REVIEW

# IMPROVING MEAT QUALITY THROUGH NATURAL ANTIOXIDANTS

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## ABSTRACT

Nowadays, consumers are demanding more natural foods, obliging the industry to include natural antioxidants in foods. Natural antioxidants have been used instead of synthetic antioxidants to retard lipid oxidation in foods to improve their quality and nutritional value. This review discusses some aspects of recent research on antioxidant activity of plant extracts and natural compounds to improve meat quality. Many herbs, spices, and their extracts have been reported as having high antioxidant capacity, such as some plants of the Lamiaceae family, e.g., oregano (*Origanum vulgare* L.), rosemary (*Rosmarinus officinalis* L.), and sage (*Salvia officinalis* L.). The antioxidant activity of these plants is attributed to their phenolic compound content, which includes volatile compounds also known as essential oils. Several factors that cause some differences on the antioxidant activity of plant extracts include: type of solvent used during extraction, measurement method, and number of samples. Some studies have demonstrated that shelf-life and meat quality can be improved by using natural antioxidants in some stages of meat production. The main effects of these compounds are reducing microbial growth and lipid oxidation during storage. Nevertheless, more research is needed to determine antimicrobial activity of natural antioxidants in meat during storage, identify the main metabolic pathway of these compounds, and its effect on other meat quality parameters.


**Key words:** antioxidant activity, essential oils, phenolic compounds, meat quality.

The increasing preference for natural foods has obliged the food industry to include natural antioxidants in various products to delay oxidative degradation of lipids, improve quality and nutritional value of foods, and replace synthetic antioxidants (Fasseas *et al*., 2007; Wojdylo *et al*., 2007; Camo *et al*., 2008). Including antioxidants in the diet has beneficial effects on human health because they protect the biologically important cellular components, such as DNA, proteins, and membrane lipids, from reactive oxygen species (ROS) attacks (Su *et al*., 2007). Synthetic antioxidants have been used to retard or minimize oxidative deterioration of foods, such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and tertiary butyl hydroquinone (TBHQ) (Fasseas *et al*., 2007). Recently, consumers have rejected synthetic antioxidants because of their carcinogenicity (Altmann *et al*., 1986; Van Esch, 1986). The advantages of natural antioxidants in foods are high consumer acceptance and their safe use. The disadvantages are their higher cost and lower effectiveness (Fasseas *et al*., 2007).

Many herbs, spices, and their extracts have been added in a variety of foods to improve their sensory characteristics and extend shelf-life (Shahidi *et al*., 1992). Herbs of the Lamiaceae family, mainly oregano (*Origanum vulgare* L.), rosemary (*Rosmarinus officinalis* L.), and sage (*Salvia officinalis* L.), have been reported as having significant antioxidant capacity (Shan *et al*., 2005; Wojdylo *et al*., 2007).

The short shelf-life of refrigerated packed meat makes its commercialization more difficult. Some studies have demonstrated that meat shelf-life and quality can be improved by natural antioxidants added in the pre-slaughter and post-slaughter stages. That is, incorporating natural antioxidants in animal diets, onto the meat surface, or active packaging.

Some authors have reported the effectiveness of rosemary and oregano extracts to reduce lipid oxidation (Djenane *et al*., 2002; 2003; Fasseas *et al*., 2007; Camo *et al*., 2008), color loss, and microbial growth (Djenane *et al*., 2002; 2003; Camo *et al*., 2008; Zinoviadou *et al*., 2009) in some types of meats.

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The aim of this review was to discuss some aspects of recent research on antioxidant activity of plant extracts and natural compounds and their use to improve meat quality.

## DISCUSSION

### Definition and chemistry of natural antioxidants

Natural antioxidants are various substances with different chemical characteristics, which are widely present in plants. Antioxidants retard or inhibit oxidation of other substances by inhibiting the initiation or propagation of oxidizing chain reactions (Velioglu *et al*., 1998). Consequently, natural antioxidants can protect the biologically important cellular components from oxidative processes caused by reactive oxygen species (ROS) (Su *et al*., 2007).

The total antioxidant capacity of fruit and vegetable extracts reflects concentrations of ascorbic acid (vitamin C), alpha-tocopherol (vitamin E), beta-carotene (vitamin A precursor), various flavonoids, and other phenolic compounds (Pennington and Fisher, 2009).

Some authors have demonstrated the high antioxidant activity of α-tocopherol, ascorbic acid, and their high radical scavenging abilities (Kulisic *et al*., 2004). Furthermore, some synergistic effects among ascorbic acid, α-tocopherol, and β-carotene have been reported against oxidation (Yeum *et al*., 2009). In addition, phenolic compounds have a high antioxidant activity through three mechanisms: free-radical scavenging activity (Zheng *et al*., 2009), transition-metal-chelating activity (Andjelković *et al*., 2006), and/or singlet-oxygen-quenching capacity (Mukai *et al*., 2005).

The antioxidant capacity of vitamins and phenolic compounds measured by different methods indicates that some natural antioxidants have a high antioxidant activity, such as gallic acid, cyanidin, quercetin, catechin, thymol, and carvacrol (Table 1). Measurements are generally based on Trolox equivalents, which are a water-soluble derivative of vitamin E used as a standard.

Table 2 shows the main phenolic compounds identified in plant extracts, such as phenolic acids (e.g., *p*-coumaric acid, caffeic acid, rosmarinic acid, and gallic acid), phenolic diterpenes (e.g., carnosic acid and epirosmanol), flavonoids (e.g., catechin and kaempferol), and volatile oils (e.g., aromatic compounds) (Shan *et al*., 2005).

**Table 1. Antioxidant capacity of vitamins and phenolic compounds.**

| | Antioxidant capacity (μmol TE mmol$^{-1}$) | | |
|---|---|---|---|
| **Compound** | **TEAC** | **DPPH** | **ORAC** |
| Vitamins | | | |
| Ascorbic acid | 1000[3] | $8.6 \times 10^{-3}$*[1] | 500-1000[3] |
| | | 500[3] $4.4 \times 10^{-3}$*[1] | |
| | | $3.8 \times 10^{-3}$*[2] $2.13 \times 10^{-3}$*[4] | |
| Flavonols | | | |
| Kaempferol | 500-1000[3] | 1000[3] | 6000[3] |
| Quercetin | 2000[3] | 1000[3] | 4000[3] |
| Anthocyanins | | | |
| Cyanidin | 2000[3] | 500-1000[3] | 4500[3] |
| Flavanons | | | |
| Naringenin | 0[3] | 0[3] | 5500[3] |
| Flavan-3-ols | | | |
| Catechin | 1500[3] | 2000[3] | 7500-8000[3] |
| Phenolic acids | | | |
| Chlorogenic acid | 1500[3] | 1000[3] | 5000[3] |
| Gallic acid | 2500[3] | 1000[3] $0.8 \times 10^{-3}$*[4] | 1000[3] |
| Volatile compound | | | |
| Thymol | | 0.5*[1] 0.16*[2] | |
| Carvacrol | | 0.4*[1] 0.25*[2] | |

TE: Trolox equivalents. TEAC: Trolox equivalent antioxidant capacity. DPPH: Scavenging of radical 2,2-diphenyl-1-picryhydrazyl. ORAC: Oxygen radical absorbance capacity.
*Concentration (g L$^{-1}$) for 50% inhibition.
[1]Kulisic *et al*. (2004); [2]Tepe *et al*. (2005b); [3]Tabart *et al*. (2009); [4]Zheng *et al*. (2009).

**Table 2. Representative components of phenolic compounds of some plant extracts.**

| Family and scientific name | Major types of phenolic compounds |
|---|---|
| Lamiaceae | |
| *Salvia officinalis* L. Common name: Sage | Phenolic acids: rosmarinic acid (Zheng and Wang, 2001; Shan *et al*., 2005), caffeic acid, neochlorogenic acid, *p*-coumaric acid, ferulic acid (Wojdylo *et al*., 2007). Phenolic diterpenes: carnosic acid. Volatile comp. (Shan *et al*., 2005). Flavonoids: quercetin, apigenin (Wojdylo *et al*., 2007), luteolin (Zheng and Wang, 2001; Wojdylo *et al*., 2007). |
| *Origanum vulgare* L. Common name: Oregano | Phenolic acids: caffeic acid (Shan *et al*., 2005; Wojdylo *et al*., 2007), neochlorogenic acid (Wojdylo *et al*., 2007), *p*-coumaric acid, rosmarinic acid, caffeoyl derivatives (Shan *et al*., 2005). Volatile comp.: carvacrol (Kulisic *et al*., 2004; Shan *et al*., 2005), thymol, γ.terpinene, *p*-cymene (Kulisic *et al*., 2004). Flavonoids (Shan *et al*., 2005). |
| *Rosmarinus officinalis* L. Common name: Rosemary | Phenolic acids: caffeic acid (Shan *et al*., 2005; Wojdylo *et al*., 2007), ferulic acid (Wojdylo *et al*., 2007), rosmarinic acid (Zheng and Wang, 2001; Shan *et al*., 2005), caffeoyl derivatives (Shan *et al*., 2005). Phenolic diterpenes: carnosic acid (Zheng and Wang, 2001; Shan *et al*., 2005), carnosol, epirosmanol. Volatile comp.: carvacrol (Shan *et al*, 2005). Flavonoids: luteolin, apigenin (Wojdylo *et al*., 2007). |
| *Thymus vulgaris* L. Common name: Thyme | Phenolic acids: caffeic acid (Shan *et al*, 2005; Wojdylo *et al*., 2007), ferulic acid (Wojdylo *et al*., 2007), gallic acid (Shan *et al*., 2005), rosmarinic acid (Zheng and Wang, 2001; Shan *et al*., 2005). Volatile comp.: thymol. Phenolic diterpenes (Shan *et al*., 2005). Flavonoids: luteolin (Zheng and Wang, 2001). |
| Lauraceae | |
| *Cinnamomum zeylanicum* Blume. Common name: Cinnamon | Phenolic acids: *p*-coumaric acid (Wojdylo *et al*., 2007). Volatile oils: 2-hydroxycinnamaldehyde, cinnamyl aldehyde derivatives. Flavan-3-ols (Shan *et al*., 2005). |
| Myristicaceae | |
| *Myristica fragrans* Houtt. Common name: Nutmeg | Phenolic acids: ferulic acid (Wojdylo *et al*., 2007). |
| Myrtaceae | |
| *Syzygium aromaticum* (L.) Merr. & L.M. Perry. Common name: Clove | Phenolic acids: gallic acid. Flavonol glucosides. Volatile oils: eugenol, acetyl eugenol. Tannins (Shan *et al*., 2005). Flavonoids: quercetin (Wojdylo *et al*., 2007). |
| Piperaceae | |
| *Piper nigrum* L. Common name: Black pepper | Volatile oils. Phenolic amides (Shan *et al*, 2005). |

Phenolic volatile compounds, also known as essential oils, are the main active ingredients in most herbs, e.g., menthol (in mint *Mentha canadensis* L.), carvacrol (in oregano and rosemary), thymol (in thyme *Thymus vulgaris* L.), and eugenol (in clove *Syzygium aromaticum* (L.) Merr. & L.M. Perry)(Shan *et al*., 2005). The main components of essential oils are terpenoids, specifically monoterpenes (C10) and sesquiterpenes (C15), as well as a variety of low molecular weight compounds (Dorman and Deans, 2000; Flamini *et al*., 2007). Bampidis *et al*. (2005) reported that the major oregano essential oil compounds were carvacrol, thymol, γ-terpinene, and *p*-cymene. On the other hand, Kulisic *et al*. (2004) obtained 35% thymol and 32% carvacrol, which were the main oregano essential oil constituents.

Some authors have demonstrated antioxidant and antimicrobial activities of essential oils (Helander *et al*., 1998; Cosentino *et al*., 1999; Burt, 2004; Tepe *et al*., 2005a; 2005b; Hussain *et al*., 2008). Essential oil antibacterial properties are attributed to their phenolic compounds (Cosentino *et al*., 1999; Rota *et al*., 2008). The presence of hydroxyl groups and their relative position in the phenolic ring enable antimicrobial activity and can explain the high antimicrobial activity of carvacrol compared to other plant phenolic compounds (Dorman and Deans, 2000; Zinoviadou *et al*., 2009). Dormans and Deans (2000) indicate that essential oil antibacterial properties are associated with their lipophilic character and functional group. Thus, essential oils interact with processes associated with the phospholipid bilayer, including electron transport, ion gradients, protein translocation, phosphorylation, and other enzyme-dependent reactions (Dorman and Deans, 2000; Burt, 2004), resulting in an increase of bacterial cell membrane permeability (Lambert *et al*., 2001). Burt (2004) suggested that Gram (-) bacteria are more resistant to essential oil compound antibacterial properties than Gram (+) bacteria because they have an external lipopolysaccharide wall surrounding the peptidoglycan cell wall, which limits access of these compounds. However, essential oil hydrophobic compounds are able to achieve periplasm of Gram (-) bacteria through proteins located in the outer membrane (Helander *et al*., 1998; Lambert *et al*., 2001). Rota *et al*. (2008) suggested a synergistic action among phenolic compounds and some terpenic hydrocarbons, alcohols, ketones, and thymol oxygenated derivatives, as well as synergism between carvacrol and its precursor *p*-cymene. On the other hand, Cosentino *et al*. (1999) noted an antagonist effect of high *p*-cymene content on antimicrobial phenol action.

Many herbs, spices, and their extracts are known to possess antioxidant effects (Zheng and Wang, 2001; Shan *et al*., 2005), especially clove (Myrtaceae), cinnamon (*Cinnamomum zeylanicum* Blume in Lauraceae), and oregano (Lamiaceae) (Shan *et al*., 2005). Some authors have attributed the antioxidant activity of these plants to their phenolic compound content, resulting in a positive linear correlation between them (Velioglu *et al*., 1998; Kähkönen *et al*., 1999; Zheng and Wang, 2001; Shan *et al*., 2005). Antioxidant activity, measured by three different methods, and total phenolic content of some plant extracts are shown in Table 3. Species with a strong antioxidant capacity have high phenolic content. One example is clove that had the highest antioxidant capacity as measured by three methods and was related to the highest phenolic content. Zheng and Wang (2001) found the strongest antioxidant activity in Mexican oregano (92.18 $\mu$mol of Trolox equivalents (TE) $g^{-1}$ fresh weight) and the highest phenolic content (17.51 mg gallic acid equivalents (GAE) $g^{-1}$ fresh weight). However, some studies did not obtain the same relationship between antioxidant capacity and total phenolic content in some species (Kähkönen *et al*., 1999; Wojdylo *et al*., 2007). For example, high antioxidant activity of apple (*Malus domestica* Borkh.) extracts with low total phenolic content may be due to the presence of other compounds that might interfere with the determination methods (Kähkönen *et al*., 1999). In addition to phenolic compounds, some species have shown a positive relationship between antioxidant activity and vitamin C, vitamin E, and beta-carotene content. Polyphenols and vitamin C are the major contributors of the high antioxidant activity of kiwifruits (*Actinidia* sp.) (Du *et al*., 2009). The same was detected in Brassica vegetables with carotenoids and Vitamin E responsible for up to 20% of total antioxidant activity (Podsędek, 2007).

Differences found in some research indicate that other factors can affect the antioxidant activity of some plants (Velioglu *et al*., 1998), which can be related to number of samples, small differences between the highest and lowest values, method used to extract antioxidant compounds, and method used to measure antioxidant capacity (Kähkönen *et al*., 1999; Kulisic *et al*., 2004; Shan *et al*., 2005; Fasseas *et al*., 2007; Su *et al*., 2007; Wojdylo *et al*., 2007; Karadag *et al*., 2009; Tabart *et al*., 2009).

**Some experiences in meat quality**

Meat quality can be improved by incorporating natural antioxidants to animal diets, adding these compounds onto the meat surface, or using active packaging. Among the positive effects of natural antioxidants on meat characteristics are retarding lipid oxidation (Djenane *et al*., 2002; 2003; Fasseas *et al*., 2007; Camo *et al*., 2008), color loss, and microbial growth (Djenane *et al*., 2002; 2003; Camo *et al*., 2008; Zinoviadou *et al*., 2009).

**Table 3. Antioxidant capacity and total phenolic compound content of some methanolic plant extracts and their effects on meat quality during 7-d refrigeration.**

| Family, scientific name and common name | Antioxidant capacity | | | Total phenolic content | Meat characteristics | | |
|---|---|---|---|---|---|---|---|
| | ABTS | DPPH | FRAP | | Lipid oxidation | Color | Antimicrobial activity |
| | | μM TE 100 $g^{-1}$ DW | | mg GAE 100 $g^{-1}$ DW | TBA value and mg MDA $kg^{-1}$ | CIE a* values and % MMG | log CFU $cm^{-2}$ |
| Lamiaceae | | | | | | | |
| *Salvia officinalis* L.<br>Common name: Sage | 17.0 ± 0.23[12] | 41.2 ± 1.11[12] | 167 ± 1.01[12] | 8.25 ± 0.09[12]<br>1.34 ± 0.09**[3] | TBA < 0.3[10] < 0.5[4]<br>MDA < 0.21[1] | | |
| *Origanum vulgare* L.<br>Common name: Oregano | 19.9 ± 1.00[12] | 79.6 ± 2.04[12] | 405 ± 2.22[12] | 0.15 ± 0.01[12]<br>11.80 ± 0.60**[3] | MDA < 0.06[14]<br>MDA < 0.4[5, 9]<br>MDA < 1[13] 2.04[7]<br>TBA < 0.2[10] < 0.8[4] | a* > 12[13]<br>MMG < 30[13] | < 3+[13] < 6[15]<br>< 6.9[2, 9] |
| *Rosmarinus officinalis* L.<br>Common name: Rosemary | 38.7 ± 0.11[12] | 513 ± 5.99[12] | 662 ± 4.66[12] | 1.71 ± 0.02[12]<br>2.19 ± 0.15**[3] | MDA < 0.19[1]<br>MDA < 0.5[6] < 0.6[8]<br>MDA < 1[13]<br>TBA < 0.6[4] | a* > 11[13]<br>a* > 17[8] > 20[6]<br>MMG < 20[6, 8, 13] | < 3+[13]<br>< 4[6] |
| *Thymus vulgaris* L.<br>Common name: Thyme | 35.4 ± 0.12[12] | 295 ± 5.83[12] | 693 ± 5.87[12] | 0.58 ± 0.02[12]<br>2.13 ± 0.11**[3] | TBA < 0.7[4] | | |
| Lauraceae | | | | | | | |
| *Cinnamomum zeylanicum* Blume<br>Common name: Cinnamon | 140 ± 3.01[12]<br>1064 ± 12.73*[11] | 253 ± 3.56[12] | 233 ± 2.10[12] | 0.13 ± 0.01[12]<br>14.82 ± 0.28**[11] | TBA < 0.8[4] | | |
| Myristicaceae | | | | | | | |
| *Myristica fragrans* Houtt.<br>Common name: Nutmeg | 33.3 ± 3.04[12]<br>191 ± 0.00*[11] | 182 ± 1.11[12] | 218 ± 3.21[12] | 8.95 ± 0.45[12]<br>2.68 ± 0.12**[11] | TBA < 0.5[4] | | |
| Myrtaceae | | | | | | | |
| *Syzygium aromaticum* (L.) Merr. & L.M. Perry<br>Common name: Clove | 346 ± 5.34[12] | 884 ± 9.04[12] | 2133 ± 6.87[12] | 8.96 ± 0.34[12] | TBA < 0.5[4] | | |
| Piperaceae | | | | | | | |
| *Piper nigrum* L.<br>Common name: Black pepper | 23.3 ± 1.44*[11] | | | 0.91 ± 0.01**[11] | TBA < 1.0[4] | | |

TE: Trolox equivalents; DW: dry weight; ABTS: scavenging of radical 2,2'-azino-bis(3-ethylbenzothiazoline)-6-sulfonic acid; DPPH: scavenging of radical 2,2-diphenyl-1-picryhydrazyl; FRAP: ferric reducing antioxidant power; GAE: gallic acid equivalents; TBA: 2-thiobarbituric acid; MDA: malondialdehyde; MMG: metmyoglobin; CFU: colony-forming unit.
*μM $g^{-1}$ of fresh weight; **mg $g^{-1}$ of fresh weight; + psychrotrophic aerobic counts.
[1]Animal diet. Lopez-Bote *et al*. (1998). [2]Meat. Skandamis and Nychas (2001). [3]Zheng and Wang (2001). [4]Meat. Tanabe *et al*. (2002). [5]Animal diet. Botsoglou *et al*. (2003b). [6]Meat. Djenane *et al*. (2003). [7]Active packaging. Oussalah *et al*. (2004). [8]Active packaging. Nerín *et al*. (2006). [9]Meat. Chouliara *et al*. (2007). [10]Meat. Fasseas *et al*. (2007). [11]Su *et al*. (2007). [12]Wojdylo *et al*. (2007). [13]Meat and active packaging. Camo *et al*. (2008). [14]Animal diet. Simitzis *et al*. (2008). [15]Active packaging. Zinoviadou *et al*. (2009).

Some authors have reported that natural antioxidants have no effect on sensory characteristics of meat. Chaves *et al*. (2008) did not detect any effect of essential oil compounds (carvacrol and cinnamaldehyde), added to the diet of growing lambs, on the sensory characteristics of sirloins. The same was observed in pork where different essential oils were included in the diet of pigs (Janz *et al*., 2007). The only evidence of the effect of natural antioxidants on inhibiting off-odor formation and discoloration of meat is active packaging (Djenane *et al*., 2003; Nerín *et al*., 2006; Camo *et al*., 2008).

Some plant extracts have had a positive effect on lipid oxidation by reducing 2-thiobarbituric acid (TBA) or malondialdehyde (MDA) formation on different types of meats during refrigeration storage (Table 3). Tanabe *et al*. (2002) reported that adding methanolic extracts of 22 selected herbs and spices decrease lipid oxidation in pork with sansho (*Zanthoxylum piperitum* L.) extracts, sage, and ginger (*Zingiber officinale* Rosc.) having the greatest effect. Oregano and sage essential oils added to beef and pork meat (Fasseas *et al*., 2007), and a rosemary and vitamin C solution sprayed onto the surface (Djenane *et al*., 2003) reduce oxidation during refrigeration. In addition, dietary incorporation of oregano, rosemary, and sage essential oils can retard lipid oxidation (MDA formation) in meat during refrigerated and frozen storage (Lopez-Bote *et al*., 1998; Botsoglou *et al*., 2002; 2003a; 2003b; Simitzis *et al*., 2008). Botsoglou *et al*. (2003a) reported that α-tocopheryl acetate supplementation was more effective than dietary incorporation of oregano essential oil to extend lipid stability of chicken meat in frozen storage. Moreover, there is a synergistic effect between dietary essential oil and α-tocopheryl acetate supplementation in retarding lipid oxidation in raw and cooked turkey during refrigeration (Botsoglou *et al*., 2003b). Lopez-Bote *et al*. (1998) observed an additional effect on meat cooked at 70 °C, which came from broilers fed on diets containing rosemary and sage extracts, during refrigerated storage for up to 4 d. The strongest effect of dietary oregano essential oil supplementation to reduce lipid oxidation has been found at levels of 100 mg $kg^{-1}$ feed in chicken meat (Botsoglou *et al*., 2002; Botsoglou *et al*., 2003a) and 200 mg $kg^{-1}$ feed in turkey meat (Botsoglou *et al*., 2003b). Janz *et al*. (2007) only noted a reduction of lipid oxidation in oregano essential oil fed to pigs when compared with other essential oil dietary inclusion treatments (rosemary, garlic *Allium sativum* L., or ginger). Lower MDA formation in dietary oregano essential oil treatments are probably the result of the presence of oregano antioxidant compounds, which might be absorbed into the circulatory system after ingestion, distributed, and retained in muscle and other tissues (Botsoglou *et al*., 2003b; Simitzis *et al*., 2008). Other plant extracts such as grape (*Vitis vinifera* L.) seed and bearberry (*Arctostaphylos uva-ursi* L.) applied onto the meat surface have been effective in decreasing lipid oxidation in raw and cooked pork patties (Carpenter *et al*., 2007). The same was obtained by adding tea catechins to beef patties, but with no effect on chicken meat patties (Mitsumoto *et al*., 2005).

Some studies have used vitamin E (α-tocopherol) in both direct application onto meat and animal diet supplementation to extend lipid stability of fresh beef during storage (Arnold *et al*., 1993; Eikelenboom *et al*., 2000; O'Grady *et al*., 2000). Mitsumoto *et al*. (1993) reported that the *post-mortem* addition of vitamin E in beef was less effective in retarding lipid oxidation than dietary supplementation. Djenane *et al*. (2002) concluded that surface application of vitamin C, taurine, rosemary, vitamin E, and combinations of the last three with vitamin C have a positive effect on oxidative stability of beef steaks packaged in a modified atmosphere.

Meat color has been reported as the most important factor when consumers assess meat quality since they relate color to freshness. However, color does not correspond to differences in eating satisfaction (Carpenter *et al*., 2001). Changes in meat color are due to oxidation of red oxymyoglobin to metmyoglobin (MMG), which give meat an unattractive brown color (Nerín *et al*., 2006). Some reports demonstrate that natural antioxidants can retard meat color loss by extending the red color (a*) and delaying MMG formation (Table 3). One example of dietary natural antioxidants affecting meat color is the higher color parameters (a* and yellowness b*) of meat from lambs fed with oregano essential oil supplementation (1 mL oregano essential oil $kg^{-1}$) (Simitzis *et al*., 2008). Another example is the reduction of MMG formation and intense red color obtained in fresh beef steaks whose surface was sprayed with a rosemary and ascorbic acid solution during refrigeration (Djenane *et al*., 2003). Carpenter *et al*. (2007) noted that the color parameters (lightness L*, b*, and a*) of raw pork patties did not vary by adding grape seed and bearberry extracts. The same results were obtained for fresh chicken breast meat (Chouliara *et al*., 2007).

Some authors have demonstrated the antioxidant effect of some vitamins to delay color loss in meat during storage. One of these vitamins, vitamin E (α-tocopherol), has been used to improve myoglobin stability of fresh beef during storage by supplementing animal diets with at least 1300 IU $d^{-1}$ (Arnold *et al*., 1993) or 2025 mg of vitamin E per day (Eikelenboom *et al*., 2000). A vitamin C solution of sodium ascorbate (5% of cut weight containing at least 4% of sodium ascorbate) injected in beef was also effective in improving color stability and extending the meat's retail display life (Wheeler *et al*., 1996).

Some authors reported that plant extracts with antimicrobial properties can be used to increase refrigerated meat shelf-life (Skandamis *et al*., 2002; Djenane *et al*., 2003; Chouliara *et al*., 2007). Table 3 shows some values of colony-forming units obtained with some plant extracts applied onto the meat surface. Eugenol, clove, oregano, and thyme extracts applied on meat were reported to be effective against *L. monocytogenes*, *A. hydrophila*, and autochthonous spoilage flora at higher concentrations than those required by *in vitro* assays (Hao *et al*., 1998a; 1998b; Skandamis and Nychas, 2001). Antibacterial activity of natural antioxidants has been determined through *in vitro* assays against *Escherichia coli* 0157:H7, *Salmonella typhimurium* (Helander *et al*., 1998; Elgayyar *et al*., 2001), *Staphylococcus aureus*, and *Pseudomonas aeruginosa* (Elgayyar *et al*., 2001; Lambert *et al*., 2001).

The antimicrobial properties of essential oils extracted from plants used against a wide range of microorganisms (Dean and Ritchie, 1987; Sivropoulou *et al*., 1996; Chao *et al*., 2000) have been considered as an alternative to antibiotics in livestock. Therefore, essential oils are promising as feed additives to improve feed efficiency and control the spread of pathogens in livestock (Benchaar *et al*., 2008).

Nowadays, active packaging has been intensely developed due to recent contamination outbreaks associated with meat products (Coma, 2008). Table 3 shows some effects of natural antioxidants included in active films. The effectiveness of antimicrobial compounds might be higher when they are incorporated in an active film applied to the food surface than if directly applied to the food surface by spraying or dipping (Coma, 2008; Zinoviadou *et al*., 2009). Oregano-based films have been effective against bacterial growth in meat. For example, active films containing oregano essential oil can reduce the growth of total flora and pseudomonas, thus inhibiting the growth of lactic acid bacteria in beef (Zinoviadou *et al*., 2009). Moreover, oregano-based films were effective against *Salmonella typhimurium* and *E. coli* O157:H7 inoculated in beef muscle slices (Oussalah *et al*., 2006). Thus, beef shelf-life can be increased by 2 when employing active films containing 1.5% oregano oil (w/w) (Zinoviadou *et al*., 2009). Skandamis and Nychas (2001) informed that oregano essential oil compounds affected both growth and metabolic activity (glucose and lactate consumption) of meat microorganisms during storage. In addition, meat packed in active film containing natural antioxidants exhibits higher antioxidant activity than meat packed in films without antioxidants (Nerín *et al*., 2006; Camo *et al*., 2008). Oregano-based films stabilized lipid oxidation in beef muscle slices during 7 d when stored at 4 °C (Oussalah *et al*., 2004). There are few studies about the effect of active film containing natural antioxidants on meat color. Camo *et al*. (2008) reported a greater effect of oregano active film against color loss and MMG formation in lamb meat than rosemary active packaging. The latter was less effective than directly adding rosemary extract onto the meat surface. Values of a* were above 10 and MMG formation was around 40% after 13 d of refrigeration using oregano active films and directly adding rosemary extract onto the meat surface. Zinoviadou *et al*. (2009) reported smaller changes in total color difference ($\Delta E$) and saturation difference ($\Delta$chroma) in beef cuts wrapped in films with different levels of oregano oil (0.5%, 1.0%, and 1.5% w/w) during refrigeration and resulted in better color retention due to oxymyoglobin stabilization .

## CONCLUSIONS

Some plant extracts are an excellent source of natural antioxidants that can improve meat shelf-life and quality mainly by retarding lipid oxidation and microbial growth. The effect of oregano essential oil on meat quality has been studied the most, whereas there is less information about other plants.

Antimicrobial activity of spices and herbs has been extensively studied. However, most of the research was done in *in vitro* assays using microbiological media rather than actual foods. Further research is needed to determine their effect on bacterial growth in raw and cooked meats during storage. Active packaging containing natural antioxidants is a promising tool in this field.

There is some evidence that dietary essential oils can improve meat quality. Since bioavailability of essential oils in meat cannot be directly demonstrated, more research is needed to identify the main metabolic pathway of these compounds and the key essential oil antioxidant compounds deposited in meat.

Further research is needed to determine the effect of natural antioxidants on other meat quality characteristics.


## RESUMEN

**Mejoramiento de la calidad de carne utilizando antioxidantes naturales.** Actualmente los consumidores están demandando alimentos más naturales, lo cual ha causado el interés de la industria de incluir antioxidantes naturales en los alimentos para retardar la oxidación de los lípidos, mejorar su calidad y valor nutricional, reemplazando los antioxidantes sintéticos. En esta revisión se discuten algunos aspectos de las investigaciones más recientes acerca de la actividad antioxidante de extractos vegetales y compuestos naturales y su uso para mejorar la calidad de carne. Se ha encontrado que muchas plantas y sus extractos tienen actividad antioxidante, tales como orégano (*Origanum vulgare* L.), romero (*Rosmarinus*

*officinalis* L.) y salvia (*Salvia officinalis* L.). La actividad antioxidante de estas plantas se atribuye a su contenido de compuestos fenólicos, los cuales incluyen compuestos volátiles llamados aceites esenciales. Algunos factores podrían causar diferencias en la actividad antioxidante de extractos de plantas, tales como: tipo de solvente utilizado en la extracción, método utilizado en las mediciones, número de muestras, entre otros. Algunos estudios han demostrado que la vida útil y la calidad de carne pueden mejorarse a través del uso de antioxidantes naturales en algunas etapas de la producción de carne. Los principales efectos de estos compuestos son la reducción del crecimiento microbiano y oxidación de lípidos durante el almacenamiento. Sin embargo, se necesita mayor investigación para determinar la actividad antimicrobiana de los antioxidantes naturales en la carne durante el almacenamiento e identificar la principal vía metabólica de estos compuestos y su efecto sobre otras características de calidad de carne.

**Palabras clave:** actividad antioxidante, aceites esenciales, compuestos fenólicos, calidad de carne.

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