doi: 10.17221/593/2014-CJFS

Effect of Plant Antioxidant and Antimicrobial Compounds on the Shelf-life of Seafood – A Review

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Abstract

Pezeshk S., Ojagh S.M., Alishahi A. (2015): **Effect of plant antioxidant and antimicrobial compounds on the shelf-life of seafood – a review**. Czech J. Food Sci., 33: 195–203.

While the use of synthetic antioxidants and antibacterials to keep the quality of seafood products has become a commonplace, consumer concern about their safety has motivated the seafood industry to seek natural alternatives. Phenolic compounds of plants are an essential part of the human diet, and are of noticeable interest due to their antioxidant and antibacterial properties. The industries processing agricultural products generate considerable quantities of phenolic-rich by-products, which could be valuable natural sources of antioxidants and antibacterials. Some of these by-products have been the subject of investigations and have been demonstrated to be effective sources of phenolic antioxidants and antibacterials. When tested in fish and seafood, phenolic-rich extracts and essential oils have shown antioxidant and antibacterial activities comparable to that of synthetic antioxidants and antibacterials. This review provides a critical evaluation of some natural antioxidants and antibacterials in maintaining the quality of some seafood products and increasing their shelf-life and a discussion on the role of phenolic compounds in delaying the bacterial spoilage and oxidative processes.

Keywords: plant extracts; essential oils; preservatives

Fresh seafood is considered as a valuable part of human nutrition, because of its high content of polyunsaturated fatty acids (PUFAs) and protein (Ozogul *et al.* 2006; Kykkidou *et al.* 2009); long-chain polyunsaturated fatty acids of these products have gained attention because of their prevention of human cardiovascular diseases (Ozogul *et al.* 2006). Despite their therapeutic and nutritional value, these products have a short shelf-life. This is due to the vast amounts of free amino acids and volatile nitrogen bases and higher final pH that limit the useful life of the product being highly susceptible to oxidation of unsaturated fatty acids (Mexis *et al.* 2009), and this can affect the flavour, taste, texture, aroma, and shelf-life of fish (Banerjee 2006). To prevent and delay the quality changes caused by lipid oxidation in foods and seafood, various synthetic antioxidants have been used (Benjakul *et al.* 2005). However, with growing concerns regarding the safety of synthetic antioxidants, alternative mechanisms of antioxidant protection by the use of natural antioxidants have been in review over the last years (Banerjee 2006).

In recent years consumers have been demanding foods that are fresh, natural and minimally processed along with the requirement for increased safety and quality. This perspective has put pressure on the food industry for progressive removal of chemical preservatives, and has fuelled research into alternative natural antimicrobials and antioxidants (Cox *et al.* 2010). Some plants and vegetables have been shown to possess valuable antioxidants and antibacterials of great nutritional and therapeutic values. Numerous extracts and essential oils from plants have been tested for their antimicrobial properties against various food-borne microorganisms (Hsieh *et al.* 2001; Nychas *et al.* 2003; Burt 2004; Boziaris *et al.* 2011). Extracts are soluble fractions that can be removed from plant materials by solubilising the component(s) of interest in an aqueous, alcohol, lipid, solvent, or supercritical CO_2 phase and then removing it (Brewer 2011). Essential oils (EOs) are volatile and aromatic oily liquids derived from plant material (Arvind & Vyas 2013) and these compounds are volatile, liquid, limpid, and rarely coloured. EOs are isolated by steam distillation, extraction, or mechanical expression from the herb material (Brewer 2011). The phenolic components are chiefly responsible for the antibacterial and antioxidant properties of EOs and extracts (Burt 2004; Lin & Lin 2005; Mexis *et al.* 2009; Carocho & Ferreira 2013).

The objective of this article is to provide an overview of published data on antioxidant and antimicrobial activities of those EOs, plant extracts and their components that can be considered appropriate for use in or on foods, and describe their possible modes of action.

Plant natural antioxidants: composition and action mechanism

The natural antioxidant system is divided into two major groups, enzymatic and non-enzymatic antioxidants. Regarding enzymatic antioxidants they are divided into primary and secondary enzymatic defences while the primary defence is composed of three important enzymes that prevent the formation or neutralise free radicals: glutathione peroxidase, catalase, superoxide dismutase and the secondary enzymatic defence includes glutathione reductase and glucose-6-phosphate dehydrogenase. These two enzymes do not neutralise free radicals directly, but have supporting roles to the other endogenous antioxidants (Carocho & Ferreira 2013). The non-enzymatic endogenous antioxidants include vitamins (C, E, and carotenoids), polyphenols (ellagic acid, gallic acid, and tannins), flavonoids (flavones, isoflavones, flavonoes, anthocyanins, and catechins) (Gupa & Sharma 2006). Reports have revealed plants to be rich sources of natural antioxidant compounds. Phenolic compounds are commonly found in plants, and have been reported to have a wide range of biological activities including antioxidant properties that directly or indirectly contribute to the inhibition or suppression of oxidation processes (Shahidi 2008; Cox *et al.* 2010). Thyme and oregano EOs have two major constituents: as percentage of the total content are the phenols carvacrol and thymol. Carvacrol and thymol comprise the main antioxidant components. In addition, the flavonoids of oregano EO are a group of compounds with antioxidant activity (Goulas & Kontominas 2007; Kykkidou *et al.* 2009). Rosemary has been reported to contain certain compounds such as rosmanol, rosmaridiphenol, rosmariquinone, and carnosol, which may be up to four times equal to butylated hydroxyanisole (BHA) and as effective as butylated hydroxyltoluene (BHT) as antioxidants (Cadun *et al.* 2008; Rohlík *et al.* 2010, 2013). The antioxidant properties of turmeric extract are mainly attributed to the curcumin and phenolic compounds as well as these properties appear to be related to the high contents of sulphur-containing compounds, flavone, and polyphenolic derivatives in the shallot extract (Pezeshk *et al.* 2011). Cinnamon has a good antioxidant potential. This plant is rich in cinnamaldehyde as well as β-caryophyllene, linalool, and other phenolic compounds (Ojagh *et al.* 2010). The antioxidant activity of phenolic compounds is reported to be mainly due to their redox properties, which can play an important role in neutralising and adsorbing free radicals, triplet oxygen, quenching singlet and/or decomposing peroxides (Bajpai *et al.* 2009). Phenolic compounds are ubiquitous in plants, and when plant foods are consumed, these phytochemicals contribute to the intake of natural antioxidants in the human diets (Balasundram *et al.* 2006).

Employment of plant natural antioxidants on sea products

In recent years, natural antioxidants have been extensively studied and it seems that most of the edible plants can behave as antioxidants (Carocho & Ferreira 2013). An overview of the literature reporting studies on the antioxidant effect of EOs or plant extracts in seafood is presented in Table 1. Mexis *et al.* (2009) examined the working of the combination of an O_2 absorber and oregano essential oil (0.4% v/w) on peroxide value (PV) and total volatile base nitrogen (TVB-N) of rainbow trout fillets (*Onchorynchus mykiss*) stored under refrigeration. The combination of the oxygen absorber and oregano essential oil was very effective in extending the shelf-life of rainbow trout fillets to 17 days, whereas samples packaged aerobically had a shelf-life of 4 days only. According to results the oregano essential oil reduced PV and TVB-N of rainbow trout fillets compared with control samples ($P < 0.05$) stored under refrigeration (Mexis *et al.* 2009). Similar results have been reported by some researchers using the oregano essential oil as a natural antioxidant on fish (Goulas & Kontominas 2007; Frangos *et al.* 2010). Cadun *et al.* (2008) investigated the effect of rosemary extract (300 ppm) on the quality of marinated deep-water pink shrimp during refrigerated storage (1°C). This study showed that an addition of rosemary extract decreased TVB-N values significantly during storage at 1°C ($P < 0.05$) and thiobarbituric acid (TBA) values of the experimental group in comparison with the control group

doi: 10.17221/593/2014-CJFS

Table 1. Overview of studies testing the antioxidant activity of essential oils (EO) and plant extracts or their components in seafoods

Seafood	EO or plant extract	Concentration	Chemical quality indices	Reduction in final amount	References
Rainbow trout fillet	oregano EO	0.4% v/w	PV TVB-N	Yes + Yes +	Mexis *et al.* (2009)
Sea bream	oregano EO	0.4% v/w	TVB-N TBA value	Yes + Yes +	Goulas and Kontominas (2007)
		0.8% v/w	TVB-N TBA value	Yes ++ Yes ++	
Trout fillet	oregano EO	0.2% v/w	TVB-N TBA value	Yes + Yes +	Frangos *et al.* (2010)
		0.4% v/w	TVB-N TBA value	Yes ++ Yes ++	
Pink shrimp	rosemary extract	300 ppm	TBA value	Yes +	Cadun *et al.* (2008)
Gilt-head sea bream fillets	rosemary extract	200 ppm	TBA value	Yes +	Gimenez *et al.* (2004)
Crucian carp	tea polyphenols	0.2% v/w	TVB-N TBA value	Yes + Yes +	Li *et al.* (201(2)
	rosemary extract	0.2% v/w	TVB-N TBA value	Yes ++ Yes +	
Atlantic salmon	barley husks	7 mg/dm^2 film	PV TBA value FFA	Yes + Yes + Yes +	Abreu *et al.* (2010)
		24 mg/dm^2 film	PV TBA value FFA	Yes + Yes + Yes +	
Rainbow trout	turmeric extract	1.5% v/v	PV TBA value TVB-N	Yes + Yes + Yes +	Pezeshk *et al.* (2011, 2013)
	shallot extract	1.5% v/v	PV TBA value TVB-N	Yes + Yes + Yes +	
Rainbow trout	cinnamon oil	1.5% v/v	PV TBA value TVB-N	Yes + Yes + Yes +	Ojagh *et al.* (2010)
Rainbow trout	cinnamon oil	1% v/v	TVB-N TBA value FFA	Yes + Yes + Yes +	Andevari and Rezaei (2011)
		1.5% v/v	TVB-N TBA value FFA	Yes + Yes ++ Yes +	
		2% v/v	TVB-N TBA value FFA	Yes + Yes ++ Yes +	
Bonito fillet	tea extract	5% v/w	PV TBA value	Yes + Yes +	Lin and Lin (2005)
Kilka	green tea polyphenols	200 ppm	PV TBA value	Yes + Yes +	Ojagh *et al.* (2005)
Mediterranean swordfish fillets	thyme oil	0.1% v/w	TBA value TVB-N	Yes + Yes +	Kykkidou *et al.* (2009)

The following classification has been used: ++ high reduction compared to control; + medium reduction compared to control; PV – peroxide value; TVB-N – total volatile base nitrogen; TBA – thiobarbituric acid; FFA – free fatty acids

remained at high quality to the end of storage (Cadun *et al.* 2008). A similar study showed that the rosemary extract was very effective in reducing the lipid oxidation of gilt-head sea bream fillets (*Sparus*

doi: 10.17221/593/2014-CJFS

aurata) stored at 1 ± 1°C (Gimenez *et al*. 2004). In a study tea polyphenols (0.2% TP) and rosemary extract (0.2% R) were used as natural preservatives to control chemical characteristics (TVB-N and TBA values) of air-packaged whole crucian carp (*Carassius auratus*) stored at 4 ± 1°C. The increases of TVB-N and TBA values were significantly delayed in both treated groups of samples compared to the control group. Generally, the results showed that either tea polyphenols or rosemary extract could be used as potential preservatives to extend the shelf-life of crucian carp during chilled storage (Li *et al*. 2012). In another study focused on the use of natural antioxidant extracts from barley husks for frozen salmon their effect on lipid oxidation during prolonged frozen storage has been reported. The results demonstrated the efficacy of barley husk extract in increasing oxidative stability and slowing down lipid hydrolysis (Abreu *et al*. 2010). Pezeshk *et al*. (2011) investigated the effects of turmeric extract and shallot extract on the quality of rainbow trout during refrigerated storage (4 ± 1°C) over the period of 20 days. This study concluded that dipping of whole gutted rainbow trout in turmeric extract (1.5%) and shallot extract (1.5%) can delay the chemical changes (TVB-N, PV, and TBA) and extend the shelf-life of the rainbow trout (Pezeshk *et al*. 2011, 2013). Some studies demonstrated the potential of cinnamon oil in the preservation of rainbow trout fresh fillets. Like most herbal extracts, the antioxidant effect of cinnamon oil has been attributed to its ability to break the free radical chain by donating a hydrogen atom (Ojagh *et al*. 2010; Andevari & Rezaei 2011). Lin and Lin (2005) tested the effect of glazes of various tea extracts upon the storage stability and the quality of bonito fillet. The combination of a glazing treatment and the application of green tea extract at a 5% concentration afforded a protection for both lipid oxidation and protein oxidation within bonito fillets (Lin & Lin 2005). Similar results have been reported about the effect of green tea polyphenols (200 ppm) on the quality of common kilka (*Clupeonella cultriventris caspia*) during storage on ice. In this study the antioxidant treated samples showed significantly lower PV and TBA values ($P < 0.05$) than the control for the same time period (Ojagh *et al*. 2005). The study evaluated TBA values and TVB-N values of Mediterranean swordfish fillets during storage at 4°C. In this research, the thyme essential oil could retard chemical changes during storage (Kykkidou *et al*. 2009).

According to studies, the use of EOs and plant extracts in consumer goods is expected to increase in the future due to the rise of 'green consumerism', which motivates the use of products derived from plants.

Plant natural antimicrobial compounds: composition and action mechanism

Essential oils and plant extracts obtained from aromatic medicinal plants have been reported to show singularly good antimicrobial effects against bacteria, filamentous fungi, yeasts, and viruses. These are very complex natural mixtures including hydrocarbons (mainly terpenoids) and oxygenated compounds (alcohols, ethers, esters, ketones, aldehydes, lactones, phenols and phenol ethers (Stefanakis *et al*. 2013). The compositions of EOs and plant extracts from a particular species of plant can differ between geographical sources and harvesting seasons. In general, EOs produced from herbs harvested during or immediately after flowering possess the strongest antimicrobial activity (Burt 2004). These compositions can constitute a powerful tool to reduce the development and dissemination of antimicrobial resistance. The means by which microorganisms are inhibited by phenolic compounds involves a sensitisation of the phospholipid bilayer of the cell membrane, causing an increase in permeability and leakage of vital intracellular constituents, or impairment of bacterial enzyme systems. Phenolic compounds act by inhibiting the amino acid decarboxylase in target bacteria (Ojagh *et al*. 2010). Some studies expressed that plant extracts and EO components appear to make the cell membrane permeable and are able to disintegrate the outer membrane of Gram-negative bacteria and these are slightly more active against Gram-positive than Gram-negative bacteria (Burt 2004; Abdollahzadeh *et al.* 2014). However, not all researches on EOs have concluded that Gram-positive bacteria are more susceptible (Wilkinson *et al*. 2003). The antimicrobial activity of essential oils and plant extracts would be related to the respective composition and structural configuration of the plant volatile oils, their functional groups and possible synergistic actions and reactions between components (Mahmoodi *et al*. 2012). Phenolic compounds comprise the main antimicrobial components in spices and their derived essential oils and extracts, and include, for instance, cinnamic aldehyde from cinnamon; thymol from thyme and oregano; eugenol from clove, allspice and cinnamon; carvacrol from oregano and anethole from anise (Mahmoud *et al*. 2004). As a result, natural antimicrobials are receiving a good deal of attention for a number of microorganism-control issues (Mahmoodi *et al*. 2012).

doi: 10.17221/593/2014-CJFS

Employment of plant natural antimicrobial compounds on sea products

A summary of studies on the antibacterial effect of EOs and plant extracts or their components in sea products is presented in Table 2. The combined effect of an oxygen absorber and oregano EO (0.4% v/w) was studied against total viable counts (TVC) of *Pseudomonas* spp., LAB, *Shewanella putrefaciens*, bacteria from the family *Enterobacteriaceae*, and *Clostridium* spp. in rainbow trout fillets stored at 4°C. The results showed that oregano EO and oxygen absorber have a synergistic effect, and oregano EO can retard the microbial growth and extend the shelf-life of the rainbow trout fillets during refrigerated storage. This may be correlated with the antibacterial properties of the phenolic constituents, carvacrol, and thymol of the oregano essential oil (Mexis *et*

Table 2. Overview of studies testing the antibacterial activity of essential oils (EO) and plant extracts or their components in seafoods

Seafood	EO or plant extract	Concentration	Bacterial species	Reduction in final population	References
Rainbow trout fillet	oregano EO	0.4% v/w	TVC *Pseudomonas* spp. lactic acid bacteria H_2S-producing bacteria	Yes + Yes + Yes + Yes +	Mexis *et al.* (2009)
Mediterranean swordfish fillets	thyme oil	0.1% v/w	TVC H_2S-producing bacteria	Yes + Yes +	Kykkidou *et al.* (2009)
Minced fish meat	thyme oil	0.4% v/w 0.8% v/w 1.2% v/w	*Listeria monocytogenes*	Yes + Yes ++ Yes ++	Abdollahzadeh *et al.* (2014)
Silver carp	tea polyphenol	0.2% w/v	TVC	Yes +	Fan *et al.* (2008)
Fish hamburger	thymol extract	110 mg/l	fish spoilage mesophilic microorganisms psychrotrophic bacteria	Yes + Yes ++	Corbo *et al.* (2008)
	grapefruit seed extract	100 mg/l	fish spoilage mesophilic microorganisms psychrotrophic bacteria	Yes + Yes +	
	lemon extract	120 mg/l	fish spoilage mesophilic microorganisms psychrotrophic bacteria	Yes + Yes +	
Sea bass slice	lemongrass EO	25% w/w	lactic acid bacteria psychrophilic bacteria spoilage microorganisms	Yes + Yes + Yes +	Ahmad *et al.* (2012)
Rainbow trout	turmeric extract	1.5% v/v	TVC psychrotrophic count	Yes + Yes +	Pezeshk *et al.* (2011, 2013)
	shallot extract	1.5% v/v	TVC psychrotrophic count	Yes + Yes +	
Rainbow trout	cinnamon oil	1.5% v/v	TVC psychrotrophic count	Yes + Yes +	Ojagh *et al.* (2010)
Rainbow trout	cinnamon oil	1% v/v	TVC psychrotrophic count	Yes + Yes +	Andevari and Rezaei (2011)
		1.5% v/v	TVC psychrotrophic count	Yes + Yes ++	
		2% v/v	TVC psychrotrophic count	Yes + Yes ++	
Crucian carp	tea polyphenols rosemary extract	0.2% v/w	TVC TVC	Yes + Yes +	Lin *et al.* (2012)

The following classification has been used: ++ high reduction compared to control; + medium reduction compared to control; TVC – total viable counts

Czech J. Food Sci., 33, 2015 (3): 195–203

doi: 10.17221/593/2014-CJFS

al. 2009). The thyme essential oil at 0.1% v/w concentration was effective at inhibiting H_2S-producing bacteria, *Pseudomonas* spp. and TVC and reducing final populations in fresh Mediterranean swordfish fillets compared to the untreated control. Thymol and carvacrol are the most active constituents of thyme EOs with a wide spectrum of antimicrobial properties (Kykkidou *et al.* 2009). Abdollahzadeh *et al.* (2014) evaluated the antilisterial activity of thyme EO in minced fish during refrigerated storage. The addition of thyme EO at 0.8 or 1.2% to minced fish meat exhibited a strong antilisterial activity during storage. The addition of EO at 1.2% showed a higher effect against *L. monocytogenes* than the addition at 0.8% during refrigerated storage. The strong antilisterial activity of thyme oil is often attributed to a high percentage of phenolic compounds (Abdollahzadeh *et al.* 2014). One study investigated the effect of tea polyphenol (TP) dip treatment on the quality changes of silver crap during iced storage. In this research changes in TVC of fish samples were determined. The results showed that dip treatment with 0.2% TP was equally effective in inhibiting the spoilage bacteria growth. The significant reduction in TVC of treated samples can be related to the inhibitory effect of TP on spoilage bacteria (Fan *et al.* 2008). Thymol (110 mg/l), grapefruit seed extract (GFSE) (100 mg/l), and lemon extract (120 mg/l) were used as antimicrobials to control the growth of fish spoilage microorganisms (*Pseudomonas fluorescens*, *Photobacterium phosphoreum*, and *Shewanella putrefaciens*), mesophilic and psychrotrophic bacteria in fish hamburgers during storage at 5°C. The concentration used in this study clearly demonstrated the evident efficacy of thymol, GFSE, and lemon extract in extending the microbial acceptability limit and these antimicrobial compounds could be successfully used to extend the shelf-life of fish hamburgers stored at refrigerated temperature (Corbo *et al.* 2008). In another investigation the impact of gelatin-based film incorporated with lemongrass EO (25% w/w) on the shelf-life extension of sea bass slices stored at refrigerated temperature was examined. Sea bass slices wrapped with lemongrass essential oil (LEO) film had the distanced growth of psychrophilic bacteria, LAB and spoilage microorganisms including *Enterobacteriaceae* and H_2S-producing bacteria throughout the storage of 12 days in comparison with the control and those wrapped with gelatin film without LEO. Hence, the incorporation of LEO into gelatin film could heighten the antimicrobial properties of the film extending the shelf-life of the sea bass slices stored at 4°C (Ahmad *et al.* 2012). Li *et al.* (2012) investigated the effect of rosemary extract (0.2%) and tea polyphenols (0.2%) on microbiological (TVC) changes of air-packaged whole crucian carp (*Carassius auratus*) stored at 4 ± 1°C for 20 days. The results demonstrated that the microbiological growth was significantly influenced by the addition of the two natural preservatives and especially rosemary extract (Li *et al.* 2012). Chitosan coatings enriched with cinnamon oil (2% w/v Ch + 1.5% v/v C) when used against the total viable count and psychrotrophic count in refrigerated rainbow trout were ineffective at extending the lag phase and reducing the final population compared to the control. Cinnamon oils contain high concentrations of *trans*-cinnamaldehyde, a well-known antimicrobial compound and also contain linalool, eugenol, and other phenolic compounds (Ojagh *et al.* 2010). This was confirmed in another experiment with refrigerated rainbow trout using the gelatin coating enriched with cinnamon oil at different concentrations (1, 1.5, and 2% v/v) (Andevari & Rezaei 2011). Turmeric extract and shallot extract were very effective at reducing the TVC and psychrotrophic count of vacuum-packaged rainbow trout when used at 1.5% (v/v) in dipping solution. The antimicrobial properties of turmeric extract are mainly related to the curcumin and phenolic compounds as well as these properties appear to be attributed to the high contents of flavone, sulphur-containing compounds, and polyphenolic derivatives in the shallot extract (Pezeshk *et al.* 2011, 2013).

Effect on organoleptic acceptance

Organoleptic assessment is the most popular way of evaluating the freshness of fish. It is simple, fast, and provides immediate quality information. Table 3 shows a summary of the results of the sensory evaluation of some studies. The organoleptic specifications of fish are clearly visible to the consumer and are essential for consumer satisfaction (Pezeshk *et al.* 2013). If plant extracts and EOs were to be more widely applied as antibacterials and antioxidants in marine products, the organoleptic impact would be important. Sea products generally associated with herbs, spices or seasonings would be the least affected by this phenomenon (Burt 2004) and information on the odour effect of turmeric extract in fish sup-

doi: 10.17221/593/2014-CJFS

Table 3. Overview of studies about effect of essential oils (EO) or plant extracts on the organoleptic properties of seafood

Seafood	EO or plant extract	Concentration	Organoleptic aspects	Effect on the organoleptic properties	References
Rainbow trout	turmeric extract	1.5% v/v	texture		Pezeshk *et al.* (2011)
			odour		
			colour	+	
Crucian carp	tea polyphenols	0.2% v/w	texture	+	Lin *et al.* (2012)
	rosemary extract	0.2% v/w	texture	+	
Rainbow trout fillet	oregano eo	0.4% v/w	odour	+	Mexis *et al.* (2009)
			taste	+	
Smoked	thyme oil	10 ppm	appearance	+	Alcicek (2011)
			taste	+	
			odour	+	
			texture	+	
Rainbow trout	thyme oil	50 ppm	appearance	++	
			taste	++	
			odour	++	
			texture	++	
Rainbow trout	cinnamon oil	1% v/v	texture	+	Andevari and Rezaei (2011)
			colour	+	
			odour	ě	
			overall	+	
		1.5% v/v	texture	+	
			colour	++	
			odour	+	
			overall	+	
		2% v/v	texture		
			colour	++	
			odour	+	
			overall	+	
Sea bass fillet	thyme EO	0.2% v/w	odour	+	Kostaki *et al.* (2009)
			taste	+	

The following classification has been used: ++ high reduction compared to control; + medium reduction compared to control

ports this. The odour of raw rainbow trout fillets treated with 1.5% (v/v) turmeric extract was found to be acceptable after storage at 4 ± 1°C (Pezeshk *et al.* 2011). The flavour and texture of the whole crucian carp treated with tea polyphenols (0.2% TP) and rosemary extract (0.2% R) were improved during storage at 4 ± 1°C (Li *et al.* 2012). The effect of oregano essential oil (0.4% v/w) on sensory (odour, taste) changes of rainbow trout fillets stored under refrigeration (4°C) was investigated. The result indicated that dipping of rainbow trout fillets in oregano essential oil can maintain the sensory attributes of treated samples during refrigerated storage (Mexis *et al.* 2009). Alcicek (2011) reported that the addition of thyme essential oils exerted no negative effects on the taste, appearance, odour, and texture of liquid-smoked vacuum-packed rainbow trout fillets during chilled storage (Alcicek 2011). The treatment of fresh rainbow trout with 1, 1.5, and 2% (v/v) cinnamon oil has been found to delay spoilage without causing any adverse sensory changes (Andevari & Rezaei 2011). Successful application of thyme oil as an antimicrobial agent yielded a distinctive but pleasant flavour to sea bass fillets substantially extending the shelf-life of the product (Kostaki *et al.* 2009).

doi: 10.17221/593/2014-CJFS

CONCLUSIONS

Phenolic components of EOs and plant extracts are most active as natural antioxidants and antibacterials in seafood. These components can delay the chemical changes, retard the microbial growth, maintain the sensory characteristics, and extend the shelf-life of seafood during storage. EOs and plant extracts can be utilized as safe methods for the preservation of fish and seafood during storage.

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Received: 2014–10–17
Accepted after corrections: 2015–01–21

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