ESSENTIAL OILS A GREEN FUNGICIDES FOR CONTROLLING POSTHARVEST DISEASES ON BANANA FRUITS: A REVIEW

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Abstract: Essential oils (EOs) are widely acceptable in cooking, medical, and food industrial products, because its low residual, low toxicity on humans, animals and plants. EOs are more attractive as antifungal at low concentrations against major plant pathogens than synthetic chemical fungicides for management postharvest diseases incidence on banana fruits during storage, transportation and marketing *i.e*., crown rot, anthracnose, neck rot and finger end rot . *In vitro*, EOs of cinnammon, clove, lemongrass, thyme, black seed, basil, tea tree and other oils at (1.0%) were effective for inhibition growth of fungal pathogens causing postharvest rots on banana fruit of various fungal genera such as *Fusarium* species, *Colletotrichum* species, *Lasiodiplodia theobromae* and *Aspergillus tamarii.* Different application methods of EOs can be used for controlling postharvest diseases incidence of banana fruits, such as fumigation, spray, dusting and soaking, with the high efficacy of soaking banana fruits in the essential oil suspensions by the rate (2-5%) for 10 minutes. The most antifungal mechanisms of (EOs) on fungi causing postharvest are inhibition synthetic of cell wall, increasing permeability of plasma membranes, morphological changes in cell originals, deterioration of cytoplasm contents, disrupt cell structure and death the cell. In addition, inhibition development mycelium, conidia production and conidial germination and also, inhibition formation of appressoria during invasion process as well as, inhibition the activities cell wall degrading enzymes of cellulose and pectineases during fungal infection of plant tissue. Furthermore, the synergistic antifungal effect of EOs with edible agents or modified atmosphere such as, EOs of lemongrass or citral in combined treatments with sodium carbonate, cinnamon oil or clove EOs in combination with modified atmosphere, cinnamon oil in combination with Arabic gum by the rate (0.4%-10%) respectively and the combination of clove oil and agar agar by the rate (2% - 0.02%). Moreover, application of nanoemulsions of tea tree oil in combination with sodium alginate, were highly effective for suppressive postharvest diseases on banana fruits, increasing shelf life of banana fruits and maintenance marketable characters. The future investigation the development EOs and their effective chemical components in encapsulation of micro- and nano formulations for increasing their efficacy for a long time, by slow release to loss degradation and evaporation after application. So, this review aims to focusing of applicable of EOs and their biological active components as well as development its in formulations as eco-friendly green fungicides for management postharvest fungal diseases on banana fruits.

Key words: banana; fruit; essential oils (EOs); fungi; postharvest; management.

INTRODUCTION

Banana species and production

Banana plant (*Musa* spp.) belonged Musaceae family, is the one of best fruit crops more than 50 species included *M. acuminata* and *M. balbisiana* originated of wild diploid species. In *M. acuminata* are included several cultivars of Cavendish, Hindi and Maghrabi. Hundered Metric Tons, of banana fruit worldwide production with high consumption as a food in most of the poorest parts in Africa the total banana consumption would comprise up to 400 kg per person per year [34]. Cavendish (*Musa acuminata*, AAA group, Cavendish subgroup) is the most edible banana than 1000 are available and large worldwide cultivation in 40–50% of banana area production, in addition Cavendish highly tolerance to biotic and a biotic agents environmental adverse conditions [123]. Banana plant (*Musa acuminata*) is the main economic crop of edible fruit were rich of, vitamins, minerals, protein and, its used as native material in food and medicinal industrial products [145]. Banana is the edible fruit of Embul banana (*Musa acuminata* AAB) the popular dessert fruit worldwide its short storage life during storage, transportation and marketing [145].

Banana fruits are a popular worldwide in more than 120 countries throughout tropical and subtropical regions on food to more than 400 million peoples, in India, Ecuador, Brazil, and China as the main portion of annual income and a source of food and usual destination for exportation in the major banana producing countries , as well as for starch production or production of a low-cost banana flour ingredient mainly from green banana pulp contains up to 70–80% starch on a dry weight [150]. The total worldwide banana production of fruits 125 million tonnes from cultivated area 5.6 million hectares, the highest production with an annual average during 2010 and 2017 years on banana fruit million tonnes of India (33), China (11), Indonesia (8.9), Philippines (7.5), Brazil (6.8), Ecuador (6.6), Philippines (5.9), Angola (4.4), Guatemala (4.2), Tanzania (3.5) and in Costa Rica (2.5) [38].

Cause of banana losses

The losses of fresh fruits and vegetable reach to 30 –40% of total yield [61]. In India, the total postharvest losses in vegetable crops by fungi and bacterial diseases (40-60%), during harvesting in the field, during packaging, in storage and transportation [132]. The postharvest losses of banana fruits during harvesting, transportation and marketing ranged from 25 to 50% regarding to physical, physiological changes, softening, in addition, 25–40% losses of banana fruit attributed to high temperature degree and percentage of humidity [5]. The considerable losses of banana fruit quality due to alternation the biochemical products included total soluble sugar, protein, ash, ascorbic acid and mineral elements due to spoilage banana fruits caused different fungal genera associated with the ripening banana during storage of *Rhizopus*

stolonifer, *Fusarium roseum*, *Gleosporium musarum* and *Aspergillus niger* [115].

Banana is the short storage life after harvest which attacking by the most common postharvest diseases on banana fruit were, crown rot, finger rot (anthracnose), neck rot and flower end rot (blossom end rot), as shown in (Fig. 1) causing high losses of banana fruit quantity and quality [1, 7, 155]. Postharvest fungal rots diseases on banana fruits are caused by fungal pathogens as shown in (Fig. 2) it included, *Fusarium* species including *F. solani, F. semitectum, F. moniliforme, F. musae* and *Colletotrichum* species of *Colletotrichum musae*, *C. gloeosporioides*, *C. siamense*, *C. theobromicola*, and *C. tropicale* as well *Lasiodiplodia theobromae* in addition, *Aspergillus tamarii* was recorded as a new fruit rot pathogen of banana [21, 28, 35, 58, 64, 66, 78, 108, 109, 121, 136, 137, 148, 151, 155, 156].

Banana postharvest disease

Banana postharvest diseases are complex, occurs in both green and ripe fruit of various banana cultivars [22]. The infection by pathogens, usually originates in the field as latent infection on uninjured green fruit by fungus hypha penetration then direct infestation usually occur during or after harvesting. Latent infection appears as small black circular streaks on flowers, skin and the end of banana fruits which develop as a brown to black color on the crown tissue where the hand was severed from the bunch [100]. The pathogens can penetration crown, finger, finger end flower and neck tissue, causing a black dry rot of fingers on banana fruits, at severely appearance diseases symptoms spots were increase rapidly in size during ripening process on fruits. Visual diseases symptoms were develop once initiated until fruit ripening from the crown into the pedicels and eventually the fingers unmarketable [65, 85]. Fungal pathogens are survival readily on dead and drying plant tissues, including banana leaves debris in soil. Pathogens are attacks wound of finger and neck tissue by spread conidia spores on plant tissue by splashing rain drop then appearance,the salmon-colored fungal acervuli with their associated conidia and mucilage in the lesions. The spots may have triangular-shaped or angular edges. The pathogen may cause symptoms on green fruit and may also enter the cut crown after hands are severed from stalks. Premature ripening of affected fruit may occur after infection [21, 85].

The little information of ecological relations fungi causal pathogens of postharvest diseases on banana fruits. The synergestic effect of *Lasiodiplodia theobromae, F. proliferatum* and *C. musae* on crown rot disease incidence of banana fruit were observed than the single for each one of pathogens [8, 44]. In addition, *Lasiodiplodia theobromae*, *F. proliferatum* and *C. musae* were the causal of crown rot disease of banana fruit synergistic in combination, than individual of each isolates on the disease severity on banana fruits [9].

Fusarium spp. were the most fungi associated with various of infection types on banana fruits in storage different banana cultivars in Egyptian marketings. First of infection type on banana fruits by each one of individual fungi of *Fusarium* spp., *Colletotrichum musae* and *T. paradoxa.* with highly incidence by *Fusarium* spp. on banana cv. Balady, while *Colletotrichum musae* highly single infection on cv. Williams, Meanwhile, *T. paradoxa* recorded single infection type with moderately percentage of infection on Maghraby. The second infection type was observed by *Fusarium* spp. + *Colletotrichum musae* on all fruits of banana cultivars with high percentage on Balady followed by Williams then Maghraby cultivars respectively. In addition, *Fusarium* spp. and *T. paradoxa* were recorded on Maghraby and Williams cultivars only [155]. Vis versa *F. moniliforme* was antagonistic to *C. musae* for incidence anthracnose on banan fruits [44]. Contrarily, the expression of finger and flower end rots on banana fruits were higher by the single infection type with *C. musae* than its combination with *Fusarium moniliforme,* was highly induce crown rot with higher disease percentage and disease severity as the single infection on banana fruit cv. Balady than *Colletotrichum musae*. Moreover, the synergistic for induce crown rot and neck rot diseases on banana fruits in case of the combination of two fungi than the individual fungal infestation [153].

Control of banana postharvest dissease

In the last half century, application of fungicides are harmful to human health, environment increasing of hazardous fungicides on practical plant diseases control has been seriously on public health of human, animals and natural environmental resources as well as become ineffective after prolonged use for commercial control of crown rot of banana [7]. However, after implementing in the International Montreal Protocol in 2005, methyl bromide and other pesticides of chloropicrin, ethylene oxide, carbon bisulfide, hydrogen cyanide and hydrogen phosphide has been used worldwide for controlling foliar, soil borne diseases and postharvest caused by plant pathogens of bacteria, fungi, viral and nematodes were phased out to protect against ozone layer of the depletion and their harmful effects on human and animals health, as well as the environmental resources [15, 86]. In this respect, essential oils (EOs) as the effective and safety promising biocontrol agents against a wide range of plant pests, pathogens, and weeds, low residues and toxicity, slow biodegradable, and compatible with beneficial microbial were developed as green pesticides rather than synthetic chemical pesticides [17, 24, 31, 33, 46, 55, 62 - 64, 71, 72, 83, 91, 96, 103, 119, 133, 149, 153, 154]. Moreover, the positive effect of human health by several essential oil such as *Salvia chionantha* had anti cholinesterase in pathogenesis of Alzheimer's disease [128].

Green pesticides

Several commercial green pesticides based on essential oils such as cinnamite and valero as aphicides, Bloxeda from clove, and Biox-N from *Mentha spicata*. Sweet orange essential oil is useful as a bactericide, fungicide, miticide, and herbicide [43, 52, 89, 95]. In this manner, clove oil was bactrericide [20, 49], eugenol was reported an antiviral [140]. EOs clove, citronella and the active components of cinnamyl acetate, methyl eugenol, cinnamyl alcohol, acetyl eugenol, isoeugenol, eugenol, and benzyl benzoate, eugenol and carvacrol had nematicidal activity [29, 37, 84]. Furthermore, comonents of EOS such as, monoterpenoids of thymol and carvacrol highly nematicidal activity against some plant parasitic nematodes [73].

. EOs of clove, dill, neem, basil and rosmary were insecticidal [6, 24, 29, 36, 63, 81, 82]. The fungicidal of several EOs and their nanoemulsion formulation were reported against major postharvest diseases [4, 39, 41, 45, 61, 83]. Formulation of EOs, of clove and citronella a nematicide [29], clove, lemongrass, thyme, mint, Arabic gum and tween 80 had fungicidal the postharvest spoilage and wilt disease caused by fungi [4,116, 146], EOs, nanoemulsions formulation of thyme and spearmint antimicrobial activites spoliage of the microbial communties on juice of fruits and insects in storage [41, 45, 61, 81, 82, 83]. In addition, nanoemulsion of savory essential oil were herbicidal of some weeds [24].

The phytotoxicity of EOs on plants depends on chemical composition, concentrations, and their adverse interference on plant cell division, cell membranes, and chlorophyll, the higher phytotoxic effect of oxygenated monoterpenes than nonoxygenated [26]. EOs of *Eucalyptus globulus, Cinnanoum zeylanicum* and *Syzygium orematicum* are phytotoxic at 5% on several weeds with no observation at 0.5% of potato plants [144], several plants, *Avena sativa, Brassica napus* and *Zea mays* of *Amaranthus retroflexus, Avena fatua, Bromus secalinus* and *Centaurea cyanus* more tolerant than weeds to the phytotoxic effect essential oils of [127], some components of EOs were phytotoixic to plants of citrus, parsley, cumin and marigold [68], EO of cotton lavender was the least phytotoxic to maize, wheat, pea, and *Lactuca sativa* plants [16]. Peppermint EO and their components are acceptable at 1-20 g/kg weight of animals while, at higher dose was cytotoxic and genotoixic in human [120]. The herbicidal effect of the EOs at high concentrations of thymol, carvacrol, carvone, trans-anethole, and linalool [135]. In this respect, the herbicidal effects of EOs can be visible as chlorosis and burning of leaves, due to interference of constitutes of EOs with some biochemical processes in the plant cells, by inhibition of mitosis, respiration and chlorophyll, membrane depolarization and oxidative damages of microtubule polymerization [102]. Furthermore, scanning electron microscopy (SEM), clear revealed the herbicidal effect of linalool extracted of *Artemisia absinthium* EO was change root structure by inhibition formation of root-hair and suppress development of metaxylem [56].

Essential oils, could be used as safe alternatives to fungicides at low concentrations of essential oils such as cinnamon (*Cinnamomum zeylanicum*), clove (*Syzygium aromaticum*) and lemongrass (*Cymbopogon citratus*) against the pathogenic fungi of postharvest diseases in banana fruits [95], and also used to maintain quality during storage, consequently, banana fruit treated with essential oil are chemically safe and acceptable to consumers [1, 7, 50, 53, 70, 79, 97].

Essential oils, as a effective antifungal agents were used for controlling banana postharvest fungal diseases as the safety natural plant extraction [21, 54, 66, 146, 156]. Essential oils, are composed of different chemical compounds including terpene, terpenoid, phenolic and phenylpropanoid, non-terpenoid aliphatic, and heterocyclic molecules its, antioxidants, anticancer and antimicrobial [134]. The antifungal properties of plant essential oil regarding to their lipophilic nature, disruption in cell wall and between components of plasma membrane, loss of membrane permeability, and leakage of cellular material and thereby negatively affecting the main cellular components particularly mitochondria [130], inducing morphological changes in the cell wall, interference in enzymatic reactions of wall synthesis, plama memebrane and which affect fungal growth and morphogenesis [117].

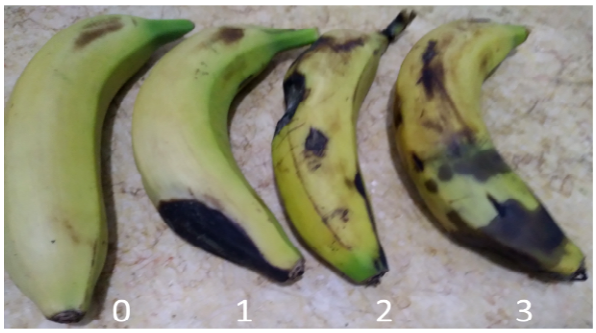

Figure 1. Fungi causing postharvest diseases on banana fruits, 0= healthy , 1= flower end rot, 2= neck rot + crown rot , 3= anthracnose

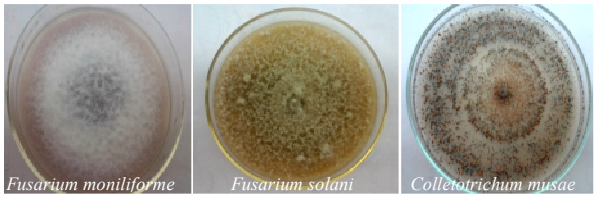

Figure 2. Photographs of growth fungi in Petri dishes, isolate from postharvest diseases in banana fruits

Essential oils for management postharvest diseases on banana

Essential oils (EOs) are the safety and effective natural promising biological agents, its secondary metabolites of higher plants were extraction by different methods from various plant parts belonging to several botanical families, Asteraceae, Euphorbiaceae,

Myrtaceae, Lamiaceae, Lauraceae, Ranunculaceae, Rutaceae, Zingiberaceae, Geraniaceae, Piperaceae and Poaceae as shown in Table 1. EOs are liquid at room temperature turned to gases by increasing temperature without decomposition [50]. EOs are applicable at low concentrations in fumigation and contact treatments, no phytotoxicity on plants, no toxicity on animals and human as well as, no residuals side effect on environmental resources in soil and water, high biodegradabile, synergistic effect with beneficial microorganisms and chemical agents as wall as high effect on various plant pests and causal pathogens [46, 102, 153], as fungicides [57, 152], bactericides [2], insecticides [36, 93] and nematicides [72, 87] EOs as a green pesticides were commercially produced more than 10 year in development countries in European United Countries and American United States [88].

Cinnamon essential oil

Cinnamon plant (*Cinnamomum zeylanicum* Blume, Family Lauraceae), possess anti-inflammatory properties and has been used in traditional medicine for digestive ailments such as indigestion, gas and bloating, stomach upset, and diarrhea [79], the main constituent of cinnamon oil is cinnamaldehyde, which is the compound containing an aldehyde group and conjugated double bond outside the ring [126], this compound possesses much stronger antifungal activity through inhibition chitin synthase enzymes of fungal cell wall [141]. Essential oil cinnamon as shown in (Table 1), the common chemical components in leaves of oil cinnamon were, benzyl benzoate (74.2%), cinnamaldehyde (31%), linalool (13.3%), cinnamaldehyde acetate (8.2%),α-felandrene (6.9%), α-pinene (3.0%), and linalool (2.7%) [97]. In this respect, cinnamaldehyde (66.2%) is the major biological active constituent in cinnamon oil which fungistatic and fungicidal activity at (0.03-0.11%) respectively against fungi causing anthracnose and crown rot of banana fruits i.e., *Colletotrichum musae*, *Lasiodiplodia theobromae* and *Fusarium proliferatum* [126]. The antifungal activity of cinnamon essential oil was tested against *Colletotrichum musae* and *Fusarium proliferatum* in banana fruit. The cinnamon oil at 0.03-0.11% (v/v) was fungistatic and had fungicidal activity against tested pathogens. Thus, they suggested that cinnamon essential oil could be used as antifungal agents to control postharvest fungal diseases of banana fruit [97]. *In vitro*, using peduncle disc, cinnamon oil at 10% was high reduction mycelial growth of crown rot pathogens on banana fruits caused by *Colletotrichum musae*, *Lasiodiplodia theobromae* and *Fusarium* spp. with high reduction of severity of crown rot incidence on banana fruits by cinnamon oil at 10% [143]. Different application methods with cinnamon oil for management postharvest diseases on banana fruits were summarized in (Table 2). Spraying Embul banana fruit with emulsions of cinnamon oil prior storage, controlled crown rot at the range of 0.64 – 1.00 mg/mL [98]. The combination between emulsions of cinnamon oil and packaging modified atmosphere was recommended for management post-harvest decay of banana fruits as a safe, cost-effective method for extending the storage life of Embul bananas up to 21 days in a cold room and 14 days at 28±2ºC without altering the organoleptic and physiochemical properties

Table 1. Essential oils components high active against postharvest plant pathogens of banana fruits

Essential oils rich of common biological active components				
English name	**Scientific name**	**Active components**	**Family**	**References**
Thyme	*Thymus vulgaris*	thymol (47.6 %)	Lamiaceae	[19]
Cinnamon	*Cinnamonum zeglanicum*	benzyl benzoate (74.2%), cinnamaldehyde (31%), linalool (2.7%)	Lauraceae	[105]
Clove	*Syzygium aromaticum*	eugenol (79.4%)	Myrtaceae,	[110]
Lemongrass	*Cymbopogon schoenanthus*	citral 83.53%), neral (43%) , limonene (30%)	Apiaceae	[76]
Black seed	*Nigella sativa*	thymoquinone (11.27), carvacrol (2.12%)	Ranunculaceae	[120]
Basil	*Ocimum basilicum*	methyl eugenol (78.02%)	Lamiaceae	[90]
Bergamot	*Monarda fistulosa*	carvacrol (24.0%) thymol (12.6%)	Lamiaceae	[148]
Tea	*Melaleuca alternifolia*	γ-terpinene, (40.3%)	Lamiaceae	[18]
Ginger	*Zingiber officinale*	geranial (25.9%)	Myrtaceae,	[118]
Cassia	*Cinnamomun cassia*	e-cinnamaldehyde (73.23%), eugenol (4.23%)	Fabaceae	[30]
Kusum	*Schleichera oleosa*	linoleic acid (43–50%), glycerol esters 37%	Sapindaceae	[114]
Citronella grass	*Cymbopogon nardus*	citronellal (27.87%), geraniol (22.77%), geranial (14.54%), citronellol (11.85%), neral (11.21%)	Poaceae	[27]
Cronquist	*Conyza bonariensis*	matricaria methyl ester (roots, 74.4%), limonene (leaves, 29.6%)	Asteraceae	[13]
Geranium	*Pelargonium* graveolens	citronellol, geraniol, linalool, isomethone, citronellyl formate, geranyl formate and guaia-6,9-diene	Geraniaceae	[111]
Piper	*Piper macedoi*	piperitone (26.48 %), silvestrene (13.03 %), and bicyclogermacrene (10.45 %)	Piperaceae	[14]
Cardamom	*Elettaria cardamomum*	α-terpinyl acetate (56.7%), 1,8-cineole (15.13%), α-terpineol (4.67%) and limonene (4.05%)	Zingiberaceae	[10]
Citriodora	*Eucalyptus citriodora*	citronellal (69.77%), citronellol (10.63%) and isopulegol (4.66%)	Myrtaceae	[130]

of fruit [99]. Cinnamon essential oil (0.4%) showed high reduction of *Colletotrichum musae* mycelial growth and conidial germination inhibition (83.2%) and delayed anthracnose disease incidence as well as maintained quality of banana fruit during storage [79]. Emulsion of cinnamon oil (5.0 %) was significantly reduce fruit rot of banana caused by *C. musae* for 11 days after immersing banana fruits for 3 minutes [23]. Cinnamon oil (1.0%) was complete inhibition growth and spore germination of *Fusarium semitectum* and complete reduction in both crown rot disease incidence and severity when spray banana fruits with cinnamon oil at 4.0% under storage conditions [1]. Cinnamon essential oil at 0.05% completely inhibited the mycelial growth of *Colletotrichum musae*, the causal of anthracnose of banana fruit [50].

In vitro different concentrations of cinnamon oil were reduced mycelial linear growth of *F. moniliforme* and *Colletotrichum musae* the causal pathogens of postharvest diseases on banana, crown rot, anthracnose, finer rot, finger end rot and flower end rot [156]. Recently cinnamon oil was highly inhibition mycelial growth of *Colletotrichum* spp. the causal of postharvest fruit rot of banana [40]. In addition, cinnamon oil was highly inhibition mycelial growth of *Colletotrichum* spp. the causal of postharvest fruit rot on banana [42]. Cinnamon oil at 20 µL/mL was completely inhibited on PDA mycelial growth of *Colletotrichum* spp. and *Fusarium* spp. the causal of postharvest on banana fruits [21].

Clove essential oil

Essential oil of clove plant (*Syzygium aromaticum* (L.) Merrill & Perry) belong to Myrtaceae family, as shown in (Table 1), the major and common chemical components in oil were eugenol (79.4%), eugenyl acetate (9.2%) and (7.0%) of isocaryophyllene [67]. Clove essential oil has strong antimicrobial activity. The antimicrobial activity of eugenol can be attributed to the presence of an aromatic nucleus and a phenolic

Table 2. Applicable essential oils as green fungicide for control postharvest diseases on banana fruits

Essential oils	Studies *in vitro* pathogen inhibition growth			Application *in vivo* disease reduction				References
	Pathogen	Dose	%	Disease	Method	Dose	%	
Cinnamon	*C. musae*	0.05%	83.2	anthracnose	Dipping	0.4%	100	[79]
(*Cinnamonum*	*F. semiticum*	1.0 %	85.8	crown rot	Spray	4.0 %	100	[1]
zeglanicum)	*C. musae*	0.05%	100.0	Anthracnose	Spray	0.075%	72.2	[50]
	C. musae	11.0 %	100.0	crown rot	Soaking	2.0 %	100	[156]
	F. moliniforme		100.0	finger rot			100	
				neck rot			80.0	
				flower end rot			70.0	
Clove	*C. musae*	--	--	anthracnose	Immersing	5 .0 %	75.8	[23]
(*Syzygium*	*C. musae*	1.0 %	100.0	crown rot	Soaking	2.0 %	100	[156]
aromaticum (L.)	*F. moliniforme*		100.0	finger rot			100	
Merrill & Perry)				neck rot			80.0	
				flower end rot			70.0	
	C. musae	1.0 %	100.0	crown rot	Soaking	2.0 %	70.0	[35]
	F. moliniforme		100.0	finger rot			80.0	
				neck rot			80.0	
				flower end rot			75.0	
	C. musae	10 µL/mL	100.0	anthracnose	Dipping	320 µL/mL	93.5	[107]
Basil	*C. musae*	0.2%	100.0	anthracnose	Spray	0.02%	73.3	[32]
(*Ocimum basilicum*)	*C. musae*	275 µL/mL	10.00	anthracnose	Spray	6000 µL/mL	100	[74]
Basil (*Ocimum*	*C. musae*	185 µL/mL	100.0	anthracnose	Spray	2000 µL/mL	100	[75]
gratissimum)								
Thyme	*F. semiticum*	1.0 %	68.0	crown rot	Spray	4.0 %	100	[1]
(*Thymus vulgaris*)	*C. musae*	500 µL/mL		anthracnose		500 µL/mL	30.8	[138]
Tea tree	*C. musae*	8 µL/mL	73.6	anthracnose	Dipping	160 µL/mL	24.0	[106]
(*Melaleuca*								
alternifolia)								
Ginger	*C. musae*	8 µL/mL	11.5	anthracnose	Dipping	160 µL/mL	48.0	
(*Zingiber officinale*)								
Karanj	*C. musae*	25.0%	53.85	fruit rot	Spray	25.0%	60.6	[67]
(*Millettia pinnata*)								
Kusum (*Schleichera*	*C. musae*	25.0%	98.68	fruit rot	Spray	25.0%	76.5	[66]
oleosa)								
Jatropha	*C. musae*	25.0 %	74.50	fruit rot	Spray	25.0%	65.8	[67]
(*Jatropha curcas)*								
Rosmary	*C.musae*	0.30%	100	anthracnose	Spray	0.30%	66.2	[50]
Bergamot	*C. musae*	4 .0 µL/mL	100	anthracnose	Vapour	66.6 µL/mL	----	[66]
(*Monarda fistulosa*)	*L. theobromae*			crown rot				
Bitter almond	*F. semiticum*	1%	78.2	crown rot	Spray	4	86.7	[1]
(*Prunus amygdalus*)								
Sweet almond	*F. semiticum*	1%	62.8	crown rot	Spray	4	97.4	
(*Prunus amygdalus*)								

--- not available, *C. musae =Colletotrichum musae*, *L. theobromae= Lasiodiplodia theobromae*, *F. = Fusarium*

OH group that are known to be reactive and can form hydrogen bonds with –SH groups in the active sites of target enzymes, resulting in the deactivation of enzymes in fungi [100]. Eugenol is the main antifungal activity (83%) of oil components [41, 140]. Clove essential oil could be used as antifungal agent to control anthracnose and crown fungal diseases on banana fruit caused by *Colletotrichum musae, Lasiodiplodia theobromae* and *Fusarium proliferatum*, the fungistatic activity and fungicidal effect against pathogens ranged at (0.03-0.11%) respectively [43]. The indication in (Table 2), fumigation of eugenol, in closed Petri dishes loaded with 15 µL/plate and incubated at 28°C was completely 100% inhibited growth of *Lasiodiplodia theobromae* the causal of stem end rot of banana. In addition, fumigation banana fruits with (200 µL/mL) in a carton box after artificial infestation by pathogen was reduced incidence of stem end rot of banana 27.4% [101]. Clove essential oil was highly inhibition mycelial linear growth, spore production and their germination of *Colletotrichum musae* the causal of anthracnose on banana fruit [107]. Clove essential oil (1%) was completely (100%) inhibited mycelial linear growth of both fungi, *F. moniliforme* and *Colletotrichum musae* the causal pathogens banana of fruit rot, and completely (100%) suppressive incidence of crown and finger rots 100% as well reduced neck rot and flower end rot by 80 and 70% respectively after soaking in clove suspension (2%) for 10 minutes [35, 156]. Clove oil (0.1 µL/mL) was completely inhibition (100%) germination of conidia and mycelial growth of anthracnose causal pathogen of banana fruits *Colletotrichum musae* and reduction development of anthracnose lesions on banana fruits [106]. Clove essential oil was tested at various concentration with high effect at 2% concentration which compeletly 100% inhibited mycelial linear growth of anthracnose causal pathogen of banana *Colletotrichum musae* [25].

Lemongrass essential oil

Essential oil of lemongrass plant (*Cymbopogon citratus* (DC) Stapf.), of Apiaceae family was mainly included the antifungal components as shown in Table 1, geranial (43%), neral (30%) and (10%) of limonene [67, 94]. In Table 2 revealed that, spray banana fruit by lemongrass oil was significantly reduced the severity of crown rot incidence under artificial infestation by pathogens [3], Lemongrass oil was completely inhibited mycelial growth of crown rot pathogens on banana fruits named, *Lasiodiplodia theobromae* and *Colletotrichum musae* respectively by 0.08, 0.06, not only reduced the crown rot severity significantly, but also increased the shelf life of banana fruits under low-temperature storage (14 °C) condition [112]. Lemongrass possess antifungal activity against *Colletotrichum musae*, *Lasiodiplodia theobromae* and *Fusarium proliferatum* the causal of banana fruit spoliage due to biological activity of rich common components, geranial (39.0%), neral (29.4%), myrcene (18.0%), limonene (10%) and citral [42]. Lemongrass oil at 0.09 was completely (100%) prevent mycelial growth and condia germination of *Lasiodiplodia theobromae*, the pathogen of crown rot on banana fruits [104], lemongrass essential oil at 0.05% and 0.4% respectively showed fungicidal effects against *Colletotrichum musae* and *Colletotrichum gloeosporioides*, the causal pathogens of anthracnose disease in banana and papaya fruits [80]. Lemongrass oil was tested in closed petri dishes with paper strips loaded with 5 and 15 µL/plate of lemongrass oil then incubated at 28°C under fluorescent light for 10 hrs it was completely (100%) inhibited mycelial growth of *Lasiodiplodia theobromae* the causal of stem end rot of banana fruits and reduction incidence of stem end rot of banana, under artificial infestation by pathogen under fumigation treatment of banana fruits in a carton box supplemented with paper strip saturated with (200 µL/mL) of oil and fixed in the six holes, incubated at 18°C for 8 days [101]. *In vitro*, lemongrass essential oil at 1% completely (100%) inhibited mycelial linear growth of *Colletotrichum musae* and *F. moniliforme* the causal pathogens of banana fruit and suppressing their postharvest diseases incidence of crown rot, finger rot, neck rot and flower end rot by 100, 100, 80, 70% respectively [156]. Lemongrass essential oil have been inhibited mycelia growth of anthracnose disease causal pathogen of banana *Colletotrichum musae*, at different concentrations tested on potato dextrose agar medium (PDA) and significant inhibition anthracnose disease incidence up to 14 days after dipping banana fruits by the rate 0.05% [125].

Citronella grass essential oil

Essential oil of citronella grass plant (*Cymbopogon nardus* Rendl. – Graminae) is an aromatic plant from Poaceae family mainly cultivation in tropical region in Asia. The biological activity of citronella oil regarding to the common chemicals with high percentage (27.87%) of citronellal, (22.77%) of geraniol, (14.54%) of geranial, (11.85%) of citronellol and neral (11.21%) shown in Table 1 [27]. Oil was highly antifungal against pathogens of banana postharvest diseases *C. musae* and *F. proliferatum* by the rate (0.2-0.6%). Citronella oil (Cymbopogan nardus Rendl. Graminae) was completely inhibited mycelial growth of crown rot pathogens *Lasiodiplodia theobromae* and *Colletotrichum musae* respectively by 0.1, 0.1% not only reduced the crown rot severity significantly, but also increased the shelf life of banana fruits. However, under low-temperature storage (14 °C) condition [112]. In addition, the synergistic antifungal effect on the pathogens and diseases incidence by oils of citronella grass in combination with basil (*Ocimum basilicum*) shown in Table 2 [9].

Java citronella essential oil

Cymbopogon winterianus an aromatic plant, of the genus Cymbopogon (Poaceae) species have been widely cultivated throughout the world for a wide

range of uses in the pharmaceutical and agricultural fields. The GCMS analysis of *(Cymbopogon winterianus*) revealed that five main compounds of fourth one chemical components were, methyl oleyl ether (40.20%), γ-Sitosterol (15.80%), 6-Methylheptan- 3-ol (7.13%), α-Terpineol (5.56%), and n-Pentadecanol (4.05%). The fungicidal activities of *Cymbopogon winterianus* extract in management *C. musae* that caused anthracnose disease in banana fruit. The minimum concentration was 1.50 g/L and can be used as a postharvest treatment on banana fruit to deter anthracnose infection, with, no visible phytotoxicity on treated banana fruit at the highest concentration of 2.5 g/L. So, *Cymbopogon winterianus* possesses an excellent fungicidal effects against *C. musae* [78].

Black cumin seeds essential oil

Black seed plant (*Nigella sativa*), Family Ranunculaceae, with different names, black seed, black cumin, and habbat-ulbaraka, as shown in Table 1 [120]. Essential oil of black cumin seeds are used mainly for culinary and several medicinal purposes as anti-carcinogenic, antiulcer, antibacterial and antifungal activities [53]. Essential oil black seed was used against several pathogenic fungi attacking numerous seed and fruit, *Aspergillus flavus, Fusarium graminearum, F. moniliforme* and *Penicillium viridicatum* [120]. The antifungal activity of black cumin seeds essential oil are attributed to its the major component of thymoquinone (8.9- 42.4 %), p-cymene (14.1-50.2 %), carvacrol (2.12% - 10.3 %), longifolene (4.4- 6.32 %) and (5.1 %) of 4-terpineol [77, 120]. In this respect as shown in Table 2, black seed essential oil at 1% was reduced mycelial growth by 70.1% and 23.3% respectively on *Colletotrichum musae* and *F. moniliforme* the causal of postharvest diseases of banana fruits i.e., crown rot, finger rot, neck rot and flower end rot [156]. Dipping banana fruits in (4.0 %) suspension of black seed cumin was maintenance banana fruit of less weight loss, fruit decay, firmness, contents of ascorbic acid and pectin [76]. Furthermore, essential oils of black seed oil showed a highly antifungal effect against mycelial growth and conidia sporulation of fungal isolates of *F. oxysporum*, *F. solani*, *F. avenisum*, and *Botryiodiplodia theobromae*, the causal pathogens of root rot of grapevine and application as a soil drench at the sowing time of grapevine transplanting by the rate of 4% was reduced root rot incidence significantly and enhanced the morphological parameters of grapevine plants [152].

Basil essential oil

Essential oil of basil plant are belong to Lamiaceae family, the main chemical constitutes in essential oil of *Ocimum basilicum* as shown in Table 1 were, methyl eugenol (78.02%), α -cubebene (6.17%), nerol (0.83%) and ε-muurolene (0.74%). While the common compounds essential oil of another species on *Ocimum minimum* were geranyl acetate (69.48%), terpinen-4-ol (2.35%) and octan-3-yl-acetate (0.72%) [90], as shown in Table 2, *Ocimum gratissimum* oil was the antifungal effect against growth of fungal causing anthracnose of banana fruits, it completely (100%) inhibition conidia spores germination and mycelial growth of *Colletotrichum musae* by the rate 185 and 275 µl/L respectively, followed by *Ocimum basilicum* at 400 and 800 µL/L, in addition *Ocimum gratissimum* and *Ocimum basilicum* were also completely inhibition anthracnose (100%) by the rate 2000 and 6000 µL/L respectively [9, 75]. Tulsi oil or Holy Basil (*Ocimum sanctum* L. – Labiatae) was completely inhibited mycelial growth of crown rot pathogens *Lasiodiplodia theobromae* and *Colletotrichum musae* respectively by 0.08, 0.06%, significantly reduced crown rot incidence and increased the shelf life of banana fruits at low-temperature storage (14°C) conditions [112]. In the same direction, *Ocimum sanctum* (holy basil) was completely inhibited mycelial growth of crown rot pathogens *Lasiodiplodia theobromae* and *Colletotrichum musae* respectively by 0.06, 0.06%, not only reduced the crown rot severity significantly, but also increased the shelf life of banana fruits. However, under low-temperature storage (14 °C) condition oil increased the shelf life of banana fruits up to 48 days without affecting their organoleptic properties it could be used as an alternative to chemical fungicides for the management of crown rot disease [112].

Holy basil *Ocimum tenuiflorum* inhibition mycelial growth of *Lasiodiplodia theobromae* up to (96%), the inhibition of fungal growth regarding to biological activities of volatiles constitutes of both oils such as eugenol, cinnamyl acetate, caryophyllene, humulene and *trans*-calamenene which suppression the activity of synthetic chitin enzyme [37]. while , basil essential oils of *Ocimum gratissimum* and *Ocimum basilicum* were inhibition anthracnose incidence on banana fruits caused by the fungal pathogen*,Colletotrichum musae* (100%) by 2000 and 6000 µl/L respectively [75], basil oil at 0.07 was completely (100%) illimination mycelial growth and condia spores germination of *Lasiodiplodia theobromae*, the caual of crown rot disease on banana fruits [104] EO of basil was the effective for management anthracnose incidence by (70.28%) at 1000 mL/L [113].

Thyme essential oil

Essential oil of thyme plant (*Thymus vulgaris*) belong to Lamiaceae family, the major constituents of oil shown in Table 1, thymol (47.6 %), γ-terpinene (30.9 %) and (8.4 %) of p-cymene [18]. Thyme essential oil (Table 2) was tested at different concentrations, 2, 4, 6 and 8 µL were highly inhibition mycelial li near growth, spore production and their germination of *Colletotrichum musae* the causal of anthracnose on banana fruits [107, 137]. Thyme essential oil was the best antifungal effect against mycelial growth of *Colletotrichum musae* and their incidence of anthracnose *in vivo* on banana fruits after soaking with 500 µL L−1 and significantly reduced weight loss, maintenance of color and firmness, and a

good quality of banana fruits [12]. The antifungal of thyme essential oil against *Lasiodiplodia theobromae* the causal of crown rot on banana fruit, performed by gas chromatography mass spectrometry (GC-MS) thymol (45.78%) the main components which MIC at 500 ppm [93]. EO thyme oil at 0.05 was completely (100%) was suppressive growth of mycelial and germination of condia spores of the *Lasiodiplodia theobromae*, and reduction by 84.73% the incidence of crown rot disease on banana fruits by the same concentration after dipping as well as extension the shelf life for 12 days after treatment [104].

Bergamot essential oil

Essential oil of bergamot plant (*Monarda fistulosa*), family Lamiaceae, the main chemical components, as shown in Table 1 were, *p*- cymene (32.5%), carvacrol (24.0%), thymol (12.6%), an aliphatic aldehyde (6.3%), the methyl ether of carvacrol (5.5%), α-pinene (3.5%), β-pinene (2.9%), sabinene hydrate (1.9%), α-terpinene [148]. In Table 2, oil was used as vapour treatment at 4 µL per petriplate exhibited (100%) growth inhibition of both the fungal pathogens, *Colletotrichum musae* and *Lasiodiplodia theobromae*, the causal of anthracnose and crown rot diseases at 66.66 µL/L significantly reduced both diseases regarding to antifungal activity of thymol, carvacrol and cinnamyl carbanilate as the mainly components in oil [57].

Tea tree essential oil

Essential oil of tea tree plant (*Melaleuca alternifolia*) of Myrtaceae family, the common chemical components of tea tree oil were in Table 1, γ-Terpinene, (40.3%), 1,8-cineole (7.0%) followed by γ-Terpinene (11.7%) of 1,8-cineole (7.0%) and (6.2%) of *p*-cymene [13]. Tea oil was highly inhibited mycelial linear growth, spore production and their germination of *Colletotrichum musae* the causal of anthracnose on banana fruit as shown in Table 2 and highly suppression incidence of anthracnose disease 48% and 24%, on banana fruit by the rate 160 and 240 µL respectively [106]. Different concentrations of tea tree essential oil was evaluate on the anthracnose incidence and severity on banana fruits. GC-MS chemical analysis of EO indicated the main components was monoterpenes (96.94%) and terpinen-4-ol (47.08%). Treatment banana fruits in water emulsions of tea tree oil at different concentrations (0.50, 1.00, 2.00, 3.00, 4.00 and 5.00 µg/mL for 8 days of storage at 25 ± 2 °C. were significantly reduced anthracnose incidence by 80%, 90%, 95%, 96%, 97% and 98%, respectively, without phytotoxicity observation and increment shelf life of banana fruits [105]. EOs of tea tree was suppression incidence of anthracnose disease on banana fruit [65].

Ginger essential oil

Essential oil of ginger plant (*Zingiber officinale*) of Zingiberaceae family, the major effective antifungal constitutes agents, as shown in Table 1 were geranial (25.9%), (9.5%) of α-zingiberene followed by (7.6%) of (E,E)-α-farnesene, (7.4%) of neral and (6.6%) of ar-curcumene [118]. EO of ginger was highly inhibition of the mycelial linear growth, spore production and their germination of *Colletotrichum musae* the causal of anthracnose on banana fruit and highly suppression incidence of anthracnose disease on banana fruit at 160 µL of ginger oil as shown in Table 2 [107].

Cassia essential oil

Essential oil of cassia plant (*Cinnamomun cassia*) belong to Fabaceae family, the common components of oil as shown in Table 1 e-cinnamaldehyde (73.23%), alpha-copaene (6.44%), and (4.23%) of eugenol [30]. Cassia EO at 6 µL and 10 µL per plate were completely (100%) inhibited mycelial growth of fungi causing anthracnose and crown rot diseases on banana fruit after harvesting caused by *Colletotrichum musae* and *Lasiodiplodia theobromae* as shown in Table 2 [65].

Kusum essential oil

Kusum tree (*Schleichera oleosa*) belonged to the Sapindaceae family mainly cultivation in India used in traditional medicine. Kusum oil shown in Table 1, contain of linoleic acid (43–50%), glycerol esters (37%) and palmitic acid (5–8%), as well hydrocyanic acid, a poisonous characters, which removed [110]. Essential oil of *Schleichera oleosa* was highly reducing mycelial growth *C. musae* and their ability for inducing decay on banana fruits as well as significantly reduced the losses of weight and storage life shown in Table 2 [67]. Kusum oil highly activity as antimicrobial, antioxidants and anticancer disease which including, several secondary metabolites of alkaloids, flavonoids, tannins, triterpenoids, polyphenols, anthocyanins, cholorogenic acids, cyanidine glycosides and quercetins [59].

Cronquist essential oil

Essential oil of (*Conyza bonariensis*) belong to family of Asteraceae, in Table 1, the major components were matricaria methyl ester in roots, (74.4%), in leaves limonene (29.6%), manool in stem, (25.3%) and carvone (21.1%) on inflorescences, [13] in Table 2 oil at 0.4-1 µL/mL was completely inhibited mycelial growth of *C. musae* the causal of anthracnose of banana fruits and significantly reduction conidial germination at (0.6 µL/mL) after exposure to 3 and 5 days as result of high damage percentage of cytoplasmic membrane conidia [74].

Geranium essential oil

Geranium essential oil (*Pelargonium graveolens* L'Her.) belong to Geraniaceae family, its grown in several African countries in Mozambique, Zimbabwe, and South Africa. *Pelargonium graveolens* was completely inhibited mycelial growth of crown rot pathogens *Lasiodiplodia theobromae* and *Colletotrichum musae* respectively by 0.8, 0.6% oils completely arrested the mycelial growth of both test

pathogens and reduced the crown rot severity significantly, but increased the shelf life of banana fruits. However, under low-temperature storage (14 °C) condition [112]. Essential oil was extraction from aerial parts for various traditional medicine as inflammation and fragrance industry. Oils rich of antioxidants, antimicrobial and anti-inflammatory activities. The common biological active components are citronellol, geraniol, linalool, isomethone, citronellyl formate, geranyl formate and guaia-6,9-diene [111].

Fenugreek essential oil

Essential oil of fenugreek plant (*Trigonella foenum*) is an annual plant of family Fabaceae exhibited significant inhibition of mycelial growth, 61% at 2µL/mL on anthracnose pathogen of banana fruits *C. musae* as shown in Table 2 [106].

Almond essential oil

Essential oil of almond plant (*Prunus amygdalus*) of Rosaceae family exhibited significant inhibition of mycelial growth of *C. musae* the causal of anthracnose by 57% at 2 µL/mL as shown in Table 2 [106].

Piper essential oil

Essential oil of *piper (Piper macedoi*) or pepper plants and pepper vines, belonging Piperaceae family. Essential oil of *P. macedoi* was extracted from leaves and GC-MS analysis indicated that the common components, were piperitone (26.48 %), silvestrene (13.03 %), and bicyclogermacrene (10.45 %). *In vitro*, essential oil of *P. macedoi* was controlling *C. musae* at the low inhibitory concentration for the IC50 (0.804 µL/mL) and IC90 (1.80 µL/mL) [14].

Cardamom essential oil

Cardamom essential oil is extracted from the fragrant seed pods of the (*Elettaria cardamomum*) plant, in the family Zingiberaceae mainly cultivation in India and indonesia now grown commercially throughout in tropical and subtropical Asia. Oil extraction from dark seeds in ligh green pods. EO of cardamom as coating agent of banana fruits was reduced the development of anthracnose incidence caused by *Colletotrichum musae* on banana fruits by (53.06%) [113]. The composition of cardamom oil from south India mainly contained α-terpinyl acetate (56.7%), 1,8-cineole (15.13%), α-terpineol (4.67%) and (4.05%) of limonene [10]. Oil are included α-terpinyl acetate (ranging from 35.97% to 43.39%), 1,8-cineole (24.30% to 38.99%), α-terpineol (2.56% to 7.20%), sab-inene (5.5% to 7.6%), limonene (2.4% to 4.1%), ter-pinene 4-ol (1.84% to 2.99%), α-pinene (0.51% to 1.8%), linalyl acetate (0.57% to 3.48%), geraniol (0.40% to 2.43%), and geranyl acetate (0.11% to 2.86%) [92].

Citrodara essential oil

Citriodora oil extraction from *Eucalyptus citriodora* plant belongs to family of Myrtaceae The plant is widely distribution in different countries like India, Egypt, Spain and South Africa, 22 chemical components presence of 95.27% of the oil. The maint compounds were citronellal (69.77%), citronellol (10.63%) and isopulegol (4.66%) [131] Citrodara oil at 0.09 was completely (100%) suppress the linear mycelial growth and condia spore germination of *Lasiodiplodia theobromae*, the causal pathogen of crown rot on banana fruits [104].

Other essential oils

Rosemary and Eucalyptus essential oils at 2% concentration was compeletly 100% inhibited mycelial linear growth of anthracnose causal pathogen of banana *Colletotrichum musae* [25].

Essential oils of mustard (*Brassica oleracea*), castor (*Ricinus communis*), neem (*Azadirachta indica*), coconut (*Cocos nucifera*) were reduced mycelial linear growth of the causal of postharvest disease of banana (*Colletotrichum musae*) respectively by 40.00, 38.70, 37.96, 32.04% compared the control [40]. Plant extracts of onion (*Allium cepa*), garlic (*Allium sativum*), Sadabahar (*Vinca rosea*), begunia (*Vitex negundo*) were inhibited 100% radial growth of *C. musae*. All plant extracts inhibited 100% radial growth in 20% of the mycelial radial growth of fungus *Colletotrichum* spp. the causal of postharvest diseases of banana fruits [108].

EOs of integrated control postharvest diseases of banana fruits

The integration management as effective treatments for suppressive incidence of crown rot disease of banana fruit was carried out by treatment mature fruits of banana Cv. Embul. *In vitro*, citral the main constitute of lemongrass oil showed fungicidal effect at 0.10-0.20 % against fungi caused crown rot on banana fruit. The combination between lemongrass oil and sodium bicarbonate were reduced between 99.9-99.8%. on the growth of crown rot fungal pathogens, *C. musae, L. theobromae* and *F. proliferatum.* Spray ripening banana fruits Cv. Embul with lemongrass oil alone or in combination with sodium bicarbonate were reduced disease severity by 25-50% of crown rot, and maintained maketable characters of banana fruits in good to excellent of odour, flavour, taste and overall acceptability [3]. In addition, in Table 3 dipping mature banana fruits in emulsions of cinnamon oil park, leaf or clove in combined with packaging modified atmosphere in bags of low-density polyethylene (0.075 mm), under cold room (14 ± 1 C, 90% RH) was maintenance up to 14 days at ambient temperature (28 ± 2 C), as effective method for increasing the storage shelf life of banana in a cold room for 28 ± 2 C and maintenance of the organoleptic and physico-chemical properties [98]. In *vitro*, Arabic gum did not antifungal but the in combination with cinnamon oil at (0.4%) and

Arabic gum (10%) on potato dextrose agar (PDA) medium was suppressing mycelial growth (73.4%) of *Colletotrichum musae* and inhibition (88%) of spore germination, application the same in combination as coating treatment of banana fruits was controlling anthracnose by (80%) under artificially inoculation, in addition banana, in this manner, coating treatment ripening banana fruits was significantly delayed, percentage of weight loss, firmness, soluble solids and titratable acidity [80]. *In vitro*, *Aloe vera* gel in combination with 0.1% of garlic oil highly antifungal effective than *Aloe vera* gel alone its significantly inhibited mycelial growth and spore germination of anthracnose pathogen *C. musae* on banana by (87.7 and 91.2%), respectively, under artificial infestation by anthracnose pathogen, application in combined treatment was significantly reduced incidence anthracnose disease on banana fruit by (92.5%) and suppress disease severity by (81.0%), delayed the loss of weight, firmness, soluble solids concentration, and titratable acidity, enhanced total phenolic contents and total antioxidant activities of banana fruit [60]. The integrated treatments by dipping banana fruits for 10 minutes in either (2.0%) suspensions of clove essential oil then coating with agar–agar gel (0.2%) was reduced the incidence postharvest diseases, crown, neck, finger and flower end rots caused by *Colletotrichum musae* and *Fusarium moniliforme* on banana fruits with no significances effects on fruit firmness loss and soluble solid concentration [35], in this manner, agar-agar, natural organic extraction from algae a nontoxic and non-degradable gelling agent for coating agent to protect banana fruit against fungal postharvest diseases *i.e.,* crown, finger, neck and flower end rots are caused by fungal isolates of *Colletotrichum musae* and *Fusarium moniliforme* with improving fruit quality at 2.0 $g \cdot L^{-1}$ significantly reduction in incidence and severity of postharvest diseases, improvement quality of banana fruits , its significantly decreased weight loss (%), firmness loss (%), and soluble solid concentration of banana fruit for 15 days at 25±2 ºC, as well as scanning electron microscopy (SEM) observation, the a smooth surface of banana fruits fewer cracks on the surface of banana fruits [151]. The highly antifungal of sodium alginate in combination with nanoemulsion of tea tree essential oil as film-forming solution against anthracnose incidence of banana fruits and improvement postharvest quality of banana fruits [144]. During storage, coatings banana fruits with Arabic gum (0.1 mg/mL) and *Conyza bonariensis* essential oil (0.4-1 µL/mL) was reduced the anthracnose incidence on banana under artificially infestation with *C. musae* during storage [74]. Combined treatment by coating banana fruits with basil essential oil at 1000 µL/mL and Aloe vera (2-4%) was the most effective treatment for reduction anthracnose incidence caused by the fungus of *Colletotrichum musae* in banana var. Kolikuttu fruit with no adverse effects on any of on banana fruits quality parameters and also, on sensory properties as well as help organic farmers for increasing the safety and quantity of banana fruits for exportation, during marketing and storage [113].

Essential oils mode of action against pathogenic fungi

EOs are worldwide used in agricultural industries, for commercial production of green pesticides due to their low residue, low toxicity, active at a low concentrations against major plant insects, mites, bacteria, fungi, weeds, viruses, and nematodes [17, 33, 52, 55, 63, 71, 72, 73, 91, 96, 119, 128, 129, 149, 154, 156]. More than 3000 commercial EOs are widely used for medical and food purposes because of their acceptance in cooking, medical, and food industrial products for human and animals [85]. The biological

Table 3. Integrated application EOs for controlling postharvest diseases of banana fruits.

Essential oil	*In vitro* studies pathogen inhibition			*In vivo* disease control disease reduction			References
	Fungal name	dose %	% inhibition	Disease	Method	% inhibition	
Lemongrass + sodium carbonate (NaHCO)	*C. musae*	0.06	99.93	crown rot	Spray	75.0	[3]
	L. theobromae	0.04	99.92				
	F.proliferatum	0.06	99.92				
Citral + sodium carbonate (NaHCO)	*C. musae*	0.04	99.93	crown rot	Spray	28.6	[3]
	L. theobromae	0.04	99.93				
	F.proliferatum	0.07	99.92				
Cinnamon oil bark + modified atmosphere	*C. musae*	------	----	crown rot	Vapor	69.0	[99]
Cinnamon oil leaf + modified atmosphere	*C. musae*	------	----	crown rot	Vapor	74.0	[99]
Clove oil + modified atmosphere	*C. musae*	------	----	crown rot	Vapor	21.0	[99]
Cinnammon+Arabic gum (0.4%+10%)	*C. musae*	0.04	73.4	Anthracnose	Coating	80.0	[81]
Clove + agar agar	*C. musae*	2.0	-----	crown rot	Soaking	40.0	[35]
	F. moliniforme			finger rot		60.0	
				neck rot		40.0	
				flower end rot		50.0	
Ola vera + garlic (1%)	*C. musae*	1.0	87.7	Anthracnose	Coating	92.5	[60]
Tea tree oil nanoemulsion + sodium alginate	*C. musae*	2.0	90.5	Anthracnose	----	----	[147]

----- = not detected, *C. musae* = *Colletotrichum musae*, *L. theobromae* = *L. asiodiplodia theobromae*, *F.* = *Fusarium*

activity of EOs against fungi, bacteria, and weeds make different chemical, physical, and biological properties due to the multiple chemical components, the limitations of EOs as well low residues, toxicity, and compatibility with a wide range of beneficial microorganisms are useful in managing plant pests and diseases caused by biotic and abiotic agents [51, 152]. EOs are rich in volatile components such as alcohol, phenols, aldehydes, and esters are the main volatiles content and terpenes of hydrocarbon monoterpenes (80%) of total hydrocarbons (60%) content of essential oils [11]. Essential oils of *Ocimum basilicum* and eugenol as the main chemical constitutes, were the highly inhibiting conidial germination of *Colletotrichum musae* and *Fusarium proliferatum* the causal fungi of crown rot on banana fruit after harvesting,, meanwhile, *O. basilicum* and *C. citratus* EOs and common components, eugenol and citral a+b) were highly change membrane permeability on conidia, suppress their germination and reduction infection incidence on the surface on banana fruits by inhibition appressoria formation of *C. musae* the causal pathogen of crown rot [47].

As shown in Fig. 3, EOs of thyme, clove and oregano its highly penetration the cell wall causing earlier several physiological alternatives by inhibition chitin and β-glucans cell wall synthesis enzymes of fungi, bacteria, and weeds [138], essential oils of oregano and fennel are deterioration *Sclerotinia sclerotiorum* mycelial growth, spores and sclerotia formation by change morphology of the fungal cell wall regarding to interference with reactions of wall synthesis enzymes, which affect fungal growth and morphogenesis [122]. The antifungal of (EOs) are increasing permeability of their plasma membranes which causing morphological changes in cell originals mainly of mitochondrial membranes and deterioration of cytoplasm contents, disrupt cell structure and finally cell death [69]. EOs of clove, almond and fenugreek were severely damaged mycelium and conidia anthracnose pathogen of banana fruits *Colletotrichum musae*, regarding to phenols, terpenes, aldehydes, and ketones [105]. During invasion process on banana fruits by crown rot pathogen of *C. musae* fungus, treatment with native essential oils of *O. basilicum* and *C. citratu*s and their constitutes of eugenol, citral a + b were inhibiting formation of appressoria, permeability of conidial membranes conidial germination and disruption of conidial activity of banana pathogens [47]. Eugenol, the main biological active component in clove essential oil, changes structure of plasma membrane, physiological characterizations, change the morphology in hyphae by accumulation of cytoplasm, and increased vaculation formation of mycelial of *Botrytis cinerea* [139]. The biological effect of black seed EOs regarding to thymoquinone a main chemical component was effective against mycelial growth of *Candida* spp by deterioration cytoplasmic cell membrane, spore germination, germ tube elongation [52]. Moreover, *Origanum compactum* EO was increase membrane permeability, disturb cell membrane integrity, and suppress quorum-sensing phenotype in bacteria [20]. In this manner, cinnamon essential oil was inhibition fungal cell wall synthesizing (chitin synthase 1) enzymes by transcinnamaldehyde [12]. In this respect, the oregano and fennel EOs clear malformations of fungal mycelial diameter, coagulations of cytoplasm, necrosis, and lysis, and changing the shape of sclerotia formation by *Sclerotinia sclerotiorum* [122]. Thymol and carvacrol on *Origanum vulgare* oil, were increasing cell permeability and damaing membrane of mitochondria of *Botrytis cinerea* [48]. Essential oil of cassia and holy basil were suppress activity of chitin synthetic enzyme for building fungal cell wall of hyphae regarding to some chemical constitutes, eugenol, cinnamyl acetate, caryophyllene, humulene and *trans*-calamenene [65]. In this respect, scanning electron microscopy revealed thymoquinone of black cumin seed oil, showed anti *Candida* spp. [52]. Scanning electron microscope revealed exposure conidia to Cronquist essential oil (*Conyza bonariensis*) at (0.6 µL/mL) to 3 and 5 days, was causing damage of cytoplasmic membrane [74]. EOs of cinnamon and clove were suppressive components for synthesis cell wall of fungi *B. dothidea* and *C. gloeosporioides* causing postharvest decay of bagging-free apples. Observation by scanning electron microscope (TEM) clarify the changing of of mycelial growth and morphology, alternation the structure shape of cell membranes of organelles as well as biological functions of cytoplasm [140]. In addition, eugenol, the main constitute in clove essential oil, strongly malformation shape of mycelial hyphae, plasma membrane, change physiological characterizations, accumulation of cytoplasm, and increasing vacuolation formation on the fungus of *Botrytis cinerea* [139]. Morover, eugenol was reported an elicitor for inducing systemic acquired resistance of plants by enhancing enzymes activity of peroxidase, polyphenol oxidase and phenylalanine ammonia-lyase as well increase salicylic acid levels as well protein-related pathogeneses [142].

CONCLUSIONS

Essential oils, of cinnamon, lemongrass, clove oil, black seed oil, bail and tea tree are the promising green fungicides showed highly effective antifungal on the mycelial growth, sporulation, spore germination and appressoria formation during infection process of the pathogenic fungi causing postharvest spoilage of banana fruits. EOs its highly responsive in combination treatments with other biotic and a biotic agents as well as with edible coating agents for increasing the shelf life and maintenance ripe banana fruits in high quality after harvesting during transportation, marketing and storage. Therefore, the development products by modern technologies for production EOs in various encapsulation as micro and nanoemulsion formulations are necessary for replacing synthetic chemical

pesticides in capsules based on slow release components during biodegradation of the polymer carriers as a green eco-friendly to permanently control a wide range of epidemic plant pests, diseases, and weeds under various conditions.

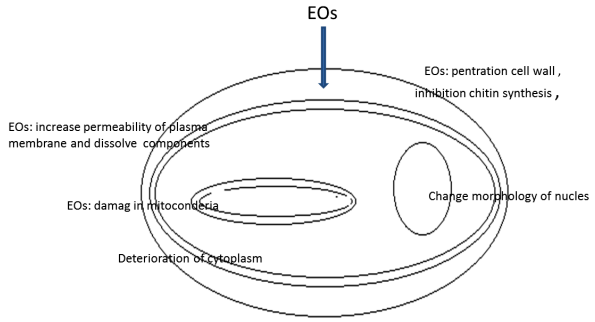

Figure 3. EOs effect on cell of microorganisms, its penetration and inhibition cell wall, degradation plasma membrane, mitochondria, nuclus, and cytoplasm

Conflict of interest: There is no actual or potential conflict of interest in relation to this article.

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