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RESEARCH ARTICLE

Efficacy of bamboo, moringa and bitter leaf extracts against fungi causing rot in Cucumber (*Cucumis sativus L.*)

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Abstract

Cucumber (*Cucumis sativus L.*) has a low caloric content and is a rich source of water-soluble vitamins and fibre. However, cucumber is highly susceptible to fungal rot. Given cucumber's susceptibility to fungal rot, effective antifungal agents are crucial for its management. In this paper, antifungal agents refer to biological chemicals that inhibit fungal growth and are vital for managing plant diseases. Ethanolic extracts from bamboo (*Bambusa vulgaris*), moringa (*Moringa oleifera*), and bitter leaf (*Vernonia amygdalina*) were tested against fungi that cause rot in cucumber (*Cucumis sativus*) in this study. *Mucor circinelloides*, *Mucor pusillus*, and *Fusarium solani* were identified as the causal agents. The results presents bitter leaf extract as the most effective antifungal agent against *M. pusillus* (3.429 ± 2.15 mm) and *F. solani* (3.586 ± 1.38 mm), whilst moringa extract shows the highest inhibition against *M. circinelloides* (5.300 ± 2.16 mm). Bamboo extract exhibits lowest efficacy across the tested fungi. The result of the Least Significant Difference (LSD) analysis (approximately 2.5 mm, 5% level) confirms that, the moringa leaf extract has the highest antifungal efficacy (3.824 ± 1.77 mm), though comparable to bitter leaf extract (3.615 ± 1.38 mm), follows by bamboo leaf extract (1.362 ± 0.55 mm). In conclusion, bitter leaf and moringa extracts hold promise as potential natural antifungal agents. Whereas, the bamboo leaf extract can be added as a supplement to either the efficient bitter leaf or moringa antifungal agent. However, further research into their bioactive compounds and applications is highly recommended in this paper. The research outcomes presented in this paper will contribute to developing natural, sustainable solutions for managing fungal diseases in cucumbers, benefiting farmers, consumers, and the environment through plant-based extracts (bamboo, moringa, bitter leaf) as alternatives to synthetic fungicides.

Keywords: Antifungal agents, *B. vulgaris*, Ethanolic extracts, *C. sativus*, *M. oleifera*, *V. amygdalina*

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1. Introduction

Cucumber (Cucumis sativus L.) is cultivated in various parts of Nigeria, including rainforest and savannah areas. According to Penn State University (n.d.), the cucumber plant has 4 or 5 main stems from which tendrils branch. Leaves are arranged alternately on the vines, with 3–7 pointed lobes and hairy texture. The cucumber plant produces yellow flowers approximately 4 cm in diameter. Its fruit varies in shape but is generally a curved cylinder, rounded at both ends, reaching up to 60 cm in length and 10 cm in diameter. Cucumber plant is an annual, surviving only one growing season, with vines up to 5 m in length (Penn State University, n.d.). Cucumber is predominantly water, making it an excellent hydrating food, remarkably low in calories (Sharma *et al*., 2020). Sharma *et al*. (2020) further expresses that, cucumber's palatable flavour and refreshing texture make it a salad staple, also processed into products like pickles and relishes. According to Chomicki *et al*., (2020), cucumber belongs to the Cucurbitaceae family, which also comprises other significant crops like melon (*Cucumis melo*), watermelon (*Citrullus lanatus*), Pumpkin (*Cucurbita moschata Duchesne*) and squash (*Cucurbita pepo*). Cucumbers can be grown in raised-bed gardens (Haas Bren, 2025) in homes and/or in greenhouses (Oregon State University, 2010) under cooler temperatures when light intensities are low. Oregon State University further states that, for cucumbers, temperatures should be kept between 75°F (24°C) and 77°F (25°C) during the day and 70°F (21°C) at night until the first picking.

Cucumbers (*Cucumis sativus*) is extensively cultivated across tropical and subtropical regions and is believed to have originated in India, where it has been grown for more than 3000 years (Singathiya *et al*., 2026). Afterwards, cucumber was introduced through trade into China in 100 B.C. and into France in the 9th century (Pal et al., 2020). In Africa, cucumbers were likely first cultivated and consumed in ancient Egypt, as evidenced by the biblical account in Numbers 11:5 (English Standard Version Bible), quote "*We remember the fish we ate in Egypt that cost nothing, the cucumbers, the melons, the leeks, the onions, and the garlic*". In Nigeria, cucumber cultivation is widespread, spanning the rainforest to savannah zones across the country's agro-ecological regions (Ndubuisi and Yaduma, 2021). According to Ndubuisi and Yaduma (2021), cucumber production patterns and volumes vary geographically, with the top five producing states being Plateau, Kaduna, Katsina, Kano, and Benue. Other notable producing states include Akwa Ibom, Oyo, Cross River, Rivers, Nassarawa, Enugu and Ebonyi.

Ogbodo *et al*. (2010) evaluated cucumber production potential in four major agricultural zones in Ebonyi State, Southeast Nigeria, namely Abakaliki, Ezzamgbo, Ikwo, and Okposi. Their results showed that Ezzamgbo outyielded Okposi and Ikwo by 21 t/ha and 8 t/ha, respectively. Abakaliki's yield surpassed Okposi and Ikwo by 16 t/ha and 3 t/ha, respectively, while Ikwo outyielded Okposi by 13 t/ha. The study also revealed significant differences ($P<0.05$) in soil properties, with Ezzamgbo and Abakaliki having higher total porosity, moisture content, and hydraulic conductivity compared to Okposi and Ikwo. Similarly, soil pH, organic matter, exchangeable bases, and cation-exchange capacity were significantly higher ($P<0.05$) at Ezzamgbo and Abakaliki than at Okposi and Ikwo locations.

Agbanaje *et al*. (2023) conducted a profit analysis of rain-fed cucumber production in eight communities across two agricultural zones in Anambra State, Nigeria. Their study revealed that, on average, rain-fed cucumber farmers generated a revenue of ₦4,400,000.00, with a total variable cost of ₦1,085,375.00 and a total cost of ₦1,334,375.00. The major cost components were seed purchase (46.80%) and labour (25.80%). In contrast to the findings of Ndubuisi and Yaduma (2021), which highlighted major cucumber-producing states without mentioning Anambra, Agbanaje *et al*. (2023) specifically demonstrated that cucumber production is a profitable venture in Anambra State.

The current study was conducted at Nnamdi Azikiwe University, Awka in Anambra State. A previous study by Ekwealor *et al*. (2021) at the same university investigated the effects of organic and inorganic manure on cucumber growth. Their results shows that 2 kg of organic manure yielded the highest leaf area increase (from

9.33±0.306cm² to 298.79±5.526 cm²) and height increase (from 6.20±0.100cm to 99.60±0.200cm) over six weeks. This result was followed by 1.5kg of organic manure (leaf area: 8.97±0.351cm² to 246.69±5.754cm²) and inorganic manure (height: 5.33±0.058cm to 88.73±4.143 cm), respectively. However, the promising growth and yield prospects of cucumber in Anambra State are often hindered by significant post-harvest spoilage of the cucumber fruits.

Adebayo and Diyaolu, (2003) assert that fungi and moulds are the primary disease-causing agents responsible for significant post-harvest losses in the cucumber value chain, encompassing production to marketing, including post-harvest handling and storage. In the context of post-harvest spoilage, moulds are bacteria that break down the fruit's cellular structure, causing rot, discoloration, and spoilage (Zaman *et al*., 2025). On the other hand, fungal rots and deterioration in cucumbers typically originate at wound sites, such as abrasions and bruises incurred during harvesting (Horticulture Innovation Australia Limited, n.d.). For instance, grey mould (Botrytis spp.) infection often occurs during flowering, however, symptoms develop post-harvest, manifesting as brown, water-soaked lesions at the blossom end, accompanied by soft, grey fungal growth. Additionally, *Fusarium spp*. can cause post-harvest infection, particularly following injury or chilling stress, resulting in sunken lesions with white, downy growth and black spore development on the fruit surface. *Fusarium spp*. are a large, widespread genus of soil-borne fungi, known as significant plant pathogens causing devastating crop diseases (wilts, blights, rots) in cereals, bananas, and other plants, while also producing harmful mycotoxins and posing opportunistic infections for humans, especially those with compromised immune systems.

In Anambra cucumbers, post-harvest losses are largely driven by fungal infections. Preliminary findings identified *Mucor circinelloides*, *Mucor pusillus,* and *Fusarium solani* as key pathogens. These species contribute to spoilage in distinct ways. According to Din *et al*. (2020), *Fusarium* wilt, caused by F. solani, is a major destructive disease in cucumber production, transmitted through infested soil and water. F. solani's morphological properties include microconidia (3.39–14.63 μm × 2.36–4.44 μm), macroconidia (7.22–50.46 μm × 2.43–6.14 μm), and 1–5 septate. Molecular identification (ITS gene sequences) confirms F. solani as a causal agent (99%–100% similarity index), while the pathogenicity tests reveal symptoms commence with yellowing of older leaves, progressing to wilting and plant death (Din *et al*., 2020).

Mucor circinelloides is a widespread dimorphic fungus found in soil, dung, and root vegetables, serving as a model organism for genetic studies. It exhibits yeast-like or mycelial growth, accumulating β-carotene as its primary carotenoid, with biosynthesis activated by blue light exposure (Dufosse, 2009). *Mucor circinelloides* is a known postharvest pathogen causing Mucor rot in cucumber fruits and stem rot in plants, typically infecting through wounds. According to Achour and Keith (2020), infected fruits rapidly decay and liquefy even in cold storage or controlled atmosphere (CA), with complete decay within two months at 0°C. Decayed tissue is light brown to golden, soft, and juicy, readily separable from healthy tissue. Abundant sporangia-containing juice is released from the infected fruit upon rupture, potentially spreading secondary infections; early symptoms may be confused with those of blue mould, although Mucor rot possesses a distinctive sweet odour (Achour and Keith, 2020).

Mucor pusillus (CABI, 2005) causes diseases in plants, including storage rot, leading to loss of stored grain. This can be controlled by preventing grain heating through adequate drying and ventilation, and preventing storage pests which often initiate heating and subsequent moulding. *Mucor pusillus* is a known spoilage agent that contributes to postharvest losses in various fruits and vegetables, including cucumbers. The problem of postharvest losses of cucumber fruits in Anambra State is of great concern to farmers, fruit-traders and consumers.

Postharvest losses of cucumber fruits in Anambra State are a significant concern for farmers, fruit traders, and consumers. Various pathogenic fungi have been implicated in rots of both immature and mature cucumber fruits (Jidda and Muhammad, 2017). However, specific species such as *Mucor pusillus*, *Mucor circinelloides*, and *Fusarium solani* have limited data documented on their prevalence and antifungal susceptibility in cucumber in

Anambra State, Nigeria. Whereas, biological control of plant pathogenic fungi is crucial due to the risks associated with chemical control of fungal diseases (Younes and Tarek, 2020). Therefore, this present study attempted to evaluate the antifungal efficacy of ethanolic extracts from bamboo (Bambusa vulgaris), moringa (*Moringa oleifera*), and bitter leaf (*Vernonia amygdalina*) against rot in cucumber (*Cucumis sativus*).

These plants contain diverse phytochemicals contributing to their antifungal properties, supporting their potential use as natural, eco-friendly antifungal agents in agricultural disease management. Antifungal agents are present in *Bambusa vulgaris*, *Moringa oleifera*, and *Vernonia amygdalina*. Antifungal agents are biological chemicals that inhibit fungal growth, playing a vital role in managing plant diseases (Chiu and Poucet, 2022). Thus, extracts from all three plants have demonstrated antifungal activity in various studies (Ambika and Rajagopa, 2017; Safari *et al*., 2026; Yu-Pei *et al*., 2025; Wang and Ng, 2003). For instance, Bambusa vulgaris extracts show activity against fungi such as *Aspergillus niger* (Ambika and Rajagopal, 2017) and *Pyricularia oryzae* (Safari *et al*., 2026), the causal agent of rice blast disease. Yu-Pei *et al.* (2025) found bamboo vinegar powder extract inhibited growth of Aspergillus terreus and Paecilomyces variotii. Bamboo shoots contain the antifungal protein *dendrocin* (Wang and Ng, 2003), which inhibits mycelial growth in fungi such as *Fusarium oxysporum*, *Botrytis cinerea*, and *Mycosphaerella arachidicola*.

Ayirezang *et al*. (2020) demonstrate the efficacy of Moringa oleifera leaf and seed extracts against foodborne fungal contaminants including *A. flavus* and *A. niger,* with a minimum inhibition concentration of 25 mg/ml. Similarly, *M. oleifera* leaf oil extract exhibits minimum inhibitory effects (MIC) against *Trichophyton rubrum, Trichophyton mentagrophytes, Epidermophyton floccosum,* and *Microsporum canis* with minimum inhibitory concentrations (MICs) of 1.6 μg/ml, 0.8 μg/ml, 0.2 μg/ml, and 0.4 μg/ml (Mahaveer and Abdul, 2024). Similarly, these findings highlight the potential of M. oleifera as a natural antifungal agent.

Previous studies have shown that extracts from bitter leaf (*Vernonia amygdalina*) exhibit antifungal properties against a range of fungi, including plant pathogens and human pathogens like *Candida albicans*. Its efficacy is attributed to bioactive compounds such as *saponins, tannins*, and *terpenoids* (Degu *et al*., 2024). Earlier, Ogo-*Oluwa* and *Liamngee* (2016) demonstrated the inhibitory potential of Vernonia amygdalina extract against fungi causing post-harvest rot of tomato fruits in Makurdi, Benue State, Nigeria, with the highest inhibition observed against Aspergillus niger (0.62±0.06 mm) and Fusarium oxysporum (0.3±0.09 mm).

Despite the established antifungal efficacy of *Bambusa vulgaris*, *Moringa oleifera*, and *Vernonia amygdalina*, as demonstrated by previous studies, no such research has been conducted on cucumbers in Anambra State. Therefore, the overall objective of this study is to evaluate the antifungal efficacy of ethanolic extracts from bamboo (*B. vulgaris*), moringa (*M. oleifera*), and bitter leaf (*V. amygdalina*) against rot in cucumber (*Cucumis sativus*) in Anambra State, Nigeria. The outcomes of this research will contribute to developing natural, sustainable solutions for managing fungal diseases in cucumbers, benefiting farmers, consumers, and the environment through plant-based extracts (bamboo, moringa, bitter leaf) as alternatives to synthetic fungicides.

2. Materials and Methods

2.1. Study area

The experiment was conducted at the Botany Science Laboratory, located at latitude 6°14'47.58''N and longitude 7°7'5.82''E within Nnamdi Azikiwe University (Ogbodo *et al*., 2020) in Awka. Awka, located between latitude 6°12' North and longitude 7°4' East (United Nations Human Settlements Programme, 2009) is the capital of Anambra State – one of the 36 States of the Federal Republic of Nigeria and one of the five States in the South-East geo-political zone of the country. Awka Capital Territory where Nnamdi Azikiwe University is located, lies due west of the Mamu River which forms its eastern boundary. Presented below is a detailed description of the study area, covering climate, temperature, vegetation, and agriculture and farming systems, as adopted from the United Nations Human Settlements Programme (2009) publication on the 'Structure Plan for Awka and Satellite Towns'.

The climate of Awka lies within the tropical wet climate zone, with clear-cut wet and dry seasons. Nearly eight out of the twelve months of the year experience rainfall, while the remaining four months fall within the dry season. These two seasons are influenced by the two predominant winds that affect the area: the south-western monsoon winds from the Atlantic Ocean and the north-eastern dry winds from across the Sahara Desert. The harmattan – a particularly dry and dusty period – occurs for about two weeks during the dry season, usually between November and February.

Awka experiences high temperatures in the range of 27–28°C, which increase to a peak of about 35°C between February and April, the hottest period. The coolest periods occur from mid-July through December to early January, coinciding with the middle of the rainy season and the harmattan, respectively. Awka's high temperatures create warm conditions with great potential for promoting outdoor recreational pursuits and tourism.

In terms of vegetation, Awka Sub-region falls within the rainforest zone of Nigeria. However, pressure on land for agriculture and commerce has largely reduced the vegetation to mixed savanna. Only along stream courses and in a few preserved areas can one find some rainforest trees such as Iroko, softwood, and domesticated species like oranges and mangoes. Palm trees and coconut trees are quite common in residential areas due to their economic value. However, the predominant natural vegetation are bamboos and mixed savanna. Wetter river valleys support dense rainforest, and rainforest of evergreen vegetation abounds along streams.

Awka is surrounded by rich agricultural lands to its north (Mgbakwu) and southeast (Isiagu). Due to the dearth of farmland around Awka, agriculture is limited to smallholder subsistence farming. The crops farmed include cassava, maize, some yam, and vegetables such as bitter leaf, moringa, and cucumber.

2.2. Methodology

2.2.1. Specimen collection

Samples of diseased *Cucumis sativus* and bitter leaf were purposefully procured from Eke-Awka market in Awka, Anambra State. Plant samples of moringa and bamboo leaves were collected from the Nnamdi Azikiwe University main campus in Awka.

2.2.2. Preparation of agar media and evaluation of antifungal activity using the agar well diffusion method

Sabouraud Dextrose Agar (SDA) used in this study was prepared according to the manufacturer's instructions as described in Saravanan *et al.* (2020). Six point five grams (6.5 g) of Sabouraud Dextrose Agar were weighed using a sensitive weighing balance and added to a 250-millilitre sterile conical flask. 100 ml of distilled water was added, and 250 mg of chloramphenicol was added to inhibit bacterial growth. The mixture of SDA, distilled water, and chloramphenicol was then shaken gently to dissolve the contents and sealed with cotton wool and Aluminium (Al) foil. The medium was autoclaved at 121°C for 15 minutes, allowed to cool to 45°C, and then 12 ml portions were poured aseptically into Petri dishes. The dishes were covered and allowed to cool and gel.

The agar well diffusion method as described by Okeke *et al.* (2001) was adapted in the study. Nine millilitres (9 mL) of Sabouraud agar was dispensed into sterile dishes and allowed to solidify. Using a sterile cork borer measuring 2.5mm in diameter, a hole was bored in each of the solid media plates. Two millilitres (2 mL) of the different concentrations of the *Bambusa vulgaris*, *Vernonia amygdalina* and *Moringa oleifera* leaf extracts were introduced into the hole using a sterile syringe. An inoculation needle was used to pick the sub-cultured pathogen and place it in the hole. The plates were placed in the incubator at 37ºC for 72 hours. The extent of inhibition was expressed in terms of the diameter of the inhibition zone as measured with a transparent ruler. Tests were carried out in triplicate.

2.2.3. Isolation of fungal pathogen from diseased Cucumis sativus

This study adapted the procedure presented in Tamilmalar *et al*. (2022) for the isolation of fungal pathogens from diseased *Cucumis sativus*. The diseased samples were cut into smaller pieces, surface-sterilised with ethanol, and rinsed using sterile distilled water. A sterile scalpel was used to excise portions of the samples showing symptoms of early rot, which were then inoculated into Petri dishes containing the cooled agar medium. The inoculated plates were incubated at room temperature for 72 hours (i.e. three (3) days) to observe fungal growth, with growth being monitored daily.

2.2.4. Characterisation and identification of the fungal isolates/spoilage moulds

As outlined by Ziedan *et al*., (2018), in this study, fungal characterisation was undertaken preliminarily through examination of cultural characteristics and utilisation of the slide culture technique to assess microscopic features. Small portions of the cucumber fruit tissues harbouring the spoilage organisms and connecting healthy tissue were surface-disinfected by cleaning with cotton wool soaked in ethanol solution. The excess disinfectant was then blotted out with sterile cotton wool. With the aid of a sterile knife and forceps, the spoilt fruit portions were obtained and plated aseptically onto Sabouraud dextrose agar (SDA) plates. Incubation was carried out at room temperature until visible growth was observed on the agar plates. The developing fungi were further purified by sub-culturing onto freshly prepared SDA plates.

2.2.5. Macroscopic examination and microscopic examination

According to Saristiana et al., (2024), macroscopic and microscopic examinations are fundamental, complementary methods in botany used for plant identification, classification, quality control, and understanding anatomy and pathology. Macroscopic study involves observing visible physical traits of plants or substances. It focuses on characteristics like colour, shape, texture, and overall appearance, aiding in identification, analysis, and quality assessment (Wisdom Library, 2025; Ondora et al. 2020). This method relies on visual observation without magnification, utilising features like odour and taste in some cases. On the other hand, microscopic examination in botany uses microscopes to study plant structures at the cellular level (cells, tissues, organelles) for identification, disease diagnosis, understanding photosynthesis, taxonomy, and evolution, revealing details invisible to the naked eye like stomata, chloroplasts, and tissue arrangements using techniques from light microscopy for basic anatomy to electron microscopy for ultra-fine structures, crucial for plant pathology and crop improvement (Saristiana et al., 2024). Microscopic examination is useful for characterising materials and understanding their properties at the microstructural level.

Accordingly, proliferation of the fungi was also observed. Microscopic examination was carried out using a microscope. A drop of cotton blue stain was introduced onto a clean, grease-free slide, and a fragment of the test fungus was removed and introduced onto the slide with the aid of a sterile straight wire loop. The fungus was spread properly on the slide, which was thereafter covered with a coverslip, avoiding bubbles. The excess water was removed by blotting with sterile cotton wool, and the slide was then viewed under the microscope. This was done based on the description of the gross morphological appearance of fungal colonies on the SDA culture medium and the modified slide culture technique using lactophenol cotton blue stain for the microscopic evaluation under X10 and X40 magnification of the microscope (Agu and Chidozie, 2021); with reference to the Manual of Fungal Atlases (Ziedan *et al*., 2018).

2.2.6. Sub-culturing of test fungi pathogenic to cucumber

The test fungi were sub-cultured by transferring hyphae tips from the colony edges to fresh plates of SDA using flame-sterilised blades. Plates were incubated at 37ºC for 72 hours. Basically, sub-culturing of test fungi pathogenic to cucumber is performed to obtain and maintain pure cultures for further study and experimentation, such as pathogenicity tests or identification (Jidda and Muhammad, 2017). This process is critical to ensure that experiments are conducted with a single, target organism (Abo-Elyousr *et al*., 2022). Thus, this method was applied to allow for the isolation of pure fungal cultures, which is crucial for accurate identification and further analysis.

2.2.7. Preparation of ethanolic leaf extracts of moringa, bamboo, and bitter leaf

The procedures for ethanolic leaf extraction as illustrated in Liga *et al*., (2025) was adapted in this study. The drying process was hastened using an oven and then the sample was ground using a grinder. 100g of the ground sample for each plant sample was dissolved in 1000ml of 70% ethanol and left for 24 hours, after which it was filtered using a Whatman No. 1 filter paper. The filtrate was then boiled at 80 degrees to retain the leaf extracts.

2.2.8. Statistical Evaluation of Treatments using Least Significant Difference (LSD)

The means were compared using Least Significant Difference (LSD) at a 5% significance level to determine differences between treatments (Williams and Abdi, 2010). This was done to ascertain the relative efficacy of the various plant extracts in inhibiting fungal growth. A 5% significance level was chosen as it provides a conventional balance between Type I error risk (false positives) and statistical power in biological research (Ugwu *et al*., 2014).

3. Results and Discussion

3.1. Results

3.1.1. Identification of fungi isolates from the cucumber samples

Three fungal organisms were isolated and identified as *Mucor circinelloides*, *Mucor pusillus*, and *Fusarium solani*. Microscopic examination revealed the following characteristics for the three identified fungi:

i. *Mucor circinelloides:* Macroscopically, it showed light brown-black colony, powdery diffused hyphae in media. Microscopically, conidial heads were blue-black, with short, circinate, branched sporangiophores bearing dark brown sporangia.
ii. *Mucor pusillus:* Colonies were fast-growing, white to greyish-brown, with simple or branched sporangiophores bearing globose to subglobose sporangia.
iii. *Fusarium solani:* Macroscopically, exhibited colonies that are brown-blue-green in color and cottony in texture. Microscopically, microconidia typically lacked septa, and their hyphae in tissue resembled those of *Aspergillus spp.*

3.1.2. Antifungal effects of plant extracts on M. pusillus

Table 1. Mean inhibition zones (mm±sd) of plant extracts against *Mucor pusillus*

Specimen	Conc. of plant extracts (%)	Mean inhibition zones (mm) ± standard deviation (SD)
Bamboo leaf	100.00	2.543±1.36
Bitter leaf	100.00	3.429±2.15
Moringa leaf	100.00	2.986±1.77
Control	0.00	0.00 ± 0.00

Source: This study

Table 1 shows the antifungal effects of bamboo, bitter leaf, and moringa leaf extracts at 100% concentration compared to a control (0% concentration) on *Mucor pusillus*. Bamboo extract shows a mean inhibition zone of 2.543 ± 1.36 mm. Bitter leaf extract has a mean inhibition zone of 3.429 ± 2.15 mm. Moringa leaf extract exhibits a mean inhibition zone of 2.986 ± 1.77 mm. The control group (0% concentration) shows no inhibition, with a mean inhibition zone of 0.00 ± 0.00 mm.

3.1.3. Antifungal effects of plant extracts on M. circinelloides

Table 2. Mean inhibition zones (mm±sd) of plant extracts against *M. circinelloides*

Specimen	Conc. of plant extracts (%)	Mean inhibition zones (mm) ± standard deviation (SD)
Bamboo leaf	100.00	0.500±0.00
Bitter leaf	100.00	3.829±1.77
Moringa leaf	100.00	5.300±2.16
Control	0.00	0.00 ± 0.00

Source: This Study

Table 2 presents the mean inhibition zones of various plant extracts against *M. circinelloides*. At a concentration of 100%, Moringa extract exhibits the largest mean inhibition zone of 5.300 ± 2.16 mm, indicating the highest antifungal activity. Bitter leaf extract demonstrates moderate efficacy, with a mean inhibition zone of 3.829 ± 1.77 mm. In contrast, Bamboo extract displays minimal inhibition, with a mean zone of 0.500 ± 0.00 mm. As expected, the control group, with 0% concentration, shows no inhibition, with a mean inhibition zone of 0.00 ± 0.00 mm. These results suggest that Moringa extract possesses the most potent antifungal properties against M. circinelloides, followed by Bitter leaf extract.

3.1.4. Antifungal effects of plant extracts on F. solani

Table 3. Mean inhibition zones (mm±sd) of plant extracts against *F. solani*

Specimen	Conc. of plant extracts (%)	Mean inhibition zones (mm) ± standard deviation (SD)
Bamboo leaf	100.00	1.043±0.55
Bitter leaf	100.00	3.586±1.38
Moringa leaf	100.00	3.186±1.41
Control	0.00	0.00 ± 0.00

Source: This Study

The results presented in **Table 3** demonstrate the antifungal effects of plant extracts against *F. solani*. At a concentration of 100%, Bitter leaf extract exhibits the highest antifungal activity, with a mean inhibition zone of 3.586 ± 1.38 mm, closely followed by Moringa extract, which displays a mean inhibition zone of 3.186 ± 1.41 mm. In contrast, Bamboo extract shows relatively low efficacy, with a mean inhibition zone of 1.043 ± 0.55 mm. These findings suggest that Bitter leaf extract is the most effective against *F. solani*, followed by Moringa extract, while Bamboo extract demonstrates limited antifungal activity.

3.1.5. Least significant difference for extract with highest fungal inhibition

Table 4. *Least Significant Difference for Extract with the Highest Fungal Inhibition*

Treatment	Mean (mm) ± SE	LSD Grouping
Moringa*	3.824± 1.77	a
Bitter leaf	3.615± 1.38	a
Bamboo	1.362± 0.55	b
Control	0.00 ± 0.00	c

LSD ≈ 2.5 mm (approximate). Means with same letter not significantly difference.
** Moringa has the highest inhibition*

Table 4 presents the effects of various plant extracts on fungal inhibition. Statistically, Moringa extract exhibits the highest inhibition (3.824 ± 1.77 mm), which is comparable to Bitter leaf extract (3.615 ± 1.38 mm). Bamboo extract shows moderate inhibition (1.362 ± 0.55 mm), whilst the control group shows no inhibition (0.00 ± 0.00 mm). The Least Significant Difference (LSD) is approximately 2.5 mm, indicating significant differences between groups with different letters.

3.2. Discussion

3.2.1. Comparative antifungal efficacy of bamboo, bitter leaf, and moringa extracts on M. pusillus

The results presented in **Table 1** indicate that bitter leaf extract exhibited the highest antifungal activity against Mucor pusillus, with a mean inhibition zone of 3.429 ± 2.15 mm, followed by moringa leaf extract (2.986 ± 1.77 mm) and bamboo extract (2.543 ± 1.36 mm). In other words, bitter leaf extract (3.429 ± 2.15 mm) is the most effective against *Mucor pusillus*, followed by moringa leaf extract (2.986 ± 1.77 mm) and then bamboo extract (2.543 ± 1.36 mm). The control group showed no inhibition, as expected (0.00 ± 0.00 mm). These findings suggest that the plant extracts possess varying degrees of antifungal activity, which is consistent with previous studies on the antimicrobial properties of plant extracts (Degu *et al*., 2024; Mahaveer and Abdul, 2024). The Mahaveer and Abdul, (2024) findings shows that, *M. oleifera* leaf oil extract exhibits minimum inhibitory effects (MIC) against *Trichophyton rubrum, Trichophyton mentagrophytes, Epidermophyton floccosum,* and *Microsporum canis* with minimum inhibitory concentrations (MICs) of 1.6 μg/ml, 0.8 μg/ml, 0.2 μg/ml, and 0.4 μg/ml.

The observed antifungal activity could be attributed to the presence of bioactive compounds in the extracts, such as flavonoids, alkaloids, and phenolic compounds, which have been reported to possess antimicrobial properties (Yu-Pei *et al.* 2025; Safari *et al*., 2026). However, the relatively low inhibition zones compared to standard antifungal agents (Onyechere *et al*., 2025; Wang and Ng, 2003) suggest that further purification and concentration of the extracts may be necessary to enhance their efficacy.

In a nutshell, the findings of this study have significant implications for the development of alternative antifungal agents, food preservation, and pharmaceutical applications. The plant extracts, particularly bitter leaf extract, show promise as potential alternatives or complements to synthetic antifungal agents. Further research is needed to identify and isolate the active compounds responsible for the antifungal activity, optimize extraction methods and concentrations, and evaluate toxicity and safety profiles. Additionally, assessing the efficacy of these extracts in real-world applications, such as food preservation and agricultural disease control, could lead to improved outcomes and reduced economic losses.

3.2.2. Comparative antifungal efficacy of bamboo, bitter leaf, and moringa extracts on M. circinelloides

The results (**Table 2**) demonstrate the varying degrees of antifungal activity exhibited by the plant extracts against M. circinelloides. Particularly, Moringa extract emerges as the most effective inhibitor, with a mean inhibition zone of 5.300 ± 2.16 mm. This finding is consistent with previous studies that have reported the antimicrobial properties of *Moringa oleifera* (Anis *et al*., 2025; Ambika and Rajagopa, 2017). Bitter leaf extract shows moderate antifungal activity (3.829 ± 1.77 mm), which corroborates the findings of (Sanchez-Silva *et al*., 2025) who reported similar efficacy against other fungal species. In contrast, Bamboo extract displays limited efficacy, with a mean inhibition zone of only 0.500 ± 0.00 mm, suggesting that further investigation is needed to optimize extraction methods or explore synergistic effects with other plant extracts. In a nutshell, the findings indicate that, at 100% concentration, moringa extract is the most effective against *M. circinelloides*, followed by Bitter leaf extract. Bamboo extract shows very little inhibition. The findings infer that Moringa extract, in particular, could be a promising candidate for the development of natural antifungal agents, potentially offering an alternative to synthetic fungicides in food preservation, agriculture, or pharmaceutical applications.

3.2.3. Comparative antifungal efficacy of bamboo, bitter leaf, and moringa extracts on F. solani

The results presented in **Table 3** indicate that Bitter leaf extract is the most effective against F. solani, followed by Moringa extract, whilst Bamboo extract demonstrates limited antifungal activity. This suggests that Bitter leaf extract may possess potent antifungal compounds that could be leveraged for the development of natural antifungal agents, potentially offering an alternative to synthetic fungicides in various applications (Onyechere *et al*., 2025). The moderate efficacy of Moringa extract against F. solani is consistent with previous studies that have reported its broad-spectrum antimicrobial properties (Jain *et al*., 2025; Berikten and Gunaydın, 2025). The limited efficacy of Bamboo extract, however, suggests that further investigation is needed to optimize extraction methods or explore synergistic effects with other plant extracts.

As an overall deduction in this study, the collective findings from **Tables [1, 2, and 3]** reveal that Bitter leaf extract exhibits the most consistent antifungal activity against the tested fungal species, namely *M. pusillus*, *M. circinelloides*, and *F. solani*. Moringa extract also shows notable efficacy, particularly against *M. circinelloides*. Bamboo extract shows the least antifungal activity across the three (3) fungal species.

3.2.4. LSD Analysis of Fungal Inhibition by Plant Extracts

The LSD (*Least Significant Difference*) value of approximately 2.5 mm indicates that any difference in fungal inhibition zones between treatments exceeding this value is statistically significant at the 5% level (Williams and Abdi, 2010; Ugwu *et al*., 2014). Moringa and Bitter leaf extracts exhibit comparable inhibition; however, both are significantly more effective than Bamboo extract and the control. Bamboo extract's inhibition is significantly higher than the control. Thus, Moringa and Bitter leaf extracts demonstrate potent antifungal activity, with Moringa being the most effective.

4. Conclusion and Recommendation

4.1. *Conclusion*

This study demonstrates that ethanolic extracts from Bitter leaf (*V. amygdalina*) and Moringa (*M. oleifera*) possess significant antifungal efficacy against rot in cucumber (*Cucumis sativus*) caused by *M. pusillus*, *M. circinelloides*, and *F. solani*, indicating their potential as natural antifungal agents. In all cases, the control group showed no inhibition, as expected (0.00 ± 0.00 mm). The findings also indicate that, at 100% concentration, Moringa extract emerges as the most effective inhibitor against *M. circinelloides*, with a mean inhibition zone of 5.300 ± 2.16 mm, followed by Bitter leaf extract. Bamboo extract shows very little inhibition. Overall, the collective findings reveal that Bitter leaf extract exhibits the most consistent antifungal activity against the tested fungal species, namely *M. pusillus*, *M. circinelloides*, and *F. solani*. Moringa extract also shows notable efficacy, particularly against M. circinelloides. Bamboo extract shows the least antifungal activity across the three fungal species. In conclusion, Bitter leaf and Moringa extracts hold promise as potential natural antifungal agents. However, further investigation into their bioactive compounds and applications is required. The outcomes of this research will contribute to developing natural, sustainable solutions for managing fungal diseases in cucumbers, benefiting farmers, consumers, and the environment through plant-based extracts (bamboo, moringa, bitter leaf) as alternatives to synthetic fungicides.

4.2. *Recommendation*

Though Moringa and Bitter leaf extracts showed stronger antifungal activity in this study, bamboo's widespread availability and sustainability make it an interesting alternative for further research into synergistic combinations with other plant extracts or novel extraction techniques. Future studies could also explore bamboo's efficacy against other pathogens or optimise extraction methods to unlock its potential as a natural antifungal agent.

Conflicts of Interest: The authors declare that they have no conflict of interest.

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