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Review

Essential oils for antimicrobial and antioxidant applications in fish and other seafood products

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A B S T R A C T

Background: Fish and other seafoods are highly perishable food products due basically to microbiological growth and lipid oxidation, which are known to be the principal causes of quality deterioration of such products. Therefore, offering safe and high quality seafoods combined with consumers' desire for natural products free from chemical preservatives creates real challenging problems. In the recent past, there has been extensive focus on antioxidant and antimicrobial effects of natural preservatives such as essential oils (EOs), as effective alternative to synthetic additives, in order to enhance oxidative and microbial stability of foods and extend their shelf life.
Scope and approach: In this review, the main spoilage mechanisms of fish and seafood products and the most common techniques used to preserve quality and extend shelf life of such products are first discussed. The chemistry and modes of action of some selected EOs are then briefly presented. The antioxidative and antimicrobial activities of some common EOs, either alone or in combination with other preservative systems, in fish and other seafoods are reviewed. Finally the limitations and the future trends are shown.
Key findings and conclusions: Several EOs have shown i) great antimicrobial activities versus many spoilage and pathogenic microorganisms, and ii) remarkable antioxidant powers against lipid oxidation in fish and other seafoods during processing or storage. However, much more works are still required in order to better understand the exact mechanism of action of EOs or their main components, the effective dose, and the best combination strategy.

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1. Introduction

In recent years, food quality and safety have become a major concern to consumers, producers, food industries, and regulatory agencies worldwide. Such recent trends may be due to the globalization of the food trade and changes in eating habits and consumer behavior, such as increasing demand for natural, fresh, minimally processed, easily prepared, and ready-to-eat products (Jayasena & Jo, 2013; Lucera, Costa, Conte, & Del Nobile, 2012). Therefore, production of safe and high quality food products in general and fish and other seafoods in particular has gained more and more attention around the world in the recent past. Due to their high nutritional value, fish and other seafoods are considered among the most important commodity for human diet, and hence their consumption has risen substantially over the past few decades (Ghanbari, Jami, Domig, & Kneifel, 2013; Sampels, 2015a). Indeed, according to the Food and Agriculture Organization of the United Nations, fish consumption increased from an average of 9.9 kg in the 1960s to around 20 kg in 2015 (FAO, 2016, pp. 1–23).

Fish and other seafoods are extremely perishable food products and are especially susceptible to both chemical and microbiological spoilage during processing or storage. For this reason, one or more adequate preservation methods are required in order to maintain the safety and quality and extend the shelf life of such products (Ghanbari et al., 2013; Hassoun & Karoui, 2017; Noseda, Vermeulen, Ragaert, & Devlieghere, 2014). Various traditional processing methods including drying, salting, smoking, marinating, fermentation and so on, have been widely used since ancient times to preserve fish quality or add more value to the product (Sampels, 2015a). Moreover, low temperature storage and chemical preservatives used for controlling water activity, enzymatic, oxidative, and microbial spoilage are extensively used in food industry (Ghaly,

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Dave, Budge, & Brooks, 2010). However, due to the growing concerns regarding the safety of chemical and synthetic preservatives, alternative mechanisms based on the use of natural compounds have been increasingly tested over the last years (Amorati, Foti, & Valgimigli, 2013; Calo, Crandall, O'Bryan, & Ricke, 2015; Hyldgaard, Mygind, & Meyer, 2012; Lucera et al., 2012). In this context, essential oils (EOs) could represent a promising option since numerous reports have confirmed their antioxidant (Amorati et al., 2013; Jayasena & Jo, 2014) and antimicrobial (Burt, 2004; Jayasena & Jo, 2013; Swamy, Akhtar, & Sinniah, 2016) effects. Thus, these natural preservatives could meet perfectly the increasing consumer demands for clean-label products that are fresh and free of chemical additives.

Although there have been several prior reviews on the use of EOs in food applications (Calo et al., 2015; De Souza, da Cruz Almeida, & de Sousa Guedes, 2016; Jayasena & Jo, 2013, 2014), the antimicrobial and antioxidant properties of EOs for application in fish and other seafoods have not yet been reviewed. Therefore, this review provides up-to-date information about the most recent published data regarding antimicrobial and antioxidant mechanisms of common EOs or their main components as well as their potential applications in fish and other seafood products.

2. Fish spoilage mechanisms

Although fish flesh is generally regarded as sterile when fish is alive, fish spoilage can occur very rapidly after catch or harvest and during the different stages of the production chain, processing, and subsequent storage conditions. Although the importance of the enzymatic autolysis, occurring mainly after capture or harvest, the following section will focus only on microbial and chemical (oxidation) spoilage occurring during processing and storage of fish.

2.1. Microbial spoilage

Fish and other seafoods have high contents of free amino acids, a high *post mortem* pH, high water contents, and many fish species contain trimethylamine oxide (TMAO) (Chaillou et al., 2015; Gram & Dalgaard, 2002). Such characteristics promote growth of bacteria, including both the Gram-positive and Gram-negative types which survive well in a wide range of temperatures. That is why the microbial growth is considered to be the major cause of quality deterioration of fish and other seafood products, causing up to 25–30% loss of such products (Ghaly et al., 2010; Gram & Dalgaard, 2002). There is a general agreement that each food product has its own unique flora, which is determined by the raw materials, the processing parameters and subsequent storage conditions, and the abilities of microorganisms to tolerate the preservation conditions. For example, it was reported that psychrotolerant Gram-negative bacteria such as species within the genera *Pseudomonas* and *Shewanella* are the most commonly spoilage bacteria of aerobically stored chilled fish, while CO_2-tolerant microorganisms, including *Photobacterium phosphoreum* and lactic acid bacteria, may dominate the microflora and become responsible for spoilage of packed fish products (Chaillou et al., 2015; Giuffrida, Valenti, Giarratana, Ziino, & Panebianco, 2013; Gram & Dalgaard, 2002; Gram & Huss, 2000).

Although freshly caught fish is contaminated naturally with various microbiota, only a small fraction of these microorganisms, called specific spoilage organisms (SSOs), are responsible for seafood spoilage (Gram & Dalgaard, 2002). In particular, the seafood SSOs have the ability to convert TMAO to TMA-N, produce ammonia, biogenic amines, organic acids and sulphur compounds from amino acids, hypoxanthine from ATP degradation products, and acetate from lactate. Microorganisms capable of converting TMAO to TMA include *Aeromonas* spp., *Enterobacteriaceae, Photobacterium phosphoreum, Shewanella putrefaciens, and Vibrio* spp. (Gram & Dalgaard, 2002). Research studies demonstrated that *Pseudomonas* was the dominant bacteria for Atlantic salmon (*Salmo salar*) packed in a modified atmosphere (Milne & Powell, 2014) and for bighead carp (*Aristichthys nobilis*) fillets sprinkled with 2% salt, whereas *Aeromonas* was the SSOs of unsalted fillets during storage at 4 °C (Liu, Zhang, Li, & Luo, 2017).

Several microbial growth parameters such as total viable counts (TVC), mesophilic aerobic counts (MAC), and aerobic plate count (APC) have been used to gives a quantitative idea about the presence of microorganisms in the investigated sample (Cheng & Sun, 2015; Rodrigues et al., 2016). For example, when the TVC of bacteria exceeds a microbial load of 10^7 colony-forming units (CFU) per gram or cm^2, it means that the fish muscle becomes dangerous for consumption and can cause very severe health problems due to the possibility of toxic substances produced (Ellis, 2002). Additionally, counts of SSOs obtained on Lyngby Iron Agar plates (Oxoid LTD., Basingstoke, Hampshire, England) after 3 days incubation at 20 °C, have been used as microbial growth parameters for number of Gram-negative and non-fermentative bacteria (Gram, Trolle, & Huss, 1987). Moreover, various other parameters have been widely measured to reveal microbiological quality of fish, such as the nucleotide degradation, the formation of biogenic amines, the production of total volatile basic nitrogen (TVB-N), trimethylamine nitrogen (TMA-N), among others (Rodrigues et al., 2016; Zhu, Ma, Yang, Xiao, & Xiong, 2016).

2.2. Oxidative spoilage

Spoilage caused by oxidation is another prevalent problem, especially for fish species containing high amounts of polyunsaturated fatty acids, resulting in several problems such as off-flavor formation, changes in color and texture, and altered nutrient value (Maqsood, Benjakul, Abushelaibi, & Alam, 2014; Secci & Parisi, 2016). Although lipid oxidation could undergo several types of oxidation, such as photo-oxidation, thermal oxidation, enzymatic oxidation, and auto-oxidation; this latter, defined as the spontaneous reaction of atmospheric oxygen with lipids, is the most common process causing oxidative deterioration (Shahidi & Zhong, 2005). This process occurs via a free radical chain reaction, and proceeds through three phases: initiation, propagation, and termination. Initiation phase starts with the abstraction of a hydrogen atom adjacent to a double bond in a fatty acid, and this may be catalyzed by light, heat, or metal ions to form a free radical. The resultant free radicals react with oxygen to form peroxyl radicals, which in turn react with other lipid molecules to form hydroperoxides and a new free radical during the propagation phase. Termination phase occurs when a build up of these free radicals interact to form non-radical products. Lipid hydroperoxides have been identified as primary products of autoxidation; being unstable, decomposition of hydroperoxides results in a complex mixture of products including aldehydes, ketones, alcohols, hydrocarbons, volatile organic acids, and epoxy compounds, which are known as secondary oxidation products (Ghaly et al., 2010; Shahidi & Wanasundara, 2002; Xu, Riccioli, & Sun, 2015).

3. Fish preservation methods

Several traditional preservation techniques can be applied in order to retard deterioration of seafood products and extend their shelf life as much as possible. Preservation techniques are usually based on the control of temperature, available oxygen, water activity, microbial loads, or several of these parameters at the same time.