Evaluation of the Efficacy of *Allium sativum (Garlic) and Syzygium aromaticum* (Clove) Against Postharvest Fungal Rot of *Ipomoea batatas* (Sweet Potato)

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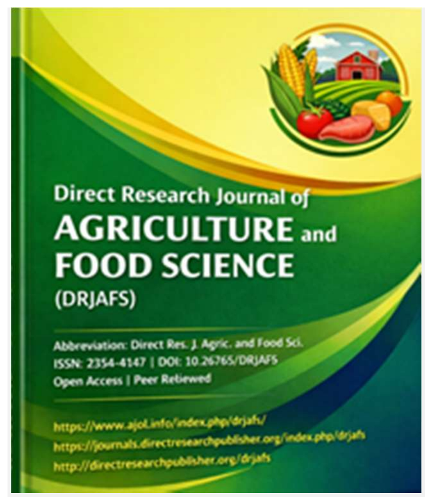
ABSTRACT

Postharvest fungal rot is a severe barrier to sweet potato (Ipomoea batatas L.) production in Nigeria, with diseases such as Rhizopus stolonifer, Fusarium spp., Aspergillus niger, and Penicillium spp. Accounting for 20-40% of storage losses. The extensive use of synthetic fungicides has prompted concerns about their environmental impact, human health, and the development of pathogen resistance, emphasizing the need for sustainable botanical alternatives. This study assessed the antifungal activity of ethanolic garlic (Allium sativum) extract and clove (Syzygium aromaticum) bud preparations in the treatment of sweet potato postharvest fungal rot. A total of 147 healthy tubers were divided into seven treatments in a perfectly randomized design with three replications. The treatments included garlic extract at doses of 75%, 50%, and 25%, clove powder, entire clove buds, mancozeb as a positive control, and an untreated control. Treated tubers were maintained at room temperature for six weeks, with weekly checks on weight loss, disease incidence, and disease severity index (DSI). Standard phytochemical screening was also performed on the plant materials. Phytochemical research revealed the presence of alkaloids, flavonoids, phenols, and steroids in garlic extract, whereas clove preparations also contained tannins and saponins. Clove powder resulted in the lowest weight reduction (17.7 ± 1.39%) compared to the untreated control (27.3 ± 0.81%). Both clove powder and 25% garlic extract significantly reduced illness incidence and severity, with efficacy comparable to mancozeb; however, treatment differences were not statistically significant (p > 0.05). The data show that clove powder and low-concentration garlic extract are effective botanical agents for preventing postharvest fungal degradation and preserving sweet potato quality. Their comparable performance to synthetic fungicides, combined with their affordability and environmental compatibility, suggests that these botanicals could serve as long-term alternatives for postharvest disease management, resulting in lower storage losses, less chemical dependence, and improved food security.

Keywords: *Ipomoea batatas, postharvest rot, garlic extract, clove powder, botanical fungicides, disease severity index, sustainable agriculture, food security*



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INTRODUCTION

Sweet potatoes (*Ipomoea batatas [L.] Lam.*) are among the world's most important root and tuber crops, contributing significantly to food and nutritional security, particularly in developing countries (FAO, 2021). It is a dicotyledonous annual, cultivated in tropics and warm temperate regions of the world (Ibeh et al., 2025). The crop is widely cultivated due to its adaptability to a variety of agroecological situations, tolerance for marginal soils, relatively short growth cycle, and high yield in low-input systems. Sweet potato is an important source of household food, income, and dietary diversity in Sub-Saharan Africa, particularly among resource-poor agricultural groups. The storage roots are high in carbohydrates, dietary fiber, vitamins, minerals, and anti-oxidant compounds, and anthocyanides whereas orange-fleshed cultivars are high in provitamin A, which helps to counteract micronutrient shortages (FAO, 2022; Ibeh et al., 2025). Despite its agronomic benefits and expanding demand, sweet potato is highly perishable, with postharvest losses ranging from 20% to 40% in underdeveloped countries, posing a significant barrier in its value chain (Agu, 2022). Sweet potato output in Nigeria has increased significantly in response to rising demand for food, livestock feed, and industrial processing; nonetheless, postharvest degradation remains a significant barrier to long-term production and utilization. Despite its agronomic and nutritional importance, sweet potato has been limited by activities of plant parasitic pathogens ranging from fungi, bacterial and viral particles with fungi known to cause significant losses (Nnebechukwu et al*.,* 2025). They are extremely perishable due to its high moisture content and vulnerability to mechanical injury during harvesting, transit, and storage caused by factors ranging from physiological, physical and microbiological (Ibeh, et al*.,* 2025). Tropical and subtropical locations continue to have significant postharvest losses due to insufficient storage infrastructure, high relative humidity, variable temperatures, and inadequate postharvest handling, which exacerbate physiological degradation and microbiological decomposition. Postharvest losses in root and tuber crops are estimated to surpass 30-40% in developing countries, affecting food availability, market value, and farmer profitability (FAO, 2022; Ray & Ravi, 2023). Storage deterioration is a recurrent concern in Nigeria and other tropical climes, particularly where curing and cold-chain systems are underdeveloped or unaffordable to smallholder growers.

Fungal infections are a major biological limitation on sweet potato storage quality. Infection is typically transmitted through wounds caused during harvesting or natural openings, leading to fast tissue degeneration and economic losses. Several fungus species have been linked to sweet potato postharvest rot, including *Ceratocystis fimbriata*, the cause of black rot; *Rhizopus stolonifer*, which causes soft rot; and *Fusarium, Aspergillus, and Penicillium* (Paul, 2021; Kwodaga et al., 2025). Symptoms of fungal degeneration include tissue maceration, shriveling, internal necrosis, discoloration, and disagreeable odors, all of which diminish consumer acceptance and marketability. Beyond quantitative losses, fungal contamination may jeopardize food safety due to the possible production of mycotoxins by some storage fungi, endangering human health, nutritional security and economic production (Desalegn, 2021). Traditionally, postharvest fungal infections have been managed by applying synthetic fungicides during harvest and storage. Although fungicides may be effective in reducing fungal development in the short term, growing worries about chemical residues, disease resistance, environmental contamination, and human health risks have limited their viability and acceptability (Sharma, 2023). Owing to the many destructive effects linked to the use of synthetic pesticides globally, many natural source alternatives from plant species have been studied and applied for the management of these diseases (Ibeh, Uzoma, and Agu 2021). Moreover, the continuous use of chemicals raises environmental concerns and poses health risks to both farmers and consumers (Jideani et al., 2021). Furthermore, smallholder farmers in underdeveloped countries frequently face barriers to accessing commercial fungicides due to high costs, limited availability, and insufficient technical understanding for efficient application. These constraints have fueled the search for sustainable, cost-effective, and environmentally friendly alternatives for postharvest disease management. Plant-derived antimicrobials have recently gained scientific attention as possible alternatives to synthetic fungicides. Botanical extracts, essential oils, and crude plant preparations provide a wide range of bioactive chemicals that can inhibit fungal growth, prevent spore germination, and reduce disease severity in stored agricultural commodities.

Studies have shown that medicinal and spice plants are effective against numerous postharvest diseases of root and tuber crops, highlighting their potential for safe disease management measures (Ibeh et al., 2025; Zhang et al., 2023). Botanicals are particularly appealing because they are biodegradable, reasonably safe for consumers, environmentally friendly, and frequently available locally to farmers. Garlic (*Allium sativum L.*) and clove (*Syzygium aromaticum* [L.] Merr. & Perry) are two medicinal plants having proven antifungal properties. Garlic includes physiologically active organosulfur compounds such as allicin, ajoene, diallyl sulphides, and thiosulfinates, which have broad antibacterial activity against bacteria, fungi, and yeast. Recent studies have shown that garlic extracts have a strong inhibitory effect against key storage fungi such as *Rhizopus, Fusarium, and Aspergillus* species (Zhang et al., 2023; Kwodaga et al., 2025). Similarly, clove contains eugenol and other phenolic chemicals renowned for their antifungal, antioxidant, and preservation qualities. Clove-based formulations have been shown to reduce postharvest deterioration and increase shelf life in root and tuber crops by inhibiting fungal colonization and delaying spoilage development (Chukwuemeka et al., 2025). Although garlic and cloves' antifungal activity has been increasingly established in various crop systems, data on their usefulness in regulating postharvest fungal rot of sweet potato under ambient tropical storage conditions is lacking, particularly in Nigeria. Existing postharvest management systems are poorly tailored to the socioeconomic reality of smallholder farmers who demand disease control solutions that are economical, safe, and easily available. As a result, there is a need to assess easily available botanical ingredients that can successfully control storage fungus while maintaining tuber quality. The researcher deemed it necessary, therefore, to try control measures using plant extract therefore, this study aimed to assess the efficacy of garlic (*Allium sativum*) extract and clove (*Syzygium aromaticum*) preparations in inhibiting postharvest fungal rot and preserving the storage quality of sweet potato (*Ipomoea batatas*) under ambient storage circumstances.

Study Area

The experiment was carried out in Jos North Local Government Area, Plateau State, Nigeria, which is located within the Guinea savannah ecological zone, between latitude 9°52′N and longitude 8°54′E, at an elevation of approximately 1,200 m above sea level. The climate is rather cool in comparison to the rest of Nigeria, with yearly mean temperatures ranging from 18 to 25°C. The average annual rainfall is 1,200-1,400 mm, with the majority falling between May and October, and the dry season lasts from November to April. The relative humidity varies between 50 and 80 percent (Plateau State Ministry of Environment, 2020) annually. These climatic conditions are important in postharvest pathology because high humidity and moderate temperatures promote fungal growth on root and tuber crops (Figure 1).

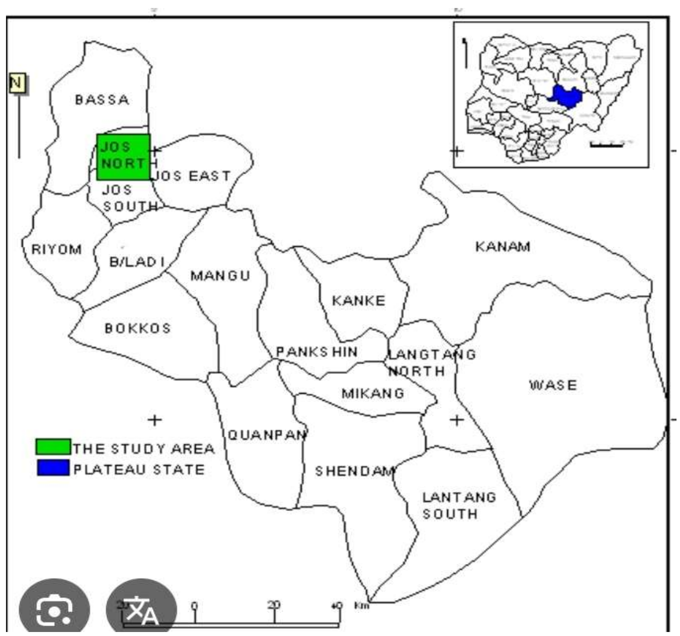

Figure 1: Map of Plateau State showing the study area in green
Source: Adopted from Bureau for Land, Survey and Town Planning, Jos Plateau State

Sample collection

Fresh garlic (*Allium sativum* L.) bulbs and dried clove (*Syzygium aromaticum* L.) flower buds were purchased from Farin Gada Market, Jos North. This market was selected due to its role as a central hub for the distribution of spices and condiments, ensuring that materials used reflect what is commonly accessible to local farmers and traders. A total of seventy (70) healthy, market-sized (ware size) sweet potato tubers (*Ipomoea batatas* L.) were carefully sorted from harvested potatoes to exclude those with visible signs of bruising, cracking, or fungal infection. The tubers were transported to the Department of Plant Science and Biotechnology, University of Jos, where soil and debris were carefully removed from their surfaces and kept prior to experimental treatment.

Extraction of Plant Material

The extraction of garlic and cloves followed the method of Dawen et al. (2024). Fresh garlic bulbs were peeled alongside cloves. A 100 g each of the pulverized plants was homogenized in a sterile blender with 200 ml of 70 % ethanol. The mixture was transferred into conical flasks, sealed with aluminum foil, and left on the laboratory table at room temperature for 72 hours with intermittent shaking to enhance extraction. After the soaking period, the samples were filtered through Whatman No. 1 filter paper, and the filtrate was concentrated using a water bath at 60 °C. The percentage yield was determined for each solvent, using the following formula:

$$\%\ \text{percentage yield of extract} = \frac{CX}{CY} \times 100$$

The crude extract was reconstituted with sterile distilled water to obtain three concentrations: 75%, 50%, and 25% (v/v).

Qualitative Phytochemical Screening

The extract was subjected to phytochemical screening as described by Dawen et al. (2023) to determine the presence of Alkaloids, Carbohydrates, Flavonoids, Saponins, Tanins, Glycosides, (cardiac, steroidal), Terpenes/terpenoids, and phenols.

Test for Saponins
Half a gram (0.5g) of the extract was dissolved in 5 mL of distilled water. The mixture was shaken vigorously. Formation of stable, persistent froth shows the presence of saponins. A further addition of 6 drops of olive oil while shaking formed an emulsion, confirming the presence of saponins.

Test for Tannins

Half a gram (0.5g) of the extract was dissolved in 10 ml of distilled water, then a few drops of 1% ferric chloride solution were added to obtain a brownish green or blue-black precipitate, which confirmed the presence of tannin.

Test for Anthraquinones

Borntrager's test was used for the detection of anthraquinones; 0.5 g of each extract was taken into a dry test tube, and 5ml of chloroform was added and shaken for 5 minutes. The extract was filtered, and the filtrate was shaken with an equal volume of 100% ammonia solution. A pink, violet, or red color in the ammoniacal layer (lower layer) indicated the presence of free anthraquinones.

Test for Cardiac Glycoside

One hundred milligrams (100mg) of the extract was dissolved in 70% alcohol and filtered. About 3 drops of lead sub-acetate were introduced into the filtrate and filtered. The filtrate was extracted with 10 mL of chloroform in a separating funnel and concentrated to dryness. The resulting residue was dissolved in 1ml of glacial acetic acid containing one drop of Ferric chloride solution. This was underplayed with 1ml of concentrated sulphuric acid. A brown ring obtained at the interphase indicated the presence of a deoxy sugar characteristic of cardenolides.

Test for steroids

About 100mg of the extract will be dissolved in 2ml of chloroform. Sulphuric acid was carefully added to form a lower layer. A reddish-brown color at the interphase was indicative of the presence of a steroidal ring.

Test for Terpenes

A little quantity of each extract was dissolved in chloroform, and 1ml of acetic anhydride was added, then two drops of concentrated Sulphuric acid were further added. A pink color, which changed to bluish green on standing, was indicative of the presence of steroids and terpenes.

Test for Flavonoids

Five milliliters (5ml) of dilute ammonia was added to 5 ml of extract, and then 5 ml of concentrated sulfuric acid was added. Formation of the yellow color indicated the presence of flavonoids.

Test for Carbohydrates

One gram (1g) of the extract was dissolved in 10 ml of distilled water. This extract was boiled with Fehling solution A and B in a test tube, and color changes were observed. The presence of brick red color indicated the presence of reducing sugar.

Preparation of Culture Media and Inoculation

Potato Dextrose Agar (PDA) was prepared according to the manufacturer's specifications (39 g L^{-1} distilled water) and sterilized in an autoclave at 121°C for 15 minutes under 15 psi pressure. After sterilization, the medium was cooled to approximately 45–50°C, supplemented with streptomycin (0.05g L^{-1}) to suppress bacterial contamination, and dispensed into sterile Petri dishes.

Experimental Design and Treatments

The experiment was laid out in a Completely Randomized Design (CRD) following the method described by Abubakar et al. (2022). Seven treatments as outlined below were tested, each replicated three times, with seven tubers per replicate, making a total of 147 experimental units.
The treatments were as follows:

1.Garlic extract (75% concentration)
2.Garlic extract (50% concentration)
3.Garlic extract (25% concentration)
4.Clove powder
5.Whole clove buds
6.Mancozeb (synthetic fungicide, positive control)
7.Untreated control
Tubers were randomized to minimize bias and ensure that environmental variations were evenly distributed among treatments.

Application of Treatments

Treatments were applied using the method of Kordy et al. (2021). For garlic treatments, tubers were dipped in the prepared extract solutions for 5 minutes, removed, and air-dried. For clove powder, each tuber was uniformly dusted with a measured quantity of the powder. For raw clove treatments, intact clove buds were mixed directly with tubers in the storage baskets. For the mancozeb treatment, tubers were spread with fungicide according to the manufacturer's recommendation. Control tubers were left untreated.

Storage and Data Collection

The experimental tubers were stored under ambient laboratory conditions, simulating a typical local Nigerian store environment, maintaining the condition of the facilities. This represents realistic conditions faced by smallholder farmers and traders. Tubers were stored in well-ventilated plastic baskets lined with clean paper to prevent direct contact with the floor, following the method of Abubakar et al. (2022). The storage period lasted six weeks, during which observations were made weekly, which included weight loss, disease incidence and disease severity.

Plating and Incubation

Sterilized tissue sections of tubers that developed infection were aseptically transferred onto PDA plates using sterile forceps, with three tissue pieces per plate. Plates were incubated at 28 ± 2°C for 5–7 days in an inverted position. The plates were observed daily for fungal growth, and emerging colonies were recorded.

Morphological Identification

Table 1: Phytochemical Constituents of Ethanolic Garlic and Clove Extracts.

Constituent	Garlic (Ethanol)	Clove (Ethanol)
Alkaloids	+	+
Saponins	-	+
Tannins	-	+
Flavonoids	+	+
Carbohydrates	-	-
Phenols	+	+
Steroids	+	+
Anthraquinones	-	-
Cardiac Glycoside	-	-
Terpenoids	-	-

KEY: -= absent, + = present

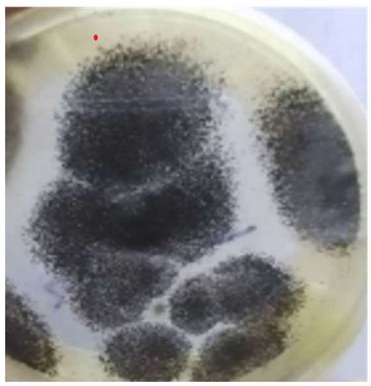

Plate 1: Microscopy/Culture of *A. niger*

Fungal isolates were identified based on their macroscopic and microscopic features. Colony morphology, including pigmentation, texture, growth rate, and sporulation, was observed on PDA. Microscopic features were examined using the lactophenol cotton blue staining method. Mycelial fragments were mounted on a slide with a drop of stain, covered with a coverslip, and examined under a compound microscope. Identification was done with the aid of fungal identification manuals.

Pathogenicity Test

Pathogenicity tests were conducted in accordance with Koch's postulates. Healthy, disease-free sweet potato tubers were washed, surface-sterilized with 70 % ethanol, and air-dried. Small wounds were made on the tuber surface with a sterile needle, and agar discs (5 mm) from 5-day-old cultures of each isolate were inserted into the wounds. Inoculated sites were covered with sterile moist cotton wool, and the tubers were incubated at 28 ± 2°C for 7–10 days in sterile containers. Control tubers were treated in the same manner but inoculated with sterile PDA discs. Development of disease symptoms was observed and recorded. Fungi were re-isolated from symptomatic tubers and compared with the original isolates to confirm pathogenicity.

Statistical Analysis

Data obtained on fungal growth inhibition, disease incidence, and disease severity were subjected to Analysis of Variance (ANOVA) using appropriate statistical software. Treatment means were separated using Duncan's Multiple Range Test (DMRT) or Least Significant Difference (LSD) at $P \leq 0.05$.

RESULTS

Phytochemical Screening of Garlic and Clove Extracts

Phytochemical screening was conducted on ethanolic extracts of garlic (*Allium sativum*) and clove (*Syzygium aromaticum*) to identify bioactive compounds potentially responsible for antimicrobial activity and preservation of stored sweet potato tubers. Garlic extract was rich in alkaloids, flavonoids, and steroids, with moderate phenols, indicating potential antimicrobial activity, while Clove extract contained high levels of alkaloids, tannins, flavonoids, and phenols, with moderate saponins and steroids, suggesting strong bioactivity. Both extracts lacked anthraquinones, cardiac glycosides, and terpenoids. The presence of bioactive compounds in both extracts indicates their potential efficacy in suppressing microbial growth and delaying deterioration in stored sweet potato tubers. Clove extract exhibited a broader spectrum of active constituents compared to garlic, which may explain differences in effectiveness observed in subsequent storage experiments (Table 1).

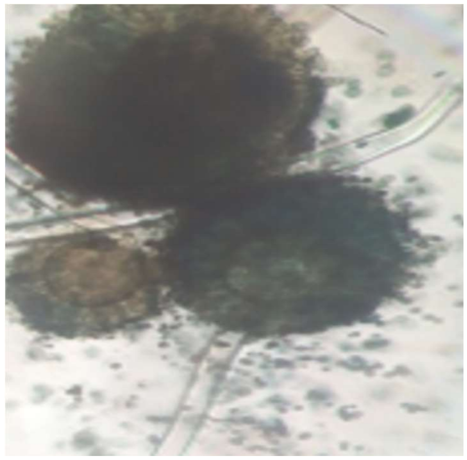

Plate 2: Microscopy of *A. niger* with an arrow pointing the sporangiophore

Plate 3: Culture isolate of *Fusarium solani*

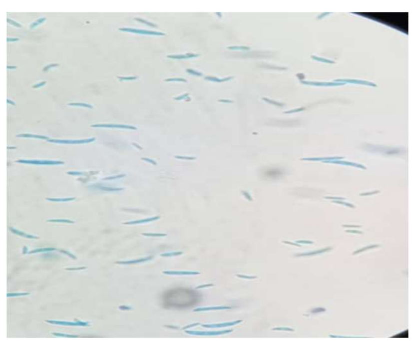

Plate 4: Microscopy of *Fusarium* sp showing spore

Macroscopic and Microscopic Features of Fungal Isolate

The fungi isolated from the diseased sweet potato tubers were Aspergillus niger, Fusarium solani, Rhizopus stolonifer, and Penicillium spp. Aspergillus niger colonies exhibited a rapid growth rate. The colonies were flat and covered by a dense layer of black conidial heads with a powdery texture, while the reverse side appeared pale yellow (Plate 1). Microscopic examination revealed septate hyphae with hyaline to pale-brown or black conidiophores that were erect, simple, and terminated in globose vesicles bearing conidial heads composed of catenulate conidia (Plate 2). *Fusarium* species produced fast-growing colonies with abundant white to cream aerial mycelia that gradually developed a pinkish to violet pigmentation, characteristic of the species (Plate 3). Microscopic observation showed septate hyphae with

Plate 5: Culture isolate of *Penicillium* sp

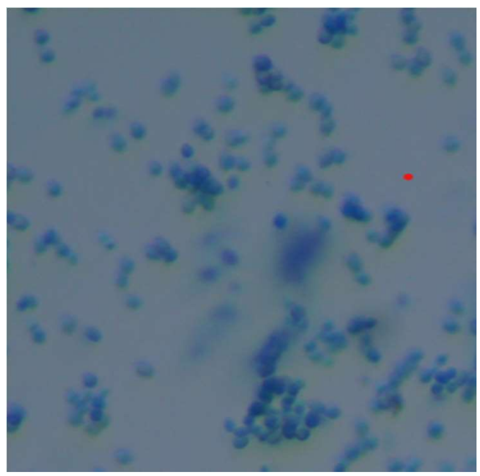

Plate 6: Microscopy of *Penicillium*

distinctive sickle-shaped (fusiform) macroconidia and oval to ellipsoid microconidia, confirming its identity as Fusarium sp (Plate 4). Penicillium spp. formed velvety colonies with green to bluish-green sporulating surfaces and pale cream to yellow reverse pigmentation (Plate 5). Under the microscope, the fungus exhibited septate hyphae with characteristic branched conidiophores terminating in brush-like penicilli bearing chains of spherical conidia, which are diagnostic features of the genus *Penicillium* (Plate 6).

Effect of Treatments on Weight Loss of Stored Sweet Potato Tubers

Weight loss of sweet potato tubers was recorded weekly over a period of six weeks, starting from the initial measurement (Week 0) and expressed as a percentage of the initial weight for each replicate. The results demonstrate progressive loss in tuber mass across all treatments, with variation in the rate and extent of weight loss. No weight loss was recorded at Week 0, as this represents the initial measurement. Weight loss increased progressively in all treatments, with the control and garlic extracts showing the highest losses. Clove powder consistently exhibited the lowest weight loss throughout the storage period, followed by raw clove and Mancozeb, indicating better preservation of tuber mass. Acceleration in weight loss was most pronounced after Week 3, suggesting increased metabolic activity or moisture loss with prolonged storage. Table 2 revealed the percentage weight loss (%) of sweet potato tubers per treatment across storage over a period of 6 weeks. Sweet potatoes treated with clove powder outperformed other treatments with the lowest weight loss in the first and last weeks, at 3.0 and 17.7, respectively. The clove powder performed better than the standard drug (Mancozeb). Garlic had the highest water loss, which is 5.55 and 26.0%, respectively. Statistically, the One-way ANOVA revealed no significant differences among treatments ($F(6,14) = 1.28$, $p = 0.33$).

Final Weight Loss (%) at Week 6 across Treatments

Untreated had the highest weight loss of 27.3, while clove (Raw) and Mancozeb (22.1) had the least mean % weight

Table 2: Average Percentage Weight Loss (%) of Sweet Potato Tubers per Treatment across Storage Weeks

Treatments	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Garlic extract (25%)	0.0	4.0	9.5	13.0	16,5	21.0	25.7
Garlic extract (50%)	0.0	5.55	10.5	14.5	18.0	21.0	26.0
Garlic extract (75%)	0.0	5.50	10.0	15.0	19.1	22.0	26.2
Clove powder	0.0	3.0	6.5	9.5	12.0	14.5	17.7
Clove buds	0.0	4.5	8.0	11.0	15.0	18.5	22.1
Mancozeb	0.0	3.5	7.5	12.0	15.0	19.0	23.4
Without treatment	0.0	5.0	10.0	14.5	18.5	23.0	27.3

Table 3: Final Weight Loss (%) at Week 6 across Treatments

Treatment	Mean % Weight Loss ± SE
Garlic extract (25%)	25.7 ± 1.3
Garlic extract (50%)	26.0 ± 0.81
Garlic extract (75%)	26.2 ± 2.08
Clove powder	25.7 ± 1.39
Clove buds	22.1 ± 3.85
Mancozeb	22.1 ± 3.85
distilled water	27.3 ± 0.81

Results are represented as M± SE.

Table 4: Average Percentage Disease Incidence (%) of Sweet Potato Tubers per Treatment across Storage Weeks

treatment	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Garlic extract (25%)	0.0	0.0	19.0	52.4	61.9	66.7	66.7
Garlic extract (50%)	0.0	9.5	28.6	52.4	76.2	76.2	76.2
Garlic extract (75%)	0.0	4.8	23.8	42.9	52.4	61.9	61.9
Clove powder	0.0	4.8	23.8	47.6	61.9	66.7	66.7
Raw clove	0.0	19.0	47.6	61.9	66.7	66.7	66.7
Mancozeb	0.0	28.6	47.6	57.1	66.7	61.9	61.9
Untreated	0.0	14.3	38.1	66.7	76.2	90.5	90.5

loss, as shown in Table 3.

Treatments' Effect on Disease Incidence of Stored Sweet Potato Tubers

Disease incidence was assessed weekly by recording the number of diseased tubers per replicate and expressing it as a percentage. This evaluation indicates the proportion of tubers affected by storage pathogens over six weeks. No disease incidence was recorded at Week 0, reflecting the initial baseline. Disease symptoms appeared as early as Week 1 in some treatments, including raw clove and Mancozeb. The control exhibited the highest disease incidence throughout the storage period, reaching 90.5% by Week 6. Garlic extract (25%) delayed the onset of disease compared to higher concentrations, reaching 66.7% at Week 6. Clove powder and raw clove initially delayed disease but ultimately reached 66.7% incidence by Week 6. Mancozeb offered moderate protection, with incidence peaking at 61.9 % by Week 6 (Table 4). One-way ANOVA indicated no significant differences among treatments ($p > 0.05$). This suggests that although certain treatments delayed the onset of disease, the final incidence levels did not differ statistically. Garlic extract (25%) performed best, achieving the lowest final disease incidence (66.7%), showing some protective effect against storage pathogens; the control had the highest disease incidence (90.5%), confirming the susceptibility of untreated tubers. Clove powder, raw clove, and Mancozeb provided moderate protection, with final incidence ranging between 61.9 and 66.7%. Overall, disease incidence increased progressively in all treatments, highlighting the challenges of preventing postharvest infection under the storage conditions used (Table 4). Table 5 presents the final disease incidence (%) recorded at Week 6 across all treatments. One - way ANOVA indicated no significant

Table 5: Final Disease Incidence (%) at Week 6 across Treatments

Treatment	Mean % Incidence ± SE
Garlic extract (25%)	66.7 ± 2.9
Garlic extract (50%)	76.2 ± 2.0
Garlic extract (75%)	61.9 ± 3.3
Clove powder	66.7 ± 3.7
Clove buds	66.7 ± 2.9
Mancozeb	61.9 ± 2.9
Untreated	90.5 ± 2.0

Table 6: Weekly Disease Severity Index (DSI %) per Treatment

Treatment	Week0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Garlic extract (25%)	0.0	1.0	10.0	25.7	35.7	44.3	52.9
Garlic extract (50%)	0.0	5.7	18.6	32.9	40.1	48.6	57.1
Garlic extract (75%)	0.0	8.6	15.7	31.4	37.1	44.3	57.1
Clove powder	0.0	5.7	15.7	28.6	37.1	42.9	50.5
Raw clove	0.0	8.6	21.4	30.5	41.9	47.1	55.7
Mancozeb	0.0	8.6	18.6	32.9	40.0	45.7	52.9
Untreated	0.0	5.7	17.1	30.5	37.1	45.7	57.1

Table 7: Final Disease Severity (DSI %) at Week 6 across Treatments

Treatment	Mean DSI % ± SE
Garlic extract (25%)	52.9 ± 3.5
Garlic extract (50%)	57.1 ± 3.5
Garlic extract (75%)	57.1 ± 5.5
Clove powder	50.5 ± 4.9
Raw clove	55.7 ± 5.9
Mancozeb	52.9 ± 5.0
Untreated	57.1 ± 5.0

differences among treatments ($p > 0.05$), suggesting that although numerical variations were observed, the final disease incidence did not differ statistically among treatments. Garlic extract (75%) and Mancozeb recorded the lowest final disease incidence (61.9%), indicating greater suppression of disease development than the other treatments. Garlic extract (25%), clove powder, and clove buds each recorded a final disease incidence of 66.7%, demonstrating moderate protective effects. Garlic extract (50%) resulted in a higher disease incidence (76.2%), whereas the untreated control recorded the highest disease incidence (90.5%), confirming the susceptibility of untreated sweet potato tubers to postharvest fungal infection (Table 5).

Effect of Treatments on Disease Severity of Stored Sweet Potato Tubers

Disease severity was evaluated weekly using a 0–5 scale, and expressed as the Disease Severity Index (DSI %). This measure indicates the intensity of infection per tuber over the storage period. No disease severity was observed at Week 0, indicating the baseline condition. Severity increased progressively from Week 1 across all treatment garlic extract (25%) and clove powder consistently showed lower severity than other treatments during mid-storage weeks. the control and garlic extracts (75% and 50%) reached the highest severity (57.1%) by Week 6. Severity increased sharply between Weeks 3 and 6, suggesting accelerated pathogen activity during this period (Table 6).

Summary of Statistical Analysis

Table 7 presents the final Disease Severity Index (DSI) at Week 6 across all treatments. One-way ANOVA indicated no significant differences among treatments ($F(6,14)$ =

0.42, p > 0.05), indicating that the observed differences in final disease severity were not statistically significant.

Plate 7: Healthy Potato before Storage

Plate 8: Treatment 7, Six Weeks after Storage

Clove powder recorded the lowest mean DSI (50.5%), followed by Garlic extract (25%) and Mancozeb, each with a mean DSI of 52.9%, suggesting relatively better suppression of disease severity. Raw clove exhibited a slightly higher DSI (55.7%), while the untreated control and Garlic extracts (50% and 75%) recorded the highest final DSI (57.1%). Although numerical differences were observed among treatments, none provided complete control of postharvest disease severity, as reflected by the absence of statistically significant differences (Table 7). Before storage, all sweet potato tubers selected for the experiment were healthy, firm, and free from visible symptoms of fungal infection or physical damage, ensuring uniformity among experimental units (Plate 7). Following six weeks of ambient storage, visible deterioration, including fungal colonization, tissue softening, discoloration, and decay, was observed in varying degrees depending on the treatment applied. The untreated tubers exhibited the greatest level of deterioration, whereas treated tubers showed comparatively reduced symptoms of postharvest fungal infection (Plate 8).

DISCUSSION

This study evaluated the antifungal potential of garlic (*Allium sativum*) extract and clove (*Syzygium aromaticum*) preparations for the management of postharvest fungal rot of sweet potato under ambient storage conditions. The findings indicated that both botanicals possess measurable protective activity against storage deterioration, although their efficacy differed across response variables. Overall, clove-based treatments, particularly clove powder, provided the most consistent suppression of postharvest losses, whereas garlic extract showed moderate but less stable effects. These outcomes support the growing body of evidence that plant-derived antifungal agents can contribute meaningfully to sustainable postharvest disease management in root and tuber crops. The phytochemical profile obtained in this study provides a plausible mechanistic basis for the observed antifungal effects. Garlic extract contained alkaloids, flavonoids, steroids and phenols, whereas clove preparations showed a broader spectrum of bioactive

enabling sustained antifungal activity. From a practical standpoint, the ability of clove powder to limit weight loss

constituents, including alkaloids, tannins, flavonoids, phenols, saponins and steroids. This wider phytochemical diversity in clove may partly explain its superior performance during storage. The antifungal activity of garlic is largely attributed to organosulfur compounds, especially allicin, ajoene and diallyl sulfides, which are known to interfere with fungal metabolism, disrupt membrane integrity and inhibit spore germination. Recent reviews have emphasized that allicin is one of garlic's most important antimicrobial metabolites, but also note that its activity is highly dependent on extraction conditions and stability after processing (Bashir et al., 2024; Górska et al., 2024). In clove, the dominant antifungal principle is eugenol, a phenolic compound with strong fungitoxic properties, capable of altering membrane permeability, denaturing proteins and suppressing fungal growth. Contemporary evidence continues to show that eugenol-rich clove preparations possess broad-spectrum inhibitory activity against postharvest fungi and can be effective against storage-associated spoilage organisms (Nnabuenyi, 2025; Pan et al., 2025). Thus, the phytochemical data generated in the present study are biologically consistent with the inhibitory effects observed during storage.

Weight loss increased progressively in all treatments over the storage period, but the rate of increase differed substantially among treatment groups. The superior performance of clove powder in minimizing weight loss suggests that it slowed deterioration by suppressing fungal invasion and limiting the breakdown of storage tissues. In root and tuber crops, postharvest weight loss is typically driven by a combination of respiration, transpiration, moisture migration and pathogen-induced tissue maceration, all of which accelerate as infection progresses. Recent work on sweet potato storage has confirmed that fungal biodeterioration is closely associated with moisture redistribution, tissue softening and progressive mass loss during storage (Sila et al., 2024). Previous studies have similarly shown that clove oil and powder retarded weight loss in yam and potato by reducing microbial spoilage and metabolic activity (Dongmo & Fekam, 2016). Likewise, current sweet potato postharvest research shows that treatments capable of inhibiting fungal growth or maintaining tissue integrity reduce the physiological and pathological processes that culminate in shrinkage and quality loss (Wang et al., 2024). The comparatively poor performance of garlic in weight-loss reduction may be linked to the instability of allicin, which is known to degrade rapidly during storage and processing, thereby reducing persistence of antimicrobial activity over time (Bashir et al., 2024; Górska et al., 2024). In contrast, eugenol is relatively more stable and lipophilic, characteristics that may favour longer retention of antifungal efficacy on stored tuber surfaces. This is evident in the report of (Hamini-Kadar et al. (2014) which reported relative stability and lipophilic properties of eugenol, is agronomically important because fresh weight is a major determinant of market quality, consumer acceptability and economic return in sweet potato storage systems. Disease incidence rose steadily throughout storage in all treatments, confirming that the ambient storage environment favored progressive fungal establishment. However, the rate of disease development was lower in treated tubers than in the untreated control, indicating that both garlic and clove delayed infection to some extent. The untreated control reached the highest final incidence, demonstrating the susceptibility of sweet potato tubers to postharvest fungal colonization when no protective measure is applied. This trend agrees with recent Nigerian studies showing that sweet potato tubers under market or ambient storage conditions are highly vulnerable to spoilage by fungi such as *Rhizopus*, *Fusarium*, *Aspergillus* and *Mucor*, with incidence increasing rapidly as storage duration extends (Okoye et al., 2024). The present findings further suggest that the antifungal efficacy of garlic may not increase linearly with concentration, since the lower garlic concentration performed better than some higher concentrations. This may reflect reduced stability of active sulfur compounds at higher extract concentrations, differences in extract diffusion, or concentration-dependent tissue effects that alter the host–pathogen interaction. Similar inconsistencies have been reported in botanical preservation systems where efficacy depends not only on concentration, but also on extract freshness, solvent system, application method and duration of exposure (Bashir et al., 2024).

The comparatively better disease suppression observed with clove preparations is consistent with current understanding of eugenol-based antifungal action. Eugenol disrupts fungal cell membranes, induces leakage of intracellular constituents, impairs mitochondrial function and can interfere with sporulation and germ tube development. Recent studies on postharvest pathogens of horticultural commodities have shown that volatile or phenolic plant-derived compounds can suppress fungal infection by simultaneously reducing mycelial growth and enhancing host resistance responses (Pan et al., 2025; Wang et al., 2024). Therefore, the lower disease incidence recorded under clove treatments in this study is likely due to both direct fungitoxicity and delayed establishment of rot-causing fungi on the sweet potato surface. A similar pattern was observed for disease severity, which increased with storage duration but remained numerically lower in the botanical treatments than in the control. Although statistical separation among some treatments was limited, the numerical reduction in disease severity is still biologically meaningful because postharvest disease management is ultimately judged by practical reduction in tissue destruction, market loss and storage life. In storage pathology, disease incidence and disease severity do not always respond identically to treatment: a botanical may not completely prevent infection but may still reduce lesion expansion, sporulation or tissue maceration after infection has begun. This appears to be the case in the present study, where clove and garlic did not eliminate infection but reduced the extent of deterioration relative to the untreated control. Current postharvest studies on sweet potato soft rot similarly show that bioactive compounds can reduce pathogen virulence and lesion development without fully abolishing infection, particularly under non-refrigerated storage conditions where pathogen pressure remains high (Wang *et al*., 2024). The stronger performance of clove relative to garlic in disease severity reduction may again be explained by differences in the chemistry and persistence of their major antifungal metabolites. Eugenol has strong membrane-active properties and remains one of the most studied natural antifungal compounds for food and crop protection applications, whereas garlic-derived allicin is highly reactive and degrades readily when exposed to heat, oxygen or prolonged storage (Bashir et al., 2024). Consequently, clove may provide a longer residual effect on stored sweet potato tubers, enabling better suppression of lesion expansion over time. This interpretation aligns with the present data, in which clove treatments were generally more consistent across weight loss, disease incidence and disease severity. Taken together, the findings of this study demonstrate that clove was more effective than garlic for postharvest rot management in sweet potato, while both botanicals performed better than the untreated control and, in some parameters, approached the performance of the synthetic fungicide treatment. This has important implications for sustainable postharvest management in Nigeria and similar tropical storage environments. Synthetic fungicides remain effective, but concerns persist regarding chemical residues, pathogen resistance, environmental contamination and user safety, particularly in smallholder systems where dosage control and protective handling may be inadequate.

Recent reviews on postharvest disease management increasingly advocate the integration of plant-derived bio fungicides, essential oils and other low-residue alternatives into storage protection strategies because they offer broad antimicrobial activity with lower ecological burden (Wang et al., 2024). For sweet potato, where postharvest losses can substantially reduce food availability and farm income, the use of accessible botanicals such as garlic and clove could represent a practical and locally adaptable intervention. The study also has wider food-security significance. Sweet potato is an important staple and income-generating crop in many parts of Nigeria, yet postharvest fungal deterioration remains a major constraint to its utilization and profitability. Recent Nigerian studies continue to report high prevalence of storage fungi and substantial quality losses in sweet potato during ambient storage (Okoye et al., 2024; Terna et al., 2024). By demonstrating that commonly available botanicals can reduce rot development and weight loss, the present work contributes to ongoing efforts to develop affordable postharvest technologies for smallholder farmers. Nonetheless, the results also show that botanical treatments did not completely eliminate spoilage, indicating that optimization is still needed. Future work should therefore focus on standardizing extraction protocols, determining the most effective concentrations, evaluating combined garlic–clove formulations, characterizing the target fungi molecularly, and testing performance under farmer-level storage conditions over longer durations. Such studies would help bridge the gap between experimental efficacy and field-scale adoption. In summary, the present findings confirm that both garlic and clove possess antifungal potential against postharvest fungal rot of sweet potato, but clove—especially in powdered form—showed superior and more consistent performance across storage quality indicators. The results support the use of clove as a promising botanical preservative for sweet potato storage and reinforce the broader value of plant-based disease management strategies in postharvest agriculture.

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