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Effectiveness of Selected Essential Oils in The Management of *Scutellonema Bradys* Infecting Stored Sweet Potato (*Ipomoea Batatas* L. (Lam.)

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Abstract

An experiment was carried out at the Faculty of Agriculture Central Laboratory, University of Ilorin, Ilorin, to assess the effects of selected essential oils (turmeric, clove, ginger, and lemon oils) against Scutellonema bradys infecting two stored sweet potato varieties (purple-fleshed and white-fleshed sweet potatoes). The essential oils were extracted using different solvent-based extraction methods. The experiment was laid out in a Completely Randomized Design (CRD) with four replications. Phytochemical screening was conducted to identify the bioactive constituents present in the oils. Data were collected on tuber rot, tuber appearance, and nematode population. Results showed that turmeric and ginger oils recorded the lowest nematode populations, ranging from 1.2–4.6 and 3.5–9.6, respectively, compared with the control (8.8–29.6) in purple-fleshed sweet potatoes. Phytochemical analysis revealed the presence of curcumin, phenols, eugenol, flavonoids, and other compounds that may be responsible for suppressing S. bradys. The study demonstrated that the essential oil treatments were effective in managing Scutellonema bradys in stored sweet potatoes and could serve as eco-friendly alternatives to synthetic nematicides.

Keywords: Sweet potato, essential oils, *Scutellonema bradys*, nematode control, phytochemicals

Introduction

Sweet potato (*Ipomoea batatas*) is a member of the family Convolvulaceae and a major staple crop that contributes significantly to food security, particularly in developing countries where hunger and malnutrition remain prevalent (Bach et al., 2021). It is widely cultivated in tropical and subtropical regions due to its adaptability to diverse environmental conditions and its low production cost. Owing to its high yield and nutritional value, sweet potato is ranked among the most important food crops globally (Sugri et al., 2017; Adewale & Abdulazeez, 2021).

Sweet potato is a tuberous-rooted perennial crop usually grown as an annual. It originated from Central America and is now cultivated worldwide. The crop exhibits wide varietal diversity, with root flesh colors ranging from white to purple and orange. Many plant parts, including roots, leaves, and vines, are edible and nutritionally valuable (Wadl et al., 2018; Amagloh et al., 2021). The crop also provides notable health benefits, including antioxidant, anti-inflammatory, and anti-diabetic properties (Alam, 2021).

Despite its importance, sweet potato is highly susceptible to postharvest losses caused by microbial pathogens and plant-parasitic nematodes during storage and marketing (Abrham et al., 2021). These losses result in deterioration of tuber quality, reduced shelf life, and significant economic losses, posing threats to food security and safety (Chakraborty et al., 2017).

Plant-parasitic nematodes such as *Scutellonema bradys* are among the major biological constraints affecting stored tubers. Conventional control methods, including synthetic nematicides, irradiation, and hydro-warming, have shown limited success and are often associated with environmental hazards, toxicity, and pathogen resistance (WHO, 2017; Phani et al., 2021). Consequently, attention has shifted toward the use of plant-based products as safer and sustainable alternatives (Van Staden et al., 2017).

Botanical pesticides derived from plant extracts and essential oils have gained considerable interest due to their nematicidal and antimicrobial properties (Prakash & Rao, 2018; Bernard et al., 2017). Several studies have demonstrated the effectiveness of ginger, citrus peel, and other plant extracts in suppressing nematode activity by inhibiting egg hatching and inducing mortality (Mzid et al., 2017; Atolani & Fabiyi, 2020).

Justification for the Study

Scutellonema bradys is a destructive pest of tuber crops, including sweet potato, causing substantial postharvest losses annually. The continuous use of synthetic nematicides has raised serious environmental and health concerns, while traditional cultural storage methods have proven ineffective in controlling nematode infestation. Therefore, the development of alternative, eco-friendly control measures such as essential oils is necessary. This study aimed to evaluate the nematicidal potential of selected essential oils against *S. bradys* in stored sweet potatoes.

Objectives of the Study

1. To determine the effectiveness of selected spice oils on the population of *Scutellonema bradys* in stored sweet potato.
2. To evaluate the bioactive constituents present in the essential oils.

Literature Review

Origin and Taxonomy of Sweet potato

Sweet potato (*Ipomoea batatas* L.) originated from Central America and is dispersed worldwide due to its high yield potential and wide adaptability (Muñoz-Rodríguez, *et al*., 2018). This plant belongs to the family of Convolvulaceae and is an important food crop which is widely grown in tropical, subtropical regions (Mu and Li 2019). Currently, there are over 6500 varieties of sweet potatoes worldwide and they are basically distinguished by storage roots, skin color, flesh color, and some, by their origin (Hayati and Anhar 2020).

Morphology

Sweet potato is a perennial plant mainly grown as an annual. The roots are adventitious, mostly located within the top 25 cm of the soil (Otálora *et al*., 2022).

Some of the roots produce elongated starchy tubers that vary largely in shape, color and texture depending on the variety. The flesh of the tubers can be white, yellow, orange and purple whereas their skin can be red, purple, brown or white. The stems are creeping slender vines, up to 4 m long (Hayati and Anhar 2020). The leaves are green or purplish, cordate, palmately veined, borne on long petioles. Sweet potato flowers are white or pale violet, axillary, sympetalous, solitary or in cymes. The fruits are round, 1-4 seeded pods containing flattened seeds. For the optimal development of the plant, it is recommended that the cultivation soil has a temperature between 15°C to 29°C, and the envir onment has a temperature variation between 24°C to 30°C (Chen *et al*., 2021).

Sweet potato production

Sweet potato (*Ipomea batatas* (L.) belongs to family Convolvulaceae, a resourceful an d appetizing vegetable which contains high nutritional value (Paul *et al.,* 2017). It was originated in Central America is now extensively cultivated and consumed throughout the world. China is the leading producer of sweet potato followed by Nigeria and Tanzania, Indonesia, and Uganda (Bhuyan *et al.,* 2022). The origin of this plant dates back to the New World, with some speculation of origin in Mexico or Venezuela. However, the exact origin of the sweet potato is unclear (Otálora *et al.,* 2023). Despite its origin in America, sweet potatoes are currently relevant as food in the daily diet of a large part of the population of developing countries in Asia, Africa, Latin America, and the Caribbean. Other countries such as the United States and some of the European Union and Oceania also use sweet potatoes as food (Otálora *et al*., 2022).

Furthermore, the sweet potato crop has important adaptive properties that facilitate its growth and cultivation by small farmers with low requirements and good yields (Chauhan *et al.,* 2021). This fact has allowed the sweet potato crop to be considered an income source and one of the food crops associated with food security in many regions, due to its good nutritional profile and relatively short cultivation time (Escobar Puentes et al., 2022). Likewise the importance of various parts of the plant in traditional medicine has been highlighted. In 2018, Africa contributed about 28% of global sweet potato production, with a harvested area of approximately 4.6 million hectares and a relatively low average yield of 5.6 tons per hectare (FAOSTAT, 2020). Sweet potatoes produce best in a well-drained, light, sandy loam or silt loam soil. Rich, heavy soils produce high yields of low-quality roots, and extremely poor, light sandy soils generally produce low yields of high-quality roots. Both surface and internal drainage are important in selecting a field (Cartabiano-Leite *et al.,* 2020). Poor surface drainage may cause wet spots that reduce yields. Poor internal drainage will also reduce yields. Soils with poor internal drainage are characterized by a high HLA-6022-2 moisture content and poor aeration, which cause sweet potato roots to be large, misshapen, cracked and rough skinned (Truong *et al.,* 2018). A three- to five-year rotation program should be used to reduce the chance of soil-borne disease problems. Sweet potatoes are tolerant of variations in soil pH between 5.5 and 6.8. However, the optimum soil pH for high yields of quality sweet potatoes is 5.8 to 6.0. Apply lime if soil pH is too low (Brandenberger *et al.,* 2017).

Economic importance of sweet potato

Sweet potatoes have fundamental importance as a staple food, used to supply the domestic market and widely used as a food supplement in the diet of several inhabitants (Truong *et al*., 2018).

According to data made available by the Food and Agriculture Organization (FAO), i n 2018, more than 91 million tons of sweet potatoes were produced worldwide, with a harvest area of around 8 million hectare, indicating that the global production of sweet potatoes showed an average yield of about 11 tons per hectare (Cartabiano-Leite *et al.,* 2020). Regarding the continents that produce sweet potatoes, the predominant component of sweet potato on a dry basis is starch, which can vary between 65% to 89% of the composit ion in different cultivars. Starch is a type of carbohydrate made up of glycosidic chains, whic h form two portions of polysaccharides called amylose and mylopectin. Starch is considered as the primary energy reserve of plants (Oyom *et al*., 2022). The sweet potato starch provides energy to the body, especially when the tuberous roots are subjected to cooking, as the starch chains are transformed into maltose which increases the glycemic index of this food (Hayati and Anhar 2020). Sweet potato leaves and branches also have several micronutrients and bioactive compounds. The physicochemical composition of the leaves reveals the presence of several nutrients such as vitamins and minerals, in addition to fibers and bioactive compounds. Sweet potato leaves are consumed as food, especially by inhabitants of countries in the African continent, Asia, and Pacific Ocean islands. The branches and leaves also have a suitable fermentation profile to be used in the production of silage for animal feed, evaluated the nutritional composition of leaves of 40 Chinese sweet potato cultivars and identified a high content of protein, sodium, potassium, and polyphenols (Shadung 2022). The high fibre content gives them a "slow burning" quality. It maintaining a low sodium intake is essential to lowering blood pressure. Rich in beta-carotene may play a protective role against prostate cancer. Sweet potatoes are a great source of B6 vitamins, which are breakdowns the homo cysteine compounds, a substance that contributes to the hardening of blood vessels and arteries. Consume sweet potatoes or extracts from sweet potatoes help to control blood glucose level (Herawati *et al.,* 2020).

The tremendous social relevance of sweet potatoes becomes evident when considering the nutritional requirement of the human being combined with the commitment to food production. Sweet potatoes are a convenient food to be used as a nutritional supplement in the diet of vulnerable people (Waseem *et al.,* 2023). The projects seek to promote improvements in the diet by encouraging the production and consumption of nutritious foods, which can prove to guarantee positive effects for the consumer's health. In this sense, sweet potato is a food capable of filling the deficiency of important nutrients for the maintenance of metabolism, as is the case of retinol, also known as vitamin A (Oyom *et al*., 2022).

Common varieties of sweet potato

i. Beauregard

Color: Purplish-red skins, deep orange flesh.
Flavor: Sweet.
Texture: Slightly stringy, juicy when cooked.
Best uses: Mashing and in baked goods and desserts (candied yams, biscuits).
This is the most common sweet potato variety in American. Beauregards have purplish-red skin and a deep orange interior (Su *et al.,* 2019). Their flesh is slightly stringier and juicier than some other varieties when cooked, so they're good for mashing and incorporating into baked goods and desserts. This early cultivar matures in 90 to 100 days and is resistant to streptomyces soil rot and fusarium wilt, but is susceptible to root-knot nematodes.

ii. Jewel

Color**:** Light orange skins, orange flesh.

Flavor**:** Lightly sweet.

Texture**:** Moist, watery.

Best uses**:** Boiling, baking, in casseroles.

Jewels have light orange skin, and are less intensely sweet than Beauregards, but can be used in many of the same recipes. These orange-fleshed sweet potatoes pack a lot of moisture, and take well to boiling, baking, and making into casseroles. Though they can get watery, jewels and Beauregards are both excellent all-purpose sweet potatoes. A mid-season semi-bush variety, this cultivar matures in 120 to 135 days.

iii. Garnet

Color*:* Dark orange-red skins, bright orange flesh.

Flavor**:** Sweet.

Texture**:** Moist.

Best uses**:** Mashing, baking.

They are recognized due to their dark orange-red skin, which conceals bright orange flesh (Elsharif *et al.,* 2020) They're even more moist than jewels or Beauregards, which makes them great for baking projects; they're our ideal sweet potato for pie, mashed sweet potato casserole, and nice and simple mashed sweet potatoes (Vagilidad *et al.,* 2020) In addition to being sweet and flavorful, they retain their lovely orange hue even after baking. Garnet' is ready for harvest 110 days after planting. . (Laura 2022).

iv. Hannah

Color: Light brown skins, white flesh.

Flavor: Sweet.

Texture**:** Dense, firm, creamy.

Best uses**:** Roasting, mashing.

White-fleshed sweet potatoes like the Hannah were some of the first to be farmed and eaten in America. Hannahs are dense, firm, and creamy, and much less prone to becoming waterlogged than orange sweet potatoes (Elsharif *et al.,* 2020). Their firmness and dense texture makes Hannah sweet potatoes ideal for roasting in chunks, turning into fries, or mashing as a side dish. Keep in mind that because these sweet potatoes are quite dense, they shouldn't be substituted in recipes that call for orange sweet potatoes, as the baking times and moisture levels won't line up. An early variety, 'Hannah' matures in about 110 days.

Plant-parasitic nematodes (PPNs)

Nematodes are recognized as important pathogens of agricultural crops worldwide. Annual global economic loss caused by PPNs is estimated to be at US$157 billion. This figure is most likely an underestimation, as most agricultural farmers are unaware of the existence of nematodes due to their microscopic nature and the more subtle effects of the widely occurring low level infestations (Coyne et al., 2018). The symptoms caused by nematode damage are also sometimes difficult to differentiate from those caused by other pathogens and thus, in the absence of nematology experts, such symptoms are conveniently attributed to the common and obvious fungal or bacterial causal agents (Coyne et al., 2018). Additionally, many PPNs do not cause total crop losses. However, the wounds inflicted on the roots during their feeding activity often provide pathways for entry of fungal and bacterial pathogens. PPNs may therefore act in synergy with other pathogens towards reducing crop quality, quantity and causing eventual yield loss (Karssen et al., 2013). Despite the difficulties in nematode damage diagnosis, severe crop losses have evidently been documented depending on nematode species. Plant parasitic nematodes (PPNs) are a serious menace to a variety of crop plants worldwide (Ali et al., 2017).

Morphology

Nematodes are simple, multi-cellular animals typically containing 1,000 cells or less (Hunt *et al.,* 2018). They are worm-like in appearance, but are taxonomically distinct from earthworms, wireworms or flatworms (Phani *et al.,* 2021). They are bilaterally symmetrical, soft-bodied (no skeleton), non-segmented round worms. Most nematode species that attack plants are microscopic (van den Berg *et al.,* 2017) . The basic body plan of a nematode is a "tube within a tube." Nematodes feed on other microorganisms and plants like bacteriovores, fungivores, omnivores, predators, and plant parasites. Some, however, are serious human, animal and plant pathogens (Talavera *et al.,* 2021).

Plant-parasitic nematodes occur in all sizes and shapes (Mitiku, 2018). The typical nematode shape is a long and slender worm-like animal, but often the adult animals are swollen and no longer even resemble worms. Plant-parasitic nematodes range from 250 um to 12 mm in length, averaging 1 mm, to about 15-35 um in width (Singh *et al.,* 2021). While nematodes may look dramatically different, they all share some common features. Nematodes often look segmented because of the numerous annulations (accordion-like transverse grooves) on the cuticle that allow the nematode to bend without kinking, but in fact nematodes are unsegmented and have no replication of body parts throughout the worm. Like higher animals nematodes possess bilateral symmetry, but with a superimposed trilateral and hexalateral symmetry (Kumar *et al.,* 2020). Developmentally, nematodes are triploblastic, containing three body layers (ectoderm, mesoderm and endoderm) in the embryo (Al-Banna *et al.,* 2021). Higher organisms are tripoblastic and have a coelom, a body cavity surrounded by mesoderm. Nematodes have a body cavity that is not totally surrounded by mesoderm, so they are pseudocoelomic (Bernard *et al.,* 2017).

Plant parasitic nematodes may attack the roots, stem, foliage and flowers of plants. All plant parasitic nematodes have piercing mouthparts called stylets (Hunt *et al.,* 2018). The presence of a stylet is the key diagnostic sign differentiating plant parasitic nematodes from all other types of nematodes (Palomares-Rius *et al.,* 2017).

Signs and Symptoms

Typical root symptoms indicating nematode attack are root knots or galls, root lesions, excessive root branching, injured root tips and stunted root systems. Symptoms on the above-ground plant parts indicating root infection are a slow decline of the entire plant (WHO, 2017), wilting even with ample soil moisture, foliage yellowing and fewer and smaller leaves (Feyisa, 2022). These are, in fact, the symptoms that would appear in plants deprived of a properly functioning root system. Symptoms of nematode infection on tubers included a scaly appearance, surface cracking as well as deeper tissue cracks, distortions, and darkened surface patches. In most cases these patches were related to sub-surface rot (Khan *et al.,* 2021).

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Dissemination

Parasitic nematodes are readily spread by any physical means that can move soil particles about equipment, tools, shoes, birds, insects, dust, wind and water. In addition, the movement of nematode-infested plants or plant parts will spread the parasites (Coyne *et al.,* 2018).

Life cycle of nematodes

The life cycles of most plant-parasitic nematodes are similar and start with an egg. The egg undergoes embryonic development resulting in a first-stage (J1) juvenile nematode (Choi *et al.,* 2017). Depending upon the nematode species, the J1 may hatch from the egg or molt within the egg, forming a second-stage juvenile (J2). The majority of plant-parasitic nematode species will hatch at the J2 stage. There are four juvenile developmental life stages (J1, J2, J3 and J4) that are separated by molting and conclude with an adult nematode (Mitiku, 2018). The complete life cycle from egg to egg requires three to six weeks depending on the nematode species, the soil temperatures and soil moisture. The reproductive potential of plant-parasitic nematodes in southeastern field crops is exponential, with multiple generations during the long growing season. Depending on the species, each nematode female can lay dozens to hundreds of eggs in her life span.

The life stage at which nematodes infect plants varies by nematode species. All juvenile stages, as well as the mature adult of the lesion and lance nematodes, are capable of infecting a crop's root system (Lu *et al.,* 2020). The lesion and lance nematodes are migratory and will feed from the inside of the root. The lesion nematode feeds on the root surface but will also enter the root and feed while migrating from cell to cell (Mandal *et al.,* 2021). The female lesion nematode lays eggs individually in the soil or in the root system as it feeds and moves through the root system. Once the eggs hatch, the juveniles start feeding. The female lance nematode lays its eggs individually in the soil as it migrates and feeds (El-Sappah *et al.,* 2022).

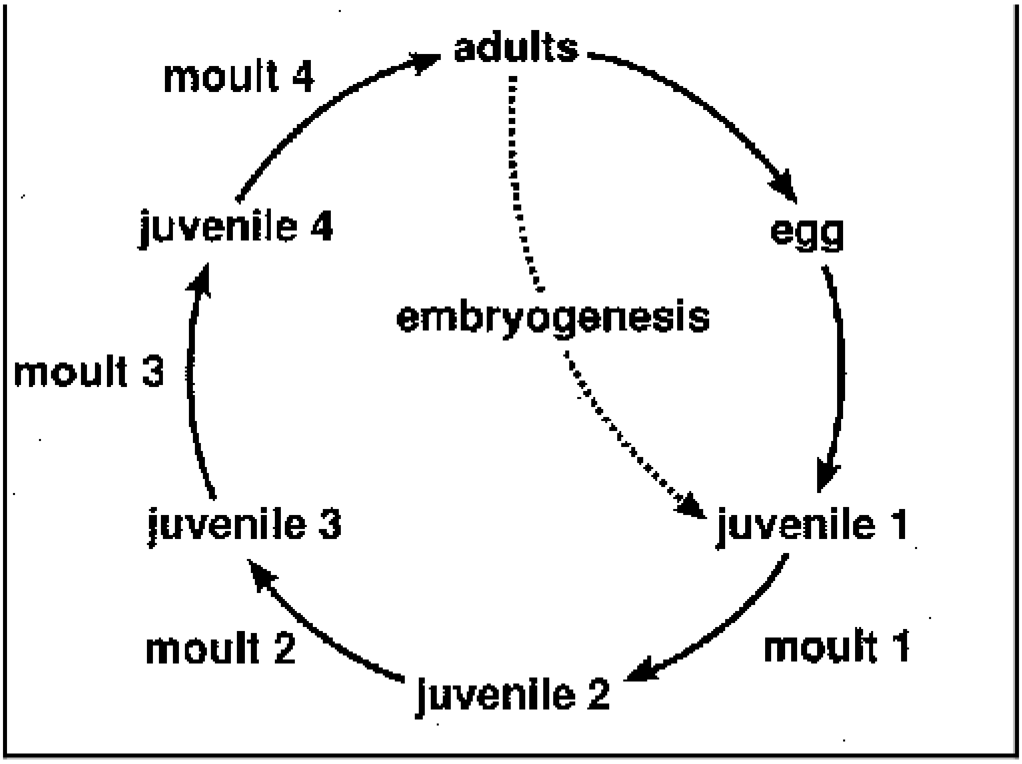

FIGURE 1: The life cycle of nematodes

Scutellonema bradys

This nematode is able to multiply in dry conditions causing complete rotting tubers, called dry rot, which decreases the commercial value of the tubers. Dry rots occur in the outer 1–2 cm of tubers (Afoha *et al.*, 2019). Symptoms of dry rot include necrotic lesions beneath the skin, followed by yellow lesions below the outer skin of the tuber. External cracks appear in the skin of the tuber (Etchiha Afoha *et al.,* 2018). The infections created by the nematode can serve as external opening facilitating fungi and bacteria colonization, causing wet rot. *Scutellonema bradys* feeds and reproduce in tubers stored after harvest. Infested tubers are greatly damaged as a result of the continued reproduction of nematode (Kolombia *et al*., 2017).

S. bradys belongs to the family Hoplolaimidae and is described as vermiform nematode when mature, measuring about 1 mm in length with a well-developed stylet. The stylet is rounded basal knobs with the anterior portion of the spear tapering towards the end of the front half of the spear length (Kolombia *et al.,* 2017).

Morphological Description

Males have a body shape similar to females. The testes are outstretched, and a large bursa enclosing the tail is clearly visible. Eggs are laid in soil or plant tissues, where they hatch, and juveniles develop into adults through successive moulting stages (Coyne et al., 2018).

Infection typically occurs through young tubers at the growing point, emerging roots and shoots, roots, or through cracks and damaged areas of the tuber skin (Jayaprakas et al., 2022). The nematode feeds intracellularly within tuber tissues, causing rupture of cell walls, loss of cell contents, and formation of cavities (Karssen et al., 2017).

The life cycle lasts approximately 21 days, and under favourable conditions, populations can increase rapidly. Population density is influenced by storage conditions, with tubers stored at 22–32 °C and 40–85% relative humidity showing population increases at twice the rate of those stored at 16–18 °C (Claudius-Cole, 2021).

Although yam is the primary host of *S. bradys*, other crops such as sweet potato (*Ipomoea batatas*), cowpea (*Vigna unguiculata*), sesame (*Sesamum indicum*), tomato (*Solanum lycopersicum*), and potato (*Solanum tuberosum*) have been reported to support nematode reproduction (De Almeida et al., 2019; Kolombia et al., 2017).

Plant-Parasitic Nematode Control

Control methods for plant-parasitic nematodes are broadly categorized into **biological**, **cultural**, and **chemical** control strategies (Bernard et al., 2017).

Biological Control

The most practical biological approach involves the use of nematode-resistant plant varieties (Bonsi et al., 2017). Resistance genes are incorporated into cultivated crops through plant breeding to enhance tolerance to nematodes (Moslehi et al., 2018). This method is cost-effective but time-consuming, as screening and breeding resistant varieties require several years (Akhter et al., 2018). Additionally, resistance sources are not available for all crops, and some nematode species can overcome plant resistance (Sanaa A. et al.). Despite these limitations, resistant varieties remain highly effective when available (Mandal et al., 2021; Mitiku, 2018).

Cultural Control Methods

Crop rotation is an effective strategy for reducing nematode populations, especially where host specificity exists, such as cyst nematodes in wheat and potatoes (Somvanshi, 2022). Susceptible crops should be rotated with non-host crops, while vegetables should be alternated with cereals to reduce root-knot nematode infestations (Charles, 2017).

Fallowing and deep ploughing during hot seasons expose nematodes to lethal heat and desiccation (Bernard et al., 2017; Kumar et al., 2019). Organic soil amendments such as compost, green manure, and oil cakes applied at 1–1.5 t/ha have also been shown to suppress nematode populations by enhancing natural enemies and releasing toxic decomposition products (Sasanelli et al., 2021; Mokrini et al., 2018).

Physical Control Methods

Soil heat treatment is commonly used to sterilize soil in nurseries and greenhouses (Singh et al., 2022). Methods include autoclaving, steam sterilization, dry heating, hot water treatment of planting materials, and soil solarization (Kumar et al., 2019; Sankari Meena et al., 2018; Zane J. Grabau, 2022). Other physical methods include irradiation, osmotic pressure, ultrasonic treatment, and electrical heating (Georgiadou et al., 2014).

Chemical Control

Nematicides remain widely used due to their rapid effectiveness and integration with other control methods (Chen et al., 2020). Their use dates back to the late 19th century, with fumigants such as carbon disulphide and methyl bromide dominating nematode control programs (Jones, 2017; Ntalli et al., 2017; Regmi et al., 2020).

Biological Methods

Biological control involves the use of biological control agents (BCAs) such as predators, parasites, pathogens, and antagonists (Stirling, 2018; Xiang et al., 2018). A wide range of organisms, including fungi, bacteria, viruses, and nematode antagonists, are known to suppress plant-parasitic nematodes (Ahmad et al., 2021).

Use of Botanicals and Essential Oils

Botanical pesticides and essential oils are environmentally friendly alternatives with minimal non-target effects (Prakash & Rao, 2018; Lengai et al., 2020). Extracts from various plant parts have shown nematicidal and nematostatic properties (Atolani et al., 2020; Mokrini et al., 2018; Mwamula et al., 2022).

Materials and Method

Materials used

Sweet potato *(ipomoea batatas),* spice oils, knife, weighing balance, syringe, petri-dish, paper tapes, serviette paper, specimen bottles**.**

Experimental site

The experiments were carried out at the Faculty of Agriculture Central laboratory, University of Ilorin, Ilorin, Nigeria.

Source of sweet potato

Fresh sweet potato tubers varieties were obtained from farmers at Alalubosa vegetable farm, Ilorin, Nigeria. The varieties obtained are; Beauregard (purple fleshed), Hannah (white fleshed)

Source of spice oil

Ginger rhizome, peel of lemon (*citrus sinesis*), turmeric rhizome and clove buds were obtained from Ipata market and taken to Chemistry Laboratory, Department of Chemistry, University of Ilorin, Ilorin, Nigeria for oil extraction.

Preparation and extraction of spice (oils)

Ginger oil

The fresh ginger roots were taken to the laboratory where, after cleaning, they were reduced to small pieces using a knife and oven-dried at 50°C for exactly 48 h. The dehydrated roots were reduced to powder and sieved using a 1 mm diameter sieve. About 200 g of sieved ginger was extracted with 800 ml of methanol using the maceration method. Samples were stirred during the extraction in view to optimize the extraction of phenolic compounds. After separation using the Whatman paper, the similar process was again repeated with ginger residues obtained from the previous extraction, but this time used 400 mL of solvent to make sure that the majority of the phenolic compounds were extracted. Upon filtration, both filtrates were mixed and vaporized under vacuum at 40°C using a rotatory evaporator. The dried extract was kept in the fridge at 4°C for analysis.

Lemon oil

1 kg of freshly peeled sweet orange (*citrus sinesis*) were placed into one liter round bottom flask containing 250 ml of distilled water. The flask were fitted with a rubber stopper attached to the condenser and heated. Water at 10ºc flowed counter-currently during the condenser to consider the ensuring steam. When the water temperature reached 100ºc it starts boiling ripping off the essential oil from the sweet orange. When the sweet orange got heated up, the essential oil than were extracted from the water vapor. Both passed through the condenser and the vapor condensed into a liquid. With the use of an ice block, cooling was prepared possible and volatilization of the essential oil was avoided. The condensate was openly collected using a 500 ml beaker and then poured into a separating funnel. This produced two layers of oil and water. The tap of separating funnel was opened to let out the water through the oil was immediately collected into a 100 ml bottle. The bottles were closed strongly to prevent vaporization of the essential oil. The sweet orange oil were collected and the volume of oil obtained also weighed

Clove oil

The clove buds were dried for 5 weeks then 1 kg of the dried bud was grounded into powdered sample. To carry out the hydro-distillation, the dried clove sample were placed into 500 ml volumetric flask and subjected to hydro-distillation for 4 – 6 hours. Subsequently the volatile distillate were collected and saturated with sodium chloride following the addition of petroleum ether (hexane). Later the hydro and ether layers are separated and dehydrated by using anhydrous sodium sulphate. Eventually, the sample is heated in water bath at 60ºc for the recovery of ether and concentration of extract**.**

Turmeric oil

A known amount (200gms) of turmeric plant rhizome, cut or chopped into smaller size (3-4 mm) or in powder form. Start the distillation process by adding water in rhizome and mix it in round bottom flask. Cover the round bottom flask and the set up with an air tight packing. Set the distillation timing minimum of 210 min using heater. At specific time and temperature the evaporation takes place. After the evaporation process, separate the oil from the solution and goes to the condenser. After condensation the oil and water both move to the container and then settle to the upper side. Due to less density, the essential oil floats on the water surface. Then it is sent to the separating funnel, here water gets removed from the funnel and oil get keep in bottle. Then store the product in an air tight container or store it in a glass or plastic bottle directly for use.

Experimental design and application of oils

The experiment was carried out using a Completely Randomized Design (CRD) with 4 replications each. 5 ml of each oils were smeared evenly on 1 kg of the sweet potato tubers except the control.

Nematode extraction procedures

The sweet potato tubers were gently peeled and macerated carefully. 100 g of the sample were used in the nematode extraction using the modified Baermann tray method. A plastic sieve was placed on a tray and a single ply of tissue (serviette paper) carefully placed in it. The samples were spread into the sieve followed by introduction of water at the base of sieve until the water submerged the samples. The set-ups were left for 48 hours for easy movement of the nematodes into the tray. Samples of the nematodes suspension were collected into a specimen bottles and left for few minutes to enable the nematodes settle. The excess water were carefully decanted. Two ml was withdrawn from the beaker using a syringe into the Petri-dish and the nematodes were observed under a stereoscopic microscope in the Crop Protection Laboratory.

Tuber scoring

The tubers were scored using Baimey *et al.,* 2009 ranging between (0-4) to determine the rate.

0- Clean tuber

1- Mild symptoms (1-25%)

2- Moderately symptoms (26- 50%)

3- Severe symptoms (51- 75%)

4- Highly severe symptoms (76 – 100%)

Data collected

The data were collected 2nd and 4th week after set-up. Data collected include tuber appearance, tuber rot and nematode population.

Data analysis

Differences in nematode population densities, tuber appearance and tuber rot between treatments were compared with ANOVA, using a descriptive scale of the SAS system according to Baimey *et al.,* 2009.

Results and Discussions

Table 1: Results shows the effect of spices oil on sweet potatoes tubers appearance and rot. Tubers treated with oils had lower symptoms value than their control counterpart. Amongst treated tubers, tubers treated with turmeric and ginger oil performed better in terms of tubers appearance and rot with values ranging from 0- 1for all the weeks respectively than other treatments. Purple fleshed sweet potatoes treated turmeric spice oil recorded lowest value as 0 for all the weeks, this was followed by purple fleshed sweet potatoes with values ranging from 0 – 1 of tubers appearance and rot. However, white fleshed sweet potatoes revealed highest range of symptoms from 1- 2 in all treated tubers. Untreated purple fleshed potatoes recorded lower range of symptoms on tubers appearance and rot as 2 – 3, meanwhile, untreated white fleshed potatoes recorded higher range of tubers appearance and rot as 2 – 4.

Figure 1: shows the results obtained from effect of spices oil on number of nematodes found in stored sweet potatoes. Tubers treated with oils had lower number of nematodes value than their control counterpart. Treated tubers with turmeric oil had the lowest number of nematodes with values ranging from 1.2-8.5, followed by ginger oil treated tubers with 3.5-9.6 nematode population for the two weeks than other treatments.

Purple fleshed sweet potatoes treated with turmeric spice oil recorded lower value of nematode population ranging from 1-4 for all the weeks. However, white fleshed sweet potatoes treated with turmeric revealed higher range of nematode population from 3-8 in all weeks. Untreated purple fleshed potatoes recorded lower range of nematode number as 8-20 meanwhile, untreated white fleshed potatoes recorded higher range of nematode population as 16-46.

Table 1: Effect of spices oil on stored sweet potatoes

Treatments &cultivars	Tubers Appearance		Tubers rot	
	2 weeks	4 weeks	2 weeks	4 weeks
Tup	0	0	0	0
Tuw	1	1	1	1
Gip	0	1	0	1
Giw	0	2	0	2
Clp	0	2	0	2
Clw	1	2	1	2
Lep	0	1	0	1
Lew	1	2	1	2
Cp	2	3	2	3
Cw	2	4	2	4

Table 1: Tubers were scored for scaly appearance, cracking and rot based on a scale of 0- 4,

Where 0= clean tuber, 1= mild symptoms (1-25%), 2= moderately symptoms (26- 50%), 3= severe symptoms (51- 75%), 4= highly severe symptoms (76 – 100%)

Key: Tup= Turmeric oil treated purple potatoes: Tuw= Turmeric treated white potatoes: Gip= Ginger oil treated purple potatoes: Giw= Ginger oil treated white potatoes: Clp= Clove oil treated purple potatoes: Clw= Clove oil treated white potatoes: Lep= Lemon oil treated purple potatoes: Lew= Lemon oil treated white potatoes: Cp = untreated purple potatoes: Cw= untreated white potatoes.

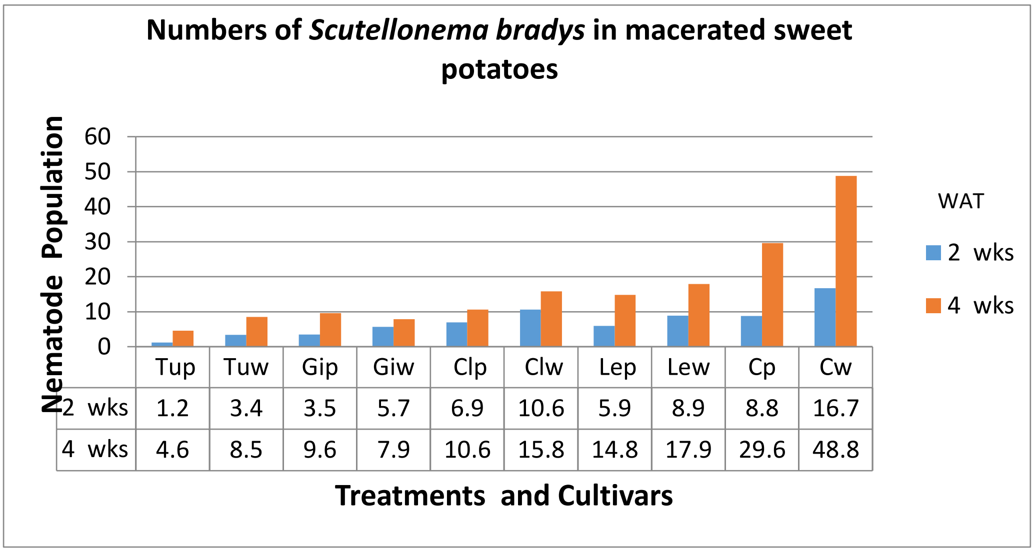

Figure 1: Effect of treatment oils on *Scutellonema bradys* population on stored sweet potatoes

Key: Tup= Turmeric oil treated purple potatoes: Tuw= Turmeric treated white potatoes: Gip= Ginger oil treated purple potatoes: Giw= Ginger oil treated white potatoes: Clp= Clove oil treated purple potatoes: Clw= Clove oil treated white potatoes: Lep= Lemon oil treated purple potatoes: Lew= Lemon oil treated white potatoes: Cp = untreated purple potatoes: Cw= untreated white potatoes.

Phytochemical analysis

The phytochemical constituents' presents in the essential oils includes curcumin (16.22%), flavonoids (6.89 %), phenols (10.41 %), tannin (3.27%), oxalates (0.97%), and limonene (11.30%). Curcumin, being the principal constituent present in turmeric oil is generally considered has its most active ingredient with anti-microbial properties. Eugenol present in clove oil with 79.26% composition is considered as its most volatile phenolic const ituents with and anti oxidant properties. Flavinoids present in ginger have inhibitory activity against disease causing organisms and possesses multiple bioactive properties.

Table 2. Phytochemical constituents present in the essential oil

Constituents	Turmeric oil	Clove oil	Ginger oil	Lemon oil
Curcumin	+	+	+	-
Limonene	-	-	-	+
Flavinoids	+	+	+	+
Phenols	+	+	+	+
Tannins	+	+	+	+
Oxalates	+	+	+	+
Eugenol	+	+	+	-
Triacetin	+	+	+	-
Caryophyllene	+	+	-	-
Saponin	+	+	+	+
Alkaloid	+	+	+	+
Zingiberene	+	-	+	-

Legend: + = present
- = absent

Scutellonema bradys are of adverse effect and highly destructive to stored sweet potato tubers. The effectiveness of spiced oils were evaluated and compared to the suppression of *S. bradys* in two varieties of sweet potato (purple fleshed and white fleshed potato). This study shows that the treated tubers performed significantly higher than the untreated ones i.e All treated tubers were effective on the actions of *Scutellonema bradys* compared with untreated tubers.

The significant reduction in appearance in sweet potato observed in the control treatment arises as a result of the negative effect of the nematode (*S. bradys*). However, turmeric and ginger oils has proven to be more effective than other treatments. The treated varieties pe rformed better than their untreated counterparts. It was observed that the turmeric and ginger oils have the lowest number of nematode count ranging from 1.2-4.6 and 3.5-9.6 than their control counterpart with value ranging from 8.8-29.6 as regards purple fleshed sweet potato. The two health promoting spices has displayed strong efficacy in the management of *S bradys* and reduction of complete rotting of sweet potatoes tubers as well retaining its market value. This study was in line with the work of Coyne et al., 2011, that reported the efficacy of ginger and turmeric essential oils for weed control and food crop production.

According to Maria and Maria, 2019 which stated that use of turmeric oils gave a promising results against crop tested and according to (Ibáñez and Blázquez 2019) that turmeric essential oils has been found to improve the shelf life of tomatoes and raw poultry milk. It has shown that toxic and fumigants activity against stored grain insects *Sitophilus oryzae* and *Rhyzopertha dominica* (Pandey *et al*., 2021). Ginger essential oils were also found to be effective against fungi such as *Aspergillus flavus* (Vitalini, *et al.,* 2023). The use of plant extracts has proven to be more efficient and economical (Gonelimali, *et al*., 2018) in reducing plant pathogen activities, increasing the shelf life of the produce and also maintaining their nutritional composition (Al-Aamri, *et al*., 2018).

The capability of the oils in the management acting as Nematostatic (inhibiting the movement of the nematodes) or as nematicides (causing mortality) might due the presence of Sesquiterpene hydrocarbons compounds which represented the main phytochemical group found in both essential oils. Eugenol present in clove oil has also shown excellent antimicrobial activity associated mainly with its antioxidant and anti-inflammatory activities (Marchese *et al.,* 2017).

Conclusions

Essential oils from ginger and turmeric, two health-promoting spices, were effective in the management of *Scutellonema bradys* infecting sweet potatoes. Purple fleshed sweet potatoes treated with turmeric oils recorded least scale value in appearances and rot of tubers as well as lowest number of nematodes.

Recommendations

This study has shown and proven how effective the application of essential oils as nematodes control. Therefore, the use of essential oils like turmeric oil, ginger oil, clove oil and lemon oil should be introduced and encouraged among farmers against the use of chemicals.

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