Overview of studies on the use of natural antioxidative materials in meat products

Seung Yun Lee [a], Da Young Lee [a], On You Kim [a], Hea Jin Kang [a], Hyeong Sang Kim [b], and Sun Jin Hur [a,*]

Department of Animal Science and Technology, Chung-Ang University, 4726 Seodong-daero, Daedeok-myeon, Anseong-si, Gyeonggi-do 17546, Korea.

*Correspondence: Sun Jin Hur, Department of Animal Science and Technology, Chung-Ang University, 4726 Seodong-daero, Daedeok-myeon, Anseong-si, Gyeonggi 456-756, Republic. Tel.: +82 31-670-4673; Fax: +82 31-675-3108; E-mail: hursj@cau.ac.kr.

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, 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 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 (M 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).

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.

Conclusions

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.

Acknowledgments

This research was supported by Main Research Program (20200764) of the Korea Food Research Institute(KFRI) funded by the Ministry of Science and ICT.

Conflicts of interest

The authors declare no conflicts of interest.

References

Aksu Mi, Özer H. 2013. Effects of lyophilized water extract of satureja hortensis on the shelf life and quality properties of ground beef. Journal of Food Processing and Preservation 37: 777-783.

Almeida JdF, Reis ASd, Heldt LFS, Pereira D, Bianchin M, Moura Cd, Plata-Oviedo MV, Haminiuk CWI, Ribeiro IS, Luz CFPd, Carpes ST. 2017. Lyophilized bee pollen extract: A natural antioxidant source to prevent lipid oxidation in refrigerated sausages. LWT - Food Science and Technology 76: 299-305.

Alp E, Aksu Mİ. 2010. Effects of water extract of Urtica dioica L. and modified atmosphere packaging on the shelf life of ground beef. Meat Science 86: 468-473.

Amany MMB, Shaker MA, Abeer AK. 2012. Antioxidant activities of date pits in a model meat system. International Food Research Journal 19: 223-227.

Andrés AI, Petrón MJ, Adámez JD, López M, Timón ML. 2017. Food by-products as potential antioxidant and antimicrobial additives in chill stored raw lamb patties. Meat science 129: 62-70.

Aslam S, Shukat R, Khan MI, Shahid M. 2020. Effect of Dietary Supplementation of Bioactive Peptides on Antioxidant Potential of Broiler Breast Meat and Physicochemical Characteristics of Nuggets. Food Science of Animal Resources 40: 55-73.

Azizkhani M, Tooryan F. 2015. Antioxidant and Antimicrobial Activities of Rosemary Extract, Mint Extract and a Mixture of Tocopherols in Beef Sausage during Storage at 4C. Journal of Food Safety 35: 128-136.

Badr HM, Mahmoud KA. 2011. Antioxidant activity of carrot juice in gamma irradiated beef sausage during refrigerated and frozen storage. Food chemistry 127: 1119-1130.

Baldin JC, Michelin EC, Polizer YJ, Rodrigues I, de Godoy SHS, Fregonesi RP, Pires MA, Carvalho LT, Fávaro-Trindade CS, de Lima CG, Fernandes AM, Trindade MA. 2016. Microencapsulated jabuticaba (Myrciaria cauliflora) extract added to fresh sausage as natural dye with antioxidant and antimicrobial activity. Meat Science 118: 15-21.

Bali A, Das S, Khan A, Patra D, Biswas S, Bhattachar D. 2011. A Comparative Study on the Antioxidant and Antimicrobial Properties of Garlic and Coriander on Chicken Sausage. International Journal of Meat Science 1: 108-116.

Banerjee R, Verma AK, Das AK, Rajkumar V, Shewalkar AA, Narkhede HP. 2012. Antioxidant effects of broccoli powder extract in goat meat nuggets. Meat Science 91: 179-184.

Barriuso B, Ansorena D, Calvo MI, Cavero RY, Astiasarán I. 2015. Role of Melissa officinalis in cholesterol oxidation: Antioxidant effect in model systems and application in beef patties. Food Research International 69: 133-140.

Basanta MF, Rizzo SA, Szerman N, Vaudagna SR, Descalzo AM, Gerschenson LN, Pérez CD, Rojas AM. 2018. Plum (Prunus salicina) peel and pulp microparticles as natural antioxidant additives in breast chicken patties. Food Research International 106: 1086-1094.

Bhattacharya D, Kandeepan G, Vishnuraj MR. 2016. Protein Oxidation in Meat and Meat Products-A Review. Journal of Meat Science and Technology| April-June 4: 44-52.

Bianchin M, Pereira, D.G., Reis, A.S., Almeida, J.D., Silva, L.D., Moura, C.O., & Carpes, S.T. 2017 Rosemary Essential Oil and Lyophilized Extract as Natural Antioxidant Source to Prevent Lipid Oxidation in Pork Sausage. Advance Journal of Food Science Technology 13: 210-217.

Biswas AK, Chatli MK, Sahoo J. 2012. Antioxidant potential of curry (Murraya koenigii L.) and mint (Mentha spicata) leaf extracts and their effect on colour and oxidative stability of raw ground pork meat during refrigeration storage. Food Chemistry 133: 467-472.

Botsaris G, Orphanides A, Yiannakou E, Gekas V, Goulas V. 2015. Antioxidant and antimicrobial effects of Pistacia lentiscus L. extracts in pork sausages. Food technology and biotechnology 53: 472-478.

Castro WF, Mariutti LRB, Bragagnolo N. 2011. The effects of colorifico on lipid oxidation, colour and vitamin E in raw and grilled chicken patties during frozen storage. Food Chemistry 124: 126-131.

Chaleshtori R, Rokni N, Rafieian-kopaei M, Drees F, Salehi E. 2015. Antioxidant and Antibacterial Activity of Basil (Ocimum basilicum L.) Essential Oil in Beef Burger. Journal of Agricultural Science and Technology 17: 817-826.

Chandralekha S, Jagadeesh Babu A, Moorthy PRS, Karthikeyan B. 2012. Studies on the Effect of Pomegranate Rind Powder Extract as Natural Antioxidant in Chicken Meat Balls During Refrigerated Storage. Journal of Advanced Veterinary Research 107-112%V 102.

Choe JH, Jang A, Lee ES, Choi JH, Choi YS, Han DJ, Kim HY, Lee MA, Shim SY, Kim CJ. 2011. Oxidative and color stability of cooked ground pork containing lotus leaf (Nelumbo nucifera) and barley leaf (Hordeum vulgare) powder during refrigerated storage. Meat Science 87: 12-18.

Choi YS, Choi JH, Kim HY, Kim HW, Lee MA, Chung HJ, Lee SK, Kim CJ. 2011. Effect of lotus (*Nelumbo nucifera*) leaf powder on the quality characteristics of chicken patties in refrigerated storage. Korean Journal for Food Science of Animal Resources 31: 9-18.

Chu SC, Chen C. 2006. Effects of origins and fermentation time on the antioxidant activities of kombucha. Food Chemistry 98: 502-507.

Ciriano MG-Id, García-Herreros C, Larequi E, Valencia I, Ansorena D, Astiasarán I. 2009. Use of natural antioxidants from lyophilized water extracts of Borago officinalis in dry fermented sausages enriched in ω-3 PUFA. Meat Science 83: 271-277.

Colindres P, Susan Brewer M. 2011. Oxidative stability of cooked, frozen, reheated beef patties: effect of antioxidants. Journal of the Science of Food and Agriculture 91: 963-968.

Coutinho de Oliveira TL, Malfitano de Carvalho S, de Araújo Soares R, Andrade MA, Cardoso MdG, Ramos EM, Piccoli RH. 2012. Antioxidant effects of Satureja montana L. essential oil on TBARS and color of mortadella-type sausages formulated with different levels of sodium nitrite. LWT - Food Science and Technology 45: 204-212.

Dai J, Mumper RJ. 2010. Plant phenolics: extraction, analysis and their antioxidant and anticancer properties. Molecules 15: 7313-7352.

Das AK, Rajkumar V, Verma AK, Swarup D. 2012. Moringa oleiferia leaves extract: a natural antioxidant for retarding lipid peroxidation in cooked goat meat patties. International journal of food science & technology 47: 585-591.

de Ciriano MG-I, Rehecho S, Calvo MI, Cavero RY, Navarro Í, Astiasarán I, Ansorena D. 2010. Effect of lyophilized water extracts of Melissa officinalis on the stability of algae and linseed oil-in-water emulsion to be used as a functional ingredient in meat products. Meat Science 85: 373-377.

Devatkal S, Narsaiah K, Borah A. 2011. The effect of salt, extract of kinnow and pomegranate fruit by-products on colour and oxidative stability of raw chicken patties during refrigerated storage. Journal of food science and technology 48: 472-477.

Devatkal SK, Narsaiah K, Borah A. 2010. Anti-oxidant effect of extracts of kinnow rind, pomegranate rind and seed powders in cooked goat meat patties. Meat Science 85: 155-159.

Devatkal SK, Thorat P, Manjunatha M. 2014. Effect of vacuum packaging and pomegranate peel extract on quality aspects of ground goat meat and nuggets. Journal of food science and technology 51: 2685-2691.

Devatkal SK, Thorat PR, Manjunatha M, Anurag RK. 2012. Comparative antioxidant effect of aqueous extracts of curry leaves, fenugreek leaves and butylated hydroxytoluene in raw chicken patties. Journal of food science and technology 49: 781-785.

Domínguez R, Pateiro M, Gagaoua M, Barba FJ, Zhang W, Lorenzo JM. 2019. A Comprehensive Review on Lipid Oxidation in Meat and Meat Products. Antioxidants (Basel) 8: 429.

El-Gharably AM, Ashoush I. 2011. Utilization impact of adding pomegranate rind powder and red beet powder as natural antioxidant on quality characteristics of beef sausage. World Journal of Dairy and Food Sciences 6: 86-97.

Falowo A, Muchenje V, Hugo A, Aiyegoro O, Fayemi P. 2017. Antioxidant activities of Moringa oleifera L. and Bidens pilosa L. leaf extracts and their effects on oxidative stability of ground raw beef during refrigeration storage. CyTA-Journal of Food 15: 249-256.

Falowo AB, Fayemi PO, Muchenje V. 2014. Natural antioxidants against lipid–protein oxidative deterioration in meat and meat products: A review. Food Research International 64: 171-181.

Garrido MD, Auqui M, Martí N, Linares MB. 2011. Effect of two different red grape pomace extracts obtained under different extraction systems on meat quality of pork burgers. LWT - Food Science and Technology 44: 2238-2243.

Gibis M, Weiss J. 2012. Antioxidant capacity and inhibitory effect of grape seed and rosemary extract in marinades on the formation of heterocyclic amines in fried beef patties. Food Chemistry 134: 766-774.

Gibis M, Weiss J. 2010. Inhibitory effect of marinades with hibiscus extract on formation of heterocyclic aromatic amines and sensory quality of fried beef patties. Meat Science 85: 735-742.

Gök V, Obuz E, Şahin ME, Serteser A. 2011. The effects of some natural antioxidants on the color, chemical and microbiological properties of sucuk (turkish dry-fermented sausage) during ripening and storage periods. Journal of Food Processing and Preservation 35: 677-690.

Haak L, Raes K, De Smet S. 2009. Effect of plant phenolics, tocopherol and ascorbic acid on oxidative stability of pork patties. Journal of the Science of Food and Agriculture 89: 1360-1365.

Hayes JE, Stepanyan V, Allen P, O'Grady MN, Kerry JP. 2011. Evaluation of the effects of selected plant-derived nutraceuticals on the quality and shelf-life stability of raw and cooked pork sausages. LWT - Food Science and Technology 44: 164-172.

Heim KE, Tagliaferro AR, Bobilya DJ. 2002. Flavonoid antioxidants: chemistry, metabolism and structure-activity relationships. The Journal of Nutritional Biochemistry 13: 572-584.

Hur SJ, Kim DH, Chun SC, Lee SK. 2013. Antioxidative changes of blueberry leaf extracts in emulsion-type sausage during in vitro digestion. Korean Journal for Food Science of Animal Resources 33: 689-695.

Hur SJ, Lee SY, Kim Y-C, Choi I, Kim G-B. 2014. Effect of fermentation on the antioxidant activity in plant-based foods. Food Chemistry 160: 346-356.

Hwang KE, Choi YS, Choi SM, Kim HW, Choi JH, Lee MA, Kim CJ. 2013. Antioxidant action of ganghwayakssuk (Artemisia princeps Pamp.) in combination with ascorbic acid to increase the shelf life in raw and deep fried chicken nuggets. Meat Science 95: 593-602.

Hwang KE, Kim HW, Song DH, Kim YJ, Ham YK, Lee JW, Choi YS, Kim CJ. 2015. Effects of antioxidant combinations on shelf stability of irradiated chicken sausage during storage. Radiation Physics and Chemistry 106: 315-319.

Ismail H, Lee EJ, Ko K, Paik H, Ahn D. 2009. Effect of antioxidant application methods on the color, lipid oxidation, and volatiles of irradiated ground beef. Journal of food science 74: C25-C32.

Jamwal A, Kumar S, Bhat Z, Kumar A, Kaur S. 2015. The quality and storage stability of chicken patties prepared with different additives. Nutrition & Food Science 45: 728-739.

Jayawardana BC, Hirano T, Han KH, Ishii H, Okada T, Shibayama S, Fukushima M, Sekikawa M, Shimada K-i. 2011. Utilization of adzuki bean extract as a natural antioxidant in cured and uncured cooked pork sausages. Meat Science 89: 150-153.

Jayawardana BC, Liyanage R, Lalantha N, Iddamalgoda S, Weththasinghe P. 2015. Antioxidant and antimicrobial activity of drumstick (Moringa oleifera) leaves in herbal chicken sausages. LWT - Food Science and Technology 64: 1204-1208.

Jia N, Kong B, Liu Q, Diao X, Xia X. 2012. Antioxidant activity of black currant (Ribes nigrum L.) extract and its inhibitory effect on lipid and protein oxidation of pork patties during chilled storage. Meat Science 91: 533-539.

Jin SK, Choi JS, Jeong JY, Kim GD. 2016. The effect of clove bud powder at a spice level on antioxidant and quality properties of emulsified pork sausage during cold storage. Journal of the Science of Food and Agriculture 96: 4089-4097.

Jongberg S, Skov SH, Tørngren MA, Skibsted LH, Lund MN. 2011. Effect of white grape extract and modified atmosphere packaging on lipid and protein oxidation in chill stored beef patties. Food Chemistry 128: 276-283.

Jongberg S, Tørngren MA, Gunvig A, Skibsted LH, Lund MN. 2013. Effect of green tea or rosemary extract on protein oxidation in Bologna type sausages prepared from oxidatively stressed pork. Meat Science 93: 538-546.

Jully KMM, Toto CS, Were L. 2016. Antioxidant effect of spent, ground, and lyophilized brew from roasted coffee in frozen cooked pork patties. LWT - Food Science and Technology 66: 244-251.

Kanatt SR, Chander R, Sharma A. 2010. Antioxidant and antimicrobial activity of pomegranate peel extract improves the shelf life of chicken products. International journal of food science & technology 45: 216-222.

Karre L, Lopez K, Getty KJK. 2013. Natural antioxidants in meat and poultry products. Meat Science 94: 220-227.

Khokhar S, Owusu Apenten RK. 2003. Iron binding characteristics of phenolic compounds: some tentative structure–activity relations. Food Chemistry 81: 133-140.

Kim HW, Hwang KE, Song DH, Kim YJ, Ham YK, Lim YB, Jeong TJ, Choi YS, Kim CJ. 2015. Wheat fiber colored with a safflower (*Carthamus tinctorius L.*) red pigment as a natural colorant and antioxidant in cooked sausages. LWT - Food Science and Technology 64: 350-355.

Kim H, Chin K. 2017. Evaluation of Antioxidative Activity of Various Levels of Ethanol Extracted Tomato Powder and Application to Pork Patties. Korean Journal for Food Science of Animal Resources 37: 242-253.

Kim S-J, Cho AR, Han J. 2013. Antioxidant and antimicrobial activities of leafy green vegetable extracts and their applications to meat product preservation. Food Control 29: 112-120.

Kim SJ, Min SC, Shin HJ, Lee YJ, Cho AR, Kim SY, Han J. 2013. Evaluation of the antioxidant activities and nutritional properties of ten edible plant extracts and their application to fresh ground beef. Meat Science 93: 715-722.

Ko CY, Lai YJ, Zeng YM, Lin RH, Deng JR, Chiou RYY, Wu SC. 2018. Stilbenes: A potential preservative for sausage products. Journal of Food Processing and Preservation 42: e13456.

Kong B, Zhang H, Xiong YL. 2010. Antioxidant activity of spice extracts in a liposome system and in cooked pork patties and the possible mode of action. Meat Science 85: 772-778.

Kulkarni S, DeSantos FA, Kattamuri S, Rossi SJ, Brewer MS. 2011. Effect of grape seed extract on oxidative, color and sensory stability of a pre-cooked, frozen, re-heated beef sausage model system. Meat Science 88: 139-144.

Kumar P, Kumar S, Tripathi M, Mehta N, Ranjan R, Bhat Z, Singh PK. 2013. Flavonoids in the development of functional meat products: A review. Veterinary World 6:

Kumar Y, Yadav DN, Ahmad T, Narsaiah K. 2015. Recent Trends in the Use of Natural Antioxidants for Meat and Meat Products. Comprehensive Reviews in Food Science and Food Safety 14: 796-812.

Kurćubić VS, Mašković PZ, Vujić JM, Vranić DV, Vesković-Moračanin SM, Okanović ĐG, Lilić SV. 2014. Antioxidant and antimicrobial activity of Kitaibelia vitifolia extract as alternative to the added nitrite in fermented dry sausage. Meat Science 97: 459-467.

Lara MS, Gutierrez JI, Timón M, Andrés AI. 2011. Evaluation of two natural extracts (*Rosmarinus officinalis L*. and *Melissa officinalis L.*) as antioxidants in cooked pork patties packed in MAP. Meat Science 88: 481-488.

Lee MA, Choi JH, Choi YS, Han DJ, Kim HY, Shim SY, Chung HK, Kim CJ. 2010. The antioxidative properties of mustard leaf (*Brassica juncea*) kimchi extracts on refrigerated raw ground pork meat against lipid oxidation. Meat Science 84: 498-504.

Lim DG, Choi KS, Kim JJ, Nam KC. 2013. Effects of Salicornia herbacea powder on quality traits of sun-dried hanwoo beef jerky during storage. Korean Journal for Food Science of Animal Resources 33: 205-213.

Lim DG, Kim JJ, Seo KS, Nam KC. 2012. Effect of natural antioxidant extracted from Citrus junos seib. or Prunus mume. on the quality traits of sun-dried Hanwoo beef jerky. Korean Journal of Agricultural Science 39: 243-253.

Liu DC, Tsau RT, Lin YC, Jan SS, Tan FJ. 2009. Effect of various levels of rosemary or Chinese mahogany on the quality of fresh chicken sausage during refrigerated storage. Food chemistry 117: 106-113.

Liu F, Dai R, Zhu J, Li X. 2010. Optimizing color and lipid stability of beef patties with a mixture design incorporating with tea catechins, carnosine, and α-tocopherol. Journal of Food Engineering 98: 170-177.

Liu F, Xu Q, Dai R, Ni Y. 2015. Effects of natural antioxidants on colour stability, lipid oxidation and metmyoglobin reducing activity in raw beef patties. Acta scientiarum polonorum Technologia alimentaria 14: 37-44.

Lobo V, Patil A, Phatak A, Chandra N. 2010. Free radicals, antioxidants and functional foods: Impact on human health. Pharmacognosy reviews 4: 118.

Lorenzo JM, González-Rodríguez RM, Sánchez M, Amado IR, Franco D. 2013. Effects of natural (grape seed and chestnut extract) and synthetic antioxidants (buthylatedhydroxytoluene, BHT) on the physical, chemical, microbiological and sensory characteristics of dry cured sausage “chorizo”. Food research international 54: 611-620.

Luo A, Feng J, Hu B, Lv J, Chen CYO, Xie S. 2017. Polysaccharides in Spirulina platensis Improve Antioxidant Capacity of Chinese-Style Sausage. Journal of Food Science 82: 2591-2597.

M M, Kativu E, C.H M, Chidewe C, Ndhlala A, M.A.N B. 2007. Phenolic Composition and Antioxidant Properties of Some Spices. American Journal of Food Technology 2:

Mariem C, Sameh M, Nadhem S, Soumaya Z, Najiba Z, Raoudha EG. 2014. Antioxidant and antimicrobial properties of the extracts from Nitraria retusa fruits and their applications to meat product preservation. Industrial Crops and Products 55: 295-303.

Mathew S, Abraham TE. 2006. Studies on the antioxidant activities of cinnamon (*Cinnamomum verum*) bark extracts, through various in vitro models. Food Chemistry 94: 520-528.

Mbah C, Orabueze I, Okorie N. 2019. Antioxidants properties of natural and synthetic chemical compounds: Therapeutic effects on biological system. Acta Scientific Pharmaceutical Sciences 3: 28-42.

Mercadante AZ, Capitani CD, Decker EA, Castro IA. 2010. Effect of natural pigments on the oxidative stability of sausages stored under refrigeration. Meat Science 84: 718-726.

Mitterer-daltoé M, Bordim J, Lise C, Breda L, Casagrande M, Lima V. 2020. Consumer awareness of food antioxidants. Synthetic vs. Natural. Food Science and Technology

Mohamed HMH, Mansour HA. 2012. Incorporating essential oils of marjoram and rosemary in the formulation of beef patties manufactured with mechanically deboned poultry meat to improve the lipid stability and sensory attributes. LWT - Food Science and Technology 45: 79-87.

Mohd-Esa N, Hern FS, Ismail A, Yee CL. 2010. Antioxidant activity in different parts of roselle (*Hibiscus sabdariffa L.*) extracts and potential exploitation of the seeds. Food Chemistry 122: 1055-1060.

Munekata PES, Calomeni AV, Rodrigues CEC, Fávaro-Trindade CS, Alencar SM, Trindade MA. 2015. Peanut skin extract reduces lipid oxidation in cooked chicken patties. Poultry Science 94: 442-446.

Naveena BM, Sen AR, Kingsly RP, Singh DB, Kondaiah N. 2008. Antioxidant activity of pomegranate rind powder extract in cooked chicken patties. International Journal of Food Science & Technology 43: 1807-1812.

Naveena BM, Sen AR, Vaithiyanathan S, Babji Y, Kondaiah N. 2008. Comparative efficacy of pomegranate juice, pomegranate rind powder extract and BHT as antioxidants in cooked chicken patties. Meat Science 80: 1304-1308.

Ng TB, Liu F, Wang ZT. 2000. Antioxidative activity of natural products from plants. Life Sciences 66: 709-723.

Nuñez de Gonzalez MT, Hafley BS, Boleman RM, Miller RM, Rhee KS, Keeton JT. 2009. Qualitative effects of fresh and dried plum ingredients on vacuum-packaged, sliced hams. Meat Science 83: 74-81.

Oh HJ, Song MH, Yun W, Lee JH, An JS, Kim YJ, Kim GM, Kim HB, Cho JH. 2020. Effects of replacing soybean meal with perilla seed meal on growth performance, and meat quality of broilers. Journal of Animal Science and Technology 62: 495-503.

Park JH, Kang SN, Shin D, Hur IC, Kim IS, Jin SK. 2013. Antioxidant Activities of Achyranthes japonica Nakai Extract and Its Application to the Pork Sausages. Asian-Australas J Anim Sci 26: 287-294.

Park SY, Chin KB. 2010. Evaluation of pre-heating and extraction solvents in antioxidant and antimicrobial activities of garlic, and their application in fresh pork patties. International Journal of Food Science & Technology 45: 365-373.

Pennington JAT, Fisher RA. 2009. Classification of fruits and vegetables. Journal of Food Composition and Analysis 22: S23-S31.

Pennisi Forell SC, Ranalli N, Zaritzky NE, Andrés SC, Califano AN. 2010. Effect of type of emulsifiers and antioxidants on oxidative stability, colour and fatty acid profile of low-fat beef burgers enriched with unsaturated fatty acids and phytosterols. Meat Science 86: 364-370.

Pereira ALF, Abreu VKG (2018) Lipid peroxidation in meat and meat products. In *Lipid Peroxidation*. IntechOpen.

Pikul J, Leszczynski DE, Kummerow FA. 1984. Relative role of phospholipids, triacylglycerols, and cholesterol esters on malonaldehyde formation in fat extracted from chicken meat. Journal of Food Science 49: 704-708.

Pokorný J. 2007. Are natural antioxidants better – and safer – than synthetic antioxidants? European Journal of Lipid Science and Technology 109: 629-642.

Puangsombat K, Jirapakkul W, Smith JS. 2011. Inhibitory Activity of Asian Spices on Heterocyclic Amines Formation in Cooked Beef Patties. Journal of Food Science 76: T174-T180.

Qin YY, Zhang ZH, Li L, Xiong W, Shi JY, Zhao TR, Fan J. 2013. Antioxidant effect of pomegranate rind powder extract, pomegranate juice, and pomegranate seed powder extract as antioxidants in raw ground pork meat. Food Science and Biotechnology 22: 1063-1069.

Ramachandraiah K, Chin KB. 2018. Effect of particle size of persimmon by-product powders on their physicochemical properties and antioxidant activities in porcine patties. Journal of Food Process Engineering 41: e12610.

Reddy GVB, Sen AR, Nair PN, Reddy KS, Reddy KK, Kondaiah N. 2013. Effects of grape seed extract on the oxidative and microbial stability of restructured mutton slices. Meat Science 95: 288-294.

Ribeiro JS, Santos MJMC, Silva LKR, Pereira LCL, Santos IA, da Silva Lannes SC, da Silva MV. 2019. Natural antioxidants used in meat products: A brief review. Meat science 148: 181-188.

Saha J, Debnath M, Saha A, Ghosh T, Sarkar PK. 2011. Response surface optimisation of extraction of antioxidants from strawberry fruit, and lipid peroxidation inhibitory potential of the fruit extract in cooked chicken patties. Journal of the Science of Food and Agriculture 91: 1759-1765.

Sánchez-Escalante A, Torrescano G, Djenane D, Beltrán JA, Giménez B, Roncalés P. 2011. Effect of antioxidants and lighting conditions on color and lipid stability of beef patties packaged in high-oxygen modified atmosphere Efecto de los antioxidantes y las condiciones de iluminación sobre el color y la estabilidad de los lípidos de hamburguesas de res envasadas en atmósfera modificada alta en oxígeno. CyTA - Journal of Food 9: 49-57.

Sasse A, Colindres P, Brewer MS. 2009. Effect of Natural and Synthetic Antioxidants on the Oxidative Stability of Cooked, Frozen Pork Patties. Journal of Food Science 74: S30-S35.

Sáyago-Ayerdi SG, Brenes A, Goñi I. 2009. Effect of grape antioxidant dietary fiber on the lipid oxidation of raw and cooked chicken hamburgers. LWT - Food Science and Technology 42: 971-976.

Sayari N, Sila A, Balti R, Abid E, Hajlaoui K, Nasri M, Bougatef A. 2015. Antioxidant and antibacterial properties of Citrus paradisi barks extracts during turkey sausage formulation and storage. Biocatalysis and Agricultural Biotechnology 4: 616-623.

Shah MA, Bosco SJD, Mir SA. 2014. Plant extracts as natural antioxidants in meat and meat products. Meat Science 98: 21-33.

Shahidi F, Ambigaipalan P. 2015. Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects – A review. Journal of Functional Foods 18: 820-897.

Shin D-K, Yang H-S, Min B, Narciso-Gaytán C, Sanchez M, Ruiz-Feria C. 2011. Evaluation of Antioxidant Effects of Vitamins C and E Alone and in Combination with Sorghum Bran in a Cooked and Stored Chicken Sausage. Korean Journal for Food Science of Animal Resources 31:

Sottero B, Leonarduzzi G, Testa G, Gargiulo S, Poli G, Biasi F. 2019. Lipid Oxidation Derived Aldehydes and Oxysterols Between Health and Disease. European Journal of Lipid Science and Technology 121: 1700047.

Suman SP, Joseph P. 2013. Myoglobin Chemistry and Meat Color. Annual Review of Food Science and Technology 4: 79-99.

Sun WQ, Zhang YJ, Zhou GH, Xu XL, Peng ZQ. 2010. Effect of apple polyphenol on oxidative stability of sliced cooked cured beef and pork hams during chilled storage. Journal of Muscle Foods 21: 722-737.

Tajik H, Farhangfar A, Moradi M, Razavi Rohani SM. 2014. Effectiveness of Clove Essential Oil and Grape Seed Extract Combination on Microbial and Lipid Oxidation Characteristics of Raw Buffalo Patty During Storage at Abuse Refrigeration Temperature. Journal of Food Processing and Preservation 38: 31-38.

Thomas R, Jebin N, Saha R, Sarma DK. 2016. Antioxidant and antimicrobial effects of kordoi (*Averrhoa carambola*) fruit juice and bamboo (*Bambusa polymorpha*) shoot extract in pork nuggets. Food Chemistry 190: 41-49.

Trindade RA, Mancini-Filho J, Villavicencio ALCH. 2010. Natural antioxidants protecting irradiated beef burgers from lipid oxidation. LWT - Food Science and Technology 43: 98-104.

Tsoukalas DS, Katsanidis E, Marantidou S, Bloukas JG. 2011. Effect of freeze-dried leek powder (FDLP) and nitrite level on processing and quality characteristics of fermented sausages. Meat Science 87: 140-145.

Turkmen N, Sari F, Velioglu YS. 2006. Effects of extraction solvents on concentration and antioxidant activity of black and black mate tea polyphenols determined by ferrous tartrate and Folin–Ciocalteu methods. Food Chemistry 99: 835-841.

Vargas-Sánchez RD, Torrescano-Urrutia GR, Acedo-Félix E, Carvajal-Millán E, González-Córdova AF, Vallejo-Galland B, Torres-Llanez MJ, Sánchez-Escalante A. 2014. Antioxidant and Antimicrobial Activity of Commercial Propolis Extract in Beef Patties. Journal of Food Science 79: C1499-C1504.

Xu Z, Tang M, Li Y, Liu F, Li X, Dai R. 2010. Antioxidant Properties of Du-zhong (*Eucommia ulmoides Oliv.*) Extracts and Their Effects on Color Stability and Lipid Oxidation of Raw Pork Patties. Journal of Agricultural and Food Chemistry 58: 7289-7296.

Ye L, Wang H, Duncan SE, Eigel WN, O'Keefe SF. 2015. Antioxidant activities of Vine Tea (Ampelopsis grossedentata) extract and its major component dihydromyricetin in soybean oil and cooked ground beef. Food Chemistry 172: 416-422.

Yıldız-Turp G, Serdaroglu M. 2010. Effects of using plum puree on some properties of low fat beef patties. Meat Science 86: 896-900.

Yim D-G, Ali M, Nam K-C. 2020. Comparison of Meat Quality Traits in Salami Added by Nitrate-free Salts or Nitrate Pickling Salt during Ripening. Food Science of Animal Resources 40: 11-20.

Yu J, Ahmedna M, Goktepe I. 2010. Potential of peanut skin phenolic extract as antioxidative and antibacterial agent in cooked and raw ground beef. International Journal of Food Science & Technology 45: 1337-1344.

Zhou H, Zhuang X, Zhou C, Ding D, Li C, Bai Y, Zhou G. 2020. Effect of fermented blueberry on the oxidative stability and volatile molecule profiles of emulsion-type sausage during refrigerated storage. Asian-Australas J Anim Sci 33: 812-824.

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[a)]	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, 2017)
	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	(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™	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	(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/1000, 2000 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)
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)

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

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)
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™/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)

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

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, 1000, 1500 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)

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

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)

[a] Not analyzed. TBARS: thiobarbituric acid reactive substances; DPPH: 2,2-diphenyl-1-picrylhydrazyl; ABTS: 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)