*., 2018; Dita *et al*., 2018). Because Foc persists in infested soil for many years as resilient chlamydospores, crop rotation is rarely practical in continuously cropped smallholder systems, and chemical fungicides are costly, environmentally hazardous and only marginally effective (Bubici *et al*., 2019; Pegg *et al*., 2019; Ploetz, 2015b). Banana is also affected by anthracnose, caused by *Colletotrichum musae*, which can infect fruit early in development and remain quiescent until ripening, when lesions develop and quality deteriorates (Cruz *et al*., 2025; Kanade *et al*., 2023). These constraints have renewed interest in biologically based and botanical alternatives. Extracts and essential oils of several plants have suppressed Foc *in vitro* or in plants, including combinations of botanical formulations and biocontrol agents (Akila *et al*., 2011), extracts of medicinal plants (Abdullahi *et al*., 2018; Kiran *et al*., 2023), essential oils (Paramalingam *et al*., 2023; Suryaningsih *et al*., 2024) and a castor (*Ricinus communis*) leaf extract that exceeded 97% inhibition *in vitro* (Anasuya and Rakesh, 2025). Plant extracts have likewise inhibited *C. musae* and other *Colletotrichum* species, with inhibition typically increasing with concentration (Pitiwittayakul *et al*., 2025; Sousa *et al*., 2022). Three locally available species are of particular interest in northern Nigeria. *Moringa oleifera* leaf extracts inhibit several plant-pathogenic fungi, including *Fusarium* spp. (Majumder *et al*., 2024; Mncube *et al*., 2023); *Daniellia oliveri* is a widely used ethnomedicinal tree whose extracts contain phenolics, flavonoids, tannins, alkaloids, terpenes and sterols (Awojide *et al*., 2025); and *Boswellia dalzielii* essential oils have shown antifungal activity, although chemical composition varies with collection site (Owolabi *et al*., 2020). However, the potency of a botanical depends on plant species, extraction solvent and test organism, so activity cannot be assumed to transfer across fungi or localities.

In Donga LGA, Taraba State, banana has been grown for decades on fertile floodplains, and farmers report poor vigour, premature yellowing and declining bunch yields consistent with Fusarium wilt. To our knowledge, however, the fungi associated with diseased banana in the area have not been isolated and identified, and no locally sourced plant extracts have been tested against them. This study therefore aimed to isolate and identify the fungal pathogens associated with diseased banana in Donga LGA, namely *F. oxysporum* and *C. musae*, and confirm their pathogenicity, and to evaluate the *in vitro* antifungal activity of aqueous, ethyl acetate and n-hexane leaf extracts of *B. dalzielii*, *D. oliveri* and *M. oleifera* against both pathogens.

Materials and Methods

Study area and sample collection

The study was conducted in Donga LGA, southern Taraba State, North-Eastern Nigeria, which lies in the southern Guinea savanna vegetation zone and has distinct rainy and dry seasons. Farming is the principal occupation, and rice, cassava, maize, plantain and banana are among the main crops. Symptomatic banana plants showing progressive yellowing of lower leaves, leaf collapse at the petiole, longitudinal splitting of the pseudo-stem and internal vascular discolouration were identified and marked in consultation with farmers on three farms (Dakinsama, Guruza and Sobbo). Three pseudo-stem, leave lesion and root were sampled from each farm location between the periods of May to June 2026. Pseudo-stem, leave and root

tissues were excised from the margin between healthy and necrotic tissue with a sterile knife, placed in sterile polythene bags, labelled, and transported in a cool box to the Plant Science laboratory, Modibbo Adama University, Yola, for immediate processing.

Isolation of the fungi

Potato dextrose agar (PDA) was prepared by suspending 39 g of dehydrated medium in 1,000 mL of distilled water and autoclaving at 121 °C for 15 min. Chloramphenicol was added to suppress bacterial contamination. Tissue pieces (about 5 × 5 mm) were cut from the advancing margin of infection, surface-sterilised in 1% sodium hypochlorite for 60seconds, rinsed three times in sterile distilled water, blot-dried on sterile filter paper, and plated on PDA following Ploetz (2006) and Anasuya and Rakesh (2025). Plates were incubated at 27±2°C for 5–7 days, and emerging colonies were purified by repeated hyphal-tip transfers to fresh PDA.

Morphological identification

Pure isolates were identified from macroscopic characters (colony colour, texture, growth pattern and pigmentation on the upper and reverse sides of PDA plates) and microscopic characters (hyphae; shape and septation of conidia; conidiophore type; presence of chlamydospores) examined under a compound microscope and compared with standard descriptions (Kanade *et al*., 2023).

Pathogenicity tests

Fusarium oxysporum. Pathogenicity was tested following Taping *et al*. (2023), with modifications. Healthy banana suckers were transplanted into sterilised soil, and the root system was gently exposed, wounded with a sterile scalpel and inoculated with a conidial suspension of the isolate adjusted to 1×10^6 spores/mL, after which the roots were covered with sterilised soil. Control plants received sterile distilled water. Plants were maintained under identical conditions and observed for 8 weeks for yellowing, wilting, leaf collapse and other symptoms of Fusarium wilt. Symptomatic tissue was then plated on PDA, and the cultural and morphological characters of the re-isolated fungus were compared with those of the original isolate to fulfil Koch's postulates.

Colletotrichum musae. Because *C. musae* is associated with anthracnose rather than vascular wilt, it was tested separately, following the artificial-inoculation approach used in recent anthracnose studies (Huang *et al*., 2021; Naik *et al*., 2026). Healthy banana leaf tissue of comparable physiological condition was surface-cleaned and lightly wounded with a sterile pin, and a conidial suspension prepared from an actively growing pure culture, adjusted to 1×10^6 spores/mL was applied to the wound. Control leaf tissue received sterile distilled water. Inoculated and control material was incubated 27±2°C and monitored for 7 days for brown to dark necrotic lesions and their expansion. The set up was replicated three times. Symptomatic tissue was then plated on PDA and the recovered fungus compared with the original isolate.

Plant materials and extract preparation

Leaves of *B. dalzielii*, *D. oliveri* and *Moringa. oleifera* were selected for their local availability and reported antimicrobial activity. Healthy leaves were collected from the study areas, authenticated at the herbarium unit of Modibbo Adama University, washed under running tap water, air-dried in the shade to constant weight, ground, and sieved (2 mm). Extracts were prepared by cold maceration of the powdered leaves in three solvents of increasing lipophilicity, namely distilled water, ethyl acetate and n-hexane, adapted from Anasuya and Rakesh (2025). Mixtures were agitated on a rotary shaker at room temperature for 24–48 h and filtered through Whatman No. 1 paper, and the filtrates were concentrated under reduced pressure on a rotary evaporator at 40–45 °C. Crude extracts were stored at 4 °C until use.

In vitro antifungal assay

Antifungal activity against each isolate was assessed by the poisoned food technique (Anasuya and Rakesh, 2025). Each extract was incorporated into molten, autoclaved PDA cooled to about 45 °C to at the concentrations of 7.5, 15, 22.5 and 30 mg/mL. PDA without extract served as the untreated control. After the medium solidified, a 5-mm mycelial disc from the margin of a 7-day-old culture of the test fungus was placed at the centre of each plate. Plates were sealed and incubated at 27±2°C, and colony diameter was measured in two perpendicular directions daily until the control colonies covered the plate (7 days). Percentage inhibition was calculated as:

Inhibition (%) = mean colony diameters in the control - mean colony diameters in the control and treated plates / mean colony diameters in the control × 100

Experimental design and statistical analysis

For each fungus, the assay was a factorial experiment in a completely randomised design (three plants × three solvents × four concentrations plus an untreated control), with three replicate plates per treatment. Data were subjected to analysis of variance in SPSS version 27, and means were separated by Duncan's multiple range test (DMRT) at $p < 0.05$. Results are presented as mean ± standard deviation.

Results

Fungi recovered from diseased banana

Two fungi were consistently recovered from diseased banana tissue: *F. oxysporum* and *C. musae* (Table 1). *F. oxysporum* was isolated from the Dakinsama and Sobbo farms but not from Guruza, whereas *C. musae* was isolated from Dakinsama and Guruza but not from Sobbo. Both fungi occurred together only on the Dakinsama farm. The distribution of the two pathogens was therefore not uniform across farms.

Table 1

Occurrence of fungi isolated from diseased banana samples on three farms in Donga LGA

Farm	*Colletotrichum musae*	*Fusarium oxysporum*
Dakinsama	+	+
Guruza	+	−
Sobbo	−	+

Note. + = recovered; − = not recovered.

Cultural and microscopic characteristics of the isolates

The two isolates differed clearly in culture and microscopy (Table 2; Figures 1 and 2). The *F. oxysporum* isolate grew rapidly and spread evenly across the plate, forming abundant, raised, cottony aerial mycelium that was initially white to cream and developed peach pigmentation. Its hyphae were septate and branched, and it produced stout, multiseptate macroconidia (usually three to four septa) that were slightly curved or canoe-shaped, together with abundant oval to kidney-shaped, mostly single-celled microconidia borne on long monophialides. In contrast, the *C. musae* isolate grew at a moderate rate and formed colonies that were initially white to pale grey, often with distinct concentric rings and velvety to sparse aerial mycelium, with a pale cream to yellowish reverse. Its hyphae were septate and hyaline, and its conidia were single-celled, hyaline, smooth-walled and cylindrical to ellipsoidal with rounded ends. These combinations of characters are consistent with *F. oxysporum* and *C. musae*, respectively.

Table 2
Cultural and microscopic characteristics of the fungal isolates on potato dextrose agar

Character	*Fusarium oxysporum*	*Colletotrichum musae*
Colony, front	Initially white to cream; peach pigmentation develops	Initially white to pale grey
Colony, reverse	Colourless to pale cream	Pale cream to yellowish
Growth pattern	Rapid; spreading evenly across the plate	Moderate; often in distinct concentric rings
Texture	Floccose (cottony); abundant, raised aerial mycelium	Velvety to sparse aerial mycelium
Hyphae	Septate and branched	Septate and hyaline
Macroconidia	Stout, multiseptate (usually 3–4 septa), slightly curved or canoe-shaped, with somewhat rounded ends	Not applicable
Microconidia / conidia	Microconidia abundant, oval to kidney-shaped, typically single-celled, borne on long monophialides	Conidia single-celled, hyaline, smooth-walled, cylindrical to ellipsoidal with rounded ends

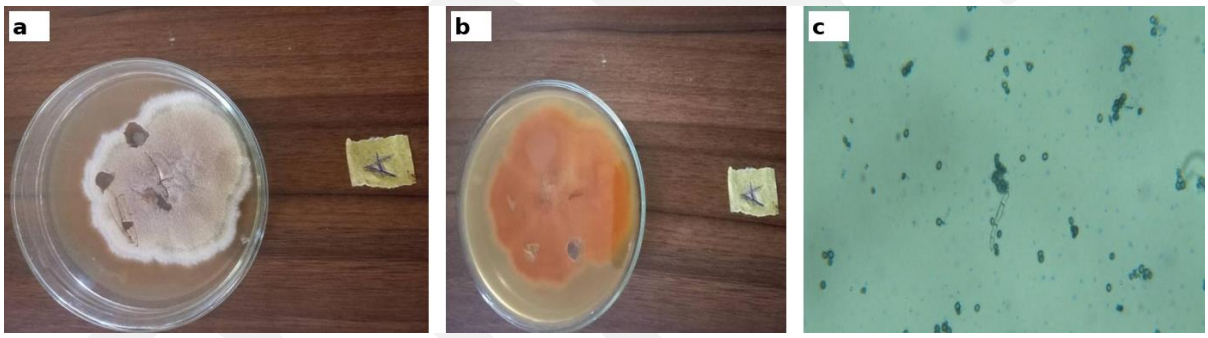


Figure 1: Isolate identified as *Fusarium oxysporum* from diseased banana: (a) colony on PDA, (b) reverse of the colony, and (c) micrograph showing conidia (500 µm.).

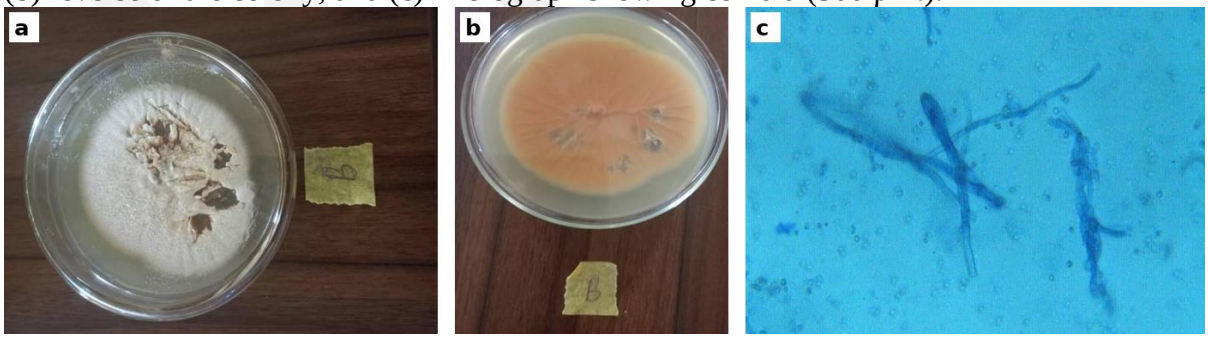


Figure 2: Isolate identified as *Colletotrichum musae* from diseased banana: (a) colony on PDA, (b) reverse of the colony, and (c) micrograph showing hyphae and conidia (500 µm.).

Pathogenicity

Banana plants inoculated with the *F. oxysporum* isolate developed progressive yellowing, loss of vigour and wilting, symptoms characteristic of Fusarium wilt and similar to those seen on naturally diseased plants in the field, whereas uninoculated control plants did not show comparable symptoms. The *C. musae* isolate also produced disease on healthy banana tissue

after artificial inoculation, with visible reactions that differed from the controls; as expected for an anthracnose pathogen, these were localised rather than a vascular wilt syndrome. Both isolates were therefore pathogenic to banana under the experimental conditions. The re-isolated *Fusarium oxysporum* and *Colletotrichum musae* showed cultural and morphological characteristic consistent with their original isolates confirming their presence.

In vitro inhibition of *Fusarium oxysporum* by plant extracts

Extract type, solvent and concentration significantly affected radial growth of *F. oxysporum* ($p < 0.05$; Table 3, Figure 3). Untreated controls recorded 0% inhibition, and every extract–solvent combination inhibited growth at every concentration tested. Inhibition increased consistently with concentration in all nine extracts, and each increase in concentration produced a significantly different mean (Table 3). Averaged over plants and solvents, inhibition rose from 25.1% at 7.5 mg/mL to 43.5%, 59.7% and 70.1% at 15, 22.5 and 30 mg/mL, respectively. *Daniellia oliveri* produced the strongest inhibition. Its ethyl acetate extract reached 56.33% at 15 mg/mL, 89.51% at 22.5 mg/mL and 97.93% at 30 mg/mL, the highest value recorded against this fungus, and its n-hexane extract reached 86.74% at 30 mg/mL, whereas its aqueous extract reached 63.08%. For *Moringa. oleifera*, the ethyl acetate extract was clearly the most active (31.94% at 7.5 mg/mL rising to 85.88% at 30 mg/mL), while the n-hexane and aqueous extracts reached only 59.90% and 50.73%, respectively. *Boswellia dalzielii* was the least inhibitory plant, with maximum inhibition of 64.75% (ethyl acetate), 70.47% (n-hexane) and 51.70% (aqueous) at 30 mg/mL.

Descriptively, mean inhibition across solvents and the four test concentrations was highest for *D. oliveri* (56.8%), followed by *M. oleifera* (47.7%) and *B. dalzielii* (44.2%). Across plants and concentrations, ethyl acetate extracts were the most inhibitory (59.2%), followed by n-hexane (50.2%) and aqueous extracts (39.4%). With n-hexane, however, *B. dalzielii* (mean 48.4%) outperformed *M. oleifera* (43.5%).

Table 3: ***Percentage radial growth inhibition of* Fusarium oxysporum *by leaf extracts of three plants in vitro***

Plant	Concentration (mg/mL)	Ethyl acetate	Aqueous	n-Hexane
B. dalzielii	0	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
	7.5	25.27 ± 1.59b	19.86 ± 1.35b	22.71 ± 2.17b
	15	43.18 ± 1.04c	31.81 ± 1.17c	43.76 ± 1.22c
	22.5	56.88 ± 2.17d	43.76 ± 1.22d	56.85 ± 2.39d
	30	64.75 ± 0.76e	51.70 ± 0.81e	70.47 ± 0.97e
D. oliveri	0	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
	7.5	28.95 ± 0.74b	22.71 ± 2.17b	29.11 ± 1.16b
	15	56.33 ± 1.44c	37.48 ± 1.88c	49.44 ± 1.70c
	22.5	89.51 ± 2.16d	51.13 ± 1.75d	69.25 ± 1.81d
	30	97.93 ± 1.79e	63.08 ± 1.79e	86.74 ± 2.20e
M. oleifera	0	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
	7.5	31.94 ± 1.96b	21.57 ± 1.32b	23.71 ± 0.76b
	15	54.49 ± 1.29c	34.07 ± 1.94c	40.68 ± 0.59c
	22.5	74.80 ± 1.60d	45.47 ± 1.24d	49.72 ± 1.27d
	30	85.88 ± 1.32e	50.73 ± 4.54e	59.90 ± 1.36e

Means that have the same letter are not significantly different according to Duncan's multiple range test ($p < 0.05$).

In vitro Inhibition of *Colletotrichum musae* by Plant Extracts

Extracts also significantly inhibited *C. musae* ($p < 0.05$; Table 4, Figure 4). Controls recorded 0% inhibition, and all treatments inhibited growth at every concentration, with inhibition generally rising as concentration increased. The pattern across plants resembled that seen for *F. oxysporum*. *Daniellia oliveri* was again the most inhibitory: its ethyl acetate extract gave 64.73% at 15 mg/mL and peaked at 97.60% at 22.5 mg/mL (97.12% at 30 mg/mL), and its n-hexane and aqueous extracts reached 91.83% and 63.66% at 30 mg/mL. The ethyl acetate extract of *Moringa oleifera* increased steadily from 32.86% at 7.5 mg/mL to 97.12% at 30 mg/mL, whereas its n-hexane and aqueous extracts reached 71.22% and 57.98%. *Boswellia dalzielii* was the least inhibitory plant overall, with maximum inhibition of 71.16% (ethyl acetate), 73.96% (n-hexane) and 51.85% (aqueous) at 30 mg/mL.

Mean inhibition across solvents and the four test concentrations was highest for *D. oliveri* (60.9%), followed by *M. oleifera* (52.9%) and *B. dalzielii* (46.7%). Ethyl acetate extracts were the most inhibitory (63.8%), followed by n-hexane (54.9%) and aqueous extracts (41.8%), and mean inhibition across plants and solvents rose from 28.0% at 7.5 mg/mL to 46.3%, 64.6% and 75.1% at 15, 22.5 and 30 mg/mL. Aqueous extracts were the weakest for all three plants. Overall, the descriptive mean inhibition of *C. musae* (53.5%) was slightly higher than that of *F. oxysporum* (49.6%), and the most active extracts (ethyl acetate extracts of *D. oliveri* and *M. oleifera*) reached about 97% against *C. musae*, compared with 98% and 86%, respectively, against *F. oxysporum*.

Table 4*: Percentage radial growth inhibition of Colletotrichum musae by leaf extracts of three plants in vitro*

Plant	Concentration (mg/mL)	Ethyl acetate	Aqueous	n-Hexane
B. dalzielii	0	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
	7.5	28.87 ± 0.88b	22.76 ± 0.78b	26.06 ± 2.01b
	15	44.80 ± 0.61c	33.89 ± 1.10c	38.95 ± 16.43b
	22.5	60.21 ± 1.20d	42.15 ± 5.95d	65.97 ± 0.81c
	30	71.16 ± 0.66e	51.85 ± 0.41e	73.96 ± 0.99c
D. oliveri	0	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
	7.5	33.34 ± 1.28b	24.56 ± 1.38b	32.84 ± 1.03b
	15	64.73 ± 1.25c	42.24 ± 0.91c	55.91 ± 1.18c
	22.5	97.60 ± 2.21d	52.92 ± 0.81d	73.56 ± 1.97d
	30	97.12 ± 2.49e	63.66 ± 1.53e	91.83 ± 1.49e
M. oleifera	0	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
	7.5	32.86 ± 0.99b	22.86 ± 2.04b	27.60 ± 1.34b
	15	55.90 ± 0.94c	37.77 ± 1.10c	42.74 ± 1.39c
	22.5	81.89 ± 1.04d	48.95 ± 1.21d	58.34 ± 1.23d
	30	97.12 ± 2.49e	57.98 ± 0.73e	71.22 ± 1.73e

Means that have the same letter are not significantly different according to Duncan's multiple range test ($p < 0.05$).

Discussion

Occurrence and identity of the pathogens

This study provides, to our knowledge, the first location-specific isolation of *Fusarium oxysporum* and *Colletotrichum musae* from diseased banana in Donga LGA. The *F. oxysporum* isolate's fast, floccose growth with peach pigmentation, canoe-shaped multiseptate macroconidia, and kidney-shaped microconidia on long monophialides match the classical description of the species by Leslie and Summerell (2006). Colony pigmentation and conidial dimensions vary considerably among isolates from different banana-growing areas, as documented for *Fusarium oxysporum* f. sp. *cubense* (Foc) in Assam, India (Baruah *et al*., 2025), so modest differences from published descriptions are expected. The *C. musae* isolate's moderate growth, concentric colony rings, and single-celled, hyaline, cylindrical conidia agree with morphological and cultural descriptions of the fungus as reporte by Kanade *et al*. (2023). The two fungi differ in ecology, which may explain their patchy distribution. *F. oxysporum* is a soil-borne vascular pathogen whose occurrence depends on cropping history, infested soil and the movement of infected planting material (Dita *et al*., 2018; Pegg *et al*., 2019), and Baruah *et al*. (2025) reported marked pathogen-ecological variation among banana belts. *C. musae* is mainly associated with fruit and can persist as a latent infection, so its recovery may be influenced by crop stage, humidity, wounding and handling (Cruz *et al*., 2025). Whether the absence of either fungus on a given farm reflects true absence, a sampling effect or differing management cannot be resolved from the present data. The recovery of *C. musae* from tissue sampled for wilt symptoms also deserves comment: its role in the wilt syndrome is not established, and it may be a co-occurring or secondary fungus. We therefore treat *F. oxysporum* as the candidate cause of the wilt symptoms and *C. musae* as a separate anthracnose pathogen.

The pathogenicity tests linked the isolates to disease on banana. Inoculated plants developed yellowing and wilting while controls did not, in agreement with banana inoculation studies in which Fusarium isolates caused leaf yellowing and vascular symptoms (Taping *et al*., 2023); these symptoms are consistent with impaired water transport after root penetration and xylem colonisation (Dita *et al*., 2018). The localised reaction to *C. musae* is consistent with its known lesion-forming behaviour on wounded banana tissue (Huang *et al*., 2021; Naik *et al*., 2026).

An important caution is that morphology alone cannot place an isolate within *F. oxysporum* f. sp. *cubense*, nor distinguish its races or vegetative compatibility groups, because the species complex contains many non-pathogenic and host-specific lineages that are morphologically similar (Fourie *et al*., 2011; Leslie and Summerell, 2006). We therefore refer to the isolate as *F. oxysporum* and do not claim that it is Foc or a particular race. Likewise, the *C. musae* identification rests on morphology, and the *Colletotrichum* genus includes closely related species that are difficult to separate by morphology. Sequencing of the translation elongation factor 1-α gene for *Fusarium* and of multi-locus markers for *Colletotrichum*, together with Foc-specific PCR assays, is needed to confirm identity and to establish whether the highly aggressive tropical race 4 is present.

Antifungal activity of the extracts

All three plants suppressed both fungi in a clear dose-dependent manner, with the best treatments (ethyl acetate extracts of *D. oliveri* at 22.5–30 mg/mL) nearly abolishing radial growth. Greater inhibition at higher concentrations is expected, since more antifungal constituents are available to interact with fungal cells, and similar concentration-dependent responses have been reported for *M. oleifera* leaf extracts against plant-pathogenic fungi including *Fusarium* (Majumder *et al*., 2024) and for plant extracts against *C. musae* and other *Colletotrichum* species (Pitiwittayakul *et al*., 2025; Sousa *et al*., 2022). The levels of inhibition we observed are comparable to the near-complete suppression of *F. oxysporum* obtained with a castor leaf extract *in vitro* (Anasuya and Rakesh, 2025), although the studies differ in extract,

solvent and concentration and cannot be compared directly. The high inhibition between 22.5 and 30 mg/mL seen for several ethyl acetate and n-hexane treatments against *C. musae* suggests that concentrations near 22.5 mg/mL may be sufficient for these extracts, which could be tested by estimating the Effective Concentration 50% (EC_{50}) values.

The strong performance of *D. oliveri* against both fungi agrees with phytochemical work showing that its extracts are rich in phenolics, flavonoids, tannins, alkaloids, terpenes and sterols (Awojide *et al*., 2025). It contrasts, however, with the report of Tittikpina *et al*. (2022), whose *D. oliveri* extracts and fractions had antibacterial but no detectable antifungal activity at the highest concentration tested (256 µg/mL). The most likely explanations are methodological: the highest concentration here (30 mg/mL) was more than 100-fold greater, the test fungi and assay (mycelial growth on solid medium rather than broth microdilution) differed, and extract composition varies with plant part, solvent and origin. The result underlines that antifungal potential is specific to the plant–pathogen–solvent combination. In the present material, phytochemical screening of the same plants detected alkaloids, tannins, saponins and coumarins in every extract, and quantitative analysis showed the lowest total levels of the measured metabolite classes in *D. oliveri* and the highest in *M. oleifera*. Bulk metabolite content therefore did not predict antifungal potency, suggesting that particular constituents, or their solubility in the extraction solvent, matter more than total quantity; this hypothesis should be tested by bioassay-guided fractionation and identification of the active compounds.

M. oleifera ranked second overall, driven largely by its ethyl acetate extract (85.88% against *F. oxysporum* and 97.12% against *C. musae* at 30 mg/mL), consistent with earlier reports of antifungal activity in moringa leaf extracts against *Fusarium* (Majumder *et al*., 2024; Mncube *et al*., 2023). *Boswellia dalzielii* was the least inhibitory overall, though still effective at higher concentrations; with n-hexane it exceeded *M. oleifera* against *F. oxysporum* and was similar to it against *C. musae* (mean 51.2% vs 50.0%). Because the composition of *B. dalzielii* essential oils varies with collection location in Nigeria (Owolabi *et al*., 2020), the activity of material from Donga may differ from that of other sources.

Ethyl acetate extracts were generally the most inhibitory and aqueous extracts the least against both fungi, suggesting that antifungal constituents are concentrated among moderately polar compounds that ethyl acetate recovers more efficiently than water. Majumder *et al*. (2024) found that aqueous moringa extracts were highly effective against some fungi, so the best solvent clearly depends on the plant and target fungus. From a practical standpoint, aqueous extracts are cheaper and safer for smallholders; the lower potency of water extracts observed here means that higher application rates, or formulation work, would be needed if they were to be used on-farm. Although both fungi responded similarly, *C. musae* appeared slightly more sensitive than *F. oxysporum* on average; this comparison is descriptive only, since the two assays were not analysed jointly.

Limitations and future work

First, both isolates were identified by morphology only. Secondly, each assay used a single isolate of each fungus; isolates from the other positive farms and from other locations were not compared, and susceptibility may vary among strains. Thirdly, the experiment included an untreated control but no solvent-residue control or reference fungicide, so possible contributions of residual solvent cannot be excluded and potency cannot be benchmarked against a standard. Fourthly, activity was expressed as inhibition at fixed concentrations of crude extract; median effective concentrations (EC_{50}) and minimum inhibitory concentrations were not determined. Finally, *in vitro* inhibition does not guarantee control in soil, on fruit or in plant. Greenhouse and field trials, post-harvest assays on fruit for *C. musae*, phytotoxicity

testing on banana, and evaluation of simple formulations are required before any farm recommendation can be made.

Conclusion

Fusarium oxysporum and *Colletotrichum musae* were isolated from diseased banana in Donga LGA, identified by their cultural and microscopic characters, and shown to be pathogenic to banana; *F. oxysporum* caused yellowing and wilting in inoculated plants. Leaf extracts of *Daniellia oliveri*, *Moringa oleifera* and *Boswellia dalzielii* inhibited both fungi *in vitro* in a concentration-dependent manner. The ethyl acetate extract of *D. oliveri* was the most effective, giving 97.93% inhibition of *F. oxysporum* at 30 mg/mL and 97.60% of *C. musae* at 22.5 mg/mL, and ethyl acetate was the most effective solvent overall. *D. oliveri* and *M. oleifera* should be prioritised for bioassay-guided fractionation, molecular confirmation of the pathogens (including Foc race determination), and greenhouse and field evaluation, alongside improved field sanitation and use of healthy planting material.

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