Plant Extracts for Postharvest Protection

Subjects: Agriculture, Dairy & Animal Science
Contributor: Kwanele Nxumalo

Various medicinal plant parts have different phytochemicals and antioxidants that can be used in crop protection and preservation. Extracts from plants such as Ruta chalepensis, Eucalyptus globulus, etc., have proven to be effective in controlling postharvest pathogens of horticultural crops and increased their shelf life when used as a substitute for synthetic chemicals. Furthermore, extracts from neem and other medicinal plants contain a predominant and insecticidal active ingredient. The application of medicinal plant extracts could be a useful alternative to synthetic chemicals in the postharvest protection and preservation of horticultural crops.

Keywords: natural preservatives ; indigenous knowledge ; food security ; quality degradation ; economic losses

1. Introduction

Medicinal plants have been the basis of the treatment of various diseases in African traditional medicine and other forms of treatment from diverse cultures of the world [1][2][3]. Despite the well-documented ethnobotanical literature, very little scientific information is available on the efficacy and phytochemistry of indigenous medicinal plants and plant extracts in postharvest protection and preservation of horticultural crops [4][5]. In contrast with countries such as China and India, the use of medicinal plants and plant extracts in Africa is greatly underdeveloped for crop protection and preservation [2][3]. Countries such as China, India, Japan, Brazil, Mexico, South Africa, Kenya, Morocco, Tunisia and Egypt are major international role players in the production and export of fresh produce globally [6]. However, these horticultural crops are highly perishable and do experience various physiological and biochemical changes which lead to the development of undesirable physiological disorders and quality degradation, leading to major economic losses [7][8][9]. Fungal infections are the major causes of postharvest losses of fresh fruits and vegetables either in transit or storage [10]. They cause significant economic losses in the commercialization phase and are rendered unfit for human consumption [7][8][9][10].

About one-third of the food produced in the world per year for human consumption is lost or wasted [11]. In Africa, postharvest losses of fruit and vegetables could be as high as 70%, while the global quantitative food losses and wastes during the year are around 40–50% for fruits and vegetables only [12]. Every year, consumers in developed countries lose almost as much food (over 220 million tons) as the total net food production in sub-Saharan Africa (around 230 million tons) [13]. Not only are losses a waste of food, but they also represent a similar waste of human effort, farm inputs, livelihoods, investments and scarce resources such as water [13][14]. Some of the major causes of these postharvest losses are physical damage, poor handling, transportation and storage, poor packaging, postharvest pathogens (*Rhizoctonia solani*, *Alternaria alternata*, *Colletotrichum gloeosporioid*, *Penicillium digitatum* and *Botrytis cineria*) and senescence [11][12]. The horticulture industry relies on the use of capital-intensive technologies during the postharvest phase of production and fungicides are also applied to reduce the losses due to postharvest diseases or decay [15][16][17]. However, there is a growing global concern about the use of fungicides. The use of synthetic chemicals is becoming increasingly restricted locally and internationally due to health concerns and consumers' requests for safe and sustainable natural alternatives. As a result, the commercial success of the horticulture industry is threatened [10][11][18][19].

Crop protection and preservation are central entities in global food sustainability and security [20][21]. Several methods of preservation have successfully prohibited food waste caused by insect infestation, environmental conditions and microbial attacks [20][21]. However, studies have revealed vast health issues relating to applications of synthetic pesticides and preservatives in crop protection and preservation [22]. This has prompted the exploration of safe and cost-effective constituents without harmful or detrimental effects to the health of consumers and the environment at large [23]. Natural preservatives and pesticides have been formulated and applied in food, pharmaceutical and agrochemical industries [23][24][25][26].

A wide range of phytochemicals such as alkaloids, cyanogenic glycosides, phenylpropanoids, polyketides, anthocyanins, carbohydrates, amino acids, lipids, nucleic acids, terpenoids, flavonoids, phenols, saponins and tannins found in most medicinal plants are essential materials in the production of several pesticides and fungicides that can be helpful in crop protection and preservation of horticultural crops [2][27][28][29][30]. For example, the antimicrobial and antioxidant properties of the medicinal plant extracts have been attributed but not limited to phytochemicals such as citral, aspilactonol B and 8-methyl-6-prenylquercetin found in *Cymbopogon citratus* [31], fukugetin and fukugiside found in *Geophagus brasiliensis* [31] and carnosic acid, carnosol and rosmanol found in *Lepidium meyenii* [32]. Therefore, there is a need to undertake different phytochemical analysis (active ingredients, nutritional and mineral content), biological activities (e.g., antimicrobial, anti-inflammatory and antioxidant) and safety evaluation (cytotoxicity and genotoxicity) of medicinal plants as a substitute for synthetic pesticides and fungicides to be used in protection and preservation of horticultural crops [4][33][34].

Regular monitoring of the pest population dynamics in agroecosystems can reveal the economic losses and importance of a particular pest which can be mitigated by medicinal plant extracts [35][36]. Despite the relatively low rates of expansion of botanically based pesticides, regulatory changes in many parts of the world are driving a renaissance for the development of new natural pest control products that are safer for human health and the environment [37][38]. Therefore, botanical pesticides can help provide new ideas for the development of new pest management products [39][40]. Hundreds of indigenous and exotic species with insecticidal properties have been reported around the world through various farmer surveys and subsequent research, many of which have been confirmed to be active against a wide range of arthropod pests [39][40]. On-farm use of insecticidal plants, particularly among resource-poor smallholder farmers, is widespread and familiar to many African and Asian farmers [38][39][40].

By 2015, more than 400,000 plant species had been identified, a majority of which are flowering plants (369,000), and each year nearly 2000 others are discovered [41][42]. These plants produce a needed wide range of primary and secondary metabolites that have antibacterial and antifungal properties [43][44][45]. Several medicinal plant extracts such as neem (*Azadirachta indica*) leaf extract [46], turmeric (*Curcuma longa*) leaves [47] and lemongrass extracts (*Cymbopogon citratus*) [48] have been successfully applied as fungicides. The activity of neem leaf extract can be attributed to the presence of compounds such as dibutyl phthalate, phytol, nonanoic acid, tritriacontane and 1,2-benzenedicarboxylic acid in the crude extracts [46]. Studies have shown that some plants produced secondary metabolites, such as essential oils and volatile compounds that can have a biocidal action against postharvest pathogens [49][50]. Commercial products of natural fungicides such as rosemary oil, neem oil, *Aloe vera* gel (AVG), tea tree oil and jojoba oil, among many others, are now used in crop protection and preservation as fungicides [51][52][53], while commercial natural insecticides include nicotine and pyrethrum, amongst others [54][55]. Medicinal plant extracts could be a useful alternative to synthetic fungicides in the control of rot fungi when handling fruits and vegetables after harvest.

2. The Renaissance of Medicinal Plants as Antimicrobial Agents in Postharvest Preservation

The possibility to control many postharvest pathogens using medicinal plants has been investigated on a wide range of horticultural crops [56][57]. In modern agriculture, the application of synthetic fungicides remains the most effective and common method to control postharvest rot of horticultural crops [57][58]. However, increasing requests by consumers for fresh produce that is free of fungicide residues has contributed to the interest of researchers in the development of alternative methods for controlling postharvest decay of fresh produce [59][60]. Increasing health hazards such as the development of cancer, infertility and effects in the offspring of pregnant women caused by the application of postharvest fungicides have led to their restriction in some commodities or total ban in organic agriculture [61][62]. In the last 10 years, the Pesticide Action Network International has banned the use of many highly hazardous pesticides for use in agriculture (Table 1).

Table 1. Pesticide Action Network (PAN) International selected list of highly hazardous pesticides (2021) for use in agriculture in the last 10 years [62].

Chemical	Application	Classification of Pesticides	Year of Ban
1,2-dibromoethane	**It is used as a soil fumigant to control nematodes and other soil pests in crops such as vegetables, ornamentals, pineapples and tobacco**	**Classified as a probable carcinogen by the US EPA**	**2010**
Ethylene dibromide	**It is used as a fumigant to protect against insects, pests and nematodes in citrus, vegetable and grain crops**	**Classified as a probable carcinogen by the US EPA**	**2010**

Chemical	Application	Classification of Pesticides	Year of Ban
Hydrogen cyanide	It is used in the treatment of citrus and other fruits for the control of scale insect and thrips, in quarantine treatments of bananas, pineapple and other commodities for the control of aphids, mealybugs and other exposed insects. It is also used in a vacuum treatment for bulbs, rhizomes, tubers, asparagus roots and strawberry plants to control certain mites and nematodes	Classified as "fatal if inhaled" (H330) according to the EU GHS.	2010
Lindane	An insecticide used to control a broad spectrum of insects in fruits and vegetables	Classified in several categories, and in 2018, IARC classified it as "Carcinogenic to humans"	2010
Metaflumizone	It is used to control the diamondback moth on Brassica leafy vegetables	Is very persistent in the water-sediment environment and the bio-concentration factor is over 5000. It is classified as P = Persistent and B = Bio-accumulative	2010
Noviflumuron	Prevents the successful molting and development of subterranean termites and eventually eliminates the colony that can cause damage to fruit tree plantations	Classified as a probable carcinogen by US EPA Annual Cancer Report and classified as WHO Class 1a	2010
Vinclozolin	It is used to control blights, rots and molds in vineyards and on raspberries, lettuce, kiwi, snap beans and onions. It is also used to protect crops against *Botrytis cinerea* and *Sclerotinia sclerotiorum*	Classified as a reproductive toxicant and endocrine disruptor	2010
Cyproconazole	It is used to control powdery mildew in cucurbits, rust on cereals and apple scab	Classified as presumed human reproductive toxicant according to EU GHS	2011
Spirodiclofen	It is used as an acaricide and insecticide on citrus, grapes, pome fruit, stone fruit and tree nut crops	Classified as a probable carcinogen by the US EPA and is now also classified as "Carc 1B" by the EU GHS	2011
Ethiofencarb	It is used as an insecticide in controlling aphids on hard and soft fruits and some vegetables	Classified as WHO Class 1b	2012
Methomyl	It is used as a broad-spectrum insecticide that inhibits cholinesterase activity. It is used in vegetables, fruit crops, cereals and orchard crops for the control of a wide range of insect species	Classified as WHO Class 1b	2015
Diquat	It is used for pre-emergence weed control on the potato and also to defoliate seed or root crops for pre-harvest desiccation	Classified as a probable carcinogen by the US EPA and is now also classified as "Carc 1B" by the EU GHS	2016
Flumioxazin	It is used as a herbicide for pre- and post-emergence control of susceptible weeds on fruit orchards, vegetables and other field crops	Classified as a reproductive toxicant	2016
Flupyradifurone	It is used to prevent sucking insects such as aphids, leafhopper, whitefly and *Lygus sp.* on citrus, pome and stone fruits, tree nuts, grapes, coffee, cocoa and leafy vegetables	Highly toxic to honey bees (oral LD_{50}) and aquatic life	2016
Malathion	It is used to control aphids, red spider mites, mealybugs, thrips, scales and whiteflies on ornamentals, fruits and vegetables	Classified as a probable carcinogen by the US EPA and is now also classified as "Carc 1B" by the EU GHS	2016
Maneb	It is ethylene (bis) dithiocarbamate fungicide used in the control of early and late blights on potatoes and tomatoes and many other diseases of fruits, vegetables, field crops and ornamentals	Classified as an endocrine disruptor	2016
Pymetrozine	It is used to control aphids, brown planthopper and whiteflies in field vegetables, ornamentals, deciduous fruit and citrus	Classified as a probable carcinogen by the US EPA and is now also classified as "Carc 1B" by the EU GHS	2016

Chemical	Application	Classification of Pesticides	Year of Ban
Quizalofop-p-tefuryl	**Used as a selective post-emergence control of annual and perennial grass weeds in potatoes, soya beans, sugar beet, peanuts, oilseed rape, sunflowers, vegetables, cotton and flax.**	**Classified as an endocrine disruptor (EDC)**	**2016**
Thiram	**It is used to control stem gall of coriander, damping-off on allium crops and neck-rot of onion**	**Classified as toxic to aquatic zooplanktons**	**2016**
Zineb	**It is used as a broad-spectrum fungicide to control the scab in apples and pears, leaf curl in peaches and anthracnose and early blight in tomatoes**	**Classified as an endocrine disruptor**	**2016**
Ziram	**It is used as a broad-spectrum-use fungicide to control scab in apples and pears, leaf curl in peaches and anthracnose and early blight in tomatoes, controlling leaf blight and scab in almonds, shot-hole in apricots, brown rot and leaf spot in cherries, scab and anthracnose in pecans and leaf spot, rust and powdery mildew in ornamentals**	**Toxic to aquatic zooplanktons**	**2016**
Propiconazole	**In bananas, it is used to control *Mycosphaerella musicola* and *Mycosphaerella fijiensis* var. *difformis*; in coffee, it is used against *Hemileia vastatrix*; in stone fruits, it is used against *Monilinia* spp., *Podosphaera* spp., *Sphaerotheca* spp. and *Tranzschelia* spp.; soft rot on stone fruits**	**Classified as presumed human reproductive toxicant according to EU GHS**	**2018**
Propineb	**It is used to control apple scab, leaf and fruit spots on pomegranate, control chili die-back and buckeye rot on tomato**	**Classified as a probable carcinogen by the US EPA Annual Cancer Report**	**2018**

The most commonly used fungicides in postharvest preservation of horticultural crops are azoxystrobin, fludioxonil, imazalil, pyrimethanil and thiabendazole, which are synthetic compounds with different modes of action that can be applied either in waxes or water [63][64]. However, the overuse of fungicides and pesticides in agriculture is now a public concern because of the harmful potential these substances have in the environment, and the food chain represents a risk for human health [61][62]. Moreover, the overuse of these synthetic fungicides has resulted in the emergence of resistant strains of pathogens and this has become a major global problem because the frequency of mutant phenotypes in the populations is high [65][66]. Some of these fungicides are suspended because of their high toxicity, and there is increased pressure on the food value chain to either remove these agents or to adopt natural alternatives for the maintenance or extension of a product's shelf life [67]. Such obstacles provide new opportunities for those seeking natural alternatives for new preservatives to be applied on horticultural crops. The control of postharvest diseases in fruits and vegetables using synthetic chemicals is associated with several hazardous effects (Table 2).

Table 2. Common control of postharvest diseases in fruits and vegetables using synthetic chemicals and their hazardous effect on human health.

Disease	Crop Affected	Symptoms	Control	Reference	Hazardous Effect According to PAN [62]
Anthracnose	**Apples**	**Black spots appear on skin of the affected fruits which gradually become sunken and coalesce.**	**Before storage, treat with hot water (50–55 °C) for 15 min or dip in benomyl solution (500 ppm) or thiobendazole (1000 ppm) for 5 min.**	**[68]**	**Can affect the reproductive system in males**
Stem end rot	**Avocado**	**The affected area enlarges to form a circular, black patch around the base of the pedicel. The pulp becomes brown and softer during storage.**	**Prune and destroy infected twigs and spray carbendazim or thiophanate methyl (0.1%) or chlorathalonil (0.2%) on a fortnightly interval during the rainy season.**	**[69]**	**Can cause infertility and destroy the testicles**

Disease	Crop Affected	Symptoms	Control	Reference	Hazardous Effect According to PAN [62]
Soft-rot	Potato	Young spots start from the stem end of the fruit as light brown watery rot. As the fruit ripens, area of the rotting increases, and the skin becomes wrinkled. A peculiar musty odour is later emitted.	Careful handling of potatoes without causing any wounds and dipping the potatoes in aureofungin-sol at 500 ppm for 20 min to control infection in storage.	[70]	Highly carcinogenic
Bitter-rot	Apple	Faint, light brown discolouration beneath the skin develops. The discolouration expands in a cone shape. The circular, rough lesions become depressed. Pink masses of spores are found arranged in defined rings.	Treatment with mancozeb to check the disease in storage.	[71]	Has detrimental effects on the nervous system and should be used with caution.
Alternaria rot	Stone fruits	Alternaria rot is characterized by circular, dry, firm, shallow lesions covered with dark, olive green to black surface mycelial growth. The infected tissue is brown, such as that caused by brown rot.	Postharvest sprays with imazalil, azoxystrobin, fludioxonil or mixtures of these may provide control.	[72]	Can cause developmental effects in the offspring of pregnant women
Botrytis rot	Brinjal	The fruits show water-soaked and softened tissue. The water-soaked spots are irregular in shape and are approximately 25 mm in diameter. The fungus that develops on the surface of the fruit shows a dark grey growth.	A pre-harvest spray of pyraclostrobin or fludioxonil will give some control.	[73]	Can cause eye injury and skin irritation
Rhizopus stolonifer	Banana	The infection starts as a circular tan area around an island of fruit. The skin will slip off from the flesh if you put slight pressure on it. Next, the fluffy white growth of the fungus becomes visible near the centre and rapidly colonizes the whole area.	Use postharvest fungicides such as benomyl, fenbuconazole and fludioxonil.	[74]	Longer exposure can result in severe liver damage
Penicillium italicum	Citrus	Early symptoms include a soft water-soaked area on the peel, followed by the development of a circular colony of white mould. Bluish asexual spores (conidia) form at the centre of the colony, surrounded by a broad band of white mycelium. The fruit rapidly spoils and collapses, with sporulation sometimes occurring internally.	Add sodium bicarbonate to either imazalil, thiabendazole, pyrimethanil or fludioxonil for improved performance.	[75]	Exposure to these chemicals can have negative effects on the respiratory system and they are known to be a carcinogen
Penicillium digitatum Sacc.	Citrus	Symptoms include a soft water-soaked area on the peel, followed by the development of a circular colony of white mould, up to 4 cm in diameter. Green asexual spores (conidia) form at the centre of the colony, surrounded by a broad band of white mycelium.	Add sodium bicarbonate to either imazalil, thiabendazole, pyrimethanil, or fludioxonil for improved performance.	[75]	Exposure to these chemicals can have negative effects on the respiratory system and they are known to be a carcinogen
Brown-rot	Stone and pome fruits	The infection of the fruit usually occurs as the fruit approaches full ripeness. A rapidly spreading firm brown rot develops, and the fungus produces masses of fawn-coloured spores often in concentric zones. Infected fruit shrivels to a ‘mummy’. Brown rotted fruit in cold storage appear black and there may be no signs of sporulation	Spray with fungicides such as Merivon, Luna Sensation and Fontelis.	[76]	Highly toxic to beneficial insects such as bees

Disease	Crop Affected	Symptoms	Control	Reference	Hazardous Effect According to PAN [62]
Sour-rot	**Citrus**	**Lesions often occur near the stem-end scar, are water-soaked and may have a white scummy growth in the cracks. The odour of these lesions is distinctive and is similar to that produced by lactic acid bacteria**	**The use of guazatine is effective in controlling this disease, while SOPP results in some protection.**	[75]	**Can cause skin cancer**

The international community has taken several important initiatives to protect the environment and people's health from chemicals. These include the Montreal Protocol on the protection of the ozone layer, the Basel Convention on the Transboundary Movement of Hazardous Wastes, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, the Stockholm Convention on Persistent Organic Pollutants and the Strategic Approach to International Chemicals Management [62]. Initiatives are being led by governments and non-governmental organisations (NGOs) for improving pesticide and crop protection policies towards safer, socially just, environmentally sustainable and economically viable pest management systems [61][62].

Medicinal plants have been used for thousands of years to treat human health disorders and prevent diseases. These medicinal plants have bioactive compounds that can be considered as good alternatives to synthetic antimicrobial and antioxidant preservatives in horticultural crops [77][78][79][80]. Results from several publications in the last two decades show that compounds derived from plants and their antimicrobial and antioxidant capacity tested both in vitro and in vivo gave positive results and are a viable alternative to the use of synthetic chemicals [2][15][81][82].

3. Medicinal Plant Extracts against Pathogens in Horticultural Crops

Although there is an array of indigenous floras in tropical, semi-arid and humid regions currently used worldwide for human medical or treatments, only a few of them have been studied for their use in protecting horticultural crops against pathogen infection [83]. Indigenous knowledge has already identified medicinal plant extracts as traditional means to control plant diseases [77][80]. The application of these medicinal plant extracts in controlling postharvest pathogens of horticultural crops has become an important field of study [78]. The family of higher plants and shrubs, particularly, tropical flora, has been shown to provide a potential source of naturally produced inhibitory chemicals [77]. The natural product of medicinal plant extracts such as volatile chemicals, essential oils and phenolic compounds has been applied successfully to control postharvest diseases of stored fruits and vegetables [84][85][86]. Documented medicinal plant extracts for use in indigenous knowledge (IK) or used in the modern day as alternatives for synthetic chemicals for crop protection and preservation are summarised in Table 3 and Table 4.

Table 3. List of commonly used medicinal plant extracts used as pesticides.

Plant Name	Country of Origin	Plant Part Used	Focus of the Study	Treatment Application	Key Findings	Reference
Azadiracta indica	**India**	**Aqueous leaf extracts**	**To control *Pieris brassicae* on cabbages**	**Aqueous concentration (10, 5, 2.5 and 1.0%) were sprayed on cabbage foliage.**	**At 5%, had an anti-feedant of 82.5%. The anti-feedant effect of the different concentrations decreased with a decrease in concentration.**	[87]

Plant Name	Country of Origin	Plant Part Used	Focus of the Study	Treatment Application	Key Findings	Reference
Azadiracta indica	India	Kernel aqueous extract	Control red slug caterpillar on tea plants	Tea leaves were sprayed with different neem kernel aqueous extract (NKAE) concentrations at 2, 4, 6 and 8%.	The anti-feedant activity was in ascending order with an increase in concentrations. The leaf area consumed was highest at 1158.6 + 254.79 cm^2 at 2% concentration in 5th instar, and it was lowest at 8% concentration in the 1st instar larva as 92.2 cm^2. The anti-feedant of 87.5% over control was attained in 3rd instar larva at 8% concentration, while it was lowest as 22.74% in the 2nd instar larva at 2% concentration.	[37]
Bobgunnia madagascariensis	Senegal	Dried pods	Aqueous extracts dried pods in controlling ladybird beetle on *Brassica napus*	Aqueous extracts applied separately at 5, 10, 15, 20 and 25% *w*/*v* under laboratory conditions. The mortality of *H. variegata* was recorded 24, 48 and 72 h post-exposure.	*B. madagascariensis* (25% *w*/*v*) caused the highest mortality (90%).	[88]
Lippia javanica	Botswana	The essential oil of leaves	To control *F. gramenearum* in sweet corn	The bioassays were carried out at concentrations of 0.87, 0.65, 0.43, 0.22, 0.11, 0.054 and 0.027 mg mL^{-1} (essential oil mL^{-1}).	The maximum antifungal activity was recorded from the concentration of 0.87 g mL-, and the least activity was recorded for the least concentration of 0.027 g mL-. After the 3rd day, the inhibition zone for 0.87 g/mL was larger (25.00 mm) while 0.027 g/mL had the smallest inhibition zone (3.33 mm). After 14 days, 0.87 g/mL had an inhibition zone of 7 mm while 0.027 g/mL had 0 mm.	[89]
Lippia javanica	Botswana	Leaf powder	Control mustard rape aphids and tomato spider mites on tomatoes	Plant extracts from leaf powder at 12.5% *w*/*v* were mixed with 0.1% *v*/*v* soap. The treatments were applied 24 h post mixing the plant materials with water at a rate of 1 L on an area of 5 m^2 using a knapsack sprayer fitted with a hollow cone spray nozzle.	Plant extracts from leaf powder at 12.5% *w*/*v* using 0.1% *v*/*v* soap can be used against rape aphids and tomato spider mites. *L. javanica* at 12.5% reduced aphids by 83% and 75.9% tomato mites.	[90]
Melia azedarach	India	Aqueous leaf extracts	Control *Pieris brassicae* on cabbages	Aqueous concentration (10, 5, 2.5 and 1.0%) was sprayed on cabbage foliage.	At 5%, had an anti-feedant of 88.3%. The anti-feedant effect of the different concentrations decreased with a decrease in concentration.	[87]

Plant Name	Country of Origin	Plant Part Used	Focus of the Study	Treatment Application	Key Findings	Reference
Melia azedarach	**India**	**Leaves plant powder**	**To control cucumber pests**	**Crushed fruits of *M. azedarach*, were tested at the rates of 30 and 60 g kg^{-1},**	**All the concentrations were effective in controlling 90% of pests than the control**	[91]
Solanum incanum	**Madagascar**	**Fruits were used as a paste**	**To control cabbage aphids**	**Bitter apple extract (BA) was mixed with distilled water to obtain BA fruit concentrations (30, 60 and 90 mL L^{-1}) The treatments were mixed with 3, 6 and 12 g of sugar, respectively.**	**The concentration of 90 mL L^{-1} had the highest mortality of cabbage aphids, and the cabbages had a good appearance.**	
Solanum incanum	**Madagascar**	**Aqueous crude fruit sap extract**	**To control green peach aphids (*Myzus persicae*) on kale**	**Kale was routinely sprayed with 10, 25, 50 and 75% *S. incanum* extract.**	**The crude extract was effective in controlling the green peach aphids. The order of the insecticidal activity of the four different concentrations was 75 > 50 > 25 > 10%.**	[92]
Solanum incanum	**Madagascar**	**Leaf powder**	**To control mustard rape aphids and tomato spider mites on tomatoes**	**Plant extracts from leaf powder at 12.5% *w*/*v* were mixed with 0.1% *v*/*v* soap. The treatments were applied 24 h post mixing the plant materials with water at a rate of one liter on an area of 5 m^2 using a knapsack sprayer fitted with a hollow cone spray nozzle.**	**Plant extracts from leaf powder at 12.5% *w*/*v* using 0.1% *v*/*v* soap can be used against rape aphids and tomato spider mites. *Solanum delagoense* (25%) reduced aphids and mites by 86.5% and 75%, respectively.**	[90]
Solanum incanum	**Madagascar**	**An aqueous crude fruit extract**	**To control ladybird beetle on *Brassica napus***	**Concentration extracts at 5, 10, 15, 20 and 25% were applied by spraying *Brassica napus* plants under greenhouse conditions.**	**Concentration extracts at 25% caused the highest mortality of 80% on collected dead ladybird beetles.**	[88]
Tephrosia vogelii	**Zimbabwe**	**Leaf extracts**	**Control green bean aphids**	**Leaf extracts were made at three different concentrations (0.5%, 2% and 5% *w*/*v*).**	***T. vogeii* at 5% *w*/*v* reduced aphid infestation by 60%, while control reduced pest infestation by 27%. This resulted in 5% *T. vogeii* having yield of 1100 kg/ha compared to 190 kg/ha of the control.**	[93]

Table 4. List of selected medicinal plant extracts used for antimicrobial (antifungal).

Plant Name	Country of Origin	Plant Part Used	Focus of the Study	Treatment Application	Key Findings	Reference
Acorus calamus	**China**	**Root**	**Control banana fruit crown rot**	**Evaluation of plant extracts at various concentrations (1%, 5%, 10%, 25% and 50%) against *C. musae* was carried out by the 'poisoned food technique'. The banana fruits were then dipped in plant extracts for 5 min and allowed to air dry for 6 h. Banana hands dipped in chemical benomyl (0.1%) served as positive control while distilled water was used as a negative control. One group was incubated at room temperature (28 ± 2 °C), and another group was held in low-temperature storage (14 °C and 90% RH) conditions.**	**Extracts of *A. calamus* (50%) significantly reduced crown-rot disease by up to 75% at room temperature (12 d of incubation) and up to 85% at cold storage (35 d of incubation) conditions.**	[94]
Allium cepa* × *Allium sativum	**Croatia**	**Leaves**	**Control banana fruit crown rot**	**Evaluation of plant extracts at various concentrations (1%, 5%, 10%, 25% and 50% concentration) against *C. musae* was carried out by the 'poisoned food technique'. The banana fruits were then dipped in plant extracts (at 25% concentration) for 5 min and allowed to air dry for 6 h. Banana hands dipped in chemical benomyl (0.1%) served as positive control while distilled water was used as a negative control. One group was incubated at room temperature (28 ± 2 °C), and another group was held in low-temperature storage (14 °C and 90% RH) conditions.**	**The dipping of banana fruits in zimmu leaf extract at 25% concentration exhibited 100% inhibition of crown-rot disease in cold storage (14 °C) up to 35 d and increased the shelf life to 64 d. However, at room storage (28 ± 2 °C), the same treatment exhibited 86% inhibition of crown-rot disease up to 12 d.**	[94]

Plant Name	Country of Origin	Plant Part Used	Focus of the Study	Treatment Application	Key Findings	Reference
Aloe vera	Oman	Leaves	Use of *Aloe vera* gel solution in controlling nectarine *Rhizopus stolonifer*, *Botrytis cinerea* and *Penicillium digitatum*	The fruits were treated by dipping with the corresponded *Aloe vera* gel solution for 10 min and allowed to dry at room temperature. After 24 h, the fruits were inoculated with *R. stolonifer*, *B. cinerea* or *P. digitatum* by depositing 20 μL the fungi stock (50 spores) inside the artificial injury made (2 × 2 × 2 mm of length, width and depth) on the nectarine cultivars and then stored in room temperature for 6 d.	*Aloe vera* (alone or with the addition of thymol) was effective in reducing fruit decay in the two nectarine cultivars by 50 and 70% depending on nectarine cultivar and fungus species.	[95]
Aloe vera	Oman	Leaves	Aloe vera gel edible coating in delaying rachis browning on grapes	The treatments were *Aloe vera* gel diluted 1:3 with distilled water, and distilled water served as control. The grapes were immersed in 5 min in respective treatments, air-dried before storage at 1 °C and 95% RH in permanent darkness for 35 d. Ten samples for both treated and control clusters were taken after 7, 14, 21, 28 and 35 d; half of them were immediately analyzed (cold storage), and the remainder were transferred to a chamber under controlled conditions at 20 °C and 90% RH and analyzed after 4 d to simulate market operations.	Results indicate severe symptoms of dehydration and browning in control rachises (plus SL scores > 3) and low effects for those clusters treated with *A. vera* gel (plus SL scores < 3) after 28 d of cold storage. After 35 days of storage, grapes treated with *Aloe vera* got plus SL score < 4, while the control got plus SL score > 5.	[96]
Datura stramonium	Mexico/Colombia	Leaves	Controlling soft-rot on mango fruits	*Datura stramonium* extracts were tested at 10%, 25% and 50% dilutions.	Control had higher mean soft-rot severity of 93.4%, while the *Datura stramonium* extracts at 25% reduced the severity of soft-rot by 41%.	[97]

Plant Name	Country of Origin	Plant Part Used	Focus of the Study	Treatment Application	Key Findings	Reference
Galenia africana	South Africa	Dried leaves	Effect of *Galenia africana* extracts alone and in combination with kresoxim-methyl for controlling *B. cinerea* on apples	The apple cultivar, Granny Smith, was wounded (5 mm in diameter and 3 mm in depth) three times halfway between the calyx and the stem end. A 20 μL drop of each plant extract and kresoxim-methyl was placed in the wounds and allowed to air-dry for 2 h before application of a 20 μL conidial suspension (1×10^4 spores mL^{-1}); the 20 μL drops had final plant extract doses of 0.0, 1.95, 3.91, 7.81, 15.63, 31.25 and 62.5 $mg·mL^{-1}$, with or without kresoxim-methyl at 0.0 and 0.005 mg mL^{-1}.	Kresoxim-methyl (2.5 $mg·mL^{-1}$) in combination with *G. africana* extract at doses of 125.0, 250.0 and 500.0 $mg·mL^{-1}$ showed high inhibition levels (73, 83.8 and 90.8%, respectively) compared to the kresoxim-methyl (72.5%). Inhibition of decay progression by 67.1% for the plant extract only (62.5 $mg·mL^{-1}$) was achieved compared to 37% of the control.	[98]
Moringa olifera	India	Leaf extracts	Effect of gum arabic (GA) coatings and moringa (M) leaf extract in controlling *Colletotrichum gloeosporioides* on 'Maluma' avocado fruit	Fruits were dipped into the treatments: GA 10%, GA 15%, GA 10% + M, GA 15% + M and CMC 1% + M, and the fruits were then stored at 5.5 °C (95% relative humidity (RH)) for 21 d and moved to ambient conditions at 21 ± 1 °C (60% RH) for 7 d to simulate a retail condition.	The study demonstrated that GA 15% + M (62.37 N) and CMC 1% + M (59.93 N) retained fruit firmness and lowered weight loss by 3.66% and 6.19%, respectively, and both suppressed mycelial growth of *C. gloeosporioides* on 'Maluma' avocado fruit by 33%.	[99]
Phyllanthus niruri	India	Leaves	*Phyllanthus niruri* as an edible coating to control postharvest anthracnose in dragon fruits	The fruits were inoculated by dipping for 2 min in a spore suspension of *C. gloeosporioides* (10^5 spores mL^-) with 0.1% (*v*/*v*) Tween 80 and air-dried at ambient (25 ± 2 °C). The fruits were then dipped for 2 min in 5.0 g L^{-1}, 10.0 g L^{-1} and 15.0 g L^{-1} for *Phyllanthus niruri* crude extract and left to dry again at room temperature. Fruits dipped in spore suspension (10^5 spores' mL^-) with 0.1% (*v*/*v*) Tween 80 for 2 min served as control. All inoculated treated and untreated fruits were then packed in commercial packaging cartons and stored at 11 ± 2 °C, 80% RH for 28 d.	Phyllanthus niruri extracts at 5.0 g L^{-1} or 10.0 g L^{-1} significantly controlled anthracnose by 80 and 90%, respectively, after 28 d of cold storage at 11 ± 2 °C and 80% RH.	[100]

Plant Name	Country of Origin	Plant Part Used	Focus of the Study	Treatment Application	Key Findings	Reference
Plumbago zeylanica	Australia	Leaves	Control banana fruit crown rot	Evaluation of plant extracts at various concentrations (1%, 5%, 10%, 25% and 50% concentration) against *C. musae* was carried out by the 'poisoned food technique'. The banana fruits were then dipped in plant extracts (at 25% concentration) for 5 min and allowed to air dry for 6 h. Banana hands dipped in chemical benomyl (0.1%) served as positive control while distilled water was used as a negative control. One group was incubated at room temperature (28 ± 2 °C), and another group was held in low-temperature storage (14 °C and 90% RH) conditions.	Extracts of *P. zeylanica* (25%) recorded a significant reduction of crown-rot disease up to 75% at room temperature (12 d of incubation) and up to 85% at cold storage (35 d of incubation) conditions.	[94]
Ruta chalepensis	Egypt	Leaves	Controlling soft-rot on mango fruits	*Ruta chalepensis* extracts were tested at 10%, 25% and 50%.	Higher mean soft-rot severity was recorded on the untreated control 4.67 (93.4% fruit area affected); while the greatest reduction in the severity of soft-rot 1.33 (26%) was recorded in the extract of *Ruta chalepensis* at 50% concentration.	[97]
Thymus vulgaris L.	Italy	Leaves	The effect of edible coatings alone or in combination with thyme oil on anthracnose incidence and severity in inoculated avocado fruits	Evaluation of plant extracts at various concentrations was carried out by the 'poisoned food technique'. The inoculated fruits were dipped in commercial treatment (prochloraz 0.05% for 5 min dip), chitosan (CH), aloe (AL), thyme oil (TO), CH+TO (3:1) and AL+TO (3:1), allowed to air dry at room temperature and stored for 5 d.	Coating with CH +TO and AL+TO combination was the most effective, and both combination treatments significantly reduced the percentage disease incidence by 80% and 75%, respectively.	[101]

Plant Name	Country of Origin	Plant Part Used	Focus of the Study	Treatment Application	Key Findings	Reference
Zataria multiflora	**Iran**	**An essential oil from leaves**	**Preventing browning of button mushrooms (*Agaricus bisporus*)**	**The treatments were control (water), TG (Tragacanth gum coating, 0.6%), TGZEO1 (0.6% TG + 1.0% 122 sorbitol + 100 ppm ZEO), TGZEO5 (0.6% TG + 1.0% sorbitol + 500 ppm ZEO), TGZEO10 (0.6% TG + 1.0% sorbitol + 1000 ppm ZEO) and SM (1000 ppm sodium metabisulphite). Mushrooms were dipped into their respective solutions for 5 min, and browning of button mushrooms was evaluated upon 16 d of storage at 4 °C.**	**Control and SM-treated samples had higher open cap mushrooms (82.2% and 80.0%, respectively). Over the same period, the percentage of open cap mushrooms coated with TGZEOs, TSs and TG were in the range 66.7–75.6%. After 16 days, the control had higher PPO and POD activity (75 and 25 units/mg protein, respectively) resulting in higher browning rate, while TG-coated mushrooms had lower browning rate in the range of 25–70 units/mg protein PPO and 15–20 units/mg protein POD.**	[102]
Zehnerria scabra	**Angola**	**Tubers**	**Control banana fruit crown rot**	**Evaluation of plant extracts at various concentrations (1%, 5%, 10%, 25% and 50% concentration) against *C. musae* by dipping the fruits in plant extracts (at 25% concentration) for 5 min and allowed to air dry for 6 h. Banana hands dipped in chemical benomyl (0.1%) served as positive control while distilled water was used as a negative control.**	**Extracts of *Z. scabra* (25%) and recorded significant reduction of crown-rot disease up to 75% at room temperature (12 d of incubation) and up to 85% at cold storage (35 d of incubation) conditions.**	[94]

3.1. Medicinal Plant Extracts against Microbes in Horticultural Crops

Medicinal plants produce secondary metabolites with antimicrobial properties. Thus, their screening can provide an alternative for producing chemical fungicides that are relatively non-toxic and cost-effective [37][103]. Most of these compounds are terpenes with fungicide properties and can be used as phenolic compounds or essential oils to inhibit microorganisms [3][104]. Medicinal plant extracts can be directly used, or substances responsible for the antimicrobial properties can be isolated [105][106]. Although several studies on the antimicrobial effects of plant extracts have been performed, many medicinal plants used in different rural communities have never been evaluated for their antimicrobial effects [105][107].

Alemu et al. [97] investigated extracts from four plants (*Ruta chalepensis* (fringed rue), *Eucalyptus globulus* (eucalyptus), *Vernonia amygdalina* (bitter leaf) and *Datura stramonium* (jimsonweed)) at 10%, 25% and 50% dilutions in controlling soft-rot on mango fruits while in storage for 16 d at 25 °C (65 ± 5% RH). Higher mean soft-rot severity was recorded on the untreated control 4.67 (i.e., nearly 93.4% fruit area affected), while the most significant reduction in the severity of soft-rot 1.33 (26%) was recorded in the extract of fringed rue at 50% concentration. Extracts from jimsonweed at 25% and 50%, eucalyptus at 50% and bitter leaf at 25% dilution also reduced the soft-rot severity within a range of 2.07–2.40. In an in vivo study reported by Navarro et al. [95] on two nectarine cultivars (‘Flavela’ and ‘Flanoba’) dipped in *Aloe vera* gel alone or with the addition of thymol (99.5%) followed by inoculation with *R. stolonifer*, *B. cinerea* or *P. digitatum*, findings show that the application of aloe treatments (alone or with the addition of thymol) led to significantly lower fungus infection volume than in non-treated nectarines after incubation at 25 °C (85% RH) for 6 d. The results show that extracts of the different plant species are substantially varied in their antifungal potentials. According to Ogbebor and Adekunle [108], these differences are expected because plants vary in their chemical constituents, habitats and stages at which they were collected.

Bordoh et al. [100] applied extracts from *Zingiber officinale* (ginger), *Curcuma longa* (turmeric) and *Phyllanthus niruri* (gulf leaf-flower) as an edible coating to control postharvest anthracnose in dragon fruits after inoculating them with *C. gloeosporioides*. After storage in commercial packaging cartons at 11 ± 2 °C and 80% RH for 28 d, results show that gulf leaf-flower extracts at 10 g L^{-1} significantly reduced the disease followed by turmeric extracts at 10 g L^{-1} compared to control. On the other hand, dipping avocado fruits in chitosan + thyme oil (3:1) and aloe gel + thyme oil (3:1) significantly reduced the disease severity of *C. gloeosporioides* 80% and 75%, respectively, after storage at 20 °C and 70 ± 5% RH for 5 d [101]. The results also show that preventative dip treatment with chitosan or *Aloe vera* gel incorporated with thyme oil or stand-alone treatments showed lower incidence of anthracnose severity. According to Singh et al. [109], the antifungal activity of plant extracts against *C. gloeosporioides* could be due to the presence of bioactive compounds such as gingerols (in ginger), curcumin (turmeric), loin and aloe-emodin (aloe) and alkaloids in dukung anak.

In trying to reduce the severity of anthracnose on naturally infected berries, Cruze et al. [110] immersed the berries in extracts of neem (*Azadirachta indica*), orange (*Citrus sinensis*) extracts, essential oil emulsions of garlic (*Allium sativum*), diesel tree (*Copaifera langsdorfii*), cinnamon (*Cinnamomum zeylanicum*) and clove (*Eugenia caryophyllata*) extracts before storage at 24 ± 2 °C and RH of 85 ± 5% for 11 d. Results show that neem and citric extract at 4% was the most efficient treatment because the disease incidence was 19.44% and the disease severity was 9.34%, while the control showed disease severity of 75.13%. Less severity and, consequently, more disease control were also achieved by immersing the berries into the emulsion of essential oil of garlic, followed by treatments with diesel tree, clove and cinnamon (Table 3). According to Bautista-Baños et al. [111], compounds such as nimbin and quercetine present in the neem have fungicide activities, and thus they were more effective than the other medicinal extracts.

Sangeetha et al. [94] dipped banana fruits (cv. Robusta) in plant extracts of sweet flag (*Acorus calamus*), haritaki (*Terminalia chebula*), dawidjies (*Zehneria scabra*), doctorbush (*Plumbago zeylanica*), shallot (*Allium cepa* × *Allium sativum*), mamijava (*Enicostemma littorale*), orange climber (*Toddalia asiatica*) and arni (*Clerodendron phlomoides*) at 25% concentration to control crown-rot of banana. After storage for 12 d at room temperature (28 ± 2 °C and 80% RH) and 35 d at low-temperature storage (14 °C and 90% RH), results show that dipping of banana fruits in aqueous leaf extract of shallot significantly reduced the crown-rot disease by 86% compared to control and other treatments (Table 4). Gosh et al. [112] reported that the antimicrobial compounds are abundantly present in medicinal plants, and these might be involved in the defence of plants against microbial pathogens in addition to their direct antimicrobial activity against crown-rot disease in bananas.

3.2. Medicinal Plant Extracts against Pests in Horticultural Crops

About 50% of total crops are lost annually because of insect and pest attacks, which adversely affect world food production and huge economic losses [12][39][113][114]. The use of pesticides has contributed immensely to the increase in agricultural productivity; however, these pesticides lead to serious environmental pollution, affecting human health and causing the death of non-target organisms [115]. There is now an increasing trend in the use of botanicals with more than 2400 bioactive medicinal plant species identified for their pesticide and antipathogenic properties [40][116].

According to Isman and Grieneisen [117], scientists continuously search for novel pest control products from medicinal plants. The rich flora found around the world provides known medicinal plant species that may exert insecticidal properties based on their chemistry and efficacy under laboratory conditions [118][119]. Using medicinal plant extracts for pest control has several advantages in terms of preventing the development of insecticide resistance due to the usual presence of several bioactive compounds, their low persistence in the environment and their generally low cost, particularly for smallholder farmers with limited income [120][121][122].

Muzemu et al. [90] reported that fever tea (*Lippia javanica*) leaf powder extract at 12.5% *w*/*v* using 0.1% *v*/*v* soap could be used against rape aphids and tomato spider mites. Extracts of fever tea leaf powder and bitter apple (*Solanum delagoense*) ripe fruit pulp were evaluated as alternatives to conventional pesticides against rape aphids and tomato red spider mites under on-station conditions. The fever tea and bitter apple applied at 12.5% and 25% reduced aphids by 83% and 75.9% and mites by 86.5% and 75%, respectively. Both extracts were more effective against aphids than mites while fever tea was more effective than bitter apple on both crop pests. According to Manenzhe et al. [123], the reduced number of aphids and mites could be due to extracts' repellent, toxic and anti-feedant effects since they contain essential oils and alkaloid constituents with pesticide properties. This shows that fever tea and bitter apple had some insecticidal effects against the vegetable pests (Table 3).

Mazhawidza et al. [88] did a trial on direct topical and residual sprays of aqueous extracts of jimsonweed (*Datura stramonium*), snake bean plant (*Bobgunnia madagascariensis*) and bitter apple against the ladybird beetle on rape (*Brassica napus*). The crude extracts of jimsonweed fresh leaves, bitter apple fresh fruits and snake bean plant dried pods were applied separately at 5, 10, 15, 20 and 25% *w*/*v* under laboratory conditions. Mortality of ladybird beetle in laboratory bioassays increased with an increase in post-exposure time, and snake bean plant (25% *w*/*v*) caused the highest mortality. Based on lethal dose at 50% (LD_{50}) values, snake bean plant extracts were most toxic (LD_{50}, 30% *w*/*v*) followed by jimsonweed (LD_{50}, 34% *w*/*v*) and bitter apple (LD_{50}, 49% *w*/*v*) 24 h post-application. Under laboratory conditions, significantly higher ladybird beetle mortality rates from snake bean plant than *D. jimsonweed* and bitter apple were observed [124]. This observation may have been due to saponins in snake bean plant and other anti-feedant compounds such as quercetin. The results show that jimsonweed and bitter apple extracts at the application rates used in the study were relatively safer to *H. variegate* than snake bean plant (25% *w*/*v*). These ladybird beetles have been reported in horticultural crops such as spinach, tomatoes, cabbage, raddish, etc. [125]. Hence, jimsonweed and bitter apple can be explored for integrated pest management programs of horticultural crops (Table 3).

Kayange et al. [93] evaluated the effectiveness of fish bean (*Tephrosia vogelii*) and candida (*Tephrosia candida*) extracts against green bean aphid (*Aphis fabae*) at three different dilutions (0.5%, 2% and 5% *w*/*v*). According to the authors, there was a high mortality rate of aphid on the plots treated with fish bean compared to plots treated with candida at the same dilution. These plant extracts at 5% significantly controlled the green bean aphid. According to Stevenson and Belmain [98], the presence of isoflavonoids which are toxic substances in fish bean might have reduced the presence and population of aphids. The active components in leaves of fish bean have anti-feedant, insecticidal, acaricidal, ovicidal and ichthyotoxic effects, which act as a stomach poison in insects [126].

Sharma and Gupta [87] evaluated the biological activity of plant extracts against cabbage moth (*Pieris* brassicae) (Linn.) on cabbages. Aqueous extracts (10, 5, 2.5 and 1.0%) from leaves of neem (*Azadirachta indica*), chinaberry tree *(Melia azedarach*), wild-sage (*Lantana camara*), hemp (*Cannabis sativa*), oleander (*Nerium indicum*), *Eucalyptus* sp., castor bean (*Ricinus communi*) and black nightshade (*Solanum nigrum*) were used as treatments. The protection of cabbage foliage at all the dilutions of *M. azedarach* was higher when compared to other plant extracts. The maximum protection was provided at 5% of chinaberry tree (88.3%) and neem (82.5%). The minimum (4.6%) protection to the cabbage foliage was observed at 1% of neem. The anti-feedant effect of the different concentrations decreased with a decrease in concentration. Irrespective of plant extract, high doses resulted in maximum mean protection to foliage (68.1%), while the lowest dose, 9.5%, resulted in the least protection (Table 3).

References

1. Kunene, E.N.; Nxumalo, K.A.; Ngwenya, M.P.; Masarirambi, M.T. Domesticating and Commercialisation of Indigenous Fruit and Nut Tree Crops for Food Security and Income Generation in the Kingdom of Eswatini. Curr. J. Appl. Sci. Technol. 2020, 39, 37–52.
2. Van Wyk, B.-E. A review of commercially important African medicinal plants. J. Ethnopharmacol. 2015, 176, 118–134.
3. Van Wyk, B.-E. A family-level floristic inventory and analysis of medicinal plants used in Traditional African Medicine. J. Ethnopharmacol. 2020, 249, 112351.
4. Van Wyk, B.E.; Gericke, N. People's Plants: A Guide to Useful Plants of Southern Africa, 1st ed.; Briza Publications: Pretoria, South Africa, 2000; p. 351.
5. Van Vuuren, S. Antimicrobial activity of South African medicinal plants. J. Ethnopharmacol. 2008, 119, 462–472.
6. Badiane, O.; Makombe, T.; Bahiigwa, G. (Eds.) Promoting Agricultural Trade to Enhance Resilience in Africa. ReSAKSS Annual Trends and Outlook Report 2013; International Food Policy Research Institute (IFPRI): Washington, DC, USA, 2014.
7. D'Aquino, S.; Palma, A.; Schirra, M.; Continella, A.; Tribulato, E.; La Malfa, S. Influence of film wrapping and fludioxonil application on quality of pomegranate fruit. Postharvest Biol. Technol. 2010, 55, 121–128.
8. Fawole, O.A.; Opara, U.L.; Fawole, O.A.; Opara, U.L. Seasonal variation in chemical composition, aroma volatiles and antioxidant capacity of pomegranate during fruit development. Afr. J. Biotechnol. 2013, 12, 4006–4019.

9. Nxumalo, K.A. Common Physiological Disorders of white/Irish potato (Solanum Tuberosum) tubers produced in Swazil and: A Review. Agron. Agric. Sci. 2018, 1, 1–9.
10. Mphahlele, R.R.; Fawole, O.A.; Opara, U.L. Influence of packaging system and long term storage on physiological attri butes, biochemical quality, volatile composition and antioxidant properties of pomegranate fruit. Sci. Hortic. 2016, 211, 140–151.
11. Food and Agriculture Organization of the United Nations [FAO]. The State of Agricultural Commodity Markets 2020. Agr icultural Markets and Sustainable Development: Global Value Chains; Smallholder Farmers and Digital Innovations; FA O: Rome, Italy, 2020.
12. Food and Agriculture Organization of the United Nations [FAO]. SAVE FOOD: Global Initiative on Food Loss and Waste Reduction; FAO: Rome, Italy, 2017; Available online: (accessed on 17 November 2020).
13. Food and Agriculture Organization of the United Nations [FAO]. Potential Impacts on Sub-Saharan Africa of Reducing F ood Loss and Waste in the European Union—A Focus on Food Prices and Price Transmission Effects; Rutten, M., Ver ma, M., Mhlanga, N., Bucatariu, C., Eds.; FAO: Rome, Italy, 2015.
14. Adeoye, I.B.; Odeleye, O.M.O.; Babalola, S.O.; Afolayan, S.O. Economic analysis of tomato losses in Ibadan Metropoli s; Oyo State; Nigeria. Afr. J. Basic Appl. Sci. 2009, 1, 87–92.
15. Ncama, K.; Magwaza, L.S.; Mditshwa, A.; Tesfay, S.Z. Plant-based edible coatings for managing postharvest quality of fresh horticultural produce: A review. Food Packag. Shelf Life 2018, 16, 157–167.
16. Nayantara, R.; Kaur, P. Biosynthesis of nanoparticles using eco-friendly factories and their role in plant pathogenicity: A review. Biotechnol. Res. Innov. 2018, 2, 63–73.
17. Riva, S.C.; Opara, U.O.; Fawole, O.A. Recent developments on postharvest application of edible coatings on stone frui t: A review. Sci. Hortic. 2020, 262, 109074.
18. Kader, A. Increasing Food Availability by Reducing Postharvest Losses of Fresh Produce. Acta Hortic. 2005, 682, 2169 –2176.
19. Kudachikar, V.B.; Kulkarni, S.G.; Prakash, M.N.K. Effect of modified atmosphere packaging on quality and shelf life of 'Robusta' banana (Musa sp.) stored at low temperature. J. Food Sci. Technol. 2011, 48, 319–324.
20. Pimentel, D. Pesticides and Pest Control. In Integrated Pest Management: Innovation-Development Process; Peshin, R., Dhawan, A.K., Eds.; Springer: Dordrecht, The Netherlands, 2009; pp. 83–87.
21. Ogunnupebi, T.A.; Oluyori, A.P.; Dada, A.O.; Oladeji, O.S.; Inyinbor, A.A.; Egharevba, G.O. Promising Natural Products in Crop Protection and Food Preservation: Basis, Advances, and Future Prospects. Int. J. Agron. 2020, 2020, 1–28.
22. Sharif, Z.; Mustapha, F.; Jai, J.; Yusof, N.M.; Zaki, N. Review on methods for preservation and natural preservatives for extending the food longevity. Chem. Eng. Res. Bull. 2017, 19, 145.
23. Food and Agriculture Organization [FAO]; World Health Organisation [WHO] of the United Nations. Pesticide Residues i n Food; WHO: Geneva, Switzerland, 2013; Available online: (accessed on 21 April 2021).
24. Dayan, F.E.; Cantrell, C.L.; Duke, S.O. Natural products in crop protection. Bioorg. Med. Chem. 2009, 17, 4022–4034.
25. Mogoşanu, G.D.; Grumezescu, A.M.; Bejenaru, C.; Bejenaru, L.E. Natural Products Used for Food Preservation. Food Preservation; Academic Press: Waltham, MA, USA, 2017; pp. 365–411.
26. Santos-Sánchez, N.F.; Salas-Coronado, R.; Valadez-Blanco, R.; Hernández-Carlos, B.; Guadarrama-Mendoza, P.C. N atural antioxidant extracts as food preservatives. Acta Sci. Pol. Technol. Aliment. 2017, 16, 361–370.
27. Thorat, P.; Kshirsagar, R.; Sawate, A.; Patil, B. Effect of lemongrass powder on proximate and phytochemical content of herbal cookies. J. Pharmacogn. Phytochem. 2017, 6, 155–159.
28. Vora, J.; Srivastava, A.; Modi, H. Antibacterial and antioxidant strategies for acne treatment through plant extracts. Infor m. Med. Unlocked 2018, 13, 128–132.
29. Yan, Y.; Liu, Q.; Jacobsen, S.E.; Tang, Y. The impact and prospect of natural product discovery in agriculture. EMBO R ep. 2018, 19, e46824.
30. Masarirambi, M.T.; Nxumalo, K.A.; Kunene, E.N.; Dlamini, D.V.; Mpofu, M.; Manwa, L.; Earnshaw, D.M.; Bwembya, G. C. Traditional/Indigenous Vegetables of the Kingdom of Eswatini: Biodiversity and Their Importance: A Review. J. Exp. Agric. Int. 2020, 42, 204–215.
31. Naves, V.; Dos Santos, M.; Ribeiro, I.; Da Silva, C.; Silva, N.; Dias, A.; Ionta, M.; Dias, D. Antimicrobial and antioxidant activity of Garcinia brasiliensis extracts. S. Afr. J. Bot. 2019, 124, 244–250.
32. Tayel, A.A.; Shaban, S.M.; Moussa, S.; Elguindy, N.M.; Diab, A.; Mazrou, K.E.; Ghanem, R.A.; El-Sabbagh, S.M. Bioact ivity and application of plant seeds' extracts to fight resistant strains of Staphylococcus aureus. Ann. Agric. Sci. 2018, 6

3, 47–53.

33. Arnold, T.H.; Prentice, C.A.; Hawker, L.C.; Snyman, E.E.; Tomalin, M.; Crouch, N.R.; Pottas-Bircher, C. Medicinal and Magical Plants of Southern Africa: An Annotated Checklist; National Botanical Institute: Pretoria, South Africa, 2002; p. 203.
34. Williams, V.; Victor, J.; Crouch, N. Red Listed medicinal plants of South Africa: Status, trends, and assessment challeng es. S. Afr. J. Bot. 2013, 86, 23–35.
35. Pareek, S.; Kitinoja, L. “5—Aonla (Emblica officinalis Gaertn.)”. Postharvest Biology and Technology of Tropical and Su btropical Fruits; Yahia, E.M., Ed.; Woodhead Publishing: Sawston, UK, 2011; pp. 65e–99e.
36. Phuyal, N.; Jha, P.K.; Raturi, P.P.; Rajbhandary, S. Zanthoxylum armatum DC.: Current knowledge, gaps and opportunit ies in Nepal. J. Ethnopharmacol. 2019, 229, 326–341.
37. Das, K.; Tiwari, R.K.S.; Shrivastava, D.K. Techniques for evaluation of medicinal plant products as antimicrobial agent: Current methods and future trends. J. Med. Plant. Res. 2010, 4, 104–111.
38. Stevenson, P.C.; Isman, M.B.; Belmain, S.R. Pesticidal plants in Africa: A global vision of new biological control product s from local uses. Ind. Crop. Prod. 2017, 110, 2–9.
39. Food and Agricultural Organisation of the United Nations (FAO). Forestry Outlook Study for Africa. African Forests: A Vi ew to 2020; African Development Bank, European Commission & FAO; FAO: Rome, Italy, 2003.
40. Mwitwa, J. The Status of Traditional Medicinal Plant Practice in the Miombo Eco-Region of Southern Africa: Zambia Ca se Study; Consultancy report prepared for WWF Southern Africa Regional Programme Office; The Subregional Office f or Southern Africa (SRO-SA): Lusaka, Zambia, 2009.
41. Van Wyk, B.E. A Review of African Medicinal and Aromatic Plants. In Medicinal and Aromatic Plants of the World—Afric a Volume 3; Neffati, M., Najjaa, H., Máthé, Á., Eds.; Springer: Dordrecht, The Netherlands, 2017; p. 3.
42. Royal Botanic Gardens Kew. The State of the World’s Plants Report—2016; Royal Botanic Gardens: Richmond, UK, 20 16; ISBN 978-1-84246-628-5.
43. Lee, S.-H.; Chang, K.-S.; Su, M.-S.; Huang, Y.-S.; Jang, H.-D. Effects of some Chinese medicinal plant extracts on five different fungi. Food Control 2007, 18, 1547–1554.
44. Verástegui, Á.; Verde, J.; García, S.; Heredia, N.; Oranday, A.; Rivas, C. Species of Agave with antimicrobial activity ag ainst selected pathogenic bacteria and fungi. World J. Microbiol. Biotechnol. 2007, 24, 1249–1252.
45. Santas, J.; Almajano, M.P.; Carbó, R. Antimicrobial and antioxidant activity of crude onion (Allium cepa, L.) extracts. Int. J. Food Sci. Technol. 2010, 45, 403–409.
46. Saxena, M.; Saxena, J.; Nema, R.; Singh, D.; Gupta, A. Phytochemistry of medicinal plants. J. Pharmacogn. Phytoche m. 2013, 1, 168–182.
47. Liu, R.H. Potential Synergy of Phytochemicals in Cancer Prevention: Mechanism of Action. J. Nutr. 2004, 134, 3479S–3485S.
48. Maitera, O.N.; Louis, H.; Oyebanji, O.O.; Anumah, A.O. Investigation of Tannin content in Diospyros mespiliformis Extra ct using Various Extraction Solvents. J. Anal. Pharm. Res. 2018, 7, 1–5.
49. Wilson, C.L.; Solar, J.M.; El Ghaouth, A.; Wisniewski, M.E. Rapid Evaluation of Plant Extracts and Essential Oils for Ant ifungal Activity Against Botrytis cinerea. Plant Dis. 1997, 81, 204–210.
50. Daferera, D.J.; Ziogas, B.N.; Polissiou, M.G. GC-MS Analysis of Essential Oils from Some Greek Aromatic Plants and Their Fungitoxicity onPenicillium digitatum. J. Agric. Food Chem. 2000, 48, 2576–2581.
51. Masih, H.; Peter, J.K.; Tripathi, P. A comparative evaluation of the antifungal activity of medicinal plant extracts and che mical fungicides against four plant pathogens. Int. J. Curr. Microbiol. Appl. Sci. 2014, 3, 97–109.
52. Rajbongshi, P.; Yumnam, D. A study on the effect of some fungicides on the population of soil mycoflora. J. Int. Acad. R es. Multidiscip. 2014, 1, 99–106.
53. Camara, M.; Faye, E.; Sarr, S.M.; Coly, E.V.; Gueye, M. Comparative Effects of Natural and Synthetic Fungicides on th e Pink Root Disease of Onion (Allium cepa L.), in Nursery. Agric. Sci. 2017, 08, 743–750.
54. Torres, R.C.; Garbo, A.G.; Walde, R.Z.M.L. Larvicidal activity of Persea americana Mill. against Aedes aegypti. Asian P ac. J. Trop. Med. 2014, 7, S167–S170.
55. Sisay, B.; Tefera, T.; Wakgari, M.; Ayalew, G.; Mendesil, E. The Efficacy of Selected Synthetic Insecticides and Botanica ls against Fall Armyworm, Spodoptera frugiperda, in Maize. Insects 2019, 10, 45.
56. Zhang, H.; Li, R.; Liu, W. Effects of Chitin and Its Derivative Chitosan on Postharvest Decay of Fruits: A Review. Int. J. Mol. Sci. 2011, 12, 917–934.

57. Malik, A.A.; Bhat, A.; Ahmed, N.; Kaul, R.K. Effect of postharvest application of plant extracts on physical parameters a nd shelf life of guava. Asian Agric. Hist. 2015, 19, 185–193.

58. Romanazzi, G.; Lichter, A.; Gabler, F.M.; Smilanick, J.L. Recent advances in the use of natural and safe alternatives to conventional methods to control postharvest gray mold of table grapes. Postharvest Biol. Technol. 2012, 63, 141–147.

59. Mari, M.; Neri, F.; Bertolini, P. Management of important diseases in Mediterranean high value crops. Stewart Postharv est Rev. 2009, 5, 1–10.

60. Talibi, I.; Boubaker, H.; Boudyach, E.; Ben Aoumar, A.A. Alternative methods for the control of postharvest citrus diseas es. J. Appl. Microbiol. 2014, 117, 1–17.

61. Quinn, L.P.; de Vos, B.J.; Fernandes-Whaley, M.; Roos, C.; Bouwman, H.; Kylin, H.; Pieters, R.; van den Berg, J. Pestic ide Use in South Africa: One of the Largest Importers of Pesticides in Africa, Pesticides in the Modern World Pesticides Use and Management; Stoytcheva, M., Ed.; InTech: London, UK, 2011; pp. 50–57. ISBN 978-953-307-459-7. Available online: (accessed on 20 September 2020).

62. Pesticide Action Network [PAN]. International List of Highly Hazardous Pesticides; Impressum: Hamburg, Germany, 20 21.

63. Kanetis, L.; Förster, H.; Adaskaveg, J.E. Comparative Efficacy of the New Postharvest Fungicides Azoxystrobin, Fludio xonil, and Pyrimethanil for Managing Citrus Green Mold. Plant Dis. 2007, 91, 1502–1511.

64. Leroux, P.; Gredt, M.; Leroch, M.; Walker, A.-S. Exploring Mechanisms of Resistance to Respiratory Inhibitors in Field S trains of Botrytis cinerea, the Causal Agent of Gray Mold. Appl. Environ. Microbiol. 2010, 76, 6615–6630.

65. Kretschmer, M.; Leroch, M.; Mosbach, A.; Walker, A.-S.; Fillinger-David, H.S.; Mernke, D.; Schoonbeek, H.-J.; Pradier, J.-M.; Leroux, P.; De Waard, M.A.; et al. Fungicide-Driven Evolution and Molecular Basis of Multidrug Resistance in Fiel d Populations of the Grey Mould Fungus Botrytis cinerea. PLoS Pathog. 2009, 5, e1000696.

66. Gabriolotto, C.; Monchiero, M.; Nègre, M.; Spadaro, D.; Gullino, M.L. Effectiveness of control strategies against Botrytis cinerea in vineyard and evaluation of the residual fungicide concentrations. J. Environ. Sci. Health Part B 2009, 44, 389 –396.

67. Seneviratne, K.; Kotuwegedara, R. Antioxidant Activities of the Phenolic Extracts of Seed Oils and Seed Hulls of Five Pl ant Species. Food Sci. Technol. Int. 2009, 15, 419–425.

68. Kim, Y.S.; Balaraju, K.; Jeon, Y. Effects of rhizobacteria Paenibacillus polymyxa APEC136 and Bacillus subtilis APEC17 0 on biocontrol of postharvest pathogens of apple fruits. J. Zhejiang Univ. Sci. B 2016, 17, 931–940.

69. Demoz, B.T.; Korsten, L. Bacillus subtilis attachment, colonization, and survival on avocado flowers and its mode of acti on on stem-end rot pathogens. Biol. Control 2006, 37, 68–74.

70. Van Der Merwe, J.J.; Coutinho, T.A.; Korsten, L.; Van Der Waals, J.E. Pectobacterium carotovorum subsp. brasiliensis causing blackleg on potatoes in South Africa. Eur. J. Plant Pathol. 2009, 126, 175–185.

71. Adaskaveg, J.E.; Förster, H.; Sommer, N.F. Principles of postharvest pathology and management of decays of edible h orticultural crops. In Postharvest Technology of Horticultural Crops, 4th ed.; Kader, A.A., Ed.; UC DANR Publications: O akland, CA, USA, 2002; pp. 163–195.

72. Pallavi, R.; Uma, T.; Nitin, D. Post-harvest fungal diseases of fruits and vegetables in Nagpur. Int. J. Life Sci. 2014, 56–58. Available online: (accessed on 25 November 2020).

73. Elad, Y.; Pertot, I.; Cotes Prado, A.M.; Stewart, A. Plant Hosts of Botrytis spp. In Botrytis–the Fungus, the Pathogen an d its Management in Agricultural Systems; Fillinger, S., Elad, Y., Eds.; Springer: Cham, Switzerland, 2016; pp. 413–48 6.

74. Wang, X.; Wang, J.; Jin, P.; Zheng, Y. Investigating the efficacy of Bacillus subtilis SM21 on controlling Rhizopus rot in peach fruit. Int. J. Food Microbiol. 2013, 164, 141–147.

75. Smilanick, J.L.; Mansour, M.F.; Gabler, F.M.; Sorenson, D. Control of citrus postharvest green mold and sour rot by pot assium sorbate combined with heat and fungicides. Postharvest Biol. Technol. 2008, 47, 226–238.

76. Yánez-Mendizábal, V.; Zeriouh, H.; Viñas, I.; Torres, R.; Usall, J.; De Vicente, A.; Pérez-García, A.; Teixidó, N. Biologica l control of peach brown rot (Monilinia spp.) by Bacillus subtilis CPA-8 is based on production of fengycin-like lipopeptid es. Eur. J. Plant Pathol. 2011, 132, 609–619.

77. Malik, A.A.; Naseer, A.; Harmeet, C.; Prerna, G. Plant Extracts in Post-Harvest Disease Management of Fruits and Veg etables-A Review. J. Food Process. Technol. 2016, 7, 1–5.

78. Jafarzadeh, S.; Jafari, S.M.; Salehabadi, A.; Nafchi, A.M.; Kumar, U.S.U.; Khalil, H.A. Biodegradable green packaging with antimicrobial functions based on the bioactive compounds from tropical plants and their by-products. Trends Food Sci. Technol. 2020, 100, 262–277.

79. Sen, T.; Samanta, S.K. Medicinal plants, human health and biodiversity: A broad review. Adv. Biochem. Eng. Biotechnol. 2015, 147, 59–110.

80. Pandey, A.K.; Chávez-González, M.L.; Silva, A.S.; Singh, P. Essential oils from the genus Thymus as antimicrobial food preservatives: Progress in their use as nanoemulsions-a new paradigm. Trends Food Sci. Technol. 2021, 111, 426–441.

81. Droby, S.; Wisniewski, M.; Macarisin, D.; Wilson, C. Twenty years of postharvest biocontrol research: Is it time for a new paradigm? Postharvest Biol. Technol. 2009, 52, 137–145.

82. Gatto, M.A.; Ippolito, A.; Linsalata, V.; Cascarano, N.A.; Nigro, F.; Vanadia, S.; Di Venere, D. The activity of extracts from wild edible herbs against postharvest fungal diseases of fruit and vegetables. Postharvest Biol. Technol. 2011, 61, 72–82.

83. Gahukar, R. Evaluation of plant-derived products against pests and diseases of medicinal plants: A review. Crop Prot. 2012, 42, 202–209.

84. Tripathi, P.; Shukla, A.K. Emerging non-conventional technologies for control of postharvest diseases of perishables. Fresh Prod. 2007, 1, 111–120.

85. Araya, H.; Du Plooy, C.P.; Phala, L.; Sathekge, R. Artemisinin content and biological activity of Artemisia annua subjective to the growth stage of the plant. In Proceedings of the 29th International Horticultural Conference (IHC), Brisbane, Australia, 17–22 August 2014.

86. Azwanida, N.N. A review of the extraction methods uses in medicinal plants, principle, strength and limitation. Med. Aromat. Plants 2015, 4, 196.

87. Sharma, A.; Gupta, R. Biological activity of some plant extracts against Pieris brassicae (Linn.). J. Biopestic. 2009, 2, 26–31.

88. Mazhawidza, E.; Mvumi, B.; Mazarura, U. Effects of crude aqueous extracts of indigenous insectidal plants on the lady bird beetle, Hippodamia variegata (Goeze) (Coleoptera:Coccinellidae). Int. J. Trop. Insect Sci. 2018, 38, 159–167.

89. Philemon, Y.K.; Matasyoh, J.C.; Wagara, I.N. Chemical composition and antifungal activity of the essential oil from Lippia javanica (Verbenaceae). Int. J. Biotechnol. Food Sci. 2015, 4, 1–6.

90. Muzemu, S.; Mvumi, B.M.; Nyirenda, S.P.M.; Sileshi, G.W.; Sola, P.; Kamanula, J.F.; Belmain, S.R.; Stevenson, P.C. Insectidal effects of indigenous plants extract against rape aphids and tomato red spider mites. In Proceedings of the 10th African Crop Science Conference, Maputo, Mozambique, 10–13 October 2011; Volume 10, pp. 169–171.

91. Cavoski, I.; Al Chami, Z.; Bouzebboudja, F.; Sasanelli, N.; Simeone, V.; Mondelli, D.; Miano, T.; Sarais, G.; Ntalli, N.; Caboni, P. Melia azedarach controls Meloidogyne incognita and triggers plant defense mechanisms on cucumber. Crop Prot. 2012, 35, 85–90.

92. Umar, A.; Piero, N.M.; Mgutu, A.J.; Ann, N.W.; Maina, G.S.; Maina, M.B.; Muriithi, N.J.; Kiambi, M.J.; Mutero, N.G.; John, M.K. Bio Efficacy of Aqueous Crude Fruit Sap Extract of Solanum incanum against Green Peach Aphids Myzus persicae Sulzer (Homoptera: Aphididae). Èntomol. Ornithol. Herpetol. Curr. Res. 2016, 5, 1–5.

93. Kayange, C.D.M.; Njera, D.; Nyirenda, S.P.; Mwamlima, L. Effectiveness of Tephrosia vogelii and Tephrosia candida Extracts against Common Bean Aphid (Aphis fabae) in Malawi. Adv. Agric. 2019, 2019, 1–6.

94. Sangeetha, G.; Thangavelu, R.; Rani, S.U.; Muthukumar, A. Antimicrobial activity of medicinal plants and induction of defence related compounds in banana fruits cv. Robusta against crown rot pathogens. Biol. Control 2013, 64, 16–25.

95. Navarro, D.; Díaz-Mula, H.M.; Guillén, F.; Zapata, P.J.; Castillo, S.; Serrano, M.; Valero, D.; Martínez-Romero, D. Reduction of nectarine decay caused by Rhizopus stolonifer, Botrytis cinerea and Penicillium digitatum with Aloe vera gel alone or with the addition of thymol. Int. J. Food Microbiol. 2011, 151, 241–246.

96. Valverde, J.M.; Valero, D.; Domingo, M.R.; Fabiaä, N.; Guilleä, N.; Castillo, S.; Serrano, M. The novel edible coating based on Aloe vera gel to maintain table grape quality and safety. J. Agric. Food Chem. 2005, 53, 7807–7813.

97. Alemu, K.; Ayalew, A.; Woldetsadik, K. Antifungal activity of plant extracts and their applicability in extending the shelf-life of mango fruits. Food Sci. Qual. Manag. 2014, 33, 47–53.

98. Fielding, B.C.; Knowles, C.-L.; Vries, F.A.; Klaasen, J.A. Testing of Eight Medicinal Plant Extracts in Combination with Kresoxim-Methyl for Integrated Control of Botrytis cinerea in Apples. Agriculture 2015, 5, 400–411.

99. Kubheka, S.F.; Tesfay, S.Z.; Mditshwa, A.; Magwaza, L.S. Evaluating the Efficacy of Edible Coatings Incorporated with Moringa Leaf Extract on Postharvest of ‘Maluma’ Avocado Fruit Quality and Its Biofungicidal Effect. Hort. Sci. 2020, 55, 410–415.

100. Bordoh, P.K.; Ali, A.; Dickinson, M.; Siddiqui, Y. Antimicrobial effect of rhizome and medicinal herb extract in controlling postharvest anthracnose of dragon fruit and their possible phytotoxicity. Sci. Hortic. 2020, 265, 109249.

101. Bill, M.; Sivakumar, D.; Korsten, L.; Thompson, A.K. The efficacy of combined application of edible coatings and thyme oil in inducing resistance components in avocado (Persea americana Mill.) against anthracnose during post-harvest sto rage. Crop Prot. 2014, 64, 159–167.

102. Nasiri, M.; Barzegar, M.; Sahari, M.A.; Niakousari, M. Tragacanth gum containing Zataria multiflora Boiss. essential oil as a natural preservative for the storage of button mushrooms (Agaricus bisporus). Food Hydrocoll. 2017, 72, 202–209.

103. Mahlo, S.M.; Chauke, H.R.; McGaw, L.; Eloff, J. Antioxidant and Antifungal Activity of Selected Medicinal Plant Extracts Against Phytopathogenic Fungi. Afr. J. Tradit. Complement. Altern. Med. 2016, 13, 216–222.

104. Baraka, M.A.; Fatma, M.R.; Shaban, W.I.; Arafat, K.H. The efficiency of some plant extracts, natural oils, bio-fungicides and fungicides against root rot disease of date palm. J. Biol. Chem. Environ. Sci. 2011, 6, 405–429.

105. Montesinos, E. Development, registration and commercialization of microbial pesticides for plant protection. Int. Microbi ol. 2003, 6, 245–252.

106. Mahlo, S.; Eloff, J. Acetone leaf extracts of Breonadia salicina (Rubiaceae) and ursolic acid protect oranges against inf ection by Penicillium species. S. Afr. J. Bot. 2014, 93, 48–53.

107. Talibi, I.; Askarne, L.; Boubaker, H.; Boudyach, E.; Msanda, F.; Saadi, B.; Ben Aoumar, A.A. Antifungal activity of Moroc can medicinal plants against citrus sour rot agent Geotrichum candidum. Lett. Appl. Microbiol. 2012, 55, 155–161.

108. Ogbebor, O.N.; Adekunle, A.T. Inhibition of Drechslera heveae (Petch) M. B. Ellis, causal organism of Bird's eye spot di sease of rubber (Hevea brasiliensis Muell Arg.) using plant extracts. Afr. J. Gen. Agric. 2008, 4, 19–26.

109. Singh, A.K.; Pandey, M.B.; Singh, S.; Singh, A.K.; Singh, U.P. Antifungal Activity of Securinine against Some Plant Path ogenic Fungi. Mycobiology 2008, 36, 99–101.

110. Cruz, M.; Schwan-Estrada, K.; Clemente, E.; Itako, A.; Stangarlin, J.; Cruz, M. Plant extracts for controlling the post-har vest anthracnose of banana fruit. Rev. Bras. Plantas Med. 2013, 15, 727–733.

111. Bautista-Baños, S.; Hernández-López, M.; Bosquez-Molina, E.; Wilson, C. Effects of chitosan and plant extracts on gro wth of Colletotrichum gloeosporioides, anthracnose levels and quality of papaya fruit. Crop Prot. 2003, 22, 1087–1092.

112. Ghosh, M.; Thangamani, D.; Thapliyal, M.; Yasodha, R.; Gurumurthi, K. Purification of a 20 KD antifungal protein from Plumbago capensis-A medicinal plant. J. Med. Aromat. Plant Sci. 2009, 24, 16–18.

113. Jitendra, K.; Nitin, K.; Kulkarni, D.K. Plant-based pesticides for control of Helicoverpa amigera on cucumis. Asian Agric. Hist. 2009, 13, 327–332.

114. Rahman, S.; Biswas, S.K.; Barman, N.C.; Ferdous, T. Plant extract as a selective pesticide for integrated pest manage ment. Biotechnol. Res. J. 2016, 2, 6–10.

115. Biswas, S.K.; Rahman, S.; Kobir, S.M.A.; Ferdous, T.; Banu, N.A. A review on impact of agrochemicals on human healt h and environment: Bangladesh perspective. Plant Environ. Dev. 2014, 3, 31–35.

116. Karunamoorthi, K. Medicinal and aromatic plants: A major source of green pesticides/ risk-reduced pesticides. Med. Aro mat. Plants 2012, 1, 1–3.

117. Isman, M.B.; Grieneisen, M.L. Botanical insecticide research: Many publications, limited useful data. Trends Plant Sci. 2014, 19, 140–145.

118. Isman, M.B. Botanical Insecticides, Deterrents, and Repellents in Modern Agriculture and An Increasingly Regulated W orld. Annu. Rev. Èntomol. 2006, 51, 45–66.

119. Stevenson, P.C.; Belmain, S.R. Pesticidal plants in African agriculture: Local uses and global perspectives. Outlooks Pe st Mannag. 2016, 10, 226–230.

120. Caboni, P.; Sarais, G.; Angioni, A.; Garcia, A.J.; Lai, F.; Dedola, F.; Cabras, P. Residues and Persistence of Neem Form ulations on Strawberry after Field Treatment. J. Agric. Food Chem. 2006, 54, 10026–10032.

121. Isman, M.B. Botanical insecticides: For richer, for poorer. Pest Manag. Sci. 2007, 64, 8–11.

122. Das, R.; Chutia, B.C.; Sarmah, M.; Rahman, A. Effect of neem kernel aqueous extract [NKAE] on growth and developm ent of red slug caterpillar, Eterusia magnifica butl. in tea in North-East India, India. J. Biopest. 2010, 3, 489–494.

123. Manenzhe, N.J.; Potgieter, N.; Van Ree, T. Composition and antimicrobial activities of volatile components of Lippia jav anica. Phytochemistry 2004, 65, 2333–2336.

124. Stevenson, P.C.; Nyirenda, S.P.; Veitch, N.C. Highly glycosylated flavonoids from the pods of Bobgunnia madagascarie nsis. Tetrahedron Lett. 2010, 51, 4727–4730.

125. Riddick, E.W. Identification of Conditions for Successful Aphid Control by Ladybirds in Greenhouses. Insects 2017, 8, 3 8.

126. Stevenson, P.C.; Kite, G.C.; Lewis, G.P.; Forest, F.; Nyirenda, S.P.; Belmain, S.R.; Sileshi, G.W.; Veitch, N.C. Distinct chemotypes of Tephrosia vogelii and implications for their use in pest control and soil enrichment. Phytochemistry 2012, 78, 135–146.