

Full Length Research Paper

Pathogenicity test of four fungi pathogens responsible for cabbages (*Brassica oleracea* L.) diseases and their *in-vitro* control using medicinal plants and medicinal mushroom extracts in the Western highlands of Cameroon

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Diseased cabbages are known for post-harvest and financial losses for farmers. The study evaluated the pathogenicity of the fungi species identified from diseased cabbages and *in-vitro* control using biological control. For the pathogenicity test, soil was sterilized and 100 cabbages planted in polythene bags. After 65 days of growth, healthy cabbages were infused with 105 spores in 1 ml of glucose solution per treatment according to Koch's postulate. For the *in-vitro* control of fungi diseases, three medicinal plants: *Commelina benghalensis*, *Clematis hirsuta* and *Telfairia occidentalis* and three medicinal mushrooms: *Lentinus* species, *Trametes pubescens*, and *Pleurotus ostreatus* were used. Three kilograms of dry products each were used for methanolic and aqueous extractions. The signs and symptoms recorded were rotting of cabbage leaves, yellowing of leaves, darkening of leaves and decaying. Pathogenicity test showed that *Fusarium oxysporum*, *Alternaria alternata*, *Curvularia senegalensis* and *Trichoderma harzianum* are responsible for cabbage diseases. The overall result reveals that aqueous and methanolic extracts of the medicinal plants and mushrooms at 20, 40 and 80%, with 80% being the best concentration can be used to control cabbage diseases as they inhibited the growth of the pathogen that can reduce post-harvest losses of cabbages.

Key words: Cabbage, pathogenicity test, *in vitro* control, medicinal plants, medicinal mushrooms.

INTRODUCTION

Cabbage (*Brassica oleracea* L. var. *capitata*) has a rich history and plays a significant role in nutrition and food

security worldwide. Cabbage has been cultivated for thousands of years and has its origins in the

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Mediterranean region (Mpumi, 2022). Ancient civilizations, including the Greeks and Romans, cultivated and consumed cabbage for its culinary and medicinal properties (Šamec et al., 2017). Over time, cabbage spread to other parts of Europe and Asia, where it became a staple crop in various cuisines (Ignatov et al., 2008). Cabbage is highly nutritious and offers several health benefits. It is low-calorie vegetable rich in vitamins, minerals, and dietary fiber. Cabbage is an excellent source of vitamin C, vitamin K, vitamin B6, folate, and manganese (Singh, 2023). It also contains antioxidants and phytochemicals that have been associated with potential health benefits, including anti-inflammatory and anticancer properties.

Consuming cabbage as part of a balanced diet can contribute to overall nutritional well-being (Thakur and Sharma, 2018). Cabbage plays a crucial role in ensuring food security in many regions. It is a hardy and versatile crop that can be grown in different climates and soil conditions (Hughes and Ebert, 2011). Cabbage has a relatively long shelf life, which makes it a valuable food source, particularly in areas where access to fresh produce is limited (Reda et al., 2021).

This crop is also a cost-effective vegetable, making it accessible to a wide range of populations. Cabbage is known for its resilience and adaptability, allowing it to be cultivated in diverse environments (Quezada-Martinez et al., 2021).

Cabbage can be grown in both small-scale and large-scale agricultural systems, making it suitable for subsistence farming as well as commercial production (Altieri and Anderson, 1986). The ability to store cabbage for an extended period, either by refrigeration or traditional preservation methods, contributes to its importance in addressing seasonal variations and ensuring a consistent food supply (Adeyeye, 2017). Furthermore, cabbage can be processed and preserved in various forms, such as sauerkraut, kimchi, pickled cabbage, and dehydrated cabbage flakes (Greene, 2011). These products offer extended shelf life and nutritional value, providing additional options for food security and dietary diversity. Cabbage also serves as a valuable component in crop rotation and intercropping systems. Its cultivation can help break disease cycles, enhance soil fertility, and contribute to sustainable agricultural practices, thus supporting long-term food security (Thrupp, 2000).

Fungal pathogens pose a significant threat to cabbage plants throughout their growth cycle, including seedling establishment, vegetative growth, and during the formation of the edible heads (Greer et al., 2023). Common fungal pathogens affecting cabbage include species from the genera *Alternaria*, *Fusarium*, *Rhizoctonia*, *Sclerotinia*, and *Plasmodiophora* (Keinath et al., 2007). These pathogens can cause diseases such as *Alternaria* leaf spot, *Fusarium* wilt, black rot, white mold, and clubroot, respectively (Sharma et al., 2018). The

assessment of fungal pathogens of cabbage involves several key aspects such as accurate identification of the fungal pathogens causing diseases in cabbage is important for effective disease management (Greer et al., 2023). This typically involves morphological, cultural, and molecular techniques to identify the specific fungal species or strains responsible for the observed symptoms. According to Khakimov et al. (2022), the assessment of fungal pathogens includes diagnosing the presence and severity of diseases in cabbage plants. Visual inspection, symptom characterization, and laboratory analysis are often used to diagnose fungal diseases accurately. Greer et al. (2023) reported that assessing the incidence and severity of fungal diseases provides crucial information about the extent of pathogen spread and the impact on cabbage crops. This assessment can involve field surveys, sampling, and data collection from affected areas.

According to Ojiambo et al. (2017), the biology and epidemiology of fungal pathogens is fundamental for developing effective disease management strategies. Assessing factors such as pathogen life cycles, host range, infection mechanisms, and environmental conditions can provide insights into disease development and guide control measures (Shahid et al., 2012). The assessment of fungal pathogens involves evaluating and developing disease management strategies, including cultural practices, crop rotation, chemical treatments, and biological control methods. Assessing the efficacy and sustainability of these strategies is essential for successful disease control. Erper et al. (2021) reported that pathogenicity tests help confirm whether a particular pathogen is responsible for causing disease in cabbage plants. By establishing a cause-and-effect relationship between a specific pathogen and the observed symptoms, researchers can better understand the pathogen's virulence and the mechanisms by which it infects and damages cabbage plants. The study seeks to evaluate pathogenicity of the fungi species identified and *in-vitro* control using organic products in the western highland of Cameroon.

MATERIALS AND METHODS

Description of the study area

The study was conducted in Santa and Dschang, with Santa being a sub-division located in the Mezam Division of the North West Region of Cameroon. Specifically, it is situated between latitudes 5°42' and 5°53' north of the equator and longitudes 9°58' and 10°18' east of the Greenwich Meridian.

According to Fogwe and Sikod (2014), the population of Santa was estimated to be approximately 99,851 in 2008, with around 90% of the residents engaged in farming or grazing activities. The area covers a surface area of approximately 532.67 km² and is bordered by Galim to the east, Wabane, Babadjou, and Mbouda to the south, Bali and Batibo Sub-Divisions to the west, and Bamenda Sub-Division to the north.

The region's climate is characterized by an average yearly

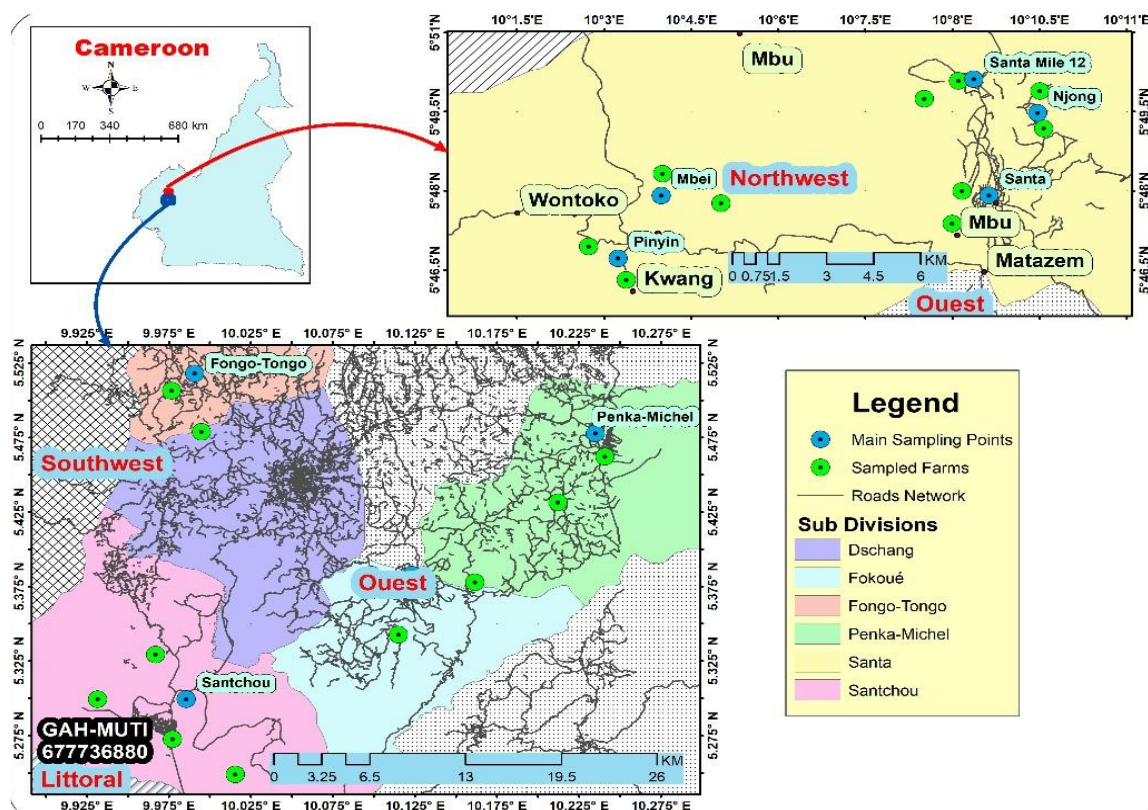


Figure 1. Map of the study area.

temperature range of 21.8 to 30.8°C, with a wet season lasting from March to September and a dry season from October to February. The area receives an annual rainfall of 2000 to 3000 mm, which supports the fertile soils that sustain a significant human population.

Santa's highland terrain, with an altitudinal range of 600 to 2600 m, makes it an ideal location for livestock rearing and crop production, including vegetables in Cameroon's Western Highlands. The area is strategically located along the Bamenda-Bafoussam highway, which serves as a major route for evacuating farm produce from the region (Konje et al., 2019).

Dschang was the second study site selected for the research, located in West Cameroon. Specifically, it is situated at an altitude of approximately 1407 m, between latitude 5°20' north and longitude 10°30' west (Nkouayep et al., 2017). The city covers a total area of 225 km² and has a mild, wet tropical climate, characterized by two distinct seasons: a rainy season from mid-March to mid-October and a dry season from November to February. The annual rainfall is approximately 1809 mm, with a unimodal pattern (Temgoua et al., 2015), and the months of August and September experience the most precipitation. The soil composition in Dschang includes ferrallitic and hydromorphic soils (Figure 1).

Pathogenicity test of the fungi responsible for cabbage diseases

The pathogenicity test was conducted using a modified method based on Okigbo et al., (2009). The experiment utilized mycelial plugs and conidia from all obtained fungal isolates (Suwannarach et al., 2024). To ensure the soil was free from fungal diseases, it was sterilized, and 100 cabbages were planted in polythene bags filled

with the sterilized soil. After 65 days of growth, healthy cabbages were inoculated with the spores of the fungal isolates. The cabbages were surface-disinfected with 70% ethanol for 3 min, rinsed five times with sterile distilled water, and dried under filter-sterilized airflow. The fungus was grown on PDA culture medium, and pure cultures of 7-day-old isolates were used as inoculum. The spore concentration was adjusted using a hemacytometer according to Nyaka et al. (2017).

A sterilized blade was used to create wounds on cabbage leaves, and a micropipette was used to deposit 1 mm of spore suspension into the wounded area, except for the control cabbages, which were inoculated with distilled sterilized water. Both inoculated and control treatments were incubated for 10 days at room temperature to allow disease development. To confirm the pathogenicity of the isolate, re-isolation of the pathogen was performed according to Koch's postulate, and the results were compared with the original isolate, as shown in Figure 2.

Antifungal potential of different medicinal plants and mushrooms in controlling fungi disease of cabbage

Three plant species from three different plant families *Commelina benghalensis* (Commelinaceae), *Clementis hirsute* (Ranunculaceae) and *Telfairia occidentalis* (Cucurbitaceae) was obtained Bambui and Bambili. All the three plants have been proven by previous studies to have antimicrobial properties. Three medicinal mushroom species was obtained from the tree bark in Bambili and Ndog and the Basidiocarp of medicinal mushrooms *Lentinus* species (Polyporaceae), *Trametes pubescens* (Polyporaceae) and *Pleurotus ostreatus* (Pleurotaceae) species were used since they have antifungal activities (Nasir et al., 2021;

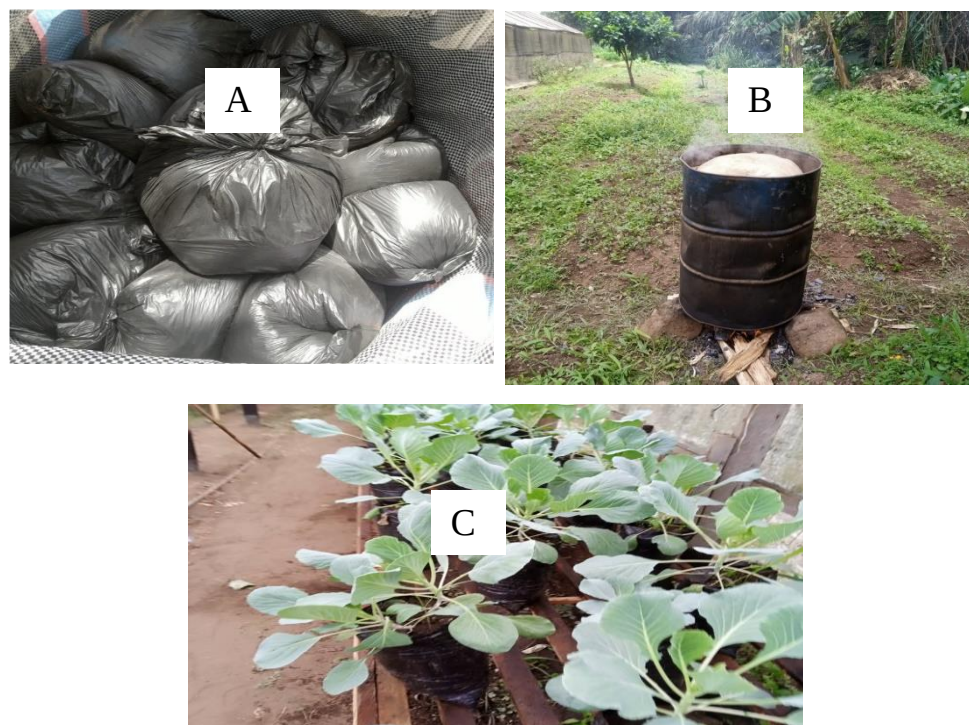


Figure 2. Process of soil sterilization by steam method A) Soil in plastic paper ready for steam sterilization, B) Steam sterilization process, C), healthy cabbage growing in sterilized soil in polythene bags in a green house.



Figure 3. Medicinal plants and medicinal mushrooms used to control fungi diseases of cabbage.

Owaid et al., 2017) (Figure 3).

Preparation of extracts

Fresh leaves of *C. benghalensis*, *C. hirsuta*, and *T. occidentalis* were used for the study. Both aqueous and organic extracts were prepared from the leaves. The fresh leaves were cut into small

pieces, shade-dried, and powdered using an electrical blender. For extraction, 10 g of the powdered material were added to 100 ml of distilled water and boiled for half an hour. The mixture was then filtered through a 4-fold muslin cloth, followed by Whatmann No. 1 filter paper, and the resulting extract was used for antifungal studies (Kumar et al., 2010). The extracts were stored in a refrigerator at 4°C until further use. Prior to efficacy testing on the sample fungi, the extracts were diluted to achieve the required concentrations.

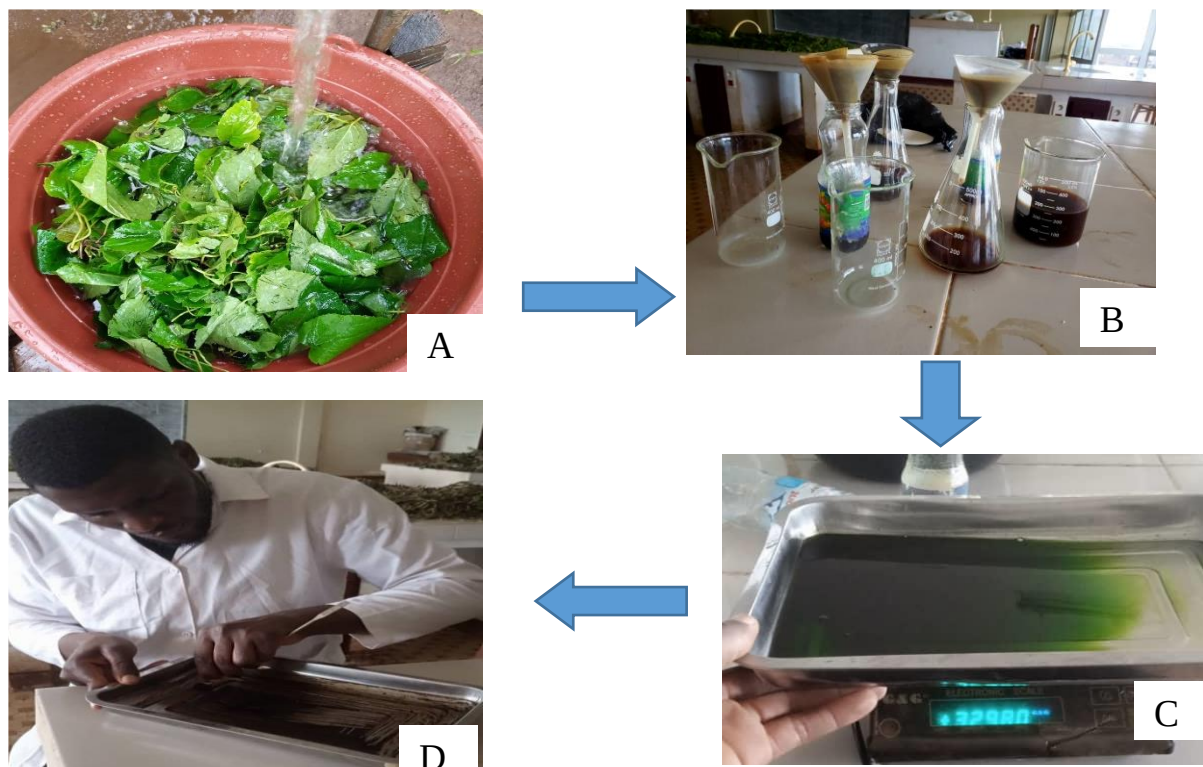


Figure 4. The process of obtaining a plant extract A) washing of leaves B) filtering of extracts C) weighing the filtered extract D) harvesting of the extract from the oven after 48 h.

The extracts from medicinal mushrooms were prepared from dried fruiting bodies of *Lentinus* spp., *T. pubescens*, and *P. ostreatus* at 45°C in an oven then powdered. The powder was then placed in distilled water at the same ratio (1:10) for each sample, and shaken in a shaker at 150 cycle/min at 25°C for 24 h (Alhajali et al., 2022). Aqueous extracts were filtered using Whatman No.1 filter paper and dried in glass dishes in hot air in an oven at 40°C until had obtained of a thickened mass, weighed then sterilized using Mollipore Sryinge filter 0.20 µ.

Blank discs (6 mm) were prepared from sterilized Whatmann No. 1. Then the amount of aqueous extract was determined from each one separately and placed on blank discs for producing extract disc concentrations 2, 4 and 8 mg/disc, transferred to incubator until dried, marked and stored in a sterilized vial at 4°C until use. By the same method, distilled water was prepared and used as control.

***In vitro* effect of plants and mushroom extracts**

The inhibitory effect of the extracts was tested following the poison food technique (Gonelimali et al., 2018). 0.4, 0.8 and 1.6 g of each extract was dissolved in 1ml sterile distilled water and then added to 19 ml molten PDA in 70 mm sterile Petri dishes in order to have final concentrations of 20, 40 and 80% w/v. PDA with just sterile distilled water served as negative control. A mycelial disc of 5 mm in diameter of the test fungus were taken from 8-day old fungi colonies from pure cultures with the help of sterilized cork borer and placed at the center of the Petri dishes containing the medium and the extracts. The experiment was repeated three times and incubated at room temperature of 25±2°C. Radial growth was measured after 8 to 10 days of incubation; time needed for the fungi colonies to fill up the Petri plates in the control. The inhibition

percent (IP) was calculated by the formula given by Dawidowicz et al. (2006).

$$IP = (GC - GT) / GC \times 100;$$

where GC=growth in the control, GT=growth in the treated groups. An average of three replications of each test was taken for calculations. Figure 4 shows some important stages in the extraction methods.

RESULTS

Pathogenicity test of the fungi pathogens responsible for the highest post-harvest losses on the different varieties cabbage

The results of the pathogenicity test showed that out of the main four isolated pathogens responsible for cabbage disease in the Western highlands all proved to be causing diseases in cabbage. The incidence of the disease appearance in the greenhouse showed that *Fusarium oxysporum* was responsible for yellowing and wilting of cabbage. *Alternaria alternata* also presented similar effects but with leaves looking dried in more severe situations. *Curvularia senegalensis* and *Trichodema hazianum* was causing rotting (decay) of cabbage heads but with the diseases incidence of

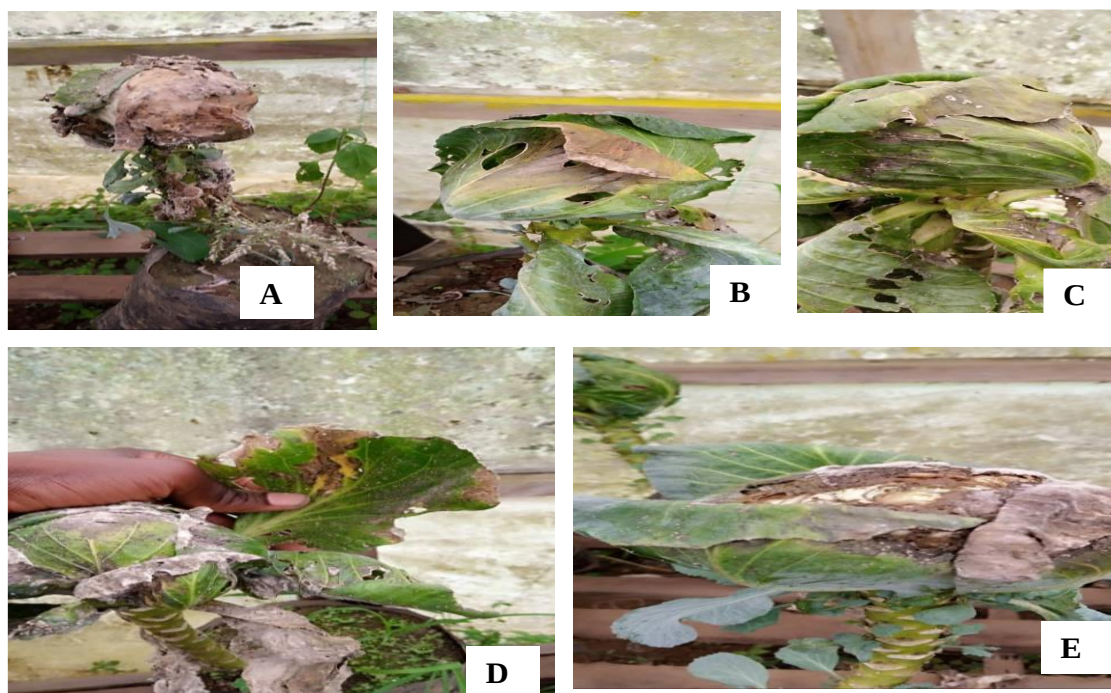


Figure 5. Symptoms obtained in the greenhouse: A) drying cabbage heads, B) browning of leaves, C) rotting of cabbage heads, D) yellowing of leaves, and E) Decay of entire head.

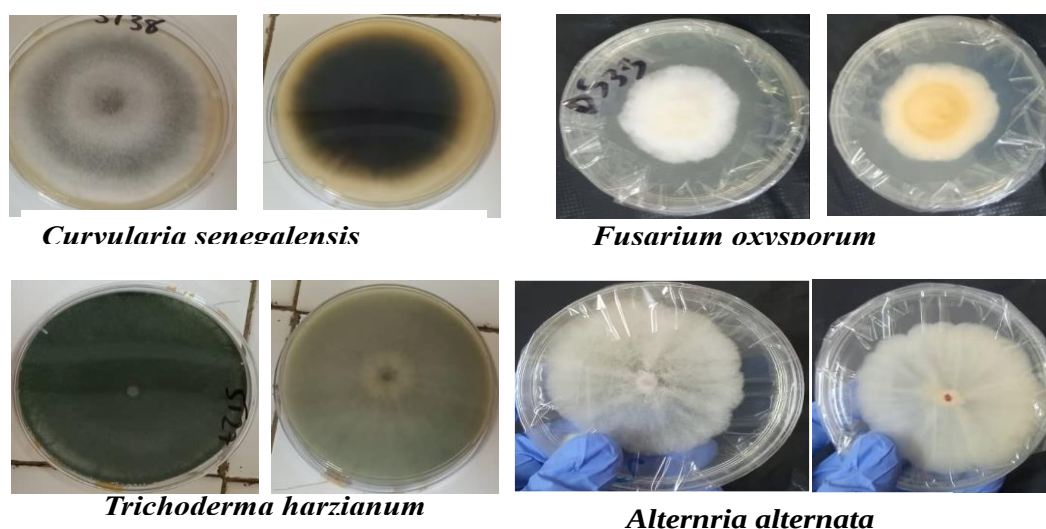


Figure 6. Cultural characteristics of fungi pathogens after pathogenicity test.

C. senegalensis being as fast in appearance as shown in Figure 5.

The cultures obtained after the pathogenicity test

The results after pathogenicity test showed that *C. senegalensis* portrays whitish brown colony colour with

darkening presentation on reversed colony colour. The results confirm that the cultural characteristics of *Fusarium* were as recently observed looking with in dishes. The characters of *Trichoderma* were not far from what was obtained during the isolation of fungi species of cabbage and the colony colour still presented a green colour. Also, *Alternaria* accepted in already document to be colour whitish undulated margins as shown in Figure 6.

Antifungal potential of different medicinal plants and mushrooms used in controlling the disease *in-vitro* growth inhibition of phytopathogens isolated from diseased cabbage from leaves extract of different plants

Table 1 presents results on the growth inhibition of various pathogens (*A. alternata*, *F. oxysporum*, *T. harzianum*, and *C. senegalensis*) using different concentrations of phyto-extracts from three plant species (*C. benghalensis*, *C. hirsuta*, and *T. occidentalis*). The pathogens were inhibited using either methanol or aqueous solvents, and the growth inhibition was measured at different concentrations of the leaf extracts. The results from *A. alternata* showed that methanol extracts showed increasing growth inhibition with higher concentrations, reaching up to 65% inhibition for *T. occidentalis* at 80% concentration while the aqueous extracts showed the highest inhibition for *T. occidentalis* at 80% concentration, reaching 100% growth inhibition. For *F. oxysporum*, the methanol extracts showed the highest inhibition for *T. occidentalis*, reaching over 90% at 80% concentration and the aqueous extracts also showed high inhibition for *T. occidentalis* and *C. hirsuta*, reaching over 90% at 80% concentration. The *T. harzianum* results from methanol extracts showed the highest inhibition for *T. occidentalis*, reaching nearly 64% at 80% concentration whereas aqueous extracts showed the highest inhibition for *C. hirsuta*, reaching 96.25% at 80% concentration lastly. *C. senegalensis* showed that the methanol extracts showed high inhibition for all three plant species, reaching over 85% at 80% concentration while the aqueous extracts showed the highest inhibition for *C. hirsuta*, reaching 97.5% at 80% concentration. The findings revealed that the phyto-extracts, especially from *T. occidentalis* and *C. hirsuta*, have significant potential for inhibiting the growth of these pathogens. The aqueous extracts indicated to be more effective than the methanol extracts in many cases.

Table 2 shows a statistically significant difference between the treatments (p -value < 0.001). This means that there is strong evidence to suggest that at least one of the treatments (aqueous extract, methanol extract, or control) has a different effect on controlling fungal disease. The high F -value (26.76) and very low p -value (0.00000026) indicate a significant difference between the treatment groups in controlling fungi disease.

In vitro growth inhibition of phytopathogens isolated from diseased cabbage using mushroom extracts

Table 3 shows the *in-vitro* control results of various fungal pathogens using different concentrations (20, 40, and 80%) of methanol and aqueous extracts from three types of mushrooms *T. pubescens*, *Lentinus* spp., and *P. ostreatus*. The results indicated that the inhibition of *A. alternata* showed that *T. pubescens* methanol and aqueous extracts showed moderate to high inhibition at

all concentrations while *Lentinus* spp. methanol extract had minimal inhibition, while the aqueous extract showed no inhibition and *P. ostreatus* methanol extract had high inhibition, while the aqueous extract showed low to no inhibition. *F. oxysporum*, *T. pubescens* methanol extract had high inhibition, while the aqueous extract showed moderate inhibition. In *T. harzianum*, *T. pubescens* methanol extract had no inhibition, while the aqueous extract had high inhibition and *Lentinus* spp. methanol extract had high inhibition, while the aqueous extract had moderate to low inhibition and *P. ostreatus* methanol extract had moderate inhibition, while the aqueous extract had high inhibition.

Lastly, in *C. senegalensis*, *T. pubescens* methanol and aqueous extracts had high inhibition other than *Lentinus* spp. methanol and aqueous extracts had low to no inhibition and *P. ostreatus* methanol and aqueous extracts had moderate to high inhibition detailed in Table 3. More so, the methanol extracts showed moderate growth inhibition, ranging from 11.11 to 16.67% at lower concentrations, and up to 81.11% at the highest concentration of *A. alternata* and aqueous extracts were more effective, with growth inhibition ranging from 27.77% at 20% concentration to 38.89% at 80% concentration whereas *T. pubescens* extract was the most effective, with 100% growth inhibition at all concentrations in the aqueous extract.

In *F. oxysporum*, methanol extracts showed variable efficacy, with *T. pubescens* and *Lentinus* spp. exhibiting higher growth inhibition (up to 98.89 and 96.67%, respectively) compared to *P. ostreatus* (up to 33.33%) while aqueous extracts were more consistent, with all three mushroom species showing high growth inhibition (over 96%) at the higher concentrations. For *T. harzianum*, methanol extracts of *P. ostreatus* were the most effective, with 97.78 to 100% growth inhibition and *T. pubescens* and *Lentinus* spp. methanol extracts showed moderate to low inhibition (6.66% to 45.56%) and aqueous extracts were less effective, with the highest inhibition observed for *T. pubescens* at 97.78% (80% concentration).

Lastly, in *C. senegalensis*, methanol extracts of *T. pubescens* and *Lentinus* spp. exhibited high growth inhibition, ranging from 93.33 to 100%. *P. ostreatus* methanol extract showed relatively low inhibition (1.11 to 4.44%) as compared to aqueous extracts of *T. pubescens* were the most effective, with 100% growth inhibition at all concentrations. The results indicated that the mushroom extracts, particularly the aqueous extracts, have the potential to be effective in inhibiting the growth of these fungal phytopathogens isolated from diseased cabbage. The efficacy varies among the different mushroom species and phytopathogens.

Comparing metabolic and aqueous mushroom extracts and plant extracts

Table 4 shows a statistically significant difference

Table 1. *In-vitro* growth inhibition of phytopathogens isolated from diseased cabbage by the leaf extract of different plants.

Pathogen	Solvent used for extraction	Conc. of phyto-extract (%)	Growth inhibition (%) at different concentration of leaf extract		
			<i>C. benghalensis</i>	<i>C. hirsuta</i>	<i>T. occidentalis</i>
<i>Alternaria alternata</i>	Methanol	20	27.50	20.27	66.25
		40	38.78	22.97	61.25
		80	43.75	21.62	65.00
		Control	100	100	100
	Aqueous	20	12.5	50	37.50
		40	23.75	64.86	47.50
		80	27.50	67.58	100
		Control	100	1000	100
<i>Fusarium oxysporum</i>	Methanol	20	13.75	56.25	78.75
		40	15.00	77.50	73.75
		80	23.75	91.25	80.00
		Control	100	100	100
	Aqueous	20	37.50	56.25	17.50
		40	61.25	73.75	61.25
		80	73.75	95.00	73.75
		Control	100	1000	100
<i>Trichoderma hazanum</i>	Methanol	20	5.13	3.75	35.00
		40	8.97	2.5	37.70
		80	21.79	17.5	63.75
		Control	100	1000	100
	Aqueous	20	19.23	37.5	25.0
		40	33.33	80	46.25
		80	44.87	96.25	62.50
		Control	100	100	100
<i>Curvularia senegalensis</i>	Methanol	20	47.5	62.50	67.50
		40	63.75	62.50	80.00
		80	85.00	78.75	88.75
		Control	100	100	100

Table 1 Cont'd.

Aqueous	20	28.75	80.00	13.00
	40	36.25	93.75	22.50
	80	46.25	97.50	87.50
	Control	100	100	100

Table 2. ANOVA test results from Rcmdr to compare metabolic and aqueous mushroom extracts in controlling fungi diseases

ANOVA test results	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatments	2	133968	66984	26.76	0.00000026 ***
Residuals	25	72592	2503		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 3. *In vitro* growth inhibition of phytopathogens isolated from diseased cabbage by the mushroom extracts.

Pathogen	Solvent used for extraction	Conc. of phyto-extract (%)	Growth inhibition (%) at different concentration of leaf extract		
			<i>Pleurotus ostreatus</i>	<i>Trametes pubescens</i>	<i>Lentinus</i> spp.
<i>Alternaria alternata</i>	Methanol	20	11.11	16.67	10.0
		40	16.67	20.00	26.67
		80	16.67	81.11	11.11
		Control	100	100	100
	Aqueous	20	27.77	100	96.67
		40	31.11	100	96.67
		80	38.89	100	100
		Control	100	100	100
<i>Fusarium oxysporum</i>	Methanol	20	11.11	94.44	88.89
		40	33.33	92.22	92.22
		80	5.56	98.89	96.67
		Control	100	100	100
	Aqueous	20	33.33	97.78	96.67
		40	32.22	98.89	96.67

Table 3 Contd.

<i>Trichoderma harzanium</i>		80	34.44	100	100
		Control	100	100	100
		20	97.78	6.66	42.22
		40	94.44	13.33	44.44
	Methanol	80	100.0	13.33	45.56
		Control	100.0	100.0	100
		20	11.11	44.44	22.22
		40	11.11	53.33	84.44
	Aqueous	80	13.33	97.78	8.89
		Control	100	100.0	100
		20	4.44	99.44	95.56
		40	1.11	100	93.33
	Methanol	80	4.44	97.78	93.33
		Control	100	100	100
		20	7.77	100	16.67
		40	6.66	100	23.33
	Aqueous	80	20.46	100	23.33
		Control	100	100	100

Table 4. ANOVA test results from Rcmdr to compare metabolic and aqueous Plant extracts in controlling fungi diseases.

ANOVA test results	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	2	109618	54809	21.41	0.00000194***
Residual	29	74226	2560		

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

between the treatments (p-value < 0.001). This means that there is strong evidence to suggest that at least one of the treatments (aqueous

extract, methanol extract, or control) has a different effect on controlling fungal diseases compared to the others. The high F-value (21.41)

and very low p-value (0.00000194) indicate a significant difference between the treatment groups.

DISCUSSION

The results base on the pathogenicity from the top 4 fungi species identified to be responsible for cabbage diseases showed that *F. oxysporum* is a well-known culprit of *Fusarium* wilt in various crops, including cabbage (Smith, 2007).

The pathogenicity test confirms its role in causing this disease in the Western Highlands. It was also observed that *A. alternata* is a common cause of leaf blight and spot diseases in cabbage (Punja and Zhang, 2003). The observed symptoms are consistent with the known effects of the pathogens. Notably, *C. senegalensis* was found to be responsible for cabbage disease, although it is less frequently reported as a significant cabbage pathogen. The findings on *T. harzianum* support the work of Djeugap et al. (2018), which reported that *T. harzianum* was responsible for leaf spot disease in *Eucalyptus saligna* and *Prunus africana* in Cameroon. However, further studies are needed to understand the specific impact of *T. harzianum* on cabbage. The study's results are also supported by Claassen et al (2021), who showed that the identified fungi species cause black leg disease in cabbage.

The results indicating the effectiveness of phyto-extracts from *C. benghalensis*, *C. hirsuta*, and *T. occidentalis* in inhibiting the growth of various pathogens such as *A. alternata*, *F. oxysporum*, *T. hazanum*, and *C. senegalensis* are significant in the context of sustainable agricultural practices. The study highlights that *T. occidentalis* exhibited the highest growth inhibition against *A. alternata*, achieving a remarkable 66.25% inhibition at a 20% concentration, and complete growth inhibition (100%) at an 80% concentration with aqueous extracts. In comparison, *C. benghalensis* and *C. hirsuta* showed lower inhibition rates, suggesting that *T. occidentalis* possesses potent antifungal properties that could be harnessed for crop protection. For instance, research has demonstrated that various plant extracts can effectively inhibit fungal pathogens, supporting the notion that natural products can serve as viable alternatives to synthetic fungicides. A study by Musheer et al. (2024) found that extracts from different plant species exhibited significant antifungal activity against *Alternaria* and *Fusarium* species, reinforcing the potential of using phyto-extracts in managing plant diseases. Moreover, the effectiveness of *T. occidentalis* in achieving complete growth inhibition at higher concentrations is particularly noteworthy. This is consistent with findings from Enyiukwu et al. (2020) reported that higher concentrations of extracts resulted in enhanced inhibition of *Fusarium* spp., suggesting a dose-dependent relationship in the antifungal efficacy of plant extracts (Margaret et al., 2020).

In the case of *T. hazanum*, the methanol extracts showed lower inhibition rates, with *T. occidentalis* achieving 63.75% inhibition at 80% concentration.

However, the aqueous extracts demonstrated a marked improvement, with *C. hirsuta* exhibiting the highest inhibition at 96.25% at the same concentration. This suggests that the aqueous extracts may be more effective against *T. hazanum*, reinforcing the importance of extraction methods in determining the antifungal efficacy of plant materials. For *C. senegalensis*, the methanol extracts indicated high inhibition across all three plant species, with *C. benghalensis* achieving 85.00% inhibition at 80% concentration. The aqueous extracts further emphasized the potential of *C. hirsuta*, which reached an impressive 97.50% inhibition at 80% concentration. This reinforces *C. hirsuta*'s role as a promising biocontrol agent against multiple fungal pathogens.

Looking at the medicinal mushroom extracts in the case of *A. alternata*, the study found that *T. pubescens* extracts exhibited moderate to high inhibition across all tested concentrations, thereby highlighting their potential as robust antifungal agents. This finding aligns well with Mishra et al. (2020) who revealed that *Trametes* species possess bioactive compounds effective against various phytopathogens. Conversely, *Lentinus* spp. demonstrated minimal to no inhibition, which is consistent with findings by Shukla et al. (2019) that indicated variability in antifungal activity among different mushroom species. The high inhibition rates (up to 98.89%) of *F. oxysporum* observed with *T. pubescens* methanol extracts are in line with studies by Kaur et al. (2021), which reported similar effectiveness of *Trametes* extracts against *Fusarium* spp. Furthermore, the study revealed that, aqueous extracts consistently outperformed methanol extracts, suggesting that the extraction method significantly influences the bioactivity of the compounds. Regarding *T. harzianum*, the methanol extracts of *P. ostreatus* were the most effective, *T. pubescens* and *Lentinus* spp. exhibited only moderate inhibition. These results imply that different solvent systems may extract varying antifungal compounds, a notion supported by the findings of Nascimento et al. (2022), which emphasized the significant role of solvent choice in determining the efficacy of natural extracts. Finally, for *C. senegalensis*, the consistently high inhibition rates of *T. pubescens* across both extraction methods reinforce their potential as natural fungicides. This finding corroborates the work of Rahman et al. (2020), which identified *T. pubescens* as promising candidates for the biological control of plant pathogens.

The study found based on the efficacy of medicinal mushrooms showed that *Trametes* spp. extracts exhibited moderate to high inhibition across all tested concentrations, highlighting its potential as a robust antifungal agent. This finding aligns with Mishra et al. (2020) who revealed that *Trametes* spp. possesses bioactive compounds effective against various phytopathogens. Conversely, *Lentinus* spp. showed minimal to no inhibition, which is consistent with findings

by Shukla et al. (2019) that indicated variability in antifungal activity among mushroom species. The high inhibition rates (up to 98.89%) observed with *T. pubescens* methanol extracts were in line with studies by Kaur et al. (2021), which reported similar effectiveness of *Trametes* extracts against *Fusarium* spp. The results also revealed that aqueous extracts consistently performed better than methanol extracts, suggesting that the extraction method significantly impacts the bioactivity of the compounds. Also, methanol extracts of *P. ostreatus* were the most effective, *Trametes* and *Lentinus* spp. showed only moderate inhibition.

The findings on in-vitro control of fungi pathogens was supported by that of Jones (2022) who found that *Lentinus edodes* extracts inhibited the growth of *Aspergillus flavus* but had limited activity against *Candida albicans*. *P. ostreatus* extracts had moderate to high inhibition, particularly with the aqueous extract. This is in line with other studies that have reported the antifungal activity of *P. ostreatus* against various fungal pathogens. The study was in line with that of Brown (2021) who demonstrated the effectiveness of *P. ostreatus* extracts against *Fusarium solani*, *Rhizoctonia solani*, and *Sclerotinia sclerotiorum*. This shows that *P. ostreatus* could be a valuable source of natural antifungal compounds for controlling fungal diseases in cabbage. In addition, the consistent high inhibition rates of *T. pubescens* across both extraction methods reinforce its potential as a natural fungicide. This finding corroborates the work of Rahman et al. (2020), who identified *T. pubescens* as a promising candidate for biological control of plant pathogens. However, methanol extracts have generally been reported to yield higher antifungal activity compared to aqueous extracts in some studies (Sami et al., 2021). However, the current study reveals that aqueous extracts of *T. pubescens* can achieve 100% growth inhibition, suggesting that aqueous extracts should not be underestimated.

Conclusions

The study highlights the pathogenicity of key fungal species affecting cabbage, particularly *F. oxysporum*, which is well-documented for causing Fusarium wilt. Additionally, *A. alternata* and *C. senegalensis* were identified as a significant contributor to leaf blight, while *T. hazianum* also proved to be responsible for cabbage diseases. The findings base on the medicinal plant extracts revealed that *T. occidentalis* and *C. hirsuta* can be used in controlling fungi diseases of cabbage. The efficacy of medicinal mushroom extracts was significance, especially with *T. pubescens*, which demonstrated high inhibition rates against these pathogens. Furthermore, the results indicated that aqueous extracts were more effective than methanol

extracts, emphasizing the importance of extraction methods in maximizing antifungal activity. Overall, the findings advocate for the use of these medicinal plants and mushroom extracts as viable alternatives in managing cabbage diseases, supporting the integration of sustainable agricultural practices.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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