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REVIEW

Overview of Studies on the Use of Natural Antioxidative Materials in Meat Products

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Abstract Studies conducted in the past decade related to the use of natural antioxidants in meat products revealed the prevalent use of plant-based antioxidative materials added as powders, extracts, or dried or raw materials to meat products. The amount of antioxidative materials varied from 7.8 ppm to 19.8%. Extracts and powders were used in small amounts (ppm to grams) and large amounts (grams to >1%), respectively. Antioxidative materials used in meat products are mainly composed of phenolic compounds and flavonoids, which are able to inhibit lipid peroxidation of meat products, thereby preserving meat quality. However, the main ingredients used in processed meat products are the traditional additives, such as sodium erythorbate, sodium hydrosulfite, and synthetic antioxidants, rather than natural antioxidants. This difference could be attributed to changes in the sensory quality or characteristics of meat products using natural antioxidants. Therefore, novel research paradigms to develop meat products are needed, focusing on the multifunctional aspects of natural antioxidants.

Keywords meat products, antioxidants, phenolic compounds, phytochemicals, flavonoid

Introduction

Antioxidants, such as polyphenolic compounds, inhibit the oxidation of food molecules by acting as free radical scavengers, singlet oxygen quenchers, metal ion chelators, and hydrogen donors (Hur et al., 2014; Mathew and Abraham, 2006). Polyphenols are good antioxidants owing to the 30–40 dihydroxy groups in their B ring and the galloyl ester in the C ring of flavonoids associated with iron binding (Chu and Chen, 2006; Khokhar and Owusu Apenten, 2003).

Meat products are susceptible to lipid oxidation in the presence of oxygen, light, heat, free radicals, and additives (sodium erythorbate, nitrite, and spices). Processing techniques, such as temperature control, heating, and packaging, can influence the oxidation of meat products (Falowo et al., 2014; Yim et al., 2020). Generally, an abundance of oxidized lipids in meat can reduce quality during storage because color and flavor are closely related to lipid oxidation. In the past decade, numerous antioxidants have been applied to meat products to prevent lipid oxidation, retard the development of off-flavors, and improve color (Kumar et al., 2015). For example, dietary antioxidants can reduce or prevent lipid oxidation in animal muscle foods, and the addition of antioxidants to meat products can improve the stability of oxidation during storage (Falowo et al., 2014; Zhou et al., 2020).

Although various antioxidative materials have been widely applied to meat products, this is less common in the meat industry. Furthermore, although natural antioxidants could conceivably replace synthetic antioxidants in meat products, they have rarely been used in the meat industry. Therefore, the purpose of this study was to investigate the reason for the lack of application of natural antioxidants in the meat industry through a comprehensive literature review, and to suggest a possible way to increase the use of natural antioxidants for manufacturing meat products.

Oxidation in Meat Products

Oxidation is one of the main factors associated with the reduction or degradation of quality of meat products without a microbial reaction. Oxidative processes affect several components, such as lipids and proteins, in meat, which contributes to not only the deterioration and acceptability failure of meat products, but also unfavorable consumer behavior or acceptance (Kumar et al., 2015). These factors lead to the development of an off-flavor, deterioration of color, and a decrease in nutritional quality due to the decomposition of essential fatty acids and vitamins (Domínguez et al., 2019).

Lipid oxidation in meat products is mainly generated through multiple factors, such as the fatty acid composition, heme proteins, and metals (Domínguez et al., 2019). Lipids are mainly composed of triglycerides and phospholipids; phospholipids, in particular, are responsible for the development of lipid oxidation and rancidity, because they are implicated in malondialdehyde formation as secondary products of lipid oxidation (Pikul et al., 1984). Pigment oxidation is caused by an iron ion binding to four N atoms within the heme protein (myoglobin). Myoglobin, called meat pigment, causes oxidation via free radical reaction, resulting in the oxidation of ferrous ions (Fe^{2+}) to the ferric form (Fe^{3+}). Protein oxidation occurs through the oxidative modification of several amino acids and free radical-mediated cleavage of the peptides and proteins, which contribute to the reaction of lipid peroxidation products (Ribeiro et al., 2019). Among amino acids, methionine, cysteine, arginine, tryptophan, and histidine residues (sulfhydryl, imidazole ring, thioether, and indole ring) are vulnerable to reactive oxygen species (ROS) through lipid peroxidation (Lobo et al., 2010). Besides, protein oxidation has been associated with the deterioration of the tenderness and juiciness of meat, as well as the reduction in the contents of essential amino acids and digestibility (Bhattacharya et al., 2016). Moreover, the multiple toxic compounds generated during lipid oxidation have been implicated in several human pathologies such as cancer, inflammation, atherosclerosis, Alzheimer's disease, and aging processes (Pereira and Abreu, 2018; Sottero et al., 2019). Thus, the use of antioxidant materials is vital in the meat industry.

Antioxidant Materials used in Meat Products

Tables 1–4 show the antioxidants used in meat products, and their active compounds and factors, as found in previous studies. These materials have been used in many meat products, including pork patties, pork sausage, ham, beef patties, beef sausage, beef jerky, chicken patties, chicken sausage, lamb meat, and goat meat products (Tables 1–4). Most studies have focused on plant-based antioxidative materials, such as phenolics, flavonoids, anthocyanin, chlorogenic acid, lycopene, quercetin, catechins, tocopherol, rutin, caffeic acid, ferulic acid, p-coumaric acid, protocatechuic acid, β-carotene, vitamin C,

Table 1. **Use of antioxidants in meat products from pork**

Meat product	Raw materials/concentration	Active compounds	Active factors	Reference
Pork patties	Ethanol extracted tomato powder/1%	Lycopene, gallic acid, catechin	DPPH radical-scavenging activity, iron-chelating ability, reducing power	(Kim and Chin, 2017)
	Ethanol extract of curry leaf, water extract of mint leaf/1%	Phenolics	DPPH, superoxide and ABTS radicals-scavenging activity	(Biswas et al., 2012)
	Spent, ground, and lyophilized brew from roasted coffee	Chlorogenic acid, Maillard reaction products	Iron-chelating ability	(Jully et al., 2016)
	Ball-milled persimmon byproduct powder/0.5%, 1%	Phenolics, flavonoids	DPPH radical-scavenging activity	(Ramachandraiah and Chin, 2018)
	Ethanol extracts of dried spices/0.05%	Phenolics	DPPH radical-scavenging activity, iron-chelating ability, reducing power	(Kong et al., 2010)
	Ethanol extracts of black currant/0.5%, 1%, 2%	Anthocyanin	DPPH and ABTS radical-scavenging activity, reducing power	(Jia et al., 2012)
	70% ethanol extracted Du-zhong/0.1%	Chlorogenic acid, caffeic acid, protocatechuic acid, rutin, quercetin, kaempferol	DPPH radical-scavenging activity, reducing power	(Xu et al., 2010)
	80% ethanol extracted pomegranate rind powder extract and seed powder extract, pomegranate juice/0.02%	NA	TBARS, POV	(Qin et al., 2013)
	Water and methanol extracted garlic	Phenolics	DPPH radical-scavenging activity, iron-chelating ability, reducing power	(Park and Chin, 2010)
	Grape seed extract™, oleoresin rosemary™, water-soluble oregano extract™/0.02%	NA	TBARS	(Sasse et al., 2009)
	Methanol extract of red grape pomace/0.06%	Phenolics, anthocyanins	TBARS	(Garrido et al., 2011)
	Air dried lotus leaf and barley leaf powder/0.1%, 0.5%	NA	TBARS, POV	(Choe et al., 2011)
	Rosemary extracts® and green tea extracts	NA	TBARS, thiol group concentration	(Haak et al., 2009)
	70% ethanol of mustard leaf kimchi/0.05%, 0.1%, 0.2%	NA	TBARS, conjugated dienes, POV, free fatty acids	(Lee et al., 2010)
	Rosemary and lemon balm extracts/ 0.03% and 0.1%	Phenolics	TBARS	(Lara et al., 2011)
Pork sausage	Waster extract of spirulina platensis and purified polysaccharide/0.1%, 0.25%, 0.5%	Maillard products	DPPH radical-scavenging activity	(Luo et al., 2017)
	Ethanol extract of rosemary, rosemary essential oil/0.2%	Phenolic compounds	DPPH and ABTS radical-scavenging activity, reducing power	(Bianchin et al., 2017)

Table 1. Use of antioxidants in meat products from pork (continued)

Meat product	Raw materials/concentration	Active compounds	Active factors	Reference
Pork sausage	Water extract of Jabuticaba/2%, 4%	Anthocyanin, phenolics	DPPH radical-scavenging activity, reducing power	(Baldin et al., 2016)
	Water extract of *Citrus paradise* bark/0.25%	Phenolics, flavonoids	DPPH radical-scavenging activity, reducing power	(Sayari et al., 2015)
	Clove bud powder/0.1%, 0.2%	Phenolics	DPPH radical-scavenging activity	(Jin et al., 2016)
	Ethanol extract of bee pollen/0.02%	*p*-Coumaric acid, ferulic acid, rutin, myricetin, *trans*-cinnamic acid, quercetin, kaempferol	DPPH and ABTS radical-scavenging activity, reducing power	(de Florio Almeida et al., 2017)
	60% ethanol extract of peanut kernel/0.01%	Stilbenes	DPPH and ABTS radical-scavenging activity, reducing power	(Ko et al., 2018)
	Methanol extract of *Pistacia lentiscus* L. leaf and fruit/0.03%	Phenolics	DPPH and ABTS radical-scavenging activity, reducing power	(Botsaris et al., 2015)
	80% ethanol extract of blueberry leaf extract/0.2%	Phenolics, chlorogenic acid	ABTS radical-scavenging activity, reducing power	(Hur et al., 2013)
	Adzuki bean extract/0.05%, 0.1%, 0.2%, 0.3%	Phenolics	TBARS	(Jayawardana et al., 2011)
	Plant-derived nutraceuticals/0.02%–0.03%	NA	TBARS	(Hayes et al., 2011)
	Water extract of *Achyranthes japonica* Nakai	Phenolics, flavonoids	DPPH radical-scavenging activity, POV	(Park et al., 2013)
	Green tea and rosemary extracts^{TM}	NA	TBARS	(Jongberg et al., 2013)
	Norbixin/10%, lycopene/10%, zeaxanthin/5%, β-carotene/10%	Norbixin, lycopene, zeaxanthin, β-carotene	TBARS	(Mercadante et al., 2010)
	Satureja montana L. essential oil/7.8, 15.6 and 31.25 ppm	NA	DPPH radical-scavenging activity, TBARS	(Coutinho de Oliveira et al., 2012)
	Safflower (*Carthamus tinctorius* L.) red pigment	NA	TBARS	(Kim et al., 2015)
Pork fermented sausage	Ethanol extract of *Kitaibelia vitifolia*/1.25%, 3%	Phenolics, flavonoids	DPPH, hydroxyl radical-scavenging activity, iron-chelating ability	(Kurćubić et al., 2014)
	Lyophilized water extracts of *Borago officinalis*/340 ppm	Phenolics	DPPH and ABTS radical-scavenging activity	(de Ciriano et al., 2009)
	Water extract of *Melissa offcinalis* L./686 ppm	NA	DPPH and ABTS radical-scavenging activity	(de Ciriano et al., 2010)
	Rosemary powder/1,000, 2,000 ppm, rosemary extract/250, 500 ppm	NA	TBARS	(Gök et al., 2011)
	Ethanol : water (1:1) extracts of grape seed and chestnut	Phenolics	DPPH and ABTS radical-scavenging activity, TBARS	(Lorenzo et al., 2013)
	Freeze-dried leek powder/0.84%, 1.68%	NA	TBARS	(Tsoukalas et al., 2011)

Table 1. Use of antioxidants in meat products from pork (continued)

Meat product	Raw materials/concentration	Active compounds	Active factors	Reference
Pork ham	Fresh and dried plum/2.5%, 5%	NA	TBARS	(Nuñez de Gonzalez et al., 2009)
	Apple polyphenol/300, 500, 1000 ppm	NA	TBARS	(Sun et al., 2010)
Pork nuggets	Kordoi fruit juice, water extract of bamboo shoot/4%, 6%	Phenolics	TBARS	(Thomas et al., 2016)

DPPH, 2,2-diphenyl-1-picrylhydrazyl; ABTS, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); NA, not analyzed; TBARS, thiobarbituric acid reactive substances; POV, peroxide value.

vitamin E, carotenoids, myricetin, caronosine, kaempferol, zeaxanthin, chrysin, chlorophyll, sesamol, rosmarinic acid, carnosic acid, carnosol, and gallic acid.

Antioxidative materials can be applied to an animal's diet either to reduce or prevent the oxidation of processed meat products (Aslam et al., 2020; Kumar et al., 2015; Oh et al., 2020). Most of the surveyed studies involved simple applications, such as adding or mixing antioxidative materials (powders, extracts, or dried or raw materials) into meat products.

In Tables 1–4, the levels of antioxidative materials used in meat products varied from 7.8 ppm to 19.8%, with levels depending on the characteristics of the antioxidative materials. For instance, extracts were used in small amounts, whereas antioxidative powders, puree, or juice were used in large amounts. Overall, the use of antioxidants in meat products contributed to the inhibition of the activities of different radicals (e.g., DPPH, ABTS, and hydroxyl radicals), TBARS, free fatty acids, volatile basic nitrogen, and peroxide value. Furthermore, the antioxidants used in meat products contribute to increased iron-chelating activity, reducing power, and superoxide dismutase.

The survey revealed that approximately 70% of the many natural antioxidant materials used in meat products have been plant extracts. Their frequent use may reflect their phenolic-rich nature, which provides a good alternative to synthetic antioxidants (Shah et al., 2014). In general, plant extracts are obtained using different solvents. Antioxidative activity is affected by the extraction methods and solvents because the yield and composition of antioxidative compounds, such as phenolic compounds and flavonoids, depend on the extraction solvents and methods. The extraction yield depends on solvent polarity, pH changes, extraction temperature, extraction time, and chemical composition of the sample. For the same extraction conditions (time and temperature), the solvent and the composition of the sample are the most important parameters (Turkmen et al., 2006). Ethanol and water are the most frequently used extraction solvents, likely because they are edible and safe. To obtain polyphenols from plant resources, polar solvents are frequently used. Ethanol is a suitable solvent for polyphenol extraction (Shah et al., 2014). Methanol is suitable for the extraction of low-molecular-weight polyphenols, and acetone is a good solvent for the extraction of high-molecular-weight flavonoids (Dai and Mumper, 2010; Shah et al., 2014). In this survey, all antioxidative materials that were used were known to exhibit antioxidative activity in meat products after cooking or during storage. Most phytochemicals, including phenolic compounds and flavonoids, are known to have antioxidative activity in other food sources. Thus, the antioxidative activity of various phytochemicals obtained from plant-based foods depends on the extraction solvents and methods, and they can inhibit oxidation in meat products through their antioxidative ability.

Mechanisms Underlying the Effects of Antioxidative Materials used in Meat Products

In meat products, lipid oxidation can reduce meat quality by the degradation of unsaturated fatty acids and the conversion

Table 2. Use of antioxidants in meat products from beef

Meat product	Raw materials/concentration	Active compounds	Active factors	Reference
Beef patties	Vitamin E, carnosine, grape seed extract, tea catechin/0.03%	Vitamin E, L-carnosine, polyphenols, catechin	TBARS	(Liu et al., 2015)
	Ethanol extracts of leafy green vegetables/1%	Polyphenols, flavonoids	DPPH and ABTS radical-scavenging activity, reducing power	(Kim et al., 2013)
	Water extracts of *Nitraria retusa*/0.5%, 0.75%, 1%	Phenolics, flavonoids, anthocyanins	DPPH radical-scavenging activity, reducing power	(Mariem et al., 2014)
	Lyophilized water extract of *Melissa officinalis*/40–500 ppm	Phenolics	Oxygen radical-absorption capacity	(Barriuso et al., 2015)
	Ethanol extracts of propolis/2%	Cinnamic acid, rutin, myricetin, quercetin, chrysin, kaempferol, apigenin	DPPH radical-scavenging activity	(Vargas-Sánchez et al., 2014)
	Ethanol : water solution (7:3) extracts of *Moringa oleifera* L. and *Bidens pilosa* L. leaf/0.1%	Carotenoid, chlorophyll	DPPH and ABTS radical-scavenging activity, TBARS	(Falowo et al., 2017)
	Rosemary powder/0.1%	NA	TBARS	(Sánchez-Escalante et al., 2011)
	Water extract of grape seed, and rosemary extract®/0.2%–1.5%	Phenolics	ABTS radical-scavenging activity	(Gibis and Weiss, 2012)
	Water extract of hibiscus/0.2%–0.8%	Phenolics	ABTS radical-scavenging activity	(Gibis and Weiss, 2010)
	Olive leaf extract/0.01%, 0.02%	NA	TBARS	(Hayes, et al., 2011)
	Grape seed extract™, oleoresin rosemary®, water-soluble oregano extract™/0.02%	NA	TBARS	(Colindres and Susan Brewer, 2011)
	White grape extract/500 ppm	NA	TBARS	(Jongberg et al., 2011)
	Tea catechins, carnosine, α-tocopherol/0.03%	Tea catechins, carnosine, α-tocopherol	TBARS	(Liu et al., 2010)
	Galangal, fingerroot, turmeric, cumin, coriander seeds/0.2%	Phenolics	DPPH radical-scavenging activity	(Puangsombat et al., 2011)
	Essential oils of marjoram and rosemary/200 ppm	NA	TBARS	(Mohamed and Mansour, 2012)
	Plum puree/5%, 10%, 15%	NA	TBARS	(Yıldız-Turp and Serdaroglu, 2010)
	Water extract of summer savory (*Satureja hortensis*)/100, 250, 500 ppm	NA	TBARS	(AKSU and ÖZER, 2013)
	Water extract of *Urtica dioica* L./200, 500 ppm	NA	TBARS	(Alp and Aksu, 2010)
	70% ethanol and water extracts of ten edible plant/0.1%, 0.5%	Phenolics, chlorophyll, vitamin C, carotenoids	DPPH radical-scavenging activity, TBARS	(Kim et al., 2013)
	80% ethanol extract of peanut skin/0.02%–0.1%	NA	TBARS, POV	(Yu et al., 2010)
	Tocopherols/0.1%, oregano-rosemary/0.05%	α-Tocopherol, β-tocopherol, γ-tocopherol, δ-tocopherol	TBARS	(Pennisi Forell et al., 2010)

Table 2. **Use of antioxidants in meat products from beef (continued)**

Meat product	Raw materials/concentration	Active compounds	Active factors	Reference
Beef patties	74% ethanol extract of vine tea (*Ampelopsis grossedentata*)	Phenolics, dihydromyricetin	DPPH radical-scavenging activity, TBARS	(Ye et al., 2015)
	Basil (*Ocimum basilicum* L.) essential oil/0.0625%, 0.125%, 0.25%	Phenolics	TBARS	(Chaleshtori et al., 2015)
	Methanol extracts of roselle (*Hibiscus sabdariffa* L.) seeds	Phenolics	DPPH radical-scavenging activity, TBARS	(Mohd-Esa et al., 2010)
	Ascorbic acid/0.05%, α-tocopherol/0.01%, sesamol/0.01%	Ascorbic acid, α-tocopherol, sesamol	TBARS	(Ismail et al., 2009)
	Rosemary and oregano extracts^{TM}/400 ppm	NA	TBARS	(Trindade et al., 2010)
	Methanol : water : acetone : formic acid (20:40:40:1) extract of date pits (*Phoenix dactylifera* L.)	Phenolics	Reducing power, TBARS	(Amany et al., 2012)
	Rosemary ethanol extract/0.05%, 0.2%, 0.5%	Rosmarinic acid, carnosol, carnosic acid	DPPH radical-scavenging activity	(Puangsombat, et al., 2011)
Beef sausage	Pomegranate rind powder/1%, 2%, 3%, red beet powder/1%, 3%, 5%	Phenolics	DPPH radical-scavenging activity, TBARS	(El-Gharably and Ashoush, 2011)
	Rosemary extract/250 ppm, mint extract/62 ppm	NA	TBARS, POV	(Azizkhani and Tooryan, 2015)
	Water extract of grape seed/100, 300, 500 ppm	NA	TBARS	(Kulkarni et al., 2011)
	Carrot juice/19.8%	Carotenoids, phenolics	TBARS, POV	(Badr and Mahmoud, 2011)
Beef jerky	*Salicornia herbacea* powder/0.5%, 1%	NA	TBARS	(Lim et al., 2013)
	Methanol extracts of *Citrus junos sieb*. and *Prunus mume*/1%	NA	TBARS	(Lim et al., 2012)

TBARS, thiobarbituric acid reactive substances; DPPH, 2,2-diphenyl-1-picrylhydrazyl; ABTS, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); NA, not analyzed; POV, peroxide value.

of oxymyoglobin to metmyoglobin pigment, resulting in the generation of free radicals that might lead to deterioration of the meat (Suman and Joseph, 2013). Therefore, retarding lipid oxidation during storage is important for preserving the quality of meat products. The content of phenolic compounds is regarded as an effective source of antioxidants to inhibit oxidation in muscle-based foods (Kumar et al., 2015; Pennington and Fisher, 2009). The aromatic ring structure primarily determines the antioxidative character of phenolic compounds, including phenolic acids, quinones, diterpenes, tannins, curcuminoids, coumarins, lignans, stilbenes, and flavonoids.

Phenolic antioxidants interfere with the oxidation process as free radical terminators and metal chelators (Shahidi and Ambigaipalan, 2015) because phenolic compounds have strong hydrogen radical ($H^{\cdot}$)-donating activity (Muchuweti et al., 2007) and the presence of aromatic hydroxyl (OH) groups in phenolic compounds is a critical determinant of their H donation and free radical-scavenging activity (Ng et al., 2000). The antioxidant potential of phenolic compounds depends on the number and arrangement of the OH groups in the molecules of interest (Shahidi and Ambigaipalan, 2015).

Table 3. Use of antioxidants in meat products from chicken

Meat product	Raw materials/concentration	Active compounds	Active factors	Reference
Chicken patties	Plum peel pulp microparticles/2%	β-Carotene, lutein, α-tocopherol, γ-tocopherol, proanthocyanidins, flavonoids	Reducing power	(Basanta et al., 2018)
	Grape dietary fiber/0.5%, 1%, 1.5%, 2%	Phenolics	ABTS radical scavenging activity, TBARS	(Sáyago-Ayerdi et al., 2009)
	Water extract of pomegranate juice, pomegranate rind powder/0.01%	Phenolics	DPPH radical scavenging activity, reducing power, TBARS	(Naveena et al., 2008)
	Colorifico/0.4%	Vitamin E	TBARS	(Castro et al., 2011)
	Aqueous extracts of curry leaves, fenugreek leaves/2%	Phenolics	DPPH radical scavenging activity, TBARS	(Devatkal et al., 2012)
	Water extract of pomegranate rind powder/50, 100, 150, 200 ppm	Phenolics	DPPH radical scavenging activity, reducing power, TBARS	(Naveena et al., 2008)
	Water extract of kinnow and pomegranate byproduct/2%	Phenolics	TBARS	(Devatkal et al., 2011)
	Lotus (*Nelumbo nucifera*) leaf powder/0.1%, 0.2%, 0.4%	NA	TBARS, VBN	(Choi et al., 2011)
	80% ethanol extract of peanut skin/3%	Phenolics	DPPH radical scavenging activity, reducing power, TBARS	(Munekata et al., 2015)
	MeOH:EtOH (1:1) extract of strawberry/0.65%, 1.3%	NA	DPPH radical scavenging activity, TBARS	(Saha et al., 2011)
	Green tea extract/400 ppm	NA	TBARS	(Jamwal et al., 2015)
Chicken sausage	Rosemary, Chinese mahogany/500, 1,000, 1,500 ppm	Phenolics	TBARS, VBN	(Liu et al., 2009)
	Drumstick (*Moringa oleifera*) leaves/0.25%, 0.5%, 0.75%, 1%	Phenolics	DPPH radical scavenging activity, TBARS	(Jayawardana et al., 2015)
	Garlic, coriander/2%, 3%, 5%	NA	TBARS	(Bali et al., 2011)
	50% ethanol extract of mugwort/0.2%	NA	TBARS	(Hwang et al., 2015)
	Sorghum bran/0.02%	NA	TBARS, POV	(Shin et al., 2011)
Chicken nuggets	*Ganghwayakssuk* (*Artemisia princeps* Pamp.)/0.01%, 0.05%, 0.1%, 0.2%	NA	TBARS, POV	(Hwang et al., 2013)
Chicken meat balls	Pomegranate rind powder extract/2.5%, 5%	NA	TBARS	(Chandralekha et al., 2012)
Chicken lollipop, chicken chili	Water extract of pomegranate peel/0.1%, 0.5%	Phenolics, flavonoids	DPPH radical and superoxide anion scavenging activity, reducing power, iron chelating ability, TBARS	(Kanatt et al., 2010)

ABTS, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); TBARS, thiobarbituric acid reactive substances; DPPH, 2,2-diphenyl-1-picrylhydrazyl; NA, not analyzed; VBN, volatile basic nitrogen; POV, peroxide value.

Table 4. Use of antioxidants in meat products from other sources

Meat product	Raw materials/concentration	Active compounds	Active factors	Reference
Lamb patties	Aqueous extracts of tomato, red grape, olive, and pomegranate byproducts/0.1%	Phenolics, lycopene, β-carotene, vitamin C	DPPH radical-scavenging activity, iron-chelating ability, reducing power	(Andrés et al., 2017)
Goat meat patties	Water extract of *Moringa oleifera* leaves/0.1%	Phenolics, flavonoids	DPPH radical-scavenging activity, reducing power, TBARS	(Das et al., 2012)
	Kinnow rind, pomegranate rind and seed powders/0.5%	Phenolics	DPPH radical-scavenging activity, TBARS	(Devatkal et al., 2010)
Goat meat nuggets	Water extract of pomegranate peel/1%	NA	TBARS	(Devatkal et al., 2014)
	Water extract of broccoli powder/1%, 1.5%, 2%	Phenolics	DPPH radical-scavenging activity, reducing power, TBARS	(Banerjee et al., 2012)
Restructured mutton slices	Grape seed extract/0.1%	NA	TBARS	(Reddy et al., 2013)
Buffalo patties	Clove essential oil/0.1%, grape seed extract/0.1%, 0.2%	NA	TBARS	(Tajik et al., 2014)

DPPH, 2,2-diphenyl-1-picrylhydrazyl; TBARS, thiobarbituric acid reactive substances; NA, not analyzed.

Free OH flavonoid groups scavenge free radicals and chelate metal ions, including Fe^{2+}, Fe^{3+}, and Cu^{2+}. Flavonoids exhibit antioxidative activity because their chemical structures contain an *o*-diphenolic group, a 2–3 double bond conjugated with the 4-oxo function, and OH groups at positions 3 and 5 (Hur et al., 2014). The flavonoid heterocycle contributes to the antioxidant activity through a free 3-OH and by permitting the conjugation between the aromatic rings (Heim et al., 2002). Polyphenols are good natural antioxidants because they have a number of OH groups, which confer antioxidative properties to these compounds (Chu and Chen, 2006; Hur et al., 2014; Khokhar and Owusu Apenten, 2003).

Therefore, antioxidative materials can inhibit lipid oxidation by preventing chain inhibition by scavenging oxidation-initiating radicals, breaking chain reactions, decomposing peroxides, decreasing localized oxygen concentrations, and binding to chain formation-initiating catalysts, such as metal ion catalysts.

Commercial Application of Antioxidative Materials in Meat Products

For several decades, numerous natural antioxidants have been widely studied in the food science field, including in meat products. However, the use of natural antioxidants in the meat industry is scarce.

We found that most of these processed meat products were prepared using traditional additives, such as vitamin C and E, sodium erythorbate, or sodium hydrosulfite, as antioxidants, instead of natural antioxidants (phytochemicals, other vitamins, or extracts). Although several processed meats are labeled as “organic” and “natural”, they do not use natural antioxidants. Therefore, we cannot present data on the development of meat products using natural antioxidants.

This indicates a lack of research attention to natural antioxidants in the development of meat products. Therefore, we offer the following suggestions or comments for the study of antioxidants and their use in the meat industry.

First, the lack of utilization of natural antioxidants could be due to the fact that using synthetic antioxidants is more cost-effective, safer, and simpler than using natural antioxidants (Mbah et al., 2019; Pokorný, 2007).

- The meat industry has difficulty in developing products using natural antioxidants because of the possibility of changing the sensory characteristics of products.
- The shelf-life of meat products can easily be extended by controlling temperature conditions, employing packaging methods, and using preservatives.
- Consumers may not be interested in the benefits of increasing the shelf life of meat products or issues related to lipid oxidation.
- Some consumers prefer meat products with a short shelf-life because they think that products with a short shelf-life lack additives or are natural.

Second, scientists already know the antioxidant activity of most natural substances containing phytochemicals, but consumers and the meat industry are less aware of this.

- Traditional spices in meat products are known to have strong antioxidative activity. These spices include rosemary, nutmeg, cloves, fennel, onion, garlic, ginger, thyme, pepper, cumin, caraway, coriander, laurel leaf, allspice, anise, basil, cardamom, oregano, and turmeric.
- The main mechanisms underlying the antioxidative activity of phytochemicals in meat products have already been discovered (Falowo et al., 2014; Kumar et al., 2013; Kumar et al., 2015).
- Because of the increasing health awareness of consumers, meat products using natural antioxidants have a positive effect on purchasing behavior (Karre et al., 2013; Mitterer-daltoé et al., 2020). Therefore, it is necessary to encourage the meat industry to use or label natural food antioxidants from this point of view.
- Most phytochemicals and many natural sources exhibit antioxidative activity, and there is a need to further confirm this for their application in the meat industry.
- There is a need to publish a paper (i.e., presenting the antioxidative effect of extracts or phytochemicals) with an accurate examination of the structure or profile of extracts from plant-based foods or phytochemicals.
- There is a need to study the exact structural profile of active compounds of new materials in addition to approaches for improving antioxidant activity.

Third, although the use of natural antioxidants is limited in developing meat products, natural antioxidants or bioactive materials should be considered multifunctional, providing antioxidative activity, reducing harmful substances, improving color stability, improving flavor, or controlling pathogens at low cost.

- Bioactive compounds such as antioxidants that are multifunctional could be more usable.
- Certain antioxidants can effectively prevent the production of carcinogens (heterocyclic amines, polycyclic aromatic hydrocarbons, biogenic amines, or benzopyrene) during cooking.
- Certain antioxidants can effectively replace sodium nitrite as a coloring agent.
- Certain antioxidants can be used as novel spices in meat products.
- Antioxidants should be safe to ingest.

- Antioxidants should be readily available and inexpensive.

Taken together, we suggest that more efforts are needed to develop safer, easy-to-obtain, easy-to-use, and cost-effective materials, and to promote these materials to consumers and the meat industry.

Conclusion

Numerous plant resources are rich in vitamins, tocopherols, phenolic compounds, and flavonoids. All these compounds possess antioxidative activity and can hence inhibit the lipid oxidation of meat products during cooking or storage. The antioxidative activity of these phytochemicals in meat products has long been recognized, widely studied, and confirmed, and the mechanisms underlying their action have already been tested. For these reasons, studies on the antioxidative effects of phytochemical or plant resources (extracts, oils, seeds, or powders) on meat products are predictable. However, despite the prospect that natural antioxidants could replace synthetic antioxidants in meat products, natural antioxidants are rarely used in the meat industry. Meat scientists must develop novel research paradigms that allow the use of bioactive compounds in the development of meat products.

Conflicts of interest

The authors declare no conflicts of interest.

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Author Contributions

Conceptualization: Hur SJ. Data curation: Lee SY, Lee DY, Kang HJ, Kim HS. Investigation: Lee SY, Lee DY, Kang HJ, Kim HS. Writing-original draft: Lee SY, Hur SJ. Writing-review & editing: Lee SY, Lee DY, Kim OY, Kang HJ, Kim HS, Hur SJ.

Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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