Control of Salmonella in foods by using essential oils: A review

Vivek K. Bajpai a, Kwang-Hyun Baeka, Sun Chul Kang b,⁎

a School of Biotechnology, Yeungnam University, Gyeongsan, Gyeongbuk 712-749, Republic of Korea
b Department of Biotechnology, Daegu University, Gyeongsan, Gyeongbuk 712-714, Republic of Korea

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ABSTRACT

During the past several years, limit of Salmonella infections has been exceeded dramatically. In spite of achieving a low rate infection in Salmonella infections, this microbe has become a challenge in food industry due to its wide-spread distribution worldwide. Salmonella bacteria are not only responsible for mild to severe infections but also they cause life-threatening infections. Salmonella bacteria are zoonotic in nature and hammer the food quality severely as well as being hazardous to human society. Several types of serotypic Salmonella have been reported; however, very less numbers of pathogens are infection responsible. Increase in foodborne infections caused by Salmonella types mainly occurs due to the development of new specific features in Salmonella majority, making them to adapt in any environmental condition. Also the alterations in human society with recent food processing and marketing methodology with live breeders contribute to facilitate these outbreaks. Salmonella resistant to commercial antibiotic drugs has emerged as a great health concern to the consumers. Literature survey has revealed that infection with Salmonella resistant to antibiotics has played a vital role to increased rate in foodborne infectious diseases. Extensive use of antibiotics in food industry against foodborne pathogens or food models has resulted in additional antibiotic resistance to Salmonella which has become a matter of great concern to the public health. There has been an increasing concern worldwide on therapeutic values of natural products. Nature has presented to humanity the gift of vast therapeutic antimicrobial agents of plant origins. There are multitudes of potential useful bioactive substances to be derived from plants. The significance of drugs cannot be over-emphasized with the recent trend of high percentage of resistance of microorganisms to the present day antibiotics. This review provides the informative literature data on antibacterial efficacy of plant essential oils (PEOs) and their volatiles. In addition, the suitability of PEOs and their volatile components for their practical applications in food or food products against Salmonella, a common cause of salmonellosis food poisoning has also been focused. The current knowledge of volatile oils and contents in food model system to control Salmonella has been discussed. Also a brief description on the legal aspects on how to use the volatile oils in food system has been presented, and the area for future research has been proposed. A mode of antibacterial action of PEOs along with their chemical nature has also been described. Although some data on Salmonella-related issues are presented, this review chiefly focused on in vivo practical utilization of plant volatile oils and components in food modelsystem as natural anti-Salmonella agents.

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⁎ Corresponding author. Fax: +82 53 850 6559.
E-mail address: sckang@daegu.ac.kr (S.C. Kang).

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1. Introduction

*Salmonella* bacteria have become the major cause of foodborne diseases which has raised a great safety concern to public health. In several geographic regions, a large proportion of foodborne diseases are confirmed by the hazardous salmonellosis caused by infectious *Salmonella* (Rabsch, Tschäpe, Andreas, & Baumler, 2001). *Salmonella* food poisoning can affect any person, especially with weakened immune systems (El-Gazzar & Marth, 1992). In these persons, the infection may initiate and spread dramatically to various body sites if the person is not treated with suitable antibiotics. In the present time, intensive cases of foodborne diseases caused by *Salmonella* have dramatically surpassed (Humphrey & Jorgensen, 2006). The meat products contaminated with *Salmonella* bacteria have become an important issue which has enhanced the number of cases of foodborne diseases (Humphrey & Jorgensen, 2006). It has been reported that meat products infected with *Salmonella* bacteria were found to play a necessary role to increase the incidences of foodborne outbreaks, hence were not subjected to distribute in the marketable form (EFSA, 2009).

Food industry, although having a number of food preservatives, is experiencing a lack of potent food preservative agents to secure the safety of food or food products (Mead et al., 1999). Although, antimicrobial drugs have supported to control the foodborne pathogens or diseases in food systems, however, acquired resistance to these antimicrobial agents is a major drawback due to their exerting several side effects (O’Brien, 2002). Hence, certain effective antimicrobial drugs are needed for their practical applications to control foodborne pathogens.

The plant volatiles or plant essential oils (PEOs) are plant secondary metabolites which are biosynthesized in glandular structures of a plant cell. PEOs are known to work as potential antimicrobial agents having the ability to control foodborne pathogenic bacteria (Bajpai, Rahman, & Kang, 2008; Burt, 2004; Oussalah, Caillet, Sauciere, & Lacroix, 2007). Use of PEOs in food and beverage industries has been exploited for decades. Besides, they have been shown to work as potent antibacterial agents because of the presence of bioactive volatile components (Conner, 1993; Didry, Dubreuil, & Pinkas, 1993). Although, all the PEOs have been shown to exert antimicrobial efficacy, a number of variations have been reported in their chemical nature and the amount of their volatiles reason being variations in the collection time of sample, abundance and/or lack of mineral components, distillation method, changes in genetic levels, environmental conditions and the portion of the plant used for distillation (Salgueiro et al., 1997; Venskutonis, 1996). Although, several PEOs, as a whole, show potent biological efficacy (Kim et al., 1995a; Lambert, Skandamis, Coote, & Nychas, 2001), the antimicrobial efficacy of PEOs has been credited due to the components present in higher amount. Besides, the components present in lower amount have been shown to exert synergistic effect with the major components of the oil (Paster, Menashero, Ravid, & Juven, 1995).

Several concerns have been raised to minimize the load of chemical preservatives in foods or storage food products. Recently, the use of PEOs has become a focal area of research for their practical applications to control the hazardous pathogens in food model system (Marino, Bersani, & Comi, 2001). Pathogenic microbes in storage food or food products are responsible to degrade or deteriorate the quality of food products, resulting in the emerging foodborne diseases in various regions of the world (Mead et al., 1999). In this regard, applications of PEOs, being potent antimicrobials and low toxic in nature, can be a good strategy to control or inhibit the foodborne pathogenic bacteria in marketable food products or processed foods with higher percentage of consumer acceptability (Deans & Sbodova, 1990; Parangama, Abeysekera, Abeywickrama, & Nugalijadd, 2003).

2. Control of *Salmonella* by the plant-based natural antimicrobials

2.1. PEOs: an overview

Although food industry has been enriched with several food practices, consumers are still aware about the health problems caused by foodborne pathogenic bacteria (Burt, 2004; WHO, 2002a). A large proportion of population is suffering from the diseases caused by foodborne pathogenic bacteria in several geographical regions of the world (Burt, 2004; WHO, 2002a). This has requested an urgent need to develop new and effective natural antimicrobials to combat with the diseases caused by foodborne pathogenic bacteria (Burt, 2004; Leistner, 1978). As per Burt (2004), Western society has appeared to experience the concern that corporates the chemical preservatives with a lesser amount of environmental impact (Smith & Gorris, 1999; Tuley de Silva, 1996). Even though small amount of salt intake can...
lower the possibilities of heart-related diseases, certain additional supplements are required to retain the shelf-life of food products (Burt, 2004; WHO, 2002b). Hence, there might be a high demand of alternative strategies to prolong the shelf-life of processed or cooked foods using PEOs (Burt, 2004).

Naturally PEOs, having aroma and flavor are isolated from the various parts of the plants (Burt, 2004; Guenther, 1948). The PEOs for commercial utilization can be isolated using various methodologies which include steam distillation, solvent extraction, and expression (Burt, 2004; Van de Braak & Leijten, 1999). According to Burt (2004), about three thousand PEOs having potent biological efficacy are commercialized, and having significant contribution to aroma and flavor industries (Van de Braak & Leijten, 1999). As reported previously, most of the PEOs exert potent biological efficacy (Boyle, 1955; Burt, 2004; Carson & Riley, 1995; Deans & Ritchie, 1987; Guenther, 1948; Mourey & Canillac, 2002; Shelef, 1983). The antimicrobial or other biological activities of PEOs are directly correlated to the presence of their bioactive volatile components (Guenther, 1948; Mahmoud & Croteau, 2002).

According to Burt (2004), the antibacterial activity of PEO was reported to perform first time in 1881 (Boyle, 1955). Further, in later dates, the use of PEOs was exploited in other industries; however, the extreme utilization rate of PEOs was reported to have in aroma and flavor industries (Burt, 2004; Guenther, 1948). Industrial utilization of PEOs has been performed greatly at wide range of utilization including various industries (Bauer & Garbe, 1985; Burt, 2004; Van de Braak & Leijten, 1999; Van Welie, 1997). Also the role of PEO components or those prepared synthetically has been exploited vigorously in several industries (Burt, 2004; Cutter, 2000; Greathead, & Kamel, 2002; Benkeblia, 2004; Burt, 2004; Holley & Patel, 2005; Lopez et al., 2005). Various antimicrobial vapor assay protocols have been evaluated for determining the antimicrobial efficacy of several PEOs (Lopez et al., 2005). Although, variations in the antimicrobial activities of PEOs have been observed, the less sensitivity of negatively charged bacteria is attributed to the extra polysaccharide layer as compared to positively charged bacteria lacking this outer cell wall coverage.

2.2. Chemistry of PEOs

PEOs are the low molecular weight volatile mixtures, biosynthesized in various organs of plants. The chemical nature of PEOs belongs to the composition of terpene compounds (mono-, sesqui- and di-terpenes), which are mainly obtained as hydrocarbon compounds or the derivatives of oxygen molecule. A few components of PEOs are

![Fig. 1. Selected antimicrobial principles of PEOs.](image-url)
nitrogenous or sulfur in nature which are found as alcohols, acids, esters, epoxides, aldehydes, ketones, amines and sulfides (Bakkali, Averbeck, Averbeck, & Idaomar, 2008). The components of PEOs are divided in two groups: (i) compounds from terpene origin and (ii) aroma compounds (Bakkali et al., 2008; Pichersky, Noel, & Dudareva, 2006).

Terpene compounds have natural occurrence in plants found as major components of most of the PEOs. Based on their structural and functional properties, terpene compounds have been classified according to their basic structural unit isoprene containing five carbons (Bakkali et al., 2008). In the formation of terpenes, prenyldiphosphosphate serves as a precursor (Bakkali et al., 2008). The terpene compounds exist in the form of mono-, sesqui-, hemi-, di-, tri-, and tetraterpenes. The monoterpene containing two isoprene units are responsible to construct the major portion of all the PEOs. These compounds work as carbure, alcohol, aldehyde, ketone, ester, ether, peroxide and phenols (Bakkali et al., 2008). The sesquiterpene compounds contain three isoprene units and the functional properties are very close to monoterpenes compounds.

The aromatic compounds are the derivatives of phenylpropane (Bakkali et al., 2008), which are aldehydes, alcohols, phenols, methoxy and methylene dioxy in nature. A few nitrogen and sulfur compounds present in PEOs are also characterized as plant essential constituents (Bakkali et al., 2008).

2.3. Mechanism of action of PEOs

Previously several researches have been performed on PEOs in order to confirm their biological efficacy against bacteria and fungi, however, no trust worthy data have been obtained on the mode of action of PEOs so far (Lambert et al., 2001; Nychas, 1995; Shelef, 1983). Because the PEOs contain a number of components, hence the antimicrobial action cannot be confirmed by the action of a single compound. Besides, different PEOs or their different components show antimicrobial mode of action not only at a particular location but also at different cell sites (Carson, Mee, & Riley, 2002; Skandamis & Nychas, 2001). Hydrophobic nature of PEOs makes them to interact well with lipid membrane of bacterial pathogens, resulting in the leakage of the inner cell components of the cell as well as affecting potassium ion reflux, and eventually leading to cell death (Cox et al., 2000; Denyer & Hugo, 1991; Gustafson et al., 1998; Helander et al., 1998; Knobloch, Weigand, Weis, Schwarm, & Vigenshoven, 1986; Lambert et al., 2001; Sikkema, De Bont, & Poolman, 1995). Generally, phenolic nature of PEOs makes them to work effectively against foodborne pathogenic bacteria (Farag, Daw, Hewedi, & El-Baroty, 1989; Juliano, Mattana, & Usai, 2000; Lambert et al., 2001). The phenolic compounds disrupt the cell membrane as well as affectively inhibit the functional properties of the cell, and eventually leaking the inner materials of the cell (Rasooli, Rezaei, & Allameh, 2006; Sikkema et al., 1995). Besides, chemistry of the composition of PEOs or their volatile compounds have great impact on their antimicrobial mechanism, phenolics containing OH—group, hence, work out effectively against foodborne pathogenic bacteria (Dorman & Deans, 2000; Ultee, Slump, Steging, & Smid, 2000).

Volatiles from PEOs not only work on single target site in the cell but also they bind to protein structures of the cell. Bacterial cell membrane contains the enzymatic proteins to maintain the functional properties, and storage of hydrocarbons to lipid membrane can make the changes in the building block of lipids and proteins, resulting in the permeability of the cell components (Juen, Kaner, Schwed, & Weisslowicz, 1994; Knobloch, Pauli, Iberl, Weigand, & Weis, 1989; Sikkema et al., 1995). Some of the PEOs and their volatiles are found to be responsible in inhibiting the enzymatic proteins in some bacterial pathogens (Wendakoon & Sakaguchi, 1995).

In addition to this, terpene compounds have been well known to affect on the bacterial cell membrane, thereby resulting in the changes of cell functions, leakage of cell components as well as making starving conditions to survive the cell or cell components (Fisher & Phillips, 2008). Hence, the functions of cell components including nucleus can be reduced by the effect of PEOs or their volatiles due to the permeability changes that occurred in the membrane of bacterial cell (Fisher & Phillips, 2008; Oussalah, Caillet, & Lacroix, 2006). The permeability on the membrane of bacterial cell also results in the release of the ionic molecules from the cell (Fisher & Phillips, 2008; Raybaudi-Massilia, Mosqueda-Melgar, & Martin-Belloso, 2006).

2.4. Antimicrobial efficacy of PEOs in food model system

A very less amount of research was conducted on commercial PEOs as natural food preservatives up to the year 1990 (Board & Gould, 1991; Burt, 2004). After that, several researches were performed on PEOs to confirm their efficacy as natural food preservatives. Although, it is now well known that higher amount of PEOs used in vitro assays is also essential to confirm their in vivo efficacy while using in food models, contradictory results have also been observed in few cases (Karatzas, Kets, Smid, & Bennik, 2001; Mendoza-Yepes et al., 1997; Pandit & Shelef, 1994; Shelef, 1983; Smid & Gorris, 1999; Stecchini, Saraïs, & Giavedoni, 1993; Ultee & Smid, 2001; Wan, Wilcock, & Coventry, 1998).

In a study conducted on salad by inoculating a foodborne pathogen reported that the PEO of oregano could suppress the growth of Salmonella community in a very less time (Koutsoumanis, Lambropoulou, & Nychas, 1999) for which the intrinsic and extrinsic properties used were the causative factors to decline the growth of this foodborne pathogen. Time-based declining pattern of Salmonella was also evaluated in order to compare the efficacy of PEOs using two food models (Gibson, Bratchell, & Roberts, 1988). The food models used by Gibson et al. (1988) were found suitable to define the usefulness of oregano oil for confirming the bacterial population under several intrinsic and extrinsic conditions (Koutsoumanis et al., 1999). In addition, the effects of Zataria multiflora oil were determined in a food model using different extrinsic conditions such as time and temperature (Moosavii et al., 2008). The growth and the number of CFUs of S. Typhimurium were also reduced at significant level by using the oil of Z. multiflora (Moosavii et al., 2008).

Findings have been observed regarding the efficacy of PEOs in vivo, however, only few reports have confirmed the precise mode of action of PEOs in food models. To determine the effect of any specific PEO at any particular growth stage of bacteria can be a focal area of research in order to visualize the adaptability of PEOs in any proposed food model (Rees, Dodd, Gibson, Booth, & Stewart, 1995). However, as reported previously, modifications in the bacterial cell membrane composition might result in susceptibility of the pathogen (Ultee & Smid, 2001). Besides, the cell rich in nutrient uptake survives better as compared to the cell lasting in starving condition (Gill, Delaquais, Russo, & Holley, 2002). In addition, both intrinsic and extrinsic conditions can be responsible to the susceptibility or resistant nature of the pathogen (Juen et al., 1994; Shelef, 1983; Skandamis & Nychas, 2000; Tassou, Drosinos, & Nychas, 1996; Tassou et al., 1995; Tsigarida et al., 2000). Besides, fatty contents may also serve as barrier to the effectiveness of the pathogen while incorporating PEO in foods due to having a higher population of pathogen in hydrophilic region (Meijholt & Dalgaard, 2002; Smith-Palmer, Stewart, & Fyle, 2001). Hence, it is assumed that fatty composition may directly have an adversary effect on the efficacy of PEOs against the tested pathogens.

In addition, interaction of terpenoid phenolics of PEOs with enzymatic substances might be a reason to limit the antimicrobial efficacy of the PEOs in food models (Pol, Mastwijk, Slump, Popa, & Smid, 2001; Smith-Palmer et al., 2001). It has been also known that food hydrocarbons have less ability to control the killing effect of PEOs against pathogens as compared to the proteinous or fatty substances (Shelef, Jyothis, & Bulpargrell, 1984). Moreover, salt-content may also
influence the efficacy of PEOs in food models (Shelef et al., 1984; Skandamis & Nychas, 2000; Tassou et al., 1995; Wendakoon & Sakaguchi, 1993).

Food properties and several other abiotic and biotic factors may influence the antimicrobial efficacy of PEOs (Skandamis et al., 2000). Miscibility of the samples in liquid or solid phase can also limit the antimicrobial potential of PEOs (Hammer, Carson, & Riley, 1999). We have immensely screened the biological efficacy of various PEOs and evaluated their MIC values against Salmonella community. The MIC treated sample when inoculated on the agar media, showing

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### Table 1

Minimum inhibitory (MIC) and bactericidal (MBC) concentrations of selected PEOs against Salmonella spp. in vitro.

<table>
<thead>
<tr>
<th>Essential oil derived from</th>
<th>Bacteria (strain)</th>
<th>MIC (µg/ml)</th>
<th>MBC (µg/ml)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sphallacarpus gracilis</strong> (seeds)</td>
<td>Salmonella Typhimurium</td>
<td>320&lt;sup&gt;a&lt;/sup&gt;</td>
<td>320&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Gao et al. (2011)</td>
</tr>
<tr>
<td></td>
<td>Salmonella Enteritidis</td>
<td>320&lt;sup&gt;a&lt;/sup&gt;</td>
<td>640&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><strong>Cestrum nocturnum (flower)</strong></td>
<td>S. Typhimurium</td>
<td>25.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td>Al-Reza, Rahman, and Kang (2009)</td>
</tr>
<tr>
<td><strong>Loniceria japonica</strong> (flower)</td>
<td>S. Typhimurium</td>
<td>125&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td>Rahman, Lee, and Kang (2009b)</td>
</tr>
<tr>
<td><strong>Metasequoia glyptostroboides</strong> (leaf)</td>
<td>S. Typhimurium</td>
<td>250&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Nandina domestica</strong> (flower)</td>
<td>S. Typhimurium</td>
<td>1000&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td>Bajpai, Al-Reza, Choi, Lee, and Kang (2009)</td>
</tr>
<tr>
<td><strong>Syzygium aromaticum (bud)</strong></td>
<td>S. Typhimurium</td>
<td>&lt;2.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Eucalyptus polybractea</strong> (bud)</td>
<td>S. Enteritidis</td>
<td>1000&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Melaleuca alternifolia</strong> (leaf/twig)</td>
<td>S. Enteritidis</td>
<td>0.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
- MIC: minimum inhibitory concentration; MBC: minimum bactericidal concentration.
- AR: antibiotic resistant pathogens.
- <sup>a</sup> Represents MIC or MBC value in µg/ml.
- <sup>b</sup> Represent MIC or MBC value in µl/ml.
no growth of target pathogen is known as minimum bactericidal concentration (MBC). However, MIC differs in the research publications, which is another hurdle to compare the efficacy of test molecule among the researches (Burt, 2004; Hammer et al., 1999). A detailed description on antibiotic efficacy as MIC and MBC values of various PEOs and their volatiles against Salmonella in food commodities is given in Tables 1 and 2, respectively.

2.5. Salmonella control in meat and poultry products

Certain PEOs and their volatiles may work as natural food preservative compared to synthetic and chemical preservatives with less toxicity. Wrapping films have been used in corporation with PEOs or their volatiles in order to confirm their efficacy against Salmonella species in food commodities. The antimicrobial films along with microorganisms or their volatiles have shown concentration-dependent activity in meat products, confirming the reduction of bacterial population at significant level (Ravishankar, Zhu, Olsen, McHugh, & Friedman, 2009). Current literature survey on the efficacy of the PEO components has also confirmed their efficacy to inhibit the growth of Salmonella bacteria up to a significant reduction in the CFU levels (Ravishankar et al., 2010). The PEO volatiles eugenol, trans-cinnamaldehyde, carvacrol, and thymol were tested against Salmonella Enteritidis in chicken cecal contents, and reduced the CFU numbers of target pathogen to an exceeding limit (Johny, Darre, Donoghue, Donoghue, & Venkatanarayanan, 2010). As reported previously, the fatty contents might have essential role in reducing the activity of PEOs in food products (Gill et al., 2002; Tassou et al., 1995).

Govaris, Solomakos, Pexara, and Chatzopoulou (2010) visualized the efficacy of oregano PEO against the microbe of Salmonella species in meat product, and it was found that the oil confirmed the acceptance level of organoleptical level. Besides, PEOs from Salvia officinalis and Schinus molle were examined against pathogenic bacteria of Salmonella species in meat or meat product (Hayouni et al., 2008). PEOs from S. officinalis and S. molle were found to exhibit remarkable inhibitory effect against the tested pathogenic species in improved sensory properties and reduced pattern of CFU numbers (Hayouni et al., 2008).

In another study conducted using PEOs of thyme and oregano incorporating packaging strategy was evaluated in order to prolong the quality of lamb meat (Karabagias, Badeka, & Kontominas, 2011). This study confirmed the marked efficacy of both PEOs in vivo and reduced the pathogen load up to a significant level during storage of meat with improved organoleptic properties, confirming the use of natural antimicrobials in meat preservation (Karabagias et al., 2011).

Several PEO components have been used to control the pathogen load in foods. Vapor phase effect of PEO component (carvacrol) was evaluated to limit the propagation of foodborne pathogen of Salmonella species in meat or meat products (Burt, Fledderman, Haagsman, van Knaph, & Veldhuizen, 2007). It was confirmed in the findings of this research that volatile compound was found to minimize the CFU numbers of target pathogen to an extended limit, and was able to maintain the shelf-life of meat produces significantly (Burt et al., 2007).

The addition, cinnamon bark PEO (7000 ppm) exerted the strongest antibacterial efficacy against Salmonella in liquid whole egg, being able to inhibit a population up to day 6. However, rosemary PEO showed low antibacterial efficacy. The bioactive components of cinnamon bark oil were found to inhibit the bacterial load to undetectable levels in egg white and whole egg. The efficacy of bioactive principles of cinnamon bark PEO was also confirmed on the basis of no changes found in °Brix with reduction in pH value. The physical properties of egg were also improved in liquid whole (Valverde et al., 2010).

The effect of defined concentration of PEO volatile (citrail) was confirmed in fisheries products against S. Typhimurium with reduced level of CFU bacterial numbers (Kim, Marshall, Cornell, Preston, & Wei, 1995b).

2.6. Salmonella control in milk and dairy products

PEO from mint was evaluated against S. Enteritidis in milk products, which was found to reduce the growth of microbial starter culture load to a significant level. However, other volatiles including the PEOs from cinnamon, cardamom and clove were found highly antibacterial against the tested foodborne pathogen in yogurt and cucumber commodities (Bayoumi, 1992; Tassou et al., 1995). In addition, some of the PEO volatile components tested against Salmonella confirmed that only orange, lemon and grapefruit were found selective to treat milk samples (Dabbah, Edwards, & Moats, 1970). These variations on the antibacterial efficacy of the tested PEOs or volatiles might occur due to the percentage of the fatty composition, which limits the killing action of the samples to the target pathogen (Holley & Patel, 2005). In addition, PEOs from clove, cinnamon, bay and thyme evaluated for their efficacy against Salmonella species in a food model of cheese showed similar pattern of antibacterial efficacy due to the variations in the fatty composition (Smith-Palmer et al., 2001).

### Table 2
Minimum inhibitory concentrations (MIC) of selected PEO components against Salmonella spp. in vitro.

<table>
<thead>
<tr>
<th>Essential oil component</th>
<th>Bacterial pathogens</th>
<th>MIC (approximate range)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eugenol</td>
<td>Salmonella Typhimurium</td>
<td>0.0125 μM</td>
<td>Devi, Arif Nisha, Saktihivel, and Pandian (2010)</td>
</tr>
<tr>
<td></td>
<td>S. Typhimurium</td>
<td>0.5 μM</td>
<td>Kim et al. (1995a)</td>
</tr>
<tr>
<td>α-Pinene</td>
<td>S. Typhimurium (AR)</td>
<td>8–16 μM</td>
<td>Shin (2005a)</td>
</tr>
<tr>
<td></td>
<td>Salmonella Enteritidis (AR)</td>
<td>8 μM</td>
<td>Shin (2005b)</td>
</tr>
<tr>
<td>α-Terpineol</td>
<td>S. Typhimurium</td>
<td>0.225 μM</td>
<td>Cosentino et al. (1999)</td>
</tr>
<tr>
<td>Carvacrol</td>
<td>S. Typhimurium</td>
<td>0.225–0.25 μM</td>
<td>Kim et al. (1995b); Cosentino et al. (1999)</td>
</tr>
<tr>
<td>Citral</td>
<td>S. Typhimurium</td>
<td>0.5 μM</td>
<td>Kim et al. (1995b)</td>
</tr>
<tr>
<td>Geraniol</td>
<td>S. Typhimurium</td>
<td>0.5 μM</td>
<td>Kim et al. (1995b)</td>
</tr>
<tr>
<td>Perillaldehyde</td>
<td>S. Typhimurium</td>
<td>0.5 μM</td>
<td>Kim et al. (1995b)</td>
</tr>
<tr>
<td>Thymol</td>
<td>S. Typhimurium</td>
<td>0.05 μM</td>
<td>Cosentino et al. (1999)</td>
</tr>
<tr>
<td>(+)-Carvone</td>
<td>S. Typhimurium</td>
<td>1 mM</td>
<td>Helander et al. (1998)</td>
</tr>
<tr>
<td>Trans-cinnamaldehyde</td>
<td>S. Typhimurium</td>
<td>10 mM</td>
<td>Helander et al. (1998)</td>
</tr>
<tr>
<td>Cinnamaldehyde</td>
<td>Salomonella sp.</td>
<td>3 mM</td>
<td>Helander et al. (1998)</td>
</tr>
</tbody>
</table>

MIC: minimum inhibitory concentration; AR: antibiotic resistant pathogens.

* Values in μg/ml.

b Values in μg/ml.
2.7. Salmonella control in fruits, vegetables and juices

Salmonella bacteria have been isolated from a variety of herbal commodities. Literature survey confirmed 8% incidence of Salmonella in vegetables (Rude, Jackson, Bier, Sawyer, & Risty, 1984). Also it has been reported that 7.5% incidences were found in Spain (Garcia Villanova-Ruiz, Galvez-Vargas, & Garcia-Villanova, 1987), and 9 to 10% incidences were reported in New Jersey (Wells & Butterfield, 1997). Ercolan (1976) found Salmonella on 68% of lettuce and 72% of fennel samples. Salmonella can be propagated on herbal commodities in the presence of favorable conditions (Wells & Butterfield, 1997). Natural phytochemicals such as PEOs or their volatiles have been used consistently to eliminate bacterial populations on fruits and vegetables.

The potential of PEO volatiles against Salmonella species was evaluated in tomato model. The findings of this study confirmed that the PEO volatiles significantly reduced the microbial load of target pathogens on tomato samples to a limit of about 6.0 log_{10} CFU/ml (Mattsson et al., 2011). It appeared that in vegetable dishes, the biological efficacy of PEOs is attributed to both intrinsic and extrinsic properties of the sample products (Skandamis & Nychas, 2000). Also the less fatty contents of vegetables may influence the biological efficacy of the tested PEOs (Singh, Singh, Bhunia, & Stroshine, 2002; Wan et al., 1998). Some of the PEO volatiles inhibited Salmonella species in the food model of alfalfa seeds effectively (Weissinger, McMatters, & Beuchat, 2001).

The efficacy of myrtle PEO was evaluated against the antibiotic resistant pathogen of Salmonella species in food models of tomato and lettuce. Treatment with myrtle PEO significantly reduced the number of microbial load on the tested food models with an expected count limit (Gunduz, Gonul, & Karapinar, 2009). In another study, some of the plant volatiles such as carvacrol and cinnamaldehyde were found to exert potent reduction rate in the CFU count of the target pathogens in the food model of kiwi fruits, however, exerted a low inhibitory effect in the food model of honeydew melon. These variations might be correlated to the intrinsic or extrinsic properties of the foods (Roller & Seedhaur, 2002).

The PEO from oregano was evaluated in order to confirm its biological potential against Salmonella species in a food model of lettuce. These findings confirmed the marked efficacy of the PEO of oregano, hence has the ability to work as a natural alternative treatment to chemical washing solution in order to retain the quality of food products (Skandamis & Nychas, 2000). Also the less fatty contents of vegetables may influence the biological efficacy of the tested PEOs (Singh, Singh, Bhunia, & Stroshine, 2002; Wan et al., 1998). Some of the PEO volatiles inhibited Salmonella species in the food model of alfalfa seeds effectively (Weissinger, McMatters, & Beuchat, 2001).

The orange PEO without terpene was evaluated against Salmonella species, and provoked significant results on the antibacterial efficacy in juice model, reducing the population of target pathogen to a desirable level (Parish, Baum, Kruger, Goodrich, & Baum, 2003). In order to confirm the potential of lemongrass and geraniol volatiles against the pathogens belonging to genus Salmonella, non-treated juices from apple, pear and lemon fruits were examined. Both PEOs were found effective to inhabit the population of target pathogens to a limit of 3 log_{10} CFU/ml in juice models (Raybaudi-Massilia et al., 2006). A literature description on the applicable efficacy of PEOs and their volatiles in food system has been summarized in Table 3.

3. Applications of PEOs in food packaging

PEO-based antimicrobial packagings serve as potent antimicrobial strategies to inhibit the propagation of foodborne pathogens in a desired food model. A number of PEOs and their volatiles were found to possess significant impact on the antimicrobial efficacy in food packaging systems, which are the natural sources to serve as potent antimicrobials in food preservation technology (Cagri, Ustunol, & Ryser, 2004; Min, Harris, Han, & Krochta, 2005; Tharanathan, 2003).

In spite of new insights in chemical preservation, concern has been raised in regard not to using chemical preservatives in food system to prolong the shelf-life of food produces except natural antimicrobials. However, contamination free food or food products have been in demand in recent time in order to diminish foodborne illnesses to human safety caused by foodborne pathogens. This has resulted in the emergence of enormous issues to secure the food safety from chemical preservation with no harmful effect to consumers (Vermeiren, Devlieghere, van Beest, Kruif, & Debevere, 1999).

Food packaging strategies using natural antimicrobials could be a safe alternative in food preservation technology. Natural antimicrobials as packaging food preservative stuffs with enhanced biological efficacy are very much in demand in recent time to maintain the prolonged life of perishable food produces (Matan et al., 2006; Suppakul, Mitlt, Sonneveld, & Bigger, 2006).

Recently, the packaging films containing natural antimicrobials have been used extensively to maintain the shelf-life of the packed food produces (Iseppi et al., 2008; Mitlt, Rydlo, Mor, & Polanyak, 2006; Plackett & Ghambari-Siahkal, 2007). In fact, the antimicrobial efficacy of PEOs has been well-known from the last many years using PEOs in food packaging actively (Gutierrez, Sanchez, Battle, & Nerrin, 2009; Lopez, Sanchez, Battle, & Nerrin, 2007; Matan et al., 2006; Rodriguez, Nerrin, & Battle, 2008). The use of PEOs and their volatiles for their practical applications as packaging material could be a unique feature in order to maintain the food safety (Gutierrez et al., 2009).

The active PEO volatiles during the preservation of food stuffs work consistently to make the foods free from microbial load and reduce their population by contact methodology (Gutierrez et al., 2009; Quintavalla & Vicini, 2002). Besides, incorporation of PEOs or their volatiles with polymer molecules can be a good strategy in food preservation technology to limit the propagation of foodborne pathogens (Appendini & Hochkiss, 2002; Oussallah, Caillet, Salmieri, Saucier, & Lacroix, 2004).

Natural herbal spices possess rich amount of phenolics which exert strong antimicrobial efficacy both in vitro and in vivo (Dadalioglu & Evrendilek, 2004; Seydim & Sarikus, 2006). Almost all the PEOs showing biological efficacy against foodborne pathogens possess higher amount of phenolic contents which also include carvacrol, eugenol and thymol (Burt, 2004; Seydim & Sarikus, 2006). According to Seydim and Sarikus (2006), whey protein films incorporating bioactive volatiles, were found to serve as better antimicrobials against the Salmonella species.

In some cases, practical use of PEOs in food preservation can deteriorate the food quality, hence, the use of PEOs in packaging films cannot give the positive results in case of some specific food product, thus can be considered of secondary use. Although, PEOs application to the packaging industry can be beneficial in food preservation, further confirmatory trials are still needed to confirm their practical application for food preservation. Previous reports on the efficacy of oregano PEO as bioactive material in other types of packaging films have confirmed the potential of PEOs or their volatiles (Dadalioglu & Evrendilek, 2004).

On the other hand, efficacy of selected combinations of several other PEOs comprising irradiation technique has been confirmed in meat or food products to minimize the microbial load of foodborne pathogens as well as to visualize the impact of such combinations on the quality of meat products (Turgis, Han, Borsa, & Lacroix, 2008).

4. Application of PEOs or their components in poultry

Salmonella can cause septicemic diseases in poultry. Exposure of Salmonella to broilers can cause stomach disorders and can prolong...
### Table 3
In vivo antibacterial activity of selected PEOs or their components against *Salmonella* spp. in foods.

<table>
<thead>
<tr>
<th>Food group</th>
<th>Food type</th>
<th>Essential oil or component</th>
<th>Concentration applied</th>
<th>Bacterial pathogens</th>
<th>Observations</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meat or poultry products</td>
<td>Fresh lamb meat</td>
<td>Thyme or oregano oil</td>
<td>0.1 or 0.3%</td>
<td><em>Salmonella</em></td>
<td>4 °C, MAP2 found more effective</td>
<td>Karabagias et al. (2011)</td>
</tr>
<tr>
<td></td>
<td>Minced sheep meat</td>
<td>Oregano oil</td>
<td>0.6 or 0.9%</td>
<td><em>Salmonella Enteritidis</em></td>
<td>Higher organoleptical attributes at 0.6% at 10 °C</td>
<td>Govaris et al. (2010)</td>
</tr>
<tr>
<td></td>
<td>Chicken cecal</td>
<td>trans-cinnamaldehyde, eugenol, carvacrol, and thymol</td>
<td>10–75 mM</td>
<td>S. Enteritidis</td>
<td>At 40 °C/log reduction (6.0 to &gt; 8.0)</td>
<td>Johny et al. (2010)</td>
</tr>
<tr>
<td></td>
<td>Chicken heart</td>
<td>Cinnamaldehyde or carvacrol</td>
<td>0.5–3%</td>
<td><em>Salmonella Enterica</em></td>
<td>At 23 °C/log reduction (6.8 to 1.6) At 4 °C/log reduction (3.0 to 0.8)</td>
<td>Ravishankar et al. (2009)</td>
</tr>
<tr>
<td></td>
<td>Minced beef meat</td>
<td><em>Salvia officinalis</em> and <em>Schinus molle</em> oils</td>
<td>0.02, 0.06, 0.1, 1.5, 2, and 3%</td>
<td>S. Anatum</td>
<td>A large reduction ranged: 1 to 3 CFU/ml or g, or fewer</td>
<td>Hayouni et al. (2008)</td>
</tr>
<tr>
<td></td>
<td>Liquid whole egg</td>
<td>Cinnamon bark essential oil</td>
<td>7000 ppm</td>
<td><em>Salmonella sp.</em></td>
<td>Reduction about 10^2 CFU/ml</td>
<td>Valverde et al. (2010)</td>
</tr>
<tr>
<td></td>
<td>Chicken noodles</td>
<td>Sage oil</td>
<td>200–500 ppm</td>
<td><em>S. Typhimurium</em></td>
<td>Slight reduction up to 1.5 log CFU/ml or g</td>
<td>Shelef et al. (1984)</td>
</tr>
<tr>
<td></td>
<td>Pieces of raw chicken</td>
<td>Carvacrol</td>
<td>20–100 ppm</td>
<td><em>S. enterica</em> serotype Enteritidis</td>
<td>Complete inhibition of log CFU at 40%</td>
<td>Burt et al. (2007)</td>
</tr>
<tr>
<td></td>
<td>Pate</td>
<td>Mint oil</td>
<td>0.5 to 2.0%</td>
<td>S. Enteritidis</td>
<td>Negligible effect</td>
<td>Tassou et al. (1995)</td>
</tr>
<tr>
<td></td>
<td>Fruits, vegetables, and juices</td>
<td>Plum tomato</td>
<td>0.25–1%</td>
<td><em>Salmonella sp.</em></td>
<td>Complete reduction in CFU by 1% carvacrol; Reduction in log CFU about 6.0</td>
<td>Ravishankar et al. (2010)</td>
</tr>
<tr>
<td></td>
<td>Tomato and shredded iceberg lettuce</td>
<td>Myrtus communis leaf essential oil</td>
<td>1000 ppm</td>
<td><em>S. Typhimurium</em></td>
<td>Reduction in log CFU about 1.66 and 1.89</td>
<td>Gunduz et al. (2009)</td>
</tr>
<tr>
<td></td>
<td>Tomato</td>
<td>Oregano oil</td>
<td>25, 40, 75 ppm</td>
<td><em>S. Typhimurium</em></td>
<td>Significant log reduction at 75 ppm</td>
<td>Gunduz et al. (2010a)</td>
</tr>
<tr>
<td></td>
<td>Kiwifruit</td>
<td>Carvacrol</td>
<td>15, 75, 100 ppm</td>
<td><em>S. Typhimurium</em></td>
<td>Log reduction about 2.78</td>
<td>Gunduz et al. (2010b)</td>
</tr>
<tr>
<td></td>
<td>Alfalfa seeds</td>
<td>Cinnamaldehyde, thymol</td>
<td>200, 600 mg/l, air</td>
<td>Natural flora</td>
<td>A large reduction about: &gt;3 log CFU/ml or g, or fewer</td>
<td>Roller and Seedhar (2002)</td>
</tr>
<tr>
<td></td>
<td>Cucumber salad</td>
<td>Mint oil</td>
<td>0.5–2.0%</td>
<td><em>S. Enteritidis</em></td>
<td>Reduction about: negotiable to 1.5 log CFU/ml or g or fewer</td>
<td>Weissinger et al. (2001)</td>
</tr>
<tr>
<td></td>
<td>Apple, pear and melon juices</td>
<td>Lemongrass or geraniol</td>
<td>0–2.0%</td>
<td><em>Salmonella</em></td>
<td>3 log CFU reduction in apple juice</td>
<td>Tassou et al. (1995)</td>
</tr>
<tr>
<td></td>
<td>Grain</td>
<td>Zataria multiflora oil</td>
<td>0–100 μl/ml</td>
<td><em>S. Typhimurium</em></td>
<td>Significant log reduction</td>
<td>Raybould-Massili et al. (2006)</td>
</tr>
<tr>
<td></td>
<td>Barley soup</td>
<td>Sage oil</td>
<td>200–500 ppm</td>
<td><em>S. Typhimurium</em></td>
<td>Negligible effect on log CFU reduction</td>
<td>Monsavvy et al. (2008)</td>
</tr>
<tr>
<td></td>
<td>Boiled rice</td>
<td>Carvacrol, citrus, geraniol</td>
<td>0.5–3.0% (dipping solution)</td>
<td><em>S. Typhimurium</em></td>
<td>Reduction about: 1.5–3.0 or up to 1.5 CFU/ml or g</td>
<td>Shelef et al. (1984)</td>
</tr>
<tr>
<td></td>
<td>Fish or fish products</td>
<td>Oregano oil</td>
<td>0.5–2.0%</td>
<td><em>S. Enteritidis</em></td>
<td>A large reduction about: &gt;3 log CFU/ml or g</td>
<td>Kim et al. (1995b)</td>
</tr>
<tr>
<td></td>
<td>Taramasalad (cod’s roe salad)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Koutsoumanis et al. (1999)</td>
</tr>
<tr>
<td></td>
<td>Milk or dairy products</td>
<td>Pasteurized milk</td>
<td>100 ml/l</td>
<td><em>Salmonella</em></td>
<td>Terpineol most effective, a large reduction about: 7 log in skinned milk, 4 log in low butterfat milk and 3 log in whole milk</td>
<td>Dabbah et al. (1970)</td>
</tr>
<tr>
<td></td>
<td>Tzatziki (Yogurt)</td>
<td>Mint oil</td>
<td>0.5–2.0%</td>
<td><em>S. Enteritidis</em></td>
<td></td>
<td>Tassou et al. (1995)</td>
</tr>
</tbody>
</table>
the shedding. Severity of the disease can increase the death rate of the chickens. Efficacy of the virulence-strain can spread the disease symptom to the other body sites, which can cause the infection in the eggs to be laid. The infection by Salmonella in chicken or broilers has been reported previously (Jamshidi, Bassami, & Afshari-Nic, 2008). Although, a number of serovars of Salmonella have been reported from poultry chickens, virulence efficacy of all the Salmonella has not been found to infect human beings.

PEOs available in market for animal production use are known to play a significant role in digestive system (Williams & Losa, 2001). Based on biological efficacy of PEOs, consideration can be made on the practical applications of PEOs as prophylactic and therapeutic agents. The intake of PEOs affects the gastrointestinal microflora composition and population. Previous investigations on the antibacterial activity of various PEOs have confirmed the potent efficacy of several PEOs on coc-cidia oocey output and the number of bacteria in broiler chicks when artificially inoculated (Evans, Plunkett, & Banfield, 2001). Marketable formulations of PEOs were given as diet supplements. This preparation indicated the antimicrobial activity in broilers (Smits, Veldman, Verstegen, & Beynen, 1997; Veldman & Enting, 1996). It was reported that dietary carvacrol versus thymol reduced the animal weight and nutritional intake, but improvements were observed in broilers when fed with their respective diet for 4 weeks (Lee, Everts, Kappert, Yeom, & Beynen, 2003). Thus, it might be concluded that PEOs may act on intestinal microflora as well as on nutrient utilization.

Ordonez, Llopis, and Penalver (2008) reported the potent antibacterial activity of Eugenia caryophyllata PEO against Salmonella bacteria in female chicken model. The PEO derived from E. caryophyllata containing rich amount of volatile Eugenol served as better disinfectant while sacrificing the hens. Also the use of volatile was helpful to prevent the egg contamination caused by Salmonella species (Ordonez et al., 2008).

The characteristic flavor of PEOs may function in poultry. PEOs can also enhance the functional activity of digestive system. Besides, PEO volatiles can also exert diverse roles of action as additive, synergistic and antagonistic patterns, when applied individually. The PEOs with well known chemical nature can provide in-depth insights for their practical applications in poultry management.

5. Synergism and antagonism between oil components

The antibacterial efficacy of PEOs can be attributed to the volatile majority of PEO; volatile ratio as well as their behavior of mode of action (Burt, 2004; Delaquis et al., 2002; Dorman & Deans, 2000; Marino et al., 2001). Antagonistic efficacy can be visualized upon the supply of two compounds where the sample mixture has low antimicrobial efficacy as compared to using them separately (Burt, 2004). Additional antimicrobial efficacy can be visualized upon the supply of two compounds where the sample mixture has similar antimicrobial efficacy while using them separately (Burt, 2004). However, when combinatorial effect of compounds is higher than the effect of individuals is known as synergism (Burt, 2004; Davidson & Parish, 1989). Literature survey has demonstrated that an oil as a whole showed better antibacterial efficacy than only a combination of major volatiles of the oil (Burt, 2004; Gill et al., 2002; Mourey & Canillac, 2002). Hence, it might be said that the minor elements of the oil have crucial roles to increase the biological effectiveness of the oil, resulting in the synergism (Burt, 2004). We reported that cone PEO of Metasequoia glyptostroboides exerted potential synergistic effect with nisin against Gram-positive bacteria at varied concentrations in whole, low and skim milks (Yoon, Bajpai, & Kang, 2011). Combined fractions of different PEOs such as cimantid, coriander, dill and eucalyptus have been shown to exert synergistic and additive mode of action (Burt, 2004; Delaquis et al., 2002). Although, proportions of volatile compounds of PEOs have been found to exhibit a complete inhibitory action on some of the foodborne pathogens, however, these volatiles could not be able to exert antibacterial efficacy when applied individually against the tested organisms (Burt, 2004; Moleyar & Narasimham, 1992). The efficacy of Z. multiflora PEO with a known chemical preservative was evaluated against S. Typhimurium in a food model (Moosavy et al., 2008). The growth of S. Typhimurium was reduced by the addition of the mixture sample of oil and chemical preservative (nisin). The biological efficacy of PEOs not only corresponds to the volatiles present in a higher quantity but also the volatiles present in low amount can influence the biological efficacy of whole PEO. Analyzing the chemical compositions of PEOs shows significant quantitative differences in the oil components.

6. Laws and regulations on the use of PEOs in foods

The European Union (EU) is currently producing the most valuable recommendations and laws for using plant volatiles and PEOs in food system to retain the quality of the food or food products which are easily hampered by the foodborne pathogenic bacteria. FDA is very likely to follow the EU over these issues. Several PEOs and volatiles in their marketable forms are sold as flavoring agents to enhance the longevity of food produces (Burt, 2004). The registration of oil or oil components at EU or FDA is considered the products to be non-hazardous as well as safe to the health of consumers which include allspice oil, anise oil, black pepper oil, caraway oil, cubeb oil, star anise oil, sweet bay oil and thymol etc. (Burt, 2004). On special recommendations, some of the component substances have been black-listed because of their genotoxic effects (Burt, 2004; Commission Decision of 23 January, 2002).

Besides, a new registration to serve as a flavoring agent can only be considered by the commission if the concerned metabolic and toxicological research has been performed (Commission Decision of 23 February, 1999; Commission Regulation (EC) No 1565/2000 of 18 July, 1565, 2000; Commission Regulation (EC) No. 622/2002 and Regulation (EC) No 2232/96; Burt, 2004).

According to Burt (2004), the flavoring agents which have registered at EU have also been used by the USA people for their daily purpose needs (http://www.cfsan.fda.gov/~dms/eafus.html, date consulted: 26 February 2003). Hence, these substances are classified as approved food additives (Burt, 2004; Smoley, 1993). Although, estragole has been prohibited to include in the list of EU as flavoring, however, further recommendations have been made for its safe utilization (Burt, 2004).

The PEOs or volatiles might be considered as new food additives if they are added to food or food stuffs for the purpose other than serving as flavoring agents (Burt, 2004). However, to serve these substances as food additives will certainly require to carrying out the studies on safety and toxicology as well as metabolic profiling. Interestingly, it will be more beneficial economically to the people of the developing countries to use herbal plant or the plant parts as a whole or a whole PEO as an ingredient as well as herbal drug than using an individual component of the PEO (Burt, 2004; Smid & Gorris, 1999).

7. Future perspectives

The most diverse and interesting area of PEOs and their volatiles for their proper utilization is to suppress hazardous pathogens including Salmonella species. The improvement in the quality of packed meat or food products as well as spoilage delay by food spoilage or foodborne pathogens might be an important area of further research. Organoleptic properties may encounter another area where the PEOs can be easily incorporated in food products (Burt, 2004). The PEOs can also be used in the food stuffs which have not been associated previously with any flavor, if one or more components of the oil together can exert the desired antibacterial efficacy at the particular amount, having no deteriorating effect on the organoleptic or sensory properties of food products (Burt, 2004).

In fact, the consumer goods are experiencing an increased influence of PEOs or their volatiles in order to develop new and effective natural antimicrobials of plant origin (Burt, 2004; Tuley de Silva,
These products can also be served as natural in other related industries for their safe use (Bassett, Pannowitz, & Barnetson, 1990; Burt, 2004). For large scale production of PEOs, biotechnological approaches of their synthesis may be useful to obtain the desired volume of PEOs (Burt, 2004; Mahmoud & Croteau, 2002; McCaskill & Croteau, 1999). In addition, standardization of the chemical nature of commercial PEOs will be needed for their safe and practical applications (Burt, 2004; Carson & Riley, 2001).

The mechanism role of PEOs and volatiles on proteins associated with cytoplasmic membrane as well as on lipid structure has not been completely studied; hence, it might be an important aspect of future studies (Burt, 2004). Moreover, evaluation of the mechanism of action of PEOs will potentially strengthen their practical applications and significance in future research (Burt, 2004).

In addition to this, research findings on the interactions between PEOs and their components as well their effect as food ingredients or food additives also require further investigation (Burt, 2004). In order to optimize the antibacterial efficacy, synergistic, antagonistic and additive effects of PEOs can be explored so as to optimize the lowest concentration required for the inhibition of any spoilage or foodborne pathogenic bacteria which will indeed be a helpful strategy in the practical application of PEO in the future (Burt, 2004).

Also to measure the stability of PEOs and their volatiles during food processing might be a focal area of future research (Burt, 2004). Besides, experimental data on various direct or indirect consequences of using PEOs and their volatiles will confirm whether the PEO or its volatiles are safe to use in the food industry (Burt, 2004).

8. Conclusion

Salmonella is one of the major foodborne pathogens. Food or food products are the major Salmonella sources to cause the foodborne diseases. Practical applications of PEOs are needed for the complete elimination of foodborne pathogens. Several PEOs and their volatiles have shown a great deal to exert antimicrobial efficacy in food model or food system to control foodborne pathogenic bacteria. The volatiles of PEOs from terpene origin are most likely to affect on the order to optimize the antibacterial efficacy of essential oil and leaf extracts of Metasequoia glyptostroboides Miki ex Hu to reduce food spoilage and food-borne pathogens. Food Chemistry, 105(3), 1061–1066. Bajpai, V. K., Rahman, A., Dung, N. T., Huh, M. K., & Kang, S. C. (2008). In vitro Inhibition of food spoilage and food-borne pathogenic bacteria by essential oil and leaf extracts of Magnolia illiciflora Desr. Journal of Food Science, 73(6), 314–320.


