Use *Carum copticum* essential oil for controlling the *Listeria monocytogenes* growth in fish model system

Soghra Rabiey¹, Hedayat Hosseini², Masoud Rezaei³

¹Department of Fisheries, Faculty of Marine Sciences, Tarbiat Modares University, Noor, Iran.
²Department of Food Sciences and Technology, Faculty of Nutrition and Food Technology, National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
³Department of Seafood Science and Technology, Faculty of Marine Sciences, Tarbiat Modares University, Noor, Iran.

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**Abstract**

This study was conducted to evaluate the antibacterial effect of *Carum copticum* essential oil (Ajowan EO) against *Listeria monocytogenes* in fish model system. Ajowan EO chemical composition was determined by gas chromatography/mass spectral analysis and the highest concentration of *Carum copticum* essential oil without any significant changes on sensory properties of kutum fish (*Rutilus frisii kutum*) was assigned. Then the inhibitory effect of Ajowan EO at different concentrations in presence of salt and smoke component was tested on *L. monocytogenes* growth in fish peptone broth (FPB), kutum broth and cold smoked kutum broth at 4 °C for 12 days. Ajowan EO completely decreased the number of *L. monocytogenes* in FPB after 12 days of storage, however, antimicrobial effect of EO significantly reduced in kutum and cold smoked kutum broth. Addition of 4% NaCl and smoke component improved the anti-listerial activity of Ajowan EO in all fish model broths.

**Key words:** *Carum copticum*, *Listeria monocytogenes*, fish model systems, Hurdle technology, *Rutilus frisii kutum*.

**Introduction**

*Listeria monocytogenes* is the agent of listeriosis, a disease with low incidence rate (0.1 to 11.3 cases per million of population), but high mortality rate (28%) (Souza et al., 2008). This pathogen can grow at a wide range of temperature (1 to 45 °C), pH (4.4 to 9.6), high salt content (100 g.L⁻¹), water activity (aw) below 0.93 and under aerobic, microaerophilic, and anaerobic (Feldhusen, 2000; Basti et al., 2006). Because of being psychrotrophic, these bacteria can be considered as a dangerous pathogenic agent in foods stored at refrigerator temperature (Campos et al., 2011). *L. monocytogenes* is widespread in nature and can be found in soil, foliage and the faeces of animals and humans and can be introduced into coastal regions and aquaculture ponds by animal manure and human waste (Feldhusen, 2000). Recently many researchers reported the occurrence of *L. monocytogenes* in raw and processed fish; Pao et al. (2008) found *L. monocytogenes* 23.5% in catfish, 5.7% in trout, 10.3% in tilapia and 10.6% in salmon purchased from internet and local retail markets (Pao et al., 2008). Basti et al. found populations of *L. monocytogenes* greater than 10² cfu.g⁻¹ in 2.6% of silver carp and 5.1% of smoked silver carp purchased in fish farms, 10% of salted Caspian anadromous shad and 20% of smoked silver carp purchased in a fish market were also contaminated (Basti et al., 2006). A study which was conducted on the prevalence of *L. monocytogenes* in gravlax salmon processing line showed occurrence of *L. monocytogenes* in salmon samples (41%), food contact surfaces (32%); non-food contact surfaces (43%) and of food handlers’ samples (34%) (Cruz et
al., 2008). Several sporadic cases and outbreaks of listeriosis associated with seafood products have been reported recently: an outbreak (29 cases, nine deaths) in New Zealand associated with fish or molluscan shellfish (Lennon et al., 1984); six to nine cases (two deaths) in Sweden caused by ‘gravad’ rainbow trout (Ericsson et al., 1997); five cases in Finland associated with vacuum-packed, cold-smoked rainbow trout (Miettinen et al., 1999); a case associated with fish consumption (Facinelli et al., 1989). Since, concern about the side effects of chemical antimicrobial agents has been arisen in recent years, attention is shifting towards natural preservatives particularly plant essential oils as alternatives in foods. Both plant essential oils as well as similar compounds in wood smoke have shown promise as natural antimicrobials (Holley and Patel, 2005). Essential oils (EOs) are aromatic and volatile oily liquid extracted from different part of aromatic plants (Burt, 2004; Cruz et al., 2008; Campos et al., 2011). These oils are “generally regarded as safe” (GRAS), have broad spectrum of antimicrobial activity and pleasant odors and taste and can be used in food industry for their perfume, flavour and preservative properties (Burt, 2004; Oussalah et al., 2006; Goudarzi et al., 2011). Ajowan (Carum copticum) is grassy, annual, essential oil bearing plant which grown in Iran, India, Pakistan and Egypt. Ajowan essential oil is rich in monoterpenes such as thymol, γ-cymene and γ-terpinene and it may be used as a natural anti-bacterial agent (Zargari, 1988). Many researchers have demonstrated the antibacterial activity of essential oils such as Ajowan EO against some foodborne pathogens (Sabanadesan et al., 2000; Rani and Khullar, 2004; Oliveira et al., 2010; Goudarzi et al., 2011). However there aren’t more studies on the effects of Ajowan EO against L. monocytogenes in fish model systems and its synergistic activity with NaCl. Thus, the aim of this work was to study the antimicrobial effect of Ajowan EO, salt, smoke component and their combination against L. monocytogenes in fish model systems in order to optimize in real fish products design.

Materials and Methods

Plant essential oil

Carum copticum (Ajowan EO) was supplied from Golgatte Essential Oil Co., Mashhad, Iran, and stored in brown bottles at 4 °C prior to use.

GC/MS analysis

The components of the EO were identified by Varian 3400 GC-MS system equipped with a DB-5 fused silica column (30 m x 0.25 mm i.d.); oven temperature was 40 °C to 240 °C at a rate of 4 °C. Transfer line temperature was 260 °C. Carrier gas was helium with a linear velocity of 31.5 cm.s⁻¹, split ratio 1/60. In addition, ionization energy was 70 eV, scan time 1 s, and mass range 40-300 amu. The components of the oil were identified by comparison of their mass spectra with those of a computer library or with authentic compounds or with the data published in the literature (Adams, 2011).

Sensory analysis

For sensory analysis kutum fish were filleted and divided into 40 g portions, one portion was dipped in 80 mL sterile 0.2% agar solution as a control, another portions were dipped in 80 mL of 0.2% agar solutions containing 0.1 to 0.6% concentrations of Ajowan EO for 15 min in room temperature. After draining off the excess liquid, the samples were placed in bags and stored at 4 °C for 24 h. Then samples were cooked in a steam-cooker for 10-15 min at 90 ± 2 °C and served warm in dishes coded with 3-digit random numbers and presented in individual booths to each panelist for evaluation. An eight-member trained panel was used, the panelists were asked to evaluate odor and flavour of fillet for on a scale from 10 to 0. According to score, acceptability was determined as having a score of over 6 (Puwastien et al., 1999; Mahmoud et al., 2004).

Bacterial strain and preparation of inoculums

L. monocytogenes PTCC 1298 from Iranian Research Organization for Science and Technology, Tehran, Iran, was used in this study. It was cultivated in Brain Heart Infusion broth (BHI) at 37 °C for 18-24 h. One hundred microlitres (100 uL) of culture were transferred to modified fish peptone broth [FPB containing 1% of sodium chloride; 0.5% of yeast extract; and 3.4% of fish peptone] and were incubated for 24 h at 37 °C. FPB bacterial cultures were diluted in saline peptone solution [0.1% bacteriological peptone; 0.85% sodium chloride solution] and used to obtain final populations of 10⁶ cfu.mL⁻¹ for inoculation in FPB, kutum and cold smoked kutum broth (Reis et al., 2011).

Preparation of fish peptone broth (FPB)

FPB was prepared with 3.4% of fish peptone, 0.5% yeast extract at two levels of salt 0 and 4%. The medium was divided into 9.9-mL aliquots in tube, sterilized for 15 min at 121 °C, and maintained at 4 °C overnight before inoculation. In order to dissolve Ajowan essential oil in fish model systems bacteriological agar at concentration level of 0.15% was used (Oliveira et al., 2010; Reis et al., 2011).

Preparation of kutum and cold smoked kutum broth

Kutum and cold smoked kutum broth were prepared according to Nilsson et al. Kutum fish (Rutilus frisii kutum) samples were boiled with distilled water for 10 min in a ra-
tio of 2:1 (w/v). The suspension was filtered in coffee filter. The juice was buffered with 5.98 g.L\(^{-1}\) of KH\(_2\)PO\(_4\) and 9.75 g.L\(^{-1}\) of K\(_2\)HPO\(_4\), and pH was adjusted to 6.2 with 1 mol.L\(^{-1}\) HCL. The broth was made at two levels of salt, 0 and 4%. The juices were divided into 9.9-mL aliquots in sterile tube, sterilized for 15 min at 121 °C and kept at 4 °C overnight before inoculation (Nilsson et al., 1999).

**Treatments**

FPB, kutum broth and cold smoked kutum broth were inoculated with 0.1 mL of saline peptone solution containing 10\(^6\) cfu.mL\(^{-1}\) of \textit{L. monocytogenes}, so that the final cell numbers on broth were 10\(^4\) cfu.mL\(^{-1}\). The treatments were as follows: Ajowan EO (0%, 0.05%, 0.15%, and 0.3% v/v) added to NaCl 4% (w/v) or not.

**Enumeration of microorganisms in fish model systems**

In all fish model experiments, bacterial populations were enumerated at days of 0, 4, 8, 12 by pure plating 1 mL of appropriate dilutions in PALCAM Listeria Selective Agar, with incubation at 37 °C for 48 h.

**Statistical analysis**

All fish model experiments were done at least three times. Logarithm of bacterial counts were subjected to analysis of variance using ANOVA SPSS 16 (SPSS Inc. Chicago, IL, USA). Differences between means were tested through Duncan and values of p < 0.05 were considered significantly different. Sensory data were analyzed using Duncan and One-sample t-test (Mahmoud et al., 2004; Solomakos et al., 2008a, Solomakos et al., 2008b).

**Results**

**Determination of EO constituents**

The chemical compositions of Ajowan EO are shown in Table 1. Seventeen (17) compounds representing 98.8% of Ajowan EO were identified. The main components were thymol (57.18%), \(\gamma\)-cymene (22.55%), \(\gamma\)-terpinene (13.07%) and trans-Anethole (1.7%). A number of studies on Ajowan EO content and constituents have been performed in Iran. Khajeh et al. showed that essential oil of Ajowan contained eight main compounds, including thymol (49%), \(\gamma\)-terpinene (30.8%), \(\rho\)-cymene (15.7%) and \(\beta\)-pinene (2.1%) (Khajeh et al., 2004). Oroojalian et al. detected 12 component, include thymol (48.9%), \(\rho\)-cymene (21.8%), \(\gamma\)-terpinene (21.3%) and \(\beta\)-pinene (2.6%) (Oroojalian et al., 2010). Goudarzi et al. showed that the main components were thymol (36.7%), \(\rho\)-cymene (21.1%), \(\gamma\)-terpinene (36.5%). Compared to other studies we found higher amounts of thymol and less \(\rho\)-cymene (Goudarzi et al., 2011).

**Sensory evaluation**

Scores of samples treated with different concentrations of Ajowan EO are shown in Figure 1. Results showed that the organoleptic properties of kutum fillet treated with Ajowan EO were acceptable by the panelists at the levels of 0.1%, 0.2% and 0.3% but unacceptable at the higher level of EO. The panel detected no difference (p > 0.05) in aroma between untreated and 0.1-0.6% EO treated fillet. Sensory studies showed that the fillet treated with EO at concentration above than 0.3% had a score lower than 6 due to undesirable flavour and may not be acceptable to some of the consumers. 0.1 and 0.2% EO treated fillet had no signifi-
cant (p > 0.05) different with untreated sample but significant different with 0.3% EO treatment (p < 0.05).

Effect of Ajowan EO on *L. monocytogenes* populations in FPB

The antimicrobial effects of Ajowan EO at 0.05%, 0.15%, and 0.3% on *L. monocytogenes* in FPB are shown in Figure 2. In the control sample *L. monocytogenes* initial count of 3.8 log cfu.mL⁻¹ increased up to 8.5 log cfu.mL⁻¹ at the end of storage at 4 °C. Addition of Ajowan EO at 0.05%, 0.15% and 0.3% in FPB showed a high inhibitory effect against *L. monocytogenes* at the end of storage time. In 0.05% treatment, numbers of *L. monocytogenes* were declined to 0.8 log cfu.mL⁻¹ after 12 days of storage. In broth with 0.15% and 0.3% Ajowan EO, *L. monocytogenes* populations immediately after inoculation reduced by 0.5-1.5 log cfu.mL⁻¹. No growth of viable cells was observed from 4 day and up to the end of the incubation trial. Addition of 4% NaCl significantly improved Ajowan EO performance (p < 0.05). In FPB with 4% NaCl and 0.05% Ajowan EO *L. monocytogenes* count completely inhibited from the 8th day, while in broth without salt the initial populations of *L. monocytogenes* decreased to 0.8 log cfu.mL⁻¹ at the end of storage period. Moreover *L. monocytogenes* population in FPB containing 4% salt was 0.4 log cfu.mL⁻¹ less than broth without salt (p < 0.05).

Effect of Ajowan EO on *L. monocytogenes* populations in kutum broth

The antimicrobial effects of EO at 0.05%, 0.15%, and 0.3% on *L. monocytogenes* in kutum broth are shown in Figure 3. After 12 days of storage at 4 °C, the *L. monocytogenes* populations increased in kutum broth by 3.9 log cfu.mL⁻¹, the final counts were 8.1 log cfu.mL⁻¹. In 0.05% treatment initial populations of the *L. monocytogenes* were significantly increased during incubation time, and final populations of the pathogen in this treatment were 2.4 log cfu.mL⁻¹ lower than those of the control. In 0.15% EO treatment number of bacteria did not significantly change during incubation period (p > 0.05). Addition of EO at 0.3% showed a higher inhibitory effect as compared to the addition at 0.15%. In 0.3% treatment, populations of *L. monocytogenes* showed a reduction of 1.7 log cfu.mL⁻¹ after 12 days of storage. In 0.15% and 0.3% treatment final population of listeria were at least 4.2-5.8 log cfu.mL⁻¹ less than control sample at the end of storage (day 12). Addition of 4% NaCl in kutum broth significantly improved Ajowan EO efficacy (p < 0.05). In broth containing 0.15% EO and 4% NaCl, *L. monocytogenes* population re-
duced by 0.5 log cfu.mL⁻¹ after 12 days of storage. The number of *L. monocytogenes* in kutum broth containing 0.05% EO and 4% salt was significantly lower than kutum broth containing 0.05% EO during test period although this different wasn't significant at the end of storage (12 day). Moreover *L. monocytogenes* count in kutum broth with 4% NaCl were 0.5 log cfu.mL⁻¹ less than on kutum broth at 12 day (p < 0.05).

**Effect of Ajowan oil EO *L. monocytogenes* populations in cold smoked kutum broth**

According to Figure 4 after 12 days storage at 4 °C, the number of *L. monocytogenes* had increased 2.6 log cfu.mL⁻¹ in cold smoked kutum broth without any salt or EO. In 0.05% EO treatment initial populations of *L. monocytogenes* were increased by 1.8 log cfu.mL⁻¹. In 0.15% EO treatment number of bacteria did not significantly change in incubation period (p > 0.05). In 0.3% treatment *L. monocytogenes* populations decreased from 3.8 log cfu.mL⁻¹ to 3.1 log cfu.mL⁻¹ (p < 0.05). Addition of 4% NaCl in cold smoked kutum broth (Figure 4) significantly improved Ajowan EO efficacy (p < 0.05) from 8th day on. In broth with NaCl, 0.05% EO showed bacteriostatic effect and 0.15% EO decreased *L. monocytogenes* population by 1.3 log cfu.mL⁻¹. The greatest decrease in populations (2.1 log cfu.mL⁻¹) was observed for 0.3% EO in broth with 4% NaCl.

**Discussion**

Recently many tests have been carried out in synthetic growth media in order to evaluate the EO efficacy against spoilage and food-borne pathogens. However, results obtained in this food model media (e.g. meat broth, vegetables broth, milk broth) may be more useful prior to further application in real food, rather than those observed using laboratorial media, since these food models media may assist in the optimized final application of EOs and would also reflect the nutrient availability and composition of food produce (Gutierrez *et al.*, 2009). Some authors used from such synthetic growth media to evaluate antimicrobial activity of plant essential oil and other antimicrobial component. Reis *et al.* (2011) evaluated the inhibitory effect of *Lippia sidoides* extract and lactic acid bacteria (LAB) against *L. monocytogenes* in model fish systems include fish peptone broth, fish broth and fish homogenate (Reis *et al.*, 2011). Oliveira *et al.* evaluated effect of combined application of thymol and carvacrol with lactic and acetic acid against *Staphylococcus aureus* in meat broth and in a food model(Oliveira *et al.*, 2010). Munoz *et al.* investigate the antimicrobial properties of plant extracts on the growth and viability of *L. monocytogenes* in laboratory medium and broccoli juice (Muñoz *et al.*, 2009). Souza *et al.* evaluated effect of *Origanum vulgare* essential oil against *Staphylococcus aureus* in nutrient broth, meat broth and in a meat model (Souza *et al.*, 2009). Prior to this study, sensory analyses were carried out to determine the highest concentration of EO without any organoleptic undesirable changes. Concentration of 0.3% was selected and EO at 0.05%, 0.15% and 0.3% were added in FPB, kutum broth and cold smoked kutum broth to evaluate antimicrobial activity. The results from this study showed that Ajowan EO showed strong antibacterial activity in FPB. In this model Ajowan EO at concentrations of 0.05%, 0.15% and 0.3% caused a sharp drop in *L. monocytogenes* count after 4 days and completely inhibited pathogen at the end of storage (day 12). In Oroojalian *et al.* study, Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC) of Ajowan EO against *L. monocytogenes* was 0.025% (Oroojalian *et al.*, 2010).The major constituents of Ajowan EO were thymol, γ-terpinene, and ρ-cymene. It has been shown that EOs containing phenolic compounds, e.g. thymol, carvacrol, γ-terpinene, and ρ-cymene, have high levels of antibacterial activity (Burt, 2004; Holley and Patel, 2005; Goudarzi *et al.*, 2011). In kutum and cold smoked kutum broth this effect significantly decreased, generally the plant...
extracts efficacy decreased in the food model media, by comparison with the in vitro control media because the rich nutrients in food model media compared to laboratory media may enable bacteria to repair damaged cells faster (Burt, 2004; Gill et al., 2002).

In kutum and cold smoked kutum broth, 0.15% EO showed bacteriostatic effect and number of bacteria did not significantly change during the incubation period, therefore this concentration can be considered as MIC of EO against L. monocytogenes in these mediums.

The results demonstrated a synergic effect of Ajowan EO and NaCl, addition of 4% salt significantly improved antimicrobial activity of Ajowan EO in FPB, kutum broth and cold smoked kutum broth. As the final concentration of NaCl in flesh of light salted fish is about 4% (Wilson and Droby, 2000), this concentration of NaCl has been applied in this model study. Synergistic effect between NaCl and plant essential oil has been observed in other studies. The combined use of NaCl and clove powder in mackerel muscle extract has totally prevent growth and histamine production by Enterobacter aerogenes (Wendakoon and Sakaguchi, 1993). Synergism between NaCl and mint oil against S. enteritis and L. monocytogenes has been recorded in taramosalata (Tassou et al., 1995). Antilisterial activity of garlic essential oil also improved by NaCl in BHI broth (Razavi Rohani et al., 2011).

This synergistic mechanism would be due to increasing effect of thymol on permeability of microorganism plasma membrane by perturbation of the lipid fraction and also inhibitory effect of NaCl on intracellular enzyme (Wendakoon and Sakaguchi, 1993; Gutierrez et al., 2009). It has been shown that with a higher saline concentration, a greater bacterial surface hydrophobicity may facilitate EO penetration or contact with microorganism (Angienda and Hill, 2011). This could explain why it was possible to inhibit bacterial growth by combining EOs and saline. In this study the bacterial counts found for the FPB, kutum and cold smoked kutum broth added 4% salt without any EO were significantly lower than the counts obtained for the broth controls (p < 0.05).

According to Figures 3 and 4 L. monocytogenes growth in cold smoked kutum broth was significantly lower than kutum broth, L. monocytogenes count in the cold smoked kutum broth was 2 log cycle less than kutum broth after 12 days of storage at 4 °C. Results showed inhibitory effect of smoke and salt against this bacterium. Sabanadesan et al. (2000) evaluated liquid smoke for its antilisterial activity in salmon fillet and found smoking for 4 h resulted in a 1.5 log cfu.mL⁻¹ reduction of Listeria innocua when smoking was done for 12 h, it gave a 3 log cfu.mL⁻¹ reduction (Sabanadesan et al., 2000). Poysky et al. reported that the use of smoke reduced the minimum heat required to kill L. monocytogenes in salmon steaks from 82 °C to 67 °C (Poysky et al., 1997). Niedziela et al. asses the antimicrobial effect of salting and smoking on L. monocytogenes in salmon fillet and found there was no significant growth in the smoked samples, whereas in the salted-only samples the number of bacterium increased by between 2-5 log cycles (Niedziela et al., 1998). In the same study commercially available phenols and formaldehyde from wood smoke in concentrations found in smoked products tested for their antimicrobial properties against L. monocytogenes in TSB with added salt at a concentration similar to that in smoked salmon, these experiments have shown that phenols and salt have a bacteriostatic, not bactericidal, effect but salt and formaldehyde have bactericidal effect. Sunen et al. (2003) reported smoke had a synergistic inhibitory effect with salt and vacuum packaging on both L. monocytogenes and A. hydrophidae in rainbow trout (Sunen et al., 2003). The main purposes of smoking are development of aroma, color, flavor and preservation of food via antioxidant and antibacterial activity. The antimicrobial effect of smoking is due to the activity of some of the smoke component such as phenols, alcohol, organic acids, carbonyls, hydrocarbons that is result to wood burning (Jay, 2000).

Conclusion

The results of this study demonstrated the advantages of hurdle technique in fish safety via application of antilisterial factors such assmoke components, low temperature (4 °C), salt at 4%, and use of Ajowan EO without any undesirable changes in organoleptic properties of fish. The lowest growth of L. monocytogenes was observed in cold smoked kutum broth with 4% salt and 0.3% Ajowan EO. Final population of L. monocytogenes in cold smoked kutum broth containing 0.3% Ajowan EO plus 4% NaCl (1.8 log cfu.mL⁻¹) was 6.2 log cfu.mL⁻¹ less than kutum broth (without any salt and EO) with final population of 1.8 log cfu.mL. Among the tested factors 0.3% Ajowan EO with 2 log cfu.mL⁻¹ reduction on initial number of bacteria was more effective on inhibition of L. monocytogenes growth. Proteins, fats and other compounds which existing in fish matrix reduced the inhibitory effects of Ajowan EO on L. monocytogenes, while NaCl and smoke components stimulated this antilisterial effect.

References

Adams RP (2001) Identification of essential oils components by gas chromatography/quadra pole mass spectroscopy, Carol Stream, IL, Allured. pp 51-367.

Angienda PO, Hill DJ (2011) The effect of sodium chloride and pH on the antimicrobial effectiveness of essential oils against pathogenic and food spoilage bacteria: implications in food safety. WASET 57:1033-1038.

Basti AA, Misaghi A, Salehi TZ, Kamkar A (2006) Bacterial pathogens in fresh, smoked and salted Iranian fish. Food Cont 17:183-188.
Burt S (2004) Essential oils: their antibacterial properties and potential applications in foods - A review. Int J Food Microbiol 94:223-253.

Campos CA, Castro MP, Glemmo MF, Schegelguerta LI (2011) Use of natural antimicrobials for the control of Listeria monocytogenes in foods. Science against microbial pathogens: Communicating current research and technological advances. Formatex, Badajoz, pp 1112-1123.

Cruz CD, Silvestre FR, Kinoshita EM, Landgraf M, Franco BDGM, Destro MT (2008) Epidemiological survey of Listeria monocytogenes in a gravlax salmon processing line. Braz J Microbiol 39:375-383.

Ericsson H, Eklow W, Danielson-Tham ML, Loncarevic S, Mentzing LO, Person I, Unnerstad H, Tham W (1997) An outbreak of listerioses suspected to have been caused by rainbow trout. J Clin Microbiol 35:2904-2907.

Facinelli B, Varaldo PE, Toni M, Casiorei C, Fabio U (1989) Ignorance about Listeria. Br Med J 299:738.

Feldhusen F (2000) The role of seafood in bacterial foodborne diseases. Microb Infect 2:1651-1660.

Gill AO, Delaquis P, Russo P, Holley, RA (2002) Evaluation of antilisterial action of Cilantro oil on vacuum packed ham. Int J Food Microbiol 73:83-92.

Goudarzi GR, Saharkhiz MJ, Sattari M, Zamorodian K (2011) Antibacterial activity and chemical composition of Ajowan (Carum copticum benth. & hook) essential oil. J Med PlantRes 13:203-208.

Gutierrez J, Barry-Ryan C, Bourke P (2009) Antimicrobial activity of plant essential oils using food model media, efficacy, synergistic potential and interactions with food components. Food Microbiol 26:142-150.

Holley RA, Patel D (2005) Improvement in shelf-life and safety of perishable foods by plant essential oils and smoke antimicrobials. Food Microbiol 22:273-292.

Jay JM (2000) Modern Food Microbiology. 6nd ed. Gaithersburg, Aspen, 679 pp.

Khajeh M, Yamini Y, Sefidkon F, Bahramifar N (2004) Comparison of essential oil composition of Carum copticum obtained by supercritical carbon dioxide extraction and hydrodistillation methods. Food Chem 86:587-591.

Lennon D, Lewis B, Mantell C, Becroft D, Dove K, Farmer S, Cruz CD, Silvestre FA, Kinoshita EM, Landgraf M, Franco BDGM, Destro MT (2008) Epidemiological survey of Listeria monocytogenes in a gravlax salmon processing line. Braz J Microbiol 39:375-383.

Muñoz M, Guevara L, Palop A, Tabera J, Fernandez PS (2009) Determination of the effect of plant essential oils obtained by supercritical fluid extraction on the growth and viability of Listeriamonocytogenes in broth and food systems using flow cytometry. Food Sci Technol 42:220-227.

Niedziela JC, MacRae M, Ogden ID, Nesvadba P (1998) Control of Listeriamonocytogenes in salmon; antimicrobial effect of salting, smoking and specific smoke compounds. Lebensm Wiss u Technol 31:155-161.

Nilsson L, Gram L, Huss HH (1999) Growth control of Listeria monocytogenes in cold-smoked salmon using a competitive lactic acid bacteria flora. J Food Prot 62:336-342.

Oliveira CEVd, Stamford TLM, Neto NJG, Souza ELd (2010) Inhibition of Staphylococcus aureus in broth and meat broth using synergies of phenolics and organic acids. Int J Food Microbiol 137:312-316.

Oroojalian F, Kasra-Kermanshahi R, Azizi M, Bassami MR (2010) Phytochemical composition of the essential oils from three Apiaceae species and their antibacterial effects on food-borne pathogens. Food Chem 120:765-770.

Oussalah M, Caïlet S, Saucier L, Lacroix M (2006) Inhibitory effects of selected plant essential oils on the growth of four pathogenic bacteria: E. coli O157:H7, Salmonella Typhimurium, Staphylococcus aureus and Listeria monocytogenes. Food Cont 18:414-420.

Pao S, Ettinger MR, Khalid MF, Reid AO, Nerrie BL (2008) Microbial quality of raw aquacultured fish fillets procured from internet and local retail markets. J Food Prot 71:1544-1549.

Poyssky FT, Paranjapye RN, Peterson ME,Pelroy GA, Gutman AE, Eklund MW (1997) Inactivation of Listeria monocytogenes on hot-smoked salmon by interaction of heat and smoke or liquid smoke. J Food Prot 60:649-654.

Puwastien P, Judprasong K, Kettwan E, Vasanaichtt K, Nakngamanon Y, Bhattacharjee L (1999) Proximate composition of raw and cooked Thai freshwater and marine fish. J Food Comp Anal 12:9-16.

Rani P, Khullar N (2004) Antimicrobial evaluation of some medicinal plants for their anti-enteric potential against multidrug resistant Salmonella typhi. Phytother Res 18:670-673.

Razavi Rohani SM, Moradi M, Mehdizadeh T, Saei-Dehkordi SS, Griffiths MW (2011) The effect of nisin and garlic (Allium sativum L.) essential oil separately and in combination on the growth of Listeria monocytogenes. Lwt Food Sci Technol 44:2260-2265.

Reis FBD, Souza VMD, Thomaz MRS, Fernandes LP, Oliveira WPd, Martins ECPD (2011) Use of Carnobacterium maltaromaticum cultures and hydroalcoholic extract of Lippia sidoides Cham. against Listeria monocytogenes in fish model systems. Int J Food Microbiol 146:228-234.

Sabanadesan S, Lammerding AM, Griffiths MW (2000) Survival of Listeria innocua in salmon following cold-smoke application. J Food Prot 63:715-720.

Singh G, Kapoor IPS, Pandey SK, Singh UK, Singh RK (2002) Studies on essential oils: Part 10; antibacterial activity of volatile oils from some species. Phytother Res 16:680-682.

Solomakos N, Govaris A, Koidis P, Botsoglou NT (2008) The antimicrobial effect of thyme essential oil, nisin and their combination against Escherichia coli O157:H7 in minced beef during refrigerated storage. Meat Sci 80:159-166.

Solomakos N, Govaris A, Koidis P, Botsoglou NT (2008) The antimicrobial effect of thyme essential oil, nisin, and their combination against Listeria monocytogenes in minced beef during refrigerated storage. Food Microbiol 25:120-127.

Souza ELd, Barros JCD, Conceição MLD Neto NJG, Costa ACVD (2009) Combined application of origanum vulgare essential oil and acetic acid for controlling the growth of...
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Souza VM, Alves VF, Destro MT, De Martinis ECP (2008) Quantitative evaluation of *Listeria monocytogenes* in fresh and processed Surubim fish (*pseudoplatystoma sp*). Braz J Microbiol 39:527-528.

Sunen E, Aristimuno C, Fernandez-Galian B (2003) Activity of smoke wood condensates against *Aeromonas hydrophila* and *Listeria monocytogenes* in vacuum-packaged, cold-smoked rainbow trout stored at 4 °C. Food Res Int 36:111-116.

Tassou C, Drosinos EH, Nychas GJE (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. J Appl Bacteriol 78:593-600.

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. J Food Prot 56:410-413.

Wilson C, Droby G (2000) Microbial Food Contamination. CRC Press LLC, Boca Raton, pp 149-171.

Zargari A (1988) Medicinal Plants. Vol. 2. Tehran University Publications, Tehran.

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