Essential Oil: Innovative Tool to Improve the Preservation of Fresh Produce – A Review

Nikos G. Tzortzakis

Department of Vegetable Science, School of Agricultural Technology, Technological Education Institute of Crete, Heraklion 71004, Greece

Correspondence: * ntzortzakis@googlemail.com

ABSTRACT

The degree of fresh produce safety obtained with the currently applied preservation methods seems to be not sufficient. The interest in the possible use of natural compounds to prevent microbial growth has notably increased in response to the consumer pressure to reduce or eliminate chemically synthesized additives in foods. This review examines the potency of essential oils as natural antimicrobial agents from plants, outlining the ranges of microbial susceptibility and factors affecting antimicrobial action. Moreover, an overview on the application of essential oils and/or components during storage on fruit quality related attributes as well as the impacts of essential oil on fruit coating edible films are demonstrated. Undesirable organoleptic effects can be limited by careful selection of essential oils according to the type/sensitivity of fresh commodity.

Keywords: antimicrobial, decay, coating edible films, fruit quality, postharvest treatments

Abbreviations: •OH, hydroxyl radicals; 
O2, singlet oxygen; ABTS, 2,2’-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt; 
BAs, bactericidal activity; CFU, colony forming unit; DPPH, 2,2-di-(4-tert-octylphenyl)-1-picylhydrazy; 
EO, essential oil; 
GRAS, Generally Regarded as Safe; 
O2, superoxide radicals; ORAC, oxygen radical absorbance capacity; 
TA, titratable acidity; TSS, total soluble solids

CONTENTS

INTRODUCTION........................................................................................................................................................................ 87
CURRENT USE OF ESSENTIAL OILS........................................................................................................................................... 88
ANTIMICROBIAL PROPERTIES OF PLANT ESSENTIAL OILS.................................................................................................. 88
IMPACTS OF ESSENTIAL OIL ON FRESH PRODUCE PRESERVATION....................................................................................... 88
EFFECTS OF ESSENTIAL OIL ON FRESH PRODUCE QUALITY.................................................................................................... 92
• Impacts of essential oil on fruit quality characteristics........................................................................................................ 92
• Impacts of essential oil on fruit coating edible films.................................................................................................................. 93
LEGAL ASPECTS AND SAFETY OF THE USE OF ESSENTIAL OILS AND THEIR COMPONENTS IN FOODS............................... 94
FUTURE WORK............................................................................................................................................................................... 95
REFERENCES................................................................................................................................................................................. 95

INTRODUCTION

Food safety is an increasingly important public health issue despite the modern improvements in slaughter hygiene and food production techniques. It has been estimated that as many as 30% of people in industrialised countries suffer from a food borne disease each year (WHO 2002). At the same time, Western society appears to be experiencing a trend of ‘green’ consumerism (De Silva 1996), desiring fewer synthetic food additives. Most perishable food products are stored at low temperature and sometimes they are packaged under modified atmosphere in order to extend their shelf-life. However, these steps do not eliminate undesirable microorganisms from these products. Alternative preservation techniques such as pulsed light, high pressure, pulsed electric and magnetic fields, irradiation and natural antimicrobial agents are being used or investigated for their application to food products. The postharvest use of chemicals as fungicides is restricted in most countries. Moreover, most of the synthetic preservatives produce several side-effects as carcinogenicity, teratogenicity and residual toxicity (Basilico and Basilico 1999). Besides, consumers demand agricultural commodities without pesticide residues. Thus, new preservation technologies are needed, which have to be considered as human-safe, environmentally friendly and reduce or eliminate food borne pathogens, possibly in combination with existing methods. One possible candidate is the use of essential oils (EOs) as antimicrobial agent.

EOs, also called volatile or ethereal oils; are aromatic oily liquids obtained from plant material (flowers, buds, seeds, leaves, twigs, bark, herbs, wood, fruits and roots). EOs are not as broad spectrum as synthetic pesticides, but their effectiveness can be improved by using them in conjunction with carefully designed packaging. The presence of free moisture in a package provides the ideal environment for the growth of many postharvest pathogens. Most of the research to date has been done testing the growth of microbes in the laboratory under ideal conditions. The difficulty may be to apply the oils effectively under commercial conditions. EOs are often fungistatic rather than fungicidal. This means that they stop the growth of the fungi while it is exposed to the oil, but once the oil is removed the fungi can continue to grow. Application of the oil as a vapour at a continuous, low concentration should prevent tainting of the product. Thin skinned products, not

Received: 27 December, 2008. Accepted: 6 April, 2009.

Invited Review
surprisingly are more prone to tainting than those with thicker skins. EOs which have been registered as food additives are much easier to register for postharvest use than new synthetic pesticides. Application of these oils via the vapour phase should also make their use more cost effective than dipping (Jobling 2000).

It has long been recognised that some EOs have antimicrobial properties (Boyle 1955). Besides antibiotic properties (Drans and Ritchie 1987; Morency and Camillia 2002; Burt 2004), EOs or their components have been shown to exhibit antiviral (Bishop 1995), antimycotic (Jayashree 1999; Mari et al. 2003), antitoxicogenic (Ultee and Smid 2001; Juglal et al. 2002), antiparasitic (Pessoa et al. 2002), herbicidal (Setia et al. 2007) and insecticidal (Nikpay 2007) properties. These characteristics are possibly related to the function of these compounds in plants (Mahmoud and Croteau 2002).

The purpose of this paper is to provide an overview of the published data on the antimicrobial activity of these EOs and their components that could be considered suitable for application in or on fresh produce as a food preservative as well as the impacts on fruit quality related characteristics.

**CURRENT USE OF ESSENTIAL OILS**

The greatest use of EOs in the European Union is in food (as flavourings), perfumes (fragrances and aftershave) and pharmaceuticals (for their functional properties). Individual components of EOs are also used as food flavourings, either extracted from plant material or synthetically manufactured (Oosterhav en et al. 1995). The antimicrobial properties of EOs and their components are exploited in such diverse commercial products such as in meat and meat products, in pork liver sausage, in fish, in dairy products such as yoghurt and cucumber salad, in milk, in rice, in cheese, on bread and bakery products, in/on fruit and vegetables, in sweets, and in processed natural products, as reviewed by Burt (2004); Rojas-Gra et al. (2006). EOs are designated as Generally Regarded as Safe (GRAS) and are regarded as alternatives to chemical preservatives, and their use in foods meets the safety demands of consumers for mildly processed natural products, as reviewed by Burt (2004). The most commonly used method for producing EOs on a commercial basis is steam distillation.

**ANTIMICROBIAL PROPERTIES OF PLANT ESSENTIAL OILS**

For combating infectious or parasitic agents, plants synthesise secondary metabolites which may be present constitutively (Rauha et al. 2003) or generated from inactive precursors in response to stress (Sofos et al. 1998). Preformed substances (pro- or inhibitory) in plant tissue include phenolic compounds, flavonoids, flavonoids, glycosides, alkaloids, and even polyacetylenes. Post-inhibitory are stored as inactive precursors which are activated by hydrolyses or oxidases, usually in the plant tissue (De laquis and Mazza 1995).

The composition, structure as well as functional groups of the oils play an important role in determining their antimicrobial activity. Usually compounds with phenolic groups are most effective (Dorman and Deans 2000). Among these, the oils of clove (Syzygium aromaticum L.), oregano (Origanum vulgare L.), rosemary (Rosmarinus officinalis L.), cinnamon (Cinnamomum zeylanicum L.), thyme (Thymus capitatus L) and sage (Salvia officinalis L.) have been found to be the most effective against microorganisms. Plant EOs have been widely tested against fungi as well as both Gram-positive and -negative bacteria. The antimicrobial activity of EOs or components is well documented (as reviewed by Deans and Ritchie 1987; Arras et al. 1994; Sivropoulou et al. 1996; Reddy et al. 1998; Plotto et al. 2003; Burt 2004; Lee et al. 2007; Tzortzakis 2007a; Tzanakaki and Tzortzakis 2008). It is apparent that the generally greater resistance of Gram-negative bacteria to EOs (Walsh et al. 2003) is likely to be due in part to the greater complexity of the double membrane-containing cell envelope of these organisms in contrast with the single membrane glycophosphotrichoic acid, or membrane glycoprotein/β-glucan-based structures of Gram-positive bacteria and yeast, respectively. While this is true of many EOs, there are some which are effective against both groups (oregano, clove, cinnamon and citral; Sivropoulou et al. 1996). There are also some nonphenolic constituents of oils which are quite effective against Gram-negative bacteria (garlic oil (Allium sativum L.); Yin and Cheng 2003). Considering the large number of different types of chemical compounds present in EOs, it is most likely that their antimicrobial activity is not attributable to one specific mechanism but that there are several targets in the cell (Carson et al. 2002). A number of potential synergies have been suggested for use with EOs: low pH, low water activity, chelators, low oxygen tension, mild heat and raised pressure, although not all of these have been researched in foodstuffs (Gould 1996).

Due to their ability to grow in almost all food products, yeasts and moulds can generate off-flavours, produce toxin, and cause discoloration and proteolysis through the action of various enzymes like lipases and proteases. The most important feature of moulds from a food safety perspective is their ability to produce mycotoxins, such as aflatoxins, which are toxicogenic secondary metabolites. Aspergillus ochraceus produces ochratoxin A which is responsible for nephropathies in pigs and humans.

**IMPACTS OF ESSENTIAL OIL ON FRESH PRODUCE PRESERVATION**

Postharvest decay is one of the major obstacles in the postharvest fruit chain, reducing the commercial value of fresh produce. Due to the economical impacts of spoiled foods and the consumer’s concerns over the safety of foods containing synthetic chemicals, a lot of attention has been paid to naturally derived compounds or natural products such as EOs from aromatic plants with antimicrobial activities for controlling pathogens and/or toxin producing microorganisms in foods. An overview of EOs studies presented in Table 1, and analyzed as follows.

Strawberries (Fragaria × ananassa Duch.) treated with EO (0.1 ml/l) of tea-tree oil (Melaleuca alternifolia L.) reduced 34% the severity of decay during storage at 10°C as compared to the control (Chanjirakul et al. 2007). Moreover, thyme oil volatiles (0.05-0.2 ml/l) examined as an antifungal preservative for strawberry fruits and suppressed Botrytis cinerea (up to 76%) and Rhizopus stolonifer (up to 75%) development, resulting in decreased decay with increases in oil volatile concentration (Reddy et al. 1998). Additionally, fruit decay decreased in strawberry-treated with cinnamon (C. zeylanicum L.) or eucalyptus (Eucalyptus citriodora L.) oil (0.05-0.5 ml/l) vapours and transferred/stored to chilled air (Tzortzakis 2007b). EOs of clove, cinnamon, oregano, cinamaldehyde-enriched cinnamon EO when used (4% v/v) in paraffin-based “active coatings” for paper packaging materials protected strawberry against fungi, and there was apparent reduction in visible or organoleptic changes in the fruit (Rodriguez et al. 2007).

Several studies examined the impact of EOs and/or compounds on severity of berries. Thus, blackberries (Rubus fruticosus L.) and raspberries (Rubus idaeus L.) treated with EO (0.1 ml/l) of tea-tree oil reduced 22 and 48% respectively the severity of decay during storage at 10°C compared to the control (Wang 2003; Chanjirakul et al. 2007). Moreover, blueberries (Vaccinium corymbosum L.) exposed to several EOs (200 mg/l, including carvacrol, anethole, cinamaldehyde, cinnamic acid, perillaldehyde, limonol, and p-cymene) inhibited fruit decay (Wang et al. 2008).

Azizi et al. (2006) reported that radial growth and spore germination of important citrus postharvest fungi (Penicillium italicum, Penicillium digitatum and Alternaria citri) were decreased (up to 59%) and/or completely inhibited when fruits exposed to different concentrations (250, 500 and 1000 mg/l) of EOs of thyme, mint, summer savory...
Table 1 Effect of essential oil or components on postharvest pathogens of fruit and vegetables.

<table>
<thead>
<tr>
<th>Essential oil or Component</th>
<th>Commodity</th>
<th>Pathogen(s)</th>
<th>Essential oil conc. (mg/l or ml/l, mM, %v/v, %v/v or purity)</th>
<th>Effects</th>
<th>Antimicrobial Produce Quality</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eugenol; thymol; menthol; eucalyptol</td>
<td>Cherry</td>
<td>Moulds, yeasts, Total aerobic mesophilic</td>
<td>Botrytis cinerea, Monilinia fructicola</td>
<td>1000 mg/l (dipping)</td>
<td>+</td>
<td>±</td>
</tr>
<tr>
<td>Thymol; carvacrol</td>
<td>Apple</td>
<td>Botrytis cinerea</td>
<td>0.004-0.008 ml/l</td>
<td>+</td>
<td>±</td>
<td>Lee et al. 2007</td>
</tr>
<tr>
<td>Eucalyptus oil; Cumin oil</td>
<td>Apple</td>
<td>Penicillium expansum; Botrytis cinerea; Colletotrichum gloeosporioides; Macrophoma kawatsuka; Monilia fructigena; Trichothecium roseum</td>
<td>1.5-3.5 mg/l</td>
<td>+</td>
<td>-</td>
<td>Li et al. 2006</td>
</tr>
<tr>
<td>Soybean oil; corn oil; peanut oil; olive oil; linseed oil; cottonseed oil</td>
<td>Apple</td>
<td>Escherichia coli; Listeria innocua; Psychrophilic aerobes; yeasts; molds</td>
<td>0.05, 0.075, 0.1, 0.3-0.5-0.6-1.0-1.5% (w/w)</td>
<td>+</td>
<td>±</td>
<td>Rojas-Grau et al. 2006, 2007</td>
</tr>
<tr>
<td>Cinnamon oil</td>
<td>Pears</td>
<td>Escherichia coli; Salmonella enterica</td>
<td>1% (v/v)</td>
<td>+</td>
<td>Na</td>
<td>Friedman et al. 2004</td>
</tr>
<tr>
<td>Oregano oil; lemongrass oil; cinnamon oil</td>
<td>Apple puree film coating</td>
<td>Escherichia coli; Listeria innocua; Psychrophilic aerobes; yeasts; molds</td>
<td>0.05, 0.075, 0.1, 0.3-0.5-0.6-1.0-1.5% (w/w)</td>
<td>+</td>
<td>-</td>
<td>Rojas-Grau et al. 2006, 2007</td>
</tr>
<tr>
<td>Cinnamon oil; clove bud oil; lemongrass oil; bitter orange oil; mandarin oil; sweet orange oil; lemon oil; tangerine oil; lime oil; grapefruit oil; palmarosa oil</td>
<td>Pears</td>
<td>Escherichia coli; Salmonella enterica</td>
<td>12 mM</td>
<td>+</td>
<td>Na</td>
<td>Moon et al. 2006; Rupasinghe et al. 2006, 2007</td>
</tr>
<tr>
<td>Soybean oil; corn oil; peanut oil; olive oil; linseed oil; cottonseed oil</td>
<td>Pears film coating</td>
<td>Escherichia coli; Salmonella enterica</td>
<td>0.06 ml/l</td>
<td>Na</td>
<td>+</td>
<td>Gou et al. 2008</td>
</tr>
<tr>
<td>Origanum oil; basil oil; thymus oil</td>
<td>Kiwifruit</td>
<td>Botrytis cinerea</td>
<td>0.50 ml/l</td>
<td>+</td>
<td>-</td>
<td>Thanassopoulos and Yanna 1997</td>
</tr>
<tr>
<td>Carvacrol; cinnamic acid</td>
<td>Total viable counts</td>
<td>5-15 mM</td>
<td>+</td>
<td>-</td>
<td>Roller and Seedhar 2002</td>
<td></td>
</tr>
<tr>
<td>Limonene</td>
<td>Kumquat</td>
<td>Penicillium digitatum</td>
<td>5 ml/l</td>
<td>+</td>
<td>Na</td>
<td>Ben-Yehoshua et al. 2008</td>
</tr>
<tr>
<td>Vanilla</td>
<td>Pineapple</td>
<td>Escherichia coli; Saccharomyces cerevisiae</td>
<td>9000 mg/l</td>
<td>+</td>
<td>+</td>
<td>Sangsuwan et al. 2008</td>
</tr>
<tr>
<td>Ceylon citronella oil; Lemongrass oil; Basil oil</td>
<td>Banana</td>
<td>Fusarium sp., Lasiodiplodia theobromae &amp; Colletotrum musae</td>
<td>0.4%</td>
<td>+</td>
<td>+</td>
<td>Anthony et al. 2003</td>
</tr>
<tr>
<td>Cinnamon oil</td>
<td>Pineapple</td>
<td>Penicillium digitatum</td>
<td>0.16%</td>
<td>+</td>
<td>Na</td>
<td>Anthony et al. 2003</td>
</tr>
<tr>
<td>Clove oil</td>
<td>Pineapple</td>
<td>Penicillium digitatum</td>
<td>0.03-0.11%</td>
<td>+</td>
<td>Na</td>
<td>Ranasinghe et al. 2002</td>
</tr>
<tr>
<td>Lemongrass oil</td>
<td>Mango</td>
<td>Colletotrichum gloeosporioides</td>
<td>40 ml/l (dipping)</td>
<td>+</td>
<td>Na</td>
<td>Duankmhanmanee 2008</td>
</tr>
<tr>
<td>Citron oil</td>
<td>Lemon</td>
<td>Penicillium digitatum</td>
<td>0.16%</td>
<td>+</td>
<td>Na</td>
<td>Anthony et al. 2003</td>
</tr>
<tr>
<td>Mint oil; Basil oil</td>
<td>Orange</td>
<td>Penicillium italicum</td>
<td>0.1 ml/l</td>
<td>+</td>
<td>Na</td>
<td>Ranasinghe et al. 2002</td>
</tr>
<tr>
<td>Ginger oil</td>
<td>Lime</td>
<td>Penicillium italicum</td>
<td>0.2 ml/l</td>
<td>0.2 ml/l</td>
<td>+</td>
<td>Na</td>
</tr>
<tr>
<td>Thyme oil; mint oil; savory oil; cumin oil; Ajowan caraway oil</td>
<td>Orange</td>
<td>Penicillium italicum; Penicillium digitatum; Alternaria citri</td>
<td>75-150-250 mg/l</td>
<td>+</td>
<td>Na</td>
<td>Azizi et al. 2006</td>
</tr>
<tr>
<td>Dill oil; coriander oil; cumin oil; rosemary oil; thyme oil</td>
<td>Orange</td>
<td>Penicillium italicum; Penicillium digitatum; Alternaria citri</td>
<td>0.3-0.6-0.9 ml/l</td>
<td>+</td>
<td>Na</td>
<td>Yigin et al. 2000</td>
</tr>
<tr>
<td>Essential oil or Component</td>
<td>Commodity</td>
<td>Pathogen(s)</td>
<td>Essential oil conc. (mg/l or ml/l, mM, %w/v, %v/v or purity)</td>
<td>Effects</td>
<td>Antimicrobial Quality</td>
<td>Reference</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-----------</td>
<td>-------------</td>
<td>---------------------------------------------------------------</td>
<td>---------</td>
<td>-----------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Thyme oil; menthol; eugenol</td>
<td>Fruit decay</td>
<td>Botrytis cinerea, Rhizopus stolonifer</td>
<td>200 mg/l</td>
<td>+</td>
<td>+</td>
<td>Wang et al. 2007</td>
</tr>
<tr>
<td>Vanillin; eugenol, geraniol, citral</td>
<td>Native and inoculated flora</td>
<td>Geotrichum candidum; Alternaria alternata</td>
<td>3000 mg/l</td>
<td>+</td>
<td>Na</td>
<td>Cerruti et al. 1997</td>
</tr>
<tr>
<td>Carvacrol; cinnamaldehyde; cinnamic acid</td>
<td>Total viable counts</td>
<td>Penicillium italicum roqueforti</td>
<td>5-15 mM</td>
<td>+</td>
<td>-</td>
<td>Roller and Seedhar 2002</td>
</tr>
<tr>
<td>Cinnamon oil; thyme oil; oregano oil</td>
<td>Aspergillus flavus; Aspergillus niger; Aspergillus tamarri; Penicillium citrinum</td>
<td></td>
<td>0.1-0.25-0.5-1.0 ml/100 g seeds</td>
<td>±</td>
<td>±</td>
<td>Rodrigues et al. 2007</td>
</tr>
<tr>
<td>Thyme oil; summer savory oil; clove oil paste</td>
<td>Aspergillus flavus</td>
<td></td>
<td>0.05-0.20-0.35-0.50 ml/l</td>
<td>+</td>
<td>-</td>
<td>Omidbeygi et al. 2007</td>
</tr>
<tr>
<td>Cinnamon oil; Orange oil</td>
<td>Colletotrichum coccodes; Botrytis cinerea</td>
<td></td>
<td>0.05-0.5 ml/l</td>
<td>±</td>
<td>±</td>
<td>Tzanakaki and Tzortzakis 2009</td>
</tr>
<tr>
<td>Cassia oil (alone or with MgSO₄)</td>
<td>Alternaria alternata</td>
<td></td>
<td>0.2-0.3-0.4-0.5-1.0 ml/l</td>
<td>+</td>
<td>0</td>
<td>Feng and Zheng 2007; Feng et al. 2008</td>
</tr>
<tr>
<td>Thyme oil; lemon balm oil</td>
<td>Total Viable Count; Lactic Acid Bacteria; Enterobacteria; Pseudomonas</td>
<td></td>
<td>0.25-0.5-1.0 ml/l</td>
<td>±</td>
<td>-</td>
<td>Gutierrez et al. 2008b</td>
</tr>
<tr>
<td>Oregano oil + thyme oil</td>
<td>Pseudomonas</td>
<td></td>
<td>0.15 ml/l;0.25 ml/l</td>
<td>+</td>
<td>+</td>
<td>Gutierrez et al. 2008a</td>
</tr>
<tr>
<td>Thyme oil; Mint oil (Fungastop™)</td>
<td>Escherichia coli</td>
<td></td>
<td>0.1-1.0 ml/l</td>
<td>±</td>
<td>Na</td>
<td>Singh et al. 2002</td>
</tr>
<tr>
<td>Oregano oil; Carrots</td>
<td>Mesophilic aerobic microorganisms; mould; yeast</td>
<td></td>
<td>0.2% (w/v)</td>
<td>+</td>
<td>+</td>
<td>Martinez-Romerio et al. 2008</td>
</tr>
<tr>
<td>Thyme oil; Holy basil oil</td>
<td>Escherichia coli</td>
<td></td>
<td>0.1-1.0 ml/l</td>
<td>+, ++</td>
<td>Na</td>
<td>Singh et al. 2002</td>
</tr>
<tr>
<td>Peanut oil</td>
<td>Botrytis cinerea</td>
<td></td>
<td>0.2 ml/l</td>
<td>+</td>
<td>+</td>
<td>Tripathi et al. 2008</td>
</tr>
<tr>
<td>Tea Tree oil</td>
<td>Botrytis cinerea</td>
<td></td>
<td>0.1 ml/l</td>
<td>+</td>
<td>+</td>
<td>Martinez-Romerio et al. 2007</td>
</tr>
<tr>
<td>Carvacrol; oregano oil</td>
<td>Botrytis cinerea</td>
<td></td>
<td>0.05-0.05-0.1-0.5 ml/l</td>
<td>+</td>
<td>+</td>
<td>Martinez-Romerio et al. 2005</td>
</tr>
<tr>
<td>Thymol; Peppermint</td>
<td>Moulds; yeasts; Total aerobic mesophilic</td>
<td></td>
<td>0.5 ml/l</td>
<td>+</td>
<td>+</td>
<td>Valero et al. 2006</td>
</tr>
</tbody>
</table>

Table 1: Pathogen(s) — (not recorded)
Effects: + (controlled microbial growth/produce quality enhanced); ++ (complete elimination of surface microflora); - (no effect on or stimulation in microbial growth/adverse effect on produce quality); ± (variable dependent on storage conditions); Na (not assessed); 0 (no effect on microbial growth or produce quality)
Grown in apples (*Malus domestica* L.) and plums (*Prunus armeniaca* L.) fruits was as *Th. vulgaris* > *T. cymricum* > *C. cymricum* > *M. piperita* and the extent of inhibition of fungal growth depended on the concentration used. Likewise, Yigin et al. (2000) reported the antifungal activity of several EOs (dill (*Anethum graveolens* L.), *Mentha arvensis* L. and *Cuminum cyminum* L.), rosemary (*Rosmarinus officinalis* L.), thyme (*Thymus spicata* L.) at 0.3-0.9 ml/l against green mold (*P. digitatum*), on oranges. Moreover, oils of mint (0.1 ml/l), ginger (*Zingiber officinale* L.) (0.2 ml/l) and oregano (*Ocimum cumanum* L.) (0.5 ml/l) controlled blue mould rot (caused by *P. italicum*) of oranges and lime fruits during storage. The mint oil-treated oranges and lime fruits showed enhancement of storage life of 6 and 8 days, respectively. The storage life of oregano oil-treated oranges and lime fruits was found to be enhanced by 6 days while in the case of ginger oil, it was for 4 and 8 days enhancement of shelf life of oranges and lime fruits, respectively (Tripathi et al. 2004).

Mandarin (*Citrus reticulata* L.) fruits fumigated with thyme EO (0.02 ml/l) reduced up to 30% green mold comparing to the control (Arras et al. 1994). The goatweed (*Ageratum corymbosum* L.) oil (0.3% v/v) employed by dipping and fumigation successfully controlled blue mould rot (*P. italicum*) of mandarins and imparted no adverse effect on the quality of treated fruits (Dixit et al. 1995). Young mature-green lemons (*Citrus lemon* L.), produced greater limonene hydroperoxides and demonstrated significantly lower decay incidence than older yellow fruit when their oil glands were punctured in the presence of postharvest wound pathogen *P. digitatum* Sacco. Furthermore, wounding of the oil glands or injection of limonene hydroperoxides into the lemon peel elicited the production of the citrus fruit phytoalexins, scoparone and scopoletin, to levels postharvest wound pathogen *Penicillium expansum*, *M. fructigena* and *G. stolonifer*.

In vivo experiments, wound-inoculated apricots (*Prunus armeniaca* L.) and plums (*Prunus salicina* L.) were reduced (up to 95%) the incidence of brown rot (*Monilinia fructicola*) following fumigation with thymol (4-8 mg/l) (Liu et al. 2002). Fumigation of apricots with 2 mg/l of thymol vapor reduced the germination of *M. fructicola* conidia to 2% compared with 98% on untreated fruit. Microscopic observations showed that the fumigated spores fumigated with thymol were shrunk and had collapsed protoplasts (Liu et al. 2002).

EOs (1.5-3.5 mg/l) extracted from clove leaves (*Syringa portulaciniata* L.) reduced the rate of rotted fruits and inhibited to some extent pathogens (*Penicillium expansum*, *B. cinerea*, *Colletotrichum gloeosporioides*, *Macrophoma kawatsuka*, *M. frutigena* and *Trichothecium roseum*) grown in apples (*Malus domestica* L.) (Li et al. 2006). The EOs of eucalyptus (0.004-0.008 ml/l) and cumin (0.005-0.010 ml/l) displayed in vivo antifungal activity up to 59% and 57% on *P. expansum* and *B. cinerea* on orange and banana fruit, respectively (Lee et al. 2007). Moreover, Friedman et al. (2004a) evaluated 17 plant EOs (apricot, bergamot (*Citrus aurantium* L.) , cinnamon bark, cinnamon Cassia, cinnamon leaf, clove bud, grapefruit (*Citrus × paradisi*), lavender (*Lavandula angustifolia* L.), lemon, lemongrass (*Cymbopogon flexuosus* L.), lime, balm oil (*Melissa officinalis* L.), orange bitter, orange Mandarin, orange sweet, oregano Spanish, tangerine (*Citrus reticulata* L.) and nine oil-fomi oil-india (cited apples nol, geraniol, linalool, linalyl acetate, terpineol, terpinen-4-ol, carvacrol, cinnamaldehyde) for antibacterial activity against the foodborne pathogens *Escherichia coli* O157:H7 and *S. enterica* in apple juices. The activity was greater for *S. enterica* than for *E. coli*, increased with incubation temperature and storage time, and was not affected by the acidity of the juices. Among the 10 most active compounds against *E. coli* (60 min BA98 range in clear juice, 0.018-0.093%) were carvacrol, oregano oil, geraniol, eugenol, cinnamon leaf oil, citral, clove bud oil, lemongrass oil, cinnamon bark oil, and lemon oil. The corresponding compounds against *S. enterica* (BA98 range, 0.0044-0.011%) were lemon balm oil, carvacrol, oregano oil, terpineol, geraniol, lemon oil, citral, lemongrass oil, cinnamon leaf oil, and linalool. The bactericidal results are related to the composition of the oils (Friedman et al. 2004a).

Fumigation of sweet cherry (*Prunus avium* L.) with thymol (0.02 ml/l) was effective in controlling gray mold and brown rot caused by previous inoculation with spores of *B. cinerea* and *M. fructicola* (Chu et al. 1999). Moreover, the microbial analysis showed that all EOs (eugenol, thymol, menthol and eucalyptol) reduced moulds and yeasts and total aerobic mesophilic colonies by 4- and 2-log CFU compared with control, respectively (Serrano et al. 2005). The brown rot incidences of *M. fructicola*-inoculated cherry dipped in 1000 mg/l thymol and carvacrol decreased up to 72% compared with the control. The effects of thymol and carvacrol were not significantly enhanced by the addition of CaCl2 or CaB2O4, a foliar calcium fertilizer. Methyl jasmonate, an elicitor of plant defense mechanisms, reduced (69-73%) stem brownning of cherry fruits only when used as a co-fumigant with thymol and carvacrol but not as an additive in dipping or fumigation experiments with thymol and carvacrol (Tsedes and Liu 2004).

Treatment with basil (*Ocimum basilicum* L.) oil (0.16% v/v), lemongrass (*C. flexuosus* L.) oil (0.16% v/v), cinnamon (*C. zeylanicum* L.) oil (0.03-0.22% v/v) and clove (*S. aromaticum* L.) oil (0.02-0.11% v/v) controlled crown rot disease complex (caused by *Fusarium sp.*, *Lasiodiplodia theobromae* and *Colletotrichum musae*) and anthracnose (*Colletotrichum musae*) prolonging storage of bananas (*Musa acuminate* L.) up to 21 days at 13.5 °C (Ranasinghe et al. 2002; Anthony et al. 2003; Rasania et al. 2005).

When lemongrass oil (40 ml/l) companied with hot water controlled better the anthracnose rot (*C. gloeosporioides*) compared with hot water treatment with carbenadazin (at 100 mg/l) for mango (*Mangifera indica* L.) fruit (Duan-khamnanee 2008). Carvacral and cinnamonic acid, were found to delay the spoilage of fresh-cut kiwifruit (*Actinidia chinensis*) at chilling temperatures (Roller and Seedhar 2002).

The outcomes of several studies employing EOs as preservative mean on tomato (*Lycopersicon esculentum* L.) are differentiated. Platto et al. (2003) reported that EOs (oregano, thyme, lemongrass, and coriander) vapors (50 mg/l) were not successful in stopping disease (*B. cinerea*, *Alternaria arborescens*, *R. stolonifer* and *Geotrichum candidum*) development in inoculated tomatoes. Additionally, some oil vapors appeared to induce phytotoxicity (introduced in different ratios or might be due to one or more compounds present in the oil) on treated fruit under long periods of exposure. In the same study, emulsions of oils of thyme and oregano at 5 ml/l and 10 ml/l as dip treatments reduced disease development in tomatoes inoculated with *B. cinerea* and *A. arborescens* (Platto et al. 2003). However, oreganum- (0.4 ml/l) and sage (0.01-0.50 ml/l)-treated tomatoes inhibited fungal development (*Colletotrichum coccodes*, *Alternaria alternata* and *B. cinerea*) (Tzanakaki and Tzortzakis 2001). The oil on treated fruit under long periods of exposure. In combination with MgSO4 (0.25-3% v/v) reduced the percentage of decayed tomatoes (Feng and Zheng 2007; Feng et al. 2008). Fruit decay decreased in tomato-treated with cinnamon or eucalyptus oil (0.05-0.5 ml/l) vapours and transfer to chilled air (Tzortzakis 2007b). No differences observed on wound-inoculated tomato fruit after cinnamon oil (0.05-0.5 ml/l) exposure against *B. cinerea* and *C. coccodes* development. However, pre-exposing tomato fruit to 0.5 ml cinnamon
implications. While the antifungal activity against brown rot (\textit{M. fructicola}) could be significant, the EOs may also induce phytotoxicity, which may be undesirable.

**Impacts of essential oil on fruit quality characteristics**

Strawberries treated with essential oil (0.1 ml/l) of tea-tree oil enhanced antioxidant capacity (antioxidant system such as oxygen radical absorbance capacity (ORAC), radical 2,2-di-(4-tert-octylphenyl)-1-picyrylhydrazyl (DPPH), radical cation 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS)), and free-radical scavenging capacity (superoxide radicals (O$_2^-$), hydroxyl radicals (\textit{OH}), and singlet oxygen (O$_2$)). However, the EOs treatments were found to delay the spoilage of fresh-cut honeydew melon at chilling temperatures without adversely affecting sensory quality (Ferreira and Seedharker 2002).

**EFFECTS OF ESSENTIAL OIL ON FRESH PRODUCE QUALITY**

Fruit quality encompasses many aspects, and includes not only flavour, colour, nutritional aspects and firmness, but also shelf life, processing attributes, resistance to pathogens and human health attributes (Brummell and Harpster 2001). EOs may induce phytotoxicity in long periods of exposure and/or increased concentrations makes them undesirable fresh commodities as well as increased risks of human health. Tomatoes treated with EOs for 24 hours observed phytotoxicity and it was apparent after 6 hours of fumigation if a fan was used to distribute the volatile oils (thyme, oregano and lemongrass) in the container. Phytotoxicity occurred when tomatoes were fumigated with the EOs, or with the respective major components alone, indicating that at least the major compounds were contributing to the phytotoxicity (Pluto et al. 2003).

Despite the antifungal activity against brown rot (\textit{M. fructicola}) of thymol on cherries, EOs vapors induced burning on the stems, affected fruit quality (Tsao and Zhou 2000). Additionally, a residual taste from thymol on fumigated cherries made this mode of treatment not commercially applicable. Plant EOs may be effective to control postharvest diseases. However, much work remains to be done to develop a formulation that maintains the fungicidal activity of the material, and yet does not induce undesirable effects.

**Impacts of essential oil on fruit quality characteristics**

Strawberries treated with essential oil (0.1 ml/l) of tea-tree oil enhanced antioxidant capacity (antioxidant system such as oxygen radical absorbance capacity (ORAC), radical $2,2$-di-(4-tert-octylphenyl)-1-picyrylhydrazyl (DPPH), radical cation 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS)) and free-radical scavenging capacity (superoxide radicals (O$_2^-$), hydroxyl radicals (\textit{OH}), and singlet oxygen (O$_2$)) during storage at $10^\circ$C as compared to the control (Chanjirakul et al. 2007). Indeed, strawberries treated with thyme, menthol, or eugenol maintained better fruit quality with higher levels of sugars, organic acids, phenolics, anthocyanins, flavonoids, and oxygen radical absorbance capacity than the untreated fruits. These data provide evidence that, in addition to possessing antimicrobial activity, the EOs also increase free radical scavenging capacity and antiproliferative activity in fruit and, in turn, enhance the resistance of fruit tissues to deterioration and spoilage (Wang et al. 2007). However, when fruit exposed to eucalyptus and cinnamon volatile oil compounds (0.05 or 0.5 ml/l) at 13°C during or following vapour exposure revealed not much effects on fruit quality related characteristics (Tzortzakis 2007b).

Blackberries treated with EOs (0.1 ml/l) of tea-tree oil enhanced antioxidant capacity (antioxidant system such as ORAC, DPPH, ABTS and free-radical scavenging (H$_2$O$_2$, \textit{OH}) during storage at 10°C as compared to the control (Chanjirakul et al. 2007). The postharvest quality of raspberries was improved (increased levels of sugars, organic acids, oxygen radical absorbance capacity and darker colour) after treatment (0.1 ml/l) with tea tree oil and storage at 0, 10 or 20°C compared with untreated fruit (Wang 2003). Moreover, treated fruits increased antioxidant capacity or the antioxidant enzyme activities (Chanjirakul et al. 2005).

Several naturally occurring EOs (200 mg/l) including...
carvacrol, anethole, cinnamaldehyde, cinnamic acid, perillaldehyde, linalool, and p-cymene increased antioxidant levels and activities in ‘Duke’ blueberries. Thus, total anthocyanins and total phenolics promoted following EOs treatment, and enhanced antioxidant activity in fruit tissues. Individual flavonoids were variably affected by the EOs. Additionally, treatment with carvacrol, anethole, or perillaldehyde increased the levels of fructose, glucose, and citric acid (Kong et al. 2009).

It has been reported that thyme EOs (0.02 ml/l) caused no injury in flavedo of ripe mandarin fruits (Arras et al. 1994).

Fumigation of apricots with thymol resulted in firmer fruit and higher surface browning, but total soluble solids (TSS) and titratable acidity (TA) were not affected. Fumigation of plum with thymol resulted in higher TSS, but firmness and TA were not affected. Indeed, thymol fumigation caused phytotoxicity on apricots but not on plums (Liu et al. 2002).

EOs (1.5-3.5 mg/l) extracted from clove leaves reduced respiration rate and brown index of apple, as well as maintained fruit firmness, TSS and TA. Adding CaCl2 can improve the efficiency of phenolic and EOs, which will be developed into potential preservative for fruit storage (Li et al. 2002).

When cherry fruit quality parameters were determined, those treated (99.5% purity) with eugenol, thymol or menthol showed benefits in terms of reduced weight loss, delayed colour changes and maintenance of fruit firmness compared with control. Stem remained green in treated cherries while they became brown in control. However, cherries packaged with eucalyptol behaved even worse than control cherries, with generation of off-flavours, loss of quality and stem browning (Serrano et al. 2005).

Treatment with 0.16% (v/v) of basil or lemongrass oil prolonged fruit storage of bananas without any detrimental effect on their organoleptic properties (Anthony et al. 2003). Similar, treated banana with cinnamon oil (0.16-0.22 % v/v) and clove oil (0.02 % v/v) did not affect the organoleptic and physico-chemical properties of fruit (Ranasinghe et al. 2005). However, oil of Ceylon citronella (Cymbopogon martinitus L.) improved fruit firmness but affected negatively the texture and the flavour of the banana fruit and reduced the overall acceptability (Anthony et al. 2003).

Dipping in 0.5 ml/l water solution of origanum oil had some effect on fungus growth in the kiwifruit flesh, but reduced fruit quality making them completely unuseful some effect on fungus growth in the kiwifruit flesh, but TSS and TA were not affected. Indeed, thymol fumigation caused phytotoxicity in apricots but not on plums (Liu et al. 2002).

Treatment with 0.16% (v/v) of basil or lemongrass oil prolonged fruit storage of bananas without any detrimental effect on their organoleptic properties (Anthony et al. 2003). Similar, treated banana with cinnamon oil (0.16-0.22 % v/v) and clove oil (0.02 % v/v) did not affect the organoleptic and physico-chemical properties of fruit (Ranasinghe et al. 2005). However, oil of Ceylon citronella (Cymbopogon martinitus L.) improved fruit firmness but affected negatively the texture and the flavour of the banana fruit and reduced the overall acceptability (Anthony et al. 2003).

Impacts of essential oil on fruit coating edible films

The increase in consumption of fresh-cut produce has resulted in frequent outbreaks of illness associated with raw fruits and vegetables. During minimal processing, spoilage and pathogenic microorganisms can gain access to the nutrients inside fruits and multiply (Thunberg et al. 2002). The presence of E. coli on the surface of fruits may adversely affect the safety of fresh and fresh-cut fruits and vegetables. Controlling the numbers and the growth of pathogenic bacteria is a challenging problem for the food processing industry (Burt and Reinders 2003). The use of edible films and coatings for a wide range of food products, including fresh and minimally processed vegetables and fruits, has received increasing interest because films can serve as carriers for a wide range of food additives, including antimicrobials (Pranoto et al. 2005). Incorporation of EOs into edible films or coatings provides a novel way to enhance the safety and shelf life of ready-to-eat foods (Cagri et al. 2001). EOs have been extensively evaluated for their abilities to protect food against pathogenic bacteria contaminating apple juice (Friedman et al. 2004b) and other foods (Burt 2004).

To assess the antimicrobial effectiveness of natural compounds and plant extracts, it has been previously evaluated the bactericidal activities of about 200 plant EOs,
oil compounds, phenolic compounds, and flavonoids against major foodborne pathogenic bacteria including antibiotic-resistant bacteria (Friedman et al. 2003, 2004a, 2004b). The physicochemical properties of edible films (color, tensile strength, water vapor, and oxygen permeability) relate to coating enhancement of the mechanical integrity of foods, inhibition of moisture loss and oxidative rancidity, and final-product appearance (Debeaufort et al. 1998). Combination of antimicrobial and physicochemical properties is crucial for predicting the behavior of antimicrobial edible films (Cagni et al. 2001). Coating fruit with wax or polymers reduces fruit softening, chlorophyll degradation and chilling injury in fruit (Sornsvichai et al. 1990; Hagenmaier and Shaw 1992; Safnatter 1999). Ju et al. (2000c) indicated that the positive effects of plant oils on fruit quality attributes may relate to delayed ethylene production, although the mechanism by which plant oils inhibit ethylene production is not clear. The mechanism by which fruit coatings delay fruit senescence is explained primarily as a response to the modification of internal atmosphere, including CO₂, O₂, and ethylene (Safnatter 1999) and warrants further investigation.

A chitosan/methyl cellulose film incorporating vanillin (4-hydroxy-3-methoxybenzaldehyde) is the major constituent of vanilla beans and has a natural antimicrobial and antifungal activity against E. coli and S. cerevisiae on fresh-cut cantaloupe (Cucumis melo cantalupensis L.) and pineapple (Ananas comosus L.) (Sangsuwana et al. 2008). Vanillin has been used to inhibit E. coli O157:H7 and L. monocytogenes in ‘Granny Smith’ apple juice (Moon et al. 2006). Rupasinghe et al. (2006) reported that total aerobic counts of fresh-cut apple slices decreased from 4.3 log CFU/g fresh weight (untreated) to 1.6 log CFU by using NatureSeal (an antibrowning agent) plus 12mM vanillin after 19 days at 4°C. Cerrutti et al. (1997) treated strawberry puree with a mild heat treatment combined with 3000 mg/l vanillin and 500 mg/l ascorbic acid. They found that the inhibition of native and inoculated flora growth for at least 60 days storage at room temperature. Penney et al. (2004) found that vanillin at 2000 mg/l suppressed fungal and total microbial growth in yoghurt significantly over the 3-week period. Pranoto et al. (2005) incorporated garlic oil (0.1 ml of garlic oil/g) in chitosan film, found antimicrobial activity against S. aureus, L. monocytogenes, and Bacillus cereus. Plant-derived EOs can be used to prepare apple-based antimicrobial edible films for various food applications. Edible films, as carriers of antimicrobial compounds, constitute an approach for incorporating plant EOs (oregano, cinnamon, and lemongrass oils) onto fresh-cut fruit surfaces providing bactericidal activities against E. coli (Rojas-Grau et al. 2006). Edible films, as carriers of antimicrobial compounds, constitute an approach for incorporating plant EOs onto fresh-cut fruit surfaces. Oregano, cinnamon, lemongrass and vanillin oils (0.05-1.5% w/w) in apple puree film-forming solution (APFFS) and in an edible film made from the apple puree solution (APEF) revealed antibacterial activity against E. coli and Listeria innocua (Rojas-Grau et al. 2006, 2007). Coated apples containing high concentrations (up to 1.5% w/w) of EOs (oregano, cinnamon, lemongrass and vanillin) following packing with polypropylene film revealed significant reduction in the rates of ethylene production and respiration rates while lemongrass containing coatings induced severe texture softening (Rojas-Grau et al. 2007).

Effects of cinnamon EOs and its mixture with chitosan and calcium chloride on the storage of ‘Dangshan’ pear (Pyrus communis L.) were investigated at low temperature (0-2°C) combined with coating treatment (Gou et al. 2008). The results showed that cinnamon EOs (0.06 ml/l) and its mixture with chitosan (1%) and calcium chloride (1%) improved fruit taste and flavor, delayed the appearance of fruit respiration peak for 10 days and restrain the increase of MDA contents, relative electric conductivity and polyphenoloxidase activity. Compared with the control, at storage of 40 days, superoxide dismutase and catalase activity were increased by 239 and 146%, but peroxidase activity is decreased by 56% (Gou et al. 2008). Plant (soybean (Glycine max L.), corn (Zea maiz L.), peanut (Arachis hypogaea L.), cottonseed (Gossypium sp.) and linseed (Linum usitatissimum L.)) oil emulsions (3, 6, and 9%) applied at harvest and stored at 0°C for 6 months, improved fruit quality of pears (cv. ‘Laiyang Chili’ and ‘Ya L’.) (Ju et al. 2006). Plant oil emulsions, regardless of the sources of oil, at 6% concentration, delayed ethylene production and respiration, maintained fruit quality attributes, such as firmness, color, TSS and TA, and controlled internal browning, completely after 6 months storage. No off-flavor was detected in either oil-treated and control fruit by sensory evaluation (Ju et al. 2000c). When applied at harvest, plant oils (corn, soybean, peanut, olive (Olea europaea L.), cottonseed, and linseed) delay climactERIC rise in ethylene and ripening and maintained fruit quality attributes in ‘Golden Delicious’ apples and ‘Bartlett’ pears (Ju et al. 2000b) and inhibit scald development and degreening in ‘Delicious’ apples (Ju et al. 2000a) during and after prolonged cold storage. Similarly, coating fruit with wax or polymers also reduces fruit softening and chlorophyll degradation (Sornsvichai et al. 1990; Safnatter 1999). The other reason for coating fruit with EOs (cinnamon, palmarosa and lemongrass) and their mixture with chitosan is to delay fruit senescence. Cerrutti et al. 2006) reported that total aerobic counts of fresh-cut apple slices decreased from 4.3 log CFU/g fresh weight (untreated) to 1.6 log CFU by using NatureSeal (an antibrowning agent) plus 12mM vanillin after 19 days at 4°C. Cerrutti et al. (1997) treated strawberry puree with a mild heat treatment combined with 3000 mg/l vanillin and 500 mg/l ascorbic acid. They found that the inhibition of native and inoculated flora growth for at least 60 days storage at room temperature. Penney et al. (2004) found that vanillin at 2000 mg/l suppressed fungal and total microbial growth in yoghurt significantly over the 3-week period. Pranoto et al. (2005) incorporated garlic oil (0.1 ml of garlic oil/g) in chitosan film, found antimicrobial activity against S. aureus, L. monocytogenes, and Bacillus cereus. Plant-derived EOs can be used to prepare apple-based antimicrobial edible films for various food applications. Edible films, as carriers of antimicrobial compounds, constitute an approach for incorporating plant EOs (oregano, cinnamon, and lemongrass oils) onto fresh-cut fruit surfaces providing bactericidal activities against E. coli (Rojas-Grau et al. 2006). Edible films, as carriers of antimicrobial compounds, constitute an approach for incorporating plant EOs onto fresh-cut fruit surfaces. Oregano, cinnamon, lemongrass and vanillin oils (0.05-1.5% w/w) in apple puree film-forming solution (APFFS) and in an edible film made from the apple puree solution (APEF) revealed antibacterial activity against E. coli and Listeria innocua (Rojas-Grau et al. 2006, 2007). Coated apples containing high concentrations (up to 1.5% w/w) of EOs (oregano, cinnamon, lemongrass and vanillin) following packing with polypropylene film revealed significant reduction in the rates of ethylene production and respiration rates while lemongrass containing coatings induced severe texture softening (Rojas-Grau et al. 2007).

A number of EOs components have been registered by the European Commission for use as flavourings in foodstuffs. The flavourings registered are considered to present no risk to the health of the consumer and include amongst others carvacrol, carone, cinnamaldehyde, citral, p-cymene, eugenol, limonene, menthol and thymol. New flavourings may only be evaluated for registration after toxicological and metabolic studies have been carried out (as reviewed by Burt 2004), which could entail a considerable financial outlay.

In spite of the fact that a considerable number of EO components are GRAS and/or approved food flavourings, some research data indicate irritation and toxicity. For example, eugenol, menthol and thymol, when applied in root canal treatments, have been known to cause irritation and some research data indicate irritation and toxicity. For example, eugenol, menthol and thymol, when applied in root canal treatments, have been known to cause irritation and toxicity. For example, eugenol, menthol and thymol, when applied in root canal treatments, have been known to cause irritation and toxicity. For example, eugenol, menthol and thymol, when applied in root canal treatments, have been known to cause irritation and toxicity. For example, eugenol, menthol and thymol, when applied in root canal treatments, have been known to cause irritation and toxicity.
dermatitis in people who use them frequently (Burt 2004). It is recommended that more safety studies be carried out before EOs are more widely used or at greater concentrations in foods that at present.

**FUTURE WORK**

There is a need to better understand how EOs components and other natural antimicrobials interact with cells to cause antifungal and bacteriostatic or bactericidal effects and the putative changes in membrane. Experimental tests could be used to develop new approaches for increasing the sensitivity of these and other more troublesome organisms in foods by taking advantage of synergies among the antimicrobials. Further work along these lines should allow better understanding of the basis for microbial species resistance to EOs and other natural antimicrobial agents. However, the extent to which bacteria can adapt to the presence of EOs in foods is also important for further evaluation; *B. cereus* has been shown to become less sensitive to carvacrol after being grown in the presence of nonlethal concentrations (Ulte et al. 2000). Antagonism between EO and food ingredients is undesirable and research is needed so it can be avoided in practical applications. The stability of EOs during food processing will also be a theoretical area of study. Experimental studies demonstrate that ESIs and their components and other food ingredients and food additives as well as fresh produce organoleptic properties, need to be investigated. Clove and oregano oils canacquire a dark pigmentation when in contact with iron (Bauer et al. 2001); this may impose limitations on their application. Synergistic effects could be exploited so as to maximise the antibacterial activity of EOs and to minimise the concentrations required to achieve a particular antibacterial effect.

**CONCLUSION**

The use of EOs in consumer goods is expected to increase in the future due to the rise of ‘green consumerism’, which stimulates the use and development of products derived from plants (De Silva 1996). This applies to the food and cosmetic sectors but also to medicinal products. Undesirable organoleptic effects can be limited by careful selection of EO according to the type of food. Synergism and antagonism between components of EOs and food constituents require more study before these substances can be reliably used in commercial applications. If the active substances are to be added to foods in greater concentrations than is currently normal practice for flavourings, further safety studies may be necessary. Several research studies took place by the present authors; more focused work on fresh produce preservation and quality related characteristics, prolonging fruit storage as well as enhance defense mechanism of fresh produce.

**REFERENCES**


Bishop CD, Reagan J (1998) Control of the storage pathogen *Botrytis cinerea* on Dutch cabbage (*Brassica oleracea* var. capitata) by the essential oil of *Melaleuca alternifolia*. *Journal of Essential Oil Research* 10, 57-60


Delauqis PJ, Maza G (1995) Antibacterial properties of *oilofishiocyanates* in food preservation. *Food Technology* 49, 73-84


Friedman M, Buick R, Elliott CT (2004a) Antibacterial activities of naturally occurring compounds against antibiotic-resistant *Bacillus cereus* vegetative cells and spores, *Escherichia coli*, and *Staphylococcus aureus*. *Journal of Food Protection* 67, 1774-1778


Tzortzakis NG (2007b) Maintaining postharvest quality of fresh produce with volatile compounds. Innovative Food Science and Emerging Technologies 8, 111-116

Tzortzakis NG (2009) Impact of cinnamon oil-enrichment on microbial spoilage of fresh produce. Innovative Food Science and Emerging Technologies 10, 97-102


