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# Fungicidal potential of three plant extracts in the management of root rot disease of sweet potato in storage

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**Abstract**

The study sought to protect sweet potato (*Ipomoea batatas* L. Lam) root tubers from storage root rot diseases caused by fungal pathogens with three indigenous plants extracts; bitter leaf (*Vernonia amygdalina*), lemon grass (*Cymbopogon citratus*) and holy basil (*Ocimum sanctum*). Fungal pathogens suspected to cause root rots were isolated and pathogenicity test performed to confirm their identity through Koch postulate. Likewise, antifungal activity of the three plants using their crude extracts against the five fungal isolates namely; *Fusarium oxysporum, Lasiodiplodia theobromae, Trichoderma harzianum, Rhizopus stolonifer,* and *Aspergillus niger* was also performed. The crude extracts reduced weight loss significantly ($P \leq 0.05$) from the first to the sixth week of storage. Sprout development was suppressed by bitter leaf on both sweet potato varieties with 87 % and 86 % on orange-flesh sweet potato (OFSP) and white-flesh sweet potato (WFSP) respectively. The highest rot inhibition was caused by bitter leaf on *F. oxysporum* inoculated root tubers for WFSP and by lemon grass on *F. oxysporum* inoculated root tubers with 73% and 65% respectively. Six point sixty-seven (6.67) and 8.0 mm were produced as the least rot lesion diameters for lemon grass against *T. harzianum* and bitter leaf against *F. oxysporum* for WFSP and OFSP inoculated root tubers respectively.

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## Introduction

Sweet potato (*Ipomoea batatas* L. Lam) is ranked as the fifth most important food crop in developing countries with 131 million tons estimated production from an area of 9 million hectares (Sapakhova *et al*., 2023). Asia is the largest producer with almost 66% of the world's production followed by Africa with 28% (Otálora *et al*., 2022). In Ghana, except for yam, cassava, and taro, sweet potato is the next enviable tuber crop on the menu of many Ghanaians concerning tuber crops in the country (Sugri *et al.*, 2017). The crop is most prominent among smallholder farmers who extensively grow the crop in the Northern, Upper East, Upper West, Central, and Volta Regions of Ghana (Bidzakin *et al.*, 2014). Sweet potato serves as a source of rich carbohydrates, and vitamin A, which is lacking in many children under six years in Sub-Saharan African countries, particularly in Ghana (Ayensu *et al*., 2019). It is a prominent food security crop due to its drought-tolerant ability as well as income-earning root tuber crop that does well in the Guinea Savanna region of Ghana. There are several constraints to sweet potatoes production, among them are pests and diseases (Echodu *et al*., 2019). Several fungi have been reported to significantly induced rots on sweet potato root tubers either on the field or in storage (Paul *et al*., 2021; Yang *et al*., 2021).

Post-harvest loss is a major hindrance to long shelf-life of the root tubers in storage (Edun *et al.*, 2019). Weight loss, sprouting, weevil damage and microbial attack are the factors that facilitate postharvest quality deterioration and rots (Olaitan, 2012; Clark *et al.*, 2013). Many different microbes, primarily moulds, have been associated with tuber rotting, but only a small number are the main pathogens (Clark *et al.*, 2013). *Aspergillus niger*, *Fusarium oxysporum*, *Rhizopus stolonifer, Botryodiplodia theobromae*, and *Penicillium* sp. are among the fungi linked to sweet potato rots in the tropics (Olaitan, 2012). For long–term storage of root tubers, farmers have resorted to synthetic fungicides such as mancozeb, benomyl and thiophanate–methyl to curb these disease causing pathogens (Nwaogu *et al*., 2022).

Meanwhile, 70-99% of them never successfully reach their intended targets but rather causing mammalian toxicities (Nwaogu *et al*., 2022). However, plants with antifungal potential against fungal disease-causing pathogens in storage have been reported (Giri *et al*., 2020; Nwaogu *et al*., 2022). Nwaogu *et al*. (2022) reported antifungal potential on aqueous leaf extracts and peel extracts of *Musa* spp. on fungal leaf spot on sweet potato.

Similarly, Nmom *et al*. (2023) reported antifungal activity of *Chromolaena odorata* leaf extracts on fungal pathogens of sweet potato. This suggest that the quantity of sweet potato that deteriorates after harvest and in storage can be reduced by the use of botanicals with broad spectrum of antifungal properties. This will enable farmers protected stored produce not only from contamination but also preserve sweet potatoes to a reasonable shelf-life for food sufficiency throughout the year as this is more environmentally save and friendlier method. The objective of the study, therefore, is to assess the antifungal potential of three plant extracts in the management of sweet potato root tuber rot in storage in northern Ghana.

## Materials and methods

*Experimental site*

The experiment was conducted in the Spanish Laboratory (Microbiology section) at Nyankpala Campus of the University for Development Studies. The experimental site is located at Longitude 0° 58" 42' W and latitude 9° 25" 41' N and situated at 1057 mm above sea level.

*Source of sweet potato tubers*

Sweet potato varieties of both white flesh and orange flesh were procured at the farm gate from

sweet potato farmers in Nyankpala, Northern Region and the neighbouring communities and were sorted into uniform sizes 30 – 80 g before being transported to the Laboratory for the study. The sample was cured in the open sun for one week before being kept on raised platforms in an airy open space in the Laboratory at laboratory conditions till the commencement of the experiment.

*Sources of botanicals*

Holy basil (*Ocimum sanctum*) was collected in the Nyankpala and its environs while lemon grass (*Cymbopogon citratus)* was obtained at the Nyankpala campus of the University for Development Studies. Bitter leaf (*Vernonia amaygdalina*) was, however, obtained at Damongo (125 km from Nyankpala) in the Savanna Region due to insufficient availability of it in Nyankpala and its environs.

*Preparation of plant extracts*

Each botanical was washed under running tap water after harvesting and then air dried on standing tables under a shaded environment till it was completely air dried. The dried samples were sent to the Savanna Agricultural Research Institute (SARI) of the Council for Scientific and Industrial Research (CSIR) food laboratory in Nyankpala for grinding. They were grounded into powder using a grinding mill fitted with a 2 mm sieve. One hundred and eighty grams (180 g) of each extracted powder was weighed and kept in aseptic bottles and dissolves in 1.8 L of distilled water to make 10% basic concentrated solutions. The extracts were manually agitated vigorously and left to stand for 24 hours. They were filtered using sterilized Whatman filter paper No. 4 and the filtrate was used as the extracts for the *in vivo* studies. Both negative and positive control experiments were set up without the extract where water was used for the negative control. Mancozeb (a synthetic fungicide) was prepared per the method used by Gwa and Richard (2018) by weighing 4 g of the chemical and dissolving it in 1 L of distilled water and stirring to make a concentration of 4 g/L for the positive control.

*Preparation of potato dextrose agar*

According to the manufacturer's specification and instruction, thirty-nine grams (39 g) of Potato Dextrose Agar (PDA, Oxoid, UK) was weighed using a weighing balance (Aczet Thailand Co. Ltd.; CY 324C; 320 g) and placed in 1 L media bottle. One tablet of amoxicillin (500 mg (September, 2022); Zylomox, Zydus Cadila, India) was added to inhibit the growth of bacteria. One litre of distilled water was added and then kept in a heated water bath for the dissolution of the PDA. The dissolved PDA was autoclaved at 121 ℃ for 15 minutes. After autoclaving, the PDA was allowed to cool in a sterilized laminar air flow chamber before pouring it into Petri plates (90.8 mm x 87.5 mm × 87.5 mm) for solidification.

*Isolation and identification of pathogens causing sweet potato root rot disease*

Small tissues of both sweet potato varieties were excised containing the periphery of both healthy and diseased parts of the rotted root tubers and then sterilized in 75% alcohol for five seconds, rinsed with distilled water severally and then air dried. The sterilized tissues were plated on solidified Potato Dextrose Agar (PDA) incorporated with one tablet of amoxicillin (500 mg; Zylomox, Zydus Cadila, India) as before to inhibit the growth of bacteria. The cultured petri dishes were wrapped with cling film and incubated on a sterilized workbench for six days at a room temperature of 27 ± 2 ℃. After six days, cultures were repeatedly sub-cultured till pure cultures of isolated pathogens were obtained. Developed pure cultures were prepared under microscopic slides, fixed, mounted and examined using light microscope and the colour and colony features of the isolates were identified with manuals of identifications (Campbell and Johnson, 2013; Barnett and Hunter, 1998).

*Pathogenicity*

Fresh and healthy sweet potato tubers were washed under running tap water and air dried on sterilized workbench. The tubers were surface sterilized with 75% alcohol and labelled according to the treatments and plugged holes of about 5 mm were created on each potato tuber. A six-day-old of 3 mm mycelial plug of each of the isolated pure fungus culture was placed into each hole at a depth of 5 mm created on the tubers and then covered up with the cylindrical tissue core before using Vaseline to completely sealed it off to prevent drying of the mycelia plug. The inoculated tubers were placed on cotton wool wet with 20 ml of distilled water in relative humidity chambers made by inserting a binding wire frame of 100 cm × 50 cm × 30 cm to give an area of 150,000 $cm^3$ into a white polyethylene bag of doubled-layered. The relative humidity chambers were sealed off and left for 14 days at a room temperature of 27 ± 2 ℃. Controls were carried out with uninoculated PDA placed in the holes created on the tubers. After, 14 days of incubation, tubers were brought out and assessed for disease development before re-isolation of the pathogens on fresh prepared PDA for confirmation of Koch's postulates.

*Antifungal activity of plant extracts against test fungi in tuber samples*

Fresh and healthy of both sweet potato varieties were surface-sterilized/disinfected with 75% of alcohol and a 5 mm diameter cylindrical borer was used to create hole on each of the tubers as before to a depth of 10 mm. Test fungal pathogens viz. *Fusarium oxysporum*, *Lasiodiplodia theobromae, Trichoderma harzianum, Rhizopus stolonifer,* and *Aspergillus niger* were inoculated into the holes according to treatment labels. Vaseline gel was again used to completely sealed off the holes to prevent drying of the mycelia plugs after replacement of the tissue cores removed earlier. Controls tubers were not inoculated with the test pathogens but with uninoculated PDA plugs. Plant extracts were prepared in rubber basins of equal sizes with the same volume of each plant extracts. Preventive method was performed where test pathogens were first inoculated into root tubers before then submerged in root tubers into the plant extracts. Similarly, negative and positive controls of root tubers were setup with water and fungicides as discussed in section 2.4 above. The inoculated tubers were placed on wet cotton wool as before wet with 20 ml of distilled water in relative humidity chambers made by inserting a binding wire frame of 100 cm × 50 cm × 30 cm to give an area of 150,000 $cm^3$ into a white polyethylene bag of doubled-layered. The relative humidity chambers were sealed off and left for 21 days at a room temperature of 27 ± 2 ℃ (Zhang *et al*., 2018). After 21 days, tubers were removed and examined for growth inhibition.

**Table 1.** Treatment combinations

| Variety | Extracts | | | Control | |
|---|---|---|---|---|---|
| | Lemon grass (Lg) | Holy basil (Hb) | Bitter leaf (Bl) | Negative control ($H_2O$) | Positive control (fungicide) |
| OFSP | Lg + OFSP | Hb + OFSP | Bl + OFSP | $H_2O$ + OFSP | Fungicide + OFSP |
| WFSP | Lg + WFSP | Hb + WFSP | Bl + WFSP | $H_2O$ + WFSP | Fungicide + WFSP |

OFSP= Orange flesh sweet potato, WFSP=White flesh sweet potato, H2O= Water

*Experimental design*

The experiment was a 2 × 3 factorial experiments laid out in a Completely Randomized Design (CRD) with three replications. The treatment consisted of two sweet potato varieties; orange-flesh and white-flesh and three plant extracts; bitter leaf, lemon grass, and holy basil with fungicide and water being positive and negative controls respectively. Each sweet potato variety was treated separately with the plant extracts to give a 1 × 5 single factor treatment combinations (Table 1).

*Parameters studied*

*Sprout development*

Tuber sprout was observed each week and those that sprouted each week were counted and then severed. At the end of the storage period, all the sprout counts for each treatment were summed up and then averaged to get the sprout count for each treatment.

*Weight loss*

Three healthy root tubers from each sweet potato variety with uniform weight range of 30 – 80 g were selected, surface sterilized with 75% ethanol, and then weighed using a weighing balance (Aczet Thailand Co., Ltd.; CY 324C; 320 g). The tubers were dipped to completely submerged in each of the aqueous solutions of the extract prepared for 10 minutes (Linus, 2014) before removal and air-dry on sterilized tissue papers. The treated root tubers were then stored at room temperature of 27 ± 2 ℃. The weight of the treated tubers was taken at 7 days intervals. Each treatment was replicated three times. Percentage (%) weight loss was calculated every week by the formulae used by Kuyu *et al.* (2019).

$$\text{Weight loss}(\%) = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

*Rot severity (%)*

This was conducted based on the protocols adopted by Amadioha (2004) and Chukwuebuka *et al.* (2016). One root tuber from each treatment was inoculated with a 5 mm diameter disc of isolated pathogens and replicated three times and incubated in relative humidity chambers for 11 days (Scruggs and Quesada-Ocampo, 2016). Rot initiation and development in the root tubers were assessed as a percentage of the final weight of inoculated and treated tubers y the rot pathogens using the formula by Chukwebuka *et al.* (2016).

$$\text{Rot sevrity}\ (\%) = \frac{\text{W} - \text{w}}{\text{W}} \times 100$$

Where;

W = Final weight of inoculated and rotted tubers at the end of storage

w = weight of rotted part of sweet potato

*Growth inhibition (%) of test fungi in tuber sample*

The antifungal effect of the extracts on the pathogens on the tuber samples in *in-vivo* was determined by transversely cutting across the point of inoculation with a sterilized knife and measuring the diameter of the rot lesion. The percentage growth inhibition was calculated by the formulae adopted by Amadioha (2003).

$$\text{Growth inhibition}\ (\%) = \frac{\text{dc} - \text{dt}}{\text{dc}} \times 100$$

Where;

dc = Average diameter of the rotted fungal lesion in the control experiment

dt = Average diameter of rotted fungal lesion of treatment

*Depth of lesion of rot*

The depth of the rot lesion was measured after diametrically cutting across the point of inoculation of the mycelia plugs.

*Data analysis*

Data collected were subjected to general Analysis of Variance (ANOVA) of the Genstat Statistical Software Package edition 12. Square root transformation $\sqrt{(x+1)}$ was performed on sprout percentage, growth inhibition, and rot severity. Means were separated using the Least Significant Difference at a 5% probability level and the results obtained were presented in tables.

**Results**

*Sprout development*

There was a significant interaction between variety and plant extracts on sprout percentage in the sweet potato varieties (Table 2). The negative control recorded the highest sprout percentage of 37.3% and 30.6% for both white-flesh (WFSP) and orange-flesh (OFSP) varieties, respectively. Contrary to the negative control for

both varieties, the positive control recorded no development of sprout in WFSP that to the positive control for OFSP recording 6%. Across the plant extracts, lemon grass produced the highest as well as the lowest sprout count in both OFSP and WFSP with 29.47% and 8.33% respectively, followed by holy basil recording 21.87% and 18.20% for both OFSP and WFSP while bitter leaf recording the least percentage sprout count of 12.54% and 13.91% in decreasing order for both OFSP and WFSP. Generally, it was observed that OFSP-treated extracts produced more sprout count than WFSP-treated extract root tubers except for treated bitter leaf white-flesh sweet potato.

**Table 2.** Effect of plant extracts on sprout count of sweet potato varieties

| Treatment | Sprout count (%) | |
|---|---|---|
| | OFSP | WFSP |
| Negative control | 30.60 (0.87)$^{d}$ | 37.30 (3.24)$^{e}$ |
| Bitter leaf | 12.54 (0.42)$^{b}$ | 13.91 (0.73)$^{c}$ |
| Lemon grass | 29.47 (0.32) $^{d}$ | 8.33 (0.71)$^{b}$ |
| Holy basil | 21.87 (0.69)$^{c}$ | 18.20 (1.10)$^{d}$ |
| Positive control | 6.00 (0.50)$^{a}$ | 0.00 (0.00)$^{a}$ |
| LSD | 2.09 | 2.81 |
| CV % | 1.40 | 5.30 |
| P≤0.01 | <0.01 | <0.01 |

*Means with Standard Errors (in brackets). The same superscript letters are not significant (P > 0.05) while superscripts with different letters have significant (P ≤ 0.05) differences between the means.

*Effect of plant extracts on weight loss of sweet potato varieties*

*Weight loss of orange-flesh sweet potato*

There was a weekly interactive effect of plant extracts on weight loss of stored root tubers of orange-flesh sweet potato (OFSP) variety. Orange-flesh root tuber treated with water (negative control) in the first week of storage recorded the highest weight loss of 20.8% which is significantly ($P \leq 0.05$) higher than all of the weight loss in the storage period while week 6 (0.73 %) recorded the least weight loss. Across the weeks, week 6 recorded both the highest and lowest weight loss at 5.62 % and 0.73% respectively for holy basil and lemon grass. However, in week 3, lemon grass recorded the second highest weight loss with 5.43% which was not significantly different ($P \leq 0.05$) in comparison with that of holy basil in week 6. The positive control recorded 3.57%, 3.27%, 3.1%, etc. in weeks 2, 4, and 1 respectively in weight loss (Table 3).

**Table 3.** Effect of plant extracts on weight loss of orange-flesh sweet potato

| Treatment | Percentage weight loss (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Init. Weight | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 |
| Negative | 83.30(8.04)$^{b}$ | 20.80(5.52)$^{b}$ | 12.22(1.89)$^{b}$ | 5.63(1.09)$^{b}$ | 8.18(1.029)$^{b}$ | 12.76(0.76)$^{c}$ | 6.59(0.05)$^{c}$ |
| Bitter leaf | 31.10(4.9)$^{a}$ | 2.80(0.07)$^{a}$ | 2.40(0.16)$^{a}$ | 2.79(0.29)$^{a}$ | 3.89(0.31)$^{a}$ | 1.12(0.10)$^{a}$ | 3.34(1.43)$^{ab}$ |
| Lemon grass | 43.20(6.97)$^{a}$ | 3.20(0.014)$^{a}$ | 2.75(0.33)$^{a}$ | 3.18(0.11)$^{ab}$ | 5.43(0.07)$^{a}$ | 2.45(0.11)$^{ab}$ | 0.73(0.22)$^{a}$ |
| Holy basil | 47.10(8.16)$^{a}$ | 3.30(0.08)$^{a}$ | 2.01(0.22)$^{a}$ | 4.369(0.20)$^{ab}$ | 4.61(0.18)$^{a}$ | 2.71(0.10)$^{b}$ | 5.62(0.23)$^{bc}$ |
| Positive con. | 29.50(1.48)$^{a}$ | 3.10(0.05)$^{a}$ | 3.56(0.035)$^{a}$ | 2.01(0.023)$^{a}$ | 3.27(0.19)$^{a}$ | 0.90(0.14)$^{a}$ | 2.61(0.15)$^{ab}$ |
| Mean | 46.80 | 6.70 | 4.59 | 3.59 | 5.08 | 3.99 | 3.78 |
| (P<0.05) | 0.001 | 0.003 | <.001 | 0.008 | <.001 | <.001 | 0.001 |
| LSD | 19.65 | 8.07 | 2.78 | 1.70 | 1.62 | 1.04 | 2.08 |
| CV % | 12.90 | 28.60 | 15.6 | 10.70 | 7.50 | 9.30 | 15.20 |

*Means with ± Standard Errors in brackets. Different superscript letters indicate significant differences (P ≤ 0.05) among the extracts. Values with the same letters are not significantly different (P > 0.05).

*Weight loss of white-flesh sweet potato*

Similarly, Table 4 showed the interactive effect of plant extracts on weight loss of white-flesh sweet potato (WFSP) variety across weeks of storage. There were significant differences ($P \leq 0.05$) in weight loss in all the weeks of storage except in weeks 5 and 6. It was observed that the white-flesh sweet potato root tuber treated with water recorded the highest weight loss in week 4 (10.35%) which is significantly higher than all of the weight loss across the weeks in storage except for week 5 recorded 13.8% and 11.5% for

the extracts of bitter leaf and holy basil respectively. Similarly, week 6 also recorded 16.1%, 13.1%, and 10.8% weight loss for bitter leaf, lemon grass, and holy basil respectively in comparison from week 1 to week 4.

Among the plant extracts, bitter leaf recorded the highest and as well as lowest weight loss with 16.1% and 3.47% in weeks 6 and 2 respectively. The second highest weight loss was recorded by lemon grass (13.8%) in week 5 and then followed by holy basil with 13.2% in week 6. The negative control lost more weight than the positive control in all the weeks of storage except week 6 with the positive control recording 10.8% weight loss in comparison to 8.7% for the negative control in the same week 6.

*Antifungal activity of plant extracts on rot severity*

*White-flesh sweet potato (WFSP)*

The results showed that, the plant extracts sufficiently ($P \leq 0.05$) reduced rot severity in inoculated root tubers with the isolated pathogens after fourteen days of incubation in humid chambers (Table 5). Generally, it was observed that 74% (26% rotten) and 71% (29% rotten) were the highest mean percentage diameter recorded by bitter leaf extract as the first and second best, respectively, in reducing rot severity on white-flesh sweet potato root tubers, followed by lemongrass with 67% (33% rotten) whereas holy basil produced the most rot among the plant extracts with 58% (42 % unrotten). The standard check (Negative control), root tubers without treatment inoculated with *Trichoderma harzianum* recorded the greatest rot with 78% (22% unrotten), followed by root tubers inoculated with *R. stolonifer* with 76% (24% unrotten), and *F. oxysporum* inoculated root tubers recording 63% (37% unrotten) as the best performance among the untreated root tubers used for negative control while *R. stolonifer* recording less rot among the root tubers with fungicide (Table 5).

**Table 4.** Effect of plant extracts on weight loss of white-flesh sweet potato

| Treatment | Percentage weight loss (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Int. weight | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 |
| Negative control | 68.60$^{ab}$ | 9.63(0.42)$^{c}$ | 8.12(.55)$^{b}$ | 8.01(0.42)$^{c}$ | 10.35(0.35)$^{d}$ | 8.30(1.71)$^{a}$ | 8.70(3.65)$^{a}$ |
| *Vernonia amygdalina* | 81.50$^{ab}$ | 6.21(0.20)$^{b}$ | 3.47(0.26)$^{a}$ | 5.80(0.63)$^{b}$ | 3.60(0.03)$^{a}$ | 13.80(0.82)$^{a}$ | 16.10(5.15)$^{a}$ |
| *Cymbopogon citratus* | 105.10$^{ab}$ | 5.98(0.08)$^{b}$ | 3.71(0.12)$^{a}$ | 4.33(0.28)$^{ab}$ | 7.97(0.38)$^{c}$ | 6.90(0.39)$^{a}$ | 13.10(1.53)$^{a}$ |
| *Ocimum sanctum* | 74.60$^{ab}$ | 5.78(0.05)$^{b}$ | 5.06(0.19)$^{a}$ | 5.36(0.10)$^{ab}$ | 4.20(0.15)$^{a}$ | 11.50(2.98)$^{a}$ | 13.20(1.36)$^{a}$ |
| Positive control | 61.20$^{a}$ | 4.22(0.26)$^{a}$ | 4.04(0.32)$^{a}$ | 3.88(0.26)$^{a}$ | 5.95(0.25)$^{b}$ | 6.90(2.77)$^{a}$ | 10.80(6.09)$^{a}$ |
| Mean | 78.20 | 6.36 | 4.88 | 5.48 | 6.41 | 9.50 | 12.40 |
| P <0.05 | 0.052 | <.001 | <.001 | <.001 | <.001 | 0.215 | 0.783 |
| LSD | 28.25 | 0.88 | 1.18 | 1.09 | 0.92 | 7.32 | 13.89 |
| CV% | 5.90 | 0.40 | 1.50 | 7.60 | 2.30 | 3.30 | 18.20 |

*Means with ± Standard Error (brackets). Different superscript letters indicate significant ($P \leq 0.05$) differences among the extracts. Values with the same letters are not significantly different ($P > 0.05$).

**Table 5.** Antifungal activity of plant extracts on rot severity of white-flesh sweet potato

| | Plant extracts | | | | |
|---|---|---|---|---|---|
| Pathogen | Negative control | Bitter leaf | Lemon grass | Holy basil | Positive control |
| *F. oxysporum* | 37.22(1.56) $^{bc}$ | 73.90(1.11) $^{j}$ | 67.31(1.55) $^{ghij}$ | 64.37(1.02) $^{efghij}$ | 60.85(7.67) $^{efghi}$ |
| *L. theobromae* | 25.65(1.05) $^{ab}$ | 66.59(0.56) $^{ghij}$ | 61.29(1.41) $^{efghij}$ | 56.08(2.38) $^{efg}$ | 64.63(1.34) $^{efghij}$ |
| *T. harzianum* | 21.91(0.19) $^{a}$ | 71.21(0.31) $^{ij}$ | 61.36(0.95) $^{efghij}$ | 52.45(0.27) $^{de}$ | 68.73(2.76) $^{ghij}$ |
| *R. stolonifer* | 23.67(1.37) $^{a}$ | 66.23(1.74) $^{ghij}$ | 64.67(1.63) $^{efghij}$ | 56.24(2.69) $^{efgh}$ | 68.88(1.78) $^{hij}$ |
| *A. niger* | 26.80(3.45) $^{ab}$ | 58.95(0.82) $^{efghi}$ | 53.43(1.45) $^{def}$ | 41.52(4.42) $^{cd}$ | 65.68 (0.06) $^{fghij}$ |
| Grand mean = 55.18 | Sig. level (P ≤ 0.05) = <.001 | | LSD = 6.61 | CV% =1.8 | |

*Means of rot severity with Standard Error of means (± SE). Bitter leaf (*Vernonia amygdalina*), Lemon grass (*Cymbopogon citratus*) and Holy basil (*Ocimum sanctum*). Different superscript letters indicate significant differences ($P \leq 0.05$) among the extracts. Values with the same letters are not significantly different ($P > 0.05$).

*Orange-flesh sweet potato (OFSP)*

The effect of the plant extracts on the percentage rot severity during the incubation period showed significant differences (*P ≤ 0.05*) on the orange-flesh sweet potato root tuber (Table 6). Generally, across the extracts, holy basil inoculated *F. oxysporum* outperformed both bitter leaf and lemon grass extracts with rot reduction of 65% (35% rotten) although it was closely followed by lemon grass inoculated *F. oxysporum* with 61% reduction (39% rotten) while bitter leaf inoculated with *A. niger* significantly (*P* ≤ 0.05) recorded the highest rot severity among the extracts with 74% (26% unrotten). Positive control inoculated *T. harzianum* recorded the least rot development with 73% of the root tuber recording no rot which was not significantly different (*P* ≤ 0.05) from root tubers inoculated with other isolated pathogens. The negative control inoculated with *A. niger* recorded the highest rot with 13% of the root tuber being wholesome (Table 6).

**Table 6.** Antifungal activity of plant extracts on rot severity (%) of orange-flesh sweet potato

| | Plant Extracts | | | | |
|---|---|---|---|---|---|
| Pathogen | Negative control | Bitter leaf | Lemon grass | Holy basil | Positive control |
| *F. oxysporum* | 32.86(2.38) $^{bcde}$ | 59.93(2.47) $^{ijklm}$ | 60.61(2.28) $^{ijklm}$ | 65.03(0.49) $^{jklm}$ | 65.29(3.0) $^{klm}$ |
| *L. theobromae* | 32.86(3.99) $^{bcde}$ | 47.08(3.8) $^{efghi}$ | 53.00(3.68) $^{fghijk}$ | 53.76(2.43) $^{ghijk}$ | 71.17(1.35) $^{lm}$ |
| *T. harzianum* | 40.15(3.79) $^{cdefg}$ | 52.13(0.68) $^{fghijk}$ | 31.19(2.11) $^{bcd}$ | 56.55(1.64) $^{hijkl}$ | 73.22(1.20)m |
| *R. stolonifer* | 22.06(5.13) $^{ab}$ | 31.73(2.17) $^{bcd}$ | 50.02(1.85) $^{fghij}$ | 43.50(1.24) $^{defgh}$ | 64.51(1.26) $^{jklm}$ |
| *A. niger* | 13.42(0.97) $^{a}$ | 25.88(2.01) $^{abc}$ | 34.72(4.93) $^{bcde}$ | 38.60(3.72) $^{cdef}$ | 61.36(2.30) $^{ijklm}$ |
| Grand mean = 47.23 | Sig. level (P < 0.05) =<.001 | | LSD = 7.82 | CV% = 1.7 | |

* Means of rot severity with Standard Error of means (± SE). Bitter leaf (*Vernonia amygdalina*), Lemon grass (*Cymbopogon citratus*) and Holy basil (*Ocimum sanctum*). Different superscript letters indicate significant differences (P ≤ 0.05) among the extracts. Values with the same letters are not significantly different (P > 0.05)

**Table 7.** Effect of plant extracts on white-flesh sweet potato root tuber rot lesion caused by fungal pathogens

| Pathogen | Lesion diameter (mm) | | | | |
|---|---|---|---|---|---|
| | Negative control | Bitter leaf | Lemon grass | Holy basil | Positive control |
| *F. oxysporum* | 17.33(2.85)$^{abcde}$ | 8.33(0.33)$^{ab}$ | 7.33(0.33)$^{a}$ | 6.87(0.59)$^{a}$ | 10.33(1.20)$^{abcde}$ |
| *L. theobromae* | 21.33(3.18)$^{cde}$ | 17.00(3.06)$^{abcde}$ | 16.50(0.29)$^{abcde}$ | 8.00(0.58)$^{ab}$ | 9.17(1.91)$^{abc}$ |
| *T. harzianum* | 16.67(2.73)$^{abcde}$ | 15.30(3.84)$^{abcde}$ | 6.67(0.33)$^{a}$ | 9.83(2.35)$^{abcd}$ | 14.0(0.58)$^{abcde}$ |
| *R. stolonifer* | 23.00(0.58)$^{e}$ | 21.67(1.86) $^{cde}$ | 15.50(0.29)$^{abcde}$ | 19.00(4)$^{abcde}$ | 13.83(0.73)$^{abcde}$ |
| *A. niger* | 22.67(0.33)$^{de}$ | 15.00(4.04)$^{abcde}$ | 17.67(0.33)$^{abcde}$ | 20.33(5.78)$^{bcde}$ | 12.67(0.33)$^{abcde}$ |
| Mean = 14.64 | Sig. Level (P < 0.05) = <.001 | | CV % = 6.68 | | |

*Means of depth lesion with Standard Error of means (± SE). Bitter leaf (*Vernonia amygdalina*), Lemon grass (*Cymbopogon citratus*) and Holy basil (*Ocimum sanctum*). Different superscript letters indicate significant differences (P ≤ 0.05) among the extracts. Values with the same letters are not significantly different (P > 0.05).

*Depth of lesion of sweet potato varieties in vivo*

*White-flesh sweet potato Variety*

Table 7 shows the impact of three plant extracts on the lesion diameter of white-flesh sweet potato root tuber *in vivo*. Generally, there were significant differences (*P* ≤ 0.05) in the effectiveness of the plant extracts in the control of rot on inoculated root tubers on white-flesh sweet potato. Root tubers inoculated without treatment recorded the highest lesion diameter with 23 ± 0.58 mm for *R. stolonifer* and was not significantly different (*P* < 0.05) from the inoculated root tubers without treatment for *A. niger* (22.67 ± 0.33 mm) while the least lesion diameter was recorded by *T. harzianum* (16.67 ± 2.7 mm) without treatment. Among the plant extracts, *R. stolonifer* recorded a greater lesion diameter

with 21.67 ± 1.86 mm for bitter leaf extract, followed by the extract of holy basil recording 20.33 ± 5.78 mm as the second highest for *A. niger* and the least impact in terms of lesion diameter was recorded by lemon grass (6.67 ± 0.33 mm) for *T. harzianum*. The positive controls recorded the lesion diameter in a range between 9.17 ±1.9 to 14 ± 0.58 mm which was not significantly different from the extract treatments.

**Table 8.** Effect of plant extracts on orange-flesh sweet potato root tuber rot lesion caused by fungal pathogens

| Pathogen | Lesion diameter (mm) | | | | |
|---|---|---|---|---|---|
| | Negative control | Bitter leaf | Lemon grass | Holy basil | Positive control |
| *F. oxysporum* | 28.70(0.17)$^{j}$ | 8.00(0.29)$^{a}$ | 9.33(0.33)$^{ab}$ | 26.67(1.45)$^{hij}$ | 20.00(1.15)$^{defghij}$ |
| *L. theobromae* | 27.00(4.38)$^{hij}$ | 10.17(2.02)$^{abc}$ | 14.00(4.38)$^{abcdef}$ | 24.33(2.31)$^{ghij}$ | 19.00(3.46)$^{cdefghi}$ |
| *T. harzianum* | 27.67(2.96)$^{ij}$ | 11.50(0.29)$^{abcd}$ | 13.67(0.33)$^{abcdef}$ | 13.33(0.88)$^{abcde}$ | 18.33(0.67)$^{bcdefgh}$ |
| *R. stolonifer* | 22.67(0.33)$^{fghij}$ | 20.00(0.29)$^{defgghij}$ | 14.50(0.87)$^{abcdef}$ | 18.50(2.57)$^{cdefgh}$ | 16.17(0.17)$^{abcdefg}$ |
| *A. niger* | 26.33(3.84)$^{hij}$ | 15.17(0.6)$^{abcdef}$ | 26.83(1.01)$^{hij}$ | 22.00(2.08)$^{efghij}$ | 21.33(4.37)$^{efghij}$ |
| Grand mean = 18.99 | | Sig. level (P < 0.05) = <.001 | | CV % = 2.60 | |

*Means of depth lesion with Standard Error of means (± SE). Bitter leaf (*Vernonia amygdalina*), Lemon grass (*Cymbopogon citratus*) and Holy basil (*Ocimum sanctum*). Different superscript letters indicate significant differences (P ≤ 0.05) among the extracts. Values with the same letters are not significantly different (P > 0.05).

*Orange-flesh sweet potato variety*

Table 8 shows the results of rot lesion on orange-flesh root tubers inoculated with fungal isolates. The results revealed significant differences (*P* ≤ 0.05) in the lesion diameter. Root tubers inoculated without treatment for *F. oxysporum* (28.7 ± 0.17) recorded greater lesion diameter although there were no statistical differences between other fungal isolates except for *R. stolonifer* (22.6 ± 0.33). With the plant extracts, lemon grass had the highest lesion diameter for *A. niger* with 26.83 ± 1.01 and was however not significantly different (*P* ≥ 0.05) in comparison with holy basil for *F. oxysporum* (26.67 ± 1.45) and *L. theobromae* (24.33 ± 2.31) whiles bitter leaf extract recording the least lesion diameter for *F. oxysporum* (8 ± 0.29). Interestingly, there were no significant differences (*P* ≥ 0.05) between the positive control and that of the extract treatments on the lesion diameter.

**Discussion**

*Percentage sprout count*

The sprout percentage of the three plant extracts was only tested in the aqueous extraction method instead of both aqueous and ethanol solvent forms on both sweet potato varieties.

This approach was due to the objective of the study seeking to find easy and accessible methods of managing sweet potato root rots as well as reducing sprouting with locally available plant species for smallholder sweet potato farmers in Ghana. Orange-flesh variety had the highest sprout percentage which was manifested in the weight loss thus losing more weight than the white-flesh variety in storage. In this study, the plant extracts are suggested to have the ability to inhibit the sprout of sweet potato root tubers in storage than root tubers without treatment. This report is in agreement with that of Belay *et al.* (2022) who reported the inhibition of sprouting on the Jalene sweet potato variety in Ethiopia after applying garlic and rosemary essential oils to sweet potato tubers. This indicates that the plant extracts possess some chemical constituents or sprouting inhibitors that can significantly reduce the sprouting of sweet potato root tubers in storage. It is assumed that essential oils prevent sprouting because their primary constituents can limit meristematic cell

division activities in comparison to the actions of auxins and cytokinins (Belay *et al*., 2022). The lowest sprouting percentage produced by WFSP (8.33%) treated with lemon grass extract is in conjunction with the findings of Giri *et al.* (2020) where 8.25% was reported to be the least percent sprout when lemon grass extracts were used in their experiment on sweet potato root tubers. They further reported that lemon grass oil significantly reduced sweet potato sprout to 13% after 90 days of storage. The effectiveness of lemon grass in suppressing sweet potato sprouts could be attributed to it containing citral (mixture of geranial and neral) which is an effective sprout suppressant (Giri *et al.*, 2020). However, the highest percent sprout as produced by the OFSP variety treated with lemon grass extract is in contrast to what was observed on WFSP lemon grass treated, could be due to their genetic variation. This assertion is supported by the works of Belay *et al*. (2022) and Frazier *et al*. (2006) who reported that due to genetic variation could affect sprouting of sweet potato tubers. Contrary to their argument, Belay *et al*. (2022) reported that essential oils of plants could either inhibit or induce sprouting on sweet potato root tubers depending on the variety.

*Weight loss of sweet potato varieties*

Weight loss is one of the principal components of root tubers in storage (Zhang *et al.*, 2018). The study revealed that sweet potato root tubers in weight loss were affected by the root tuber size, plant extracts, and the sweet potato variety. The rapid deterioration encountered in weight loss during the storage period decreases from the first week of storage to the last week of storage. Bigger root tubers in both varieties were observed to have greater weight loss in comparison to medium-sized root tubers. It is reported that the bigger the surface area of the tuber, the greater the transfer of moisture into the environment and vice versa (Dramani, 2013). This natural phenomenon could be attributed to the high moisture content of the root tubers in the initial stage of storage. This corroborates with the findings of Kou *et al.* (2023) that weight loss is experienced due to the dissipation of high moisture content (50 % - 80 %) from the surface of the sweet potato root tubers in storage. This phenomenon results in delicate skin as well as tuber shrivelling at the tuber tips.

In comparison, the rate of weight loss was affected by variety. Orange-flesh variety experienced higher weight loss than the white-flesh sweet potato variety. Similar studies conducted by Picha (1985), suggested that the white-flesh variety was stored longer due to its low weight loss and pithiness. This might be due to the physicochemical variation between the two sweet potato varieties. This assertion is in support of (Dramani, 2013) who reported that hemicellulose and cellulose except for lignin were altered with weight loss in yam tuber varieties after storage. In contrast, Afoakwa and Sefa-Dedeh (2001) deduced that fibre content increases in tubers after long storage but varies with tuber variety. Furthermore, the higher weight loss by the orange-flesh variety may be due to factors such as high dehydration as well as respiration and thin skin occurring in the orange-flesh variety. This view conforms with that of Kou *et al.* (2023) who reported that sweet potato varieties respire differently after treatment with ethylene. A higher respiration rate and undesirable environmental impacts might have affected the storage process and hence exacerbated excessive weight loss, which was associated with moisture loss of the orange-flesh variety.

The performance on weight loss for the plant extracts varied between the two varieties. However, bitter leaf gave average best performance though many differences were not observed between bitter leaf and the other two plant extracts. This could be attributed to the phytochemical constituents of the bitter leaf containing flavonoids, saponins, and triterpenes which is correlated to the antioxidant activity on the stored root tubers.

*Effect of plant extracts on rot severity and depth lesion and severity*

The plant extracts defence mechanism was tested on fresh and healthy root tubers inoculated with each test pathogen *in vivo*. Necrotic lesions on the stored root tubers were more necrotic at the proximal point of inoculation on all the inoculated tubers. On average, the orange-flesh variety had a greater depth lesion as well as rot severity than that of the white-flesh variety. This could be attributed to the varietal differences in moisture content between the varieties.

The high moisture content of the orange-flesh (50 – 80%) variety might have resulted in soft skin for easy colonization of the tuber. This corroborates with the findings of Gwa and Richard (2018) that the variation in moisture content between the regions in the tuber is a major contributor to tuber rot severity by pathogens. The low rot severity in that of the white-flesh variety could be due to the phytochemical constituents possessed by the plant extracts in conjunction with the production of enzymes in the white-flesh variety that inhibited the pathogens in *in-vivo.* The chemical composition differs between varieties and the differences in sweet potato varieties' susceptibility to rot severity can be explained by the composition of the skin and tubers, in particular, anti-fungal phenolic compounds. This supports the idea by Gwa and Richard (2018) that, 'ogaja' tubers were able to resist the attack of pathogens due to the production of phytoalexins in the yam tuber.

Regardless, the three plant extracts used reduced rot severity in both sweet potato varieties. This suggests that the plants have antifungal properties against the test organisms in *vivo*.

Gwa and Richard (2018) reported on the effectiveness of *Zingiber officinale*, *Azadirachta indica,* and *Piper guineense* in controlling yam tuber rots in storaget. However, the effectiveness of the plant extracts on the tubers in *vivo* differs with bitter leaf which happened to give a little better performance above lemon grass while holy basil was less effective on *A. niger*. The less effectiveness of holy basil on *A. niger* in this study could be attributed to the concentration level of the plant extract as well as the solvent extraction method. This supports the report by Sisodia and Rathore (2023) where they used holy basil with different solvent methods of extraction to inhibit the growth of *A. brasiliensis* and reported that methanol, acetone, and chloroform extraction methods gave a zone of inhibition with increasing concentration levels while the aqueous did not show any inhibition.

**Conclusion**

This study revealed that bitter leaf, lemon grass, and holy basil extracts have the potential to protect and suppress sweet potato root rot diseases caused by fungal pathogens. Comparably, among the three plant extracts, bitter leaf followed by lemon grass and holy basil gave a promising botanical management of sweet potato root rot diseases at the postharvest stage of sweet potato production. These plants can serve as alternative for synthetic fungicides in sweet potato storage as it is less expensive and environmentally friendly.

**References**

**Afoakwa EO, Sefa-Dedeh S.** 2001. Chemical composition and quality changes occurring in *Dioscorea dumetorum* pax tubers after harvest. Food Chemistry **75**(1), 85–91. https://doi.org/10.1016/S0308-8146(01)00191-1

**Amadioha AC.** 2003. Evaluation of some plant leaf extracts against *Colletotrichum lindemuthianum* in cowpea. Acta Phytopathologica et Entomologica Hungarica **38**(3–4), 259–265.

**Amadioha AC.** 2004. Control of black rot of potato caused by *Rhizoctonia bataticola* using some plant leaf extracts. Archives of Phytopathology and Plant Protection **37**(2), 111–117. https://doi.org/10.1080/0323540042000202067

**Ayensu J, Lutterodt H, Annan RA, Edusei A, Loh SP.** 2019. Nutritional composition and acceptability of biscuits fortified with palm weevil larvae (*Rhynchophorus phoenicis* Fabricius) and orange-fleshed sweet potato among pregnant women. Food Science & Nutrition **7**(5), 1807–1815. https://doi.org/10.1002/fsn3.1024

**Barnett HL, Hunter BB.** 1998. Illustrated genera of imperfect fungi, 4th ed. The American Phytopathological Society, Minnesota, USA.

**Belay DW, Asfaw Z, Lulekal E, Kassa B, Kifele H.** 2022. Effects of essential oils on potato tuber sprouting at room temperature storage in Ethiopia. Heliyon **8**(3). https://doi.org/10.1016/j.heliyon.2022.e09090

**Bidzakin JK, Acheremu K, Carey EE.** 2014. Needs assessment of sweet potato production in northern Ghana: Implications for research and extension efforts. ARPN Journal of Agricultural and Biological Science **9**(9), 315–319.

**Campbell CK, Johnson EM.** 2013. Identification of pathogenic fungi. In: Warnock DW (ed.). 2nd ed., John Wiley & Sons.

**Chukwuebuka AK, Sunday AN, Benjamin OC, Uche N, Charity MI, Nnamdi U.** 2016. Mycological deterioration and pathogenicity studies of post-harvest cassava. Food Science and Technology **4**(2), 23–30. https://doi.org/10.13189/fst.2016.040202

**Clark CA, da Silva WL, Arancibia RA, Main JL, Schultheis JR, van-Esbroeck ZP, Jiang C, Smith J.** 2013. Incidence of end rots and internal necrosis in sweetpotato is affected by cultivar, curing, and ethephon defoliation. HortTechnology **23**(6), 886–897. https://doi.org/10.21273/HORTTECH.23.6.886

**Dramani Y.** 2013. Effect of postharvest waxing treatments, yam variety and tuber size on shelf life of white yam (*Dioscorea rotundata* Poir). MPhil Thesis, Department of Crop Science, University of Ghana, 1–93.

**Echodu R, Edema H, Wokorach G, Zawedde C, Otim G, Luambano N, Ateka EM, Asiimwe T.** 2019. Farmers' practices and their knowledge of biotic constraints to sweetpotato production in East Africa. Physiological and Molecular Plant Pathology **105**, 3–16. https://doi.org/10.1016/j.pmpp.2018.07.004

**Edun BT, Lurwanu Y, Sunusi M, Aliyua RS.** 2019. Effect of storage methods and management of sweet potato on the incidence of tuber rot induced by *Rhizopus stolonifer* in Kano, Nigeria. Journal of Tropical Crop Science **6**(1).

**Frazier MJ, Kleinkopf GE, Brey RR, Olsen NL.** 2006. Potato sprout inhibition and tuber quality after treatment with high-energy ionizing radiation. American Journal of Potato Research **83**, 31–39.

**Giri K, Gurung S, Pokharel S, Karn R, Subedi AP.** 2020. Effect of different plant extracts on sprouting, storability and post-harvest loss of potato in Baglung district, Nepal. Malaysian Journal of Sustainable Agriculture **4**(1), 16–21. http://doi.org/10.26480/mjsa.01.2020.16.21

**Gwa VI, Richard IB.** 2018. Susceptibility of white yam (*Dioscorea rotundata* Poir) tuber to rot fungi and control with extracts of *Zingiber officinale* Rosc. *Azadirachta indica* **9**(9), 1–7. https://doi.org/10.4172/2157-7471.1000452

**Kou J, Zang X, Li M, Li W, Zhang H, Chen Y, Zhu G.** 2023. Effects of ethylene and 1-methylcyclopropene on the quality of sweet potato roots during storage: A review. Horticulturae **9**(6), 667.https://doi.org/10.3390/horticulturae9060667

**Kuyu CG, Tola YB, Abdi GG.** 2019. Study on post-harvest quantitative and qualitative losses of potato tubers from two different road access districts of Jimma zone, South West Ethiopia. Heliyon **5**(8), e02272.

**Linus B.** 2014. Evaluation of the efficacy of three organic extracts in controlling storage rot in sweet potato. Dissertation, Department of Horticulture, Kwame Nkrumah University of Science and Technology, 1–93.

**Nmom WF, Worlu WC, Churchill OT, Njoku C.** 2023. Antifungal effect of *Chromolaena odorata* leaf extract on some post-harvest fungal pathogens of sweet potatoes (*Ipomoea batatas* L.). World Journal of Pharmacy and Pharmaceutical Sciences **12**, 1–11. https://doi.org/10.20959/wjpps20234-24164

**Nwaogu AG, Obani FT, Iheanacho FN, Enyiukwu DN.** 2022. *In vitro* evaluation of aqueous leaf and peel extracts of *Musa* species for low-input management of fungal leaf spots of sweet potato (*Ipomea batatas* Linn.). Cropsaver **5**(1), 7–14. https://doi.org/10.24198/cropsaver.v5i1.39519

**Olaitan OO.** 2012. Bio-deterioration of sweet potato (*Ipomoea batatas* Lam) in storage, inoculation-induced quality changes, and control by modified atmosphere. Journal of Applied Sciences and Environmental Management **16**(2), 189–193.

**Otálora A, García-Quintero A, Mera-Erazo J, Lerma TA, Palencia M.** 2022. 'Sweet potato, batata or camote' (*Ipomoea batatas*): An overview about its crop, economic aspects and nutritional relevance. J. Sci. Technol. Appl. **100**, 1–10. https://doi.org/10.34294/j.jsta.24.17.100

**Paul NC, Park S, Liu H, Lee JG, Han GH, Kim H, Sang H.** 2021. Fungi associated with postharvest diseases of sweet potato storage roots and *in vitro* antagonistic assay of *Trichoderma harzianum* against the diseases. Journal of Fungi **7**(11), 927. https://doi.org/10.3390/jof7110927

**Picha DH.** 1985. Crude protein, minerals, and total carotenoids in sweet potatoes. Journal of Food Science **50**(6), 1768–1769. https://doi.org/10.1111/j.1365-2621.1985.tb10592.x

**Sapakhova Z, Raissova N, Daurov D, Zhapar K, Daurova A.** 2023. Sweet potato as a key crop for food security under the conditions of global climate change: A review. Plants **12**(13), 2516. https://doi.org/10.3390/plants12132516

**Scruggs AC, Quesada-Ocampo LM.** 2016. Cultural, chemical, and alternative control strategies for *Rhizopus* soft rot of sweetpotato. Plant Disease **100**(8), 1532–1540.

**Sisodia H, Rathore P.** 2023. Assessment of *Ocimum sanctum* extracts as an antifungal agent against *Aspergillus brasiliensis*. International Journal of Health Sciences Research **13**(6), 148–152. https://doi.org/10.52403/ijhsr.20230626

**Sugri I, Maalekuu BK, Kusi F, Gaveh E.** 2017. Quality and shelf-life of sweet potato as influenced by storage and postharvest treatments. Trends in Horticultural Research **7**(1), 1–10.

**Yang Y, Fang B, Feng S, Wang Z, Luo Z, Yao Z, Zou H, Huang L.** 2021. Isolation and identification of *Trichoderma asperellum*, the novel causal agent of green mold disease in sweetpotato. Plant Disease **105**(6), 1711–1718. https://doi.org/10.1094/PDIS-07-20-1484-RE

**Zhang J, Tian H, Zhan P, Du F, Zong A, Xu T.** 2018. Isolation and identification of phenolic compounds in Chinese purple yam and evaluation of antioxidant activity. LWT **96**, 161–165. https://doi.org/10.1016/j.lwt.2018.05.019

**Zhang M, Liu M, Pan S, Pan C, Li Y, Tian J.** 2018. Perillaldehyde controls postharvest black rot caused by *Ceratocystis fimbriata* in sweet potatoes. Frontiers in Microbiology **9**, 1102. https://doi.org/10.3389/fmicb.2018.01102