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The Use of Essential Oils and Bacteriocins as Natural Antimicrobial and Antioxidant Compounds

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ABSTRACT

Food-borne illness resulting from consumption of food contaminated with pathogenic bacteria has been of vital concern to public health. To reduce the health hazards and economic losses due to food-borne microorganisms, the use of natural products as antimicrobial compounds seem to be an interesting way to control the presence of pathogen in food. Spices are rich in phenolic compounds such as flavonoids and phenolic compounds, witch exhibit a large range of biological effects, including antimicrobial and antioxidant properties. Lactic acid bacteria (LAB) have been also used for centuries as a preservation method of food using fermentation process. Antimicrobial activities of LAB have been demonstrated in various species and their antagonist actions are demonstrated against numerous intestinal and food-borne pathogens. The preservative ability of LAB in foods is attributed to the production of anti-microbial metabolites. Bacteriocins are antimicrobial metabolites category, recognized as small peptides and designated as bacteriocins. Bacteriocins have attracted attention as potential substitutes for antibiotics to cure and/or prevent bacterial infections and are widely employed in food preservation. The inclusion of essential oils and bacteriocins in food products should lead to beneficial effects such as improved safety, quality and flavour; and potential in the biopreservation of food. This review highlights the mechanism of action of these antimicrobial and antioxidant compounds, and their application in food systems.

Keywords: antibacterial, peptides, polyphenols, terpenoids, lactic acid bacteria

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INTRODUCTION

In spite of modern technologies and safety concepts, such as HACCP, the reported numbers of food-borne illnesses and intoxications are still increasing (O'Sullivan *et al*. 2002). According to the According to the United Nations, more than 30% of the mortality rate world-wide is caused by alimentary diseases. According to Health and Welfare Canada, the annual costs to treat food borne illness are estimated at $1 billion in Canada and from $5 to $86 billion in the United States. The estimated cost from five bacterial foodborne pathogens total 6.9 billion/year in 2000 (Anon 1994; USDA 2000). *Campylobacter*, *Listeria*, *Shigella*, *Escherichia coli* and *Salmonella* are the most important bacteria responsible for food-borne illness in Canada. However, *Salmonella*, *Campylobacter jejuni*, *E. coli* 0157:H7, *Listeria monocytogenes*, *Staphylococcus aureus* and *Clostridium botulinum* can contaminate meat, poultry, eggs, seafood and dairy products.

The desire of most countries to make food safer for consumption requires better food preservation and production techniques. In this regard, the use of natural antimicrobial compounds is an interesting alternative to be considered.

Essential oils (EOs) have long served as flavouring agents in food and beverages, and due to their versatile content of antimicrobial and antioxidant compounds; they possess potential as natural agents for food preservation (Conner 1993; Oussalah *et al*. 2007a). Lactic acid bacteria (LAB) can produce important antimicrobial metabolites called bacteriocins. This paper will review some applications of these natural compounds in food systems in order to kill pathogens and also to increase their shelf life.

ESSENTIAL OILS

EOs are secondary metabolites of the plant and are used in many applications of the spice and food industry. Each variety has a different physiological and biochemical form with special enzymatic equipment, genetically codified, which directs biosynthesis by a preferential formation of the components (Russo *et al*. 1998). They are commonly concentrated in one particular region such as leaves, bark or fruit,

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and when they occur in various organs in the same plant, they frequently have different composition profiles. EOs have long served as flavouring agents in food and beverages, and due to their versatile content of antimicrobial compounds, they possess potential as natural agents for food preservation (Connor 1993).

Steam distillation is the most commonly used method for producing EOs on a commercial basis (Burt 2004). Extraction by liquid carbon dioxide under low temperature and high pressure seem to produce a more natural organoleptic profile and may also influence antimicrobial properties (Moyler 1998) and the use of hexane for the extraction have been shown to exhibit greater antimicrobial activity than corresponding steam distillation (Packiyasothy and Kyle 2002). It was also established that the antioxidative properties of most herb extracts were greatly dependent on the extraction solvent used (Yanishlieva *et al*. 2006) and supercritical carbon dioxide extraction can also protect the antioxidant property of the extract (Tipsrisukond *et al*. 1998). The major active compounds present in EOs are terpenoids and phenolic compounds (Oussalah *et al*. 2007a).

Antimicrobial properties

EOs from spices and herbs have been shown to possess antimicrobial functions and could serve as a source of antimicrobial agents against food pathogens (Janssen *et al*. 1985; Deans and Ritchie 1987; Kim *et al*. 1995). More particularly, EOs and their components are known to be active against a wide variety of microorganisms. Depending of the Eos and the microorganism evaluated a minimal inhibitor concentration of 1 mM for active compounds to 3% for less active compound was observed when tested against. *E.coli* or *S*. Typhimurium (Kim *et al*. 1995; Helander *et al*. 1998; Skaltsa *et al*. 2003). The use of EOs as natural antibacterial compounds seem to be an interesting way to control the presence of pathogenic bacteria and to extend the shelf life of food. According to Cragg (1997) over than 78% of the drugs from natural origins are for antibacterial uses. Jantova *et al*. (2000) observed an inhibition of 42% of *S. aureus* growth when in presence of *Philadelphus microphyllus* (Philadelphaceae). This extract also inhibited 32% of *Enterococcus faecalis*. According to his study, *Gymnocladus dioicus*, *Amelanchier ovalis, Exochorda racemosa*, *Holodiscus discolor*, *Philadelphus microphyllus*, *Philadelphus coronaries* and *Pelargonium tabulare* had the strongest antimicrobial effect. Billing and Sherman (1998) compared the antimicrobial properties of 43 spices traditionally used in the meat-based cuisines in 36 different countries. According to these authors, spices help cleanse foods of pathogens and thereby contribute to the health, longevity and reproductive success of people. Between the 30 spices evaluated, some of them (garlic, onion, allspice, oregano) inhibited all bacteria evaluated (more than 35 bacterial species), 80% of spices inhibited more than 50% of bacteria tested, 50% of spices inhibited more than 75% of bacteria tested (**Table 1**). In general, Gram-positive bacteria are more sensitive than Gram-negative and *Pseudomonas* species are least sensitive to bioactive agents (Ceylan and Fung 2004). Huhtanen (1980) reported that 31 ppm alcoholic extracts of mace and achiote (*Cannato*, *Bixa orellanal*) were the most inhibitory spices among 33 spices tested against *Clostridium botulinum* in culture media. Nutmeg bay leaf (*Myristica fragrans* Houtt), white and black peppers (*Piper nigrum* L.) (125 ppm) were moderately inhibitory while paprika (*Capsicum annuum* var. *angulosum* Mill.), rosemary (*Rosmarinus officinalis*), cloves (*Syzygium aromaticum* L.), oregano (*Origanum vulgare*), turmeric (*Curcuma domestica* Loir.) and thyme (*Thymus serpyllum*) (500 ppm) were slightly inhibitory. Shelf-life of chicken, beef and mutton cuts sprayed with water extracts of ginger (*Zingiber officinale* Rosc.), garlic (*Allium sativum*) and onion (*Allium amaryllis*) were extended at ambient temperature (Ziauddin *et al*. 1996). Garlic was the most effective showing a longer shelf-life than ginger and onion treatments (Ziauddin *et al*. 1996). Garlic juice was effective to eliminate the growth of *Staphylococcus*, *Streptococcus*, *Vibrio cholerae* and the growth of some zoophatogenic fungi and many strains of yeast (Block 1985). A concentration of garlic juice (1%) can inhibit the growth of *E. coli*, *S*. Typhosa and *S. aureus*. Addition of onion is less effective. A concentration of 4% is needed to eliminate completely *S. aureus* and to reduce by 48% the growth of *E. coli* (Al-Delaimy and Ali 1970). Various organic sulphur compounds related to the flavour of garlic and onion are believed to be antimicrobial (Sharma *et al*. 1979; Garlic and Health Group 2007). Stecchini *et al*. (1993) have shown that clove extract can inhibit the growth of *Aeromons hydrophila* in cooked pork. Cinnamon (*Cinnamomum cassia*) and clove have a greater inhibition on the growth of *L. monocytogenes* compared to garlic, onion and mustard (Bahk *et al*. 1990). Eugenol and pimento extract (one-tenth ml of ethyl alcohol extract/25-g beef sample) exhibited a great inhibition of *A. hydrophila* and *L. monocytogenes* in cooked beef (Hao *et al*. 1998). The use of methyl chavico, a compound present in basil is bactericidal against *A. hydrophila* and *Pseudomonas fluorescens* at a respective concentration of 0.125 and 2%, respectively (Wan *et al*. 1998). A decoction of 100% sage (*Santolina* sp.) or thyme reduces significantly the population of *Yersinia lipolytica* on chicken (Ismail *et al*. 2001). The furocoumarins present in parsley (0.12-8%) was found to have antimicrobial properties against *L. monocytogenes*, *E. coli* 0157:H7 and spoilage microorganisms (Manderfeld *et al*. 1997). Also, EOs containing monoterpenes, eugenol, cinnamaldehyde, thymol, citronellol, limonene and geraniol and phenolic compounds present in carrots seem to have strong antilisterial activity (Lis-Balchin and Deans 1997).

EOs have also antifungal properties. When antibiotics are not employed, chicken can be contaminated by the growth of *Candida* and *Rhodutorula*. Clove, coriander (*Coriandrum sativum* L. Vernacular), cinnamon, cardamom (*Elettaria cardamomum* L.), thyme, tea tree (*Melaleuca alternifolia*), marjoram (*Pelargonium* spp.), ho leaf (*Acanthopanax sieboldianus*), rosemary, peppermint (*Mentha* × *piperita*), palmarosa (*Cymbopogon martinii*), lemon grass (*Cymbopogon citratus*) and sage EOs in the range of 50–500 µg/ml possessed stronger antimicrobial activity against yeast than bacterial cultures (Hili *et al*. 1997). Vanillin (2000 ppm), a major constituent of vanilla beans, has a significant inhibitory effect against spoilage yeast like *Saccharomyces cerevisiae*, *Zygosaccharomyces rouxii*, *Debaryomyces hansenii* in apple puree (Cerutti and Alzamora 1996). Garlic culture inhibits the growth of *Candida*, *Cryptococcus*, *Thodotorula torulopsis* and *Trichosporon* (Moore and Atkins 1977). The addition of ground oregano, thyme and their extract in growth media inhibit the production of aflatoxins (B_1 and G_1) of *Aspergillus parasiticus* (Salmeron *et al*. 1990). Thymol and carvacrol (0.0025 and 0.05%) at pH 5.5 can inhibit completely the growth of *Aspergilus flavus*, *Aspergilus niger*, *Geotricum candidum*, *Mucor* spp., *Penicillium* spp. in potato dextrose agar (Akgul and Kivanc 1988). Cinnamon at 0.02, 0.2, 2.0 and 20% inhibited the growth of *Aspergilus parasiticus* by 16, 23, 31 and 100% and aflatoxin production by 25, 68, 97, and 100%, respectively (Bullerman 1974). Mustard oil can inhibit the growth

Table 1 Proportional inhibitory property of spices against bacterial strains tested[1].

Percent bacterial inhibition	Spice
75-100%	Garlic, onion, allspice, oregano, thyme, cinnamon, tarragon, cumin, cloves, lemon grass bay leaf, capsicums, and rosemary.
50-75%	Marjoram, mustard, caraway, mint sage, fennel, coriander, dill and nutmeg.
Less than 50%	Basil, parsley, cardamom, pepper (black and white), ginger, anise seed, celery seed, lemon, and lime.

[1] Adapted from Billing and Sherman 1998.

of *Saccharomyces ellipsoideus*, *Saccharomyces cerevisiae* and *Mycoderma vini* in pickles and sauerkraut (Shelef 1984).

Several other studies were done on the antimicrobial activity of EOs (Conner and Beuchat 1984; Carson and Riley 1993; Panizzi *et al*. 1993; Helander *et al*. 1998; Cox *et al*. 2000; Nielsen and Rios 2000; Delaqui *et al*. 2002; Mejholm *et al*. 2002; Araujo *et al*. 2003; Burt and Reinders 2003). According to these studies, the antimicrobial activity of EOs is assigned to a number of small terpenoids and phenolic compounds, which also in pure form have been shown to exhibit higher antibacterial or antifungal activity (Karapinak and Aktung 1987; Conner 1993; Didry *et al*. 1993; Juven *et al*. 1994; Oosterhaven *et al*. 1996; Suppakul *et al*. 2003). According to Cosentino *et al*. (1999) an essential oil rich in phenolic compounds presents higher antimicrobial properties as compared to EOs rich in terpenoids. However, some minor components can play a role by producing a synergistic effect with other components. This has been observed with sage (Marino *et al*. 2001), certain species of thyme (Marino *et al*. 1999), oregano (Paster *et al*. 1995; Turgis *et al*. 2007) and clove (Turgis *et al*. 2007). EOs of spices damage the structural and metabolic enzymes, and inhibit the repair of heat-injured yeasts (Conner and Beuchat 1984). The antibacterial properties of the compounds present in EOs are normally associated with their lipophilic character, leading to accumulation in membranes and to subsequent attack of the integrity of the membrane, energy depletion (Conner 1993; Sivropoulow *et al*. 1996), a significant damage of the external envelope (Rhayour *et al*. 2003) or plasmic membrane (Lambert *et al*. 2001). The hydrophilic/lipophilic balance, presence of a phenolic-OH group that can easily react and form hydrogen bonds with enzymes and other factors could also determine the extent of the inhibition of EOs (Farag *et al*. 1989). The presence and location of a hydroxyl group on the molecule, the lipid solubility and the degree of steric hindrance also determines the antimicrobial activity of phenolic antioxidants (Raccach 1984). Aliphatic aldehydes with one or more double bonds conjugated to their carbonyl group had much higher antifungal activity than those that did not have double bonds (Kurita *et al*. 1981). The presence of alkyl group on benzene ring of phenol or guaiacol enhanced the antifungal activity of the phenolic compounds (Ceylan and Fung 2004). Allicin is the principal antibacterial compound in garlic and acts as an inhibitor towards –SH group enzymes (Beuchat and Golden 1989). Allicin also affects fatty acids, lipid biosynthesis and RNA synthesis of microorganisms, inhibits acetyl-CoA synthetase in fatty acid biosynthesis, acetate kinase and phosphotransacetylase enzyme systems (Focke *et al*. 1990). Adetumbi *et al*. (1986) reported that garlic extract interfered with enzymes in lipid biosynthesis. Ghannoum (1988) has also observed that the structure and the integrity of the outer surface of *Candida albicans* was affected, that there was a loss of intracellular components and morphological changes, a decrease of the lipid content, a higher proportion of phosphatidylserines and lower proportions of phosphatidylcholines. Oussalah *et al*. (2006a) evaluated the mechanism of the antimicrobial action of Spanish oregano, Chinese cinnamon and savory (*Satureja montana*) EOs. Cell membranes and walls of bacteria was studied by the measurement of the intracellular pH (pH_{in}) and ATP concentration, the release of cell constituents and the electronic microscopy observations of the cells when these EOs at their minimal inhibitory concentration (MIC) were in contact with *E. coli* O157:H7 and *L monocytogenes*. *E. coli* O157:H7 and *L. monocytogenes* as Gram-negative and Gram-positive bacterial models. Treatment with these EOs at their MIC (from 0.025 to 0.05%) was able to affect the membrane integrity of bacteria and to induce depletion of the intracellular ATP concentration. An increase of the extracellular ATP concentration was observed only when Spanish oregano and savory oils were in contact with *E. coli* O157:H7 and *L. monocytogenes*. Also, a significantly higher ($P \leq 0.05$) cell constituents release was observed in the supernatant when *E. coli* O157:H7 and *L. monocytogenes* cells were treated with Chinese cinnamon and Spanish oregano oils. Chinese cinnamon oil was more effective to reduce significantly the pH_{in} of *E. coli* O157:H7, whereas Chinese cinnamon and Spanish oregano decreased more significantly the pH_{in} of *L. monocytogenes*. Electronic microscopy observations revealed that except for the cells treated with cinnamon, the cell membranes of both treated bacteria was significantly damaged. These results suggested that degradation of the cytoplamic membrane involves the toxic action of EOs. The concentration of membrane muropeptide of higher molecular weight was 6 times higher in the murein of cells treated with EOs. Also, the concentration of muropeptide of lower molecular weight in the presence of the EOs at their MIC was 2 times weaker than in the presence of 0.5 of the MIC concentration (Caillet *et al*. 2005, 2006a). Transmission electron microscope observations revealed that EOs significantly affect the cell wall structure. The authors concluded that the murein is not disrupted by antimicrobial treatments, but its composition and relative percentage of muropeptides were severely modified so that they become critical for the physical integrity of the cell wall. Ultee *et al*. (2000a, 2000b) also observed that carvacrol, one of the major components of oregano and thyme, can interact with the cell membrane, where it dissolves the phospholipid bilayer and is assumed to align between the fatty acid chains. This distortion of the physical structure would cause expansion and destabilisation of the membrane, increasing membrane fluidity, which in turn would increase passive permeability (Ultee *et al*. 2002a, 2000b). Some EOs can inhibit the production of enzymes. For example, eugenol present in clove inhibits the production of amylase and proteases by *Bacillus cereus* (Farag *et al*. 1989). The hydroxyl group of eugenol is thought to bind to proteins, preventing enzyme action in *Enterobacter aerogenes* and cell wall deterioration and high degree of cell lysis were also noted (Thoroski *et al*. 1989; Wendakoon and Sakaguchi 1995). Other compounds do not affect the cell wall. For example, cinnamaldehyde inhibit the growth of *E. coli*, *Salmonella* and *E. coli* 0157:H7 but do not disintegrate the outer membrane or deplete the intracellular ATP pool (Helander *et al*. 1998; Oussalah *et al*. 2006a). The carbonyl group is thought to bind to proteins, preventing the action of amino acid decarboxylases in *E. aerugenes* (Wendakoon and Sakaguchi 1995).

Chemical analysis of the most efficient oils like thyme, oregano and cinnamon had shown that the principal active constituents are principally carvacrol, thymol, citral, eugenol, 1,8-cineole, limonene, α-pinene, linalool and their precursors (Lataoui and Tantaoui-Elaraki 1994; Sikkema *et al*. 1995; Juliano *et al*. 2000; Demetzos and Perdetzoglou 2001). There are often large differences in the reported antimicrobial activity of oils from the same plant. The reasons of this variability can be due to the different geographical sources, the harvesting season, the genotype, the climate, the drying procedure and the distilled part of the plant. All of these variabilities influence the chemical composition and the relative concentration of each constituent in the EOs (Salzer 1972; Rhyu 1979; Arrebola *et al*. 1994; McGimpsey and Douglas 1994; Viollon and Chaumont 1994; Juliano *et al*. 2000). A number of EOs constituents exhibit significant antimicrobial properties when tested separately (Kim *et al*. 1995; Ultee *et al*. 1998; Ultee *et al*. 2000a, 2000b; Lambert *et al*. 2001). However, there is evidence that EOs are more strongly antimicrobial than is accounted for by the additive effect of their major antimicrobial components; minor components appear, therefore, to play a significant role (Lataoui and Tantaoui-Elaraki 1994; Paster *et al*. 1995).

Even though the essentials oils are generally regarded as safe (GRAS) (Kabara 1991; Lambert *et al*. 2001), their use is often limited to organoleptical criteria. For this reason, it is necessary to determine the MIC of pathogenic bacteria. The EOs that exhibit a low MIC have the potential to be added to food as an antimicrobial compound without affecting its sensorial quality. Oussalah *et al*. (2007a) evaluated

Table 2A Plant species, common name, origin, plant part source and main compounds of selected essential oils against pathogenic bacteria.

Plant species	Common name	Origin	Distilled part	Main compounds (Area %)
Cinnamomum cassia	Chinese cinnamon	China	Leaf-branch	Cinnamaldehyde (65), methoxy-cinnamaldehyde (21)
Cinnamomum verum	Ceylon cinnamon	Skri Lanka	Bark	Cinnamaldehyde (87)
Cinnamomum verum	Ceylon cinnamon	Madagascar	Leaf	Eugenol (63), β-caryophyllene (5)
Coriandrum sativum	Coriander	Russia	Fruit	Linalool (70), α-pinene (6)
Corydothymus capitatus	Spanish oregano	Spain	Flowering plant	Carvacrol (76)
Cymbopogon citratus	Lemongrass	Guatemala	Herb grass	Geranial (45), neral (32), limonene (9)
Cymbopogon flexuosus	Indian lemongrass	India	Herb grass	Geranial (46), neral (31)
Cymbopogon martinii var. motia	Indian palmarosa	India	Herb grass	Geraniol (80), geranyl acetate (9)
Cymbopogon nardus	Ceylon citronella	Skri Lanka	Herb grass	Geraniol (19), limonene (10), camphene (9)
Cymbopogon winterianus	Java citronella	Vietnam	Herb grass	Citronnellal (34), geraniol (21), Citronnellol (11)
Eugenia caryophyllus	Clove	Madagascar	Flower bud	Eugenol (78), eugenyl acetate (14)
Inula graveolens	Sweet inula	France	Flowering plant	Bornyl acetate (51), borneol (23), camphene (7)
Lavandula hybrida reydovan	reydovan lavandin	France	Flowering plant	Linalool (51), linalyl acetate (19), camphor (8)
Lavandula latifolia spica cineolifera	Spike cineole lavander	France	Flowering plant	Linalool (34), 1,8-cineole (22), camphor (15)
Melaleuca linariifolia	Narrow melaleuca	Australia	Leaf	Terpine ol4 (30), γ-terpinene (19), 1.8 cineole (14)
Origanum compactum	Oregano	Morocco	Flowering plant	Carvacrol (22), γ-terpinene (23), thymol (19)
Origanum heracleoticum	Greek oregano	France	Flowering plant	Carvacrol (54), paracymene (14), γ-terpinene (14)
Origanum majorana	Sweet marjoram	Egypt	Flowering plant	Terpinene-4-ol (26), γ-terpinene (12), thuyanol (10)
Pimenta dioica	Allspice	Antilles	Leaf	Eugenol (48), myrcene (27), geraniol (10)
Satureja hortensis	Summer savory	France	Flowering plant	Carvacrol (41), γ-terpinene (33), *p*-cymene (6)
Satureja montana	Winter savory	Slovenia	Flowering plant	Thymol (43), *p*-cymene (12), γ-terpinene (9)
Thymus mastichina	Borneol thymol	Spain	Flowering plant	1.8 cineole (47), linalool (24), limonene (7)
Thymus satureoides	Mother of thyme	Morocco	Flowering plant	Borneol (26), camphene (9), carvacrol (7)
Thymus serpyllum	Common carvacrol thyme	Albania	Flowering plant	Cavacrol (23), *p*-cymene (20), γ-terpinene (18)
Thymus vulgaris carvacroliferum	Common carvacrol thyme	France	Flowering plant	Cavacrol (32), *p*-cymene (24), thymol (12)
Thymus vulgaris linaloliferum	Common linalol thyme	France	Flowering plant	Linalool (60), linalyl acetate (10)
Thymus vulgaris thuyanoliferum	Common Thyjanol thyme	France	Flowering plant	Thujanol 4 (44), mycene 8-ol (13)
Thymus vulgaris thymoliferum	Common thymol thyme	France	Flowering plant	Thymol (38), *p*-cymene (19), γ-terpinene (17)

Adapted from Oussalah *et al.* (2007a).

Table 2B Minimal Inhibitory Concentration (MIC) and Maximal Tolerate Concentration (MTC) of selected essential oils against pathogenic bacteria.

Plant species	A	B	C	D
	MIC/MTC	MIC/MTC	MIC/MTC	MIC/MTC
Cinnamomum cassia	0.05/0.013	0.025/0.013	0.025/0.013	0.05/0.025
Cinnamomum verum	0.025/0.006	0.05/0.025	0.025/0.013	0.05/0.013
Cinnamomum verum	0.1/0.013	0.1/0.013	0.05/0.013	0.2/0.006
Coriandrum sativum	0.2/0.006	0.2/0.003	0.2/0.1	>0.8/0.2
Corydothymus capitatus	0.025/0.003	0.025/0.006	0.013/0.006	0.025/0.013
Cymbopogon citratus	>0.8/0.1	0.8/0.1	0.1/0.05	0.4/0.006
Cymbopogon flexuosus	>0.8/0.4	0.4/0.1	0.1/0.025	0.4/0.1
Cymbopogon martinii var. motia	0.2/0.1	0.2/0.025	0.1/0.025	0.2/0.013
Cymbopogon nardus	>0.8/0.1	0.8/0.013	0.4/0.1	0.8/0.013
Cymbopogon winterianus	>0.8/0.05	0.4/0.1	0.05/0.025	0.4/0.2
Eugenia caryophyllus	0.1/0.013	0.1/0.025	0.05/0.025	0.2/0.006
Inula graveolens	>0.8/0.013	>0.8/0.4	0.2/0.1	0.8/0.1
Lavandula hybrida reydovan	>0.8/0.1	0.4/0.1	0.8/0.4	>0.8/0.2
Lavandula latifolia spica cineolifera	>0.8/0.025	0.8/0.2	0.2/0.1	>0.8/0.4
Melaleuca linariifolia	>0.8/0.025	0.8/0.4	0.4/0.2	>0.8/0.1
Origanum compactum	0.025/0.006	0.05/0.006	0.013/0.006	0.1/0.013
Origanum heracleoticum	0.025/0.006	0.05/0.013	0.013/0.006	0.05/0.006
Origanum majorana	>0.8/0.013	0.4/0.025	0.2/0.05	>0.8/0.8
Pimenta dioica	0.1/0.025	0.1/0.025	0.1/0.025	0.2/0.006
Satureja hortensis	0.05/0.006	0.05/0.003	0.013/0.006	0.1/0.006
Satureja montana	0.05/0.013	0.05/0.013	0.013/0.006	0.05/0.013
Thymus mastichina	>0.8/0.003	>0.8/0.4	0.8/0.4	>0.8/0.006
Thymus satureoides	0.2/0.05	0.2/0.025	0.05/0.025	0.4/0.1
Thymus serpyllum	0.1/0.025	0.1/0.05	0.05/0.025	0.2/0.006
Thymus vulgaris carvacroliferum	0.05/0.003	0.05/0.006	0.025/0.013	0.1/0.013
Thymus vulgaris linaloliferum	>0.8/0.025	0.2/0.1	0.1/0.05	>0.8/0.4
Thymus vulgaris thuyanoliferum	0.8/0.05	0.4/0.1	0.4/0.2	>0.8/0.4
Thymus vulgaris thymoliferum	0.05/0.003	0.1/0.013	0.025/0.006	0.2/0.013

[a]According to the data of the gas chromatography analysis of essential oils provided by the manufacturer.
A*: E.coli* O157:H7
B*: S. typhimurium*
C: *S.aureus*
D: *L. monocytogenes*

twenty eight EOs for their antibacterial properties, against four pathogenic bacteria: *E. coli* O157:H7, *L. monocytogenes* 2812 1/2a, *S.* Typhimurium SL 1344 and *S. aureus*. Between them, *Corydothymus capitatus*, *Cinnamomum cassia*, *Origanum heracleoticum*, *Satureja hortensis*, *Satureja montana*, and *Cinnamomum verum* (bark) showed the low-

est MIC (≤0.05%) for all bacteria tested. *Thymus vulgaris thymoliferum*, *Thymus serpyllum*, *Thymus satureioides*, *Cymbopogon martinii*, *Pimenta dioica*, *Cinnamomum verum* (leaf) and *Eugénia caryophyllus* showed a lower antimicrobial activity showing a MIC ranging between 0.05% and 0.4% (v/v) against the four bacteria tested. Also thirteen others EOs were less active showing a MIC value ≥0.8% (v/v) (**Table 2**).

Even if the organoleptic impact is important, storage and cooking can enhance the degradation of EOs permitting the used of a higher concentration of EOs. It was observed for example that the addition of 0.8% v/w oregano oil was found to be acceptable after storage at 5°C and cooking (Tsigarida *et al*. 2000). The flavour, odour and colour of minced beef containing 1% v/w oregano oil improved during storage under MAP and vacuum at 5°C (Skandamis and Nychas 2001). The flavour of oregano also gradually decreased during storage at 2°C (Mejlholm and Dalgaard 2002). Fish cubes inoculated with *S.* Typhimurium (10^7 CFU/mL) were treated by immersion with carvacrol, citral or geraniol at 0.5, 1.5 and 3% (w/v) and a dose of 3% showed a complete inhibition of the bacteria in the presence of carvacrol and geraniol (Kim *et al*. 1995b). The addition of 0.9% (v/w) in a coating formulation sprayed on cooked shrimps had no detrimental effect on the appearance and flavour; however at higher concentration (1.8%) the coating decreased significantly the acceptability of shrimps (Ouattara *et al*. 2001). Carvacrol also affects the taste of fish (Kim *et al*. 1995b). It was found also that some compounds develop a more pronounced odour during storage. This phenomenon is observed after addition of thyme and oregano on whole sea bass at 0.05% (Mejlholm and Dalgaard 2002).

The food composition, the pH of the food, the temperature of storage and of the process, the external condition of storage (e.g. atmosphere packaging) affect significantly the efficiency of the EOs. Some compounds (e.g. mint oil) are effective against *S. enteritidis* in low fat yoghurt and cucumber salad (Tassou *et al*. 1995). It seems that the EOs are more effective in vegetables since these have a low fat content (Singh *et al*. 2002). The antimicrobial activity of sage increased with an increase in water content but decreased with an increase in fat and protein content (Shelef *et al*. 1984). Inhibition of *S.* Typhimurium, *S. aureus*, and *Pseudomonas* sp. was higher in broth (minimal inhibitor concentration (MIC) = 0.1-1%) and diminished in rice (MIC = 0.4->2.5%) and little or no inhibition was observed in meat at <2.5%. According to Skandamis and Nychas (2000), the activity of EOs depends on the pH, the storage temperature and EO concentration. A higher antimicrobial activity was observed at high temperature (15°C as compared to 10 and 5°C) and low pH (pH 4 as compared to pH 4.5 and 5).

Also, some compounds are not effective alone, however, when combined together, a synergistic effect could be found. For example, the use of spice blends such as chilli powder (red pepper, onion, paprika, garlic, cumin and oregano) and oriental five (pepper, cinnamon, anise, fennel, and cloves) in food produced powerful antimicrobial effects (Ceylan and Fung 2004). Lemon juice can synergistically enhance the antimicrobial effects of other spices (Mahrour *et al*. 2003a). In acidic environments the synergistic effect of lemon was higher due to the high amount of undissociated form of the acid (Ceylan and Fung 2004). The addition of essential oil under acidic conditions can also dissolve and/or attack to the lipid phase of the bacterial membrane (Skandamis and Nychas 2000). *p*-Cymene is not an effective antimicrobial compound, however, when combined with carvacrol, synergism has been observed against *B. cereus* (Ultee *et al*. 2000a, 2000b). It seems that *p*-cymene, incorporated in the lipid bilayer of bacteria, facilitates transport of carvacrol across the cytoplasmic membrane (Ultee *et al*. 2002a, 2002b). A mixture of cilantro, coriander, dill and eucalyptus EOs at different ratios resulted in an additive synergistic or antagonist effects (Delaquis *et al*. 2002). According to Moleyar and Narasimham (1992) a mixture of cinnamaldehyde and eugenol can inhibit *Staphylococcus* sp., *Micrococcus* sp., *Bacillus* sp., and *Enterobacter* sp. for more than 30 days completely at a concentration as low as 500 µg/ml. Rosemary extract have little bactericidal effect on the growth. A concentration of 5% was needed to obtain a bactericidal effect of *S. aureus* in mechanically deboned poultry meat (Farbood *et al*. 1976). However, the addition of sage and citric acid to rosemary can inhibit Gram-positive bacteria, *L. monocytogenes*, *L. innocua*, *S. aureus* and *Lactobacillus brevis* at 400 ppm in culture media. The use of EOs can also reduce the level of chemical additives. The addition of 0.08% spice extracts in mechanically deboned chicken frankfurters to substitute for nitrites and nitrates increased the lag phase of microbial growth for an extended period of time when stored at 7.2°C (MacNeil and Mast 1973). The use of carvacrol, cinnamaldehyde, thymol, and oregano oil at 0.1-2% can inhibit the growth of toxin production by *Clostridium perfringens* during chilling time of ground poultry (Juneja and Friedman 2007). Finally, it seems that most of the EOs are slightly more active against Gram-positive than Gram-negative bacteria (Lambert *et al*. 2001; Harpaz *et al*. 2003). It seems that the outer membrane surrounding the cell wall of Gram-negatives restricts diffusion of hydrophobic compounds through its lipopolysaccharide covering (Ratledge and Wilkinson 1988; Vaara 1992). However, a study testing 50 commercially available EOs against 25 genera found no evidence for a difference in sensitivity between Gram-positive and Gram-negative organisms (Deans and Ritchie 1987).

Since the active compounds are not stable over time and during processes, some studies have evaluated the possibility to protect the compound during storage and also to assure a controlled release during storage time. One study found that encapsulated rosemary oil was much more effective than standard rosemary EOs against *L. monocytogenes* in pork liver sausage; however the effect of EOs concentration was not evaluated in this study (Pandit and Shelef 1994). More recently, milk protein-based edible films containing oregano and/or piment EOs were applied on beef. Oregano-based films (1% w/v) were the most effective films to protect against the growth of *E. coli 0157:H7* or *Pseudomonas* sp. (Oussalah *et al*. 2004). Spanish oregano, Chinese cinnamon and winter savory EOs were used to protect the quality of bologna and ham. The EOs were immobilized in alginate-based films and applied on prepared meat. The results showed that the polymer was able to protect and assure a control release of the active compounds present in the EOs and protect the meat against pathogen contamination during storage (Oussalah *et al*. 2007b).

Antioxidant properties

Lipid oxidation is one of the major concerns in food technology (Yanishlieva *et al*. 2006). With the growing interest in natural antioxidants found in plants EOs from spices and herbs are the most important targets. The antioxidant properties of herb extracts vary depending of the food system. This is due in part to the composition of the extract and the food. It seems that the more polar antioxidants are more active in pure lipids and non-polar antioxidants are more active in a polar substrate (Frankel *et al*. 1996). Rosemary is one of the most effective spice extracts widely used in food processing. Rosemary was considered as both lipid antioxidant and meat chelator. According to Bracco *et al*. (1981), the antioxidant properties of rosemary is related essentially to the presence of carnosol and carnosic acid. Several other diterpenes such as rosmaridiphenol and rosemaniquinone have also been reported to contribute to the antioxidant properties of rosemary extract. Some of these compounds have greater antioxidant properties than synthetic compounds. For example carnosic acid is more active than BHT and BHA (Auroma *et al*. 1992); rosmanol and carnosol are more effective than BHA, BHT and α-tocopherol (Nakatani and Inatani 1983; Yanishlieva *et al*. 2006). According to the authors, rosemary extract inhibits

the formation of polar substances and polymers and the decomposition of polyunsaturated triacylglycerols. Rosemary antioxidants were found suitable for deep-frying of edible oils (Gordon and Kourimska 1995a), especially in presence of ascorbil palmitate (Gordon and Kourimska 1995b). Sage extract is also in the same family as rosemary (*Labiatae*). It is not surprising to find the presence of carnosol, carnosic, rosmadial and rosmanol as well as an important antioxidant property (Schwarz and Ternes 1992; Cuvelier *et al*. 1994). Oregano has both antioxidant and antimicrobial properties. It is primarily composed of carvacrol and thymol (Lagouri *et al*. 1993). It was found that thymol was a better antioxidant for triacylglycerols of sunflower than those of lard (Yanishlieva *et al*. 1999). Thyme and oregano are rich in thymol and carvacrol and are also known to inhibit lipid peroxidation (Yanishlieva *et al*. 1999). Mild oregano, strong oregano, sage and mint showed also good antioxidant properties (Caillet *et al*. 2007). Spanish oregano, pimento and oregano-pimento (1:1) EOs were immobilized in milk proteins-based films for meat preservation (Oussalah *et al*. 2004). The antioxidant properties of the films were evaluated and showed that oregano-based films were able to stabilized lipid oxidation in beef muscle, whereas pimento-based films presented the highest antioxidant activity. Salmieri and Lacroix (2006) have incorporated Spanish oregano, Chinese cinnamon or winter savory as natural antioxidant and antimicrobial agents in alginate/polycaprolactone-based films. The antioxidant properties have shown that the oregano-based films had the highest antiradical properties. Oregano-based films showed also a better level of active compounds in films during storage of whole beef, ham and bologna as compared to cinnamon or savory based-films (Oussalah *et al*. 2006b, 2007b). These results mean a better control release of the active compounds during storage. Nutmeg, mace and turmeric also have good antioxidant properties. Some examples have been reported on lard (Chipault *et al*. 1952, 1955) and on oil for the protection of α-tocopherol (Beddows *et al*. 2000). A strong synergistic effect was found between the rosemary extract (0.02%) and α-tocopherol (0.05%) in sardine oil for protection against lipid oxidation at 30°C and in frozen-crushed meat models (Wada and Frang 1992). The combination of Butylated HydroxyToluene (BHT) and rosemary or a combination of sage and citric acid has a synergistic effect for the prevention of lipid oxidation (Jaswir *et al*. 2004). Oleoresin rosemary and sage were also found to be effective phytochemical antioxidants, protecting palm olein against oxidative deterioration during frying (Jaswir *et al*. 2005). Other compounds like lecithin, ascorbyl palmitate, and amino acid salts of phosphatic acids, amino acids and lower peptides could be used to act in synergy with the herb or spice extracts. The activities of the extracts are higher in food containing protein, as sulphur and amino groups of the polypeptide chains interact with hydroperoxides, thus decreasing the free radical level (Pokorny 1999).

Essential oils in combined treatments

The activities of spice extracts could be increased by synergistic activity of other harmless compounds. Simultaneous application of a bacteriocin (nisin) and an essential oil (carvacrol or thymol) caused a larger decline in viable counts for strains of *B. cereus* than was observed alone. The use of spice extract in combination with sodium chloride, sugar and organic acids might provide a synergistic effect during the thermal process in controlling microbial growth (Shelef *et al*. 1980). When mild heat treatment (45°C, 5 min.) was applied a higher reduction of viability could be achieved (Periago *et al*. 2001). Mild heat treatment (45°C, 30 min.) in the presence of carvone could permit a 1.31 log reduction of viable cell numbers of *L. monocytogenes*. According to the authors, the high degree of unsaturation causes the cell membranes to be more fluid at 45°C than the membranes of cells grown at 8°C. This higher fluidity would enable carvone to dissolve more easily into the lipid bilayer of cells grown at 8°C than into the bilayer of cells grown at 45°C. Membranes of cells grown at 45°C are less fluid because there is a normal ratio of saturated to unsaturated fatty acids in their phospholipids and carvone is therefore less effective against them (Karatzas *et al*. 2000). Low oxygen levels can enhanced the antibacterial efficiency of EOs. The use of vacuum packing increase the efficiency of oregano when applied on beef fillets (Paster *et al*. 1990). The lethal effect of clove and coriander EOs is more pronounced on *Aeromonas hydrophila* on pork loin when packed under vacuum (Stecchini *et al*. 1993). The application of oregano before packing minced beef under modified atmosphere conditions can delay the microbial growth as compared to the packing under air where no shelf life extension was found (Skandamis and Nychas 2001) and modified atmosphere is effective in controlling the growth of *Clostridium jejuni* (Paster *et al*. 1990). Low oxygen tension might yield less oxidative changes in the oils and/or anaerobic conditions might increase the sensitivity of bacterial cells to the antimicrobial activity of the oils (Ceylan and Fung 2004). The antimicrobial activity of thyme oil or thymol against *S. aureus* and *S.* Typhimurium was greater under anaerobic conditions (Naigre *et al*. 1996). The addition of EOs before a cold pasteurization can significantly increase the radiosensitivity of bacteria in meat. Mahrour *et al*. (2003) observed that a marinade treatment before irradiation is highly effective, and has an additive effect with gamma irradiation (0, 3 and 5 kGy) to reduce the microorganism load, and to control the proliferation of the total endogenous microorganisms during storage of poultry. No *Salmonella* was observed during 12 days of storage in marinated and irradiated chicken at 3 kGy. A dose of 5 kGy was needed to eliminate *Salmonella* in non-marinated poultry. More recently, Chiasson *et al*. (2004, 2005) evaluated the effect of thyme or its principal constituents (carvacrol or thymol) addition on ground beef, on the radiation D_{10} values for *E. coli* and *S.* Typhi. The results of these studies have demonstrated that the addition of carvacrol significantly reduced the radiation D_{10} of both bacteria. An additive effect of carvacrol addition and packaging under modified atmosphere was also observed on bacterial radiosensitization. Compared to the samples packed under air, the relative sensitivity was increased from 2 to 2.7 for *E. coli* and to 10 for *S.* Typhi. Caillet *et al*. (2006b, 2006c) obtained similar results when irradiation (0.07-2.5 kGy) was done on carrots coated with edible coating containing *trans*-cinnamaldehyde in order to eliminate *L. monocytogenes* in ready to use carrots. Moreover, the results indicated that elimination of *L. monocytogenes* by irradiation was done at a lower dose when irradiation was done under modified atmosphere. These results indicated that the combination of natural antimicrobial compounds, irradiation and modified atmosphere play an important role in the radiosensitization of *L. monocytogenes*. A marinated mixture containing thyme and rosemary in lemon juice was also able to protect against the phospholipid oxidation present in chicken legs and preserve their sensorial quality during irradiation treatment (Mahrour *et al*. 2003b). Lacroix *et al*. (2000) reported that natural antioxidants from rosemary and thyme caused a substantial reduction in the generation of volatile hydrocarbons from arachidonic and linoleic acids generated during irradiation at 3 and 9 kGy.

BACTERIOCINS

Fermentation is a well known process in order to preserve food quality. LAB have been used for centuries in the fermentation of variety of dairy products (O'Sullivan *et al*. 2002). LAB include the genera *Lactococcus*, *Streptococcus*, *Lactobacillus*, *Pediococcus*, *Leuconostoc*, *Enterococcus*, *Carnobacterium* and *Proprionibacterium* (Nettles and Barefoot 1993; Savadogo *et al*. 2007). Antimicrobial activities of LAB have been demonstrated in various species and their antagonist actions are demonstrated against numerous intestinal and food-borne pathogens such as *E. coli*, *L. monocytogenes*, *S. aureus*, *Clostridium difficile* and others (Heik-

kila and Saris 2003; Mahoney and Henriksson 2003; Ghrairi *et al*. 2004; Plummer *et al*. 2004; Millette *et al*. 2007a). The preservative ability of LAB in foods is attributed to the production of anti-microbial metabolites. These metabolites include organic acids, diacetyl, carbone dioxide, hydrogen peroxide, reuterin, derivatives of lactic acid such as hydroxyl lactic acid and also small peptides designated bacteriocins (Millette *et al*. 2007b). Bacteriocins have attracted attention as potential substitutes for antibiotics to cure and/or prevent bacterial infections and are widely employed in food preservation (Riley and Wertz 2002). Bacteriocins have been shown to have potential in the preservation of meat, dairy products, canned food, fish, alcoholic beverage, salads, egg products, high-moisture bakery products, and fermented vegetables (Chen and Hoover 2003). When screened for food applications, the producing strain should have GRAS; the bacteriocin should have a broad spectrum of inhibition; the bacteriocin should be heat-stable and have no associated health risks; the inclusion of the bacteriocin in the food products should lead to beneficial effects such improved safety, quality and flavour; it should have high specificity and potential in the biopreservation of food (Cotter *et al*. 2005).

Bacteriocins are divided into three or four groups (Nes *et al*. 1996; Cleveland *et al*. 2001). Class I bacteriocins are small peptides that have from 19 to 38 and sometimes more than 50 amino acids and are characterized by their unusual amino acids such as lanthionine, dehydrobutyrine and dehydroalanine. Generally the elongated amphilic cationic lantibiotics (e.g. nisin) are active through the formation of pores, leading to the dissipation of membrane potential and the efflux of small metabolites from sensitive cells. Globular lantibiotics (e.g. mersacidin) act through enzyme inhibition. However, the binding of nisin to lipid II facilitates a dual mechanism of action involving the prevention of peptidoglycan synthesis and pore formation (Cotter *et al*. 2005). Class Ia consist of cationic and hydrophobic peptides that form pores in target membranes and have flexible structure compared to the more rigid class Ib. Compared to Class Ia bacteriocin, Class Ib bacteriocins are globular peptides and have no charge or a net negative charge (Altena *et al*. 2000). Class II bacteriocins contains small (< 10 kDa) and heat-stable, non modified peptides. The majority of class II bacteriocins are active in the nanomolar range by inducing membrane permeabilization and the subsequent leakage of molecules from target bacteria (Cotter *et al*. 2005). Class IIa bacteriocins includes pediocin- active peptides with a conserved N-terminal sequence Tyr-Gly-Asn-Gly-Val and two cysteines forming an S-S bridge in the N-terminal half peptide. Pediocin-like bacteriocins have a narrow spectrum of activity but display a high specificity against *L. monocytogenes* (Herchard and Sahl 2002). Class III bacteriocins are normally large and heat labile. Their mechanism of action is distinct from that of bacteriocins as they function through the lysis of sensitive cells by catalyzing cell-wall hydrolysis (Cotter *et al*. 2005). The Class IV consist of bacteriocins forming complexes with other macromolecules (Klaenhammer 1993).

Antimicrobial properties

The incorporation of bacteriocins as a biopreservative ingredient into model food systems has been studied extensively and has been shown to be effective against the growth of pathogens and spoilage microorganisms in foods. Numerous bacteriocins with potential biopreservatives including various nisins, lacticins, lactostrepcins, lactococcins and lactocins (Carolissen-Mackay *et al*. 1997; Moll *et al*. 1999; Twomey *et al*. 2002), sakacin B (Samelis and Roller 1994), plantaricin C (Gonzalez *et al*. 1994), leucocin A-UAL187 (Leisner and Greer 1996), enterocin A (Ennahar and Deschamps 2000), carnocin U149 (Stoffels and Sahl 1993), piscicolin 126 (Jack *et al*. 1996), divercin V41 (Duffes *et al*. 1999) are produced by LAB. Several strains of *Pediococcus* genera such as *P. acidilactici*, *P. pentosaceus* and *P. parvulus* were found to produce pediocins. Pediocins thus far described have been reviewed by Ray and Miller (2000). Millette *et al*. (2007c, 2007d) were also the first to isolate bacteriocin-producing strains of *P. acidilactici* MM33 and *Lactococcus lactis* subsp. *lactis* MM19 from human intestine. Their study showed that the supernatant of the culture have important antimicrobials properties. The antimicrobial metabolites were heat-stable, and were active at a large pH range (2-10). The supernatant from *Lactococcus lactis* culture inhibited *Enterococcus faecium*, various species of *Lactobacillus* and *S. aureus* while those in the supernatant from the *P. acidilactici* culture inhibited *Enterococcus* spp., some lactobacilli and various serotypes of *L. monocytogenes*. The minimal inhibitor concentration obtained for *L. monocytogenes* was 200 AU/ml showing that these strains might be useful for control of enteric and food pathogens (Millette *et al*. 2007d). Purification of the bacteriocin was performed by cationic exchange chromatography followed by a reverse phase step. Biochemical, mass spectrophotometry, plasmid and amino acid sequence analysis showed that the bacteriocin secreted by *P. acidilactici* is identical to pediocin PA-1 (Millette *et al*. 2007d).

These antimicrobial metabolites can inhibit or destroy target microorganisms such as molds, yeasts, vegetative bacteria and bacterial spores. However, bacteriocins are produce in the ribosome and kill related bacteria (Klaenhammer 1993). Also, studies applied on food systems should be done to confirm their efficiency in presence of different nutrients and under different media, processes and storage conditions. Liu and Hansen (1990) have observed that nisin is significantly more soluble at pH 2 than pH 8. Davies *et al*. (1999) have observed that lower fat content is correlated with higher nisin activity. It seems that the effective concentration of nisin depends also of the food product. For example, the effective concentration of nisin in kimchi (lactobacilli), ricotta cheese (*L. monocytogenes*), bologna (*Lactobacilllus sake* and *Lactobacillus curvatus*), cottage cheese (*L. monocytogenes*), and skim milk (*B. cereus* spores) are respectively (100, 100, 1000, 2000, 4000 IU/ml) (Ferreira and Lund 1996; Davies *et al*. 1997; Davies *et al*. 1999; Wandling *et al*. 1999; Choi and Park 2000).

Among the studies done, pediocins (Class IIa bacteriocins) were evaluated for their effectiveness to control *L. monocytogenes* contamination in food, for example during manufacture of chicken summer sausage, and also for the preservation of wine and baked products (Baccus-Taylor *et al*. 1993; Schoeman *et al*. 1999). Pediocins were also evaluated on cheese sauce and showing that when 100 AU/ml is added, a 5 log reduction of *L. monocytogenes* was observed (Pucci *et al*. 1998). Leucocin showed effectiveness to delay the spoilage of meat by *L. sake* for up to 8 weeks (Leisner *et al*. 1996). Enterocin showed a good ability to control *L. monocytogenes* growth in ham, pork, chicken breast, pate and sausage under several conditions (Aymerich *et al*. 2000a, 2000b). Lacticin 3147 was also able to control *L. monocytogenes* in cottage cheese. A 99.9% reduction in the numbers of *L. monocytogenes* was observed within 5 days at 4°C (McAuliffe *et al*. 1999). Sakacin A was also used to control *L. monocytogenes* in ground beef (Schillinger *et al*. 1991). Nisin is an antimicrobial peptide or Class Ia bacteriocin, produced by several strains of *Lactococcus lactis*. This bacteriocin is approved for use in over 40 countries and has been in use as a food preservative for more than 50 years (Cleveland *et al*. 2001). Nisin is also recognized as GRAS by the United States Food and Drug Administration as stated in the Code of Federal Regulations (CFR section 184.1538). This bacteriocin can be added directly to cheese to prevent the growth of *Clostridium* and *Listeria* (Hirsch *et al*. 1951; Chung *et al*. 1989; Siragusa *et al*. 1999; Cleveland *et al*. 2001) and liquid egg ingredients (Siragusa *et al*. 1999) or combating contamination in wines by *Leuconostoc* and *Pediococcus* (Radler 1990a, 1990b; Daeschel *et al*. 1991). Nisin has been used throughout the world to preserve salad dressings (Delves-Broughton *et al*. 1996), canned foods

(Thomas *et al*. 2000) or meat (Cutter and Siragusa 1998). Nisin addition (2000 IU/g) in long-life cottage inoculated with 10^4 cfu/g of *L. monocytogenes* can reduce by 1000-fold the content of this bacteria after 7 days storage at 20°C (Ferreira and Lund 1996) and a complete growth inhibition of this bacteria was observed during 55 days in ricotta cheese stored under refrigeration when 2.5 mg/l of nisin was added in presence of 10^3 cfu/ml. Nisin is now known to form poration complexes in target cell membranes through a multi-step process that includes binding of the C-terminal via electrostatic interaction, then, the N-terminal part of nisin is inserted into the lipid phase of the bilayer. A depletion of the transmembrane potential ($\Delta\psi$) and /or the pH gradient, resulting of the leakage of cellular materials (Okereke and Montville 1992). It then results in the rapid efflux of small cytoplasmic compounds, e.g. amino acids, potassium, inorganic phosphate, and ATP, and finally to the cell death (Bauer and Dicks 2005). However, the effectiveness of nisin on meat surface is dependent of the meat system and the type of micro-organisms (Davies *et al*. 1999). Antimicrobial efficacy of nisin is dependent upon numerous factors including salt and fat content, basic pH, presence of curing agents and food particle size (Jung *et al*. 1992). Binding of nisin to food components make it unavailable to inhibit microorganisms or reduce its solubility and its dispersion throughout the foodstuff which decrease its antimicrobial capacity. Nisin is also relatively insoluble due to its hydrophobic nature and loses its efficacy at pH >5 (Scannell *et al*. 1997; Pol and Smid 1999). Storage temperature, MAP, state of the meat (raw or cooked) and the presence of other preservatives can also affect nisin efficacy (Murray and Richards 1998). Organisms normally sensitive to nisin *in vitro* are not necessarily sensitive to nisin in a meat system. For example, the concentration needed to inhibit *C. botulinum* spores is significantly higher in cooked meat than in nutritive media (Scott and Taylor 1981). According to Rose *et al*. (1999), nisin could be inactivated by the presence of small amount of glutathione, a low molecular mass thiol compound present in fresh raw ground beef. Cutter and Siragusa (1996) observed a lack of effectiveness to control the growth of *Brochothrix thermosphacta* when nisin was applied directly on beef carcass surface for a long period of storage. Nisin can also bind sulfudryl groups or meat particles and interacts strongly with phospholipids which limit its activity in meat with a high fat content (Henning *et al*. 1986; Chung and Dickson 1989). However, nisin is stable at low temperature and could be used for meat preservation. Also, nisin in combination with lower concentrations of nitrate can prevent the growth of *Clostridium* in meat products (Rayman *et al*. 1981, 1983). In order to protect the nisin against deleterious agents in fresh beef and to improve the efficiency of this bacteriocin, nisin (500 or 1000 IU/mL) was immobilized into palmitoylated alginate-based films or in activated beads in order to control a pathogen in meat product. Results demonstrated a 2 log reduction of *S. aureus* after one week of storage of slice meat covered by the film containing 1000 IU/mL of nisin (Millette *et al*. 2007b). The palmitoylation of alginate can be used to produce hydrophobic and water-vapor resistant beads and films. These matrices act also as a control delivery vehicle or to protect the bioactivity of the immobilized compound (le Tien *et al*. 2004). Nisin was also immobilized in plastic film for food application. Their results have shown that nisin-activated film may inhibit *Micrococcus luteus* ATCC 10240 in trypsic soya broth and control bacterial growth in raw and pasteurized milk during storage. The release of nisin was pH and temperature dependant but was able to maintain food quality, safety and extending the shelf life of milk when stored at 4°C during 7 days (Mauriello *et al*. 2005).

Bacteriocins in combined treatments

The narrow inhibitory spectrum, the poor penetration and solubility in meat, and the possible degradation by native proteolytic proteolytic enzymes in meat are the major limits uses in food (Mahapatra *et al*. 2005). Food treated with bacteriocins could not be safer just by the utilization of bacteriocins. The use of combined treatments with bacteriocins could have synergistic effects and the combination may be effective in controlling the microorganisms in food and assure the sensorial quality of foods. For example, high hydrostatic pressure inactivation of *E.coli* and *L. innocua* inoculated in liquid whole egg was improved significantly when done in presence of nisin at 1.25 and 5 mg/l. A reduction of almost 5 $\log^{10}$ units for *E. coli* and more than 6 $\log^{10}$ units for *L. innocua* was obtained at 450 MPa and 5 mg/l of nisin (Ponce *et al*. 1998). The combined effects of moderate heat (60°C, 5 min or 65°C, 2 min) in presence of nisin (25 mg/kg) increase the sensitivity of *L. monocytogenes* in cans of cold-pack lobster (Budo-Amoako *et al*. 1999). The use of bacteriocins and EOs combination is also an effective treatment. According to Singh *et al*. (2001), the use of nisin (0-200 IU/ml) and garlic extract (0-6 mg/ml) could help to overcome the problem of nisin resistance in Gram-positive bacteria. It seems that the presence of garlic extract can improve the activity of nisin in broth media and in food system (hummus). This phenomenon was also observed in presence of other food additives and spices extracts (James and Johnson 2001). Other natural additives like organic acids (polylactic and lactic) at 2% are more effective when added in presence of bacteriocins (nisin) at 200 IU/mL. This combined treatment was effective to lower the microbial population of psychrotrophic, *Enterobacteriaceae*, *Pseudomonas* and *Lactobacillus* and to inhibit *L. monocytogenes* for 42 d in vacuum-packaging beef (Ariyapitipun *et al*. 1999, 2000). Nisin (500 IU/g) was also mixed with 1.5% (sodium lactate or sodium citrate) and this combined treatment was also effective to control the growth of *Clostridium perfringens* DSM 756, *Salmonelle Kentucky* AT 1, non-pathogenic *L. innocua* DPC 1770 and increase protection against common pathogenic contaminants in fresh pork sausage (Scannell *et al*. 2000). The used of enzymes (lactoperoxydase) and other proteins (lysosyme, lactoferrin) could be useful to increase the bacterial sensitivity in food system i.e. milk to inhibit *L. monocytogenes*, to inhibit *E. coli*, *Salmonella* and *Campylobacter* in beef and dairy products (Boussouel *et al*. 2000; Davidson and Harrison 2002). The use of bacteriocins in combination with irradiation was also evaluated to determine their efficiency to eliminate *L. monocytogenes* on frankfurters. An addition of 6000 AU of pediocin and irradiation of 2.3 kGy was effective for inhibition of the pathogen for 12 weeks at 4 or 10°C (Chen *et al*. 2004).

CONCLUSION

A number of EOs and some of their constituents have important antimicrobial properties against food-borne pathogens. A high concentration of phenolic compounds is a key factor for the efficiency of the biological activity of the EOs. The organoleptic quality could be protected by selection of the extracts or the compounds, the determination of the maximal concentration that could be added in the product, the treatment applied and the storage conditions of the food. Synergistic effects could be obtained by combination of compounds and/or treatments. As alternative to the traditional chemical preservatives, bacteriocins have also considerable promise. However, bacteriocins do not have a broad host range. The use of EOs in combination with bacteriocins and with a combined treatments could be could have synergistic effects and the combination may be effective in controlling the microorganisms in food, assure the safety of food and protect the sensorial quality of foods.

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REFERENCES

Adetumbi M, Javor GT, Lau BH (1986) *Allium sativum* (garlic) inhibits lipid biosynthesis by *Candida albicans*. *Antimicrobial Agents and Chemotherapy* **30**, 499-501

Akgul A, Kivanc M (1988) Inhibitory effects of selected Turkish spices and oregano compounds on some foodborne fungi. *International Journal of Food Microbiology* **6**, 263-268

Al-Delaimy KS, Ali SH (1970) Antimicrobial action of vegetable extracts on the growth of pathogenic bacteria. *Journal of Science and Food Agriculture* **21**, 110-112

Altena K, Guder A, Cramer C, Bierbaum G (2000) Biosynthesis of the lantibiotic mersacidin: organization of a type B thesis of the lantibiotic gene cluster. *Applied Environmental Microbiology* **66**, 2565-2571

Anon (1994) Food-borne pathogens, risk and consequences. Council for Agricultural Science and Technology. Task Force Report No. 122, Ames, IA, USA

Arrebola ML, Navarro MC, Jiménez J, Ocána FA (1994) Yield and composition of the essential oil of *Thymus serpylloides* subsp. *Serpylloides*. *Phytochemistry* **1**, 67-72

Araújo C, Sousa MJ, Ferreira MF, Leão C (2003) Activity of essential oils from Mediterranean *Laminaceae* species against food spoilage yeasts. *Journal of Food Protection* **66**, 625-632

Ariyapitipun T, Mustapha A, Clarke AD (1999) Microbial shelf life determination of vacuum-packaged fresh beef treated with polylactic acid lactic acid and nisin solutions. *Journal of Food Protection* **62**, 913-920

Ariyapitipun T, Mustapha A, Clarke AD (2000) Survival of *L. monocytogenes* Scott A on vacuum-packaged raw beef treated with polylactic acid, lactic acid, and nisin. *Journal of Food Protection* **63**, 131-136

Aruoma OI, Halliwell B, Aeschbach R, Löligers J (1992) Antioxydant and pro-oxidant properties of active rosemary constituents: carnosol and carnosic acid. *Xenobiotica* **22**, 257-268

Aymerich T, Garriga M, Ylla J, Vallier J, Monfort JM, Hugas M (2000a) Application of enterocins as biopreservatives against *L. innocua* in meat products. *Journal of Food Protection* **63**, 721-726

Aymerich T, Artigas MG, Garriga M, Monfort JM, Hugas M (2000b) Effect of sausage ingredients and additives on the production of enterocin A and B by *Enterococcus faecium* CT492. Optimization of *in vitro* production and anti-listerial effect in dry fermented sausages. *Journal of Applied Microbiology* **88**, 686-694

Baccus-Taylor G, Glass KA, Luchansky JB, Maurer AJ (1993) Fate of *Listeria monocytogenes* and pediococcal starter cultures during the manufacture of chicken summer sausage. *Poultry Science* **72**, 1772-1778

Bahk J, Yousef AE, Marth EH (1990) Behavior of *Listeria monocytogenes* in the presence of selected spices. *Lebensmittelwissenchaften und Technologien* **23**, 66-69

Bauer R, Dicks LM (2005) Mode of action of lipid II-targeting lantibiotics. *International Journal of Food Microbiology* **101**, 201-16

Beddows GG, Jagait C, Kelly MJ (2000) Preservation of α-tocopherol in sunflower oil by herbs and spices. *International Journal of Food Science and Nutrition* **51**, 327-339

Beuchat LR, Golden DA (1989) Antimicrobials occurring naturally in foods. *Food Technology* **43**, 134-142

Billing J, Sherman PW (1998) Antimicrobial functions of spices: why some like it hot. *The Quarterly reviews of Biology* **73**, 134-142

Bullerman LB (1974) Inhibition of aflatoxin production by cinnamon. *Journal of Food Science* **39**, 1163-1165

Boussouel N, Mathieu F, Revol-Junelles AM, Milliere JB (2000) Effects of combinations of lactoperoxidase system and nisin on the behavior of *L. monocytogenes* ATCC 15313 in skim milk. *International Journal of Food Microbiology* **61**, 169-175

Bracco U, Löliger JL (1981) Production and use of natural antioxidants. *Journal of American Oil Chemistry Society* **61**, 686-690

Budo-Amoako E, Ablett RF, Harris J, Delves-Broughton J (1999) Combined effect of nisin and moderate heat on destruction of *L. monocytogenes* in cold-pack lobster meat. *Journal of Food Protection* **62**, 46-50

Burt S (2004) Essential oils: their antibacterial properties and potential applications in foods-a review. *International Journal of Food Microbiology* **94**, 223-253

Burt SA, Reinders RD (2003) Antimicrobial activity selected plant essential oils against *Escherichia coli* O157:H7. *Letters in Applied Microbiology* **36**, 162-167

Caillet S, Yu H, Lessard S, Lamoureux G, Ajdukovic D, Lacroix M (2007) Fenton reaction applied for screening natural antioxidants. *Food Chemistry* **100**, 542-552

Caillet S, Lacroix M (2006a) Effect of gamma irradiation and oregano essential oil on murein and ATP concentration of *Listeria monocytogenes*. *Journal of Food Protection* **69**, 2961-69

Caillet S, Millette M, Turgis M, Salmieri S, Lacroix M (2006b) Influence of antimicrobial compounds and modified atmosphere packaging on radiation sensitivity of *Listeria monocytogenes* present in ready-to-use carrots (*Daucus carota*). *Journal of Food Protection* **69**, 221-227

Caillet S, Millette M, Salmiéri S, Lacroix M (2006c) Combined effects of antimicrobial coating, modified atmosphere packaging, and gamma irradiation on *L. innocua* present in ready-to-use carrots (*Daucus carota*). *Journal of Food Protection* **69**, 80-85

Caillet S, Shareck F, Lacroix M (2005) Effect of gamma-irradiation and oregano essential oil on murein and ATP concentration of *E. coli* O157:H7. *Journal of Food Protection* **68**, 2571-2579

Carolissen-Mackay V, Arendse G, Hastings JW (1997) Purification of bacteriocins of LAB: problems and pointers. *International Journal of Food Microbiology* **34**, 1-16

Carson CF, Riley TV (1993) Antimicrobial activity of the essential oils of *Melaleuca alternifolia* – A review. *Letters in Applied Microbiology* **16**, 49-55

Cerrutti P, Alzamora SM (1996) Inhibitory effects of vanillin on some food spoilage yeasts in laboratory media and fruit puree. *International Journal of Food Microbiology* **29**, 379-386

Chen CM, Sebranek JG, Dickson JS, Mendonça AF (2004) Combining pediocin with postpackaging irradiation for control of *Listeria monocytogenes* on frankfurters. *Journal of Food Protection* **67**, 1866-1875

Chen H, Hoover DG (2003) Bacteriocins and their food applications. *Comprehensive Reviews in Food Science and Food Safety* **2**, 82-100

Chiasson F, Borsa J, Lacroix M (2005) Combined effect of carvacrol and packaging conditions on radiosensitivity of *Escherichia coli* and *Salmonella* Typhi in ground beef. *Journal of Food Protection* **68**, 2567-2570

Chiasson F, Borsa J, Ouattara B, Lacroix M (2004) Radiosensitization of *Escherichia coli* and *Salmonella* Typhi in ground beef. *Journal of Food Protection* **67**, 1157-1162

Ceylan E, Fung DY (2004) Antimicrobial activity of spices. *Journal of Rapid Methods and Automation in Microbiology* **12**, 1-55

Chipault JR, Mizuno GR, Hawkins JM, Lundberg WO (1952) The antioxidant properties of natural spices. *Food Research* **17**, 46-55

Chipault JR, Mizuno GR, Hawkins JM, Lundberg WO (1955) Antioxidant properties of spices in oil-in-water emulsion. *Food Research* **20**, 443-448

Choi MH, Park YH (2000) Selective control of lactobacilli in kimchi with nisin. *Letter of Applied Microbiology* **30**, 173-177

Conner DE, Beuchat LR (1984) Sensitivity of heat-stressed yeasts to essential oils of plants. *Applied and Environmental Microbiology* **47**, 229-233

Chung KT, Dickson JS, Crouse JD (1989) Effects of nisin on growth of bacteria attached to meat. *Applied and Environmental Microbiology* **55**, 1329-1333

Cleveland J, Montville TJ, Nes IF, Chikindas ML (2001) Bacteriocins: safe, natural antimicrobials for food preservation. *International Journal of Food Microbiology* **71**, 1-20

Cosentino S, Tuberoso CIG, Pisano B, Satta M, Mascia V, Arzedi E, Palmas F (1999) *In vitro* antimicrobial activity and chemical composition of Sardinian *Thymus* essential oils. *Letters in Applied Microbiology* **29**, 130-135

Cutter CN, Siragusa GR (1996) Reduction of *Brochothrix thermosphacta* on beef surfaces following immobilization of nisin in calcium alginate gels. *Letters in Applied Microbiology* **23**, 9-12

Cutter CN, Siragusa GR (1998) Incorporation of nisin into a meat binding system to inhibit bacteria on beef surfaces. *Letters in Applied Microbiology* **27**, 19-23

Cuvelier ME, Berset C, Richard H (1994) Separation of major antioxidants in sage by high performance liquid chromatography. *Science des Aliments* **14**, 811-815

Conner DE (1993) Naturally occurring compounds. In: Davidson P, Branen AL (Eds) *Antimicrobials in Foods*, Dekker, New York, pp 441-468

Conner DE, Beuchat LR (1984) Effects of essential oils from plants on growth of food spoilage yeasts. *Journal of Food Science* **49**, 429-434

Cotter PD, Hill C, Ross P (2005) Bacteriocins: developing innate immunity for food. *Nature Reviews* **3**, 777-788

Cox SD, Mann CM, Markham JL, Bell HC, Gustafson JE, Warmington JR, Wyllie SG (2000) The mode of antimicrobial action of the essential oil of *Malaleuca alternifolia* (tea tree oil). *Journal of Applied Microbiology* **88**, 170-175

Cragg GM, Newman DJ, Snader, KM (1997) Natural products in drug discovery and development. *Journal of Natural Products* **60**, 52-60

Cutter CN, Siragusa GR (1998) Incorporation of nisin into a meat binding system to inhibit bacteria on beef surfaces. *Letter of Applied Microbiology* **27**, 19-23

Daeschel MA, Jung DS, Watson BT (1991) Controlling wine malolactic fermentations with nisin and nisin-resistant strains of *Leuconostoc oenos*. *Applied and Environmental Microbiology* **57**, 601-603

Davidson PM, Harrisson MA (2002) Resistance and adoption to food antimicrobials, sanitizers and other process controls. *Food Technology* **56**, 69-78

Davies EA, Milne CF, Bevis HE, Potter RW, Harris JM, Williams GC, Thomas LV, Deans SG, Ritchie G (1987) Antibacterial properties of plant essential oils. *International Journal of Food Microbiology* **5**, 165-180

Delaquis PJ, Stanich K, Girard B, Mazza G (2002) Antimicrobial activity of individual and mixed fractions of dill, cilantro, coriander and eucalyptus essential oils. *International Journal of Food Microbiology* **74**, 101-109

Delves-Broughton J (1999) Effective use of nisin to control lactic acid bacterial spoilage in vacuum-packed bologna-type sausage. *Journal of Food Protection* **62**, 1004-1010

Davies EA, Bevis HE, Delves-Broughton J (1997) The use of the bacteriocin, nisin, as a preservative in ricotta-type cheeses to control the food-borne pathogen *Listeria monocytogenes*. *Letters of Applied Microbiology* **24**, 343-346

Deans SG, Ritchie G (1987) Antibacterial properties of plant essential oils. *International Journal of Food Microbiology* **5**, 165-180

Delaquis PJ, Stanich K, Girard B, Mazza G (2002) Antimicrobial activity of individual and mixed fractions of dill, cilantro, coriander and eucalyptus essential oils. *International Journal of Food Microbiology* **74**, 101-109

Delves-Broughton J, Blackburn P, Evans RJ, Hugenholtz J (1996) Applications of the bacteriocin, nisin. *Antonie Van Leeuwenhoek* **69**, 193-202

Demetzos C, Perdetzoglou DK (2001) Composition and antimicrobial studies of the oils of *Origanum calcaratum* Juss. and *O. scabrum* Boiss. Heldr. from Greece. *Journal of Essential Oil Research* **13**, 460-462

Didry N, Dubreuil L, Pinkas M (1993) Antibacterial activity of thymol, carvacrol, and cinnalmaldehyde singly or in combinations. *Pharmazie* **48**, 301-308

Duffes F, Corre C, Leroy X, Dousset P, Boyaval P (1999) Inhibition of *Listeria monocytogenes* by in situ produced and semi-purified bacteriocins of *Carnobacterium* spp. Strains in a simulated cold smoked salmon. *Journal of Food Protection* **62**, 1394-1403

Ennahar S, Deschamps N (2000) Anti-Listeria effect of enterocin A, produced by cheese-isolated *Enterococcus faecium* EFM01, relative to other bacteriocins from lactic acid bacteria. *Journal of Applied Microbiology* **88**, 449-457

Farag RS, Daw ZY, Hewedi FM, El-Baroty GSA (1989) Antimicrobial activity of some Egyptian spice essential oils. *Journal of Food Protection* **52**, 665-667

Farbood MI, Macneil JH, Ostovar K (1976) Effects of rosemary spice extractive on growth of microorganisms in meats. *Journal of Milk Food Technology* **39**, 675-679

Ferreira MA, Lund BM (1996) The effect of nisin on *Listeria monocytogenes* in culture medium and long-life cottage cheese. *Letters of Applied Microbiology* **22**, 433-438

Focke M, Feld A, Lichtenthaler HK (1990) *Allicin*, a naturally occurring antibiotic from garlic, specifically inhibit acetyl-CoA synthetase. *FEBS Letters* **261**, 106-108

Frankel EN, Huang SW, Aeschbach R, Prior E (1996) Antioxidant activity of rosemary extract and its constituents, carnosic acid, carnosol and rosmarinic acid, in bulk oil and oil-in-water emulsion. *Journal of Agricultural and Food Chemistry* **44**, 131-135

Garlic and Health Group (2007) Special section. *Medicinal and Aromatic Plant Science and Biotechnology* **1**, 1-36

Ghannoum MA (1988) Studies on the anticandidal mode of action of *Allium sativum* (garlic). *Journal of General Microbiology* **134**, 2917-2924

Ghrairi T, Manai M, Berjeaud JM, Frere J (2004) Antilisterial activity of lactic acid bacteria isolated from rigouta, a traditional Tunisian cheese. *Journal of Applied Microbiology* **97**, 621-628

Gordon MH, Kourimska L (1995a) The effect of antioxidants on changes in oils during heating and deep frying. *Journal of the Science and Food Agriculture* **68**, 347-353

Gordon MH, Kourimska L (1995b) Effect of antioxidants on losses of tocopherols during deep-fat frying. *Food Chemistry* **52**, 175-177

Gonzalez B, Arca P, Mayo B, Suarez JE (1994) Detection, purification, and partial characterization of plantaricin C, a bacteriocin produced by a *Lactobacillus plantarum* strain of dairy origin. *Applied Environmental Microbiology* **60**, 2158-2163

Hao YY, Brackett RE, Doyle MP (1998) Inhibition of *Listeria monocytogenes* and *Aeromonas hydrophila* by plant extracts in refrigerated cooked beef. *Journal of Food Protection* **61**, 307-312

Harpaz S, Glatman L, Drabkin V, Gelman A (2003) Effects of herbal essential oils used to extend the shelf life of freshwater-reared Asian sea bass fish (*Lates calcarifer*). *Journal of Food Protection* **66**, 410-417

Hechard Y, Sahl HG (2002) Mode of action of modified and unmodified bacteriocins from Gram-positive bacteria. *Biochimie* **84**, 545-557

Heikkila MP, Saris PE (2003) Inhibition of *Staphylococcus aureus* by the commensal bacteria of human milk. *Journal of Applied Microbiology* **95**, 471-478

Helander IM, Alakomi HL, Latva-Kala K, Mattila-Sandholm T, Pol I, Smid E J, Gorris LGM, von Wright A (1998) Characterization of the action of selected essential oil components on gram-negative bacteria. *Journal of Agricultural and Food Chemistry* **46**, 3590-3595

Henning S, Metz R, Hammes WR (1986) Studies on the mode of action of nisin. *International Journal of Food Microbiology* **3**, 121-134

Hili P, Evans CS, Veness RG (1997) Antimicrobial action of essential oils: the effect of dimethylsulphoxide on the activity of cinnamon oil. *Letters of Applied Microbiology* **24**, 269-275

Hirsch A, Grinsted E, Chapman HR, Mattick ATR (1951) A note on the inhibition of an anaerobic spore former in Swiss-type cheese by a nisin-producing *Streptococcus*. *Journal of Dairy Research* **18**, 205-206

Huhtanen CN (1980) Inhibition of *Clostridium botulinum* by spice extracts and aliphatic alcohol. *Journal of Food Protection* **43**, 195-196

Ismail SAS, Deak T, El-Rahman HAA, Yassien MAM, Beuchat LR (2001) Effectiveness of immersion treatments with acids, trisodium phosphate, and herb decoctions in reducing populations of *Y. lipolytica* and naturally occurring aerobic microorganisms on raw chicken. *Journal of Food Microbiology* **64**, 13-19

Jack RW, Wan J, Gordon J, Harmark K, Davidson BE (1996) Coventry, Characterization of the chemical and antimicrobial properties of piscicolin 126, a bacteriocin produced by *Carnobacterium piscicola* JG126. *Applied and Environmental Microbiology* **62**, 2897-2903

Janes ME, Johnson MG (2001) Food grade additives and garlic enhance the activity of nisin against *L. monocytogenes in vitro* and on chicken. Presented at the 23-27 June 2001, *Institute of Food Technology*. *Annual Meeting*, New Orleans, LA, USA, 142 pp

Janssen AM, Scheffer JJC, Svendsen A, Aynehchi YB (1985) Composition and antimicrobial activity of the essential oils of *Ducrosia anethifolia*. In: Scheffer JJC, Svendsen A (Eds) *Essential Oils and Aromatic Plants*, Martinus Nijhoff Publishers, Dordrecht, The Netherlands, pp 213-216

Jantova S, Nagy M, Ruzekova L, Grancai D (2000) Antibacterial activity of plant extracts from the families *Fabaceae*, *Oleaceae*, *Philadelphaceae*, *Rosaceae* and *Staphyleaceae*. *Phytotherapy Research* **14**, 601-603

Jaswir I, Che Man YB, Hassan TH (2005) Performance of phytochemical antioxidant systems in refined-bleached-deodorized palm olein during frying. *Asia Pacific Journal of Clinical Nutrition* **14**, 402-413

Jaswir I, Kitts DD, Man YBC, Hassan TH (2004) Synergistic effect of rosemary, sage and citric acid on fatty acid retention of heated flaxseed oil. *Journal of Oleo Science* **53**, 581-591

Juliano C, Mattana A, Usai M (2000) Composition and *in vitro* antimicrobial activity of the essential oils of *Thymus herba-barona* Loisel growing wild in Sardinia. *Journal of Essential Oil Research* **12**, 516-522

Juneja VK, Friedman M (2007) Carvacrol, cinnamaldehyde, oregano oil, and thymol inhibit *Clostridium perfringens* spore germination and outgrowth in ground turkey during chilling. *Journal of Food Protection* **70**, 218-222

Jung DS, Bodyfelt FW, Daeschel MA (1992) Influence of fat and emulsifier on the efficacy of nisin in inhibiting *Listeria monocytogenes* in fluid milk. *Journal of Dairy Science* **75**, 387-393

Juven BJ, Kanner J, Schwed F, Weisslowicz H (1994) Factors that interact with the antimicrobial action of thyme essential oil and its active constituents. *Journal of Applied Bacteriology* **76**, 626-631

Kabara JJ (1991) Phenols and chelatoes. In: Russell NJ, Gould GW (Eds) *Food Preservatives*, Blackie, London, pp 200-214

Karapinar M, Aktung SE (1987) Inhibition of foodborne pathogens by thymol, eugenol, menthol and anethole. *International Journal of Food Microbiology* **4**, 161-166

Karatzas AK, Bennik MHJ, Smid EJ, Kets EPW (2001) Combined action of S-carvone and mild heat on *Listeria monocytogenes* Scott A. *Journal of Applied Microbiology* **89**, 296-301

Kim J, Marshall MR, Vei C (1995a) Antimicrobial activity of some essential oil components against five foodborne pathogens. *Journal of Agricultural and Food Chemistry* **43**, 2839-2845

Kim J, Marshall MR, Cornell JA, Preston JF, Wei CI (1995b) Antibacterial activity of carvacrol, citral, and geraniol against *Salmonella* typhimurium on culture medium and on fish cubes. *Journal of Food Science* **60**, 1364-1374

Klaenhammer TR (1993) Genetics of bacteriocins produced by lactic acid bacteria. *FEMS Microbiology Reviews* **12**, 39-85

Kurita N, Miyaji M, Kurane R, Takahara Y (1981) Antifungal activity of components of essential oils. A*gricultural and Biological Chemistry* **45**, 945-952

Lacroix M, Smoragiewicz W, Jobin M, Latreille B, Krzystyniak K (2000) Protein quality and microbiological changes in aerobically-or vacuum-packaged, irradiated fresh pork loins. *Meat Science* **56**, 31-39

Lagouri V, Blekas G, Tsimidou M, Kokkini S, Boskou D (1993) Composition and antioxidant activity of essential oils from oregano plants grown wild in Greece. *Zeitschrift Für Lebensmittel-Untersuchung und Forschung* **197**, 20-23

Lambert RJW, Skandamis PN, Coote P, Nychas GJE (2001) A study of the minimum inhibitory concentration and mode of action of oregano essential oil, thymol and carvacrol. *Journal of Applied Microbiology* **91**, 453-462

Lataoui N, Tantaoui-Elaraki A (1994) Individual and combined antibacterial activity of the main components of three thyme essentials oils. *Rivista Italiana EPPOS* **13**, 13-19

Leisner JJ, Greer GG, Styles ME (1996) Control of beef spoilage by a sulphide-producing *Lactobacillus sake* strain with bacteriocinogenic *Leuconostoc gelidum* UAL 187 during anaerobic storage at 2°C. *Applied and Environmental Microbiology* **62**, 2610-2614

le Tien C, Millette M, Mateescu MA, Lacroix M (2004) Modified alginate and chitosan for lactic acid bacteria immobilization. *Biotechnology and Applied Biochemistry* **39**, 110-118

Lis-Balchin M, Deans SG (1997) Bioactivity of selected plant essential oils against *Listeria monocytogenes*. *Journal of Applied Microbiology* **82**, 759-762

Liu W, Hansen JN (1990) Some chemical and physical properties of nisin, a small protein antibiotic produced by *Lactococcus lactis*. *Applied and Envi-*

ronmental Microbiology **56**, 2551-2558

Macneil JH, Mast MG (1973) Frankfurters without nitrates or nitrites. *Food Products Development* **7**, 36, 38-40

Mahapatra A, Muthukumarappan K, Julson JL (2005) Applications of ozone, bacteriocins and irradiation in food processing: A review. *Critical Reviews in Food Science and Nutrition* **45**, 447-461

Mahoney M, Henriksson A (2003) The effect of processed meat and meat starter cultures on gastrointestinal colonization and virulence of *Listeria monocytogenes* in mice. *International Journal of Food Microbiology* **84**, 255-261

Mahrour A, Caillet S, Nketsia-Tabiri J, Lacroix M (2003a) Microbial and sensory quality of marinated and irradiated chicken. *Journal of Food Protection* **66**, 2156-2159

Mahrour A, Caillet S, Nketsia-Tabiri J, Lacroix M (2003b) The antioxidant effect of natural substances on lipids during irradiation of chicken legs. *Journal of the American Oil Chemists' Society* **80**, 679-684

Manderfeld MM, Schafer HW, Davidson PM, Zottola EA (1997) Isolation and identification of antimicrobial furocoumarins from parsley. *Journal of Food Protection* **60**, 72-77

Marino M, Bersani C, Comi G (1999) Antimicrobial activity of the essential oils of *Thymus vulgaris* L. measured using a bioimpedometric method. *Journal of Food Protection* **62**, 1017-1023

Marino M, Bersani C, Comi G (2001) Impedance measurements to study the antimicrobial activity of essential oils from *Lamiacea* and *Compositae*. *International Journal of Food Microbiology* **67**, 187-195

Mauriello G, de Luca E, la Storia A, Villani F, Ercolini D (2005) Antimicrobial activity of a nisin-activated plastic film for food packaging. *Letters in Applied Microbiology* **41**, 464-469

McAuliffe O, Hill C, Ross RP (1999) Inhibition of *Listeria monocytogenes* in cottage cheese manufactured with a lacticin 3147-producing starter culture. *Journal of Applied Microbiology* **86**, 251-256

McGimpsey JA, Douglas MH (1994) Seasonal variation in essential oil yield and composition from naturalized *Thymus vulgaris L.* in New Zealand. *Flavour and Fragrance Journal* **9**, 347-352

Mejholm O, Dalgaard P (2002) Antimicrobial effect of essential oils on the seafood spoilage micro-organism *Photobacterium phosphoreum* in liquid media and fish products. *Letters in Applied Microbiology* **34**, 27-31

Millette M, Luquet JF, Lacroix M (2007a) *In vitro* growth control of selected pathogens by a *Lactobacillus acidophilus* and *L. casei*-fermented milk. *Letters in Applied Microbiology* **44**, 314-319

Millette M, le Tien C, Mateescu MA, Smoragiewicz W, Lacroix M (2007b) Inhibition of *Staphylococcus aureus* on beef by nisin-containing modified alginate films and beads. *Food Control* **18**, 878-884

Millette M, Dupont C, Archambault D, Lacroix M (2007c) Partial characterization of bacteriocins produced by human *Lactococcus lactis* and *Pediococcus acidilactici* isolates. *Journal of Applied Microbiology* **102**, 274-282

Millette M, Dupont C, Shareck F, Ruiz MT, Archambault D, Lacroix M (2007d) Pediocin production by *Pediococcus acidilactici* MM33, a new human intestinal strain. *Journal of Applied Microbiology*, in press

Moler D (1998) CO_2 extraction and other new technologies an update on commercial adoption. International Federation of Essential Oils and Aroma Trades-21st *International Conference on Essential Oils and Aroma's IFEAT*, London, pp 33-49

Moleyar V, Narasimham P (1992) Antibacterial activity of essential oil components. *International Journal of Food Microbiology* **16**, 337-342

Moll GN, Konings WN, Driessen AJM (1999) Bacteriocins: mechanism of membrane insertion and pore formation. *Antonie Van Leeuwenhoek* **76**, 185-198

Moore GS, Atkins RD (1977) The fungicidal and fungistatic effects of an aqueous garlic extract on medically important yeast like fungi. *Mycologia* **69**, 341-348

Murray M, Richards JA (1998) Comparative study on the antilisterial activity of nisin A and pediocin AcH in fresh ground pork stored aerobically at 5°C. *Journal of Food Protection* **60**, 1534-1540

Nakatani N, Inatani R (1983) A new diterpene lactone, rosmadial, from rosemary (*Rosmarinus officinalis* L.). *Agricultural and Biological Chemistry* **47**, 353-358

Naigre R, Kalck P, Roques C, Roux I, Michel G (1996) Comparison of antimicrobial properties monoterpenes and their carbonylated products. *Planta Medica* **62**, 275-277

Nes IF, Dipe DB, Havarstein LS, Bruberg MB, Eijsink V, Holo H (1996) Biosynthesis of bacteriocins in lactic acid bacteria. *Antonie Van Leeuwenhoek* **70**, 113-128

Nettles CG, Barefoot SF (1993) Biochemical and genetic characteristics of bacteriocins of food-associated lactic acid bacteria. *Journal of Food Protection* **56**, 338-356

Nielsen PV, Rios R (2000) Inhibition of fungal growth on bread by volatile components from spices and herbs, and the possible application in active packaging, with special emphasis on mustard essential oil. *International Journal of Food Microbiology* **60**, 219-229

Okereke A, Montville TJ (1992) Nisin dissipates the proton motive force of the obligate anaerobe *Clostridium sporogenes* PA 3679. *Applied and Environmental Microbiology* **58**, 2463-2467

Oosterhaven K, Chambel Leitao A, Gorris LGM, Smid EJ (1996) Comparative study on the action of S-(+)-carvone, *in situ*, on the potato storage fungi *Fusarium solani* var. *coeruleum* and *F. sulphureum*. *Journal of Applied Bacteriology* **80**, 535-539

Ouattara B, Sabato SF, Lacroix M (2001) Combined effect of antimicrobial coating and gamma irradiation on shelf life extension of pre-cooked shrimp (*Penaeus* spp.). *International Journal of Food Microbiology* **68**, 1-9

Oussalah M, Caillet S, Saucier L, Lacroix M (2007a) Inhibitory effects of selected plant essential oils on the growth of four pathogenic bacteria : *E. coli* 0157:H7, *Salmonella typhimurium*, *Staphylococcus aureus* and *Listeria monocytogenes*. *Food Control* **18**, 414-420

Oussalah M, Caillet S, Saucier L, Lacroix M (2007b) Antimicrobial effects of alginate based films containing essential oils on *Listeria monocytogenes* and *Salmonella* Typhimurium present in bologna and ham. *Journal of Food Protection* **70**, 901-908

Oussalah M, Caillet S, Lacroix M (2006a) Mechanism of action of Spanish oregano, Chinese cinnamon and savory essential oils against cell membranes and walls of *Escherichia coli* 0157:H7 *and Listeria monocytogenes*. *Journal of Food Protection* **69**, 1046-1055

Oussalah M, Caillet S, Salmiéri S, Saucier L, Lacroix M (2006b) Antimicrobial effects of alginate-based film containing essential oils for the preservation of whole beef muscle. *Journal of Food Protection* **69**, 2364-2369

Oussalah M, Caillet S, Salmieri S, Saucier L, Lacroix M (2004) Antimicrobial and antioxidant effects of milk protein-based film containing essential oils for the preservation of whole beef muscle. *Journal of Agricultural and Food Chemistry* **52**, 5598-5605

O'Sullivan L, Ross RP, Hill C (2002) Potential of bacteriocin-producing lactic bacteria for improvements in food safety and quality. *Biochimie* **84**, 593-604

Packiyasothy EV, Kyle S (2002) Antimicrobial properties of some herb essential oils. *Food Australia* **54**, 384-387

Pandit VA, Shelef LA (1994) Sensitivity of *Listeria monocytogenes* to rosemary (*Rosmarinus officialis* L.). *Food Microbiology* **11**, 57-63

Panizzi L, Flamini G, Coni PL, Morelli I (1993) Composition and antimicrobial properties of essential oils of four Mediterranean *Laminaceae*. *Journal of Ethnopharmacology* **39**, 167-170

Paster N, Menasherov M, Ravid U, Juven B (1995) Antifungal activity of oregano and thyme essential oils applied as fumigants against fungi attacking stored grain. *Journal of Food Protection* **58**, 81-85

Paster N, Juven BJ, Shaaya E, Menasherov M, Nitzan R, Weisslowicz H, Ravid U (1990) Inhibitory effect of oregano and thyme essential oils on moulds and foodborne bacteria. *Letters in Applied Microbiology* **11**, 33-37

Periago PM, Moezelaar R (2001) Combined effect of nisin and carvacrol at different pH and temperature levels on the variability of different strains of *Bacillus cereus*. *International Journal of Food Microbiology* **68**, 141-148

Plummer S, Weaver MA, Harris JC, Dee P, Hunter J (2004) *Clostridium difficile* pilot study: effects of probiotic supplementation on the incidence of *C. difficile* diarrhoea. *International Microbiology* **7**, 59-62

Pokorny J (1999) Antioxydants in food preservation. In: Rahman S (Ed) *Handbook of Food Preservation*, Marcel Dekker, New York, USA, pp 309-337

Radler F (1990a) Possible use of nisin in winemaking. I. Action of nisin against lactic acid bacteria and wine yeasts in solid and liquid media. *American Journal of Enology and Viticulture* **41**, 1-6

Raccach M (1984) The antimicrobial activity of phenolic antioxidants in foods: A review. *Journal of Food Safety* **6**, 141-170

Radler F (1990b) II. Experiments to control lactic acid bacteria in the production of wine. *American Journal of Enology and Viticulture* **41**, 7-11

Ratledge C, Wilkinson SG (1988) An overview of microbial lipids. In: Ratledge C, Wilikson SG (Eds) *Microbial Lipids* (Vol 1), Academic Press, London, pp 3-22

Ray B, Miller KW (2000) Pediocin. In: Naidu AS (Ed) *Natural Food Antimicrobial Systems*, CRC Press, Boca Raton, FL, USA, pp 525-566

Rayman MK, Aris B, Hurst A (1981) Nisin: a possible alternative or adjunct to nitrite in the preservation of meats. *Applied and Environmental Microbiology* **41**, 375-380

Rayman K, Malik N, Hurst A (1983) Failure of nisin to inhibit outgrowth of *Clostridium botulinum* in a model cured meat system. *Applied and Environmental Microbiology* **46**, 1450-1452

Pol IE, Smid EJ (1999) Combined action of nisin and carvacrol on *Bacillus cereus* and *Listeria monocytogenes*. *Letters of Applied Microbiology* **29**, 166-170

Ponce E, Pla R, Sendra E, Guamis B, Mor-Mur M (1998) Combined effect of nisin and high hydrostatic pressure on destruction of *L. innocua* and *E. coli* in liquid whole egg. *International Journal of Food Microbiology* **43**, 15-19

Pucci MJ, Vedamuthu ER, Kunka BS, Vandenberg PA (1998) Inhibition of *Listeria monocytogenes* by using bacteriocin PA-1 produced by *Pediococcus acidilactici* PAC 1.0. *Applied and Environmental Microbiology* **54**, 2349-2353

Rhayour K, Bouchikhi T, Tantaoui-Elaraki A, Sendide K, Remmal A (2003) The mecanism of bactericidal action of oregano and clove essential oils and of their phenolic major components on *Escherichia coli* and *Bacillus subtilis*. *Essential Oil Research* **15**, 356-362

Rhyu HY (1979) Gas chromatographic characterization of sages of various geographic origins. *Journal of Food Science* **44**, 758-762

Riley MA, Wertz JE (2002) Bacteriocins: evolution, ecology, and application.

Annals Review of Microbiology **56**, 117-137
Rose NL, Sporns P, Stiles ME, McMullen LM (1999) Inactivation of nisin by glutathione in fresh meat. *Journal of Food Science* **64**, 759-62
Russo M, Galletti GC, Bocchini P, Carnacini A (1998) Essential oil chemical composition of wild populations of Italian Oregano spice (*Origanum vulgare* ssp. Hirtum (Link) Ietswaart): A preleminary evaluation of their use in chemotaxonomy by Cluster analysis. 1. Inflorescences. *Journal of Agricultural and Food Chemistry* **46**, 3741-3746
Salmeron J, Jordano R, Pozo R (1990) Antimycotic and antiaflatoxigenic activity of oregano (*Origanum vulgare* L.) and thyme (*Thymus vulgaris* L.). *Journal of Food Protection* **53**, 697-700
Salmieri S, Lacroix M (2006) Physicochemical properties of alginate/polycaprolactone-based films containing essential oils. *Journal of Agricultural and Food Chemistry* **54**, 10205-10214
Salzer UJ (1977) The analysis of essential oils and extracts (oleoresins) from seasonings-a critical review. *Critical Review in Food Science* **9**, 345-373
Samelis S, Roller J (1994) Metaxolous, Sakacin B, a bacteriocin produced by *Lactobacillus sake* isolated from Greek dry fermented sausages. *Journal of Applied and Environmental Microbiology* **60**, 2158-2163
Sarkar SK, Phan CT (1979) Naturally occurring and ethylene-induced phenolic compounds in the carrot root. *Journal of Food Protection* **42**, 526-534
Savadogo A, Ouattara CAT, Traore AS (2007) Potential of lactic acid bacteria in human nutrition. *Food* **1**, 79-84
Scannell AGM, Ross RP, Hill C, Arendt EK (2000) An effective lacticin biopreservation in fresh pork sausage. *Journal of Food Protection* **63**, 370-375
Scannell AGM, Hill C, Buckley DJ, Arendt EK (1997) Determination of the influence of organic acids and nisin on shelf-life and microbiological safety aspects of fresh pork. *Journal of Applied Microbiology* **83**, 407-412
Schwarz K, Ternes W (1992) Antioxidative constituents of *Rosmarinus officinalis* and *Salvia officinalis*. II. Isolation of carnosic acid and formation of other phenolic diterpenes. *Zeitschrift Für Lebensmittel-Untersuchung und-Forschung* **195**, 99-103
Schillinger U, Kaya M, Lucke FK (1991) Behaviour of *Listeria monocytogenes* in meat and its control by a bacteriocin-producing strain of *Lactobacillus sake*. *Journal of Applied Bacteriology* **70**, 473-478
Schoeman H, Vivier MA, Du TM, Dicks LM (1999) The development of bactericidal yeast strains by expressing the *Pediococcus acidilactici* pediocin gene (*ped*A) in *Saccharomyces cerevisiae*. *Yeast* **15**, 647-656
Scott VN, Taylor SL (1981) Temperature, pH and spore load effects on the ability of nisin to prevent the outgrowth of *C. botulinum* spores. *Journal of Food Science* **46**, 121-126
Sharma A, Tewari GM, Shrikhande AJ, Padwal-Desai SR, Bandyopadhyay C (1979) Inhibition of aflatoxin-producing fungi by onion extracts. *Journal of Food Science* **44**, 1545-1547
Sikkema J, de Bont JAM, Poolman B (1995) Mechanism of membrane toxicity of hydrocarbons. *Microbiological Review* **59**, 201-222
Shelef LA, Jyothi EK, Bulgarelli MA (1984) Growth of enteropathogenic and spoilage bacteria in sage-containing broth and foods. *Journal of Food Science* **49**, 737-740
Shelef LA, Naglik OA, Bogen DW (1980) Sensitivity of some common foodborne bacteria to the spices sage, rosemary, and allspice. *Journal of Food Science* **45**, 1042-1044
Singh N, Singh RK, Bhunia AK, Stroshine RL (2002) Efficacy of chlorine dioxide, ozone and thyme essential oil or a sequential washing in killing *Escherichia coli* 0157:H7 on lettuce and baby carrots. *Lebensmittelwissenchaften und Technologien* **35**, 720-729
Singh B, Falahee MB, Adams MR (2001) Synergistic inhibition of *L. monocytogenes* by nisin and garlic extract. *Food Microbiology* **18**, 133-139
Siragusa GR, Cutter CN, Willet JL (1999) Incorporation of bacteriocin in plastic retains activity and inhibits surface growth of bacteria on meat. *Food Microbiology* **16**, 229-235
Sivropoulou A, Papanikolaou E, Nikolanou C, Kokkini S, Lanaras T, Arsenakis M (1996) Antimicrobial and cytotoxic activities of *Origanum* essential oils. *Journal of Agricultural and Food Chemistry* **44**, 1202-1205
Skaltsa HD, Demetzos C, Lazari D, Sokovic M (2003) Essential oil analysis and antimicrobial activity of eight *Stachys* species from Greece. *Phytochemistry* **64**, 743-752
Skandamis PN, Nychas GJ (2000) Development and evaluation of a model prediction the survival of *Escherichia coli* 0157:H7 NCTC 12900 in homemade eggplant salad at various temperatures, pHs, and oregano essential oil concentrations. *Applied and Environmental Microbiology* **66**, 1646-1653
Skandamis PN, Nychas GJE (2001) Effect of oregano essential oil on microbiological and physico-chemical attributes of minced meat stored in air and modified atmospheres. *Journal of Applied Microbiology* **91**, 1011-1022
Stecchini ML, Sarais I, Giavedoni P (1993) Effect of essential oils on *Aeromonas hydrophila* in a culture medium and in cooked pork. *Journal of Food Protection* **56**, 405-409
Stoffels G, Sahl HG, Gudmundsdottir A (1993) Carnocin U149, a potential biopreservative produced by *Carnobacterium piscicola*: large scale purification and activity against various gram-positive bacteria including *Listeria* sp. *International Journal of Microbiology* **20**, 199-210
Suppakul P, Miltz J, Sonneveld K, Bigger SW (2003) Antimicrobial properties of basil and its possible application in food packaging. *Journal of Agricultural and Food Chemistry* **51**, 3197-3207
Tassou C, Drosinos EH, Nychas G-JE (1995) Effects of essential oil from mint (*Mentha piperita*) on *Salmonella enteritidis* and *Listeria monocytogenes* in model food systems at 4°C and 10°C. *Journal of Applied Bacteriology* **78**, 593-600
Tripsrisukond M, Fernando LN, Clarke AD (1998) Antioxydant effects of essential oils and oleoresin of black pepper from supercritical carbon dioxide extractions in ground pork. *Journal of Agricultural and Food Chemistry* **46**, 4329-4333
Thoroski J, Blank G, Biliaderis C (1989) Eugenol induced inhibition of extracellular enzyme production by *Bacillus cereus*. *Journal of Food Protection* **52**, 399-403
Tsigarida E, Skandamis P, Nychas GJE (2000) Behaviour of *Listeria monocytogenes* and autochthonous flora on meat stored under aerobic, vacuum and modified atmosphere packaging conditions with or without the presence of oregano essential oil at 5°C. *Journal of Applied Microbiology* **89**, 901-909
Twomey D, Ross RP, Ryan M, Meaney B, Hill C (2002) Lantibiotics produced by lactic acid bacteria: structure, function and applications. *Antonie Van Leeuwenhoek* **82**, 165-185
Ultee A, Bennink MHJ, Moezelaar R (2002) The phenolic hydroxyl group of carvacrol is essential for action against the food-borne pathogen *Bacillus cereus*. *Applied and Environmental Microbiology* **68**, 1561-1568
Ultee A, Slump RA, Steging G, Smid EJ (2000a) Antimicrobial activity of carvacrol toward *Bacillus cereus* on rice. *Journal of Food Protection* **63**, 620-624
Ultee A, Kets EPW, Alberda M, Hoakstra FA, Smid EJ (2000b) Adaptation of the food-borne pathogen *Bacillus cereus* to carvacrol. *Archives of Microbiology* **174**, 233-238
Ultee A, Gorris LG, Smit EJ (1998) Bactericidal activity of carvacrol towards the food-borne pathogen *Bacillus cereus*. *Journal of Food and Applied Microbiology* **85**, 211-218
USDA (2000) Economics of foodborne disease: Estimating the benefits of reducing foodborne disease. Available online: www.ers.usda.gov/briefing/FoodborneDisease/features.htm
Vaara M (1992) Agents that increase the permeability of the outer membrane. *Microbiological Reviews* **56**, 395-411
Viollon C, Chaumont JP (1994) Antifungal properties of essential oils and their main components upon *Cryptococcus neoformans*. *Mycopathologia* **128**, 151-153
Wada S, Fang X (1992) The synergistic antioxidant effect of rosemary extract and α-tocopherol in sardine oil model system and frozen-crushed fish meat. *Journal of Food Processing and Preservation* **16**, 263-274
Wan J, Wilcock A, Conventry MJ (1998) The effect of essential oils of basil on the growth of *Aeromonas hydrophila* and *Pseudomonas fluorescens*. *Journal of Applied Microbiology* **84**, 152-158
Wandling LR, Sheldon BW, Foegeding PM (1999) Nisin in milk sensitizes *Bacillus* spores to heat and prevents recovery of survivors. *Journal of Food Protection* **62**, 492-498
Wendakoon CN, Sakaguchi M (1993) Combined effect of sodium chloride and clove on growth and biogenic amine formation of *Enterobacter aerogenes* in mackerel muscle extract. *Journal of Food Protection* **56**, 410-413
Yanishlieva NV, Marinova EM, Pokorny J (2006) Natural antioxidants from herbs and spices. *European Journal of Lipid Science and Technology* **108**, 776-793
Yanishlieva NV, Marinova EM, Gordon MH, Raneva VG (1999) Antioxidant activity and mechanism of action of thymol and carvacrol in two lipid systems. *Food Chemistry* **64,** 59-66
Ziauddin KS, Rao HS, Fairoze N (1996) Effect of organic acids and spices on quality and shelf life of meats at ambient temperature. *Journal of Food Science and Technology* **33**, 255-258