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MODERN APPROACHES TO THE APPLICATION OF ESSENTIAL OILS AS NATURAL ANTIOXIDANTS IN OIL STABILIZATION

DOI: 10.5937/PIM26276S

Abstract:
Oil oxidation is one of the main causes of quality deterioration in lipid-containing products in both the food and cosmetic industries. This process leads to changes in odor, taste, color, and nutritional value, as well as a reduction in product shelf life. Synthetic antioxidants such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) are commonly used to prevent oxidation; however, due to the increasing demand for natural additives, research has been focused on natural antioxidants. Essential oils, rich in phenolic compounds, exhibit significant antioxidant activity and can contribute to improving the oxidative stability of vegetable oils. Their application is limited due to volatility and their impact on the sensory properties of products, which is why modern delivery systems such as microencapsulation and nanoemulsions are being developed. Based on the literature review, it can be concluded that essential oils represent a potential natural alternative to synthetic antioxidants in the stabilization of vegetable oils in the food and cosmetic industries.

Keywords: *Essential oils, lipid oxidation, natural antioxidants, microencapsulation, nanoemulsions, oil stability*

Introduction

Oils and fats have significant applications in the food, cosmetic, and pharmaceutical industries, but they are susceptible to oxidation, especially oils rich in unsaturated fatty acids. Lipid oxidation leads to the formation of peroxides and secondary oxidation products, which cause changes in odor, taste, and product quality [1,2]. Therefore, synthetic antioxidants such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) are most commonly used for oil stabilization, but

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due to the increasing demand for natural additives, natural antioxidants are being increasingly investigated [3,4].

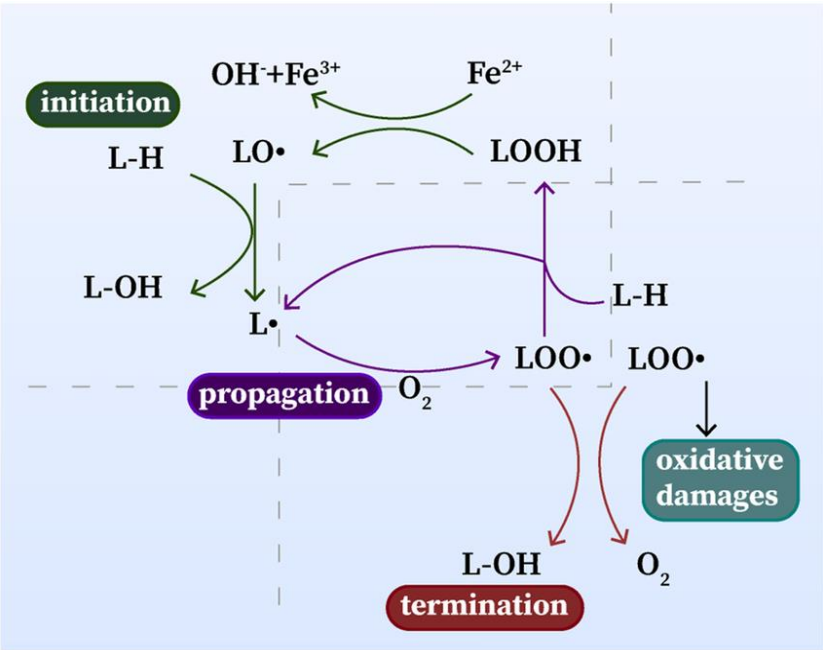
Essential oils are natural mixtures of bioactive compounds that exhibit antioxidant and antimicrobial activity and can be used for the stabilization of oils and lipid-containing products [5,6]. However, their application is limited by volatility and sensitivity to external conditions, which is why modern delivery systems such as microencapsulation and nanoemulsions are being developed to improve the stability and efficiency of essential oils [7,8].

The aim of this paper is to review recent research on the application of essential oils as natural antioxidants in the stabilization of vegetable oils, with particular emphasis on comparison with synthetic antioxidants and modern methods of their application.

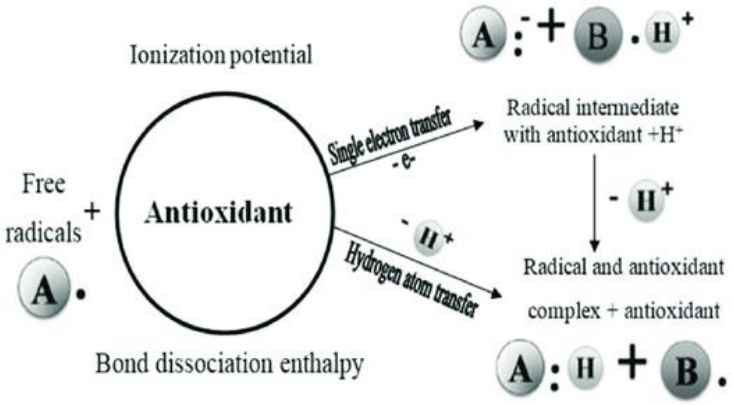
1. Lipid oxidation and oxidative stability of oils

Lipid oxidation is a complex chemical process that occurs through a free radical mechanism. This process involves the reaction of unsaturated fatty acids with oxygen, leading to the formation of hydroperoxides as primary oxidation products and secondary oxidation products such as aldehydes, ketones, and alcohols, which are responsible for rancidity and changes in sensory properties of oils [1,2,9]. Lipid oxidation occurs in three main stages: initiation, propagation, and termination (Picture 1). During initiation, free radicals are formed due to the influence of heat, light, metal ions, or other factors. In the propagation phase, free radicals react with oxygen, forming peroxyl radicals and hydroperoxides as primary oxidation products. In the termination phase, radicals react with each other to form stable oxidation products [10].

The degree of oil oxidation is determined by monitoring primary and secondary oxidation products, most commonly using peroxide value (primary oxidation products), anisidine value, and TBARS method (Thiobarbituric Acid Reactive Substances) (secondary oxidation products, mainly aldehydes and malondialdehyde) [2]. To prevent lipid oxidation, antioxidants are used to slow down oxidation by interrupting free radical chain reactions. The mechanism of antioxidant activity is based on donating hydrogen atoms or electrons to free radicals, stabilizing them and interrupting the chain reaction of lipid oxidation, as shown in Picture 2 [2].



Picture 1. *Lipid peroxidation: initiation, propagation and termination. L•: lipid radical; LO•: alkoxyl radical; L-OH, lipid alcohol; L–H, lipid; LOOH, lipid hydroperoxide; LOO•: epoxy peroxyl radical (source: https://www.researchgate.net/publication/363354774_Ferroptosis_A_mixed_blessing_for_infectious_diseases#full-text)*



Picture 2. *Mode of action of antioxidant reacting with free radicals (source: https://www.researchgate.net/publication/346421037/Picture/fig1/AS:974023974023555@1609236720462/Mode-of-action-of-antioxidant-reacting-with-free-radicals.png)*

2. Essential oils as a natural alternative to synthetic antioxidants

Essential oils are complex mixtures of volatile compounds of plant origin obtained by distillation of aromatic plants and containing a large number of bioactive components, among which monoterpenes, sesquiterpenes, terpenoids, and phenolic compounds are the most important. Phenolic compounds play a key role in the antioxidant activity of essential oils, which is why essential oils rich in these compounds show the greatest ability to slow lipid oxidation [5,6]. The most important antioxidant components of essential oils are thymol, carvacrol, and eugenol, which is why oregano, thyme, rosemary, and clove essential oils are most commonly reported as oils with pronounced antioxidant activity [6,11,12]. Numerous studies have shown that spices and essential oils from plants such as rosemary, thyme, and oregano can significantly slow lipid oxidation and increase the stability of oils and fats [13]. The effectiveness of essential oils depends on chemical composition, concentration, oil type, and storage conditions such as temperature, light, and the presence of oxygen [10]. Essential oils rich in phenolic compounds exhibit greater antioxidant activity compared with essential oils containing lower levels of phenolic constituents [3,4,6,11]. Table 1 presents the most important essential oils, their main active components, and fields of application.

Table 1: *Essential oils, their main active components, and application areas*

Essential oil	***Main active component***	***Antioxidant activity***	***Application area***
Oregano	Carvacol	Very high	Oil, Food, Cosmetics
Thyme	Thymol	Very high	Oil, Food
Rosemary	Rosmarinic acid	High	Oil, Cosmetics
Clove	Eugenol	High	Oli, Pharmaceuticals
Sage	Fenolic compounds	Moderate	Cosmetics
Lavender	Linalool	Moderate	Coscmetics
Peppermint	Menthol	Moderate	Cosmetics, Pharmaceuticals

Source: Bakkali et al., 2008; Miguel, 2010; Burt, 2004; Yanishlieva et al., 1999.

3. Comparison with Synthetic Antioxidants

Synthetic antioxidants such as BHT, BHA, tert-butylhydroquinone (TBHQ), and propyl gallate (PG) have long been used because of their high efficiency, good lipid solubility, and relatively low cost [1,2]. However, due to the increasing demand for natural additives, research has been directed toward finding natural antioxidants that could replace synthetic ones [10]. Studies have shown that essential oils can, in some cases, exhibit antioxidant activity comparable to that of synthetic antioxidants, especially when used at an appropriate concentration and in a suitable type of oil. Nevertheless, synthetic antioxidants still show greater stability and efficiency at high temperatures and during longer storage periods [1].

In addition to antioxidant activity, essential oils also possess antimicrobial properties, which is a significant advantage over synthetic antioxidants, since they can simultaneously slow oxidation and inhibit microbial growth [14]. On the other hand, their application may be limited by strong aroma, volatility, and sensitivity to temperature and light. Table 2 presents a comparison between synthetic antioxidants and essential oils.

Table 2. *Properties of natural and synthetic antioxidants*

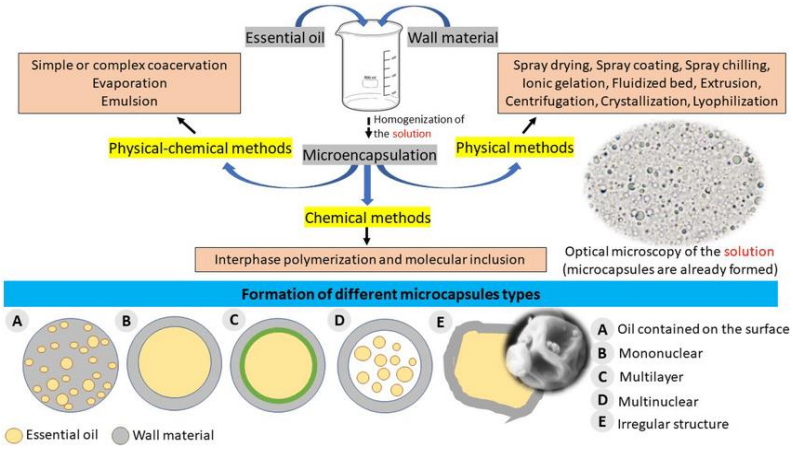
Antioxidant	Efficiency	Advantage	Disadvantages
BHT	Very high	Stability, Low concentration	Synthetic additive
BHA	Very high	Stability	Synthetic additive
TBHQ	Very high	Effective at high temperatures	Synthetic additive
Essential oils	High	Natural, Antimicrobial	Strong aroma, Volatility

Source: Shahidi and Zhong, 2010; Choe and Min, 2006; Taghvaei and Jafari, 2013; Pokorný, 2007.

From Table 2, it can be concluded that synthetic antioxidants exhibit greater stability, but essential oils represent an important natural alternative, particularly due to their natural origin and additional antimicrobial activity. Because of certain disadvantages of essential oils, current research is focused on developing new application methods, such as microencapsulation and nanoemulsions, which improve their stability and efficiency as antioxidants [7].

4. Modern Approaches to the Application of Essential Oils as Antioxidants – Microencapsulation and Nanoemulsions

Essential oils exhibit significant antioxidant activity, but their application is limited by volatility, sensitivity to light, oxygen, and temperature, as well as their pronounced effect on the sensory properties of products. Therefore, modern research is focused on developing new methods for the application of essential oils that enable increased stability, controlled release of active components, and reduced impact on product aroma [7,8]. One of the most important modern approaches is microencapsulation, which is a process in which the active substance is enclosed in a protective coating, thereby protecting the essential oil from external influences and enabling controlled release. Microencapsulated essential oils show greater stability than free essential oils because the protective coating prevents evaporation and degradation of active components during storage [8,15]. The principle of microencapsulation of essential oils is shown in Picture 3.



Picture 3. *Simplified scheme of microencapsulation methods of essential oils and types of microcapsules formed (source: https://www.researchgate.net/Picture/Simplified-scheme-of-microencapsulation-methods-of-essential-oils-and-types-of_fig4_358772072)*

In addition to microencapsulation, nanoemulsions also have important applications. Nanoemulsions are dispersion systems with very small droplets of essential oil (20–200 nm) distributed in a continuous phase. The small droplet size enables better distribution of essential oil and greater availability of active components, thereby increasing antioxidant efficiency. According to literature data, the addition of essential oils can

significantly improve the oxidative stability of vegetable oils. Studies indicate that the addition of oregano and thyme essential oils can reduce the rate of lipid oxidation by 20–50% compared to a control sample without antioxidants, depending on concentration and oil type [10]. Furthermore, the application of microencapsulated essential oils can increase the oxidative stability of oils by an additional 30–40% compared to free essential oils due to reduced volatility and controlled release of active components [8,13]. Essential oil nanoemulsions show even greater efficiency because the small droplet size enables better distribution of antioxidants and enhances their effectiveness in preventing lipid oxidation [7].

5. Conclusion

Based on the literature review, it can be concluded that essential oils represent an important natural alternative to synthetic antioxidants in the stabilization of oils and lipid-containing products. Essential oils rich in phenolic compounds exhibit pronounced antioxidant activity, but their application is limited by volatility and their effect on the sensory properties of products. The application of modern methods such as microencapsulation and nanoemulsions improves the stability and efficiency of essential oils, thereby expanding their use as natural antioxidants. Future research should focus on optimizing application conditions and evaluating the stability and sensory properties of products.

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