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Review

APPLICATION OF ESSENTIAL OILS AND THEIR BIOLOGICAL EFFECTS ON EXTENDING THE SHELF-LIFE AND QUALITY OF HORTICULTURAL CROPS

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ABSTRACT
Essential oils are volatile, natural, complex compounds characterized by a strong odour and are formed by aromatic plants as secondary metabolites. EOs or ethereal oils are also aromatic oily liquids obtained by steam or hydro-distillation from plant materials such as flowers, buds, seeds, leaves, twigs, bark, herbs, wood, fruits and roots. An estimated 3000 EOs are known, of which about 300 are commercially important. Food products such as fruits and vegetables are now often sold in areas of the world far from their production sites, thus the need for extended safe shelf-life for these products has also expanded. The widespread use of pesticides has significant drawbacks including increased cost, handling hazards, concern about pesticide residues on food, and threat to human health and environment. Thus, the potential value of these agents as secondary preservatives is considered for the safe extension of perishable products shelf-life and these substances can be used to delay or inhibit the growth of microorganisms. This paper will be review the recent research on the application and mode of action of EOs in postharvest perishable products such as fruits and vegetables.

Key words: Essential oils, Antimicrobial, Postharvest, Fruits, Shelf-life.

INTRODUCTION

EOs also called volatiles are aromatic oily liquids extracted from various aromatic plants materials such as flowers, buds, seeds, leaves, twigs, bark, herbs, wood, fruits and roots (1). An estimated 3000 EOs are known, of which about 300 are commercially important destined chiefly for the flavors and fragrances market (2). For combating infectious or parasitic agents, plants synthesize secondary metabolites which may be present constitutively or generated from inactive precursors in response to stress. Preformed substances pro- or inhibitions in plant tissue include phenolic compounds, flavonols, flavonoids, glycosides, alkaloids, and even poly-'acetylenes (3, 4). Although spices have been used for their perfume, flavor and preservative properties since antiquity, of the known EOs, only oil of turpentine was mentioned by Greek and Roman historians (5). Distillation as a method of producing EOs was first used in the Egypt, India and Persia more than 2000 years ago and was improved in the 9th century by the Arabs. EOs was being made by pharmacies and their pharmacological effects were described in pharmacopoeias (1). But their use does not appear to have been widespread in Europe until the 16th century. In the 17th century the preparation of EOs were well known and pharmacies generally stocked 15-20 different oils. The use of tea tree oil for medical purposes has been documented since the colonization of

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Australia at the end of the 18th century, although it is likely to have been used by the native Australians before that (5). There are several methods for extracting essential oils. These may include use of liquid carbon dioxide or microwaves, and mainly low or high pressure distillation employing boiling water or hot steam. Steam distillation is the most commonly used method for producing EOs on a commercial basis. EOs are volatiles and therefore need to be stored in airtight containers in the dark in order to prevent compositional changes (5). Most of the commercialized essential oils are identified and quantified by gas chromatography and mass spectrometry analysis (6). EOs have been largely employed for their properties already observed in nature, i.e. for their antibacterial, antifungal and insecticidal activities (5).

EOs PROPERTIES

The first experimental measurement of the bactericidal properties of the vapours of EO is said to have been carried out by Dla Croix in 1881 (5). In the course of the 19th and 20th centuries the use of EOs in medicine gradually became secondary to their use for flavour and aroma. EOs, aromatic volatile products of plant secondary metabolism, has formed the basis of many applications in food flavoring and preservation industries (7). Several studies have demonstrated that complex natural nutrients like vegetables, fruits, herbs and spices contain numerous antioxidant molecules such as carotenoids, retinoids, tocopherols, ascorbic acid, phenolic acids, flavonoids and polyphenols (2). EOs also includes antioxidants such as terpenoid and phenolic components. The antioxidant property of essential oils and components has been very often verified *in vitro* by physical/chemical methods. In particular, the antioxidant capacity of some phenolic compounds has been invoked to promote their use as natural food additives. For example, some essential oils showing different levels of cytotoxicity exhibited different antioxidative capacities depending on the composition of the oil and especially on their phenolic content (2). The phenolic components of EOs are chiefly responsible for the antibacterial properties (5,8). Most chemical components of EOs are terpenoids, including monoterpenes, sesquiterpenes, and their oxygenated derivatives. The active antimicrobial compounds of Eos also are generally terpenes (7). The antifungal properties of eighteen essential oils were evaluated *in vitro* by addition to the fungal growth medium of five pathogens (*Lasiodiplodia theobromae*, *Colletotrichum gloeosporioides*, *Alternaria citrii*, *Botrytis cinerea* and *Penicillium digitatum*) isolated from mango, avocado, citrus, grapes and cactus pear (6). Thymol, thyme oil, and zataria oil are also EOs which have been found effective against some bacteria and fungi, and are used for controlling plant diseases, particularly on fruit (2, 8). The antioxidant activity of EOs was compared to that of ascorbic acid. This synthetic additive would not be allowed in organically produced vegetables. Nevertheless, it is a chemical additive commonly used in food systems. Although the antioxidant effects of the natural EOs were lower compared to synthetic ascorbic acid solutions, they would provide other benefits as antimicrobial agents (9). The data obtained indicate that while the EOs of sage, mint, hyssop and camomile had generally a bacteriostatic activity, the essential oil from oregano appeared to be bactericidal at concentrations above 400 ppm, probably because of high contents in phenolic compounds (10). EOs because of their antibacterial, antifungal, antioxidant and anti-carcinogenic properties can be used as natural additives in many foods. In general, the levels of EOs and their compounds necessary to inhibit microbial growth are higher in foods than in culture media (11). Moreover, the use of vapor treatments is ideal for controlling food spoilage because it leaves no residual EOs (7). Although EOs and botanical extracts are commercially available as preharvest fungicides for organic farming, fewer studies have been directed towards postharvest application. According to Smale et al. (2000), the chemical composition of *Eucalyptus olida* EOs shows significant interspecies variability which appears to depend on both the genetic characteristics of the plants as well as the conditions under which they are grown (12). EOs compositions are largely determined by genetic, climatic, geographical and seasonal factors (6). The composition of EOs from a particular species of plant can differ between harvesting seasons and between geographical sources (4).

IMPORTANT EOs

Plant volatiles are low-molecular-weight compounds (below 300 Da) and can be divided into three major classes, terpenoids (also known as isoprenoids), phenylpropanoids/benzenoids, and fatty acid derivatives **(Figure 1).** Moreover, volatiles derived from amino acids are often present in scent and aromas released from flowers and fruits. Although volatile compounds are synthesized via a few major biochemical pathways, various forms of enzymatic modifications such as hydroxylations, acetylations, and methylations, add to the diversity of emitted volatiles by increasing their volatility at the final step of their formation (13). Volatile terpenoids represented by mainly isoprene (C_5), monoterpenes (C_{10}) and sesquiterpenes (C_{15}) constitute the largest class of plant volatile compounds. All terpenoids are synthesized from the universal five carbon precursors, isopentenyl diphosphate (IPP) and dimethylallyl diphosphate (DMAPP), which are derived from two alternate biosynthetic pathways localized in different subcellular compartments (4, 14). Among these, the oils of clove, oregano, rosemary, thyme, sage and vanillin have been found to be most consistently effective against microorganisms. They are generally more inhibitory against Gram-positive than against Gram negative bacteria (3). The phenolic compounds are chiefly responsible for properties of EOs. The major EOs are summarized as following:

1. Carvacrol

Carvacrol is one of the important EOs which present as main component in thyme and oregano oils. Carvacrol has the hydroxil group on the phenolic ring. *P*-cymene as the biological precursor of carvacrol is hydrophobic and causes swelling of the cytoplasmic membrane to a greater extent than does carvacrol. *P*-cymene is not an effective antibacterial when used alone (5, 4). The greater efficiency of *p*-cymene at being incorporated in the lipid bilayer of *Bacillus cereus* very likely facilitates transport of carvacrol across the cytoplasmic membrane (15). The volatile terpenes carvacrol, *p*-cymene and thymol are probably responsible for the antimicrobial activity of oregano, thyme and savory (3). Carvacrol has been recognised as one of the most potent monoterpenoid with antifungal activity against *Botrytis* and inhibited totally the spore germination and mycelium development in potato dextrose agar (PDA) (16).

2. Eugenol

Eugenol is a major component (approximately 85%) of clove oil. Sub-lethal concentrations of eugenol have been found to inhibit production of amylase and proteases by *B. cereus*. Cell wall deterioration and a high degree of cell lysis were also noted (17). The hydroxyl group on eugenol is thought to bind to proteins, preventing enzyme action in *E. aerogenes* (5). Applied different formulations amended with eugenol oil (*Eugenia caryophylata*) to two apple cultivars and successfully reduced the disease incidence after cold storage (18).

3. Thymol

Thymol is strucurally very similar to carvacrol, having the hydroxil group at the different location on the phenolic ring. Thymol, thyme oil, and zataria oil are also EOs which have been found effective against some bacteria and fungi, and are used for controlling plant diseases, particularly on fruit (2, 4).

4. Other EOs

Activity of sage and rosemary is due to borneol and other phenolics in the terpene fraction (3). Lemon grass oil was found to contain the highest concentration of citral (42.5% geraniol and 31.7% neral, totalling 84.8% citral) compared to the other citral-rich oils (6). *Lippia scaberrima* Sond. (*Verbenaceae*), a medicinal aromatic plant indigenous to South Africa, yields an essential oil rich in R-carvone, (d)-limonene and 1,8-cineole. EOs of *Lippia scaberrima* Sond. contains limonene and carvone as main components (19).

Aloe vera has been used for many centuries for its curative and therapeutic properties and although over 75 active ingredients from the inner gel have been identified, therapeutic effects have not been correlated well with each individual component. Many of the medicinal effects of aloe leaf extracts have been attributed to the polysaccharides found in the inner leaf parenchymatous tissue, but it is believed that these biological activities should be assigned to a synergistic action of the compounds contained therein rather than a single chemical substance. The three structural components of the *Aloe vera* pulp are the cell walls, the degenerated organelles and the viscous liquid contained within the cells. The raw pulp of *A. vera* contains approximately 98.5% water, while the mucilage or gel consists of about 99.5% water. The remaining 0.5 – 1% solid material consists of a range of compounds including water-soluble and fat-soluble vitamins, minerals, enzymes, polysaccharides, phenolic compounds and organic acids.

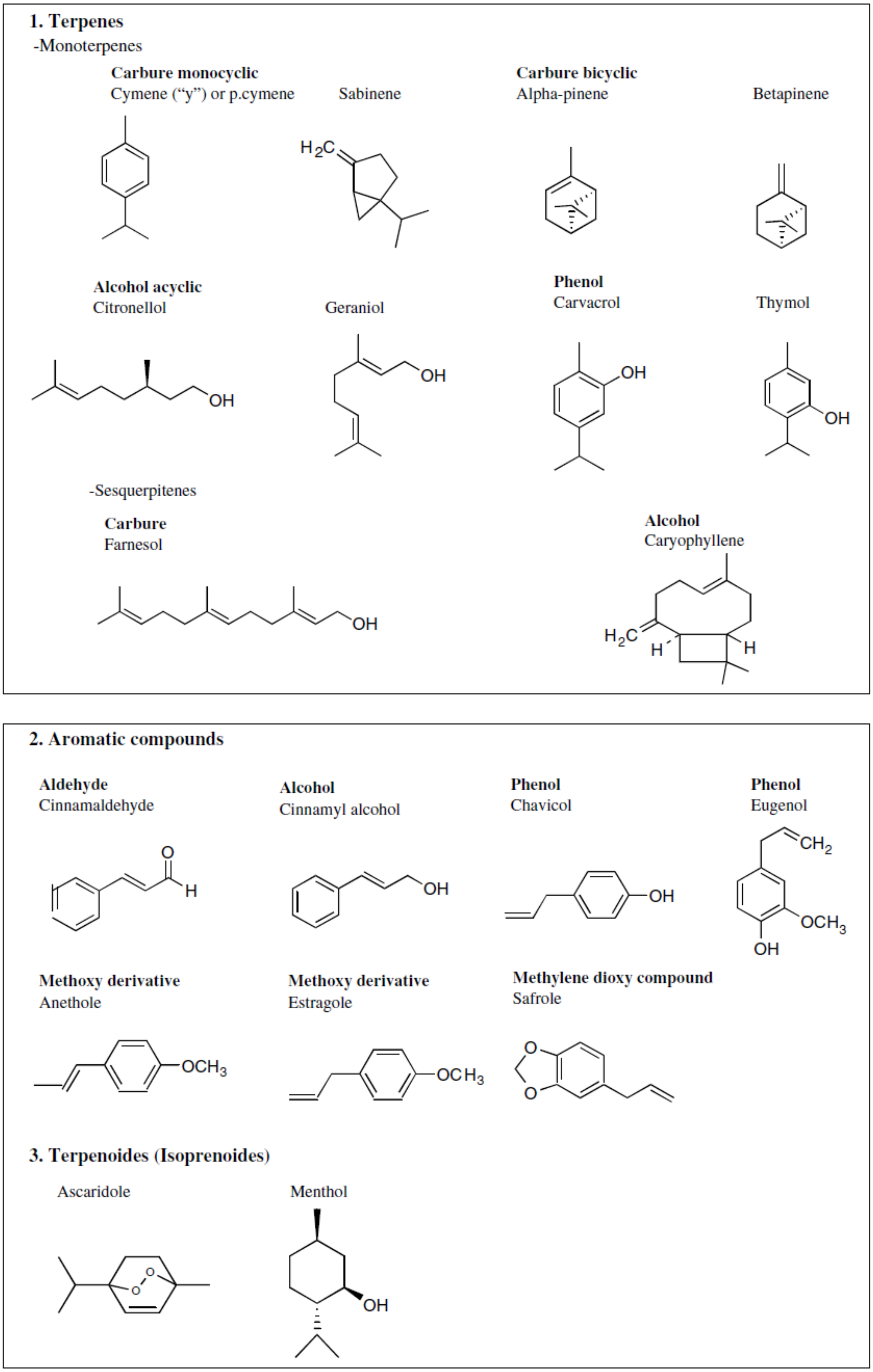

Figure 1. Chemical structures of some selected components of essential oils.

The aloe parenchyma tissue or pulp has been shown to contain proteins, lipids, amino acids, vitamins, enzymes, inorganic compounds and small organic compounds in addition to the different carbohydrates (20). For centuries, *Aloe vera* has been used by many different cultures as a medicinal plant due to its therapeutic properties. Aloe gel is the colorless mucilaginous gel obtained from the parenchymatous cells in the fresh leaves of *Aloe spp.* Currently, there is an increasing interest in the use of *A. vera* gel in the food industry as a resource of functional foods in drinks, beverages and ice creams. *A. vera* gel was added at several concentrations on potato dextrose agar (PDA) to test its efficacy on inhibiting mycelium growth of two common fungi responsible for fruit decay (*Penicillium digitatum* and *Botrytis cinerea*). For both fungi, the inhibition of mycelium growth rate increased with Aloe concentration (21). *Aloe barbadensis* Miller is a perennial succulent xerophyte, which develops water storage tissue in the leaves to survive in dry areas of low or erratic rainfall. The innermost part of the leaf is a clear, soft, moist and slippery tissue that consists of large thin-walled parenchyma cells in which water is held in the form of viscous mucilage. Therefore, the thick fleshy leaves of aloe plants contain not only cell wall carbohydrates such as cellulose and hemicellulose but also storage carbohydrates such as acetylated mannans (20). Lemongrass (*Cympopogon citratus* L.) is a plant in the grass family that contains 1 to 2% essential oil on a dry basis with widely variation of the chemical composition as a function of genetic diversity, habitat and agronomic treatment of the culture. Lemongrass essential oil is characterized by a high content of citral, which is used as a raw material for the production of ionone, vitamin A and beta-carotene (11). All four oils from Eucalyptus species exhibited poor activities against most of the pathogens, but were effective against *P. digitatum* from citrus and cactus pear (6). Pure 1,8- cineole proved to be far more effective against all the avocado and mango pathogens than the Eucalyptus oils (6). Also, cinnamon oil, rich in eugenol (81.2%), demonstrated good fungicide potential (6)

UNDERLYING MECHANISMS OF EOs

Generally, the susceptibility of bacteria to the antimicrobial effect of EOs also appears to increase with a decrease in the pH of the food, the storage temperature and the amount of oxygen within the packaging. At low pH the hydrophobicity of an EOs increases, enabling it to more easily dissolve in the lipids of the cell membrane of target bacteria (5). Most chemical components of EOs are terpenoids, including monoterpenes, sesquiterpenes, and their oxygenated derivatives. The active antimicrobial compounds of essential oils also are generally terpenes. The mechanism of action of this class of compounds is not fully understood, but it is speculated to involve membrane disruption by these lipophilic compounds. The low-molecular weight, highly lipophilic compounds of essential oils easily pass through cell membranes to induce biological responses (4, 7).

There is overwhelming evidence that many of these antimicrobials act at the cytoplasmic membrane, altering its function and in some instances structure, causing swelling and increasing its permeability. Efflux of K^+ is usually an early sign of damage and is often followed by efflux of cytoplasmic constituents. The loss of the differential permeability character of the cytoplasmic membrane is frequently identified as the cause of cell death (3). The hydrophobicity of EOs enables them to partition in the lipids of the cell membrane and mitochondria, rendering them permeable and leading to leakage of cell contents. Gram-negative organisms are slightly less susceptible than gram-positive bacteria (4, 5).

The mechanism action of an important EOs like carvacrol against fungi is not well known, but the general hypothesis is focused on membrane and cell wall damages with morphological deformation, collapse and deterioration of the conidia and/or hyphae (16). It was concluded that carvacrol forms channels through the membrane by pushing apart the fatty acid chains of the phospholipids, allowing ions to leave the cytoplasm (5). However, the precursor of carvacrol, *p*-cymene, is hydrophobic and causes swelling of the cytoplasmic membrane to a greater extent than does carvacrol (15). Thymol has been determined to be an effective antifungal essential oil with potential application for the control of plant diseases, particularly on fruits. Svircev et al. (2007) have shown that the efficacy of thymol in the control of plum brown rot (*Monilinia fructicola*) is dependent on the collection of thymol crystals on the cellular membranes of *Monilinia fructicola* spores and mycelia. Thymol crystal deposited on the fungal surface appears to induce serious disintegration of membranes and organelles on the cellular level (22).

Oregano EOs, containing carvacrol as a major component, causes leakage of phosphate ions from *Staph. aureus* and *B. aeruginosa* (5). It has previously been concluded that the high activity of oxygenated monoterpenes against pathogens results from interference with enzymatic reactions during cell wall synthesis. Further speculation by Inouye et al. (2000) suggests that the mode of antifungal action of essential oils could be dependent on two different mechanisms. Some oil components may irreversibly disrupt the cell membrane by cross linkage reactions, causing a leakage of electrolytes and subsequent depletion of amino acids and sugars, while others may selectively be inserted into the lipid rich portion of the cell membrane, thereby disturbing membrane function (23). In fact, the phenolic compounds are capable of dissolving within the bacterial membrane and thus penetrating inside the cell, where they interact with cellular metabolic mechanisms (9).

5. APPLICATION OF EOs IN HORTICULTURAL CROPS

Nowadays, EOs are used in horticultural sciences aspects such as sterilizing of explants in plant *In Vitro* culture, extending shelf life of fruits and vegetable and vase life of cut flowers. However, there is a little available information on the use of EOs on vase life of cut flowers and *In Vitro* culture. In one study author and co-workers (2009) reported that vase-life of gerbera flowers extended by addition of either 50 or 100 mg L^{-1} carvacrol from 8.3 to 16 day for the first time (2). Taghizadeh and Solgi (2013) also reported the application of thymol and carvacrol as novel sterilization agents in tissue culture of Bermuda grass (*Cynodon dactylon*). Sterilization treatments (i.e. thymol and carvacrol) were applied at different concentrations (100 and 200 mg L^{-1}) and exposure times of 30, 60 and 120 min. According to our results, infection of bermudagrass explants was controlled successfully by thymol and carvacrol. We concluded that these novel agents could be used as an alternative to common chemicals treatment for elimination and control microbial population explants in the *in vitro* conditions (24).

Since fruits and vegetables are the main crops in horticulture and are consumed freshly, their postharvest are so important. However, improvements in the cold distribution chain have made international trade of perishable foods possible, but refrigeration alone cannot assure the quality and safety of all perishable foods. Fruits deteriorate rapidly after harvest and in some cases do not reach consumers at optimal quality after transport and marketing. The main causes of fruit deterioration are dehydration, with the subsequent weight loss, color changes, softening, surface pitting, browning, loss of acidity and microbial spoilage. Climacteric fruit, such as apple, apricot, avocado, banana, peach, plum, and tomato are characterized by their increased respiration and ethylene biosynthesis rates during ripening. Contrarily, in non-climacteric fruit, such as citrus, eggplant, sweet cherry, grape, pepper, and strawberry, ethylene is not required for the coordination and completion of ripening. Fruit quality refers to a range of attributes that in the case of fruits are related to appearance, color, texture, flavour and aroma. These attributes are considered at maximum level with the optimum ripening stage and immediately after harvest. Color is one of the main fruit attributes for consumer acceptance and during ripening there is a degradation of chlorophyll and accumulation of either anthocyanins or carotenoids (25). Significant fruit losses after export result from decay caused by fungi such as *Penicillium digitatum* (green mould) (18). During postharvest periods, fruit deteriorate rapidly, the main causes being weight loss, color changes and softening, which are accompanied by occurrence of decay mainly due to species of genera *Penicillium*, *Botrytis*, *Monilia* among others. Fruit decay is the main postharvest problem, since fungal spoilage can cause great economic losses, although rot occurrence and severity depend on fruit type (21).

The control of fungal decay of fruit is closely linked to the use of pesticide. Fungicides, including prochloraz, guazatine, imazalil, thiabendazole and pyrimethanil, used to treat fruit crops such as mango, avocado and citrus, are applied by passing freshly harvested fruit through large volume dip solutions. The identification of natural antimicrobial agents able to reduce or eliminate toxic packhouse effluents, while still maintaining pathogen control, would be extremely valuable. Although essential oils and botanical extracts are commercially available as preharvest fungicides for organic farming, fewer studies have been directed towards postharvest application. However, throughout the world the use of synthetic agricultural fungicides is increasingly being restricted (6). Although the value of traditional food preservatives has been recognized, their safety has been questioned (3). The widespread use of pesticides has significant drawbacks including increased cost, handling hazards, concern about pesticide residues on food, and threat to human health and environment (11). Despite growing negative perceptions, synthetically manufactured fungicides are commonly used to control these diseases. However, a decreased efficacy may occur due to the buildup of pathogen resistance, too (23). Because of greater consumer awareness and concern regarding synthetic chemical additives, foods preserved with natural additives have become popular. The potential value of these agents as secondary preservatives is considered as well as the effectiveness and use of similar aromatic and phenolic compounds in wood smoke for the safe extension of perishable food shelf-life (3). These substances can be used to delay or inhibit the growth of pathogenic or spoilage microorganisms (10). The natural antimicrobial compound such as an essential oil could be a promising approach for controlling postharvest decay in fruit while also reducing the risk of fungicide usage in fruit preservation (26). The essential oils and individual terpenoids appeared to enhance the ability of the coatings to control gas exchange, thereby reducing moisture loss and increasing juiciness (18). The non-specificity of the fungicide eliminates beneficial microorganisms, thereby allowing pathogenic species to flourish during postharvest storage. The ability of the plant for self-protection against invasive fungi has prompted researchers to consider these oils for the development of safer antifungal agents in postharvest applications. Effective postharvest mycobiocides can reduce the necessity for repeated application of fungicides in the orchard, thereby reducing harmful residues in the fruit (8,19).

Antimicrobial agents are incorporated onto the packaging and slowly released into the packages (26). The development of the active packaging based on essential oils added to modified atmosphere packaging (MAP) was designed to respond to a number of issues related to fruit quality deterioration during postharvest storage. The use of this active packaging improves the benefits of MAP only, based on maintenance of organoleptic parameters and controlling the microbial spoilage. From the results reported herein and the reviewed literature, it can be concluded that the use of pure EOs such as eugenol, thymol or menthol in combination with MAP is an innovative and useful tool as alternative to the use of synthetic fungicides in fruits and vegetables, especially for those which are highly perishable and have a reduced shelf-life (25). Vegetables generally have a low fat content, which may contribute to the successful results obtained with EOs (1). Treatment with basil oil controlled crown rot and anthracnose prolonging storage of bananas as well as cinnamon and eucalyptus oil-enrichment reduced fruit decay and improved fruit quality of tomato and strawberries (11).

Edible coatings are mainly used to improve food appearance and preservation of the fruit since they can provide selective barriers against respiration, moisture loss and decay. Gum arabic (GA) is one of the biopolymers, obtained from stems and branches of Acacia tree and is composed of galactose, rhamnose, arabinose and glucoronic acid. This polysaccharide is of interest as a potential film or coating component because of its unique emulsifying properties. Anthracnose, caused by *Colletotrichum spp*. is the most devastating disease of fruit and vegetables in tropical countries of the world. Being a latent infection, the fungus infects immature fruit in the field while symptoms appear only after ripening. Management of anthracnose caused by *Colletotrichum spp*. is the most important issue for the tropical fruit industry because of resulting financial losses. Hot water treatments in combination with synthetic fungicides are generally used to reduce the incidence of postharvest diseases in various fruit and vegetables. However, heat treatments affect nutritional quality and sensory properties while continuous use of synthetic fungicides may lead to development of fungicide-resistant strains of the pathogen. Moreover, fungicide residues present on the fruit surface may pose serious threats to consumers and the environment. This has prompted the development of non-hazardous approaches to control postharvest anthracnose in major tropical fruit such as banana and papaya (26).

1. Banana and Papaya

Recently, it was found that essential oils of lemongrass (LG) and cinnamon (CM) have antifungal properties (26).Treatment with basil oil controlled crown rot and anthracnose prolonging storage of bananas as well as cinnamon and eucalyptus oil-enrichment reduced fruit decay and improved fruit quality of tomato and strawberries (11).The composite edible coatings of GA combined with LG and CM showed the synergistic effects and the greatest potential to control anthracnose in bananas and papayas and maintained quality for up to 33 days. Some phytotoxic effects were observed on banana and papaya fruit when LG and CM were used alone and fruit were spoiled earlier as compared with the fruit treated with GA combined with LG and CM. This phenomenon could be explained by the fact that direct application of LG and CM on to the fruit might have changed the capacity of the fruit epidermis tissue to retain spore germination. It can be concluded that 80% control of anthracnose on banana and 71% on papaya achieved with 10% gum Arabic combined with 0.4% cinnamon oil concentration is sufficient to consider the effectiveness of this composite edible coating as an alternative to synthetic fungicides (26).

2. Grape

Table grapes (*Vitis vinifera* L.) have severe problems since acceleration of quality loss occurs during postharvest storage due to weight loss by dehydration, tissue softening, rachis browning and occurrence of "off-flavour" and anomalous aromas attributable to over-ripeness accompanied in most cases with high incidence of berry decay mainly due to *Botrytis cinerea*, which limits commercialization and consumption (21).Table grape is a non-climacteric fruit which shows severe problems during postharvest handling, storage and marketing. As many fruits, grapes have a relatively low pH and thus very sensible to fungal growth, which could be accelerated by storage conditions, especially high relative humidity. *Botrytis cinerea* causes grey mould even at low temperature, which is considered the most important disease of table grape. The inoculation of control berries with *B. cinerea* induced softening and watering of the infected zone as well as mycelium growth. Several means have been used to solve this problem, the most common being the use of SO_2 as synthetic fungicide, but the required high concentration affects berry quality inducing bleaching, accelerated water loss and browning. Moreover, sulphite residue is another important problem associated with SO_2 fumigations. Thus, consumer's concern for the human well-being and environmental pollution have forced the food industry to search for new strategies as alternative means to control fruit postharvest decay (16).

Use of carvacrol is an innovative and useful tool as alternative to the use of synthetic fungicides such as SO_2 to avoid decay in table grapes during storage. Carvacrol has been recognized as one of the most potent monoterpenoid with antifungal activity against *Botrytis.* The fungal growth, spore germination and mycelium development was also reduced and dependent on carvacrol concentration. Ethylene and respiration rate of berries increased drastically in control inoculated-grapes, while these increases were lower as higher were the carvacrol applied doses. Control berries exhibited the highest respiration rate compared to treated fruits, which could be attributed to the alleviation of damage severity by carvacrol. There is evidence supporting the relationship between respiration rate and fungal decay in fruits. Moreover, the alleviation of damage by carvacrol would permit the reduction in respiration rate thorough maintenance of tissue integrity, since damaged tissue in apricot exhibited higher respiration rate than non-damaged fruits (16).

Based on another research, *Aloe vera* gel at 250 mLL^{-1} was applied as a pre-harvest treatment to table grape vineyards 1 or 1 and 7 days before harvesting. Fruit were cold-stored for 35 days and sampled weekly. Respiration rate and weight loss were significantly reduced in treated samples, while ripening parameters such as color and fruit firmness were significantly delayed. Both mesophilic aerobics and mould and yeasts counts were significantly lower at harvest in treated samples, the effect being persistent during storage. At the end of the experiment, the percentage of rotted berries was significantly lower in treated than in control fruit. From these results it could be inferred that *A. vera* could be considered as a promising pre-harvest treatment to maintain table quality during postharvest storage (21).

Jalili Marandi et al. (2010) applied the effects of essential oils extracted from *Thymus kotschyanus* and *Carum copticum* for efficacy in the control of postharvest fungal decay in Thompson seedless table grape. Results showed that the tested oils exhibited good inhibitory activity against fungal decay in oil-treated grapes. In addition, the essential did not show a negative impact on the sensory quality of the grape. The profile of the oil components showed that carvacrol (28.54%) and thymol (63.18%) were the main compounds available in *T. kotschyanus* and *C. copticum* respectively. Results of this research showed that the evaluated essential oils may be used as a preservative for reduction of postharvest losses (27).

3. Citrus

Citrus fruits are produced in subtropical regions distant from consumer markets and often must be stored for the market economy as dictates. Months-long delay between harvest and consumption may result in postharvest losses due to pathological and physiological diseases. A new approach to the control of postharvest pathogens, while maintaining fruit quality, has been implemented by the application of essential oil amended coatings to citrus. This approach eliminates the need for synthetic fungicides, thereby complying with consumer preferences, organic requirements and reducing environmental pollution. *In vitro* studies indicated that the essential oils and some of the terpenoid components tested were active against *Penicillium digitatum*. Excellent disease control was achieved with the amended coatings, while measured quality parameters indicated that overall fruit quality was maintained. Moreover, moisture loss was decreased significantly in fruit treated with essential oil enriched coatings. The advantage of using coatings amended with essential oils, rather than vapour, is that there is closer contact between the essential oils and fruit surfaces, allowing exposure of each fruit to similar concentrations of inhibitor over a longer period. The large volumes of citrus treated annually internationally, as well as the increasing demand for organically produced fruit, emphasize the need to replace synthetic fungicides with safer and biodegradable alternatives (28,29).The use of citral and alicine from garlic [30] are examples of the potential efficacy of plant extracts for the control of *P. digitatum.* Trans isomerized jojoba oil was applied by Ahmed et al. (2007) as a coating for 'Valencia' oranges. They effectively maintained fruit quality for up to 60 d using concentrations of 20–30% of (trans)-jojoba oil (18).

Furthermore, the antifungal action of four essential oils of *Foeniculum vulgare* (fennel), *Thymus vulgaris* (thyme), *Eugenia caryophyllata* (Clove) and *Salvia officinalis* (sage) was tested in vitro against *Penicillium digitatum* Sacc. Direct contact and vapour phase were used to test the antifungal activity of these essential oils against *P. digitatum* that is responsible for green mould rot of citrus fruits. The vapour phase and direct contact of clove and thyme essential oils exhibited the strongest toxicity and totally inhibited the mycelial growth of the test fungus. Thyme and clove essential oils completely inhibited *P. digitatum* growth either when added into the medium or by their volatiles per Petri dish. In *in vitro* mycelial growth assay showed fungi-static and fungicidal activity by clove and thyme essential oils. Sage and fennel oils did not show any inhibitory activity on this fungus (28).

(*d*)-Limonene was included as a terpenoid for coating supplementation, because it naturally occurs in citrus rind. Findings by Eckert and Ratnayake (1994) have shown that germination of *Penicillium* spores is stimulated when exposed to volatiles released by wounded citrus fruit. Droby et al. (2008) found that (*d*)-limonene, a known major constituent of orange oil, stimulates germ tube elongation in green and blue Moulds (30).

Both curative and preventative treatments with coatings supplemented with *Lippia scaberrima* were compared in one study and found to be superior to the standard commercial application of synthetic fungicides. Further general observation was that amended coatings yielded fruit exhibiting no shrivelling or browning even after ten days of storage (18).

4. Mango

Mango (*Mangifera indica* L.) is one of the top five fruit crops in the world. It is adaptable to a wide range of climates, ranging from wet tropical to dry subtropical. Among the various constraints, the most important is anthracnose caused by *Colletotrichum gloeosporioides* Penz.

Flower blight, fruit rot, and leaf spots are among the symptoms of this disease. The use of some plant essential oils *i.e.* basel oil (*Ocimum basilicum*), orange oil (*Citrus sinensis)*, lemon oil (*Citrus medica*) and mustard oil (*Brassica juncea* L.) to reduce postharvest losses induced by *Colletotrichum gloeosporioides* (Penz.) in mango fruits was studied. In this study, the antifungal activity of essential oils under *in vitro* condition were assayed by tested various concentrations and under *in vivo* condition by used different essential oil concentrations on inoculated mango fruits. Results showed that orange oil at all tested concentrations were a significant reducing the fungal linear growth if compared with other tested essential oils. At low concentration (50 μg/ml) orange oil caused 10.0% reduction in fungal growth, while at 100 μg/ml caused 72.2% and at high tested concentration (150 μg/ml) caused a complete reduction in mycelium linear growth of pathogenic fungus. Meanwhile, at low tested concentration, mustard oil caused a highly significantly reduction of the percentage of fungal spore germination by 70.8 % followed by basil oil by 64.7%. Results of *in vivo* studies showed that, at low doses (250 ppm), mustard oil caused a highly reduction of anthracnose incidence of mango fruits by 79.9% followed by basil oil with 66.7%. On the other hand, orange and lemon oil at low concentration were showed a highly effect to reducing the percentage of rotting fruit tissue by 84.5 and 75.0%, respectively if compared with other treatments and un-treated fruits (32).

Regnier et al. (2008) proved that modification of fruit coatings using essential oil of *Lippia scaberrima*, containing (*d*)-limonene, R-carvone and 1,8-cineole as main constituents, was an effective *in vivo* control measure against two mango postharvest spoilage pathogens. The antifungal role of R-carvone against *Penicillium citrinum* as indicated by Saleh et al. (2006), and against mango pathogens,was confirmed by the *in vitro* results obtained in this study against *P. digitatum* (23). Spearmint oil, which contains more than 80% R-carvone, was equally effective in inhibiting fungal growth [8]. The spearmint oil contained a substantially higher concentration of R-carvone (87.9%) than that of L. scaberrima (49.3%) (6). Spearmint oil exhibited better activity than thyme oil against the *P. digitatum* (Fort Beaufort) strain and in general demonstrated good antifungal properties against all the *Penicillium* strains (6). It has been demonstrated that essential oils incorporated into fruit coatings are effective in the packhouse environment to control postharvest pathogens of mango and citrus (18, 23).

The use of a commercial wax coating is primarily to maintain the postharvest quality of mangoes during prolonged export periods. In contrast to findings by Plaza et al. (2004), supplementation of the wax coating used on mango was found to offer effective control of *Colletotrichum gloeosporioides* and *Botryosphaeria Parva* as postharvest pathogens. Initial results suggest that the addition of essential oil from *Lippia scaberrima* to a commercial coating maintains the organoleptic characteristics such as fruit colour, aroma, or firmness. This increased efficiency of the commercial wax together with maintenance of the organoleptic integrity support findings by Tzortzakis (2007).

5. Avocado

Pre- and postharvest spoilage of avocado (*Persea americana* Mill.) is caused by a number of well-known pathogens. Mycobiocides are attracting research interest worldwide as possible postharvest pathogen control measures to replace synthetic fungicides. Results indicate that essential oils rich in R-carvone could be valuable alternatives to synthetic fungicides for the postharvest management of avocado fruit. The combination of essential oils with a commercial coating, acceptable to the organic market, offers additional protection to this vulnerable commodity. Most losses are ascribed to *Colletotrichum gloeosporioides* L. In the simulated export trial, all treated fruit displayed significantly better quality retention when compared to untreated fruit (19).

6. Tomato

Cherry tomato (*Lycopersicon esculentum*) is an important food crop in many other countries. It is susceptible to attack by various microorganisms such as *Aspergillus* and *Alternaria* species because of the warm and humid climate. Apart from their potential to cause yield losses and food decay, many species represent a serious risk for consumers because of production of dangerous secondary metabolites. Aflatoxins are a group of extremely hazardous and common mycotoxins, carcinogenic metabolites produced by some species of Aspergillus, especially *Aspergillus flavus* and *A. parasiticus*. About 4.5×10^9 people are subjected to uncontrolled amounts of aflatoxin in developing countries Aflatoxins are carcinogenic and causing food safety concerns and economic losses in many food industries. In one study, the effects of EOs from *Cicuta virosa L.var Latisecta* on *Aspergillus flavus*, *Aspergillus oryzae*, *Aspergillus niger* and *Alternaria alternata* was carried out. *C. virosa var. latisecta* is mainly distributed in Russia, Japan, and China. The most abundant components of its essential oil were γ-terpinene (40.92%), *p*-cymene (27.93%), and cumin aldehyde (21.20%). Results showed that, when the essential oil concentration increased, a visible reduction in the percentage of spore germination was observed in the test fungi. The results indicated the percentage of infected fruits is significantly reduced by essential oil at 18 °C for 21 days. The percentages of decayed cherry tomatoes were significantly reduced in all three treatment groups compared with the control groups and also significantly reduced with increasing concentration of EOs. Almost all the cherry tomatoes were spoiled the absence of essential oil (7).

7. Leafy vegetables

Enzymatic browning in fruit and vegetable tissues can cause undesirable quality changes during handling, processing and storage. This reaction results mostly from polyphenol oxidase and peroxidase. Peroxidase is a plant enzyme associated with off-flavors in fruits and vegetables. Inactivation of the peroxidase enzyme is considered necessary to minimize the possibility of deterioration. Inhibition of these enzymes in fruits and vegetables is generally achieved using physical or chemical treatments such as heating (blanching), lowering pH or Aw or adding chemical additives. Sulfur dioxide is commonly used of this purpose. Because the consumer market demands less use of chemicals on such products, more attention has been given to the search for alternative anti-browning compounds. The effectiveness of natural essential oils eucalyptus (*Eucalyptus globulus*), tea tree (*Melaleuca alternifolia*), melisa (*Melissa officinalis*), roomer (*Rosmarinus officinalis*), clove (*Syzygium aromaticum*) and lemon (*Citrus limonum*) to reduce peroxidase activity of organic leafy vegetables extracts was evaluated. The peroxidase activity of leafy vegetable extracts, butter lettuce, cabbage and spinach, showed the greatest resistance against the action of all the essential oils assayed, while romaine lettuce extract showed the least resistance. The reductions of peroxidase activity in vegetable extracts were 87% in spinach; 74% in butter lettuce; 56% in romaine lettuce and ca. 35% in chard and cabbage (9).

8. Peach

Botrytis cinerea (grey mould rot) is a ubiquitous pathogen, which causes severe damage in many fruits, vegetables and ornamental crops in pre- and postharvest. In one research the antifungal effects of the essential oils against fungal pathogen *Botrytis cinerea* the causal agent of grey mould disease of peach (*Prunus persica* L.) under *in vitro* and *in vivo* conditions. Treatments consisted of four essential oils (anise, ammi, ziziphora and cinnamon) and five concentrations (0, 200, 400, 600 and 800 $\mu L.L^{-1}$). Results of *in vitro* experiment showed that all of used essential oils at all applied concentrations inhibited grey mould growth. All of these EOs in concentration 800 $\mu L.L^{-1}$ were without germination spores of grey mould. The EOs application significantly decreased weight loss percentage and increased life storage fruits. Also, essential oils positively affected on postharvest quality factors including total soluble solids, titrable acidity, anthocyanin, carbohydrate content and pH value. It was observed that treated fruits with ammi essential oil at the concentration of 800 $\mu L.L^{-1}$ had the highest total soluble solids; titratable acidity, anthocyanin, and carbohydrate content and it had the lowest decay and acidity. Thus, these results showed that EOs have strong impact on postharvest decay and fruit quality of peach (33).

CONCLUSION

In conclusion, consumers prefer fresh fruits and vegetables that are prepared for convenient consumption without the loss of quality such as texture, flavor and appearance. So, the innovative method of coating application proposed in this paper not only promotes crop moisture retention while maintaining quality, but completely eliminates the use of fungicide. The exclusion of fungicide eradicates the need to dispose of toxic waste, thereby contributing significantly to a reduction in environmental pollution. The use of commercial wax coatings enriched with essential oils led to reduced fungal infection by pathogens. The use of essential oils can improve food safety by eliminating fungal spread, and they also leave no detectable residues after storage. Hence, EOs would be economical in application, with considerable commercial significance and worthy of further investigation when used as fumigant in storage containers. In addition, some further experiments are required to standardize organoleptic characteristics, such as fruit color, aroma, or firmness with EOs.

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