OPEN ACCESS

GAVIN PUBLISHERS

Food & Nutrition Journal

Review Article

Reddy DM, et al. Food Nutr J 3: 173.
DOI: 10.29011/2575-7091.100073

Application of Natural Antioxidants in Meat and Meat Products-A Review

D. Maheswara Reddy[1], G. Vijay Bhaskar Reddy[1], Prabhat Kumar Mandal[2*]

[1]College of Veterinary Science, Tirupati, India

[2]Rajiv Gandhi Institute of Veterinary Education and Research, Puducherry, India

[*]**Corresponding author:** Prabhat Kumar Mandal, Rajiv Gandhi Institute of Veterinary Education and Research, Puducherry, India. Tel: +919489585699; Email: mandalpkm@gmail.com

Citation: Reddy DM, Reddy GVB, Mandal PK (2018) Application of Natural Antioxidants in Meat and Meat Products-A Review. Food Nutr J 3: 173. DOI: 10.29011/2575-7091.100073

Received Date: 16 March, 2018; **Accepted Date:** 03 April, 2018; **Published Date:** 11 April, 2018

Abstract

Presently consumers are demanding more natural foods, obliging the industry to include natural antioxidants in foods. Antioxidants can act as metal chelators and free radical or oxygen scavengers, which can slow the progression of lipid oxidation. Lipid oxidation may have negative effects on the quality of meat and meat products, causing changes in sensory attributes such as colour, texture, odour and flavour, and nutritional quality. Several synthetic antioxidants have been used to successfully prevent lipid oxidation in the meat industry, but consumers are concerned about the health risks related to consumption of some synthetic antioxidants. Therefore, there has been a growing interest in natural antioxidants. Nowadays, compounds obtained from natural sources such as grains, oilseeds, spices, fruit and vegetables have been investigated to decrease the lipid oxidation. Recent investigations have been directed towards the identification of natural antioxidants from various plant sources. Antioxidants work as functional additives by providing health promoting effect in human body system. This article evaluates the efficacy of various natural antioxidants on the quality and shelf life enhancement of meat and meat products during processing, storage, distribution till it reaches to consumer. The potential effects of natural antioxidants that are widely used in meat and meat products are also discussed.

Keywords: Free Radicals; Lipid Oxidation; Meat; Meat Products; Natural Antioxidants; Quality; Rancidity; Synthetic Antioxidant

Introduction

Meat is rich source of proteins, lipids, vitamins and minerals. Meat products are spoiled by two major causes: microbial growth and chemical deterioration. The most common form of chemical deterioration is oxidative rancidity as lipids are integral components of muscle. The oxidative rancidity occurred in meat and meat products can vary greatly, ranging from extensive flavor changes, color losses and structural damage on proteins [1] to a subtler "loss of freshness" that discourages repeat purchases by consumers. Lipid oxidation leads to the formation of numerous other compounds which have adverse effects on the quality attributes and nutritive value of meat products [2] and this process frequently limits the shelf-life of processed meat. Oxidation is a well-known non-microbial cause of quality loss in meat. Oxidative stress occurs due to uneven generation of free radicals Reactive Oxygen Species (ROS) and Reactive Nitrogen Species (RNS) which triggers oxidative and/or nitrosamine stress and damage of macromolecules including the lipid and protein fractions. Antioxidants are compounds that are capable of donating hydrogen ($H^{\cdot}$) radicals for pairing with other available free radicals to prevent the propagation reaction during the oxidation process. This effectively minimizes rancidity, retards lipid oxidation, without any damage to the sensory or nutritional properties, resulting in maintaining quality and shelf-life of meat products. Antioxidants reduces or prevent the oxidation and have ability to counteract damaging effects of free radicals in tissues and thus are believed to protect against cancer, atherosclerosis, heart disease and several other diseases [3]. The use of natural antioxidants has the advantage of being more acceptable by the consumers as these are considered as non-chemical. In addition, they don't require safety tests before being used. Moreover, natural antioxidants are reported to be more powerful than the synthetics. The demand for natural antioxidants has recently increased because of the toxicity and carcinogenicity of synthetic antioxidants [4]. Many natural plant extracts contain primarily phenolic compounds, which are potent antioxidants [5]. Including antioxidants in the diet has beneficial effects on human

health because they protect the biologically important cellular components, such as DNA, proteins, and membrane lipids, from Reactive Oxygen Species (ROS) attacks [6]. Recently, consumers have rejected synthetic antioxidants because of their carcinogenicity [7]. Many herbs, spices, and their extracts have been added in a variety of foods to improve their sensory characteristics and extend shelf-life [8]. In this review natural antioxidants that are widely used in meat products and their effects on meat & product's quality were evaluated.

Mechanism of Lipid Oxidation in Meat and Meat Products

Lipid oxidation can take place at 3 stages: at pre-slaughter (live muscle), during slaughtering (conversion of muscle to meat) and after slaughtering (processing and storage). In live animals, intrinsic factors are available that can control the oxidation reaction in muscular tissues, such as enzymes (superoxide dismutase, catalase etc.) and certain proteins and their mechanisms (transport proteins), or oxidative reaction-breaking antioxidants (vitamin E and C) [9]. After slaughtering, these factors lose their antioxidative potential due to various post-slaughter conditions, such as anaerobic environment, presence of prooxidants (P_0), and lack of enzymatic antioxidative mechanisms [10]. Hemoglobin and myoglobin, which are also considered as prooxidants [11], along with other processing parameters, result in lipid oxidation during processing and storage of meat and meat products. Lipid oxidation is described as an oxygen-dependent, deterioration of saturated and unsaturated fatty acids. This modification of fatty acid is principally carried out by an autocatalytic mechanism of free radicals, called auto-oxidation and consisting of 3 phases: initiation, propagation and termination. Lipid oxidation in muscle foods is initiated in the highly unsaturated phospholipids fraction of subcellular bio-membranes, unsaturated portions of fatty acid esters (triglycerides or phospholipids) react with molecular oxygen to form peroxides, hydroperoxides and carbonyl compounds [12]. The hydroperoxides are unstable and are reductively cleaved in the presence of trace elements to produce new free radicals and non-radical compounds including aldehydes, ketones, alcohols and acids that cause the off odor, off flavor, change in nutritive value and safety of muscle foods.

Types of Antioxidants

Classification I

Primary antioxidants: Also called as chain-breaking antioxidative compounds react directly with lipid radicals and inhibit or retard oxidation by scavenging free radicals by donation of hydrogen atoms or electrons, which converts them to more stable products.

Secondary antioxidants: They reduce the rate of oxidation by different mechanism of action, including binding of metal ions (Fe^{2+}, Fe^{3+}, and Cu^{2+}), by scavenging oxygen, by converting hydroperoxides to non-radical species, by absorbing UV radiation or deactivating singlet oxygen, by inhibiting enzymes [13]. Some natural phenolic compounds function as both primary and secondary antioxidants.

Classification II

Exogenous antioxidants: are incorporated in the meat system from the external sources. These includes, flavonoids (quercetin, rutin), spices (rosemary, thyme, sage, cloves), polyphenols (catechins, proanthocyanidins, ellagic acid, tannins), plant extracts (tea, nutmeg, garlic, plums, grape seed) etc.

Endogenous antioxidants: These are produced in the body/muscles due to various metabolic reactions and provide innate resistance to the meat for oxidation. It varies from species to species, breed to breed and animal to animal. These includes non-enzymes (carnosine, tocopherol, ascorbic acid), formed antioxidants.

Classification III

Natural antioxidants: Ingredients widely present in natural sources which exhibit antioxidative potential in a food model system are considered as natural antioxidants. Phenolic compounds present in plants have a high antioxidant activity through three mechanisms: free-radical scavenging activity [14], transition-metal-chelating activity [15], and/or singlet-oxygen quenching capacity [16].

Synthetic antioxidants: These are the chemicals having antioxidative properties, BHA (Butylated Hydroxyanisole), BHT (Butylated Hydroxytoluine), PG (Propyl Gallate), and TBHQ (Tert-Butylhydroquinone) are examples of synthetic antioxidants.

Mechanism of Action of Natural Antioxidants

The majority of natural antioxidants are phenolic compounds, and the most important are the tocopherols, flavonoids, and phenolic acids. The major antioxidative phenolics are: phenolic acids, phenolic diterpenes, flavonoids, and volatile oils. Phenolics present in the natural antioxidants have strong $H^{\cdot}$-donating activity [17] or have high radical-absorbance capacity. Decreasing localized oxygen concentrations; preventing chain initiation by scavenging initiating radicals; decomposing peroxides, chain-breaking to prevent continued hydrogen abstraction by active radicals. Some phenolics prevent the formation of free radicals and propagation of ROS, whereas, other scavenge free radicals and chelate prooxidants (transition metals) [18]. Phenolic acids trap free radicals; flavonoids scavenge free radicals and chelate metals (Fe^{2+}, Fe^{3+}, and Cu^{2+}) as well.

Use of Natural Antioxidants in Meat Products

Use of natural antioxidants in meat and meat products is presented in Table 1 along with their active principles. The further

details about the use of different natural preservatives in meat and meat products are discussed below under different category.

S. No	Natural source	Extraction methods	Active ingredients (analyzed)	Reference
1	Mustard (*Brassica juncea*) leaf kimchi extract	70% Ethanol	NA	[19]
2	Oregano (*Origanum vulgare*) essential oils	Hydro-distillation	Thymol, *p*-cymene, gamma-terpinene, carvacrol	[20]
3	Sage (*Salvia officinalis*) essential oils	Hydro-distillation	Eucalyptol, camphor, α-pinene	[20]
4	Lotus (*Nelumbo nucifera*) rhizome knot and lotus leaf extract	Distilled water	Phenolics, tannins, flavonoids	[21]
5	Curry (*Murraya koenigii L.*) & mint leaves (*Mentha spicata*)	Ethanol, hot water, ethanol + hot water	Phenolics	[22]
6	Carrot juice	Squeezing/evaporative concentration	Phenolics, carotenoids	[23]
7	Mung bean (*Vigna radiata*), Bengal gram (*Cicer arietinum*), pigeon pea (*Cajanus cajan*) hulls	Distilled water/evaporative concentration	Phenolics, flavonoids	[24]
8	Rosemary (*Rosmarinus officinalis L.*) and oregano (*Origanum vulgare L.*) leaves extracts	Chloroform, ethanol, chloroform + ethane	Phenolics, rosmarinic acid, rosmanol carnosic acid, carnosol	[25]
9	Rosemary, sage, and thyme decoction	Decoction obtained after water vapor distillation	NA	[26]
10	Chitosan+mint (*Mentha spicata L.*) extract	Described elsewhere	NA	[27]
11	Pomegranate (*Punica granatum*, var-kabul) juice, pomegranate rind extract	Grinding and filtration boiled distilled water	Phenolics	[28]
12	Grape (Vitis vinifera var. Cencibel) antioxidant dietary fiber (GADF)	Freeze drying, milling	Phenolics mainly tannins catechins, flavonols, anthocyanidins	[29]
13	Pomegranate (*Punica granatum* var-kabul) fruit juice phenolics	70% Acetone and diethyl ether	Phenolics, pro-anthocyanidins, tannins	[30]
14	Various spices/Maillard reaction products (MRPs)	Spices-as wet paste MRPsb-Refluxing of glucose and lysine (60 mM)	NA	[31]
15	Different kimchi extracts	75% ethanol	Phenolics, flavonoids	[32]
16	Grape (*Vitis labrusca L.*) seeds and peels extract	80% ethanol	Phenolics	[33]
17	Green tea extract	Boiled water	NA	[34]
18	*Thymbra spicata* oil	steam distillation	NA	
19	Red grape pomace extract	Methanol, instantaneous pressure change	Total polyphenolics, total anthocyanins	[35]
20	Sea buckthorn (*Hippophae rhamnoides*) berry residues	Ethanol	Polyphenols	[36]
21	Oregano extract	Diethyl ether, ethyl alcohol, and distilled water	NA	[37]
22	Borage (*Borago officinalis L.*) leaves extract	Preheated (96˚C) water, sonication	Phenolics	[38]

23	*Melissa officinalis L.* leaves extract	Preheated (100°C) water, refluxing	Phenolics, rosmarinic acid	[39]
24	Arbutus-berries (*Arbutus unedo L.*), common hawthorns (*Crataegus monogyna L.*), dog roses (*Rosa canina L.*) elm-leaf blackberries (*Rubus ulmifolius Schott.*)	Absolute ethanol	NA	[40]
25	Maillard reaction products (MRPs) from MDCR hydrolysates	Enzymatic hydrolysis of MDCR	NA	[41]
26	Defatted canola (*Brassica napus*) meal	70% acetone	Sinapic, ferulic, *p*-hydroxybenzoic acids	[42]
27	Thuza (*Thuja occidentalis*) cones extract	Boiled sterilized distilled water	Phenolics, flavonoids	[43]
28	Curry (*Murraya koenigii L.*) berry extract	Boiled sterilized distilled water	Phenolics, flavonoids	[44]
NA: Not Analysed				

Table 1: Active ingredients in natural antioxidants for meat and meat products.

Herbs, Spices and Teas

The use of plant derived nutraceuticals may allow meat processors to develop novel meat products with enhanced nutritional and health benefits, improved shelf-life, quality and profile.

Rosemary*:* Rosemary (*Rosmarinus officinalis* L.) is a popular herb belonging to the Lamiaceae family with high antioxidant activity. The antioxidant activity of rosemary extracts has been associated with the presence of several phenolic diterpenes such as carnosic acid, carnosol, rosmanol, isorosmanol, rosmariquinone, rosmaridiphenol and rosmary-diphenol which break free radical chain reactions by hydrogen donation [45,46] reported that rosemary extracts improved the color stability of turkey rolls in addition to their inhibition of lipid oxidation. [47] reported the addition of rosemary in refrigerated turkey sausage as an effective way to suppress lipid oxidation and to increase the shelf life. [48] observed that clove, rosemary and cassia bark extracts to be highly effective antioxidants in cooked pork patties as they inhibited lipid oxidation and stabilized red colour (myoglobin) during refrigerated storage.

Sage*:* Sage *(Salvia officinalis)* is a common aromatic and medicinal plant. The antioxidant properties were found to be related with the presence of phenolic compounds such as rosmarinic acid, carnosic acid, salvianolic acid and its derivatives carnosol, rosmanol, epirosmanol, rosmadial, isorosmanol, galdosol and methyl carnosate [49-51]. Major Oregano and sage essential oils added to beef and pork meat reduce oxidation during refrigeration and antioxidant activity of sage oil more potent in cooked meat than in raw meat [20].

Oregano: Oregano (*Origanum vulgare)* is well known for its antioxidant activity contains more than 30 compounds with carvacrol and thymol being responsible for its antioxidant activity [52]. [20] reported lowered levels of oxidation after 12 days of refrigerated storage of pork and beef added with 3% oregano oil. Dietary incorporation of oregano, rosemary, and sage essential oils can retard lipid oxidation (MDA formation) in meat during refrigerated and frozen storage. Lower MDA formation in dietary oregano essential oil treatments are probably the result of the presence of oregano antioxidant compounds, which might be absorbed into the circulatory system after ingestion, distributed, and retained in muscle and other tissues [53]. The higher color parameters of meat from lambs fed with oregano essential oil supplementation [53]. Active films containing oregano essential oil can reduce the growth of total flora and pseudomonas, thus inhibiting the growth of lactic acid bacteria in beef [54]. Moreover, oregano-based films were effective against *Salmonella typhimurium* and *E. coli* O157:H7 inoculated in beef muscle slices [55].

Garlic*:* Garlic is used traditionally as a flavour enhancer in foods and has medicinal properties due to wide spectrum of actions such as antibacterial, antiviral, antifungal and antiprotozoal. It also has beneficial effects on the cardiovascular and immune systems [56]. Garlic demonstrated effective antioxidant activity *in vivo* and *in vitro* [57] due to organ sulphur compounds and their precursors, allicin, diallyl sulphide and diallyl trisulfide [58,59] graded the antioxidant activity of the various materials in the following order fresh garlic<garlic powder<BHA<garlic oil in raw chicken sausages during cold storage (3°C). Garlic juice reduces the TBARS, peroxide value, residual nitrite in emulsified sausage during cold storage [60] and in fresh pork during cold storage [61].

Onion *(Allium cepa* L.): Onion is much valued for its flavouring components and has high flavonoids, quercetin (284-486 mg/kg) which act as antioxidant in cooked ground turkey [62] and in cooked ground lamb [63], oven-cooked turkey breast.

Mint *(Mentha spicata* L): Spearmint or garden mint, family Lamiaceae (Labiatae) is often used as a flavour enhancer, is a rich source of polyphenolic compounds with strong antioxidant properties [64,22]. Mint leaves contains eugenol, caffeic acid, rosmarinic acid and alpha-tocopherol. Raw ground pork meat treated with mint leaf extract showed a significantly lower TBA value than control during refrigerated storage at 4 ± 1^0C [22].

Colorifico: Colorifico is a spice consisting essentially of a mixture of annatto (*Bixa orellana*) and corn flour. Colorifico has higher capacity of scavenging free radicals than onion and coriander [65]. [66] reported that the addition of colorifico (0.4 g/100 g) to minced chicken meat was an alternative for enhancing chicken colour and also minimising lipid oxidation during storage of grilled patties at 18^0C for 120 days.

Cinnamon: The antioxidant activity of cinnamon is due to the scavenging capacity of cinnamaldehyde which can scavenge 2, 2-Diphenyl-1-Picryl Hydrazyl Radical (DPPH) and the hydroxyl radical (OH radical). The scavenging of DPPH and OH radicals by cinnamon oil is attributed to the hydrogen donating capacity of the phenolic component of cinnamic oil [67]. Essential oil of cinnamon reduces the TBARS values in minced chicken meat during 10 days refrigerated storage [68]. Deodorized aqueous extract (CinDAE) was evaluated for its antioxidant potential in chicken meatballs under chilled conditions [69] and antioxidant effect of *Cinnamomum Zeylanicum* Essential Oil (CZEO) in cooked sausage was evaluated by [70] and it was concluded that 20 and 40 ppm CZEO treatment resulted in lower peroxide and TBARS values than the control ($P < 0.05$), without affecting the sensory characteristics of the meat samples.

Thyme: Thyme contains phenolic acids: caffeic acid, ferulic acid, gallic acid, rosmarinic acid, volatile compounds- thymol, phenolic diterpenes and flavonoids- luteolin. [71] reported the antioxidant effect of thyme and balm essential oils in fresh chicken breast meat stored at 4°C for 3 weeks. It was shown that thyme reduced DPPH radical formation, lipid peroxidation and the deterioration of sarcoplasmic proteins, helping to preserve the meat even after 2 wk of storage. Thyme essential oil exhibited very strong free-radical scavenging ability and inhibited Fe^{2+}/ascorbate and Fe^{2+}/H_2O_2 induced lipid oxidation [72].

Green tea leaf extracts: Green tea leaf extracts are becoming increasingly important as a functional food in human diet because of their high polyphenol contents. The antioxidative property of green tea extract is due to the presence of Tea Catechins (TC), Epicatechins (EC), Epigallocatechin (EGC), epigallocatechin gallate (EGCG) and Epicatechin Gallate (ECG) [73]. These compounds have high affinity for lipid bilayers of muscle and the radical scavenging activity which prevent lipid oxidation and also have antibacterial action [74]. The tea catechins and other polyphenols are free radical scavengers, metal chelators, inhibitors of transcription factors, and enzymes as reported by [75] in frozen broiler meat by adding rosemary, echinacea, green tea extracts and ascorbic acid. [76] in refrigerated luncheon roll meat added green tea extract and thyme oil. TC can also reduce the formation of peroxides more effectively than alpha-tocopherol or BHA in porcine lard and chicken fat [77] and fish muscle model system [78].

Rooibos tea extract: [79] investigated that the addition of 0.25 % (RBTE) rooibos tea extract resulted in improved lipid stability and sensory attributes of the droewors. The unfermented green rooibos inclusion considerably lowered the TBARS content of ostrich patties; and the fermented form (0.5% and 1%) was also effective in delaying lipid oxidation in ostrich salami up to 15 day of ripening.

Cocoa leaves: These are effective antioxidants similar to green tea polyphenol. These can be used as extract and it has lower astringency and bitterness [80]. Therefore, can be used in higher concentrations, for increased effectiveness as antioxidant.

Marjoram: Marjoram (*Origanum majorana* L.) essential oil inhibits formation of primary oxidation compounds (conjugated dienes) by 50% and the secondary generation of oxidation products (linoleic acid) by 80% in a model system [81]. The purified active compound isolated from marjoram, T3b, a phenolic substance, is a better superoxide anion radical scavenger and have epigallocatechin gallate, quercetin, epicatechin [82] and destroys the superoxide anion by converting it to H_2O_2.

Evening primrose: Evening primrose extract inhibited the formation by 43.6-72.6 % of conjugated dienes, hexanal, and total hydrogen peroxide (H_2O_2), hydroxyl radical (•OH), and superoxide radical (O_2-) in cooked comminuted pork when used @ 1% and 2%, [83].

Bamboo leaves: Dried bamboo leaves powder are traditionally used as antioxidant due to flavones, lactones, phenolic acids [84], which impairs chain reaction and chelate transitional metal ions, and therefore, can be used as primary and secondary antioxidant. Furthermore, bamboo leaves powder can help in the partial or complete replacement of the nitrites in cured meat. It inhibits the synthesis of N-nitrosamine, and has antibacterial, bacteriostatic, deodorizing, aroma enhancing functions.

Fruits and Vegetables

Plum derived ingredients: Plum-derived food ingredients have been reported to function as antioxidants, antimicrobials, fat

replacers, and flavourings. Due to principal phytochemicals in dried plums viz., phenolic acid derivatives, flavonoids and coumarins [85] including neoclorogenic, chlorogenic and cryptochlorogenic acid. Dried plum puree at 3% or higher level has been shown to retard lipid oxidation in precooked pork patties [86] and 2.5% fresh plum juice concentrate or dried plum juice concentrate in precooked beef roasts [87].

Pomegranate: Pomegranate fruit parts have bioactive compounds like tannins, anthocyanins, flavonoids and other phenolic compounds which prevent low-density lipoprotein oxidation, prostate cancer, platelet aggregation and various cardiovascular diseases [88]. [28] compared the efficacy of pomegranate juice, pomegranate rind powder extract and BHT as antioxidants in cooked chicken patties and observed that the lipid oxidation inhibition effect was highest in refrigerated chicken patties incorporated with pomegranate rind powder.

Avocado: The antioxidative effects of the peel, pulp, and seed from 2 avocados (*Persea americana* Miller) varieties ("*Hass*" and "*Fuerte"*) were studied in pork meat patties [89]. It was reported that the avocado extracts protected meat lipids and proteins against oxidation as peels and seeds were rich in catechins, procyanidins, and hydroxycinnamic acids, and the pulp was particularly rich in hydroxybenzoic acid, hydroxycinnamic acid, and procyanidins.

Cherry: Cherry fractions contain phenolic compounds such as flavones, isoflavones, anthocyanins, anthocyanidins and phenolic glycosides. [90] investigated that thiobarbituric acid-reactive substances values and cholesterol oxidation for raw and cooked ground beef patties containing cherry tissue were significantly lower and the formation of mutagenic/carcinogenic HAAs during frying of the patties was inhibited by components in the cherry tissue.

Tomato: The main active compound of tomatoes is lycopene. It is highly effective antioxidant owing to its ability to act as free radical scavenger and has the highest singlet oxygen quenching rate than all carotenoids tested in biological system [91]. [92] confirmed that antioxidant effect of tomato paste in beef during refrigerated storage, beef patties [93], dry tomato peel in dry fermented sausage [94] could be successfully used up to a level of 12% without any negative effect on the processing and quality characteristics of the product throughout its storage.

Banana and Sapodilla: Banana and Sapodilla/ Chikoo peel extracts significantly reduced the lipid oxidation in chicken meat during refrigerated storage [95].

Grape Seed Extract (GSE): Grapes are used in various forms as seed extract, dietary fiber, pomace, grape wine etc. Grape Seed Extract (GSE) rich in proanthocyaninidins in the form of oligomers and polymers of polyhydroxy flavan-3-ols such as catechin and epicatechin [96]. Antioxidant effect of GSE evaluated on cooked beef [97], turkey patties and refrigerated turkey meat [98]. GSE shows reduced lipid oxidation effectively as reported in beef, chicken, and turkey during refrigerated storage [99] in both raw and cooked meat systems during refrigerated and frozen storage, in raw and cooked pork patties [100] and in cooked pork meatballs during 16-day aerobic retail refrigerated storage conditions [101]. Grape pomace is a concentrate of grape seeds, stems and peel. This is a rich source of flavonoids including monomeric phenolic compounds, such as catechins, epicatechin and epicatechin-3-Ogallate and dimeric, trimeric and tetrameric procyanidins [102]. It can be used as dietary supplement in broiler chickens to oxidative resistance of poultry meat [103]. Grape Antioxidant Dietary Fiber (GADF) effectively used (0.5, 1, 1.5 and 2% concentrations) in raw and cooked chicken breast hamburger by [104] during refrigerated storage. GADF addition resulted in reduction in lightness and yellowness and an increase in redness in raw and chicken hamburgers without affecting the acceptability of the products. Grape seed extract@ 0.1 % had excellent antioxidant properties, improved microbiological quality and had superior sensory scores compared to control and butylated hydroxyl anisole during refrigerated storage of restructured mutton slices under aerobic and vacuum conditions [105].

Citrus extract: Citrus fruit essential oils are the most widely used essential oils in the world [106] contains flavonoids (flavanones, flavones and flavonols), anthocyanins and coumarins [107] A natural citrus extract was evaluated as an antioxidant, and the activity was compared with α-tocopherol [108]. It was concluded that the citrus extract-coated trays effectively inhibited lipid oxidation in cooked turkey meat slices, which was represented by significantly lower TBARS and hexanal values.

Green Vegetables: Extension of meat and meat products with green vegetables could reduce production costs and improve the nutritional qualities of the products. However, the suitability of vegetables in the production of meat products relates to their properties such as water binding, emulsification, yield and sensory properties. Addition of 2% carrot and 10% spinach improved the oxidative stability of poultry hamburgers [109]. Lutein is a carotenoid that is present abundantly in dark green leafy vegetables such as spinach and kale, and is often termed as 'the eye-protective nutrient' as it is one of the most important dietary antioxidants for eye health [110]. The experiments conducted by [111] showed antioxidative potential of various vegetable powders (10 g/145 g meat) in cooked turkey meat patties. Six (spinach < yellow pea < onion < red pepper < green pea < tomato) of 11 (beetroot, broccoli, carrot, celery, green pea, onion, red pepper, spinach, swede, tomato, and yellow pea) vegetable powders significantly ($P < 0.05$) improved oxidative stability of patties by 20% to 30%.

Oil Seeds

The by-products of different oilseeds are rich sources of phenolic

compounds which can improve the nutritional value of the product. Some of them are listed as under:

Canola extract: The antioxidative properties of canola extracts (500 and 1000 ppm) were more active than BHA, BHT and TBHQ [112].

Camelina meal: The camelina meal also contains flavonols (quercetin glycosides), hydroxycinnamic acid derivatives (sinapine, and sinapic acids) and tocopherols. It exhibits more potential in inhibiting the oxidation of proteins than rapeseed phenolics.

Rapeseed meal: Rapeseed meal contains α-tocopherol (52 μg/g) and phenolic hydroxycinnamic acid derivatives including sinapine (2,400 - 2,900 μg/g) and sinapic acid (280 μg/g) which inhibit hexanal formation (≥85%). It is also used in combination with commercial CO_2 extract of rosemary (0.04 g/100 g meat) and was excellent to prevent oxidation of meat lipids [113].

Sesame oil: Sesamol is a natural phenolic antioxidant and has been shown to significantly reduce lipid oxidation in bovine [114] and porcine muscle model systems [115] raw and cooked pork patties [116], salami [117], turkey breast [118] and irradiated turkey sausages [119].

Olive leaf extract: Olive leaf extract is a phenolic compound derived from olive leaves and is known to have antioxidative, antimicrobial, antiviral and anti-inflammatory properties and to protect low-density lipoprotein from oxidation, to have the capacity to inhibit lipid oxidation.

Miscellaneous

Almond skins: Naturally occurring antioxidants in almond skins include phenolic acids and flavonoids. Application of electron beam irradiated almond skin powder (0.5% w/w) significantly lowered lipid oxidation in raw minced top round beef [120] and potentially acted as a natural and inexpensive antioxidant in meat and meat products [121].

Edible mushroom: [122] evaluated the antioxidant activity of hydrophilic extract prepared from edible mushroom (*Flammulina velutipes*) and the stabilizing effect on fresh color of bigeye tuna (*Thunnus obesus*) meat. The addition of 5 mL extract to 100 g minced bigeye tuna meat was more effective with regard to prevention of lipid oxidation.

Hydrolyzed potato protein: The antioxidant effect of hydrolyzed potato protein (HPP) (0% and 2.5%) was investigated in frankfurters formulated at 2 fat levels (15% and 30%), and stored for 7 days [123]. Meat emulsions with added HPP had lower redness and yellowness values. The addition of HPP (2.5%) significantly ($P < 0.05$) decreased cooking losses and fracture force, and had a significant ($P < 0.05$) inhibitory effect on lipid oxidation in cooked frankfurters.

Honey: Honey alters the water activity, thereby indirectly affecting oxidation rate. Moreover, it facilitates the Maillard reaction during the cooking process and thus the development of an antioxidant effect. Honey (15% w/w) was reported to retard lipid oxidation in cooked beef patties [124], turkey meat [125], chicken [126] and ground beef [127].

Rice hull extract: Rice hull is an attractive protective source due to its easily extractable antioxidant compounds. Furthermore, radiations (FIR) of rice hull liberate and activate covalently bound phenolic compounds that have antioxidant activities.

Soy protein hydrolysates: These are very frequently utilized in meat products as functional ingredients. Soy protein hydrolysates demonstrated inhibition of TBARS formation in an iron-catalyzed liposomal system [128].

Dry soya sprouts: These are rich in phenolics and flavonoids as well as have little amount of vitamin C and play an important role in preventing and treating chronic diseases such as heart ailments, osteoporosis, cancer, kidney ailments and menopausal syndromes [129]. DPPH radical scavenging activity was comparable to BHA and could be used as a cheap natural antioxidant source for meat and meat products.

Potato peel extract: Potato Peel Extract (PPE) has a high phenolic content (catechin, chlorogenic acid). The effective utilization of potato peel, as an antioxidant in radiation processed lamb meat was investigated by [130]. The antioxidant activity of PPE was found to be comparable to Butylated Hydroxytoluene (BHT).

Endogenous Antioxidants

Vitamin E (α-tocopherol): **α**-tocopherol has the ability to neutralize free radicals by reacting with peroxyl radicals to stop chain propagation and with alkoxyl radicals to inhibit the decomposition of the hydroperoxides and decrease the formation of aldehydes in cellular and subcellular membranes and protects oxymyoglobin oxidation. Postmortem addition of vitamin E was less effective. Thus, dietary vitamin E supplementation would be a safer and more effective method for retarding pigment and lipid oxidation in meat.

Ascorbic acid: Ascorbic Acid (AA) is a chelating agent that binds metal ions, scavenges free radicals and acts as a reducing agent. At high levels (> 1000 mg/kg), AA inhibits oxidation, however, at low levels (< 100 mg/kg) act as pro-oxidant and lead to Warmed Over Flavor (WOF) development [131]. The solubility of ascorbate affects its ability to prevent discoloration [132]. AA work synergistically with phosphates, sesamol and tocopherol to inhibit lipid oxidation [133].

Animal Sources

Milk proteins: Milk and milk components have been frequently

used in the enhancement of nutritional and technological properties of a wide variety of foods. A feasible application of peptides or hydrolysates as antioxidants is being explored especially in muscle foods.

Whey: Whey is a cheap by-product of the cheese industry. Whey and whey ultra-filtration permeate have been used as a natural antioxidant in foods. Whey Protein Concentrate (WPC) showed a higher efficacy as antioxidant in cooked pork patties [134]. Whey protein isolates at 2% and their hydrolytic products not only reduced the cooking loss but also suppressed lipid oxidation in cooked pork patties during refrigerated storage [128].

Casein peptides: Addition of casein peptides (20 mg/mL), obtained by the proteolytic enzymes alcalase and Flavourzyme [135] effectively inhibit lipid oxidation in ground beef homogenates and Mechanically Deboned Poultry Meat (MDM). The phosphorylated Caseinophosphopeptides (CPP) has the ability to scavenge free peroxyl radicals as well as to chelate transition metals such as iron, copper, and zinc [136]. Incorporation of casein calcium peptides (2%) inhibited about 70% of lipid oxidation and prevents formation of an off-flavour in meat products [137].

Carnosine: Carnosine is a naturally occurring skeletal muscle dipeptide, which consists of alanine and histidine which act as both a buffering agent and as an antioxidant. The antioxidant activity is due to its ability to act as a chelator, free radical scavenger and hydrogen donor [138,139]. Concluded that the combination of carnosine (50mM) with ascorbic acid (500 ppm) provided the best antioxidant protection for meat (beef steaks) during refrigerated storage.

Bone protein hydrolysates: These can be prepared by limited alcalase hydrolysis. It possessed significant antioxidant activity, which increased with the increasing hydrolysates concentration. Bone protein hydrolysates at 2% application level are able to not only stabilize meat colour but also suppress lipid oxidation in pork patties during storage and better sensory quality.

Conclusions

Most suitable antioxidant should be selected based on the character of food and the targets which should be attained. Synthetic antioxidants such as BHA, BHT and gallates were introduced in the 1940s. In recent years the meat industry is demanding antioxidants from natural sources to replace synthetic antioxidants because of the negative health consequences of some synthetic antioxidants and adverse toxicological reports on many synthetic compounds. Thus most of the recent investigations have been targeted towards identification of novel antioxidants from natural sources. Natural antioxidants have great impact on the safety and acceptability of the food system and will continue to do so. Not only do they keep the food stable against oxidation but can also be effective in controlling microbial growth. Therefore, the influence of these ingredients on meat quality parameters merits investigation as the use of natural antioxidants may afford the meat industry an opportunity to develop novel meat products with enhanced nutritional and health benefits, improved shelf-life and quality. However, further researches are needed to examine how different times and levels of supplementation, and how interactions with other natural antioxidants and food additives will affect the results.

References

1. Xiong Y (1996) Impacts of oxidation on muscle protein functionality. Proceedings of the Reciprocal Meat Conference 46: 79-86.
2. Decker EA and Faraji H (1990) Inhibition of Lipid Oxidation by Carnosine, a ß- Alanine- Histidine Dipeptide. Journal of American Oil Chemists Society 67: 650-652.
3. Barlow SM (1990) Toxicological Aspects of Antioxidants Used as Food Additives, in: B.J.F. Hudson Ed.). Food Antioxidants, Barking, England, Elsevier Science Publishers Ltd 253-307.
4. Juntachote T, Berghofer E, Srebenhandl S, Bauer F (2006) The oxidative properties of Holy basil and Galangal in cooked ground pork. Meat Science 72: 446-456.
5. Wong JW, Hashimoto K, Shibamoto T (1995) Antioxidant activities of rosemary and sage extracts and vitamin E in a model meat system. Journal of Agricultural and Food Chemistry 43: 2707-2712.
6. Su L, Yin JJ, Charles D, Zhou K, Moore J, et al. (2007) Total phenolic contents, chelating capacities and radical-scavenging properties of black peppercorn, nutmeg, rosehip, cinnamon and oregano leaf. Food Chemistry 100: 990-997.
7. Van Esch GJ (1986) Toxicology of Tert-Butylhydroquinone (TBHQ). Food Chemistry and Toxicology 24: 1063- 1065.
8. Shahidi F, Wanasundara, Janhita PK (1992) Phenolic antioxidants. Critical Review in Food Science and Nutrition 32: 67-103.
9. Chan KM, Decker EA, Faustman C (1994) Endogenous skeletal muscle antioxidants. Critical Review on Food Science and Nutrition 34: 403-426.
10. Carlsen CU, Moller JKS, Skibsted LH (2005) Heme-iron in lipid oxidation. Chemical Review 249: 485-498.
11. Maqsood S, Benjakul S, Kamal-Eldin A (2012) Haemoglobin-mediated lipid oxidation in the fish muscle: A review. Trends in Food Science and Technology 28: 33-43.
12. Benzie IF (1996) Lipid peroxidation: a review of causes, consequences, measurement, and dietary influences. International Journal Food Science Nutrition 47: 233-261.
13. Rice-Evans CA (1996) Structure-antioxidant activity relationships of flavonoids and phenolic acids. Free Radical Biology and Medicine 20: 933-956.
14. Zheng G, Xu L, Wua P, Xie H, Jiang Y, et al. (2009) Polyphenols from longan seeds and their radical-scavenging activity. Food Chemistry 116: 433-436.
15. Andjelkovic M, Van Camp J, De Meulenaer B, Depaemelaere G, Socaciu C, et al. (2006) Iron-chelation properties of phenolic acids bearing catechol and galloyl groups. Food Chemistry 98: 23-31.

16. Mukai K, Nagai S, Ohara K (2005) Kinetic study of the quenching reaction of singlet oxygen by tea catechins in ethanol solution. Free Radical Biology and Medicine 39: 752-761.

17. Muchuweti M, Kativu E, Mupure CH, Chidewe C, Ndhlala AR, et al. (2007) Phenolic composition and antioxidant properties of some spices. American Journal Food Technology 2: 414-20.

18. Ozsoy N, Candoken E, Akev N (2009) Implications for degenerative disorders: antioxidative activity, total phenols, flavonoids, ascorbic acid, beta-carotene and beta-tocopherol in Aloe Vera. Oxid Med Cell Long 2: 99-106.

19. Lee MA, Choi JH, Choi YS, Han DJ, Kim HY, et al. (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.

20. Fasseas MK, Mountzouris KC, Tarantilis PA, Polissiou M, Zervas G (2008) Antioxidant activity in meat treated with oregano and sage essential oils. Food Chemistry 106: 1188-1194.

21. Huang B, He J, Ban X, Zeng H, Yao X, et al. (2011) Antioxidant activity of bovine and porcine meat treated with extracts from edible lotus (*Nelumbo nucifera*) rhizome knot and leaf. Meat Science 87: 46-53.

22. 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.

23. Badr HM, Mahmoud KA (2011) Antioxidant activity of carrot juice in gamma- irradiated beef sausage during refrigerated and frozen storage. Food Chem 127: 1119-30.

24. Kanatt S R, Sharma A (2011) Antioxidant and antimicrobial activity of legume hulls. Food Research International 44: 3182-3187.

25. Hernandez HE, Ponce-Alquicira E, Jaramillo-Flores ME, Guerrero Legarreta I (2009) Antioxidant effect rosemary (*Rosmarinus officinalis* L.) and oregano (*Origanum vulgare* L.) extracts on TBARS and colour of model raw pork batters. Meat Science 81: 410-7.

26. Mielnik MB, Sem S, Egelandsdal B, Skrede G (2008) By-products from herbs essential oil production as ingredient in marinade for turkey thighs. LWT-Food Science and Technology 41: 93-100.

27. Kanatt SR, Chander R, Sharma A (2008) Chitosan and mint mixture: A new preservative for meat and meat products. Food Chemistry 107: 845-52.

28. 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 and Technology 43: 1807-1812.

29. Sayago-Ayerdi SG, Brenes A, Goni I (2009) Effect of grape antioxidant dietary fiber on the lipid oxidation of raw and cooked chicken hamburgers. LWT-Food Science and Technology 42: 971-97*6*.

30. Vaithiyanathan S, Naveena BM, Muthukumar M, Girish P S, Kondaiah N (2011) Effect of dipping in pomegranate (*Punica granatum*) fruit juice phenolic solution on the shelf life of chicken meat under refrigerated storage (4°C). Meat Science 88: 409-414.

31. Jayathilakan K, Sharma GK, Radhakrishna K, Bawa AS (2007) Effect of natural antioxidants on the lipid stability of fluidised bed-dried mutton. Food Chemistry 100: 662-66*8*.

32. Lee MA, Choi JH, Choi YS, Kim HY, Kim HW, et al. (2011) Effects of kimchi ethanolic extracts on oxidative stability of refrigerated cooked pork. Meat Science 89: 405-411.

33. Selani MM, Contreras-Castillo CJ, Shirahigue LD, Gallo CR, Plata-Oviedo M, et al. (2011) Wine industry residues extracts as natural antioxidants in raw and cooked chicken meat during frozen storage. Meat Science 88: 397-403.

34. Bozkurt H (2006) Utilization of natural antioxidants: Green tea extract and (*Thymbra spicata*) oil in Turkish dry-fermented sausage. Meat Sci 73: 442-450.

35. Garrido MD, Auqui M, Marti 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.

36. Pussa T, Pallin R, Raudsepp P, Soidla R, Rei M (2008) Inhibition of lipid oxidation and dynamics of polyphenol content in mechanically deboned meat supplemented with sea buckthorn (*Hippophae rhamnoides*) berry residues. Food Chemistry 107: 714-721.

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

38. Ciriano MG-Id, Garcia-Herreros C, Larequi E, Valencia I, Ansorena D, et al. (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.

39. Ciriano MG-Id, Rehecho S, Calvo MI, Cavero RY, Navarro I, et al. (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.

40. Ganhao R, Morcuende D, Estevez M (2010) Protein oxidation in emulsified cooked burger patties with added fruit extracts: Influence on colour and texture deterioration during chill storage. Meat Science 85: 402-409.

41. Sun W, Zhao M, Cui C, Zhao Q,Yang B (2010) Effect of Maillard reaction products derived from the hydrolysate of mechanically deboned chicken residue on the antioxidant, textural and sensory properties of Cantonese sausages. Meat Science 86: 276-282.

42. Brettonnet A, Hewavitarana A, DeJong S, Lanari MC (2010) Phenolic acids composition and antioxidant activity of canola extracts in cooked beef, chicken and pork. Food Chem 121: 927-933.

43. Yogesh K, Ali J (2014) Antioxidant potential of *thuja* (*Thuja occidentalis*) cones and peach (*Prunus persia*) seeds in raw chicken ground meat during refrigerated (4 ± 1°C) storage. Journal of Food Science Technology 51: 1547-1553.

44. Yogesh K, Jha SN and Yadav DN (2012) Antioxidant activities of (*Murraya koenigii* L.) spreng berry extract: Application in refrigerated (4±1°C) stored meat homogenates. Agricultural Research 1: 183-189.

45. Basaga H, Tekkaya C, Acikel F (1997) Antioxidative and free radical scavenging properties of rosemary extract. Lebensm. Wiss. Technol 30: 105-108.

46. Yu L, Scanlin L, Wilson J, Schmidt G (2002) Rosemary extract as inhibitors of lipid oxidation and color change in cooked turkey products during refrigerated storage, Journal of Food Science 67: 582-585.

47. Barbut S, Josephson DB, Maurer AJ (1985) Antioxidant properties of rosemary oleoresin in turkey sausage. Journal of Food Science 50: 1356-1359.

48. 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.

49. Nakatani N (2003) Biologically functional constituents of spices and herbs. Journal of Japanese Society Nutrition Food Science 56: 389-395.

50. Chang SS, Ostric-Matijasevic B, Hsien OAL, Huang CL (1977) Natural antioxidants from rosemary and sage. Journal of Food Science 42: 1102-1106.

51. Cuvelier M E, Berset C, Richard H (1994) Antioxidant constituents in sage (*Salvia officinalis*). Journal of Agriculture Food Chemistry 42: 665-669.

52. Vekiari SA, Oreopoulou V, Tzia C, Thomopolos CD (1993) Oregano flavonoids as lipid antioxidants. Journal of American Oil Chemists Society 70: 483-487.

53. Simitzis PE, Deligeorgis SG, Bizelis JA, Dardamani A, Theodosiou I, et al. (2008) Effect of dietary oregano oil supplementation on lamb meat characteristics. Meat Science 79: 217-223.

54. Zinoviadou KG, Koutsoumanis KP, Biliaderis CG (2009) Physicochemical properties of whey protein isolate films containing oregano oil and their antimicrobial action against spoilage flora of fresh beef. Meat Science 82: 338-345.

55. Oussalah M, Caillet S, Salmieri S, Saucier L, Lacroix M (2006) Antimicrobial effects of alginate-based film containing essential oils for the preservation of whole beef muscle. Journal of Food Protection 69: 2364-2369.

56. Leuschner RGK, Ielsch V (2003) Antimicrobial effects of garlic, clove and red hot chilli on Listeria monocytogenes in broth model systems and soft cheese. International Journal of Food Sciences and Nutrition 54: 127-133.

57. Jackson R, McNeil B, Taylor C, Holl G, Ruff D, et al. (2002) Effect of aged garlic extract on casepase-3 activity, *in vitro*. Nutritional Neuroscience 5: 287-290.

58. Ankri S, Mirelman D (1999) Antimicrobial properties of allicin from garlic. Microbes and Infection1: 125-129.

59. Sallam KI, Ishioroshi M, Samejima K (2004) Antioxidant and antimicrobial effects of garlic in chicken sausage. LWT - Food Science and Technology 37: 849-855.

60. Park WY, Kim YJ (2009) Effect of garlic and onion juice addition on the lipid oxidation, total plate counts and residual nitrite contents of emulsified sausage during cold storage. Korean Journal of Food Science Animal Resources 29: 612-618.

61. Kim Y, Jin S, Park W, Kim B, Joo S and Yang H (2010) The effect of garlic or onion marinade on the lipid oxidation and meat quality of pork during cold storage. Journal of Food Quality 33: 171-185.

62. Younathan MT, Marjan ZM, Arshad FB (1980) Oxidative rancidity in stored ground turkey and beef. Journal of Food Science, 45: 274-275.

63. Jurdi-Haldeman D, Macneil JH, Yared DM (1987) Antioxidant activity of onion and garlic juices in stored cooked ground lamb. Journal of Food Protection 50: 411-413.

64. Dorman H J D, Kosar M, Kahlos K, Holm Y, Hiltunen R (2003) Antioxidant properties and composition of aqueous extracts from Mentha species, hybrids, varieties, and cultivars. Journal of Agricultural and Food Chemistry 51: 4563-4569.

65. Mariutti LRB, Barreto GPM, Bragagnolo N, Mercadante AZ (2008) Free radical scavenging activity of ethanolic extracts from herbs and spices commercialized in Brazil. Brazilian Archives of Biology and Technology 51: 1225-1232.

66. 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.

67. Erich Schmidt (2006) Composition of antioxidant activity of essential oil of cinnamon. Jeobp 9: 170-182.

68. Yadav, AS, Pandey, NK, Singh RP (2005) Studies on the use of natural preservatives for preservation of chicken meat. Indian Poultry Science Association XXIII Annual Conference and National symposium.

69. Chan K, Khong NH, Iqbal S, Chang S, Younas U, et al (2012) Cinnamon bark deodorized aqueous extract as potential natural antioxidant in meat emulsion system: a comparative study with synthetic and natural food antioxidants. Journal Food Science and Technology 51: 3269-3276.

70. Moarefian M, Barzegar M, Sattari M (2013) *Cinnamomum zeylanicum* essential oil as a natural antioxidant and antibactrial in cooked sausage. Journal of Food Biochemistry 37: 629.

71. Fratianni F, DeMartino L, Melone A, DeFeo V, Coppola R, et al. (2010) Preservation of chicken breast meat treated with thyme and balm essential oils. Journal of Food Science 75: 528-535.

72. Bozin B, Mimica-Dukic N, Simin N, Anackov G (2006) Characterization of the volatile composition of essential oils of some Lamiaceae spices and the antimicrobial and antioxidant activities of the entire oils. Journal Agriculture Food Chemistry 54: 1822-1828.

73. Higdon JV, Frei B (2003) Tea catechins and polyphenols: health effects, metabolism, and antioxidant functions, Critical Reviews in Food Sci. and Nutrition 43: 89-143.

74. Goto K, Kanaya S, Ishigami T, Hara Y (1999) Effects of tea polyphenols on fecal conditions: the effects of tea catechins on the fecal conditions of elderly residents in long-term care acility. Journal of Nutritional Science and Vitaminology 45: 135-141.

75. Mirshekar R, Dastar B, Shabanpour B (2009) Effect of Rosemary, Echinacea, Green Tea extracts and Ascorbic acid on broiler meat quality. Pakistan Journal of Biological Sciences 12: 1069-1074.

76. Ferial M, Abu-Salem, Esmat A, Abou-Arab, Hayam M, et al. (2011) Effect of Adding Green Tea Extract, Thyme Oil and/or their Combination to Luncheon Roll Meat during Refrigerate Storage. Journal of American Science 7: 538-548.

77. Chen ZY, Wang LY, Chan PT, Zhang Z, Chung HY, et al. (1998) Antioxidative activity of green tea catechin extract compared with that of rosemary extract. Journal of American Oil Chemists Society 75: 1141-1145.

78. He Y, Shahidi F (1997) Antioxidant activity of green tea and its catechins in a fish meat model system. Journal of Agricultural and Food Chemistry 45: 4262-4266.

79. Hoffman LC, Jones M, Muller N, Joubert E, Sadie A (2014) Lipid and protein stability and sensory evaluation of ostrich (*Struthio camelus*)

droëwors with the addition of rooibos tea extract (*Aspalathus linearis*) as a natural antioxidant. Meat Science 96: 1289-96.

80. Osman H, Nazaruddin R, Lee SL (2004) Extracts of cocoa (*Theobroma cacao L*) leaves and their antioxidation potential. Food Chemistry 86: 41-46.

81. Schmidt E, Bail S, Buchbauer G, Stoilova I, Krastanov A, et al. (2008) Chemical composition, olfactory evaluation and antioxidant effects of the ssential oil of *Origanum majorana* L. from Albania. Natural Products Communication 3: 1051-1056.

82. Jun WJ, Han BK, Yu KW, Kim MS, Chang IS, et al. (2001) Antioxidant effects of *Origanum majorana* L. on superoxide anion radicals. Food Chemistry 75: 439-444.

83. Wettasinghe M, Shahidi F (1999) Evening Primrose Meal: A Source of Natural Antioxidants and Scavenger of Hydrogen Peroxide and Oxygen-Derived Free Radicals. Journal of Agriculture and Food Chemistry 47: 1801-1812.

84. Zhang Y, Zhang JCX, Wu X, Zhang Y (2007) Addition of Antioxidant of Bamboo Leaves (AOB) Effectively Reduces Acrylamide Formation in Potato Crisps and French Fries. Journal Agriculture Food Chemistry 55: 523-528.

85. Macheix J, Fleuiret A, Billot J (1990) Fruit phenolics. Boca Roton, FL: CRC press, Inc.

86. Nunez de Gonzalez M T, Boleman R M, Miller R K, Keeton J T, Rhee K S (2008) Antioxidant properties of dried plum ingredients in raw and precooked pork sausage. Journal of Food Science 73: 63-71.

87. Nunez de Gonzalez MT, Hafley BS, Boleman RM, Miller RK, Rhee KS, et al. (2008) Antioxidant properties of plum concentrates and powder in precooked roast beef to reduce lipid oxidation. Meat Science 80: 997-1004.

88. Adhami VM, Mukhtar H (2006) Polyphenols from green tea and pomegranate for prevention of prostate cancer. Free Radical Res 40: 1095-1104.

89. Rodriguez-Carpena J Gn, Morcuende D, Andrade Ma Js, Kylli P, Estevez M (2011) Avocado (*Persea americana* Mill.) phenolics, *in vitro* antioxidant and antimicrobial activities and inhibition of lipid and protein oxidation in porcine patties. Journal of Agriculture and Food Chemistry 59: 5625-5635.

90. Britt C, Enayat A, Gomaa J, Gray I, Booren AM (1998) Influence of Cherry Tissue on Lipid Oxidation and Heterocyclic Aromatic Amine Formation in Ground Beef Patties. Journal Agriculture Food Chemistry 46: 4891-4897.

91. Hanldelman GJ (1996) Carotenoids as scavengers of active oxygen species. In: Cadenas E. and Packer L (eds), Handbook of antioxidants 259-315.

92. Osterlie M, Lerfall J (2005) Lycopene from tomato products added minced meat: Effect on storage quality and colour. Food Research International 38: 925-29.

93. Escalante AS, Torrescano G, Djenane D, Beltran JA, Roncales P (2003) Stabilisation of colour and odour of beef patties by using lycopene-rich tomato and peppers as a source of antioxidants. Journal of the Science of Food and Agriculture 83: 187-94.

94. Calvo MM, Garcia ML, Selgas MD (2008) Dry fermented sausages enriched with lycopene from tomato peel. Meat Science 80: 167-72.

95. Devatkal S, Kadam D, Naik P, Sahoo J (2011) Quality characteristics of gluten free chicken nuggets extended with sorghum flour. Journal of Food Quality.

96. Weber HA, Hodges AE, Guthrie JR, O'Brien BM (2007) Comparison of proanthocyanidins in commercial antioxidants: Grape seed and pine bark extracts. Journal of Agricultural and Food Chemistry 55: 148-156.

97. Ahn HS, Jeon TI, Lee JY, Hwang SG, Lim Y, et al. (2002) Antioxidative activity of persimmon and grape seed extract: *in vitro* and *in vivo*. Nutrition Research 22: 1265-1273.

98. Lau DW, King AJ (2003) Pre- and post-mortem use of grape seed extract in dark poultry meat to inhibit development of thiobarbituric acid reactive substances. Journal of Agricultural and Food Chemistry 51: 1602-1607.

99. Brannan RG, Mah E (2007) Grape seed extract inhibits lipid oxidation in muscle from different species during refrigerated and frozen storage and oxidation atalyzed by peroxynitrite and iron/ascorbate in a pyrogallol red model system. Meat Science 77: 540-546.

100. Carpenter R, O'Grady MN, O'Callaghan YC, O'Brien NM, Kerry JP (2007) Evaluation of the antioxidant potential of grape seed and bearberry extracts in raw and cooked pork. Meat Science 76: 604-610.

101. Price A, Diaz P, Banon S, Garrido MD (2013) Natural extracts versus sodium ascorbate to extend the shelf life of meat-based ready-to-eat meals. Food Science and Technology International 19: 427-38.

102. Yilmaz Y, Toledo RT (2004) Major flavonoids in grape seed and skins: Antioxidant capacity of catechin, epicatechin and gallic acid. Journal of Agricultural and Food Chemistry 52: 255-260.

103. Ayerdi SG, Brenes A, Viveros A, Goni I (2009) Antioxidative effect of dietary grape pomace concentrate on lipid oxidation of chilled and long term frozen stored chicken patties. Meat Science 83: 528-33.

104. Reddy GV, Sen AR, Nair PN, Reddy KS, Reddy KK, et al. (2013) Effects of grape seed extract on the oxidative and microbial stability of restructured mutton slices, Meat Science 95: 288-294.

105. Bousbiaab N, Vianc MA, Ferhata MA, Meklatia BY, Chemat F (2009) A new process for extraction of essential oil from Citrus peels: Microwave hydrodiffusion and gravity. Journal of Food Engineering 90: 409-413.

106. Berhow M, Tisserat B, Kanes K, Vandercook C (1996) Survey of Phenolic compounds produced in citrus. U.S. Department of Agriculture, Agricultural Research Service. Technical Bulletin Pg No: 1856.

107. Contini C, Katsikogianni MG, O'Neill FT, O'Sullivan M, Dowling DP, et al. (2012) PET trays coated with Citrus extract exhibit antioxidant activity with cooked turkey meat. LWT-Food Science and Technology 47: 471-477.

108. Pizzocaro F, Senesi E, Veronese P and Gasparolo P (1998) Mechanically deboned poultry meat hamburgers II. Protective and antioxidant effect of the carrot and spinach tissues during frozen storage, Industrie Alimentari 37: 710-720.

109. Alves-Rodrigues A and Shao A (2004) The science behind lutein. Toxicology Letters 150: 57-83.

110. Duthie G, Campbell F, Bestwick C, Stephen S, Russell W (2013) Antioxidant effectiveness of vegetable powders on the lipid and protein oxidative stability of cooked turkey meat patties: Implications for health. Nutrients 5: 1241-1252.

111. Wanasundara UN, Shahidi F (1994) Canola extract as an alternative natural antioxidant for canola oil. Journal of American Oil Chemists Society 71: 817-822.

112. Salminen H, Estevez M, Kivikari R, Heinonen M (2006) Inhibition of protein and lipid oxidation by rapeseed, camelina and soy meal in cooked pork meat patties. European Food Research Technology 223: 461-468.

113. Joshi R, Kumar MS, Satyamoorthy K, Unnikrisnan MK, Mukherjee T (2005) Free radical reactions and antioxidant activities of sesamol: Pulsed radiolytic and biochemical studies. Journal of Agriculture and Food Chemistry 53: 2696-2703.

114. Hayes JE, Stepanyan V, Allen P, O'Grady MN, O'Brien NM, et al. (2009) The effect of lutein, sesamol, ellagic acid and olive leaf extract on lipid oxidation and oxymyoglobin oxidation in bovine and porcine muscle model systems. Meat Science 83: 201-208.

115. Chen X, Jo C, Lee JI, Ahn DU (1999) Lipid oxidation, volatiles and colour changes of irradiated pork patties as affected by antioxidants. Journal of Food Science 64: 16-19.

116. Ghiretti GP, Zanardi E, Novelli E, Campanini G, Dazzi G, et al. (1997) Comparative evaluation of some antioxidants in salame milano and mortadella production. Meat Science 47: 167-176.

117. Lee EJ, Ahn DU (2003) Effect of antioxidants on the production of off-odor volatiles and lipid oxidation in irradiated turkey breast meat and meat homogenates. Journal of Food Science 68: 1631-1638.

118. Du M, Ahn DU (2002) Effect of antioxidants on the quality of irradiated sausages prepared with turkey thigh meat. Poultry Science 81: 1251-1256.

119. Prasetyo M, Chia M, Hughey C, Were L (2008) Utilization of electron beam irradiated almond skin powder as a natural antioxidant in ground top round beef. Journal of Food Science 73: T1-T6.

120. Teets AS, Were LM (2008) Inhibition of lipid oxidation in refrigerated and frozen salted raw minced chicken breasts with electron beam irradiated almond skin powder. Meat Science 80: 1326-1332.

121. Bao HND, Ushio H, Ohshima T (2009) Antioxidative activities of mushroom (*Flammulina velutipes*) extract added to bigeye tuna meat: dose-dependent efficacy and comparison with other biological antioxidants. Journal of Food Science 74: 162-169.

122. Nieto G, Castillo M, Xiong YL, Álvarez D, Payne FA, et al. (2009) Antioxidant and emulsifying properties of alcalase-hydrolyzed potato proteins in meat emulsions with different fat concentrations. Meat Science 83: 24-30.

123. Antony S, Rieck JR, Acton JC, Han IY, Halpin EL, et al. (2006) Effect of Dry Honey on the Shelf Life of Packaged Turkey Slices. Poultry Science 85: 1811-1820.

124. McKibben J, Engeseth NJ (2002) Honey as a protective agent against lipid oxidation in ground turkey. Journal Agriculture Food Chemistry 50: 592-595.

125. Hashim IB, McWatters KH, Hung YC (1999) Marination method and honey level affect physical and sensory characteristics of roasted chicken. Journal of Food Science 64: 163-166.

126. Johnson JE, Shipe HA, Miano CL, Brannan RG, Alderton AL (2005) Honey inhibits lipid oxidation in ready-to-eat ground beef patties. Meat Science 70: 627-631.

127. Pena-Ramos EA, Xiong YL (2003) Whey and Soya protein hydrolysates inhibit lipid oxidation in cooked pork patties. Meat Science 64: 259-263.

128. Pardeshi IL, Murumkar RP, Tayade PT (2014) Optimization of Process for Spray Drying of Soymilk and Sprouted Soybean Milk. Journal of Grain Processing and Storage 1: 13-20.

129. Kanatt SR, Chander R, Radhakrishna P, Sharma A (2005) Potato Peel Extract a Natural Antioxidant for Retarding Lipid Peroxidation in Radiation Processed Lamb Meat. Journal Agricultural Food Chemistry 53: 1499-1504.

130. Ahn DU, Nam KC (2004) Effects of ascorbic acid and antioxidants on color, lipid oxidation and volatiles of irradiated ground beef. Radiation Physics and Chemistry 71: 151-156.

131. Mancini RA, Hunt MC, Seyfert M, Kropf DH, Hachmeister KA, et al. (2006) Effect of antioxidant solubility and concentration on discoloration of beef vertebrae marrow during display. Journal Food Science 71: 489-494.

132. Ismail HA, Lee EJ, Ko KY, Ahn DU (2008) Effects of aging time and natural antioxidants on the color, lipid oxidation and volatiles of irradiated ground beef. Meat Science 80: 582-591.

133. McCarthy TL, Kerry JP, Kerry JK, Lynch PB, Buckley DJ (2001) Evaluation of the antioxidant potential of natural food/plant extracts as compared with synthetic antioxidants and vitamin E in raw and cooked pork patties. Meat Science 57: 45-52.

134. Rossini K, Norena CPZ, Cladera-Olivera F, Brandelli A (2009) Casein peptides with inhibitory activity on lipid oxidation in beef homogenates and mechanically deboned poultry meat. LWT - Food Science and Technology 42: 862-867.

135. Kim GN, Jang HD, Kim CI (2007) Antioxidant capacity caseinophosphopeptides prepared from sodium caseinate using Alcalase. Food Chemistry 104: 1359-1365.

136. Sakanaka S, Tachibana Y, Ishihara N, Juneja LR (2005) Antioxidant properties of casein calcium peptides and their effects on lipid oxidation in beef homogenates. Journal of Agricultural and Food Chemistr 79 53: 464-468.

137. Decker EA, Mei L (1996) Antioxidants mechanisms and applications in muscle foods. In: Proceedings of the Reciprocal Meat Conference. Pg No: 64-72.

138. Djenane D, Martinez L, Sanchez-Escalante A, Beltran JA, Roncales P (2004) Antioxidant effect of carnosine and carnitine in fresh beef steaks stored under modified atmosphere. Food Chemistry 85: 453-459.

139. Diao J, Diao X, Kong B, Chen H (2009) The Inhibiting Effect of Bone Protein Hydrolysates on Lipid Oxidation in Pork Patties. Journal of Northeast Agricultural University 16: 29-34.