JOURNAL OF HORTICULTURE AND POSTHARVEST RESEARCH
2025, VOL. 8(1), 15-26

Journal of Horticulture and Postharvest Research

Journal homepage: www.jhpr.birjand.ac.ir

University of Birjand

Bio-protective solutions for carrot spoilage: exploring the antifungal properties of ginger, garlic, onion, and *Moringa*

Eugenia Amaka Njoku[1], Florence Nwakaego Mbaoji[2], Justus Amuche Nweze[3,*], Bonaventure Chukwujindu Echezona[1] and Kayode Paul Baiyeri[1]

1, Department of Crop Science, Faculty of Agriculture, University of Nigeria, Nsukka, Nigeria
2, Department of Pharmacology and Toxicology, Faculty of Pharmaceutical Sciences, University of Nigeria, Nsukka, Nigeria
3, Department of Science Laboratory Technology, Faculty of Physical Sciences, University of Nigeria, Nsukka, Nigeria

ARTICLE INFO

Original Article

Article history:
Received 1 June 2024
Revised 14 August 2024
Accepted 5 September 2024

Keywords:
Antifungal activity
Carrot
Fungi
Plant extracts
Postharvest preservation

DOI: 10.22077/jhpr.2024.7713.1386
P-ISSN: 2588-4883
E-ISSN: 2588-6169

***Corresponding author:**
Department of Science Laboratory Technology, Faculty of Physical Sciences, University of Nigeria, Nsukka, Nigeria.

Email: justus.nweze@unn.edu.ng

ABSTRACT

Purpose: To address postharvest losses in the carrot supply chain caused by pathogenic fungi, this study evaluates the antifungal potential of ethanol extracts from *Allium cepa*, *Zingiber officinale*, *Allium sativum*, and *Moringa oleifera* against carrot spoilage fungi, including *Aspergillus niger, Aspergillus fumigatus, Aspergillus flavus, Fusarium oxysporum,* and *Fusarium solani*. **Research Method:** Filtered plant extracts were obtained using ethanol extraction method. This study evaluated the efficacy of various plant extracts in reducing microbial load and inhibiting fungal growth on carrot roots using standard microbiological procedures, including agar well diffusion and broth microdilution techniques. **Findings:** The study demonstrated that ethanol extracts, particularly from ginger, significantly ($p < 0.05$) reduced fungal load on carrot roots. The inhibition zone analysis revealed that ginger and *Moringa* extracts, along with ketoconazole, effectively inhibited *A. niger* and *A. fumigatus*, with ketoconazole producing the largest inhibition zones. Ginger showed the highest antifungal effectiveness, with minimal inhibitory concentrations ranging from 31.25 mg/ml to 250 mg/ml, particularly against *A. niger* and *A. fumigatus*, demonstrating higher antifungal activity compared to other treatments. Garlic consistently exhibited an MIC of 250 mg/ml against all test fungi. Additionally, the minimum fungicidal concentration results highlighted ginger extract's potent biocidal effects, especially against *A. flavus*, with an MIC of 62.5 mg/ml. **Research limitations:** The study is limited to *in vitro* assessments; field conditions may affect the efficacy of the extracts due to environmental factors. **Originality/Value:** This research highlights ginger's potential as a natural antifungal agent, offering practical applications for improving carrot preservation and reducing postharvest losses.

INTRODUCTION

Carrot (*Daucus carota*) is among the premium vegetable crops due to its high health and nutrient-packed quality. Carrot assists in regular maintenance of body needs through the provision of beta carotene, vitamin K1, fiber, and antioxidants (Ahmad et al., 2019; Motegaonkar et al., 2024). In sub-Saharan Africa, where the system is still developing, the loss of vegetables such as carrot is sustained before harvest, during harvest, and under storage. In Nigeria, for example, immeasurable losses are incurred in the vegetable sector due to zero to insufficient levels of post-harvest handling procedures (Odeyemi, 2019). Fungi are among the plant pathogens that account for about 30% loss in both quality and yield of horticultural crops along the food value chain (Xi et al., 2022; Moradinezhad & Ranjbar, 2023). *Fusarium* species (*F. oxysporum* and *F. solani*), known soil and waterborne diseases, cause both field and storage damage in various crop produce such as carrot and tomatoes (Rahimi Kakolaki et al., 2024). The shelf life of carrot is also affected by activities of other species of fungal pathogens, including *Aspergillus* species (*A. niger, A. fumigatius, A. flavus,* etc) (Alegbeleye et al., 2022). *Aspergillus* species contaminate edible materials through the secretion of toxic substances (mycotoxins), which have the potential to cause cancer. These substances (hepatocarcinogens) pose serious health risks to both humans and animals (Alshammari, 2023). These pre and postharvest pathogenic issues in carrot production are commonly treated with chemical fungicides. However, currently, due to concerns arising from the potential bio-disaster resulting from constant application of chemical fungicides in agriculture, there is a need for risk-free, antifungal, bio-alternatives with a broad spectrum of action (Rawal & Singh Adhikari, 2016).

Since the 1990s, extracts from plant materials and similar medicinal substitutes for ailment therapy have been widely used. Studies have shown that less than 10% of plant species in nature are utilized by humans and animals; however, a higher percentage are assumed to be used for therapeutic purposes (Sezer et al., 2024). Many of these medicinal plants have been studied, and their active phyto-constituents extracted and characterized (Habiba & Yasmeen, 2023). In a previous study, the antimicrobial activities of *Zingiber officinale* isolates against bacterial and fungal loads were confirmed (Santo Grace et al., 2017). *Moringa* species have been recognized by folk medicine practitioners to be effective in treating tumors (Harcourt, 2015) and it contains many phytochemical compounds that contributes to its biological efficacy (Bridgemohan et al., 2020; Goordeen & Mohammed, 2021). In addition to the nutritional benefits of the garlic plant, it has significant medicinal relevance (antioxidant and antimicrobial properties), making it a globally sought-after vegetable crop (Phan et al., 2019). Previous studies have demonstrated the effectiveness of plant extracts, such as those from ginger, garlic, and onion, in controlling spoilage pathogens, including fungi. These findings highlight the potential of these extracts for use in food preservation industries (Adl et al., 2024; Bridgemohan et al., 2020; El-Samawaty et al., 2021; Suharti et al., 2020).

Despite the large amount of research work on carrot, problems of postharvest handling chain still exist. There is a need for more research on the best agronomic treatment approach that will reduce post-harvest losses (Elik et al., 2019). In addition, considerable attention should be paid to the use of affordable and available indigenous botanical extracts to extend the shelf lives of edible carrot roots (Alegbeleye et al., 2022). Taking into account all the facts mentioned above, the present study was conducted to ascertain the protective effect of *Allium cepa, Z. officinale, Allium sativum,* and *Moringa oleifera* ethanol extracts against fungal growth during the storage of carrot roots and to determine which of the plant extracts, and the doses that will offer optimum protection against the fungal pathogens.

MATERIALS AND METHODS

The study was conducted in the Department of Microbiology Research Laboratory at the University of Nigeria, Nsukka (UNN). Freshly harvested Carrot Touchon roots, grown with 10 t/ha of poultry manure and 200 kg of 15 15 15 NPK fertilizer, were obtained from the Department of Crop Science, UNN. The botanicals (onion bulbs, ginger rhizomes, garlic cloves, and *Moringa* leaves) were purchased from a local market in Nsukka, Enugu State. The study adopted a completely randomized experimental design (CRD) with three replicates. The treatments included the four botanicals, a positive control drug (ketoconazole) at concentrations of 500, 250, and 125 mg/ml, two negative controls (water-treated root and untreated root), and three levels of plant extract concentrations (500, 250, and 125 mg/ml).

Preparation, extraction and reconstitution of plant extracts

An optimized cold maceration procedure was used for the extraction. The blended air-dried plant materials (500 g each) were separately macerated with 1000 ml of 95% ethanol for 96 hours with intermittent agitation (Ndu et al., 2008). The filtrate was concentrated using a rotary evaporator, weighed, and stored in a refrigerator at 4 ℃ for future use. The extracts were reconstituted by dissolving 25,000 mg (25 g) of each extract in 50 ml sterile distilled water to produce a 500 mg/ml stock solution; it was further serially diluted to obtain 250 and 125 mg/ml concentrations.

Preparation of culture media

SDA (65 g in liter demineralized water (dH_2O)) and Mueller Hinton Broth (MHB) (38 g in a litre dH_2O) were prepared according to the manufacturer's instructions. The agar was autoclaved at a temperature of 121°C for 20 minutes, cooled, and dispensed into sterile 15 × 100 mm Petri dishes.

The carrot-dip and spoilt tissue preparation

Freshly harvested carrot roots were dipped in the various treatments for two minutes, and each root was transferred to a sterile foil. The foils were placed on the bench at room temperature (26 °C) and monitored every 5 days for three weeks. Segments of tissue (One gram) from the spoiled areas of carrots were cut out with a sterile scalpel and introduced into flat-bottomed flasks containing 100 ml of previously prepared nutrient broth. The flasks were incubated at 28 °C for 72 hours, after which serial ten-fold dilutions of the enriched culture were made.

Enumeration and isolation of fungi

Approximately one-tenth of a milliliter of the serially diluted samples was introduced into plates containing sterile Saboraud Dextrose Agar (SDA) with chloramphenicol (0.05 mg/ml to inhibit bacterial growth). The plates were uniformly spread with a sterile glass rod and incubated in an inverted position at 28 °C for 5 days to allow the development of fungal colonies.

The test fungi (*A. niger, A. fumigatus, A. flavus, F. oxysporium,* and *F. solani)* were isolated from spoilt Carrot Touchon root tissue used for the study and were reserved as stock culture, maintained in SDA slants at 4 °C in a refrigerator.

Purification and maintenance of the microbial isolates

Distinct fungal colonies that developed on the plates were randomly picked and sub-cultured on SDA plates, before transferring to SDA slants. These stock isolates were stored at 4°C in a refrigerator.

Characterization and identification of the fungi isolates

The colonial and microscopic characteristics of the isolated fungi were determined using the lactophenol cotton blue staining method and the slide culture test.

Slide Culture Test: Fungal isolates were introduced on a clean slide and stained with two drops of lactophenol cotton blue solution, then observed under a microscope. According to the description by Oyeleke and Manga (2008), the isolates were identified. Slides containing SDA were inoculated with fragments of aerial mycelia and incubated at 28 °C for 42-72 h. Subsequently, they were stained with lactophenol cotton blue dye and viewed fewer than 100 × magnifications.

Antimicrobial susceptibility test

Agar well diffusion method

The method of Magaldi et al (2004) was used to determine the susceptibility of test fungi to the plant extracts, based on the ability of the extract to diffuse through the agar surface. Fungal isolates on SDA plates (65 g/L) were incubated for 48-72 h. The test fungi were collected in respective test tubes containing normal saline solution (0.85% m/v). The 0.5 McFarland standard was prepared by withdrawing 0.5 ml from a 1% concentration of H_2SO_4 (v/v) and replacing it with the same volume from a 1.1% $BaCl_2$ solution. The resulting turbid solution was adjusted to a 0.5 McFarland standard equivalent to 1-5.0 x 10^6 cfu/ml. The standardized test fungi were inoculated onto the entire MHA plates and allowed to stand for 15 min. A sterile cork-borer (6 mm in diameter) was used to create wells in the plates. Subsequently, 200 µL of various concentrations of the plant extracts were introduced into the wells using a micropipette. The plates were incubated for about 72 h at 28 °C. The diameter of the inhibition zone was recorded based on the observation of the clearance zone around the well.

Determination of minimum inhibitory concentration (MIC) using broth macro-dilution method

This was done according to a modified method of Committee for Antimicrobial Susceptibility Testing of the European Society of Clinical Microbiology & Diseases (EUCAST, 2003). Standardized inoculums of half McFarland turbidity were further increased by two logs to produce a final working concentration of 10^4 cfu/ml. Two serial dilutions of plant extract (of 500 mg/ml stock concentration) were performed in Eppendorf tubes containing 200 µL sterile MHB (38 g/L). This resulted in final extract concentration gradients of 250, 125, 62.5, and 31.25 mg/ml. Each of the tubes was inoculated with equal volumes of the standard inoculum and incubated for 72 hours at 28 °C. The lowest concentration of the test plant extract that showed inhibition of the test fungi was considered the MIC. The positive control was 40 mg/L, while the negative control was the drug-free tube (containing the broth and test organism only).

Determination of minimum fungicidal concentration

The tube(s) indicating the MIC and other preceding tubes (also showing inhibition of the bioactive compound) were streaked on MHA plates and incubated for about 72 hours at 28 °C. The absence of (or very scanty) growth after incubation indicated the minimum fungicidal

concentration (MFC) of the plant extract (Committee for Antimicrobial Susceptibility Testing of the European Society of Clinical Microbiology & Diseases, 2003).

Statistical analysis

Data obtained were analyzed using a One-way Analysis of Variance (ANOVA), and the treatment means were compared using Fisher's Least Significant Difference (F-LSD) at a 5 % probability level (Hayter, 1986). Data collected were also described with descriptive statistics such as averages, standard deviations, percentages, and charts.

Table 1. Antifungal efficacy of plant extracts on carrot root microbial load over time.

Plant Extract	Conc. (mg/ml)	Initial load × 10 CFU	5 DUO × 10 CFU (%)	10 DUO × 10 CFU (%)	15 DUO × 10 CFU (%)	20 DUO × 10 CFU (%)
Onions	500	66.00	55.11 (16.5)	47.12 (28.60)	33.28 (49.57)	14.61 (77.87)
Garlic	500	76.33	55.04 (27.89)	39.17 (47.63)	30.57 (59.95)	18.00 (76.42)
Ginger	500	46.00	25.50 (44.57)	21.90 (52.39)	16.36 (64.44)	8.74 (80.99)
Moringa	500	59.00	49.97 (15.30)	44.70 (24.23)	38.20 (35.25)	19.10 (67.63)
Ketoconazole	500	71.00	37.89 (46.64)	28.14 (60.37)	17.02 (76.03)	11.07 (84.41)
LSD $_{(0.05)}$		NS	24.72	26.29	23.76	NS
Onions	250	60.33	53.43 (11.43)	46.39 (23.10)	34.76 (42.39)	20.60 (65.85)
Garlic	250	34.00	29.43 (13.45)	26.53 (21.98)	20.72 (39.06)	13.91 (59.10)
Ginger	250	48.00	35.61 (25.81)	27.12 (43.50)	20.08 (58.16)	16.20 (66.25)
Moringa	250	45.00	41.68 (7.38)	38.09 (15.35)	31.18 (30.71)	23.04 (48.80)
Ketoconazole	250	57.00	33.07 (41.99)	25.82 (54.71)	17.50 (69.30)	10.39 (81.77)
LSD $_{(0.05)}$		NS	22.13	25.84	18.58	17.66
Onions	125	67.00	60.73 (9.36)	52.29 (21.95)	45.06 (32.74)	30.37 (54.67)
Garlic	125	32.00	30.19 (5.66)	28.20 (11.88)	22.93 (28.33)	16.76 (47.64)
Ginger	125	41.00	37.15 (9.38)	34.65 (15.48)	32.50 (20.72)	30.82 (24.82)
Moringa	125	41.67	39.36 (5.55)	37.20 (10.73)	31.67 (24.01)	27.52 (33.96)
Ketoconazole	125	76.67	46.20 (39.74)	37.05 (51.68)	25.92 (66.19)	14.96 (80.49)
LSD $_{(0.05)}$	-	20.86	15.45	16.95	15.96	15.08
H_2O	-	31.00	32.37 (-4.42)	35.75 (-15.32)	39.74 (-28.2)	43.22 (-39.42)
Untreated cont.	-	45.00	55.25 (-22.78)	66.43 (-47.62)	72.45 (-61.01)	79.06 (-75.68)
LSD $_{(0.05)}$	-	9.44	NS	18.25	42.38	28.17

The table shows the percentage reduction of microbial load on carrot roots treated with various plant extracts at different concentrations (125, 250, and 500 mg/ml) and a positive control (Ketoconazole) over a period of 20 days. The negative controls include water-treated (H2O) and untreated roots. DUO represents Days Under Observation, and values in parentheses indicate the percentage reduction or increment of microbial load compared to the initial load. LSD refers to the Least Significant Difference at a 0.05 level of significance.

RESULTS

Microbial load reduction on carrot roots by plant extracts and ketoconazole

The plant extracts significantly ($p < 0.05$) reduced the microbial loads on carrot roots (Table 1). At 20 days under observation (DUO), the different extracts at the highest dose (500 mg/ml) did not differ in their response to microbial load reduction. Throughout the observation period, the positive control (Ketoconazole) had a better effect on the percentage bio load reduction, although, at five DUO, it had a similar response with ginger extract. However, *Moringa* poorly protected the carrot root against the pathogens throughout the study period, although, at 5 DUO, it significantly ($p < 0.05$) had a similar effect with onion extract. Furthermore, at 250 mg/ml, ketoconazole had a higher percentage microbial load reduction than the other treatments, with *Moringa* having the least antifungal activity. Interestingly, it had a similar effect with onions and garlic at five DUO, and with garlic at 15 and 20 DUO. Notably, throughout the observation period, all the extracts at 125 mg/ml had poorer antifungal activity than ketoconazole. It was also observed that the percentage reduction in colony-forming units increased with days across all the concentrations (Table 1). The same table revealed that the three concentrations significantly ($p < 0.05$) affected the percentage reduction in microbial load on carrot roots. All the three concentrations of positive control (Ketoconazole) did not react differently to microbial load reduction. Among the negative control treatments (H_2O treated roots and untreated roots), there was a significant effect on the bio load increment. The microbial load increased in the two negative controls, but the mean percentage bio load increment in untreated roots was significantly ($p < 0.05$) higher than the values for water-treated roots (Table 1).

Inhibition zones of plant extracts and ketoconazole against test fungi isolates

It was revealed that ginger and *Moringa* extracts, along with the positive drug control (Ketoconazole) at given concentrations, had clear zones of inhibition against the test fungi isolates (Table 2). Ketoconazole at concentrations of 500, 250, and 125 mg/ml produced mean inhibition zones of 22.5 mm, 22 mm, and 14 mm, respectively, against *A. niger*, while 500 mg/ml of *Moringa* extract had the least mean inhibition zone diameter (10 mm). The highest and intermediate concentrations (500 and 250 mg/ml) of ginger exhibited activity against *A. fumigatus* and produced mean inhibition zone diameters of 12 mm each. Ketoconazole, at all levels of concentrations, produced clear zones of inhibition against *A. fumigatus*, with the highest mean inhibition zone diameter (24.5 mm) at 500 mg/ml and the least diameter (15 mm) at the lowest concentration (125 mg/ml). The plant extracts provided no inhibition against *A. flavus* and *F. oxysporum*, while Ketoconazole produced the highest mean inhibition zone of 19 mm against *A. flavus* at 500 mg/ml and the least inhibition zone diameter (14 mm) at 125 mg/ml concentration. Similarly, the highest inhibition zone diameter of 22.5 mm against *F. oxysporum* was produced at 500 mg/ml by Ketoconazole, while the least microbial activity (9 mm IZD) was produced at 125 mg/ml concentration. The same table showed that the least inhibition zone diameter (8 mm) against *F. solani* was produced at 125 mg/ml by ginger, while ketoconazole had the highest clearance zone of 20 mm at 500 mg/ml.

Minimum inhibition concentrations of plant extracts and ketoconazole against fungal strains

The treatments inhibited the activities of all the test fungi at a given minimum inhibition concentrations (MIC) (Table 3). The extracts of ginger and *Moringa* had higher inhibitory activity against *A. niger* than the other treatments with MIC of 62.5 mg/ml each while garlic produced the least effect by inhibiting the reference test fungi at highest MIC value (250

mg/ml). Among the treatments, ginger and ketoconazole had the lowest MIC value (62.5 mg/ml each), and was more active while onions and garlic poorly inhibited *A. fumigatus* with MIC value of 250 mg/ml each. The inhibitory activity of ginger against *A. flavus* at MIC of 31.5 mg/ml was more than the other treatments whereas; garlic and onions had the least activity against *A. flavus* at higher MIC of 250 mg/ml each. Ketoconazole's inhibitory action against *F. oxysporum* at MIC of 31.5 mg/ml was more than the inhibition offered by all the plant extracts while, garlic and ginger had the least activity against the reference test fungi at a higher MIC (250 mg/ml) value. Ginger among the plant extracts and the positive control had higher inhibitory activity (i.e. at MIC 62.5 ml/ml each) against *F. solani* than the other treatments with their inhibitory activity at the same MIC (250 mg/ml) (Table 3).

Table 2. Inhibition zone diameter at a given concentration of botanical extracts and ketoconazole against test fungi.

		Test fungi/IZD (mm)				
Botanicals	Conc. (mg/ml)	*A. niger*	*A. fumigatus*	*A. flavus*	*F. oxysporum*	*F. solani*
Ginger	500	No zone	12.0 ± 00	No zone	No zone	10.0 ± 00
Ginger	250	No zone	12.0 ± 00	No zone	No zone	9.0 ± 1.41
Ginger	125	No zone	No zone	No zone	No zone	8.0 ± 00
Moringa	500	10.0 ± 2.83	No zone	No zone	No zone	No zone
Ketoconazole	500	22.5 ± 0.71	24.5 ± 2.12	19.0 ±1.41	22.5 ± 4.95	20.0 ± 00
Ketoconazole	250	22.0 ± 0	22.5 ± 3.54	18.5 ± 2.12	22.0 ± 2.12	18.0 ± 2.83
Ketoconazole	125	14.0 ± 2.83	19.0 ± 1.41	15.0 ± 00	16.0 ± 2.12	16.5 ± 4.95
Ketoconazole	62.5	No zone	18.0 ± 1.41	No zone	13.0 ± 2.83	12.0 ± 00
Ketoconazole	31.25	No zone	15.0 ± 2.12	No zone	9.0 ± 1.41	12.0 ± 00

The inhibition zone diameters (IZD) of ginger, *Moringa*, and ketoconazole at various concentrations against different test fungi. The data show the antifungal activities of these substances against test fungi.

Table 3. Minimum inhibitory concentration of botanical extracts against test fungi.

	Test fungi/MIC (mg/ml)				
Botanicals	*A. niger*	*A. fumigatus*	*A. flavus*	*F. oxysporum*	*F. solani*
Garlic	250	250	250	250	250
Ginger	62.5	62.5	31.25	250	62.5
Moringa	62.5	125	125	125	250
Onions	125	250	250	125	250
Ketoconazole	125	62.5	125	31.25	62.5

This table displays the MIC values (in mg/ml) of different botanical extracts and ketoconazole against various strains of test fungi. MIC refers to the lowest concentration of a substance required to inhibit the growth of a microorganism. The table shows that each treatment inhibited the activities of all the test fungi at a given minimum inhibition concentration (MIC).

Table 4. Minimum biocidal concentration of botanicals against test fungi.

	Test fungi/MBC (mg/ml)				
Botanicals	*A. niger*	*A. fumigatus*	*A. flavus*	*F. oxysporum*	*F. solani*
Garlic	>250	>250	>250	>250	>250
Ginger	62.5	125	31.25	250	250
Moringa	>250	>250	>250	>250	>250
Onions	>250	>250	>250	>250	>250
Ketoconazole	>250	>250	125	31.25	>250

This table presents the MBC values (in mg/ml) for various botanical extracts and ketoconazole against different strains of test fungi. The symbol ">" indicates that the MBC value was greater than the highest concentration tested.

Minimum fungicidal concentrations of plant extracts and ketoconazole against fungal strains

Among the treatments, only the extract of Ginger at 62.5 mg/ml and 125 mg/ml were fungicidal to *A. niger and A. fumigatus* respectively (Table 4). The extracts of ginger and ketoconazole were able to eliminate *A. flavus* at MBC of 62.5 mg/ml and 125 mg/ml, respectively while the other treatments had non-biocidal action on the same test fungi. Ketoconazole and extract of Ginger were equally biocidal to *F. oxysporum* at MBC of 31.25 mg/ml and 250 mg/ml respectively while the other treatments had no activity. However, among the treatments, only the ginger extract produced biocidal effect on *F. solani* at 250 mg/ml.

DISCUSSION

The phytoconstituents inherent in the various plant extracts were implicated in the reduction of bio-load seen in carrot roots. The present study however, established the effectiveness of the highest dose of ginger extract in reducing bio-load than the lowest dose. This result is line with the findings of (Xi et al., 2022) that ginger rhizome extract gave higher antifungal activity at higher dose and drastically reduced *F. solani* colony forming units and subsequent spores' advancement. Furthermore, the higher percentage reduction in bio-load by ginger extract over other plant extracts proved its higher potency and broad spectrum of activity. This present finding concurs with that of Onyeagba et al. (2004) where ginger rhizome extract was more effectiveness than other ethanol extracts of garlic and lime against isolates of *A. niger* and *A. flavus*, etc. This may be probably, due to numerous (over 400) bioactive compounds (zingerone, traces of monoterpnoid, shogoal, etc.) associated with ginger ingredient (Chrubasik et al., 2005; Grzanna et al., 2005). The fungal bio load reduction caused by highest dose (500 mg/ml) of ginger extract was comparable to that of standard drug (250 mg/ml). Interestingly, the efficacy of ginger extract is in tandem with the earlier report where it was implicated in effective retardation of infectious spore multiplication and growth as result of its unlimited fungicidal properties (Xi et al., 2022). However, the reverse was the case with negative controls (water treated control and untreated control), where there was massive microbial growth which was higher in the untreated roots. This may be because of absence of drug protection (treatment), immunity degeneration, and subsequent breakdown of the root tissues, following ageing and senescence in the course of the study. The degradation process is always associated with increased respiration and immunity collapse during prolonged storage. This is in concordance with Ciccares et al. (2013) that decay and death of stored produce may be traced to high rate of catabolic process at the expense of the reserved energy. Clearance zones of inhibition against test fungi were recorded in ginger and *Moringa*. These extracts at concentrations of 125 mg/ml and above, exhibited clearance zone of inhibition (8.00 mm to 10.00 mm) against *A. niger* and *A. fumigatus, F. solani*, respectively. Several studies established the anti-fungal activity of *Moringa* in arrays of extraction solutions: ethanol against *A. niger*, *Rhizopus stolonifera* and *Candida albican* (Aisha et al., 2016) inhibition against *A. niger*, *Sclerotium rolfsii, Botryodiplodia theobromae* etc. with petroleum ether extraction (Paray et al., 2018), and ethanol, methanol, water etc. extracts against *Aspergillus* spp, *Rhizopus* spp., *Penicillium* spp, and *Trichodema* spp (Oniha et al., 2021). Likewise, fungal inhibitory activity of ginger rhizome extract against *F. solani* was reported in a previous study where the activity of the extract was higher than the extract from other parts (stem and leaves) (Peng et al., 2022). The absence of inhibition zones observed in the onion and garlic extracts may be probably due to inability of the ingredients to diffuse freely into the agar media (MHA).

However, all the test fungi isolates displayed varying levels of susceptibility to all the plant extracts and control drug. The present study observed a higher susceptibility of all the isolates to garlic and onion extracts which reflected in the high MIC (125 to 250 mg/ml) and higher MBC (>250 mg/ml) values. This is line with report where the MIC and MBC of garlic and onion extracts were established, although against a bacterial pathogen, *Staphylococcus aureus* (Anyamaobi et al., 2020). Furthermore, in another study, the anti-fungal activity of aqueous extracts of garlic (MIC/MBC: 325 mg/ml) was more effective than that of onions (MIC/MBC >900 mg/ml) and Leek (MIC: 900 and MBC: >900 mg/ml) against *A. niger* (Irkin & Korukluoglu, 2007).

Surprisingly, *Moringa* inhibited the growth of test fungi but inhibited *A. niger* at MIC: 62.5 mg/ml) more. This result is similar to the result of postharvest study on onions rot where antifungal potency of *Moringa* was proved. In the same study, the ethanol leaf extract of the *Moringa* inhibited *A. niger* at 75% concentration in potato dextrose broth (Arowora & Adetunji, 2014).

Notably, among the botanicals tested in the study, ginger was the only extract biocidal to all the test fungi. This may be because, ginger possesses a wider range of organic compounds and metabolites that may have countered normal biological metabolic process rendering the cell membrane porous, destroying building up process of respiratory system, and compromising cell wall integrity (Liu et al., 2017; Mandal & Domb, 2024). Also, among the two fungi species *Aspergillus* and *Fusarium*, the ginger extract was more fungicidal (31.25 to 125 mg/ml) to the three isolates of *Aspergillus* than to the two isolates of *Fusarium* (250 mg/ml).

CONCLUSION

The study highlights the potential of plant extracts, particularly ginger, garlic, and *Moringa*, as alternative treatments for reducing fungal growth in stored carrots. Ginger extract was found to be the most effective against all test fungi, followed by garlic and onion extracts. *Moringa* extract inhibited the growth of test fungi but was more effective against *A. niger*. The results suggest that plant extracts could be a viable alternative to synthetic fungicides in the food preservation industry, although further research is needed to investigate their mechanisms of action and safety. Additionally, the study emphasizes the importance of controlling *F. oxysporum*, a more resistant pathogen, in postharvest carrot handling. Overall, these findings provide valuable insights into the use of plant extracts for reducing fungal growth in stored carrots and suggest potential avenues for future research.

Funding
No funding.

Conflicts of interest/Competing interests
The authors declare that they have no conflicts of interest or competing interests with respect to the research, authorship, and/or publication of this article. The authors have no personal, professional, or financial affiliations that could potentially influence the outcomes of this study.

Availability of data and material
The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' contributions

EAN designed the experiment in collaboration with FNM, JAN, BCE, and KPB. FNM, JAN, BCE, and KPB provided guidance and expertise throughout the research process for EAN to conduct the research and write the initial manuscript. JAN & KPB revised the manuscript. All authors reviewed and approved the final version of the manuscript.

Acknowledgments

We would like to express our gratitude to Chidebelu Paul for his invaluable guidance and assistance throughout the course of this research project. His expertise and support were instrumental in the completion of this work.

REFERENCES

Adl, E., Jahani, M., & Aminifard, M. H. (2024). Investigating the antifungal effects of essential oils on *Aspergillus* sp. in strawberry (*Fragaria ananassa* Duchesne) fruit. *Journal of Horticulture and Postharvest Research*, *7*(2), 141–154. https://doi.org/10.22077/JHPR.2024.7065.1349

Ahmad, T., Cawood, M., Iqbal, Q., Ariño, A., Batool, A., Sabir Tariq, R. M., Azam, M., & Akhtar, S. (2019). Phytochemicals in *Daucus carota* and their health benefits—review article. *Foods*, *8*(9), 424. https://doi.org/10.3390/FOODS8090424

Aisha, Kutama, & Kabir. (2016). Phytochemical screening and antifungal activity of *Moringa oleifera* on some selected fungi in Dutse, Jigawa State. *Global Advanced Research Journal of Agricultural Science*, *5*(6), 243–248.

Alegbeleye, O., Odeyemi, O. A., Strateva, M., & Stratev, D. (2022). Microbial spoilage of vegetables, fruits and cereals. *Applied Food Research*, *2*(1), 100122. https://doi.org/10.1016/j.afres.2022.100122

Alshammari, N. (2023). Mycotoxin source and its exposure causing mycotoxicoses. *Bioinformation*, *19*(4), 348–357. https://doi.org/10.6026/97320630019348

Anyamaobi, P. O., Wokem, G. N., Bessie Enweani, I., Nwamaka Okosa, J., Emmanuel Opara, C., & Nwokeji, M. C. (2020). Antimicrobial effect of garlic and ginger on *Staphylococcus aureus* from clinical specimens in Madonna University Teaching Hospital, Nigeria. *International Journal of Recent Scientific Research*, *11*(3), 37840–37845. https://doi.org/10.24327/ijrsr.2020.1103.5189

Arowora, K. A., & Adetunji, C. O. (2014). Antifungal effects of crude extracts of *Moringa oleifera* on *Aspergillus niger* v. tieghem associated with post harvest rot of onion bulb. *SMU MEDICAL JOURNAL*. https://worldveg.tind.io/record/52606

Bridgemohan, P., Goordeen, A., Mohammed, M., & Bridgemohan, R. S. H. (2020). Review of the agro-ecology, phytochemistry, postharvest technology and utilization of moringa (*Moringa oleifera* Lam.). *Journal of Horticulture and Postharvest Research*, *3*(2), 311–332. https://doi.org/10.22077/JHPR.2020.3037.1116

Chrubasik, S., Pittler, M. H., & Roufogalis, B. D. (2005). *Zingiberis rhizoma*: a comprehensive review on the ginger effect and efficacy profiles. *Phytomedicine : International Journal of Phytotherapy and Phytopharmacology*, *12*(9), 684–701. https://doi.org/10.1016/J.PHYMED.2004.07.009

Committee for Antimicrobial Susceptibility Testing of the European Society of Clinical Microbiology, E., & Diseases, I. (2003). Determination of minimum inhibitory concentrations (MICs) of antibacterial agents by broth dilution. *Clinical Microbiology and Infection*, *9*(8), 9-15. https://doi.org/10.1046/j.1469-0691.2003.00790.x

El-Samawaty, A. E. R. M. A., El-Wakil, D. A., Alamery, S., & Mahmoud, M. M. H. (2021). Potency of plant extracts against *Penicillium* species isolated from different seeds and fruits in Saudi Arabia. *Saudi Journal of Biological Sciences*, *28*(6), 3294. https://doi.org/10.1016/J.SJBS.2021.02.074

Elik, A., Yanık, D. K., Yanik, D. K., Guzelsoy, N. A., Yavuz, A., & Gogus, F. (2019). Strategies to reduce post-harvest losses for fruits and vegetables. *International Journal of Scientific and Technological Research*. https://doi.org/10.7176/JSTR/5-3-04

Goordeen, A., & Mohammed, M. (2021). Growth, development, maturation indices, proximate and mineral composition of moringa (*Moringa oleifera*). *Journal of Horticulture and Postharvest Research*, *4*(4), 427-438. https://doi.org/10.22077/jhpr.2021.4296.1205

Grzanna, R., Lindmark, L., & Frondoza, C. G. (2005). Ginger--an herbal medicinal product with broad anti-inflammatory actions. *Journal of Medicinal Food*, *8*(2), 125–132. https://doi.org/10.1089/JMF.2005.8.125

Habiba, U., & Yasmeen, H. (2023). Article 7 Part of the Alternative and Complementary Medicine Commons Recommended Citation Recommended Citation Afzal, I. *Journal of Bioresource Management*, *10*(4). https://corescholar.libraries.wright.edu/jbm

Harcourt, P. (2015). Antimicrobial activity of the leaf and seed extracts of *Moringa Oleifera* on some bacteria isolates. *Journal of Medical Science and Clinical Research*, *3*(1), 3904–3912. https://worldveg.tind.io/record/53698

Hayter, A. J. (1986). The maximum familywise error rate of Fisher's least Significant difference test. *Journal of the American Statistical Association*, *81*(396), 1000. https://doi.org/10.2307/2289074

Irkin, R., & Korukluoglu, M. (2007). Control of *Aspergillus niger* with garlic, onion and leek extracts. *African Journal of Biotechnology*, *6*(4), 384–387. https://www.ajol.info/index.php/ajb/article/view/56223

Liu, K., Zhou, X., & Fu, M. (2017). Inhibiting effects of epsilon-poly-lysine (ε-PL) on *Pencillium digitatum* and its involved mechanism. *Postharvest Biology and Technology*, *123*, 94–101. https://doi.org/10.1016/J.POSTHARVBIO.2016.08.015

Magaldi, S., Mata-Essayag, S., Hartung De Capriles, C., Perez, C., Colella, M. T., Olaizola, C., & Ontiveros, Y. (2004). Well diffusion for antifungal susceptibility testing. *International Journal of Infectious Diseases*, *8*(1), 39–45. https://doi.org/10.1016/j.ijid.2003.03.002

Mandal, M. K., & Domb, A. J. (2024). Antimicrobial activities of natural bioactive polyphenols. *Pharmaceutics 2024, Vol. 16, Page 718*, *16*(6), 718. https://doi.org/10.3390/PHARMACEUTICS16060718

Moradinezhad, F., & Ranjbar, A. (2023). Advances in postharvest diseases management of fruits and vegetables: A review. *Horticulturae*, *9*(10), 1099. https://doi.org/10.3390/horticulturae9101099

Motegaonkar, S., Shankar, A., Tazeen, H., Gunjal, M., & Payyanad, S. (2024). A comprehensive review on carrot (*Daucus carota* L.): the effect of different drying methods on nutritional properties and its processing as value-added foods. *Sustainable Food Technology*, *2*(3), 667–688. https://doi.org/10.1039/D3FB00162H

Ndu, O. O., Akah, P. A., Ochiogu, I. S., Ezike, A. C., & Mbaoji, F. N. (2008). Effects of ethanolic root and leaf extracts of *Cissampelos mucronata* on length of gestation period. *Planta Medica*, *74*(09), PA131. https://doi.org/10.1055/S-0028-1084129

Odeyemi, O. (2019). Postharvest handling practices and losses of some major fruits sold in Abeokuta, South-western Nigeria. *Nigeria Journal of Horticultural Society*, *24*(1), 113–121.

Oniha, M., Eni, A., Akinnola, O., Omonigbehin, E. A., Ahuekwe, E. F., & Olorunshola, J. F. (2021). In vitro antifungal activity of extracts of *Moringa oleifera* on phytopathogenic fungi affecting *Carica papaya*. *Open Access Macedonian Journal of Medical Sciences*, *9*(A), 1081–1085. https://doi.org/10.3889/OAMJMS.2021.6794

Onyeagba, R. A., Ugbogu, O. C., Okeke, C. U., & Iroakasi, O. (2004). Studies on the antimicrobial effects of garlic (*Allium sativum* Linn), ginger (*Zingiber officinale* Roscoe) and lime (*Citrus aurantifolia* Linn). *African Journal of Biotechnology*, *3*(10), 552–554. https://doi.org/10.5897/AJB2004.000-2108

Oyeleke, S. B., & Manga, S. B. (2008). Essentials of laboratory practicals in microbiology. In *Minna, Nigeria: Tobest Publishers*.

Paray, A. R., Rasool, A., Bhakat, M., Mohanty, T. K., Behare, P., Lone, S. A., Parry, U. R., Kumar, R., Sinha, R., Yadav, H. P., Rahim, A., Danish, Z., & Shah, N. (2018). Antimicrobial activity of crude aqueous extracts of *Moringa oleifera*, *Azadirachta indica*, *Carica papaya*, *Tinospora cordifolia* and *Curcuma longa* against certain bacterial pathogens. *Journal of Pharmacognosy and Phytochemistry*, *7*(4).

Peng, H., Hu, H., Xi, K., Zhu, X., Zhou, J., Yin, J., Guo, F., Liu, Y., & Zhu, Y. (2022). Silicon nanoparticles enhance ginger rhizomes tolerance to postharvest deterioration and resistance to *Fusarium solani*. *Frontiers in Plant Science*, *13*, 816143. https://doi.org/10.3389/FPLS.2022.816143/BIBTEX

Phan, A. D. T., Netzel, G., Chhim, P., Netzel, M. E., & Sultanbawa, Y. (2019). Phytochemical characteristics and antimicrobial activity of Australian grown garlic (*Allium Sativum* L.) cultivars. *Foods 2019, Vol. 8, Page 358*, *8*(9), 358. https://doi.org/10.3390/FOODS8090358

Rahimi Kakolaki, M., Omidi, A., Rasooli, A., & Shekarforoush, S. S. (2024). *In vitro* antifungal activity of barberry fruit extract (*Berberis* spp.) against *Fusarium* spp.. *Journal of Horticulture and Postharvest Research*, *7*(Special Issue - Postharvest Technologies), 47-60. http://doi.org/10.22077/jhpr.2023.6783.1333

Rawal, P., & Singh Adhikari, R. (2016). Evaluation of antifungal activity of *Zingiber officinale* against *Fusarium oxysporum* f. sp. lycopersici. *Advances in Applied Science Research*, *7*(2), 5–9. www.pelagiaresearchlibrary.com

Santo Grace, U., Sankari, M., & Gopi. (2017). Antimicrobial activity of ethanolic extract of *Zingiber officinale* – An *in vitro* study. *Journal of Pharmaceutical Sciences and Research*, *9*(9), 1417–1419.

Sezer, F., Deniz, S., Sevim, D., Chaachouay, N., & Zidane, L. (2024). Plant-derived natural products: A source for drug discovery and development. *Drugs and Drug Candidates 2024, Vol. 3, Pages 184-207*, *3*(1), 184–207. https://doi.org/10.3390/DDC3010011

Suharti, T., Nugraheni, Y. M. M. A., Suita, E., & Sumarni, B. (2020). Effect of plant extracts and chemical fungicide on viability and percentage of seed-borne fungal infection on calliandra (*Calliandra callothyrsus*) seed. *IOP Conference Series: Earth and Environmental Science*, *533*(1), 012040. https://doi.org/10.1088/1755-1315/533/1/012040

Xi, K. Y., Xiong, S. J., Li, G., Guo, C. Q., Zhou, J., Ma, J. W., Yin, J. L., Liu, Y. Q., & Zhu, Y. X. (2022). Antifungal activity of ginger rhizome extract against *Fusarium solani*. *Horticulturae*, *8*(11), 983. https://doi.org/10.3390/HORTICULTURAE8110983/S1