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# Plant extracts as natural antioxidants in meat and meat products

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**Abstract**

Antioxidants are used to minimize the oxidative changes in meat and meat products. Oxidative changes may have negative effects on the quality of meat and meat products, causing changes in their sensory and nutritional properties. Although synthetic antioxidants have already been used but in recent years, the demand for natural antioxidants has been increased mainly because of adverse effects of synthetic antioxidants. Thus most of the recent investigations have been directed towards the identification of natural antioxidants from various plant sources. These natural antioxidants have been extracted from various plant materials by using different solvents and extraction methods. Plant extracts prepared from plant materials are rich in phenolics and provide a good alternative to synthetic antioxidants. Grape seed, green tea, pine bark, rosemary, pomegranate, nettle and cinnamon have exhibited similar or better antioxidant properties compared to some synthetic ones. This review provides the recent information on plant extracts used as natural antioxidants in meat and meat products, specifically red meat.

***Keywords***: Plant extracts; meat; lipid oxidation; natural antioxidants; patties.

**Introduction**

Meat is the muscle tissue of slaughter animals composed of water, proteins, lipids, minerals and a small proportion of carbohydrates. Meat and meat products are susceptible to quality deterioration due to their rich nutritional composition (Devatkal et al., 2012). The quality deterioration is due to chemical and microbial changes. The most common form of chemical deterioration is the oxidation of meat lipids. Lipid oxidation is a complex process and depends on chemical composition of meat, light and oxygen access and storage temperature (Kanner, 1994). It is also affected by some technological procedures to which meat is subjected during processing. It leads to the formation of several other compounds which have negative effects on the quality of meat and meat products causing changes in sensory (color, texture and flavor) and nutritional quality (Karakaya et al., 2011). Lipid oxidation can be reduced or inhibited by the use of antioxidants in meat and meat products and thus the product quality and shelf-life can be improved.

Antioxidants can prevent lipid peroxidation using the following mechanisms: preventing chain inhibition by scavenging initiating radicals, breaking chain reaction, decomposing peroxides, decreasing localized oxygen concentrations and binding chain initiating catalysts, such as metal ions (Dorman et al., 2003). There are a huge number of compounds that have been proposed to possess antioxidant activity, but only a few can be used in food products. The use of antioxidants in food products is controlled by regulatory laws of a country or international standards (Karre et al., 2013).

The antioxidants can be of synthetic or natural origin. Synthetic antioxidants such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), tert-butylhydroquinone (TBHQ), and propyl gallate (PG) have been widely used in meat and poultry products (Biswas et

al., 2004; Formanek et al., 2001; Jayathilakan et al., 2007). But the demand for natural antioxidants, especially of plant origin has increased in the recent years due to the growing concern among consumers about these synthetic antioxidants because of their potential toxicological effects (Juntachote et al., 2006; Naveena et al., 2008; Nunez de Gonzalez et al., 2008).

Plants are persistently the generous source to supply man with valuable bioactive substances (Tayel & El-Tras, 2012) and thus different plant products are being evaluated as natural antioxidants to preserve and improve the overall quality of meat and meat products. These natural antioxidants from plants, in the form of extracts, have been obtained from different sources such as fruits (grapes, pomegranate, date, kinnow), vegetables, (broccoli, potato, drumstick, pumpkin, curry, nettle), herbs and spices (tea, rosemary, oregano, cinnamon, sage, thyme, mint, ginger, clove) and investigated to decrease the lipid oxidation (Mansour & Khalil, 2000; Mc Carthy et al., 2001a, b; Kanatt et al., 2007; Akarpat et al., 2008; Shan et al., 2009; Devatkal et al., 2010; Huang et al., 2011; Wojciak, et al., 2011; Das et al., 2012; Nissen et al., 2004; Rojas & Brewer, 2007, 2008). These plant extracts are prepared from the plant materials by using different solvents and extraction methods. These extracts are rich in phenolics and provide a good alternative to synthetic antioxidants. The antioxidant properties of plant extract can be determined by diphenyl-1-picrylhydrazyl (DPPH), superoxide anion scavenging assay, phosphomolybdate assay (total antioxidant capacity), hydrogen radical scavenging assay, hydrogen peroxide scavenging activity, 2,2-azinobis-3-ethylbenzthiazoline-6-sulphonic acid (ABTS) radical scavenging activity and reducing power (Saeed et al., 2012). The antioxidant activity of a plant extract is affected by the extraction method and the solvent used, since the

extraction procedure strongly influence the composition of the extract (Schwarz et al., 2001; Trojakova et al., 2001; Brewer, 2011).

Much of the work has been already done on plant products as natural antioxidants in meat and meat products. The objective of this paper is to review the latest literature on plant extracts used as natural antioxidants in meat and meat products, specifically red meat, with emphasis on sources, extraction and applications of plant extracts.

**Sources**

The natural antioxidants that have been studied in meat include a huge number of plant sources (Table 1). These antioxidants have been extracted from different plant parts like leaves, roots, stems, fruits, seeds and bark. Some of these natural antioxidants are also available commercially and several studies have been carried out by different authors applying commercially available natural antioxidants of plant origin to meat (Table 2).

Mansour and Khalil (2000) used potato peel, fenugreek seeds and ginger rhizomes extracts in ground beef patties. Mc Carthy et al. (2001a) applied the extracts of aloe vera, fenugreek, ginseng, mustard, rosemary, sage, tea catechins in pork patties. Rosemary (*Rosmarinus officinalis*) and hyssop (*Hyssopus officinalis*) extracts obtained from leaves and secondary branches, were used in pork meat (Frenandez-Lopez et al., 2003). White peony (*Paeeonia lactiflora*), red peony (*P. lactiflora*), mountan peony (*P. moutan*), sappan wood (*Caesalpinia sappan*), rehmania (*Rehmania glutinosa*), angelica, Korean (*Angelica gigas*), rosemary (*Rosemarinus oficinalis*) extracts were used in ground goat meat (Han & Rhee, 2005). Mint (*Mentha spicata* L.) leaf extract was evaluated by Kanatt et al. (2007) in lamb meat. Myrtle (*Myrtus communis myrtillus* L.), rosemary (*Rosmarinus officinalis* L.), nettle (*Urtica dioica*) and

lemon balm (*Melissa officinalis* L.) leaves extract was investigated in beef patties (Akarpat et al., 2008). Karabacak and Bozkurt (2008) applied extracts of *Urtica diocia* and *Hibiscus sabdariffa* L. (Roselle) flowers to sucuk (Turkish dry-fermented sausage). Extract from the bulbs of *Eleutherine americana* were applied to cooked pork meat (Ifesan et al., 2009). Shan et al. (2009) used cinnamon stick (*Cinnamomum burmannii*) cortex, oregano (*Origanum vulgare* L.) leaf, clove (*Eugenia caryophylata* Thunb.) bud, pomegranate (*Punica granatum* L.) peel and grape (*Vitis vinifera* L.) seed extracts in pork meat. *U. dioica* L. leaf extract was investigated in ground beef (Alp & Aksu, 2010). Kinnow (*Citrus reticulate*) peel, pomegranate (*Punica granatum*) peel and seed extracts were applied to goat meat patties (Devatkal et al., 2010). Peanut skin extract was used by Yu, Ahmedna and Goktepe (2010) in ground beef. Garrido et al. (2011) applied red grape (*Vitis vinifera* var. Monastrell, Murcia, Spain) pomace to pork burgers. Rhizome knots and dried leaf of *Nelumbo nucifera* extracts were applied to porcine and bovine meat (Huang et al., 2011). Green tea leaves were used in goat meat (Rababah et al., 2011). Black seed (*Nigella sativa*), cinnamon (*Cinnamomum verum*) bark, garlic (*Allium sativum* L.) aerial parts, lemon grass (*Cymbopogon citrates*) leaves, licorice (*Glycyrrhiza glabra*) root and pomegranate (*Punica granatum* L.) peel extract were used in ground beef (Tayel & El-Tras, 2012). Green tea leaves, rosemary and sweet red pepper extracts were applied to ground pork meat (Wojciak et al., 2011). Summer savory (*Satureja hortensis* L.) leaf extract was used in ground beef (Aksu & Ozer, 2013). Date (*Phoenix dactylifera* L.) pit extract was used in ground beef (Amany et al., 2012). Broccoli (*Brassia oleracea* L.) powder extract was applied to goat meat nuggets (Banerjee et al., 2012) and ground beef and patties (Kim et al., 2013a; Kim et al., 2013b). Curry (*Murraya koenigii* L.) and mint (*Mentha spicata*) leaf extract was investigated in ground pork meat (Biswas et al., 2012). *Moringa oleiferia* leaf extract was used in goat meat patties (Das et al.,

2012) and pork patties (Muthukumar et al., 2012). Pomegranate (*Punica granatum*) peel extract was applied to ground goat meat and nuggets (Devatkal et al., 2012). Ginger (*Zingiber officinale* Rosc.), onion (*Allium cepa* L.) and garlic (*Allium sativum* L.) extracts were applied to stewed pork (Cao et al., 2013). Naveena et al. (2013) used carnosic acid extracted from rosemary (*Rosmarinus officinalis*) leaves in buffalo meat patties. Leaf extracts of butterbur (*Petasites japonicus* Maxim), chamnamul (*Pimpinella brachycarpa* (Kom.) Nakai), bok choy (*Brassica campestris* L. ssp. chinensis), Chinese chives/leek (*Allium tuberosum* Rottler ex Spreng), crown daisy (*Chrysanthemum coronarium* L.), fatsia (*Aralia elata* Seem), pumpkin (*Curcubita moschata* Duch.) (Kim et al., 2013a, b), sesame (*Perilla frutescens* var. japonica Hara), stonecrop (*Sedum sarmentosum* Bunge) (Kim et al., 2013a), acanthopanax (*Acanthopanax sessiliflorum* Seeman), soybean (*Glycine max* L. Merr) were applied to ground beef and patties (Kim et al., 2013a, b).

**Extraction**

The aim of the extraction process is to provide the maximum yield of substances with the highest quality in terms of concentration of target compounds and antioxidant power of the extracts. There are many techniques to recover antioxidants from plants, such as Soxhlet extraction, maceration, supercritical fluid extraction, subcritical water extraction, and ultrasound assisted extraction. Generally, the plant material is cleaned, dried, ground into fine powder followed by solvent extraction. Different solvents, either separately or in combination have been used for extraction process (Table 1). These solvent systems included absolute ethanol (Biswas et al., 2012; ), 90% ethanol (Mansour and Khalil, 2000), 80% (Shan et al., 2009; Yu et al., 2010), 70% ethanol (Tayel & El-Tras, 2012; Kim et al., 2013a, b), acetone (Naveena et al., 2013),

methanol (Garrido et al., 2011; Amany et al., 2012), dimethyl sulfoxide (Frenandez-Lopez et al., 2003), hexane (Naveena et al., 2013), and water (Akarpat et al., 2008; Karabacak and Bozkurt, 2008; Alp & Aksu, 2010; Devatkalet al., 2010; Cao et al., 2013; Banerjee et al., 2012; Kanatt et al., 2007; Huang et al., 2011; Das et al., 2012; Muthukumar et al., 2012).

Mansour and Khalil, (2000) prepared three different extracts from dried potato peel, fenugreek seeds and ginger rhizomes. These materials were ground separately, sieved through a 60 mesh screen and defatted using four volumes of petroleum ether. The dried residues, after removing petroleum ether, were extracted thrice with four volumes of 90% ethanol by shaking for 1 h followed by filtration. The filtrates from each material were concentrated in a rotavapor and then frozen overnight and freeze-dried at -60 °C. Cao et al. (2013) prepared extracts from ginger, onion and garlic by mixing about 100 g each of three chopped spices with 600 mL of distilled water and extracted for 30 min at 40 °C in enclosed flasks with ultrasonic extractor (200 W, 40 kHz). After filtration (Whatman No. 1 filter paper), the residue was re-extracted with an additional 400 mL of distilled water for additional 30 min, filtered and the all the filtrates were combined.

The dried herbs (white peony, red peony, mountan peony, sappan wood, rehmania, angelica (Korean), rosemary) were finely ground separately and then extracted thrice with 95% ethanol (herb:ethanol, 1:4). Every time the ground herbs were stirred with ethanol on a hot plate at ~40 °C for 3 hour and filtered. The combined filtrate was evaporated to dryness under vacuum (Han & Rhee, 2005). Rosemary and hyssop leaves extracts were prepared from dried powdered samples by using dimethyl sulfoxide (DMSO) (40 mg of dry weight/mL of DMSO) for 5 hour at room temperature with occasional stirring, then left overnight. The extract was obtained from mixture by filtration (Frenandez-Lopez et al., 2003).

Akarpat et al. (2008) prepared aqueous extracts from dried leaves of myrtle, rosemary, nettle and lemon balm by mixing a 20 g material with 400 mL deionized water using a Waring blender for 15 min. The extract was obtained by filtrated through filter paper (Whatman No. 1). Similarly, aqueous extracts of *Urtica dioica* and *Hibiscus sabdariffa* flowers were prepared from their dried and ground samples. 2 g of plant material was macerated in 100 ml distilled water at 60 °C for 1 hour and the extract was obtained by filtration through Whatman No. 41 filter paper (Karabacak & Bozkurt, 2008).

Rababah et al. (2011) prepared extracts from green tea leaves by mixing the powdered sample with water (1:10) and boiled for 10 min. After vacuum filtration, the filtrate was then frozen to -20 °C and freeze-dried (at <100 millitorr vacuum) to obtain the dry extract.

*Moringa oleiferia* leaf extracts were prepared from dry leaves (Das et al., 2012; Muthukumar et al., 2012). The dried leaves were powdered, sieved (No. 20) and extracted (100 g) successively with 600 mL of water in a Soxhlet extractor for 18-20 hour. The extract was concentrated to dryness under reduced pressure and controlled temperature (40-50 °C) (Das et al., 2012).

Shan et al. (2009) prepared different extracts from freeze-dried plant materials (cinnamon stick cortex, oregano leaf, clove bud, pomegranate peel and grape seed). Dried plant materials were further air dried in a ventilated oven at 40 °C for 24 hour and also ground to a fine powder and passed through a 24-mesh sieve. Each powdered sample (40 g) was extracted with 1000 mL of 80% ethanol at room temperature (~20 °C) for 24 hour in a shaking water bath. The extract was filtered through a Durapore 0.45 μm nylon membrane filter (Millipore, Cork, Ireland) under vacuum at 20 °C. The filtrate was concentrated in a rotavapor and then freeze-dried.

Garrido et al. (2011) prepared two different types of extracts from industrial red grape pomace using methanol as solvent: Grape pomace extract Type I (High-Low Instantaneous Pressure - HLIP + methanolic extraction - GPI) and Grape pomace extract Type II (methanolic extraction, GPII). Preceding to the alcoholic extraction procedure, in case of GPI, the pomace tissues was subjected to sudden pressures changes ($1 \times 10^5$ to $5 \times 10^3$ Pa ($N/m^2$) so as to increase their permeability to the extraction solvents by crating microchannels in the pomace tissues. The extracts were obtained by mixing about 10 g of each powdered sample (grape pomace with and without HLIP treatment) separately with 100 mL of methanol and stirring for 10 min at room temperature. After filteration, the retentate cake was washed with methanol and reextracted twice with the same solvent. Finally, the entire volume of the three extractions was mixed together in a flask and solvent was removed by rotavapor at 50 °C and 200 rpm in order to obtain a dry sample.

Date pits extracts with different solvents and their combinations were prepared. Date pits were milled in a heavy-duty grinder to pass 1-2 mm screens. About 0.02 gm powdered sample was shaked with 5 ml of solvent (4 solvents-water; methanol; methanol: water (50:50, v/v), methanol, water: methanol: acetone: formic acid (20:40:40:0.1)) in a glass tube at room temperature, two times for 30 min and centrifuged. Methanol: water (50:50, v/v), methanol, water: methanol: acetone: formic acid (20:40:40:0.1) were used as the best solvents. The extraction was carried out using four different solvents to compare the antioxidant activities and the total phenolic contents of each extract (Amany et al., 2012).

The presence of various antioxidant compounds with different chemical characteristics and polarities may or may not be soluble in a particular solvent (Turkmen et al., 2006). Polar solvents are frequently used for recovering polyphenols from plant matrices. The most suitable

solvents are aqueous mixtures containing ethanol, methanol, acetone, and ethyl acetate. Ethanol has been known as a good solvent for polyphenol extraction. Methanol has been generally found to be more efficient in extraction of lower molecular weight polyphenols, whereas aqueous acetone is good for extraction of higher molecular weight flavanols (Dai & Mumper, 2010). Pre-treatment of the sample, solvent–sample ratio, type of solvent, temperature and time of extraction are the main factors affecting the extraction process efficiency (Casazza et al., 2011). A number of studies have shown that extraction method can alter the antioxidant activity and total phenolic content (Sikora et al., 2008; Chan et al., 2007; Yeh et al., 2014). The extraction method must enable complete extraction of the compounds of interest and must avoid their chemical modification (Zuo, Chen, & Deng, 2002).

Khokhar and Magnusdottir (2002) found water to be the best solvent for extracting tea catechins compared with 80% methanol and 70% ethanol. According to Yu et al. (2005), the total antioxidant activities of water and ethanol extracts of peanut skin were 3.39 and 4.10 mM Trolox Equivalent/mM of total phenolics. Turkmen et al. (2006), reported that the antioxidant activity percentage (as measured by DPPH assay) for two different teas extracts was influenced by using different solvents such as water, acetone, N,N-dimethylformamide, ethanol or methanol at various concentrations. Fifty percent acetone from black tea and 50% ethanol extract from mate tea had the highest antioxidant activity. Also, the results showed that solvent with different polarity had significant effect on polyphenol content and antioxidant activity. For extracting flavonoids from tea, aqueous ethanol performed better than aqueous methanol and aqueous acetone (Wang & Helliwell, 2001). Extracts with the greatest antioxidant activity were obtained in mate tea and black tea by using 50% aqueous ethanol and 50% aqueous acetone, respectively (Turkmen et al., 2006).

According to Chan et al. (2007), methanol showed high extraction efficiency of leaves of *Etlingera* species. Methanol has been recommended for the extraction of phenolic compounds from fresh plant tissues due to its ability to inhibit polyphenol oxidase, which could alter antioxidant activity (Yao et al., 2004). Garrido et al. (2011) reported that the grape pomace extract prepared by using methanolic extracton in combination with high-low instantaneous pressure showed more total polyphenolic index (546.00) and antioxidant capacity (141.81 mmol/L Trolox) as compared to the extract prepared from methanolic extraction only. Cheng et al. (2012), prepared extracts from wine residue (seeds, skin and pomace) subjected to extraction process using three different solvents (50% aqueous acetone, 50% aqueous ethanol or 50% aqueous methanol) and reported that the aqueous acetone extracts resulted in the highest antioxidant activities ($p<0.05$) of the extracts compared to other solvents.

Extraction efficiency is affected by the chemical nature of phytochemicals, the extraction method used, sample particle size, the solvent used, as well as the presence of interfering substances (Stalikas, 2007). The yield of extraction depends on the solvent with varying polarity, pH, temperature, extraction time, and composition of the sample. Under the same extraction time and temperature, solvent and composition of sample are known as the most important parameters (Turkmen et al., 2006). According to Spigno et al. (2007), the extraction process was slow, with higher yields at 60 °C than at 45 °C, and with apparent thermal degradation of constituents beyond 20 hours, while investigating extraction kinetics of phenolic compounds from grape marc with different temperatures and solvent systems. Phenols yield increased for water content of ethanol from 10% to 30% and remained constant for water content from 30% to 60%, while phenols concentration of extracts decreased for water content above 50%. Do et al. (2013) used water and various concentrations (50%, 75%, and 100%) of methanol, ethanol, and acetone in

water as solvent for the preparation of extract from *Limnophila aromatic*. The extract obtained by 100% ethanol showed the highest total antioxidant activity. The same extract also exhibited the highest phenolic content (40.5 mg gallic acid equivalent/g of defatted sample). The highest extraction yield was obtained by using 50% aqueous acetone. The combined use of water and organic solvent may facilitate the extraction of chemicals that are soluble in water and/or organic solvent. This may be the reason why yields of aqueous methanol, ethanol, and acetone extracts are higher than yields of water, methanol, ethanol, and acetone extracts (Do et al., 2013).

Generally, organic solvents are very effective for extraction of antioxidants but they can affect human health if residues left in the final product which will not be acceptable for consumers. So, extra precautions are needed to remove all the traces of the extracting solvent. Water is the safest solvent, but less efficient in extracting all the antioxidants. Also, the processing methods affect the nature of the extract. Therefore, the use of safer alternative solvents and methods of extraction needs to be further examined for extraction processes. In addition, the cost-effectiveness of the extraction processes needs to be monitored to minimize the cost of natural antioxidants and ensure their wider utilization in the food industry (Vuong et al., 2011).

**Application**

Lipid oxidation (apart from microbial spoilage) in meat and meat products is the main cause of their quality loss. A large number of compounds are generated during the oxidation processes which adversely affect texture, color, flavor, nutritive value and safety of meat products (Lahucky et al., 2010) and this limits the shelf-life of meat (Karakaya et al., 2011). To prevent or delay these oxidation processes antioxidants can be applied. Although synthetic

antioxidants have been applied to meat and meat products but in recent years their use has been discouraged because of their toxic effects and consumer interest in natural products. This has led the meat industry to search new economical and effective natural antioxidants that can replace synthetic antioxidants without adversely affecting the quality of finished products and consumer perceptions (Karre et al., 2013).

Plant extracts have been used as natural antioxidants in meat and meat products by several authors (Table 3). Mansour and Khalil (2000) applied the freeze-dried extracts from potato peels, fenugreek seeds and ginger rhizomes in beef patties and found that the ginger rhizome and fenugreek seed extracts were more effective than potato peel extract in controlling lipid oxidation and color changes during cold storage. Also, ginger rhizome extract showed the highest antioxidant activity, comparable to commercial antioxidants, sustane HW-4 (20% BHT and 20% BHA) and sustane 20 (20% TBHQ and 10% citric acid) (Mansour & Khalil, 2000). Antioxidant activities of aloe vera, fenugreek, ginseng, mustard, rosemary, sage and tea catechins were evaluated in pork patties (Mc Carthy et al., 2001a, b). These ingredients were more effective in reducing lipid oxidation in patties made from frozen (-20 °C) than fresh pork. Tea catechins, rosemary and sage were identified as being the most effective antioxidants with potency decreasing in the order: tea catechins >rosemary >sage and optimum levels of 0.25, 0.10, 0.05 % respectively. However, fenugreek (0.01%) was more effective in increasing Hunter *a** values in patties manufactured from frozen pork (Mc Carthy et al., 2001a). In another study, these ingredients were evaluated against synthetic antioxidants butylated hydroxyanisole/ butylated hydroxytoluene (BHA/BHT) (0.01%). in raw and cooked pork patties with optimum levels of (0.25%), (0.01%), (0.25%), (0.10%), (0.10%), (0.05%) and (0.25%) for aloe vera, fenugreek, ginseng, mustard, rosemary, sage and tea catechins respectively. Cooking resulted in

a four-fold increase in thiobarbituric acid-reactive substances (TBARS) values over raw patties with tea catechins being the most effective antioxidant having significantly ($p<0.001$) lower TBARS values than the cooked control during the storage period. BHA/BHT had the most beneficial effect on cooked meat redness with Hunter $a^*$ values being significantly ($p<0.05$) higher than the control during the storage period. Hunter $L^*$ and $b^*$ values showed no significant difference over the storage period in either raw or cooked patties (Mc Carthy et al., 2001b). Rosemary and hyssop extracts were applied to cooked pork meat stored for 8 days at 4 °C. It was found that both extracts inhibited the lipid oxidation and degradation of heme pigments caused by cooking and storage. Also, both of them delayed metmyoglobin formation and stabilized the red meat color of the cooked meat during storage (Frenandez-Lopez et al., 2003). Antioxidative efficiency of extracts of rosemary (200 ppm), green tea (200 ppm), coffee (50 ppm) and grape skin (200 ppm) in precooked, vacuum pakaged pork patties held at 4.5± 0.5 °C for 10 days were evaluated. The antioxidative efficiency of the extracts was in the order: rosemary > grape skin > tea > coffee > reference. TBARS value of the rosemary treated cooked pork patty was 9.3 μmol MDA/kg, whereas the control was 30.0 μmol MDA/kg. Hexanal values were 4.9 and 21.6 ppm in rosemary-containing cooked pork patties and control, respectively (Nissen et al., 2004). A commercial rosemary extract applied to frozen and precooked-frozen pork sausage at concentrations of 1500 and 2500 ppm, and from 500 to 3000 ppm in refrigerated, fresh pork sausage. It was reported that the rosemary extract at 2500 ppm showed similar results as that of BHA/BHT for refrigerated sausage. Also, the rosemary extract maintained low TBARS values of precooked-frozen sausage similar to BHA/BHT. However, the rosemary extract was more effective than BHA/BHT for preventing increased TBARS values or loss of red color in raw frozen sausage (Sebranek et al., 2005).

Grape seed extract (ActiVin$^{TM}$) and pine bark extract (Pycnogenol®) significantly improved the oxidative stability of cooked beef at 3 days of refrigerated storage. TBARS values, hexanal content, and warmed-over flavor were reduced during the storage period (Ahn et al., 2002). In another study, grape seed extract (ActiVin $^{TM}$), pine bark extract (Pycnogenol), oleoresin rosemary (Herbalox) and BHA/BHT were used in cooked ground beef. The control showed significantly higher TBARS and hexanal content over storage. BHA/BHT, ActiVin $^{TM}$, Pycnogenol, and Herbalox retarded the formation of TBARS by 75%, 92%, 94%, and 92%, respectively, after 9 days, and significantly lowered the hexanal content throughout the storage period. The color of cooked beef treated with ActiVin $^{TM}$ was less light ($L^*$), more red ($a^*$), and less yellow ($b^*$) than those treated with BHA/BHT, Pycnogenols, and Herbaloxs. ActiVin $^{TM}$ and Pycnogenols effectively retained the redness in cooked beef during storage (Ahn et al., 2007).

Green tea extract (GTE, 300 mg/kg of meat) and grape seed extract (GSE, 300 mg/kg of meat) were evaluated for antioxidant properties in low sulphite (100 mg $SO_2$) raw beef patties and compared with ascorbate. The results showed the possibility of using low $SO_2$-plant extract combinations to preserve raw meat products. ST (100 $SO_2$ + 300 GTE), SG (100 $SO_2$ + 300 GSE) and SA (100 $SO_2$ + 400 sodium ascorbate) delayed redness loss and lipid oxidation, thus increasing the shelf life of the raw sulphite beef patties by 3 days. ST, SG and SA also delayed the onset of rancid flavors in cooked patties. Ascorbate, GTE and GSE improved the preservative effects of $SO_2$ on beef patties, especially against meat oxidation (Banon et al., 2007). The antioxidant effect of grape seed extract was determined in raw or cooked ground muscle during refrigerated or frozen storage. It was found that grape seed extract was more effective than gallic acid in inhibiting oxidation. The formation of lipid hydroperoxides (LOOH) and TBARS was inhibited by grape seed extract (0.1% and 1.0%) compared to untreated controls. Furthermore,

the results showed that grape seed extract at concentrations as low as 0.1% is a very effective inhibitor of primary and secondary oxidation products in various meat systems (Brannan & Mah, 2007).

The effect of grape seed extract (0.01% and 0.02%), oleoresin rosemary (0.02%) and water-soluble oregano extract (0.02%) on oxidative and color stability of cooked beef and pork patties stored at 4 °C for 8 days was determined. Patties with added extracts were cooked to an internal temperature of 71 °C, overwrapped in polyvinyl chloride (PVC), and stored at 4 °C. It was reported that grape seed extract showed the best antioxidant activity based on TBARS values and off-odors associated with lipid oxidation such as rancidity, wet cardboard (for beef patties), and grassy (for beef and pork patties) in both meat species. It did not changed instrumental color and also reduced the visual green discoloration in beef patties. Further, the higher grape seed concentration (0.02%) showed more antioxidant activity than the lower concentration (0.01%) (Rojas & Brewer, 2007). In another study, the same extracts and concentrations were evaluated in raw beef and pork patties, vacuum packaged and stored frozen for 4 months. Fresh beef or pork lean was ground, mixed individually with fat (30%) from their respective species and antioxidants were added. The patties were formed; vacuum packaged and stored at -18 °C for 4 months. It was reported that the grape seed extract provided small degrees of protection against oxidation based on the TBARS values in both meat species. It did not alter ($P<0.05$) the sensory perception of oxidation and color (Rojas & Brewer, 2008).

The effect of grape seed extract (0.02%), oleoresin rosemary (0.02%), water-soluble oregano extract (0.02%), propyl gallate (0.02% of fat), butylated hydroxyanisole (0.02% of fat), and butylated hydroxytoluene (0.02% of fat) on the oxidative and color stability of precooked pork patties stored at -18 °C for up to 6 months was determined. Pork lean and trim were ground,

mixed with 30% fat and added with the above antioxidants. Patties were formed, cooked to 71 °C, over wrapped in PVC, and stored at -18 °C for 6 months. Based upon TBARS values, propyl gallate (0.21mg MDA/kg) and grape seed extract (0.23) had more antioxidant activity over the storage period than did water-soluble oregano extract, oleoresin rosemary, BHA and BHT. Grape seed extract had no effect on *a** or *b** values (Sasse et al., 2009). In another study, grape seed extract was compared to ascorbic acid and propyl gallate in a pre-cooked, frozen, stored meat model system sausage was manufactured from lean beef (70%), pork fat (28%), and salt (2%). Antioxidants added for comparison with control included grape seed extract (100, 300, and 500 ppm), ascorbic acid (100 ppm of fat) and propyl gallate (100 ppm of fat). Product was formed into rolls, frozen, sliced into patties, cooked on a flat griddle to 70 °C, overwrapped in PVC, then frozen at -18 °C for 4 months. Grape seed extract and propyl gallate containing samples retained their fresh cooked beef odor and flavor longer ($p<0.05$) than controls during storage. Rancid odor and flavor scores of grape seed extract-containing samples were lower ($p<0.05$) than those of controls after 4 month of storage. The *L** value of all samples increased ($p<0.05$) during storage. TBARS of the control and ascorbic acid-containing samples increased ($p<0.05$); those of grape seed extract-containing samples did not change significantly ($p>0.05$) over the storage period (Kulkarni et al., 2011).

Colindres and Brewer (2011) investigated the use of grape seed extract (GSE), oleoresin rosemary (OR), water-soluble oregano extract (WO), propyl gallate (PG), butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT) in cooked, frozen, reheated ground beef patties, overwrapped in commercial PVC film, and stored frozen (-18 °C) for 6 months. PG and GS treated samples showed lower rancid odor scores and TBARS than controls, after 6 months of storage. BHT treated and control samples did not differ statistically in sensory grassy

or rancid odor, indicating that they were the most oxidized. Based on TBARS, these antioxidants showed the effectiveness in the order: PG and GSE > OR > BHA > WO and BHT > control. These antioxidants also protected *a** values during storage (Colindres & Brewer, 2011).

The effect of grape seed extract (0.01, 0.03, 0.05, 0.1, 0.3 and 0.5%) on the quality properties of frankfurters was evaluated against the control. The moisture, fat, pH and color values of frankfurters were found significantly different ($p<0.05$). The results showed that with the increase in level of grape seed extract in frankfurters there was a decrease in the 2-thiobarbituric acid (TBA) values of the products, probably due to the high antioxidant content. Sensory evaluation indicated that frankfurters containing 0.01, 0.03, 0.05 and 0.1% grape seed extract were as acceptable as the control ($p>0.05$) at the beginning of storage according to the overall acceptability (Ozvural & Vural, 2012).

Two different types of red grape pomace extracts (GPI and GPII) obtained by two different extraction methods, at a concentration of 0.06 g/100 g final product, were investigated in pork burgers packed under aerobic conditions at 4 °C for 6 days. GPI showed the highest color stability, lipid oxidation inhibition and the best global acceptability after 6 days of storage (Garrido et al., 2011).

Tajik et al. (2014) studied the effect of clove essential oil (0.1%) and grape seed extract (0.1 and 0.2%) on lipid oxidation of raw buffalo patties during storage at 8 °C for 9 days. It was reported that the TBA values of control samples increased rapidly throughout the storage whereas samples containing 0.1% clove essential oil had TBA values 27.5–39% lower than the TBA values of samples containing 0.1 and 0.2% GSE. Samples with 0.1% clove essential oil had the lowest degrees of lipid oxidation, which was 73% lower than the control.

Reddy et al. (2013) applied grape seed extract in restructured mutton slices under aerobic and vacuum packaging conditions stored at refrigerated temperatures. The restructured mutton slices treated with grape seed extract had significantly ($P<0.05$) lower TBARS values and free fatty acids (FFA) % compared to control and BHA treated restructured mutton slices during storage. The grape seed extract treated mutton slices showed significantly ($P<0.05$) higher scores of color, flavor, juiciness and overall palatability than control and BHA treated restructured mutton slices. The TBARS values and FFA % increased significantly ($P<0.05$) during storage.

Rababah et al. (2011) investigated the effect of green tea extract, commercial grape seed extract, combination of green tea and commercial grape seed extract and synthetic TBHQ at different concentrations on lipid oxidation and the redness of goat meats stored at 5 °C for 9 days was evaluated. Fresh boneless Baladi goat meats were ground and mixed at varying concentrations (3000 and 6000 ppm) of green tea or grape seed extract alone or combination with TBHQ (200 ppm). The antioxidant activity of the plant extracts and the TBHQ ranged from 4.6–10.2 h induction time using an oxidative stability instrument. Plant extracts and TBHQ significantly decreased lipid oxidation of the goat meats. Further, higher level addition of antioxidants was more effective in minimizing lipid oxidation. Grape seed extract significantly increased the redness, while green tea extract decreased it. TBHQ had no effect of on the redness of goat meats (Rababah et al., 2011). Green tea catechins (GTC) and green coffee antioxidant (GCA) were added to both linseed oil (LGTC 200 and LGCA 200) and fish oil (FGTC 200 and FGCA 200) substituted (15% of the pork back fat) fresh pork sausages at a level of 200 mg/kg. Raw and cooked pork sausages were either over-wrapped with oxygen permeable film (aerobic storage) or stored in modified atmosphere packages (MAP) containing 80% $O_2$:20% $CO_2$ or 70% $N_2$:30% $CO_2$, respectively for 7 days at 4 °C. Raw and cooked linseed oil containing sausages

showed low lipid oxidation. Lipid oxidation was significantly reduced in raw fish oil containing sausages treated with GTC (200mg/kg) after 7 days of storage. Color parameters in raw pork sausages were not affected by the packaging atmosphere. *L** lightness values were lower ($P<0.05$) in LGTC 200 and *a** redness values lower ($P<0.05$) in LGTC 200 and FGTC 200 after 7 days of storage. Sensory scores of cooked pork sausages remained unaffected by the addition of linseed oil. GTC treated cooked sausages containing fish oil showed improved flavor and overall acceptability scores (Valencia et al., 2008). The extracts from green tea (catechins, epigallocatechins), rosemary (rosmariquinone, rosmaridiphenol) and red pepper (capsaicinoids) were applied to pork meat products stored for 30 days at refrigerated temperatures. All these plants extracts effectively reduced the lipid oxidation in cooked pork compared to the control. Pepper extract was effective in maintaining redness and low TBARS values in sample during chilling storage. Addition of these extracts in curing meat process helped in nitrosomyoglobin formation and thus prevented the metmyoglobin formation which stabilized the color of product during chilling storage (Wojciak et al., 2011).

Mint leaf extract was evaluated for its antioxidant activity in radiation-processed lamb meat stored at chilled temperatures (Kannat et al., 2007). It was reported that mint leaf extract containing good amounts of total phenolic and flavonoid exhibited excellent antioxidant activity. The antioxidant activity of mint leaf extract was found to be equivalent to BHT. TBARS values of mint leaf extract containing irradiated meat were significantly lower ($p<0.05$) than samples without the extract. After 4 weeks of chilled storage, TBARS in irradiated meat containing mint leaf extract (0.1%) was half of that in untreated irradiated meat (Kannat et al., 2007).

Biswas et al. (2012) investigated different solvent extracts of curry and mint leaf for their effect on oxidative stability and color of raw ground pork meat stored at 4±1 °C. It was reported

that the ethanol extract of curry leaf (EHEC) and the water extract of mint leaf (WEM) showed higher DPPH and ABTS activity. Total phenolic content was highest for EHEC and lowest for WEM. WEM showed the highest superoxide anionic scavenging activity (%). The pork meat samples treated with EHEC and WEM showed a decrease in the Hunter $L^*$ and $a^*$ values and an increase in $b^*$ value during storage. However, the TBARS values were higher in control samples irrespective of storage periods.

Myrtle, rosemary, nettle and lemon balm leaf extracts were applied to beef patties stored at frozen temperatures (-20±2 °C) for 120 days (Akarpat et al., 2008). Ground beef was treated separately with 10% of each of the plant extracts. Patties (25 g) were wrapped with polyethylene film and oxidative and sensory changes were evaluated during the storage period. These extracts slowed down the lipid oxidation of beef patties. Myrtle and rosemary extracts showed the highest antioxidant effects than nettle and lemon balm extracts. Myrtle extract protected the color properties of frozen beef patties. In terms of overall acceptability, myrtle and rosemary extracts containing patties were given higher preference. Further, the addition of 10% myrtle leaf extract to the beef patties at frozen storage prevented the oxidative damage in lipids and color changes in beef patties (Akarpat et al., 2008).

Shan et al. (2009) applied cinnamon stick, oregano, clove, pomegranate peel and grape seed extracts in pork meat. These extracts increased the stability of raw pork against lipid oxidation. Clove was the most effective for retarding lipid oxidation and offered the highest antioxidant activity in raw pork. The color parameters of the extract-treated pork samples changed slightly, in comparison with significant changes in the control during storage (Shan et al., 2009). Kinnow rind powder (KRP), pomegranate rind powder (PRP) and pomegranate seed powder (PSP) extracts were investigated in goat meat patties stored at 4±1 °C. It was found that

these extracts are rich in phenolic compounds and have free radical scavenging activity. Hunter Lab *L** value were significantly ($p<0.05$) lower in PRP followed by PSP and KRP treated patties. Sensory evaluation indicated no significant differences among patties. Further, a significant ($p<0.5$) reduction in TBARS values (lipid oxidation) during storage of goat meat patties was observed in PRP, PSP and KRP as compared to control patties. The overall antioxidant effect was in the order of PRP > PSP > KRP (Devatkal et al., 2010). The effect of vacuum packaging and pomegranate peel extract on ground goat meat and cooked nuggets during refrigerated storage (4±1 °C) was evaluated. Vacuum packaging along with 1 % pomegranate peel extract (VP + PPE) resulted in a more stable color than meat stored in atmospheric packaging (AP). TBARS values were significantly ($p<0.05$) lower in VP + PPE than AP. In ground meat, VP + PPE reduced the TBARS by 41 % while in nuggets, it was decreased by 40 %. Thus VP and PPE have a synergistic antioxidant effect and VP extended the refrigerated shelf life of goat meat and nuggets (Devatkal et al., 2012).

The effect of *Urtica dioica*, *Hibiscus sabdariffa*, BHT and nitrite/nitrate were investigated in sucuk (Turkish dry-fermented sausage) during the ripening periods. TBARS values increased from 0.52 to about 0.95 mg/kg significantly ($p<0.05$) during the first 4 days in control, and *H. sabdariffa* added batters. Hunter *L** values were not affected ($p>0.05$) from ripening time and addition of antioxidants into batter. The Hunter *a** value increased ($p<0.05$) during the ripening periods, however, *b** values decreased (<0.05) from 12.58 to about 10.53. Overall sensory quality evaluated from color, flavor and ease of cutting scores increased ($p<0.05$) from 3.25 to about 9.00 (Karabacak & Bozkurt, 2008). Effects of lyophilized *Urtica dioica* L. water extract (LUWE) and modified atmosphere packaging (MAP) on the quality and shelf life of ground beef were investigated (Alp & Aksu, 2010). Ground beef was stored as

aerobic control, MAP (80%$O_2$+20% $CO_2$), MAP+250 ppm LUWE and MAP and 500 ppm LUWE at 2±0.5 °C for 14 days. Treatment with 500 ppm LUWE+MAP showed the lowest TBARS values compared to other groups during storage. 80% $O_2$-MAP increased TBARS values. Treatment had no significant effect on *L** and *b** values of the exterior of the ground beef, but had significant effects on the color of interior sections (Alp & Aksu, 2010).

Han and Rhee (2005) applied white peony (WP), red peony (RP), sappanwood (SW), moutan peony (MP), rehmania (RE) or angelica (AN) extracts separately to ground goat meat at 0.5–2.0% (g dry extract/100 g final meat sample). Extract containing raw and cooked samples were aerobically stored at refrigerated temperatures for 6 days. These extracts and rosemary extract (RO) were also separately added to salted or unsalted ground beef at 0.01–0.25% and refrigerated as above. WP, RP, RE, SW and MP markedly reduced ($p<0.05$) lipid oxidation in cooked–stored goat meat. Lipid oxidation during storage was minimal in raw and cooked patties (plain or salted) treated with 0.25% of WP, RP, SW, MP or RO; raw patty redness values at day 6 were higher ($p<0.05$) for SW, WP, RP or MP than RO treatment or the control. At 0.01%, SW showed more antioxidative effect ($p<0.05$) than the other extracts.

Naveena et al. (2013) investigated the effect of oil soluble and water dispersible carnosic acid (CA) extracted from dried rosemary leaves using HPLC at two different concentrations (22.5 ppm and 130 ppm) in raw and cooked ground buffalo meat patties. It was reported that CA extracts reduced ($p<0.05$) the TBARS by 39-47% at lower concentration (22.5 ppm) and by 86–96% at higher concentration (130 ppm) in cooked buffalo meat compared to controls. The CA extracts were also effective in inhibiting ($p<0.05$) peroxide value and free fatty acids in cooked buffalo meat patties. These extracts were effective in stabilizing raw buffalo meat color at higher concentrations.

The ethanolic extract from *Eleutherine Americana* was applied in pork, cooked in the microwave at different concentrations and stored at 4 °C for 9 days. The antioxidant activity of the extract increased with increase in extract concentrations and retarded lipid oxidation in the cooked pork. The sensory results revealed that the extract treated pork samples and the control sample were not significantly different from day 0 to 6 as revealed by the sensory results; however, on day 9 the treatments significantly scored higher than the control. Also, the addition of the extract led to an increase in the redness values of the pork which was acceptable from the sensory point of view (Ifesan et al., 2009).

Raw and cooked pork (*M. longissimus thoracis et lumborum*) patties containing added lutein (100, 200 μg/g muscle), sesamol (250, 500 μg/g muscle), ellagic acid (300, 600 μg/g muscle) and olive leaf extract (100, 200 μg/g muscle) were stored aerobically or in modified atmosphere packages (MAP) for 12 days. Lipid oxidation was reduced ($p<0.001$) in raw and cooked pork patties stored in aerobic packages and in MAP (80% $O_2$:20% $CO_2$) treated with sesamol, ellagic acid and olive leaf extract. Antioxidant effectiveness in raw and cooked patties was in the order: sesamol = ellagic acid > olive leaf extract > lutein. Lutein increased ($P<0.001$) *b** yellowness values in raw pork patties. Addition of lutein, sesamol, ellagic acid and olive leaf extract to pork had no detrimental effects on the organoleptic properties of cooked patties but altered ($p<0.05$) instrumental textural attributes (Hayes et al., 2010a). In another study, the above plant ingredients were also evaluated in raw beef patties (*M. longissimus thoracis et lumborum*) stored aerobically and in modified atmosphere packs (80% $O_2$:20% $CO_2$) (MAP) at 4 °C for up to 8 and 12 days, respectively. The addition of sesamol, ellagic acid and olive leaf extract reduced ($p<0.001$) TBARS in raw beef patties in both packaging systems. Addition of sesamol to beef resulted in lower ($p<0.01$) *a** redness values and increased oxymyoglobin oxidation.

Conversely, lutein and olive leaf extract reduced ($p<0.001$) oxymyoglobin oxidation relative to the control (Hayes et al., 2010b).

Hayes et al. (2011) applied lutein (200 μg/g meat), sesamol (250 μg/g meat), ellagic acid (300 μg/g meat) and olive leaf extract (200 μg/g meat) in fresh and cooked pork sausages stored in aerobic or modified atmosphere packages (MAP). Addition of sesamol, ellagic acid and olive leaf extract reduced ($p<0.001$) lipid oxidation in all packaged raw and cooked pork sausages. Antioxidant potency followed the order: sesamol 250 > ellagic acid 300 > olive leaf extract 200 > lutein 200 for both raw and cooked pork sausages. Meat treated with lutein, sesamol, ellagic acid and olive leaf extract had no detrimental effect on pH, cooking losses, tenderness, juiciness, texture or product flavor (Hayes et al., 2011).

The effect of extracts: Liposterine (non-purified) or Exxenterol (purified) obtained from Carob fruit on cooked pork meat systems during chilling and frozen storage was investigated with that of α-tocopherol (Bastida et al., 2009). Meat lipid oxidation was evaluated as TBARS and polar material-related triglyceride compounds followed by high-performance size-exclusion chromatography (HPSEC). TBARS levels were lower ($p<0.05$) in samples containing Liposterine (LM), Exxenterol (EM), and a-tocopherol (TM) than in control sample under chilled storage. TBARS formation was similar ($p>0.05$) for LM and EM but lower ($p<0.05$) than for TM. Polar material increased several times in all samples, but significantly less in TM and EM than in LM. Thermal oxidation compounds determined by HPSEC were lower ($p<0.05$) in EM than in LM or TM. The changes in polar material were proportionally smaller after six months frozen storage than after chilled storage, with Exxenterol displaying the highest antioxidant protection (Bastida et al., 2009).

Extracts from lotus rhizome knot (LRK) and lotus leaf (LL) were investigated in porcine and bovine meat. Both of these meats were ground treated with LRK (3% w/w), and LL (3% w/w) and compared with control (no extract). Raw and cooked samples were stored at 4 °C for 10 days. Antioxidant activity significantly increased in all meat samples with the addition of both LRK and LL, but LRK was more effective against lipid oxidation (Huang et al., 2011). Peanut skin extract (PSE) was applied in cooked and raw ground beef and it was reported that addition of PSE to raw ground beef before cooking significantly inhibited the formation of peroxides and TBARS in cooked ground beef during the refrigerated storage. PSE at concentration ≥0.06% was as effective as BHA/BHT at 0.02% in inhibiting lipid oxidation. PSE also inhibited the oxidation of meat pigments thereby preserving the fresh redness of treated meat when used at 0.02–0.10% (Yu et al., 2010).

A commercial adzuki bean extract (AE) was applied in cured and uncured cooked pork sausages. AE at 0.2% was equally effective as 0.1% BHT in reducing TBARS values in uncured sausages. Also, AE at 0.2% significantly ($p<0.01$) reduced the TBARS in cured sausages. Addition of 0.2% AE into sausages produced higher ($p<0.05$) CIE lab color $a^*$ value and lower ($p<0.05$) $L^*$ and $b^*$ values. Sensory evaluation did not show any difference in color, odor, taste, flavor, and overall acceptance in uncured pork sausages treated with 0.2% AE. However, there were adverse changes in the color and odor of cured sausages, even though the taste, flavor, and overall acceptance were similar (Jayawardana et al., 2011).

The effect of lyophilized water extract of Summer savory (*Satureja hortensis* L.) (LSHWE) at different concentrations on the shelf life of ground beef was evaluated. Ground beef was treated with various concentrations of LSHWE (0, 100, 250 and 500 ppm) and stored at 4±0.5 °C for 72 hours. Depending on LSHWE concentrations, lipid oxidation decreased, and 500

ppm of LSHWE showed the lowest TBARS values (11.57 ± 4.07 μmol malonaldehyde/kg) at the end of storage. LSHWE levels had also significant effects on color values (*L**, *a** and *b**) of the ground beef (Aksu & Ozer, 2013).

The effect of date pits (*Phoenix dactylifera* L.) phenolic compounds compared to BHT as synthetic antioxidant on lipid oxidation and quality of ground beef during refrigerated storage at 0.00 ± 0.50 °C for up to 10 days was investigated. Results indicated that the highest antioxidant was shown by the date pits extract (Water: methanol: acetone: formic acid), therefore 0.5, 0.75 and 1.00 % of either date pits extract and BHT were added to minced meat and evaluate its effects on the lipid peroxidation of ground beef during storage process. The date pits extract (Water: methanol: acetone: formic acid) had significantly the highest levels of total polyphenols and antioxidant activity. Also, the obtained results indicated that phenolic compounds in date pits had high antioxidative effect in reducing the formation of hydroperoxides during storage (Amany et al., 2012).

Das et al. (2012) applied *Moringa oleiferia* leaf extract (MLE) in cooked goat meat patties refrigerated storage conditions and reported that MLE has excellent antioxidant activity as determined by DPPH. MLE extract (0.1%) was found to retard lipid peroxidation of cooked goat meat patties as measured by TBARS value during refrigerated storage. The increase in TBARS value in MLE–treated samples was very low and remained lowest (0.53 mg malonaldehyde per kg sample) up to 15 days. The antioxidant activity of MLE was found to be comparable to BHT. Addition of MLE did not affect any of the sensory attributes of patties. The MLE at a level of 100 mg/100 g meat was sufficient to protect goat meat patties against oxidative rancidity for periods longer than the most commonly used synthetic antioxidant like BHT (Das et al., 2012). In another study, the effect of different levels of MLE (300, 450 and 600 ppm equivalent *M.*

*oleifera* leaves phenolics) and BHT (200 ppm) in raw and cooked pork patties during refrigerated storage was investigated. A concentration dependent increase in reducing power and DPPH radical scavenging activity of both MLE and BHT was noticed. Higher *a** and lower TBARS values were observed in MLE 600 and BHT 200 compared to control (no antioxidant). Addition of MLE did not affect the sensory attributes (Muthukumar et al., 2012).

Pork sausage batter treated with 1, 2 and 4% *radix puerariae* (RP) extract and 0.02% BHA/BHT, were cooked and stored for 28 days at 4 °C. RP and BHA/BHT treated pork sausages had lower pH values than the control (without antioxidant) after 14 days. It was reported that lightness decreased upon the addition of RP. TBARS values decreased in the RP treated sausage compared to the control. Also, 1% RP was more effective in delaying lipid oxidation compared to the other added RP treatments (Jung et al., 2012).

Boerewors, a South African fresh sausage, was treated with rosemary (260 mg/kg) and compared with 450 mg/kg sulphur dioxide ($SO_2$). Color, lipid and sensory characteristics were evaluated. Rosemary showed comparable lipid stability to $SO_2$. Rosemary had a better effect on the sensory taste, but $SO_2$ was still preferred. Reduced levels of 100 mg/kg $SO_2$ showed good color effects in combination with rosemary as antioxidant and improving the sensory properties (Mathenjwa et al., 2012).

*Hypericum perforatum* L. extract (Hp) at two concentrations (0.0005% and 0.001%) of Hp in the meat matrix (Hp5 and Hp10 samples) was applied in heated meat batters formulated with a healthier oil combination (olive, linseed and fish oils) during chilled storage and compared with the combination of synthetic phenolic antioxidants (BHA+BHT). The incorporation of BHA+BHT and Hp induced oxidative protection during the preparation process and storage of meat batters with the lowest alteration in samples containing BHA+BHT. Storage

increased linearly the polar material, thermal oxidized compounds, and TBARS in all samples with the lowest trend-variation for BHA+BHT followed by Hp10 and Hp5 samples (Sánchez-Muniz et al., 2012).

Banerjee et al. (2012) investigated the effect of broccoli powder extract (BPE) in goat meat nuggets at three different concentrations 1, 1.5 and 2% and compared with control and BHT (100 ppm). Addition of 1.5 and 2% BPE decreased ($p<0.05$) the pH value of the meat nuggets. Total phenolics in product with 2% BPE was similar to BHT nuggets. Chroma value of products with 1.5 and 2% BPE was lower ($p<0.05$) than control and BHT nuggets. TBARS value of BPE nuggets was lower ($p<0.05$) than control throughout the storage (Banerjee et al., 2012).

Antioxidant activities of 70% ethanolic extracts of ten leafy green vegetables were determined and applied in raw beef patties. The extracts and BHT (positive control) were separately added to patties at 0.1% and 0.5% (w/w) concentrations and the patties were stored at 4 °C for 12 days. The addition of extracts and BHT resulted in concentration dependent decreases in TBARS values in the beef patties and also improved meat color stability. The fatsia extract had more effective antioxidant than the chamnamul (Kim et al., 2013a). In another study, the antioxidant efficacy of 70% ethanol and water extract of 10 leafy edible plants was evaluated in ground beef patties. Plant extracts (butterbur and broccoli extracts) and BHT were seaparately added to the patties at 0.1% and 0.5% (w/w) concentrations and stored at refrigerated conditions for 12 days. TBARS values were significantly lower ($p\leq0.05$) in the samples containing plant extracts or BHT than the non-treated control. In addition, the beef patties formulated with the selected plant extracts showed significantly ($p\leq0.05$) better color stability than those without antioxidants (Kim et al., 2013b).

Cao et al. (2013) studied the effect of 1% or 0.5% chitosan (CHI), 10% or 5% aqueous extract of ginger, onion and garlic (GOG) and their composite solutions (Mix 1=1% CHI + 10% GOG, Mix 2=0.5% CHI + 5% GOG) on quality and shelf life of stewed-pork. pH, total volatile basic nitrogen (TVB-N), peroxide value (PV), 2-thiobarbituric acid (TBA) and sensory characteristics were analyzed periodically during refrigerated storage at 4 °C for 12 days. CHI and/or GOG treatments retarded the increases in pH, TVB-N, PV and TBA. CHI showed weaker antioxidant activity than GOG. Composite treatment had positive effect while the high concentration of composite solution (Mix1) had adverse effect on odor and overall acceptance.

**Conclusion**

In the recent years, there has been a huge demand for natural antioxidants mainly because of adverse toxicological reports on many synthetic compounds. Thus most of the recent research has been directed towards identification of novel antioxidants from natural sources, particularly of plant origin. These natural antioxidants have been extracted from different plant parts like leaves, roots, stems, fruits, seeds and bark. Different solvents and methods can be utilized to prepare the plant extracts and the properties of an extract will depend on the method and solvent used for extraction. Plant extracts prepared from different plant materials are rich in phenolics and provide a good alternative to synthetic antioxidants. The application of plant extracts as antioxidants have been studied extensively in different types of meat and meat products. These studies show promising results regarding the use of plant extracts as antioxidants in meat. These extracts inhibit lipid oxidation and degradation of meat pigments, and thus help to delay the onset of rancid flavors and stabilize the color of meat. Application of these extracts improved the overall sensory and nutritional quality of meat and meat products and hence their shelf life.

Although, these extracts are derived from plant generally regarded as safe, but further research is needed to determine their safe limits and toxicological effects in meat and meat products as the extraction or processing conditions may alter their properties.

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**Table 1. Plant sources used as natural antioxidants in meat and meat products**

| Source | Scientific name | Part used | Extraction solvent | Reference |
|---|---|---|---|---|
| Rosemary | *Rosmarinus officinalis* | Leaf & secondary branches | Dimethyl sulfoxide | Frenandez-Lopez et al., 2003 |
| | | Leaf | Deionized water | Akarpat et al., 2008 |
| | | Leaf | Acetone, hexane | Naveena et al., 2013 |
| Nettle | *Urtica dioica* | Leaf | Water | Akarpat et al., 2008; Alp & Aksu, 2010 |
| | | Flower | Water | Karabacak & Bozkurt, 2008 |
| Pomegranate | *Punica granatum* | Peel | 70% ethanol | Tayel & El-Tras, 2012 |
| | | Peel | Water | Devatkal et al., 2010 |
| | | Peel | 80% ethanol | Shan et al., 2009 |
| Ginger | *Zingiber officinale* | Rhizome | 90% ethanol | Mansour & Khalil, 2000 |
| | *Zingiber officinale* Rosc. | Rhizome | Water | Cao et al., 2013 |
| Broccoli | *Brassica oleracea* | Flowering head | Water | Banerjee et al., 2012 |
| | *Brassica oleracea* L. var. italica Plenk | Flowering head | 70% ethanol | Kim et al., 2013a, b |
| Mint | *Mentha spicata* | Leaf | Water | Kanatt et al., 2007, 2008 |
| | | Leaf | Water, ethanol and 50%ethanol:50%water | Biswas et al., 2012 |
| Grape | *Vitis vinifera* | Seed | 80% ethanol | Shan et al., 2009 |
| | *Vitis vinifera* var. Monastrell, Murcia, Spain | pomace | Methanol | Garrido et al., 2011 |
| Garlic | *Allium sativum* | Aerial parts | 70% ethanol | Tayel & El-Tras, 2012 |
| | | Bulb | Water | Cao et al., 2013 |
| Lotus | *Nelumbo nucifera* | Rhizome knot | Water | Huang et al., 2011 |
| | | Leaf | Water | Huang et al., 2011 |
| Drumstick | *Moringo olifera* | Leaf | Water | Das et al., 2012; Muthukumar et al., 2012 |
| Myrtle | *Myrtus communis myrtillus* | Leaf | Water | Akarpat et al., 2008 |
| Hyssop | *Hyssopus officinalis* | Leaf & secondary branches | Dimethyl sulfoxide | Frenandez-Lopez et al., 2003 |
| Potato | *Solanum tuberosum* | Peel | 90% ethanol | Mansour & Khalil., 2000 |
| Fenugreek | ***Trigonella foenum****-graecum* | Seed | 90% ethanol | Mansour & Khalil, 2000 |
| Lemon balm | *Melissa officinalis* | Leaf | Water | Akarpat et al., 2008 |
| Eleutherine | *Eleutherine americana* | Bulb | 95% ethanol | Ifesan et al., 2009 |
| Cinnamon stick | *Cinnamomum burmannii* | Cortex | 80% ethanol | Shan et al., 2009 |
| Oregano | *Origanum vulgare* | Leaf | 80% ethanol | Shan et al., 2009 |
| Clove | *Eugenia caryophylata* | Bud | 80% ethanol | Shan et al., 2009 |
| Peanut | *Arachis hypogaea* | Skin | 80% ethanol | Yu et al., 2010 |
| Black seed | *Nigella sativa* | Seeds | 70% ethanol | Tayel & El-Tras, 2012 |

| | | | | |
|---|---|---|---|---|
| Cinnamon | *Cinnamomum verum* | Bark | 70% ethanol | Tayel & El-Tras, 2012 |
| Lemon grass | *Cymbopogon citratus* | Leaf | 70% ethanol | Tayel & El-Tras, 2012 |
| Licorice | *Glycyrrhiza glabra* | Root | 70% ethanol | Tayel & El-Tras, 2012 |
| Summer savory | *Satureja hortensis* | Leaf | Water | Aksu & Ozer, 2013 |
| Date | *Phoenix dactylifera* | Pits | Water, methanol, methanol:water (50:50 v/v) and methanol:water: 40% acetone:formic acid (20:40:40:0.1 v/v) | Amany et al., 2012 |
| Curry | *Murraya koenigii* | Leaf | Water, ethanol and 50%ethanol:50%water | Biswas et al., 2012 |
| Butterbur | *Petasites japonicus* Maxim | Leaf | 70% ethanol | Kim et al., 2013a, b |
| Chamnamul | *Pimpinella brachycarpa* (Kom.) Nakai | Leaf | 70% ethanol | Kim et al., 2013a, b |
| Bok choy | *Brassica campestris* L. ssp. chinensis | Leaf | 70% ethanol | Kim et al., 2013a, b |
| Chinese chives/Leek | *Allium tuberosum* Rottler ex Spreng | Leaf | 70% ethanol | Kim et al., 2013a, b |
| Crown daisy | *Chrysanthemum coronarium* | Leaf | 70% ethanol | Kim et al., 2013a, b |
| Fatsia | *Aralia elata* Seem | Leaf | 70% ethanol | Kim et al., 2013a, b |
| Pumpkin | *Curcubita moschata* Duch. | Leaf | 70% ethanol | Kim et al., 2013a, b |
| Sesame | *Perilla frutescens* var. japonica Hara | Leaf | 70% ethanol | Kim et al., 2013a |
| Stonecrop | *Sedum sarmentosum* Bunge | Leaf | 70% ethanol | Kim et al., 2013a |
| Acanthopanax | *Acanthopanax sessiliflorum* Seeman | Leaf | Water; 70% ethanol | Kim et al., 2013b |
| Soybean | *Glycine max* L. Merr | Leaf | Water; 70% ethanol | Kim et al., 2013b |
| Green tea | *Camellia sinensis* | Leaf | Water | Rababah et al., 2011 |
| Kinnow | *Citrus reticulate* | Peel | Water | Devatkal et al., 2010 |
| Onion | *Allium cepa* L. | Bulb | Water | Cao et al., 2013 |
| Roselle | *Hibiscus sabdariffa* | Flower | Water | Karabacak & Bozkurt, 2008 |

**Table 2. Commercially available natural antioxidants of plant origin applied to meat and meat products**

| Name of extract | Trade name | Company | Meat/ meat product tested | References |
|---|---|---|---|---|
| Grape seed extract | ActiVin™ | InterHealth (Benicia, Calif., USA. | Ground beef | Ahn et al., 2002 |
| | ActiVin | -- | Beef sausages | Kulkarni et al., 2011 |
| | Gravinol-S | -- | Beef and pork | Brannan & Mah, 2007 |
| | Gravinol Super ™ | -- | Beef and pork patties | Rojas & Brewer, 2007, 2008 |
| | Gravinol Super ™ | -- | Frozen pork patties | Sasse et al., 2009 |
| | Gravinol Super™ | Kikkoman (Tokyo, Japan). | Beef patties | Colindres & Brewer, 2011 |
| | -- | -- | Ground goat meat | Rababah et al., 2011 |
| | -- | -- | Beef frankfurters | Ozvural & Vural, 2012 |
| | -- | -- | Restructured mutton slices | Reddy et al., 2013 |
| White grape extract | -- | Danisco A/S, Denmark | Chilled beef patties | Jongberg et al., 2011 |
| Grape skin extract | -- | Unilever, Vlaardingen, Holland. | Pork patties | Nissen et al., 2004 |
| Pine bark extract | Pycnogenol® | Natural Health Science (Hillside, NJ., U.S.A. | Ground beef | Ahn et al., 2002 |
| Green tea extract (Catechins) | -- | New Kinglong Natural Products Co. Ltd, Hunan, China. | Pork sausages | Valencia et al., 2008 |
| Green tea extract | -- | Nestle Research Centre, Lausanne, Switzerland. | Pork patties | Nissen et al, 2004 |
| Coffee extract | -- | Nestle Research Centre, Lausanne, Switzerland. | Pork patties | Nissen et al, 2004 |
| Green coffee antioxidant | GCA® | Applied Food Sciences, LLC, Austin, Texas. | Pork sausages | Valencia et al, 2008 |
| Olive leaf extract | -- | Guinness Chemicals (Ireland) Ltd. (Clonminam Industrial Estate, Portlaoise, Co. Laois, Ireland). | Beef, pork patties, pork sausages | Hyaes et al., 2010 a, b, 2011 |
| Water-soluble oregano extract | Origanox™ WO | RAD Natural Technologies Ltd (Barrington Chemical Corp., Harrison, NY, USA. | Beef patties | Colindres & Brewer, 2011 |
| | Origanox ™ WS | RAD Natural Technologies Ltd., Barrington Chemical Corp., NY., USA. | Beef and pork patties | Rojas & Brewer, 2007, 2008; Sasse et al., 2009 |
| Adzuki bean | -- | Cosmo Foods Co., Ltd, Tokyo, | Pork sausages | Jayawardana et al,, 2011 |

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|---|---|---|---|---|
| extract | | Japan. | | |
| Rosemary oleoresin | Herbalox ® Seasoning HT-25 | Kalsec Inc., Kalamazoo, MI, USA. | Beef and pork patties | Rojas & Brewer, 2007, 2008; Sasse et al., 2009; Colindres & Brewer, 2011 |
| | -- | Kalsec Inc. (Kalamazoo, Mich., USA). | Ground beef | Ahn et al., 2002 |
| Rosemary extract | Flavor'Plus™ Ref. # 050501 | SharonBolel Chemical Marketing, South Africa. | Boerewors- South African fresh sausage | Mathenjwa et al., 2012 |
| | Herbalox HT-25 | Kalsec, Inc., Kalamazoo, MI,USA. | Irradiated ground beef patties | Movileanu et al., 2013 |
| | Fortium™ R20 | Kemin Americas, Inc., Des Moines, IA. | Pork sausage | Sebranek et al., 2005 |
| | -- | Nestle Research Centre, Lausanne, Switzerland. | Pork patties | Nissen et al., 2004 |
| Carob fruit extracts | Liposterine® | Exentia, Madrid, Spain. | Cooked pork | Bastida et al., 2009 |
| | Exxenterol® | | | |

**Table 3. Applications of plant extracts as natural antioxidants in meat and meat products**

| Plant extract | Concentration of plant extract used | Meat/ meat product tested | Storage conditions of meat/meat product | Results | References |
|---|---|---|---|---|---|
| Rosemary extract | 200 ppm | Pork patties | Vacuum packaged, 4.5 °C, 10days | Reduced TBARS and hexanal values. Antioxidant efficiency in the order: Rosemary>Grape skin>Green tea>Coffee extract. | Nissen et al., 2004 |
| Grape skin extract | 200 ppm | | | | |
| Green tea extract | 200 ppm | | | | |
| Coffee extract | 50 ppm | | | | |
| White peony extract | 0.5-2 % | Raw and cooked goat meat patties | Refrigerated storage, 6 days | Reduced lipid oxidation, higher redness values than control. | Han & Rhee, 2005 |
| Red peony extract | | | | | |
| Moutan peony extract | | | | | |
| Sappanwood extract | | | | | |
| Rehmania extract | | | | | |
| Angelica extract | | | | | |
| Rosemary extract | 500 and 300 ppm | Raw frozen and precooked frozen sausage | Refrigerated storage | Reduced TBARS values and hexanal value, maintained red color in raw frozen sausage. | Sebranek et al., 2005 |
| Grape seed extract (Activin) | 1 % | Cooked ground beef | 4 °C, 9 days | Reduced TBARS values by 92% (grape seed extract and oleoresin rosemary extract), 94% (pine bark extract). Also, reduced hexanal content. | Ahn et al., 2007 |
| Pine bark extract (Pycnogenol) | | | | | |
| Oleoresin rosemary extract (Herblox) | | | | | |
| Green tea extract | 300 mg/kg meat | Low sulphite raw and cooked beef patties | Aerobic packaging, 4 °C, 9 days | Reduced lipid oxidation and redness loss in raw patties, delayed rancid flavor development in cooked patties. | Banon et al., 2007 |
| Grape seed extract | | | | | |
| Grape seed extract | 0.1, 1.0 % | Ground raw, cooked beef and pork | Refrigerated, frozen storage | Inhibited primary and secondary oxidation products. GSE more effective in inhibiting lipid oxidation than gallic acid. | Brannan & Mah, 2007 |
| Mint leaf extract | 0.1 % | Radiation processed lamb | Chilled temperature, 4 | Reduced TBARS values. Mint leaf | Kannat et al., 2007 |

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| | | meat | weeks | extract showed antioxidant activity equivalent to BHT. | |
| Grape seed extract | 0.01, 0.02 % | Cooked beef, pork patties | Patties overwrapped in PVC, 4 °C, 8 days | Reduced oxidative rancidity. Also reduced visual green discoloration in beef patties. GSE showed best antioxidant activity based on TBARS values. | Rojas & Brewer, 2007 |
| Oleoresin rosemary extract | 0.02 % | | | | |
| WS oregano extract | 0.02 % | | | | |
| Grape seed extract | 0.01, 0.02 % | Raw beef, pork patties | Vacuum packaged, -18 °C, 4 months | Reduced oxidative rancidity. Grape seed extract showed best antioxidant activity based on TBARS values. | Rojas & Brewer, 2008 |
| Oleoresin rosemary | 0.02 % | | | | |
| WS oregano extract | 0.02 % | | | | |
| Myrtle extract | 10 % | Beef patties | Wrapped in PE film, -20 °C, 120 days | Reduced lipid oxidation. Myrtle and rosemary extracts showed highest antioxidant activity than nettle and lemon balm extracts. Myrtle extract prevented color changes. | Akarpat et al., 2008 |
| Rosemary extract | | | | | |
| Nettle extract | | | | | |
| Lemon balm extract | | | | | |
| Urtica extract | 300, 600 ppm | Sucuk (lamb meat) | 60-90% RH, 18-25 °C | Reduced TBARS values and biogenic amine formation. Both extracts were more effective than BHT. | Karabacak & Bozkurt, 2008 |
| Hibiscus extract | | | | | |
| Carob fruit extracts (Liposterine and Exxenterol) | 30g/kg | Cooked pork | Chilled and frozen storage, 6 months | Reduced TBARS values and decreased thermal oxidation products | Bastida et al., 2009 |
| *E. americana* extract | 2.7, 5.4, 10.8 mg/100g | Cooked pork | 4 °C, 9 days | Retarded lipid oxidation, increased redness value. | Ifesan et al., 2009 |
| Grape seed extract | 0.02 % | Cooked frozen pork patties | Cooked patties overwrapped in PVC, -18 °C, 6 months | Reduced TBARS values. Grape seed extract showed more antioxidant activity than oleoresin rosemary, Water soluble oregano extract, BHT and BHA. | Sasse et al., 2009 |
| Oleoresin rosemary extract | | | | | |
| Water soluble oregano extract | | | | | |
| Cinnamon stick extract | 100 ml/25 g | Aerobically packaged raw pork | ~20 °C, 9 days | Retarded lipid oxidation. Clove was most effective | Shan et al., 2009 |
| Oregano | | | | | |

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| extract | | | | antioxidant. | |
| Clove extract | | | | | |
| Pomegranate peel extract | | | | | |
| Grape seed extract | | | | | |
| Nettle extract | 200, 500 ppm | Ground beef | MAP (80% $O_2$, 20% $CO_2$), 2 °C, 14 days | Retarded lipid oxidation. 500 ppm showed highest antioxidant effect. | Alp & Aksu, 2010 |
| Kinnow rind extract | 10 ml/500 g | Cooked goat meat patties | 4 °C, 12 days | Reduced TBARS values. Pomegranate rind extract showed highest antioxidant activity. | Devatkal et al., 2010 |
| Pomegranate rind extract | | | | | |
| Peanut skin extract | 0.02, 0.04, 0.06, 0.08, 0.10 % | Raw, cooked ground beef | 4 °C, 4 weeks | Inhibited the formation of peroxides and TBARS values. 0.06 % of peanut skin extract showed same effectiveness as 0.02 % BHA/BHT. Also inhibited oxidation of meat pigments at 0.02-0.10% level. | Yu et al., 2010 |
| Olive leaf extract | 100, 200 µg/g meat | Raw beef patties | MAP (80%$O_2$, 20% $CO_2$), aerobically packed, 4 °C, 12 days | Reduced TBARS value and oxymyoglobin oxidation relative to control. | Hayes et al., 2010a |
| | | Raw and cooked minced pork | MAP (80% $O_2$, 20% $CO_2$), 4 °C, 12 days aerobically packed, 4 °C, 8 days | | Hayes et al., 2010b |
| Grape seed extract (GSE) | 0.2 g/kg | Cooked, frozen, reheated beef patties | -18 °C, 6 months, overwrapped with PVC film | Reduced TBARS values. Antioxidant effectiveness was in the order of GSE>OR>WO. | Colindres and Brewer, 2011 |
| Oleoresin rosemary extract (OR) | | | | | |
| Water soluble oregano extract (WO) | | | | | |
| Olive leaf extract | 200 µg/g meat | Raw and cooked sausages | MAP (80%$O_2$, 20% $CO_2$), (70%$N_2$, 30%$CO_2$), and aerobic packaging, 4 °C, 21 days | Reduced lipid oxidation in both packagings. | Hayes et al., 2011 |
| Lotus rhizome knot extract | 3% | Raw and cooked ground beef and pork | 4 °C, 10 days | Lotus rhizome knot was more effective against lipid | Huang et al., 2011 |
| Lotus leaf | | | | | |

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| extract | | | | oxidation. | |
| Adzuki bean extract | 0.05, 0.1, 0.2, 0.3 % | Cured and uncured cooked pork sausages | 37 °C, 5 days | Reduced lipid oxidation, 0.2% adzuki bean extract was equally effective as 0.1% BHT in reducing TBARS values. 0.2 % increased *a** value but decreased *L** and *b** value. | Jayawardana et al., 2011 |
| Grape seed extract | 100, 300, 500 ppm | Pre-cooked, frozen, reheated beef sausage | -18 °C, 4 months, overwrapped in PVC | Reduced lipid oxidation. Lower concentrations (100 and 300 ppm) protected these samples against oxidation as well as or better than propyl gallate. | Kulkarni et al., 2011 |
| Green tea extract<br>Grape seed extract | 500, 3000, 6000 ppm | Raw and cooked goat meat | 5 °C, 9 days | Effective in reducing lipid oxidation. Grape seed extract increased redness, while green tea extract decreased it. | Rababah et al., 2011 |
| Green tea extract<br>Rosemary extract<br>Red pepper extract | 10 % | Cooked pork | 4 °C, 30 days | All plants extracts effectively reduce lipid oxidation in cooked pork meat compared to the control. Pepper extract was effective in maintaining redness and low TBARS values. | Wojciak et al., 2011 |
| Summer savory extract | 100, 250, 500 ppm | Ground beef | 4 °C, 72 hours | Lipid oxidation decreased, depending on the extract concentrations, 500 ppm gave the lowest TBARS values. | Aksu & Ozer, 2013 |
| Date pits extract | 0.50, 0.75, 1.00 % | Ground beef | 0 °C, 10 days | Reduced lipid oxidation. | Amany et al., 2012 |
| Broccoli powder extract | 1, 1.5, 2 % | Goat meat nuggets | Aerobically packaged, refrigerated storage, 16 days | Reduced lipid oxidation. 2 % was most effective. | Banerjee et al., 2012 |
| Curry leaf extract<br>Mint leaf extract | 5 ml/500 g meat | Raw ground pork meat | 4 °C, 12 days | Ethanol extract of curry leaf and water extract of mint leaf reduced the lipid oxidation. Also, decreased *L** and *a** | Biswas et al., 2012 |

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| | | | | values and increased *b** value. | |
| Moringa leaf extract | 0.1 % | Cooked goat meat patties | 4 °C, 15 days | The antioxidant activity of Moringa leaf extract was found to be comparable to BHT. | Das et al., 2012 |
| Moringa leaf extract | 300, 450, 600 ppm | Raw and cooked pork patties | 4 °C, 9 days and 15 days | Moringa leaf extract (600 ppm) was more effective in reducing lipid oxidation compared to Moringa leaf extract (450 and 300 ppm) but less effective compared to BHT (200 ppm) in both raw and cooked pork patties. Higher *a** and lower TBARS values were observed in Moringa leaf extract ( 600) and BHT (200 ppm) compared to control. | Muthukumar et al., 2012 |
| Pomegranate peel extract | 1 % | Ground goat meat and nuggets | Vacuum packaging, 4 °C, 9 days | Reduced lipid oxidation in both ground meat and nuggets. | Devatkal et al., 2012 |
| Rosemary extract | 260 mg/kg | Boerewors is a South African fresh sausage | 4 °C, 9 days and -18 °C, 100 days | Rosemary extract showed comparable lipid stability to $SO_2$ but better compared to chitosan. | Mathenjwa et al., 2012 |
| Grape seed extract | 0.01, 0.03, 0.05, 0.1, 0.3 and 0.5 % | Frankfurters (beef) | Vacuum packed, 4 °C, 90 days | Increased level of grape seed extract decreased the 2-thiobarbituric acid values of the product. | Ozvural & Vural, 2012 |
| St. John's wort extract | 5 mg/kg, 10mg/kg | Heated meat batters formulated with a healthier oil combination (olive, linseed and fish oils). | 2 °C, 19 days | Reduced lipid oxidation. | Sanchez-Muniz et al., 2012 |
| Ginger, onion, garlic extract | 5, 10 % | Stewed pork | 4 °C, 12 days | Retarded lipid oxidation. | Cao et al., 2013 |
| Rosemary leaf extract (Carnosic acid) | 22.5 ppm, 130 ppm | Raw and cooked ground buffalo meat patties | Raw patties aerobically packaged stored at 4 °C for 9 days; Cooked patties packed 28 | Reduced lipid oxidation, higher doses also stabilized color. | Naveena et al., 2013 |

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| | | | days | | |
| Grape seed extract | 0.1 % | Restructured mutton slices | Aerobic and vacuum packaging, 14 and 28 days respectively, 4 °C | Reduced lipid oxidation, compared to control and BHA (0.01%). Addition of grape seed extract at 0.1% enhanced the shelf-life of the product to at least 28 days. | Reddy et al., 2013 |

PVC- Polyvinyl chloride PE- Polyethylene TBARS- Thiobarbituric acid reactive substances RH- Relative humidity
MAP- Modified atmospheric packaging BHA- Butylated hydroxyanisole BHT- Butylated hydroxytoulene