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Mechanisms and Applications of Essential Oils as Natural Preservatives in Meat Products: A Review

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Abstract

The increasing global demand for meat products illustrates the importance of safe and effective preservation methods. Butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and tertiary butylhydroquinone (TBHQ) are common synthetic preservatives that stop microbial growth and lipid oxidation. However, they have been linked to negative health effects. Consequently, natural alternatives such as essential oils (EOs) have gained attention due to their antimicrobial and antioxidant activities. Mechanistically, EOs disrupt microbial cell membranes, inhibit key metabolic enzymes, and scavenge free radicals that initiate lipid oxidation. This review discusses the mechanisms and applications of various essential oils as natural preservatives in meat and meat products. Essential oils, which are high in phenolic compounds, work by breaking down microbial cell membranes, stopping enzymatic systems, and neutralizing free radicals that cause oxidation. Several studies have demonstrated that essential oils (EOs) function as a promising natural preservative in meat products by utilizing specific mechanisms to enhance chemical, microbiological, and sensory quality. For instance, rosemary essential oil (REO), when integrated into vacuum packaging, effectively extends the shelf life of chicken meatballs by inhibiting microbial growth and scavenging free radicals to prevent lipid oxidation. Similarly, oregano essential oil (OEO) exhibits strong antimicrobial action against foodborne pathogens like *Salmonella enteritidis* and *Escherichia coli* in dried meat while enhancing sensory properties. In sausage products, nutmeg essential oil (NO) demonstrates its antioxidant capacity by significantly reducing lipid oxidation indicators such as thiobarbituric acid reactive substances (TBARS), suppressed mesophilic bacteria growth, and improved aroma stability during storage. Collectively, these findings confirm that essential oils represent promising natural preservatives that offer a safer multi-target alternative to synthetic additives, especially in the mechanism of cell membrane damage and lipid peroxidation inhibition.

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Introduction

Over the past fifty years, the demand for meat around the world has steadily grown. This is because meat is the main source of animal protein in the diet, which provides the amino acids that are necessary for human growth and metabolism. Meat quality is a multifaceted attribute influenced by numerous factors, both intrinsic and extrinsic to the animal. Key indicators of meat quality include the composition of amino acids, protein solubility, water holding capacity, tenderness, color, and overall sensory attributes like flavor and aroma (Geletu et al., 2021). Meat and its derived products are highly perishable due to their rich nutritional composition, high moisture content, and near-neutral pH, which create an ideal environment for microbial growth. Natural preservatives, which come from plants, animals, or microbes, are a healthier choice. These include essential oils, plant extracts, phenolic compounds, and bacteriocins, which possess both antimicrobial and antioxidant properties. For example, plant-based phenolic molecules have shown efficacy in inhibiting microbial growth and delaying oxidation in comminuted meats due to their aromatic structures and hydroxyl groups (Beya et al., 2021).

Natural preservatives, such as essential oils (EOs) and polyphenolic-rich plant extracts, exert their potential for enhancing the safety, shelf life and sensory appeal of meat products through dual mechanisms. i.e. antimicrobial action and antioxidant activity. Rosemary contains bioactive compounds like phenolic diterpenes, flavonoids, and triterpenes, which are effective in reducing oxidative reactions and microbial growth in meat products, thereby extending shelf life (Kaur et al., 2023)). In addition to rosemary, polyphenolic-rich plants and their extracts serve as natural preservatives. These compounds, such as those found in olives, fruits, grapes, and vegetables, possess antimicrobial and antioxidant properties due to their structure, which typically includes aromatic rings with hydroxyl groups (Beya et al., 2021). When incorporated into meat products, these natural preservatives can inhibit spoilage microorganisms and food-borne pathogens by disrupting microbial cell membranes and inhibiting protein synthesis (Yu et al., 2021).

Numerous studies have explored their potential application in meat systems. For instance, Sarıcaoglu and Turhan (2020) found that the incorporation of clove and rosemary oils into deboned chicken meat effectively suppressed microbial growth and oxidative reactions, extending product shelf life despite some limitations in color stability. Similarly, basil essential oil improved the microbiological quality and sensory characteristics of minced pork (Ibrahim et al., 2018). Other essential oils with proven preservative potential include oregano oil (antibacterial, antifungal, antioxidant) (Souza et al., 2007), cinnamon oil (antiseptic, antipyretic, anti-inflammatory) (Kędzia, 2011), garlic oil (immune-regulating) (Kirkpinar et al., 2014), and black pepper oil (anticancer, antifungal, antioxidant) (Kozłowska-Lewecka et al., 2011).

Given these findings, essential oils represent a natural, safe, and effective alternative to synthetic preservatives for maintaining meat quality and extending shelf life. Therefore, this review aims to provide an overview of essential oil applications in meat and meat products and their potential role in sustainable meat preservation. However, despite numerous studies on essential oils, there is limited consolidated information on their comparative effectiveness in different meat products and preservation systems. The existing literature often focuses on single EO product combinations, leaving unclear how mechanisms, optimal application strategies, or product-specific responses differ across meat types and specific bioactive components also associated mechanisms of multiple powerful essential oils. Therefore, this review aims to provide a comprehensive overview of essential oil mechanisms and their applications in meat and meat products, while addressing current knowledge gaps and highlighting their potential contribution to sustainable meat preservation.

Meat products

Meat products encompass a diverse group of processed meats that differ in formulation, structure, and processing techniques, yet share similar goals in improving palatability, stability, and consumer acceptability. Among the widely consumed meat products across regions are meatballs, dried meat (jerky), and sausages. Although these products differ in terms of moisture content, processing steps, and texture, they are closely related in how they respond to preservation strategies, including the application of essential oils. The following section provides an overview of these products to illustrate their characteristics and processing approaches.

Meatball is one of the popular meat products that is produced from comminuted meat from chicken, pork, ground beef, and fish (Kartikawati and Purnomo, 2019). (Romans et al., 1994) stated that meatball is made by mixing tapioca, ground beef, sodium tripolyphosphate (STP), and cooking salt and formed into a round ball (Ping Pong-like size), then boiled until cooked. The important ingredients in meatballs that determine their quality are starch, fat or oil, and water (Ikhlas et al., 2011). However, while the mixture of meatballs can be shaped into various forms based on consumer demand, most commonly, they are shaped like balls. The preparation and formula for making meatballs can vary in each region or country, depending on the consumer's demand. Fischer (1996), stated that the formula of batter is one of the important factors during the preparation of meatballs. Furthermore, Fischer (1996),) added that usually, the composition of a meatball consists of 17% fat and other ingredients such as monosodium glutamate (MSG) and salt, 53% lean beef, and 30% ice cubes, then mixed and sometimes added with starches. Purnomo and Rahardiyan (2008) reported that meatballs are a meat product that is popular in Asian countries and some European countries. Meatballs are known in some countries with different names; for example, in Italy, the meatball is called "polpette," while in Turkey, it is known as "koefte"; in Vietnam, people know it as "nunh hoa"; it is called "Chinese meatball" in China and "curried kofter" in India (Serdaroglu and Degirmencioglu, 2004).

Dried meat is defined as a whole muscle that has been processed by dehydration to obtain unique organoleptic quality and improve stability (Skandamis and Gounadaki, 2009). The concept of drying meat is to lower the water activity of meat by removing water that inhibits microorganism growth, thus extending the shelf life (Thiagarajan, 2008). The basic concept of dehydration is reducing the moisture content of meat by evaporation, which results from the migration of water from inside of meat to the surface of the peripheral zone (Food Agricultural Organization, 1990). This process involves some changes in physical quality, such as crystallization, puffing, and shrinkage, which affect some physical properties, including odor, color, and texture (Mujumdar and Devahastin, 2000). The changes in meat will provide it with the characteristics of being thinner, smaller, and, to some degree, wrinkled. As a result, meat's consistency will become harder (Food Agricultural Organization, 1990). The temperature of drying is essential to be considered in the drying process, as it affects the drying rate. (Mishra and Maiti, 2017) stated that drying at high temperatures results in undesirable final products due to the hardening effect. Furthermore, some advantages of meat drying can be obtained, such as less storage space, shelf-life stability, and convenience. Jean-Jacques and François (2007) reported that the drying process could be conducted by different methods, such as using pressure or heat sources to remove water from inside the product or mechanical energy to remove water from its surface. The traditional technique of utilizing sun-drying can also be used (Talib et al., 2014). Ayanwale, Ocheme and Oloyede, 2007 stated that sun drying is recommended if it can be done under hygienic conditions. The final quality of dried meat is affected by the raw material quality and pretreatments used before the drying process (Deng et al., 2019). Dried meat is also known in some countries with different names; for example, in the USA it is known as beef jserky, pastirma in Turkey, biltong in South Africa, shafu and rougan in China, and bundner fleisch in Switzerland (Feiner, 2006).

Sausage is defined as restructured meat product made from poultry, pork, beef, lamb, or a combination of those with binders, water, and seasoning and usually is cured, cooked, or smoked, then stuffed into a casing (Essien, 2003). Sausage is known as a meat product with many modification processes to obtain desirable sensory properties. Regarding the sausage shape, it is defined as a meat product with cylindrical ends in a hemispherical shape. However, the shape and size can vary. Marchello and Robinson-Garden (2017) stated sausage is classified into some categories: fresh sausages such as fresh pork sausage; cooked smoked sausages such as bologna, Cotto salami, and Frankfurter; uncooked smoked sausages such as Keilbasa pork sausage and mettwurst; semi-dry sausages such as Cervelot, Lebanon bologna, Thuringer, and summer sausage; and dry sausages such as pepperoni and Genoa salami. The ingredient of meat in producing sausage should be fresh, as it determines the quality of the sausage itself. Meat should have a proper lean-to-fat ratio, have satisfactory binding qualities, not be contaminated, and have spices and seasoning used in proper amounts to create desirable organoleptic quality (Marchello and Robinson-Garden, 2017). Essien (2003) stated that sausage could be produced in a premium, middle, or cheaper quality range. Sausage also can be grilled, browned, and fried and is usually served with accompaniments such as chips, hot dog rolls, salad, and mashed potato. Akpan (2017) stated that in terms of casing used in sausage production, it is categorized into some groups. The first type is natural casing, which should be preserved in salt for future use and soaked in warm water before use; the second type is special grade smooth polyethylene, popular for its attractive presentation; the third type is cellulose casing, which utilizes a natural antimicrobial system; the fourth type is co-extruded casing made from alginate and collagen; and the fifth type is liquid form casing, which is alginate-based and exists in liquid form.

Essential oil

Essential oil is defined as a mixture of compounds with oily characteristics and derived from the secondary metabolism of plants (Silva et al., 2013). Naeem et al. (2018) stated that essential oils are volatile, therefore, they can be extracted through distillation. Preedy (2015) added that regarding the method of extraction, each method has its advantage and drawback; for example, 1) steam distillation results in a medium yield with a longer extraction time and requires energy for heating, 2) solvent extraction may produce solvent residue, 3) cold pressing produces a low yield with a medium extraction time, 4) microwave-assisted extraction results in a high yield with a shorter time and needs less energy, and 5) supercritical fluid extraction produces the highest yield in a shorter time but requires a high cost. The essential oil can be solid or liquid at room temperature and have different colors, from blue to dark reddish-brown or light yellow to emerald green (Campelo, Mediros and Silva, 2019). Bassolé and Juliani (2012) stated that essential oil could be synthesized from different plant parts such as wood or bark, seeds, stems, flowers, roots, fruits, and leaves. The choice of extraction method directly influences the chemical profile and purity of essential oils, including the concentration of key bioactive compounds such as phenolics, terpenes, and aldehydes. These variations determine how effectively essential oils function as antimicrobial and antioxidant agents in meat matrices, where interactions with fat, proteins, and moisture can modify their activity.

Regarding their functionality and health benefits, essential oils are well-known as an excellent potential source for food preservatives and have antioxidant and antimicrobial action (Elaissi et al., 2011). The composition of each essential oil can be influenced by some factors, such as environmental and climatic conditions. Sienkiewicz, Denys and Kowalczyk, (2011) added that essential oil composition is also determined by the season of harvest, spices or genus, plant family, and the geography of the plant. Furthermore, the efficacy of its antioxidant and antimicrobial properties is affected by the method of extraction and its chemical structure (Vilela et al., 2016).

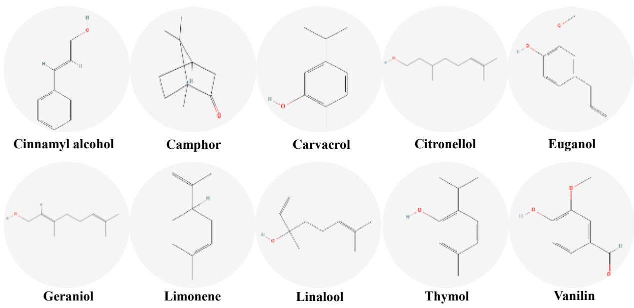

Figure 1. Representative Compounds commonly found in Essential Oils (Pubchem)

Regarding the mechanism of action, Viuda-Martos et al. (2011) reported that essential oil, which can play a role as an antimicrobial, has a specific mechanism against microorganisms. It has a hydrophobic component that allows action over lipids present in microorganisms, specifically in the mitochondria of the cell membrane. This action results in damage to cellular content and makes the bacteria more susceptible. Some popular essential oils that are widely used around the world are thyme oil, oregano oil, garlic oil, cinnamon oil, lavender oil, black pepper oil, tea tree oil, peppermint oil, and sage oil. For cinnamon, oregano, and thyme, the essential oil was found to possess the ability of microorganisms in most pathogens (Mucha and Witkowska, 2021). Many researchers have been conducting studies about the antioxidant activity of various essential oils to find an alternative to chemical preservatives. Wei and Shibamoto (2010) reported that thyme essential oil showed the most significant antioxidant effect among 25 tested essential oils. Furthermore, Thymus spathulifolius has been reported to have thymol for 36.5% and carvacrol 29.8%, thus possessing good antioxidant activity (Sokmen et al., 2004). Figure 1 shows some structures of compounds present in essential oils.

Mechanism of action of essential oil

Antimicrobial mechanisms

The potent antimicrobial activity of EOs is primarily attributed to their phenolic compounds, such as thymol, carvacrol, and eugenol (Barbosa et al., 2009). Burt, (2004) stated that certain sites are related to the action of essential oil compounds in microorganism cells, it could be including damaging membrane proteins and disturbing the phospholipid bilayer, which results in the loss of cellular constituents. In addition, essential oils work by destroying genetic material (Solomakos et al., 2008) and impairing enzymes involved in synthesizing the structural components of the membrane (Burt, 2004).

Swamy et al. (2016) reported that essential oil could destroy membrane integrity, thus causing changes in some vital processes, such as in synthesizing macromolecules. Additionally, the essential oil can penetrate the cell and produce leakage. Each essential oil constituent has a different mechanism of action; for example, the compound of carvacrol causes a change in fatty acid composition, which influences the permeability of the membrane. The essential oil can prevent the growth of molds by attacking their life cycle. Furthermore, Viuda-Martos et al. (2011) explained that the action of essential oil is associated with blocking biochemical pathway in the cell, for instance inhibiting enzyme activity by preventing the activity of protective enzyme. Regarding antioxidant action, Karre et al. (2013) reported that essential oil can reduce oxygen concentration, decompose peroxides, and catalyze metal ions. (Krishnan et al., 2014) added that these mechanisms involve neutralizing free radicals in food. Figure 2 shows the mechanism of antimicrobial compounds in essential oils.

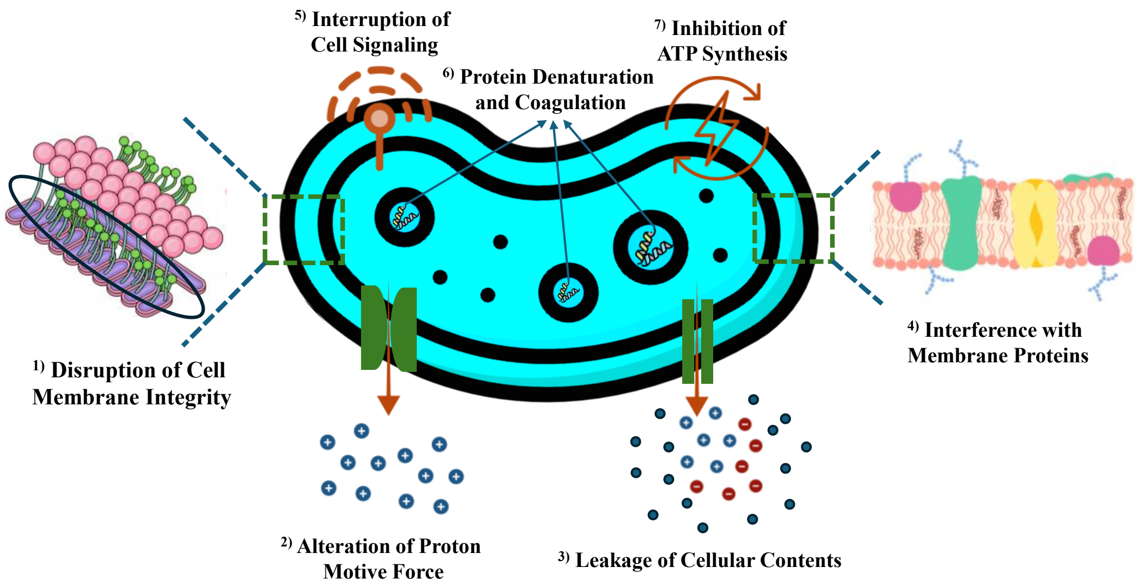

Figure 2. Antimicrobial mechanism of essential oil

Antimicrobial mechanisms

Antioxidant activity in various essential oils depends on their chemical composition. Essential oils consist of organic compounds, which have the ability to donate hydrogen and therefore can retard free radicals (Zhang, 2005). The mechanism of antioxidants in essential oils works in two major ways: first is by donating electrons to terminate oxidation and forms a more stable, non-radical EO compound (Allen & Cornforth, 2010) and second is by removing free radical initiators, by binding to pro-oxidant metal ions, such Fe^{2+} or Cu^{2+} (Antolovich, 2002). Jayaprakasha (2011) reported that Cinnamon zeylanicum has the major compounds, which are cinnamaldehyde, eugenol, and camphor. Gulcin (2011) also added that eugenol showed the most significant antioxidant activity and radical-scavenging activities among identified essential oils when assessed by the DPPH method. Another plant used in food preservation is peppermint (Mentha piperita), the major constituents of peppermint essential oil are menthone, linalool, menthol, eucalyptol, and epoxyocimene (Nascimento et al. 2020). Wu et al. (2011) stated that menthol and menthone, which contain hydroxy radicals, showed radical scavenging activity. While Ocimum basililium contains eugenol, linalool, methyl chavicol, and methyl cinnamate as the major compounds, and linalool in basil essential oil is at the highest level (Nascimento et al. 2020). Figure 3 shows the antioxidant mechanism to terminate oxidation.

Effects of Essential oils in several meat products

Essential oils have been applied in various meats and meat products. The properties of antioxidants and antimicrobials in essential oils can delay or inhibit the growth of microorganisms in meat, thus preventing meat spoilage during storage. Furthermore, it prevents spoilage and improves other quality parameters and the microbiological safety of both meat and meat products (Kirkpinar et al., 2014). Zhai et al. (2018) added that the application of essential oil in meat also makes for better overall acceptability. Nevertheless, the concentration

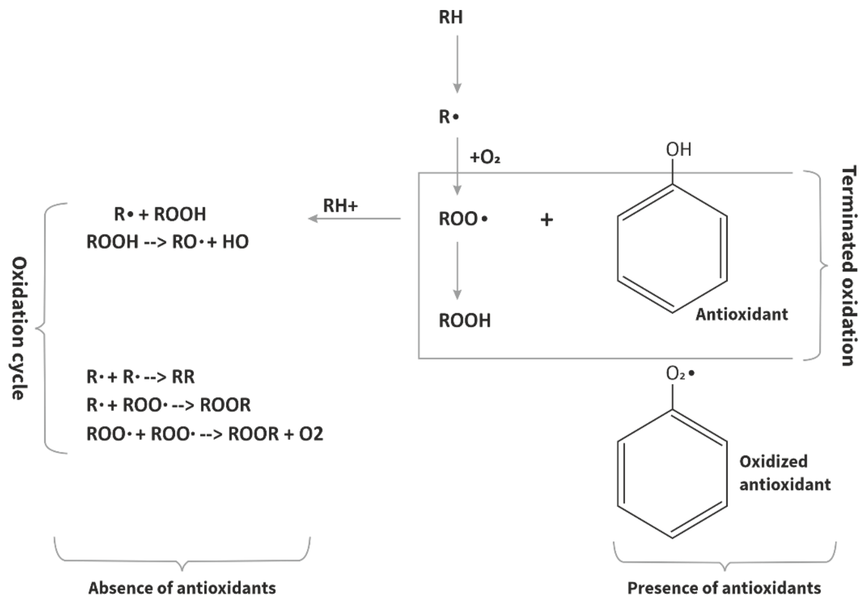

Figure 3. Antioxidant mechanism to terminate oxidation cycle (Adapted from Falowo et al. 2014)

used should be highly considered, as it can impart an undesirable aroma or taste. Some studies have been conducted to utilize the properties of essential oil; for example, research by Ha´c-Szyma ´nczuk and Cegiełka (2015) that was conducted on pork products used sage essential oil during 5 and 10 days of storage. The result demonstrated that sage essential oil decreased the TBARS value, which was relatively lower than the control sample.

Another study also done by Estevez et al. (2007) investigated sage essential oil in pork pate. The result indicated that sage essential oil could delay lipid oxidation, and its antioxidant ability was more effective compared to synthetic preservatives. The use of essential oils can be coated in edible films as part of the packaging of meat products. A study by Vital et al. (2016) explained the effect of rosemary and oregano essential oils as materials for edible coatings to improve beef product quality. The result indicated that edible coatings containing essential oil gave better protection against lipid oxidation compared to the control group due to their higher antioxidant activity. Furthermore, regarding sensory assessment, edible coating with essential oil exhibited a higher score and was more acceptable than uncoated samples. The benefits of EO can be observed much more in meat product preservation (Table 1).

However, some essential oils from certain plant sources might present the possibility of undesirable sensory changes, such as off-flavor. It can be explained in a study conducted by Bonilla et al. (2014), the application of basil and thyme essential oil in the film showed the change in color, which affects consumers' acceptability. An important aspect to consider is that essential oils are sensitive to various external factors, including temperature, pH, light, and oxygen (Dima and Dima, 2015). Furthermore, advanced techniques such as encapsulation can control the release of essential oil. Thus, the shelf life can be more extended (Dima and Dima, 2015).

Various essential oil from large plant species has been investigated related to their antimicrobial activity against pathogens include *Enterococcus sp., Salmonella spp, Staphylococcus aureus, Pseudomonas aeruginosa, Shigella, Escherichia coli*, and coagulase-negative *Staphylococcus* (Fisher and Phillips, 2008). Benjilali and Ayadi (1986) investigated that *Cymbopogon citratus* essential oil can inhibit *Staphylococcus aureus*, *Escherichia coli*, and *Salmonella typhimurium* with different minimum inhibitory concentrations of each pathogen. In comparison, *Pimenta dioica* essential oil was proved to be beneficial in delaying the growth of *Acinetobacter*, *Proteus vulgaris*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Staphylococcus epidermidis*, and *Enterococcus faecalis* (Aumeeruddy-Elalfifi, Gurib-Fakim and Mahomoodally, 2015). Martuccia et al. (2015) stated that a higher concentration of phenolic compounds found in a plant's essential oil determines the degree of inhibition against microorganisms.

Each type of essential oil has its own mechanism of action, for example, Hyldgaard, Mygind and Meyer, 2012) reported that *Cuminum cyminum* essential oil has an action against pathogens by changing the cytoplasm of the membrane. For cinnamon essential oil, it effectively prevents the spoilage of food by disrupting the cell of membrane (Zhang et al., 2016). In addition, Hyldgaard, Mygind and Meyer (2012) indicated that *allium sativum* essential oil could be observed by its ability to induce leakage in a membrane cell.

Effect of essential oil on the quality of chicken meatball

Many studies have been conducted to investigate the effectiveness of essential oils on the quality of meatballs and compare essential oils as natural preservatives and synthetic preservatives for meat and meat product preservation. A study was done by Can and Sahin (2019) that evaluated the effect of rosemary essential oil (REO) on the chemical, organoleptic and microbiological properties of chicken meatballs during storage time at 4°C. The samples of treatment used in this study were packaged by vacuum packaging material, which was prepared by rosemary essential oil coating at 0% (control), 0.3% (REO1), and 0.5% (REO2). The microbiological test was composed of a total of

Table 1. The effect of essential oils in meat products

Type of EO	Key compounds	Type of meat	Mechanism of action	Reference
Basil or thyme EO	Thymol, carvacrol	Minced pork meat	Prevent fat oxidation	Bonilla et al. (2014)
Rosemary, thyme, clove	Cymol, α-pinene, eucalyptol	Mechanically deboned chicken meat protein	Retard oxidation and inhibit microbial activity	Saricaoglu and Turhan (2020)
Thyme and cinnamon	cinnamaldehyde, benzaldehyde, limonene, linalool and eugenol	Ground beef	Inhibit microorganism growth and improve sensory qualities	Shaltout et al. (2017)
Blue mint bush	Carvacrol, thymol, p-cymene	Chicken meatball	Inhibit microbial growth	Shahbazi et al. (2017)
Rosemary	Carnosol, carnosic acid, rosmanol, rosmadiol	Chicken meatball	Inhibit microbial growth, reduce lipid oxidation, improve sensory quality	Can & Sahin (2019)
Thyme	Thymol	Dried meat (jerky)	Inhibit microbial growth	Hernandez et al. (2018)
Nutmeg	Borneol, geraniol, linalool	Cooked pork sausage	Slow lipid oxidation, inhibit microbial growth, improve aroma quality	Sojic et al. (2015)
Oregano	Carvacrol and thymol	Dried meat (jerky)	Inhibit microbial growth, improve sensory properties	Hernandez et al. (2016)

psychrophilic viable yeast or mold counts, *lactic acid bacteria* (LAB), and *Enterobacteriaceae*. The chemical quality test included thiobarbituric acid values (TBA) and pH, and organoleptic properties consist of general acceptability, taste, and appearance. The packaging material prepared was low-density polyethylene with rosemary essential oil (REO) poured into the package and well distributed on the surface using a brush. Chicken meatballs were stored for 0, 3, 5, 7, and 9 days at 4°C. The chemical analysis expressed by TBA was calculated as malonaldehyde (MDA). The sensory test was conducted in a booth under programmed conditions of humidity, light, and temperature. The evaluation was done by eight panelists, and the characteristics used were 1 for awful, 2 for inadequate, 3 for normal, 4 for satisfactory, and 5 for very satisfactory.

Total psychrophilic bacteria in the control group on the 7th day were 7.3 log10, above the minimum limit (7 log10). From the result obtained, the control sample was not acceptable for consumption, as it was considered spoiled on the 7th day. Meanwhile, the samples containing REO, specifically REO1 and REO2, exhibited significantly lower levels of psychrophilic bacteria, likely due to the antimicrobial compounds in REO that inhibit microbial growth. Furthermore, Enterobacteriaceae, which is responsible for foul odors in meat, was found to have a lower value in the sample group with REO than in the control group. The value of Enterobacteriaceae in the control sample was considered to be highest on the 7th day (4.2 log10 cfu/g). In contrast, samples REO1 and REO2 achieved the total value on the 9th day of 3.9 and 3.1 log10 cfu/g, respectively. These results proved that the more effective concentration of REO against Enterobacteriaceae was found in 0.5% REO. The total lactic acid bacteria were higher in the control group on the 7th day of storage, with the value of 5.9 log10 cfu/g. Meanwhile, the total lactic acid bacteria achieved in samples with REO were far lower compared to the control group. For yeast and mold counts, the samples with REO were significantly different compared to the control group on the 5th and 7th day of storage, where samples REO1 and REO2 had the lowest value of yeast/mold.

The chemical analysis indicated that the pH value significantly differed between the control group and the REO group on the 7th day. While the control group experienced an increase in pH value during storage from 6.50 to 6.92, it might be due to the degradation of protein by bacteria (Zhang et al., 2016). Another chemical analysis involved measuring thiobarbituric acid, which is expressed as the malonaldehyde value. According to the results obtained, the value of TBARS in the REO group was lower during storage time compared to the control group. The difference can be observed on the 3rd, 5th, and 7th days of storage. A significant difference in TBA value was expected as a result of the antimicrobial effect of REO against microorganisms, and REO was also responsible for inhibiting lipid oxidation due to its antioxidant effect. Further analysis was conducted to evaluate organoleptic parameters of general acceptability, appearance, and taste. However, no significant differences were found between the control samples and the REO samples during storage; nevertheless, the panelists preferred the sample containing 0.3% REO. From this study, it can be concluded that the control group got spoiled on the 7th day, while samples with REO were still acceptable up to the end of storage.

Another study was conducted by Shahbazi, Karami and Shavisi (2017), who evaluated the microbiological, sensory, and chemical quality of chicken meatballs with the addition of *Ziziphora clinopodioides* essential oil (ZEO) at 4°C for 12 days of storage. The treatments used in this study were 0% (control), 0.1%, 0.2%, and 0.3% ZEO. Sensory analysis of odor was conducted with 25 trained panelists with the range from 1 to 8 (8 = extremely chicken-like to 1 = non-chicken-like) and off-odor with the range from 5 = no off-odor to 1 = extreme off-odor. For psychotropic bacteria, the treated sample had less than 7 log CFU/g during storage. Compared to the control group, treated samples had a slower growth rate of psychotropic bacteria. For *Enterobacteriaceae*, the highest amount was found in the control group (7.23 log CFU/g), and the lowest was in ZEO with 0.3%. In this study, the treated sample did not reach 6 log CFU/g during storage time. Regarding thiobarbituric acid (TBA), the value in the control group was higher (4.04 mg MDA/kg) in comparison with the treated group. The TBA value in the control group remained low, between 1.05 and 1.94 mg MDA/kg. The previous study has proven that the TBARS value in meat products treated with natural preservatives was significantly lower than the untreated sample during storage time (Karabagias, Badeka and Kontominas, 2011). For sensory evaluation in this study, samples with ZEO showed better sensory properties in comparison with the control group, and the appearances of treated samples were more acceptable to panelists.

The effect of essential oil on microbial load and sensory attributes of dried meat

A research paper was conducted to evaluate the effect of oregano essential oil (OEO) on microbial (*Salmonella enteritidis* and *Escherichia coli*) and organoleptic qualities of dried meat. In this study, the samples were dried at 55°C for 6 h with a relative humidity of 30 to 45%. A filter paper was dipped in OEO and put in front of the fan of the dryer. The study was going to determine the MIC (minimum inhibitory concentration) of OEO for each pathogen. For Salmonella enteritidis, the doses used were 1.5 mL, 2 mL, and 3 mL, and for E. coli, the doses used were 0.75 mL, 1.5 mL, and 3 mL. Sodium nitrite was used to compare with OEO. For sensory analysis, the evaluation was performed by 51 experienced assessors. Sensory descriptors used in this study were general appearance, general pleasantness of the smell, general intensity of the smell, intensity of oregano smell, general pleasantness of the texture, juiciness, chewiness, general pleasantness of the taste, general intensity of the taste, oregano taste, salty, bitter, astringent, pungent, and overall evaluation. Those descriptors were evaluated with the scale orientation ranging from 0 to 100%.

Regarding microbial load, after drying and pre-enrichment for 6 h, control and treated samples with synthetic preservatives had more Salmonella enteritidis compared to samples with OEO, 5.621 log cfu g^{-1} and 4.631 log cfu g^{-1}, respectively. This difference was significant in the samples with 1.5 and 2 mL of OEO. Furthermore, a study proved that OEO has an excellent antimicrobial effect (Exarchou et al., 2002). Furthermore, another study has been conducted on minced meats, which indicated that OEO also worked effectively in delaying *Salmonella enteritidis* growth.

For *Escherichia coli* evaluation, the result showed no significant difference between control and samples with synthetic preservatives. It indicated that synthetic preservatives did not work very effectively in inhibiting pathogen growth. In contrast with 1.5 mL of OEO samples, *Escherichia coli* was the lowest in value (1.161 log CFU g-1). Another study done by Burt and Reinders (2003) indicated that OEO effectively inhibited *Escherichia coli* by damaging the cell membrane. In terms of sensory analysis, the panelist evaluated six different treated samples: control, control+salt, treated with 0.75 mL of OEO, treated with 0.75 mL of OEO + salt, treated with 1.5 mL of OEO, and treated with 1.5 mL of OEO + salt. From the results obtained, 0.75 mL of OEO and 0.75 mL of OEO + salt had a higher score in general pleasantness of the smell and were more intense in the general intensity of the taste, the intensity of the smell, and the intensity of the oregano smell. Meanwhile, the general pleasantness and appearance of the texture showed no significant differences when compared to the control. The pungent, bitter, and astringent samples treated with 1.5 mL of OEO and 1.5 mL of OEO + salt exhibited higher values compared to the other samples. Moreover, those samples also showed a higher value in oregano taste compared to the control. Furthermore, samples treated with 0.75 mL of OEO and 0.75 mL of OEO + salt were evaluated to be more intense in oregano taste and juiciness than the control. However, for chewiness, the values between all the samples were not significantly different. But the higher value of chewiness can be judged in samples with 0.75 mL and 1.5 mL of OEO. For overall evaluation, the assessor preferred the samples with 0.75 mL of OEO over those with 1.5 mL of OEO.

In another study (Hernandez et al., 2018), the evaluation of Escherichia coli was conducted using thyme essential oil (TEO), and the same experimental conditions were applied to treated samples of OEO from the previous study. According to the results obtained, TEO has successfully delayed the growth of *Escherichia coli*. The doses used were 0.75 mL, 1 mL, and 1.5 mL; the results indicated that the highest concentration of TEO provided the most effective inhibition of Escherichia coli, resulting in a significant decrease in its counts, with the amount of Escherichia coli in some samples nearly eliminated.

The effect of essential oil on microbial and sensor quality of sausage

In one study conducted by Sojic *et al*. (2015), nutmeg *Myristica fragrans* was used to investigate the effect of its nutmeg essential oil (NO) on the oxidative and microbial stability of sausage during refrigerated storage. The concentrations of 10 ppm (NO1) and 20 ppm (NO2) of NO were applied, and the determination of the qualities was done on the 60th day (1st, 30th, 45th, and 60th days of storage). The parameters in this study were color, microbial quality, thiobarbituric acid-reactive substance (TBARS), and sensory aroma properties.

Samples were stuffed into cellulose casings and pasteurized at 75°C using steam. Then samples were stored at refrigerated temperature (4°C) until analysis. The color of CIE L^* (lightness), CIE b^* (yellowness), and CIE a^* (redness) were measured. The microbiological quality was assessed, encompassing aerobic mesophilic bacteria (incubated for 72 hours at 30°C), total yeast and mold count (incubated for 120 hours at 25°C), *Escherichia coli* (incubated for 24-48 hours at 37°C), and Clostridium spp. (incubated for 24-48 hours at 37°C), and *Enterobacteriaceae* (incubated for 24-48 hours at 37°C). The organoleptic property of aroma was evaluated by seven experienced panelists with distinctive levels ranging from 5 (excellent) to 0 (terrible). For pH parameters, all samples experienced a decrease in pH during storage time. However, NO1 and NO2 samples showed a higher value of pH than the control on the 30th and 45th days. Still, the pH values of all groups were similar at the end of the storage period. Regarding the color quality of sausage, the result obtained showed that the NO_2 sample did not experience a change in the CIE L^* value and the CIE b^* value. In contrast, the CIE a^* value was different in the control and NO1 groups, with a decline of approximately 0.2 units in both, while the CIE a^* value in the NO2 group remained the same during storage. The change in pH is a cause of interaction between the product of lipid oxidation and pigments (Kulkarni et al., 2011).

In terms of thiobarbituric acid-reactive substance (TBARS) value, an increase was seen in all samples during storage time. However, at the end of storage, after 60 days, the value of TBARS was significantly lower than the control in both samples, NO1 and NO2, with the values of 1.21 mg MDA/kg and 0.95 mg MDA/kg, respectively. Furthermore, NO_2 sausage did not show a value above 1 mg MDA/kg until the end of the storage. Regarding bacteria counts, the total number of mesophilic bacteria was found to be the highest in the control sample (25.0 cfu/g) and the lowest in the NO_2 sample (20.0 cfu/g). This trend continued until the end of the storage; on the 45th and 60th days, the total number of mesophilic bacteria was found to be higher in the control (155 cfu/g; 185 cfu/g) compared to the NO1 (93.3 cfu/g; 137 cfu/g) and NO2 samples (28.3 cfu/g and 78.3 cfu/g). Firouzi et al. (2007) stated that the lower value in the treated sample might be due to the antimicrobial effect of nutmeg essential oil. *Enterobacteriaceae*, *E. coli*, *Clostridium spp*., and yeasts and molds were not detected in all sample groups. For sensory aroma quality, until 30 days, the tested samples did not show any significant difference. However, on the 45th day, the degradation of aroma quality can be evaluated. Furthermore, after storage on the 60th day, the aroma value of NO1 and control sausages was significantly lower than the aroma of NO2. The aroma change can be associated with the product produced by lipid oxidation in the NO1 and control groups, while in the NO2 group, there was a minor lipid oxidative change. Another study was conducted by Sojic *et al*. (2017), which investigated the effect of *Juniperus communis L.* essential oil (JO) on the quality of pork sausage. This study used five different concentrations of JO essential oil; 0.1 µl/g (JO1), 0.5 µl/g (JO2), 1.0 µl/g (JO3), 2.0 µl/g (JO4) and 5,0 µl/g (JO5). All samples of pork sausage were stuffed into artificial casings and pasteurized at 75°C using steam, after that stored at 4°C in a cooling chamber until analysis. For sensory evaluation, 7 experienced panelists were assigned to assess samples' color and flavor on a scale from 0 to 6 (0 = no difference to 6 = very large difference).

Regarding pH evaluation, the use of JO in pork sausage had no significant difference compared to the control samples, the lowest pH value in control 6.35 to 6.38 in the JO3 sample. The color measurement was conducted with the parameters of redness (CIE a^* value), yellowness (CIE b^* value), and lightness (CIE L^* value). From the evaluation obtained, in terms of lightness (CIE L^* value) and yellowness (CIE b^* value), all JO samples had significantly higher than the control group. Meanwhile, in redness (CIE a^* value), the samples with 0.1, 0.5, and 1.0 µl/g of JO experienced an increase in this parameter, but on both samples, 2.0 and 5.0 µl/g of JO were not a significant difference.

The evaluation of Thiobarbituric acid-reactive substance (TBARS) value, samples with JO higher than 1.0 µl/g gave a significant decrease on TBARS value compared to other samples. The addition of JO in pork sausage with a concentration lower than 1.0 µl/g did not show any significant effect on TBARS value. The lowest TBARS (0.14 mg MDA/kg) value could be observed in the highest concentration of JO (JO5). This result indicated that *Juniperus communis L.* essential oil has an antioxidant effect. Further analysis was done on the microbiological quality of pork sausage. For the total number of mesophilic bacteria, the addition of JO gave a significant antimicrobial effect compared to the control. The highest number of aerobic mesophilic bacteria can be observed in the control group (137 cfu/g), while the lowest (10.0 cfu/g) was in the JO5 sample, for E.coli, mold and yeats, *Clostridium spp,* and *Enterobacteriaceae* were not detected in all samples. In terms of color quality evaluated by panelists, the result explained that the samples with the addition of JO had redder and darker colors, with the highest value in the JO3 sample and the lowest was in the control group. Also, for flavor parameters, samples with 0.1 and 0.5 µl/g showed slight to moderate differences, while for the rest of the samples, with the exception of the control group, the flavor observed was moderate or large to very large differences.

One of the limitations of applying essential oil on meat and meat products is the change in the sensory quality, especially in flavor and overall acceptability. This was proved in research conducted by (Kirkin et al., 2019), who investigated the effects of tarragon essential oil (0.1%) on organoleptic properties of frankfurter sausage. The result obtained, it indicated that the addition of essential oil on some sensory characteristics (odor, color, and hardness) did not show significant differences. A parameter of spiciness was found to be higher in treated samples than in the control group. The spiciness value in the treated sample was 5.0 while in control was 3.7. However, the parameter of the flavor of frankfurter sausage containing tarragon essential oil was lower compared to the control groups, 3.0 and 3.6, respectively. Moreover, the general acceptability parameter also showed a significant difference in treated and control samples, samples with the addition of tarragon essential oil had a lower value (2.9) in general acceptability than the control sample (4.1).

Conclusion

From all the study discussed above, many studies have been done regarding the effect of various essentials oil on the quality of meat and meat products, ranging from chemical quality, microbiological quality and sensory quality in comparison with synthetic preservative and untreated meat and meat products. It can be concluded that essential oils have good potential as alternative to synthetic preservative regarding food healthy and safety improvement, especially in meat and meat products which are prone to spoilage during storage. It was observed that application of rosemary and *Ziziphora clinopodioides* essential oil in chicken meatballs and its packaging not only extend the shelf life of meatball by inhibiting microbial growth (psychrophilic total viable counts, yeast and mold, lactic acid bacteria and *Enterobacteriaceae*) and reduce lipid oxidation, but also improve organoleptic properties of products. It also can be concluded that the use oregano and thyme essential oils of dried meat (jerky) were effective in delaying the growth of pathogens (*Salmonella entritidis* and *Escherichia coli*) and can significantly improve sensory quality of dried meat. Additionally, for sausage product, the application of nutmeg (*Myristica fragrans*), *Junniperus communis L* and tarragon essential oil had a significant effect on chemical, microbial and organoleptic quality. It can be observed from TBARS value which was been lower than control sample and microbial stability of aerobic mesophilic bacteria that can be inhibited during the storage time, and regarding organoleptic peoperty, the use of essential oil can enhance the value of flavor and overall acceptance. According to this, the utilization of essential oil in meat products can be highly considered as an alternative to synthetic preservative.

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