

Supplementary Materials

Review

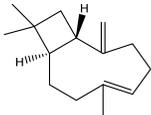
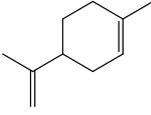
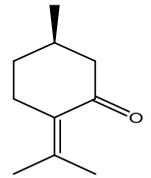
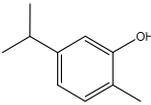
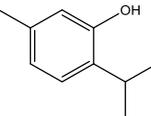
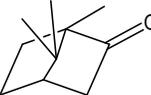
Synergistic Antioxidant and Antibacterial Advantages of Essential Oils for Food Packaging Applications

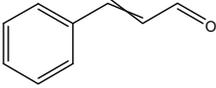
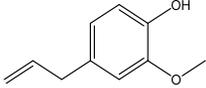
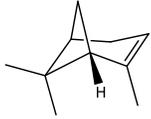
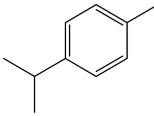
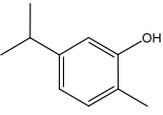
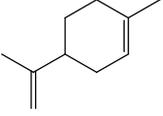
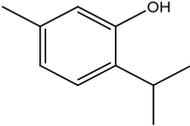
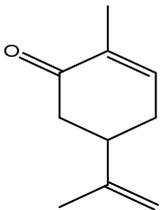
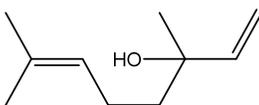
Nagaraj Basavegowda and Kwang-Hyun Baek *

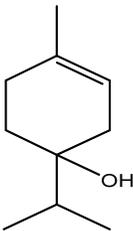
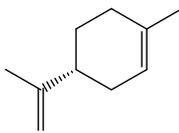
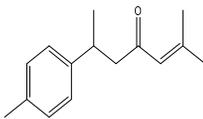
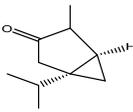
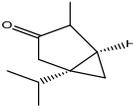
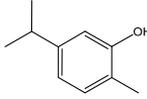
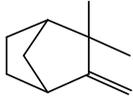
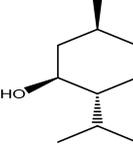
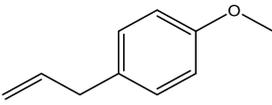
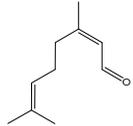
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Table S1. Overview of studies on antioxidant properties of selected essential oils.

Essential Oils	Plant Source	Major Components	Molecular Structure	Assay	Ref.
Shady calamint	<i>Clinopodium umbrosum</i>	β -Caryophyllene, germacrene D, spathulenol		DPPH, FRAP, LPI, TAC	[1]
Lemon beebrush	<i>Aloysia triphylla</i>	Limonene, geranial, myrcene		DPPH, TPC	[2]
Tipollo	<i>Minthostachys mollis</i>	Pulegone, menthone, limonene		DPPH, TPC	[2]
Dittany	<i>Origanum dictamnus</i>	Carvacrol, γ -terpinene, <i>p</i> -cymene		DPPH	[3]
Thyme	<i>Thymus fontanesii</i>	Thymol, <i>p</i> -cymene		DPPH, FRAP	[4]
White Wormwood.	<i>Artemisia herba-alba</i>	Camphor, chrysanthenone		DPPH, FRAP	[4]
Rosemary	<i>Rosmarinus officinalis</i>	1,8-Cineole, camphene, α -pinene		DPPH, FRAP	[4]

Cinnamon	<i>Cinnamomum zeylanicum</i>	Cinnamaldehyde, β -caryophyllene		DPPH, BCB, FIC	[5]
Clove	<i>Syzygium aromaticum</i>	Eugenol, β -caryophyllene		DPPH, BCB, FIC	[5]
Black pepper	<i>Piper nigrum</i>	α -Pinene, β -pinene, β -Caryophyllene		DPPH, BCB, FIC	[5]
Winter savory	<i>Satureja montana</i>	<i>p</i> -Cymene, borneol, γ -terpinene		DPPH	[6]
Oregano	<i>Origanum vulgare</i>	Carvacrol, γ -terpinene, <i>p</i> -cymene		DPPH	[6]
Lemon	<i>Citrus limon</i>	β -Pinene, Limonene, Linalool		DPPH, BCB	[7]
Thyme	<i>Thymus quinquecostatus</i>	Thymol, γ -terpinene, <i>p</i> -cymene		DPPH, ABTS, FRAP	[8]
Laminaria (Kumbu)	<i>Laminaria japonica</i>	Tetradecanoic acid, hexadecanoic		DPPH, ABTS	[9]
Spearmint	<i>Mentha viridis</i>	Carvone, 1,8-cineole, terpinen-4-ol		DPPH, ABTS, FRAP	[10]
Basil	<i>Ocimum basilicum</i>	Linalool, estragole, methyl cinnamate		DPPH	[11]

Tea tree	<i>Melaleuca alternifolia</i>	Terpinen-4-ol, γ -terpinene, α -terpinene		DPPH, TBARS	[12]
Neroli	<i>Citrus aurantium</i>	D-limonene, γ -terpinene, linalool		DPPH, ABTS	[13]
Turmeric	<i>Curcuma longa</i>	α -Turmerone, β -turmerone, ar-turmerone		DPPH, ABTS	[14]
Costmary	<i>Tanacetum balsamita</i>	β -Thujone, α -thujone, eucalyptol		DPPH, FRAP	[15]
Tansy	<i>Tanacetum vulgare</i>	trans-Chrysanthenyl acetate, β -thujone, (E)-dihydrocarvone		DPPH, FRAP	[15]
Shirazi thyme	<i>Zataria multiflora</i>	Carvacrol, thymol, thymol acetate		Phosphomolybdate assay	[16]
Ginger	<i>Zingiber officinale</i>	Camphene, β -phellandrene, 1,8-cineole		DPPH, FRAP, BCB	[17]
Peppermint	<i>Aetheroleum menthae piperitae</i>	Menthol, menthone, isomenthone		DPPH	[18]
Anise Hyssop	<i>Agastache foeniculum</i>	Methyl chavicol, limonene, spathulenol		DPPH ABTS	[19]
Dill	<i>Anethum graveolens</i>	Neral, carvone, limonene		DPPH, FRAP, BCB	[17]

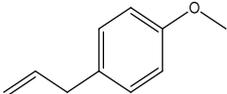
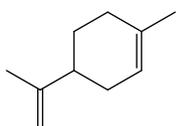
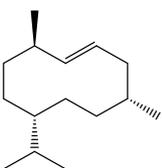
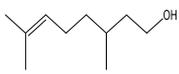
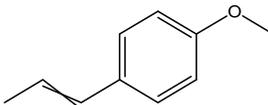
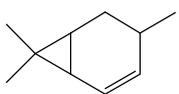
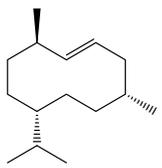
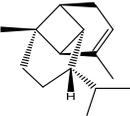
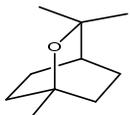
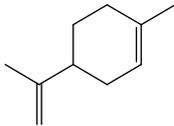
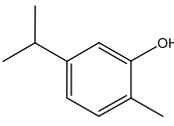
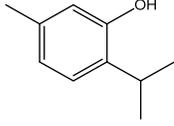
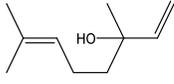
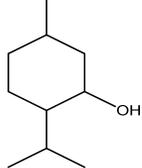
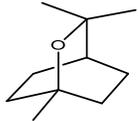
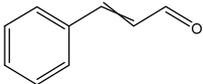
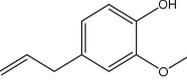
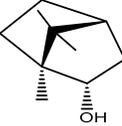
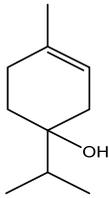
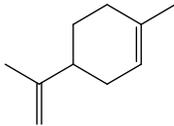
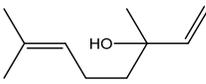
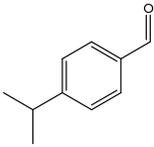
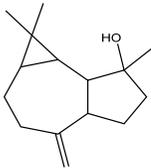
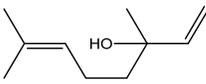
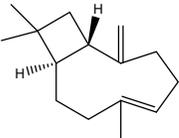
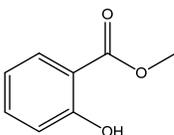
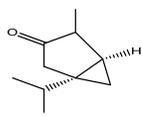
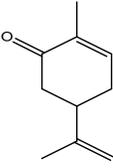
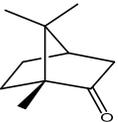
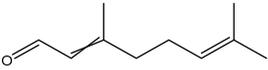
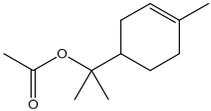
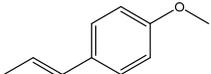
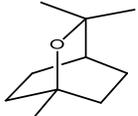
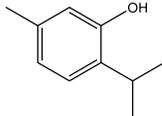
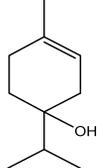
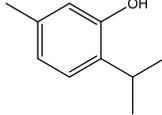
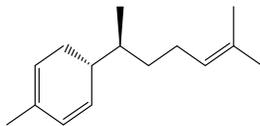
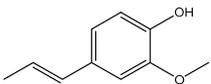
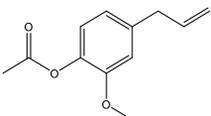
Terragon	<i>Artemisia dracunculus</i>	<i>p</i> -Allylanisole, ocimene (E)- β , ocimene (Z)- β		DPPH, TPC, TFC	[20]
Khat	<i>Catha edulis Forsk</i>	Limonene, tritetracontane, 1-phenyl-1,2-propanedione		DPPH	[21]
Chamomile	<i>Ormenis mixta</i>	Germacrene, 1,8-cineole, cis-methyl isoeugenol		DPPH	[22]
Geranium	<i>Pelargonium asperum</i>	Citronellol, citronellyl formate, geraniol		DPPH	[22]
Saxifrage	<i>Pimpinella saxifraga</i>	Anethole, pseudoisoeugenol, p-anisaldehyde		DPPH, FRAP	[23]
Pistachio	<i>Pistacia vera</i>	4-Carene, α -pinene, D-limonene		DPPH, FRAP	[24]
Jashir	<i>Prangos gaubae</i>	Germacrene D, caryophyllene oxide, (E)-caryophyllene		ABTS, FRAP	[25]
Cattley guava	<i>Psidium cattleianum</i>	α -Copaene, eucalyptol, δ -cadinene		DPPH	[26]
Eucalyptus	<i>Eucalyptus globulus</i>	1,8-Cineole, α -pinene, o-cymene		DPPH, BCB	[27]
Laurel	<i>Laurus nobilis</i>	1,8-Cineole, α -terpinyl acetate, 4-terpineol		DPPH, FRAP, BCB	[17]

Table S2. Antibacterial efficacy of various essential oils and their components against different pathogenic bacteria.

Essential Oils	Plant Source	Major Constituents	Molecular Structure	Microbial Strains	Ref.
Lemon	<i>Citrus limon</i>	Limonene, β -pinene, α -pinene		<i>S. aureus</i> , <i>E. faecalis</i> , <i>E. coli</i> , <i>K. pneumonia</i> , <i>P. aeruginosa</i>	[28]
Oregano	<i>Origanum vulgare</i>	Carvacrol, monoterpenoid phenol		<i>S. aureus</i> , <i>E. faecalis</i> , <i>E. coli</i> , <i>K. pneumonia</i> , <i>P. aeruginosa</i>	[28]
Thyme	<i>Thymus vulgaris</i>	Thymol, γ -terpinene, carvacrol		<i>S. aureus</i> , <i>E. faecalis</i> , <i>E. coli</i> , <i>K. pneumonia</i> , <i>P. aeruginosa</i>	[28]
Lavender	<i>Lavandula angustifolia</i>	Linalool, linalyl acetate		<i>S. aureus</i> , <i>Enterococcus sp.</i>	[29]
Peppermint	<i>Mentha spicata</i>	Menthol, mentone, cineol		<i>S. aureus</i> , <i>E. coli</i>	[30]
Cajuput	<i>Melaleuca cajuputi</i>	1,8-Cineole, γ -terpinene, limonene		<i>S. aureus</i> , <i>S. epidermidis</i> , <i>B. cereus</i>	[30]
Cinnamon	<i>Cinnamomum Zeylanicum</i>	Cinnamaldehyde, eugenol		<i>S. aureus</i> , <i>E. coli</i> , <i>P. aeruginosa</i>	[31]
Clove	<i>Syzygium aromaticum</i>	Eugenol, β -caryophyllene		<i>S. aureus</i> , <i>E. coli</i> , <i>P. aeruginosa</i>	[31]
Eucalyptus	<i>Eucalyptus globulus</i>	1,8-Cineole, α -pinene		<i>S. aureus</i> , <i>E. coli</i>	[32]
Sage	<i>Salvia officinalis</i>	Borneol, camphor, 1,8-cineole		<i>B. subtilis</i> , <i>S. epidermidis</i>	[33]

Tea Tree	<i>Melaleuca alternifolia</i>	Terpine-4-ol, teripene, α -terpinene		<i>S. aureus</i> , <i>E. coli</i> , <i>P. aeruginosa</i>	[34]
Caraway	<i>Carum carvi</i>	Limonene, carvone, β -myrcene		<i>E. coli</i> , <i>B. bronchiseptica</i>	[35]
Coriander	<i>Coriandrum sativum</i>	Linalool, λ -terpinene, α -pinene		<i>E. coli</i> , <i>B. bronchiseptica</i>	[35]
Cumin	<i>Cuminum cyminum</i>	Cuminaldehyde, γ -terpinene,		<i>E. coli</i> , <i>B. bronchiseptica</i>	[35]
Vassoura	<i>Baccharis dracunculifolia</i>	Spathulenol, trans-nerolidol		<i>S. aureus</i> , <i>B. cereus</i> , <i>P. aeruginosa</i>	[36]
Basil	<i>Ocimum basilicum</i>	Linalool, estragole		<i>S. aureus</i> , <i>S. pyogenes</i> , <i>E. coli</i>	[37]
Black pepper	<i>Piper nigrum</i>	β -Caryophyllene, caryophyllene oxide		<i>B. cereus</i> , <i>L. monocytogenes</i> , <i>M. luteus</i>	[5]
Wintergreen	<i>Gaultheria procumbens</i>	Methyl salicylate, α -pinene, myrcene		<i>P. syringae</i>	[6]
Armoise	<i>Artemisia herba alba</i>	β -Thujone, camphor, α -thujone		<i>S. aureus</i> , <i>E. coli</i> , <i>P. aeruginosa</i>	[38]
Dill weed	<i>Anethum graveolens</i>	Carvone, limonene, carvocrol		<i>S. aureus</i> , <i>E. coli</i>	[39]

Camphor	<i>Cinnamomum camphora</i>	D-camphor, linalool, cineole		<i>B. subtilis</i> , <i>S. aureus</i> , <i>E. coli</i>	[40]
Lemon grass	<i>Cymbopogon citratus</i>	Citral α , citral β , nerol,		<i>S. aureus</i> , <i>E. coli</i>	[41]
Cardamom	<i>Elettaria cardamomum</i>	A-terpinyl acetate, 1,8-cineole, linalyl acetate		<i>S. aureus</i> , <i>E. coli</i>	[39]
Anise	<i>Pimpinella anisum</i>	Trans-anethole, p-anisaldehyde, methyl chavicol		<i>B. subtilis</i> , <i>S. aureus</i> , <i>E. coli</i>	[40]
Rosemary	<i>Rosmarinus officinalis</i>	1,8-Cineole, camphor, α -pinene, limonene		<i>B. subtilis</i> , <i>E. coli</i> , <i>L. monocytogenes</i>	[42]
Savory	<i>Satureja hortensis</i>	Thymol, γ -terpinene, o-cymene		<i>E. coli</i> , <i>L. monocytogenes</i> , <i>S. aureus</i>	[43]
Pepper	<i>Zanthoxylum bungeanum</i>	Terpinene-4-ol, 1,8-cineole, limonene		<i>B. subtilis</i> , <i>S. aureus</i> , <i>E. coli</i>	[40]
Zataria	<i>Zataria multiflora</i>	Thymol, p-cymene, carvacrol		<i>B. cereus</i> , <i>S. aureus</i> , <i>E. coli</i>	[16]
Ginger	<i>Zingiber officinale</i> <i>Roscoe</i>	Zingiberene, β -phellandrene, sesquiphellandrene		<i>E. coli</i> , <i>E. faecalis</i> , <i>K. pneumoniae</i>	[44]
Arina	<i>Psiadia arguta</i>	Isoeugenol, isoeugenyl acetate		<i>S. epidermidis</i> , <i>S. aureus</i> , <i>E. faecalis</i>	[45]
Betel leaf	<i>Piper betle</i>	Eugenol acetate, eugenol, β -caryophyllene		<i>S. epidermidis</i> , <i>S. aureus</i> , <i>E. faecalis</i>	[45]

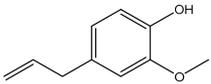
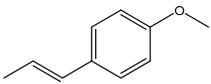
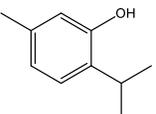
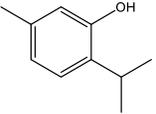
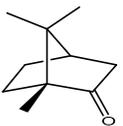
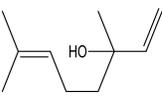
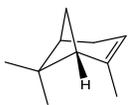
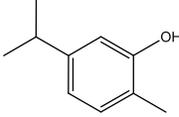
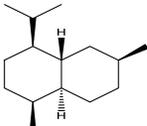
Allspice	<i>Pimenta dioica</i>	Eugenol, methyl eugenol, β -caryophyllene		<i>S. epidermidis</i> , <i>S. aureus</i> , <i>E. faecalis</i>	[45]
Aniseed	<i>Pimpinella anisum</i>	Trans-anethole, estragole, γ -himachalene		<i>C. perfringens</i>	[46]
Garlic	<i>Allium sativum</i>	Diallyl trisulfide, diallyl disulfide, methyl allyl trisulfide		<i>E. coli</i>	[47]

Table S3. Synergistic antioxidant effects of different essential oils, their major constituents, with various in vitro assays.

Essential Oils	Plant Source	Major Constituents	Molecular Structure	Assay	Ref.
Thyme/ Rosemary	<i>Thymus fontanesii</i> / <i>Rosmarinus officinalis</i>	Thymol, <i>p</i> -cymene/1,8-cineole, camphre		DPPH, FRAP	[4]
Thyme/White Wormwood.	<i>Thymus fontanesii</i> / <i>Artemisia herba-alba</i>	Thymol, <i>p</i> -cymene/Camphor, chrysanthenone		DPPH, FRAP	[48]
White Wormwood/Rose mary	<i>Artemisia herba-alba</i> / <i>Rosmarinus officinalis</i>	Camphor, chrysanthenone/1,8- cineole, camphre		DPPH, FRAP	[48]
Coriander/ Cumin	<i>Coriandrum sativum</i> / <i>Cuminum cyminum</i>	Linalool, <i>p</i> -coumaric acid/cuminaldehyde, <i>p</i> -cymene		DPPH	[48]
Thyme/Celery/ Coriander	<i>Thymus vulgaris</i> / <i>Apium graveolens</i> / <i>Coriandrum sativum</i>	α -Pinene, thymol/citronellol, geraniol/linalool		FRAP, ABTS	[49]
Thyme/Oregano	<i>Thymus leptobotrys</i> / <i>Origanum compactum</i>	Carvacrol, <i>p</i> -cymene/ β -Myrcene, α -phellandrene		DPPH	[50]
Marigold/ Oregano	<i>Calendula officinalis</i> / <i>Origanum compactum</i>	α -Cadinene, δ -cadinene/ β - myrcene, α -phellandrene		DPPH	[50]

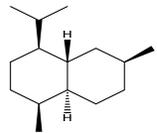
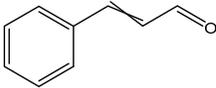
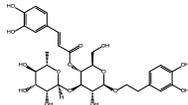
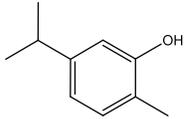
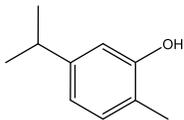
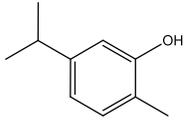
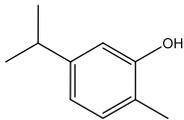
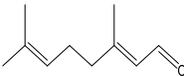
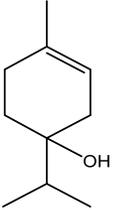
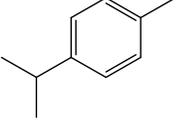
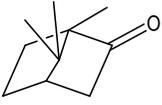
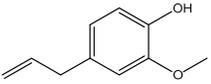
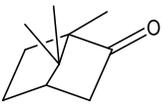
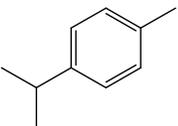
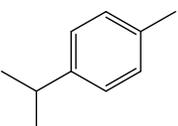
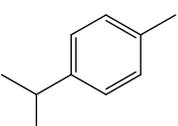
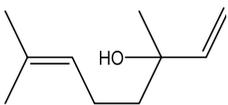
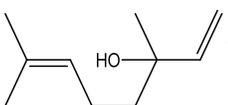
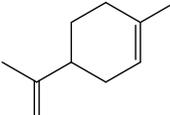
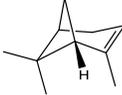
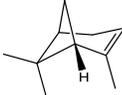
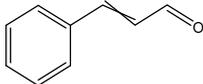
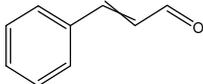
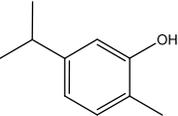
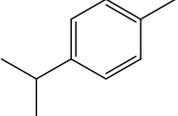
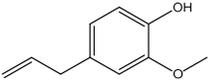
Marigold/ Thyme	<i>Calendula officinalis</i> / <i>Thymus leptobotrys</i>	α -Cadinene, δ - cadinene/carvacrol, p-cymene		DPPH	[50]
Cinnamon/Clove	<i>Cinnamomum zeylancium</i> / <i>Syzygium aromaticum</i>	Cinnamaldehyde, linalool/eugenol, eugenol acetate		DPPH	[51]
Sweet olive/ Green tea	<i>Osmanthus fragrans</i> / Green tea	Acteoside, salidroside/caffeine, gallic acid		DPPH	[52]
Oregano/ Ajowan	<i>Oreganum vulgare</i> / <i>Trachyspermum ammi</i>	Carvacrol, thymol/ γ -terpinene, p-cymene		DPPH, BCB	[53]
Ajowan/ Borage	<i>Trachyspermum ammi</i> / <i>Plectranthus amboinicus</i>	γ -Terpinene, p- cymene/carvacrol, γ -terpinene		DPPH, BCB	[53]
Borage/ Oregano	<i>Plectranthus Amboinicus</i> / <i>Oreganum vulgare</i>	Carvacrol, γ - terpinene/Carvacrol, thymol		DPPH, BCB	[53]
Oregano/ Ajowan/ Borage	<i>Oreganum vulgare</i> / <i>Trachyspermum ammi</i> / <i>Plectranthus amboinicus</i>	Carvacrol, thymol/ γ -terpinene, p-cymene/carvacrol, γ -terpinene		DPPH, BCB	[53]
Lemon myrtle/Kakadu plum/Finger lime/Australian sprouts	<i>Backhousia citriodora</i> / <i>Terminalia ferdinandiana</i> / <i>Citrus australasica</i> / <i>Lophopyrum ponticum</i>	Geranial, neral/linoleic acid, oleic acid/bicyclogermacrene, α - pinene		DPPH	[54]

Table S4. Combination of different essential oils with major constituents and their antibacterial interactions against various microorganisms.

Essential Oils	Plant Source	Major Constituents	Molecular Structure	Microbial Strains	Ref.
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Lavender/ Marjoram	<i>Lavandula dentata/ Origanum majorana</i>	Terpinene-4-ol, trans-4- thujanol/ β -pinene, 1,8- cineole		<i>S. aureus, E. coli</i> [55]
Thyme/ Marjoram	<i>Thymus serpyllum/ Origanum majorana</i>	<i>p</i> -Cymene and γ - terpinene/ β -pinene and 1,8- cineole		<i>S. aureus, E. coli</i> [55]
Fingerroot/ Basil	<i>Boesenbergia pandurata /Ocimum sanctum</i>	Camphor, 1,8-cineole/ eugenol, methyl-eugenol		<i>L. monocytogenes, S. aureus, E. coli, S. enterica</i> [56]
Basil/ Lemongrass	<i>Ocimum sanctum/Cymbopogon citratius</i>	Eugenol, methyl- eugenol/citral		<i>E. coli, S. enterica</i> [56]
Fingerroot/ Lemongrass	<i>Boesenbergia pandurata /Cymbopogon citratius</i>	Camphor, 1,8-cineole/ citral		<i>S. enterica</i> [56]
Thyme/ Parsley	<i>Thymus capitatus/ Petroselinum sativum</i>	<i>p</i> -Cymene/myristicin		<i>L. monocytogenes</i> [57]
Thyme/ Cumin	<i>Thymus capitatus/ Cuminum cyminum</i>	<i>p</i> -Cymene/cuminaldehyde, <i>p</i> -cymene		<i>S. aureus</i> [57]
Thyme/Garlic	<i>Thymus capitatus/ Allium sativum</i>	<i>p</i> -cymene/diallyl disulfide		<i>S. aureus</i> [57]
Lavender/ Camphor	<i>Lavandula latifolia/ Cinnamomum camphora</i>	Linalool, 1,8- cineole/camphor, linalool		<i>L. monocytogenes, S. aureus</i> [58]
Coriander/ Cumin	<i>Coriandrum sativum/Cuminum cyminum</i>	Linalool, <i>p</i> -coumaric acid/cuminaldehyde, <i>p</i> -cymene		<i>S. typhimurium/M. Luteus</i> [59]

Black pepper/ Cumin/Cinnamon/ Turmeric	<i>Piper nigrum/Cuminum cyminum/Cinnamomum verum/Curcuma longa</i>	Limonene/cuminaldehyde/ eugenol/ β -Turmerone		<i>S. epidermidis</i>	[60]
Black pepper/Cinnamon	<i>Piper nigerium/Cinnamomum zeylancium</i>	α -Pinene, β - pinene/cinnamaldehyde, linalool		<i>L. monocytogenes, S. aureus, S. typhimurium</i>	[61]
Black pepper/Clove	<i>Piper nigrum/Syzygium aromaticum</i>	α -Pinene, β -pinene/eugenol, β -caryophyllene		<i>L. monocytogenes, S. aureus, S. typhimurium</i>	[61]
Cinnamon/Clove	<i>Cinnamomum zeylancium/Syzygium aromaticum</i>	Cinnamaldehyde, linalool/eugenol, eugenol acetate		<i>L. monocytogenes, S. aureus, S. typhimurium</i>	[61]
Cinnamon/ Oregano	<i>Cinnamomum zeylanicum/Origanum vulgare</i>	Cinnamaldehyde, linalool/carvacrol, <i>p</i> -cymene		<i>S. aureus</i>	[62]
Oregano/ Rosemary	<i>Origanum vulgare/ Rosmarinus officinalis</i>	Carvacrol, <i>p</i> -cymene/ 1,8-cineole, camphor		<i>L. monocytogenes, Y. enterocolitica, A. hydrophilla.</i>	[63]
Lippia/ Peppermint	<i>Lippia multiflora/ Mentha piperita</i>	<i>p</i> -Cymene, β - caryophyllene/menthol, menthone		<i>E. coli, E. aerogenes</i>	[64]
Clove/ Rosemary	<i>Syzygium aromaticum/ Rosmarinus officinalis</i>	Eugenol, β - caryophyllene/1,8-cineole, α -pinene		<i>C. albicans</i>	[65]

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