Review Article

Polyphenols as Natural Antioxidants: Mechanisms and Applications in Meat and Fish Preservation

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ABSTRACT

Lipid oxidation is the primary reason for the decline in meat quality during and storage process. The free radical formation can be prevented by using antioxidants which slow down lipid oxidation, maintain sensory attributes, and minimize the introduction of unacceptable flavours. The usage of plant extract-based antioxidants appears to be a promising alternative to synthetic antioxidants, which adversely affect human health, such as toxicity and carcinogenicity. To provide safe and affordable meat to customers, researchers, and industry are exploring the potential of natural antioxidants as a substitute for synthetic antioxidants. The most effective method for partially or completely replacing synthetic food preservatives is to use plants rich in polyphenolic compounds as natural substitutes. These natural sources include fruits, plant extracts, essential oils, vegetables, spices, olives, and herbs. The antibacterial and antioxidant properties of these phenolic compounds stem from the existence of aromatic rings with hydroxyl groups, which is a shared characteristic among all these compounds.

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1. Introduction

Meat is a great source of lipids, proteins, and minerals (Nupur *et al.,* 2022). Triglycerides, composed of three fatty acids linked by ester bonds, constitute most of the fat in meat and are primarily responsible for rancidity (Domínguez *et al.,* 2019). The susceptibility to lipid oxidation increases with the number of double bonds present; for example, linoleic acid (C18:2) oxidizes ten times more readily than oleic acid (C18:1) (Yun & Surh, 2012). The composition of chicken meat varies depending on feed type and breed, typically containing approximately 32-36% saturated fatty acid (SFA),33-43% monounsaturated fatty acids (MUFA), 20-34% polyunsaturated fatty acids (PUFA). This high concentration of polyunsaturated fatty acids (PUFA) makes chicken meat particularly vulnerable to lipid oxidation (Domínguez *et al.,* 2019). According to Bonacina and Decker (2021), meat's high lipid content and reduced water activity make it more susceptible to fat oxidation, which can result in a decline in nutritional quality, an unsatisfactory consistency and flavor, and a fall in water-holding capacity (WHC). The breakdown of hydroperoxides formed during cooking leads to the production of different volatile organic compounds, which contribute to the oxidative flavor, loss of pigments and vitamins, and reduction in sensory characteristics of meat products (Ruiz-Hernández *et al.,* 2023). This can also cause disruption of the structural integrity of muscle cells, inactivation of antioxidative enzymes, and production of catalytic iron from myoglobin, creating a severe pro-oxidant environment that can affect lipids and proteins. Grinding can further enhance lipid oxidation by breaking down muscle cell membranes and allowing unsaturated lipids to interact with pro-oxidants such as non-heme iron (Mediani *et al.,* 2022).

Heme pigments such as myoglobin and hemoglobin undergo oxidation in a linked lipid-pigment reaction, leading to a change in color. To delay lipid oxidation, antioxidants can be applied during meat processing. Phytochemicals and essential oils are two natural sources of bioactive chemicals that extend the meat shelf-life. Industry uses chemical preservatives such as tert-butyl hydroquinone (TBHQ), butylated hydroxytoluene (BHT), propyl gallate (PG), butylated hydroxyanisole (BHA), and nitrite. However, the use of these synthetic antioxidants has been restricted due to possible health hazards and toxic effects, leading to a search for alternative natural antioxidants (Gutiérrez-Del-río *et al.,* 2021; Khezerlou *et al.,* 2022). Fish contains higher levels of polyunsaturated fatty acids (PUFAs) than other animal protein sources such as poultry, ruminants, and pork (Van Hecke *et al.,* 2019). This characteristic makes fish more susceptible to lipid degradation and the production of undesirable compounds that lead to rancidity, negatively impacting the taste, texture, and nutritional content of fish products (Biswas *et al.,* 2023; Rasul *et al.,* 2022).

Various approaches have been employed to mitigate lipid oxidation during fish preservation. These methods include enhancing fish feed with antioxidants like vitamin E and astaxanthin (Elbahnaswy & Elshopakey, 2024), utilizing modified storage conditions such as freezing at -80oC (Suárez-Medina *et al.,* 2024), implementing advanced packaging techniques to minimize oxygen exposure (Siddiqui *et al.,* 2024), and incorporating plant extracts rich in polyphenols as natural preservatives during storage and processing to limit lipid breakdown (Parmar *et al.,* 2024). Different research is being conducted to find alternatives to synthetic antioxidants. Plants are a source of several beneficial chemicals such as phenolics, carotenoids, and tocopherols. Essential oils (EOs) are frequently utilized in the food industry because they prevent food deterioration, improve sensory quality, and inhibit pathogen growth (Maurya *et al.,* 2021). Elshafie et al. (2023) reported that plant-derived polyphenols, which are replacements for EOs, have anti-inflammatory, anticarcinogenic, antioxidant, and antibacterial effects. The study used databases like "Web of Science" and "Google Scholar" to collect data from the previous six years. Using the following precise keywords, the search was limited to peer-reviewed publications, encompassing both research and review articles: "polyphenols," "natural preservatives," "meat preservation," "fish preservation," "lipid oxidation," and "plant extracts." This review paper only included research that compared polyphenolic substances with synthetic antioxidants in randomized controlled trials. The goal was to include information about lipid oxidation in meat and fish products to the paper's content. This review discusses the potential use of various polyphenolic substances obtained from plants, herbs, and spices in Fish, and meat products.

2. Mechanism of Lipid Oxidation

Lipid oxidation can be initiated by factors like metallic ions, reactive oxygen species (ROS), and reactive nitrogen species (RNS) (Figure 1). This process activates oxygen, leading to the production of hydrogen peroxides, superoxide anions ($O_2\bullet-$), and hydroxyl radicals ($\bullet OH$), with singlet oxygen facilitating ROS production (Domínguez *et al.,* 2019). Oxygen activation in lipid oxidation can be affected by numerous factors, such as temperature, light, pro-oxidants, prior ROS, and transition metals. There are two primary types of activation: photo-oxidation and autoxidation. Autoxidation is especially crucial in the meat industry because it accelerates the degradation of meat products by promoting the reaction between unsaturated fatty acids and oxygen (Falowo *et al.,* 2014).

Lipid oxidation encompasses three key phases: initiation, propagation, and termination (Manessis *et al.,* 2020). During initiation, an unsaturated fatty acid loses a hydrogen atom, forming an alkyl radical. This radical either advances to the propagation phase or combines with another alkyl radical, resulting in a non-radical product. During propagation, peroxide radicals are very reactive products of the reaction between alkyl radicals and molecular oxygen. After reacting with unsaturated fatty acids, these peroxide radicals can take out hydrogen atoms, forming hydroperoxides and other alkyl radicals as their main byproducts. Furthermore, organic peroxides can be produced by the reaction of peroxide radicals with alkyl or other peroxide radicals. Alkoxy and hydroxyl radicals might result from the breakdown of the produced hydroperoxides. Alkyl radicals can break down into secondary products such as volatile alkanes, ketones, and aldehydes, enhancing lipid oxidation. The termination stage is characterized by reactions between free radicals that yield non-radical compounds, effectively ceasing their propagation. Additionally, interactions between free radicals and antioxidants occur during this stage, helping to mitigate the oxidative process.

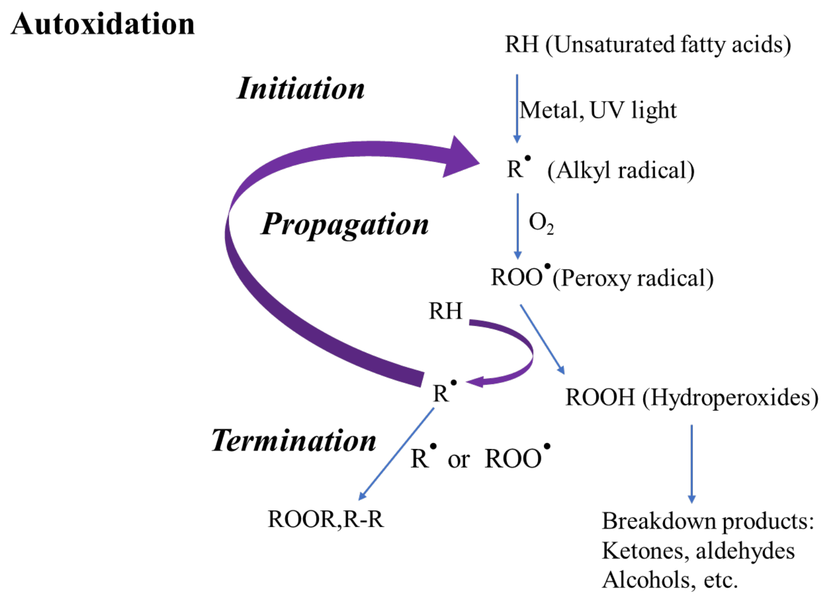

Figure 1 Mechanism of lipid oxidation (Manessis *et al.,* 2020)

3. Effects of Lipid Oxidation

Lipid oxidation in meat during processing can be influenced by several factors: high levels of polyunsaturated fatty acids, low antioxidants, elevated pro-oxidants, and reactive radicals, increased salt (NaCl), and pervasive free molecular oxygen. According to Mariutti and Bragagnolo (2017) research, salt has the potential to decrease the activity of glutathione peroxidase, superoxide dismutase, and catalase. As a result, the meat shelf life is shortened due to oxidative deterioration, which results in the alteration of flavors, and color, the generation of harmful chemicals, the reduction of nutrients, and drip losses (Palmieri & Sblendorio, 2007;Contini *et al.,* 2014). Moylan et al. (2014) claimed that molecular oxygen produces free radicals under physiological conditions, which can form ROS and RNS, which react with biomolecules and genetic molecules. Some homeostatic mechanisms involve them as intermediaries. Oxidative stress, caused by an imbalance between ROS production and antioxidants, leads to damage in muscle organelles. During storage, ROS affects myofibril protein, harming cellular structure and lowering meat quality. Furthermore, ROS can diminish muscle collagen synthesis, leading to hardness in the meat and decreased collagen solubility (Archile-Contreras & Purslow, 2011; Falowo *et al.,* 2014).

4. Mechanism of Action polyphenols as Antioxidant

Aziz and Karboune (2018) showed that the coordinated transfer of an H-atom from a phenolic molecule to a radical is what starts the antioxidant process (Figure 2). This mechanism aims to minimize the initiation phase of oxidation reactions or prevent the production of further free radicals. According to Senanayake (2013), Antioxidants can be divided into two categories: (1) primary antioxidants, which interfere with the propagation stage of autoxidation by stabilizing free radicals by donating free electron or hydrogen atoms, and (2) secondary antioxidants that scavenge oxygen, absorb UV light, bind metal ions, deactivate singlet oxygen, and promote the renewal of primary antioxidants. According to Kelly et al. (2002), Combining aromatic rings with hydroxyl (OH) groups in their chemical structure makes antioxidants efficient in binding and slowing down or preventing the oxidation of lipids and proteins. Specifically, the more OH groups a plant-based polyphenol has, the more bioactive it is. As Cao et al. (1997) and Michel et al. (2021) reported the number of OH groups affects the scavenging of peroxyl and hydroxyl radicals by flavones and flavanols, respectively. Additionally, the molecular structure's aromatic ring arrangement affects the antioxidant's activity, with luteolin having significantly greater scavenging power than kaempferol due to the presence of a B-ring catechol in its structure (Saskia *et al.,* 1996). Furthermore, Transition metals can promote lipid peroxidation by converting lipid hydroperoxides into lipid alkyl radicals. However, By engaging with these free radicals, polyphenols can neutralize them; this interaction is dependent on the molecular arrangement as well as the amount and location of hydroxyl groups (Milić *et al.,* 1998; Senanayake 2013). For instance, Heim et al. (2002) demonstrated that the configuration and total amount of OH groups on the polyphenol molecule had a significant impact on several antioxidant activity methods.

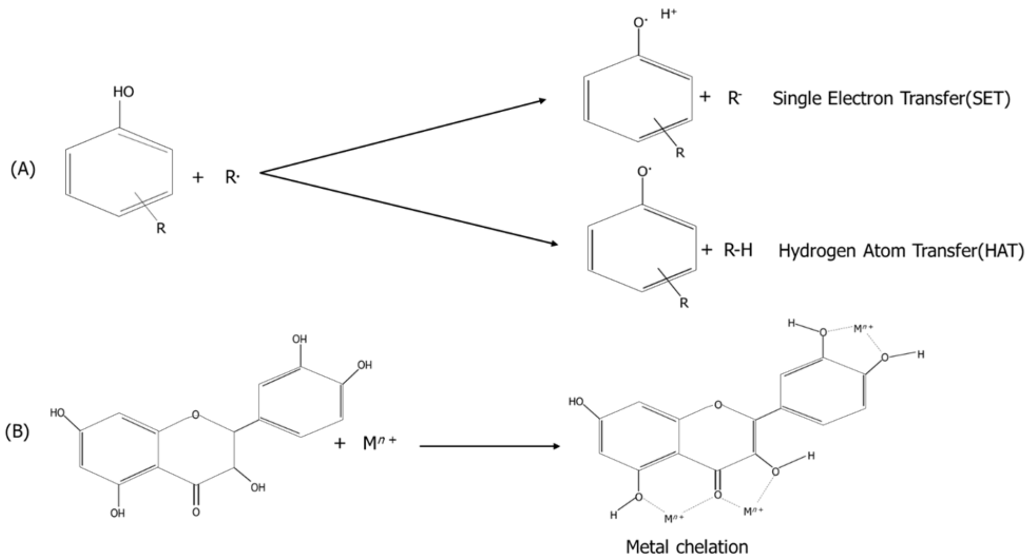

Figure 2 Mechanism action of polyphenols as an antioxidant (Aziz & Karboune, 2018)

5. Polyphenols

Natural phenolic compounds are secondary metabolites of plant tissues and are biomolecules having at least one aromatic ring connected to hydroxyl substituents (Kim *et al.,* 2003; Ainsworth & Gillespie, 2007; Efstratiou *et al.,* 2012; Babiker *et al.,* 2019). Surai (2014) reported that these extracts can be found in fruits, vegetables, spices, herbs, different parts of plants, and even black and green tea. Lemon, onion, rosemary, oregano, tea, grapes, coffee, olive, ginger, blueberries, clove, thyme, pomegranates, and so forth are some examples of naturally occurring sources of polyphenolic chemicals (Serra *et al.,* 2021). Studies show that because polyphenols can scavenge free radicals and chelate metals like iron and copper, they act as natural antioxidants and may help prevent oxidative stress (OS) and impair the proteins, genetic material, and biomolecules (Heleno *et al.,* 2015; Vuolo *et al.,* 2019). Grape seeds also include polyphenols in the form of epicatechin, monomeric catechin, and gallic acid. Numerous investigations have demonstrated these polyphenols' capacity as antioxidants (Rocha-Pimienta *et al.,* 2020). Furthermore, a variety of vegetables and fruits, including parsley, artichokes, and Brussels sprouts, as well as berries, cherries, and pomegranates, contain polyphenols that have antioxidant properties (Ruiz-Torralba *et al.,* 2018).

Tea is abundant in antioxidant-rich catechins. Advanced methods such as pulsed electric fields and ultrasound-assisted ultrafiltration were employed to extract tea's polyphenolic components, which exhibit encouraging antioxidant potential (Zderic & Zondervan, 2016; Vickers, 2017). A recent study assessed the contents and antioxidant activity of commercial teas, revealing that extractable polyphenols had higher antioxidant activity compared to non-extractable polyphenols(Yan *et al.,* 2020). Another polyphenol that is taken out of black tea is called theaflavin. Electro-analytical results on theaflavin demonstrate strong antioxidant activity (Sharma *et al.,* 2020). Traditionally, the antioxidant qualities of spices and herbs have made it possible to preserve food. Polyphenols are responsible for these characteristics. Polyphenols found in cloves, cinnamon, and mint have the potential to be antioxidants. Polyphenolic compounds have been researched for their possible application as bio-preservatives in the food sector to extend the shelf life of meat and prevent microbiological deterioration. Because of their antioxidant and antimicrobial actions, these chemicals can stop oxidative processes, the growth of spoilage, and harmful bacteria in meat and related products(Ullah *et al.,* 2022). Polyphenols may change protein regulation, deactivate microbial enzymes, interfere with the formation of biofilms, and restrict bacterial cell enzymes of metal ions and substrates by reacting with elements of the bacterial cell wall and cell membrane. Commercially available polyphenols can reduce levels of primary and secondary lipid peroxidation, limit lipoxygenase activity, enhance the stability of meat color, reduce the degradation of sulfhydryl groups and salt-soluble myofibrillar protein, and slow the growth of bacteria. The oxidation and proliferation of microbes can be delayed or inhibited by phenolic compounds, whose biological activity offers a preventive effect against food deterioration (Bouarab Chibane *et al.,* 2019; Munekata *et al.,* 2020; Efenberger-Szmechtyk *et al.,* 2021).

6. Polyphenols as an Antioxidant in Meat Preservation

Polyphenols play an important role in meat preservation (Table 1). According to recent research, adding polyphenols to meat and fish products may enhance their nutritional profile, safety, and quality (Hamma *et al.,* 2020). These antioxidants improve sensory attributes, reduce rancidity, and increase oxidative stability(Rasuli *et al.,* 2021). Additionally, they improve juiciness and tenderness, boost nutritional value, and increase the content of monounsaturated fatty acids(Kong *et al.,* 2024). Furthermore, polyphenolic compounds can prevent the formation of spoilage microorganisms, satisfying consumer preference for natural additions over artificial ones(Abdallah Salman *et al.,* 2022).Various studies show that using olive oil or olive byproducts can prolong shelf life and improve the sensory quality of meat. One study indicates that beef treated with olive oil by using vacuum or aerial packaging resulted in lower lipid oxidation and microbial counts (Hashem *et al.,* 2023). Other researchers reported a delay in lipid and protein oxidation and improved chemical indices and consumer acceptance when rabbit meat was dipped in olive or mulberry leaf extract (Moawad *et al.,* 2020). Lemon peel can enhance the sensory attributes and shelf life of meat. In a study, Sheep meat was coated with lemon peel extract resulting in a decrease in Thiobarbituric acid reactive substances (TBARS) value, improved water-holding capacity, and sensory traits as compared to the control group (Hamma *et al.,* 2020). Research showed the reduction of lipid peroxidation when poultry raw meat was coated with pullulan or chitosan combined with lemon peel (Maru *et al.,* 2021). Incorporating lemon peel powder into chicken patties improved oxidative stability, sensory attributes, and microbial quality during storage (Abdel-Naeem *et al.,* 2022). Another study found that the application of lemon peel powder on minced beef showed significant improvement in lipid stability, sensory characteristics, and reduction in microbial growth (Eldahrawy *et al.,* 2022)

Moreover, Research revealed that applying an edible covering containing clove essential oil to buffalo meat during refrigeration reduced lipid oxidation and microbiological development (Noshad *et al.,* 2021). Studies demonstrated that thyme aqueous and alcoholic extracts significantly inhibited the growth of microorganisms in beef mince (Abdallah Salman *et al.,* 2022). Additionally, other studies revealed that beef meat steaks' shelf life was increased and bacterial counts were efficiently decreased by thyme essential oil (Atia *et al.,* 2022). A few research indicates that pomegranate juice can extend the Meat shelf life. A study demonstrated that buffalo meat marinated with pomegranate peel extract (PPE) reduced fat oxidation and growth of microbial species during refrigeration (Rasuli *et al.,* 2021).

Dipping chicken breast in pomegranate juice improved the sensory, microbiological, chemical, and lipid stability, improved by applying pomegranate- juice (1%,2%, 4%) on chicken breast, during storage (El Asuoty & Gerges, 2022). Preservation of odor and flavor by using pomegranate seed oil as a natural antioxidant to preserve the meat quality(Das *et al.,* 2021).

Table 1 Studies regarding the application of polyphenols to enhance meat preservation

Treatment and level added	Sample	Storage condition	Effect	Ref.
Clove bud extract (CE), Mentha leaves (ME), Thyme leaves extract (TE), BHT (200ppm each)	Lamb Patties	Refrigerated for 12 days.	Thiobarbituric acid (TBA) value reduced significantly	(Baker, 2023)

Rosemary essential oil (REO) (0,2,4%)	Chicken meat fillet	stored at 4° C for 12 days.	Lower pH, TBA value, and microbial count	(Shahrampour & Razavi, 2023)
Banana, grapefruit, orange, and lemon peel powder (1% each)	Chicken (patties)	Frozen (-40 °C, 30 min) then stored frozen (-18 °C, 3 months)	Lower TBA value than control	(Abdel-Naeem *et al.,* 2022)
Clove powder (0,2,4 and 6%)	Beef burger	Refrigerated for 12 days	Lower TBARS value and microbial count	(Ahmed *et al.,* 2022)
Clove and lemon verbena essential oil 0.5% each	Chicken breast	Modified atmosphere (65% CO_2, 30% N_2, and 5% O_2) and ambient atmosphere and refrigerated at for 15 days	Reduced value of TBARS and showed an antibacterial effect.	(Hosseini *et al.,* 2021)
Clove extract (CE) 0.1%, BHT 0.02 % Ascorbic acid (AA) 0.05%	Cooked beef patties	Packed in polyethylene pack and refrigerated for 10 days	Reduced protein and lipid oxidation	(Zahid Choi, *et al.,* 2020)
Olive leaf extract (OLE) 0.25,0.5, and 1 %	Chicken meat	Stored for 15 days at 4°C	Reduced lipid oxidation	(Saleh *et al.,* 2020)
Rosemary 800ppm, 1600ppm	Femur beef meat fillets	Refrigerated for 28 days	Reduced lipid oxidation	(Rashidaie Abandansarie *et al.,* 2019)
Thyme, cumin, and garlic essential oils 1% each	Beef meat streaks	Packed and refrigerated for 18 days	Reduced lipid oxidation and microbial count	(Atia *et al.,* 2022)
Rosemary essential oil (REO) 0.5%, 1% and 2% (v/v)	Poultry meat	Refrigerated for 15 days	Significant reduction in TBARS value	(Souza *et al.,* 2019)
Clove extracts	Goat meatballs	Refrigerated for 20 days	Reduced TBARS value	(Singh *et al.,* 2022)
Olives Leave Extract (OLE) and mulberry leaf extract (MLE), 2% each	Rabbit Meat	Refrigerated for 4 days	Significant Reduction in TBARS value and microbial load	(Abdelmaguid, 2020)
Starch Film from red cabbage extract (RCE) and sweet whey	Ground beef	Refrigerated for 4 days	Significant reduction in lipid oxidation	(Sanches *et al.,* 2021)
Mushroom stem waste (2%,4%,6%)	Goat leg meat	Packed and refrigerated for 9 days	Reduced lipid oxidation	(Banerjee *et al.,* 2020)
Clove extract CE (0.1%) Butylated hydroxytoluene BHT (0.02%) Ascorbic acid AA (0.05%)	Beef patties	Packed and stored -21°C for 6 months	CE showed a significantly reduced TBARS value	(Zahid, Seo, *et al.,* 2020)
Lobularia maritina(Lm) flavonoid extract (LmFV,), BHT,	Beef (minced)	Refrigerated for 14 days	Reduction in TBARS value and microbial count	(Ben Akacha *et al.,* 2023)

Linalool(Lin)				
Pomegranate peel extract (PPE) and Thymus essential oil (TEO)	Beef	Stored for 21 days at 4ºC	Significant reduction in TBRAS value	(Mehdizadeh *et al.,* 2020)
Zataria multiflora essential oil (ZEO), Naoemulsion Zataria multiflora essential oil (NZEO), Cinnamaldehyde (CIN)	Ground beef patties	Stores at 4ºC for 20 days	Showed the best antioxidant effect	(Amiri *et al.,* 2019)
Black cumin (*Nigella sativa*)0.1%,0.2%,0.3% and Butylated hydroxyl anisole (BHA) 0.1%	Cooked beef patties	Refrigerated for 15 days	The black cumin-treated sample showed the lowest TBARS value	(Rahman *et al.,* 2021)
Nanostructured biopolymer matrix reinforced with TiO2 and rosemary oil 2%	Lamb leg semimem branosus muscle	Refrigerated for 15 days	Significant reduction in PV and TBARS value	(Alizadeh-Sani *et al.,* 2020)
Chitosan edible coating, 0.15% oregano essential oil (OEO), 0.60% cinnamon essential oil (CEO)	Roast duck slices	Modified atmosphere pressure-packed and refrigerated for 21 days	Significant reduction in TBARS value	(Chen *et al.,* 2021)
Copaiba (*Copaifera officinalis L*) 0.05%, 0.1% BHT	Beef burgers	Refrigerated for 14 days	Significant reduction in lipid oxidation	(Monteschio *et al.,* 2021)
Lentinan (LNT) (0.5,1,2,4%)	Goose breast meatballs	Vacuum-packed and refrigerated for 12 days	Significant reduction in TBARS value	(Fu *et al.,* 2022)
Grewia tenax fruit dried-ground (GTF-DG)	Beef burger	Refrigerated for days	Reduced microbial count and TBARS Value	(Hamami *et al.,* 2024)
Lentinus edodes	Carp surimi	Stored at -20ºC for 3 days	Lipid and protein oxidation inhibited remarkably	(Kong *et al.,* 2024)

7. Effect of polyphenol on fish preservation

Fish is among the unique foods in various countries around the globe. According to FAOSTAT (The Food and Agriculture Organization Corporate Statistical Database), Europe contains some countries with the highest level of per capita consumption rates, including Iceland (90.71kg), Portugal (56.84 kg), Spain (42.47 kg), France (34.37 kg), and Italy (29.80 kg). The characteristics of fish include low levels of lipids and high values of both micro and macronutrients: protein with a significant value of 16 to 21% along with fatty acids of 0.2 to 25% (Honrado *et al.,* 2022). Several health advantages of fish consumption have been associated with polyunsaturated fatty acids (PUFAs), particularly docosahexaenoic acid (DHA), omega three-linolenic acid, and eicosapentaenoic acid (EPA), which are present in substantial concentrations in

most fish (Pietro *et al.,* 2020). Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are highly prone to lipid oxidation. A severe issue that frequently results in a reduction of shelf-life, consumer appeal, functionality, nutritional content, and safety is the process of lipid oxidation of fish oil and other PUFA-rich foods. Lipid oxidation is a major factor in the depletion of product quality and the development of an off flavor (rancidity) in many foods during processing and storage. Lipid oxidation causes discoloration, changes in texture, and a loss of nutritional value (Shah *et al.,* 2014; Wu *et al.,* 2022).
The use of natural antioxidants as a substitute for synthetic preservatives for maintaining food quality is widely requested by both customers and food processors because of the increasing demand for less processed and healthier foods (Bouarab Chibane *et al.,* 2019; Rico *et al.,* 2007). Phenolic compounds are well recognized for their antibacterial properties, in addition to their antioxidant, anti-cancer, anti-inflammatory, anti-hypertensive, immune-stimulating, anti-diabetic, and cognitive functions that are advantageous for overall optimal health. (Araya-Cloutier *et al.,* 2017; Couladis *et al.,* 2003; Sun *et al.,* 2017). Fruits, fruit juices, and vegetables are the primary sources of polyphenols. Beverages like tea and coffee, as well as wine, are also significant sources of polyphenols (Cianciosi *et al.,* 2022). Increased levels of Clove leaf oil concentrations led to a notable reduction of bacterial counts and significantly enhanced fish meat preservation (Rukmawati *et al.,* 2021). Immersion in rosemary extract before freezing reduced the oxidative reactions in proteins, and lipids as well as exhibited reduced peroxide value, and decline in thiobarbituric acid value (Shahrampour & Razavi, 2023). The lipid oxidation parameters in meat exhibited positively to the application of Inolens 4 treatment. Rosemary extracts "Inolens 4" at a concentration of 0.5% had the lowest microbiological counts and yielded the highest sensory evaluations in cooked meat (Linhartová *et al.,* 2019). In comparison to other treatments, the grape seed extract treatment was of good quality and strengthened the favorable effects on sensory qualities. Notably, the shelf life of tilapia under refrigeration was greatly prolonged by using both green tea and grape seed extracts (Zhao *et al.,* 2019). The shelf life of rainbow trout flesh during its seven days in cold storage can be prolonged, allowing it to maintain its quality, by using essential oils in combination with vacuum packing (Ježek & Buchtová, 2014). Immersing fillets of carp fish in the extracts of turmeric, lemon, and cinnamon had a positive impact on spoilage indices as well as effectively extended the shelf life of the fillets (Mugahi *et al.,* 2022). Lipid oxidation in fish patties was significantly delayed by using the natural extracts that were derived from rosemary, pomegranate, and hydroxytyrosol (Martínez *et al.,* 2019). Marinating the rainbow trout fillets with natural antioxidants significantly decreased lipid oxidation and improved color stability during storage at 4°C (Fellenberg *et al.,* 2020).

8. Conclusion and Future Perspective

Botanical extracts, which are naturally rich in antioxidants, can be utilized to prolong the shelf life and improve the quality of fish and meat products. Spices, leaves, seeds, and flowers have compounds that can delay lipid oxidation, color stability, preserve sensory attributes, and prevent microbial spoilage. It should be remembered that the intense flavor of these natural additions may have unfavorable sensory effects on meat, therefore restricting their use. They ought to be combined with nitrite, fat, and salt reduction techniques, as well as novel processing techniques and sustainability initiatives.These extracts hold the capability to enhance the quality and extend the shelf life of meat products by applying them in active packaging systems and exploring innovative techniques like high-pressure processing, pulsed electric field, and ultrasound, along with natural antioxidants. This all-encompassing strategy, which blends cutting-edge technologies with natural substances, has the potential to transform the meat business and bring it into compliance with consumer health preferences and sustainability objectives.

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