AN OVERVIEW OF SOME NATURAL ANTIOXIDANTS USED IN MEAT AND POULTRY PRODUCTS

by

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Abstract

In response to recent claims that synthetic antioxidants have the potential to cause toxicological effects and consumers' increased interest in purchasing natural products, the meat and poultry industry has been seeking sources of natural antioxidants to replace synthetic antioxidants, which are currently being used by the industry. Due to their high phenolic compound content, fruits and other plant materials provide a good alternative to conventional antioxidants. Plum, grape seed extract, cranberry, pomegranate, bearberry, pine bark extract, rosemary, oregano, other spices, irradiated almond skins, and green tea have functionality as antioxidants in meat and poultry products. Pomegranate, pine bark extract, cinnamon, and cloves have exhibited stronger antioxidant properties than some of the synthetic antioxidants currently used by the meat and poultry industry. Of the discussed natural antioxidants, grape seed extract, cranberry, sage extract, thyme extract, basil extract, ginger extract, pine bark extract, and a Chinese 5-spice (cinnamon, clove, fennel, pepper, and star anise) blend had the highest percent antioxidant activity (% AOA). The quality of the antioxidant used may also impact its ability to function as an antioxidant.

Some of these natural antioxidants have impacted color and sensory properties of finished meat and poultry products. Plum products used in meat and poultry products have increased redness of the finished product. In some products such as pork sausage or uncured meats, an increase in red color may be desired. Grape seed extract, pine bark extract, rosemary, almond skin powder, some spices and green tea extract have been shown to impact the color of finished meat or poultry products. Plum products and many other spices affect the overall sensory

properties of meat or poultry products as well. Depending on the finished product, consumers may view these changes as positive or as negative. When selecting a natural antioxidant to use in a meat or poultry product, the sensory and quality impact on the product should be considered in order to achieve a product with the desired traits.

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CHAPTER 1 - Introduction

In response to recent demand from consumers for natural products, and their willingness to pay significant premiums for natural foods (Sebranek and Bacus 2007), the meat and poultry industry is actively seeking natural solutions to minimize oxidative rancidity and increase the shelf-life of their products (Naveena and others 2008b). Due to their high content of phenolic compounds, fruits and other plant materials are a good source of natural antioxidants and provide a good alternative to currently used conventional antioxidants (Nunez de Gonzales and others 2008a).

In the meat and poultry industry, a natural product is defined by United States Department of Agriculture's Food Safety and Inspection Service (USDA/FSIS) as a product that does not contain "any artificial flavor, coloring ingredient or chemical preservative, or any other artificial or synthetic ingredient; and the product and its ingredients are not more than minimally processed" (USDA, 2005). Some of the natural antioxidants that will be discussed may not fit the USDA/FSIS definition of a "natural product." However, they have been obtained from natural sources and while they are not synthetic compounds, they may have received some form of processing prior to incorporating into meat or poultry products.

For instance, the antioxidant potential of irradiated almond skin is discussed in this paper. This ingredient may not be considered natural because irradiation is viewed as more than "minimally processed," but as with spices, almond skin powder does not need to be labeled as irradiated on a finished product (USDA 2001). It may not be possible to make any natural claims regarding the finished product if using irradiated almond skin powder, but the finished product ingredient statement is much more consumer-friendly when compared to similar products using synthetic antioxidants.

Other fruit or plant material extracts that could be considered consumer friendly may be extracted using solvents. Again, solvent extraction may classify these ingredients as more than minimally processed, and using these extracts may not qualify the finished product for any natural claims. However, these ingredients only need to be labeled as extracts with no mention of the solvent used. This will also allow for a cleaner ingredient statement when comparing it to similar products that use synthetic antioxidants.

Some natural antioxidants discussed in this paper impact the color of finished meat or poultry products. In many cases, these products may appear to be more red, which may lead consumers to believe that a fully cooked product is not done. Product appearance should never be used as an indication of doneness. A meat thermometer should always be used to determine when a product is fully cooked. Products should be cooked to temperature guidelines set by the USDA (USDA 2006).

In some meat and poultry products, the increase in red color may be a benefit to processors. Products that are naturally light in color because of their high fat content, like pork sausage, may benefit from the boost in red color that plum and other natural antioxidants may add. Uncured meat products, which may lack a pink color due to the absence of nitrites added directly to the product, may also benefit from the increase in red color from some natural antioxidants.

Lipid oxidation is important to the meat and poultry industry because it is one of the major causes of quality deterioration (Raghavan and Richards 2007). Lipid oxidation can impart negative effects on sensory attributes such as color, texture, odor, and flavor, as well as negatively impacting the nutritional quality of the product (Nunez de Gonzalez and others 2008b). Before meat is cooked, lipids in the meat undergo autoxidation (St. Angelo and others 1990). This autoxidation requires an oxidizing agent, which is typically oxygen (Rojas and Brewer 2008). During cooking, these oxidized lipids produce secondary oxidative compounds such as hexanal, pentanal, heptanal, octanal, and secondary volatile aldehydes, which contribute to the development of Warmed Over Flavor (WOF) (Rojas and Brewer 2007). The onset of WOF is rapid in cooked refrigerated product, and may occur in as little as a few days (Jayathilakan and others 2007). WOF is commonly described as “stale,” “wet cardboard,” “painty,” “grassy,” or “rancid” (Rojas and Brewer 2007).

Processed meats are highly susceptible to lipid oxidation because they are commonly ground, they are often cooked, and they generally contain salt (Rojas and Brewer 2008). Grinding promotes lipid oxidation because it increases the exposure of lipids to air. Cooking a product releases iron from denatured myoglobin and hemoglobin, which catalyzes lipid oxidation, and salt is a lipid proxidant at concentrations from 0.5% - 2.5% (Rojas and Brewer 2008).

The extent of lipid oxidation is generally determined by measuring the amount of malondialdehyde (MDA) that reacts with thiobarbituric acid (TBA). However, TBA is not specific for MDA; therefore, the results are generally expressed as thiobarbituric acid-reactive substances (TBARS) (Ahn and others 2002). TBARS values are commonly recorded as mg MDA/kg sample. A strong correlation exists between the amount of TBARS formation and formation of WOF (Campo and others 2006). TBARS values above 0.5 ppm indicate some oxidation has occurred, and values about 1 ppm are considered to be unacceptable (Warriss 2000). Hexanal is a secondary oxidative compound formed during lipid oxidation. Measuring the amount of hexanal formation is another way to measure the amount of lipid oxidation in a product (Shahidi and others 1994).

For over 50 years, synthetic antioxidants such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), *tert*-butylhydroquinone (TBHQ) and propyl gallate (PG) have been used as antioxidants in meat and poultry products (Formanek and others 2001; Jayathilakan and others 2007; Biswas and others 2004). The use of these synthetic antioxidants has fallen under scrutiny due to their potential toxicological effects (Nunez de Gonzalez and others 2008b; Naveena and others 2008b; Raghavan and Richards 2007). The meat and poultry industry is in need of economical and effective natural antioxidants that can replace these synthetic antioxidants without negatively impacting their finished product quality and consumer perceptions.

Consumers' demand for natural products, as well as their concern over commonly used synthetic antioxidants, suggests that it is important to identify functional natural antioxidants to use in meat and poultry products. There is a significant amount of research regarding the use of fruit and other plant materials as antioxidants in meat and poultry products. However, there is no comprehensive review on how natural ingredients such as cranberry, plum, pine bark extract, grape seed extract, and others may be used, and what their functional characteristics are in meat and poultry products. The continued demand for natural products warrants a thorough review of the natural antioxidants that have been studied thus far.

CHAPTER 2 - REVIEW OF LITERATURE

Fruits

Recently, fruits have gathered interest from the public and from the scientific community because of their health-promoting properties. The benefits of fruits have been attributed to their high phenolic compound content, which act as antioxidants (Zuo and others 2002). It is because of this high phenolic content that many fruits are a good source of natural antioxidants to use in meat and poultry products. There have been numerous studies conducted on the antioxidant potential of many fruits. A review of studies evaluating the antioxidant potential of plum, grape seed extract, cranberry, pomegranate, and bearberry in various meat and poultry products will be discussed.

Plum

Food ingredients derived from plums function as antioxidants, antimicrobials, fat replacers, and flavorants (Nunez de Gonzalez and others 2008b). Plums have expressed antioxidant properties in a multitude of products such as precooked pork sausage, irradiated turkey, and precooked roast beef (Nunez de Gonzalez and others 2008a; Lee and Ahn 2005; Nunez de Gonzalez and others 2008b).

Nunez de Gonzalez and others (2008a) evaluated raw and cooked pork sausage patties treated with 3% and 6% dried plum puree, 3% and 6% dried plum and apple puree (fruit purees obtained from the California Plum Board, Sunsweet Growers Inc., Yuba City, California), and butylated hydroxyanisole (BHA)/butylated hydroxytoluene (BHT) at 0.02% (based on sausage fat content). An untreated sample served as the control. In this study, pork sausage was formulated to 32% fat. The sausage was formulated with dried plum puree or dried plum and apple puree at 3% and 6%, cooked to an internal temperature of 71.1 °C, and stored in vacuum packaging. Samples were either stored at 4 °C for 28 d, or frozen at -20 °C for 90 d. The precooked pork sausage patties treated with 3% and 6% dried plum puree, or 6% dried plum and apple puree showed a reduction ($p < 0.05$) in TBARS values for refrigerated patties after 28 d when compared with the control (Table 2-1). The TBARS value of the control sample was 1.00 mg MDA/kg sample. In the sample treated with 3% dried plum puree, the TBARS value was 0.44 mg MDA/kg sample, and the 6% dried plum puree sample had a TBARS value of 0.34 mg MDA/kg sample. The 3% and 6% dried plum and apple puree samples resulted in TBARS values higher than the samples treated with dried plum puree, and the 3% dried plum and apple puree sample had a TBARS value higher than the control. The 3% and 6% dried plum puree treatments were very similar ($p > 0.05$) to the BHA/BHT treatment, which had a TBARS value of 0.39 mg MDA/kg sample. The 3% and 6% dried plum and apple puree treatments had higher ($p < 0.05$) TBARS values than the BHA/BHT treatment.

Control precooked pork sausage patties stored frozen (-20 ˚C) for 90 d also had a significantly higher TBARS value of 1.98 mg MDA/kg sample, compared to patties with 3% dried plum, 6% dried plum puree, and 3% dried plum and apple puree. TBARS values of these samples were 0.95, 0.46, and 1.46 mg MDA/kg sample, respectively. The BHA/BHT treatment had a TBARS value of 1.05 mg MDA/kg sample and was higher

($p < 0.05$) than the 6% dried plum treatment, but was not significantly different from the 3% dried plum treatment. The 6% dried plum and apple puree treatment did not lower ($p > 0.05$) TBARS values when compared to the control.

Table 2-1 – TBARS[1] values of raw and precooked pork sausage formulated with dried plum puree ingredients and stored at 4 ˚C for 28 d and -20 ˚C for 90 d (Nunez de Gonzalez 2008a).

Storage treatment[2]	Antioxidant treatment	TBARS
RR[3]	Control	0.28[f]
	DP 3%	0.29[f]
	DP 6%	0.31[f]
	DPA 3%	0.27[f]
	DPA 6%	0.29[f]
	BHA/BHT	0.29[f]
	SEM[4]	0.06
PR	Control	1.00[c,d]
	DP 3%	0.44[f]
	DP 6%	0.34[f]
	DPA 3%	1.29[b]
	DPA 6%	0.72[e]
	BHA/BHT	0.39[f]
	SEM	0.06
PF	Control	1.98[a]
	DP 3%	0.95[d]
	DP 6%	0.46[f]
	DPA 3%	1.46[b]
	DPA 6%	1.86[a]
	BHA/BHT	1.05[c,d]
	SEM	0.08

[1] TBARS was reported on a sample weight basis (mg MDA/kg sample).
[2] Treatments: Control = no antioxidant; DP = dried plum puree; DPA = dried plum and apple.
[3] RR = raw pork sausage refrigerated at 4 °C; PR = precooked pork sausage refrigerated at 4 °C; PF = precooked pork sausage frozen at – 20 °C.
[4] SEM = standard error of the mean.
[a-f] Least square means in the same column without a common superscript letter differ ($p < 0.05$).

Lee and Ahn (2005) found that plum extract (obtained from the California Plum Board, Sunsweet Growers Inc., Yuba City, California) used at 3% in irradiated turkey breast rolls reduced ($p < 0.05$) lipid oxidation. Plum extract was added to samples, cooked to an internal temperature of 75 °C, sliced and vacuum packaged, and irradiated at 0 and 3 kGy. In this study, TBARS value for the control product was 0.95 mg MDA/kg meat, and the 3% plum extract treatment had a reduced ($p < 0.05$) TBARS value of 0.84 mg MDA/kg meat after 7 d of storage at 4 °C.

Nunez de Gonzalez and others (2008b) found that lipid oxidation was reduced ($p < 0.05$) in precooked roast beef when treated with fresh plum juice concentrate, dried plum juice concentrate, and spray dried plum powder (all plum products obtained through California Plum Board from Sunsweet Growers, Inc., Yuba City, CA). In this study, beef top rounds were brine injected (20% by weight of raw product) with the above plum products added at 2.5% and 5% of the brine. These products were cooked to an endpoint temperature of 62.8 °C and stored at < 4 °C for 10 wk. Meat treated with the 5% fresh plum juice concentrate treatment (0.16 mg MDA/kg) was found to have the lowest TBARS value of all the treatments. The TBARS value of the control was 0.62 mg MDA/kg.

Color measurements (C.I.E.) are commonly reported using the L*, a*, and b* color scale. The a* value is a measurement of the redness of the product. The larger the a* value is, the more red the color of the product is. L* is a measurement of the lightness of a product. L* values range from 0 (black) to 100 (white). The yellowness of a product is represented by the b* value. The larger the b* value, the more yellow in color a product is.

Various plum products increased ($p < 0.05$) a* values and decreased L* values (Lee and Ahn 2005; Nunez de Gonzalez and others 2008b). The color differences noted in these studies may be caused by the dark purple color of the plum extract (Lee and Ahn 2005). However, Nunez de Gonzalez and others (2008a; 2008b) report the opposite for a* when samples were treated with dried plum puree or fresh plum juice concentrate. Cooked roast beef samples treated with 2.5% and 5% fresh plum juice concentrate and stored for 10 wk at < 4 °C were shown to have lower ($p < 0.05$) redness color scores than the untreated control treatments (10.2). The 2.5% fresh plum juice concentrate treatments had an a* value of 9.5 and the 5% fresh plum juice concentrate treatment had an a* value of 9.4.

Sensory evaluations of meat and poultry products treated with plum products have shown little difference when compared to untreated products. Nunez de Gonzalez and others (2008a) used a 7-member trained expert descriptive attribute sensory panel and found that dried plum puree may mask pork and spicy flavors in pork sausage. The overall liking of pork sausage treated with 3% dried plum puree did not score differently ($p > 0.05$) from control, and pork sausage treated with 6% dried plum puree was acceptable, but less preferred than the control (Nunez de Gonzalez and others 2008a).

In precooked roast beef treated with plum products, there were marginally detectable differences found by a 7-member expert descriptive attribute sensory panel in sweet taste between treated and control samples (Nunez de Gonzalez and others 2008b). Lee and Ahn (2005) used a 10-member trained sensory panel to evaluate odor characteristics, color, and texture of irradiated turkey breast rolls treated with plum extract. No major flavor differences ($p > 0.05$) were reported between untreated irradiated turkey breast rolls and those treated with plum extract. However, panelists did note that at 3%, plum extract worked as a humectant because it improved the texture and mouthfeel of the product.

Plum products exhibit antioxidant properties in a variety of meat and poultry products and under several different processing and storage conditions. Minor flavor differences and some color variations have been noted with the use of plum products. These color and flavor differences were not shown to be significant using sensory analysis. It is possible that consumers may detect the flavor differences observed in these studies. The differences noted in red color may lead consumers into believing that their cooked product is not fully cooked. Further consumer testing should be conducted to determine the acceptable upper limits of plum products that may be added in various meat and poultry products.

Grape Seed Extract

Grape seed extract has an antioxidant potential twenty and fifty times higher than vitamin E and vitamin C, respectively (Carpenter and others 2007). Numerous studies conclude grape seed extract is an effective antioxidant in raw and cooked pork (Carpenter and others 2007; Rojas and Brewer 2007; Brannan 2008; Mielnik and others 2006; Lau and King 2003; Ahn and others 2007; Ahn and others 2002).

Ahn and others (2002) showed that the grape seed extract ActiVin (InterHealth, Benicia, California) used at 0.05% and 0.1% in cooked ground beef (20% fat, fresh meat basis), and held for 3 d in refrigerated storage (4 °C) reduced ($p < 0.05$) hexanal content when compared to a control, and was equal to samples treated with a combination of BHA/BHT at 0.02% (Table 2-2). Over the 3 d storage period, hexanal values increased ($p < 0.05$) for all treatments with the exception of the BHA/BHT treatment. The control, rosemary, and α-tocopherol treatments showed the largest increase in hexanal values.

Table 2-2 – Hexanal content (ppm) ± standard error and as compared to day 0 of cooked ground beef treated with different antioxidants during refrigerated storage (Ahn and others 2002).

	Hexanal content during storage time (d)			
Antioxidant[1]	**0**	**1**	**2**	**3**
Control	$^{a}0.14 \pm 0.04^{y}$	$^{a}1.23 \pm 0.16^{x}$	$^{a}1.25 \pm 0.17^{x}$	$^{a}2.90 \pm 0.59^{w}$
ActiVin 0.05%	$^{c}0.04 \pm 0.00^{x}$	$^{d}0.08 \pm 0.01^{x}$	$^{d}0.11 \pm 0.03^{x}$	$^{ef}0.22 \pm 0.04^{w}$
ActiVin 0.10%	$^{c}0.04 \pm 0.01^{y}$	$^{d}0.06 \pm 0.00^{wx}$	$^{d}0.06 \pm 0.01^{wx}$	$^{f}0.08 \pm 0.01^{w}$
BHA/BHT 0.02%	$^{c}0.05 \pm 0.01^{w}$	$^{d}0.06 \pm 0.01^{w}$	$^{d}0.07 \pm 0.02^{w}$	$^{f}0.08 \pm 0.03^{w}$
Pycnogenol 0.05%	$^{c}0.06 \pm 0.01^{y}$	$^{cd}0.21 \pm 0.03^{wx}$	$^{c}0.36 \pm 0.08^{x}$	$^{de}0.64 \pm 0.11^{w}$
Pycnogenol 0.10%	$^{c}0.04 \pm 0.00^{y}$	$^{e}0.09 \pm 0.01^{x}$	$^{d}0.13 \pm 0.03^{wx}$	$^{ef}0.18 \pm 0.03^{w}$
Rosemary 0.05%	$^{bc}0.07 \pm 0.01^{z}$	$^{c}0.41 \pm 0.03^{y}$	$^{b}0.73 \pm 0.10^{x}$	$^{cd}1.09 \pm 0.12^{w}$
Rosemary 0.10%	$^{c}0.06 \pm 0.01^{y}$	$^{cd}0.27 \pm 0.04^{xy}$	$^{bc}0.53 \pm 0.10^{wx}$	$^{ed}0.77 \pm 0.14^{w}$
α-Tocopherol 0.05%	$^{ab}0.12 \pm 0.03^{z}$	$^{b}0.77 \pm 0.07^{y}$	$^{a}1.24 \pm 0.16^{x}$	$^{b}1.68 \pm 0.22^{w}$
α-Tocopherol 0.10%	$^{ab}0.12 \pm 0.04^{y}$	$^{b}0.68 \pm 0.07^{x}$	$^{a}1.13 \pm 0.17^{w}$	$^{bc}1.63 \pm 0.15^{w}$

[1] Treatments: Control = untreated, ActiVin = grape seed extract, BHA/BHT = butylated hydroxyanisole/butylated hydroxytoluene, Pycnogenol = pine bark extract.
[a- f] Means in the same column without a common superscript letter differ ($p < 0.05$).
[w-z] Means in the same row without a common superscript letter differ ($p < 0.05$).

In another study by Ahn and others (2007), ActiVin used at 1.0% inhibited TBARS values by 92% in ground beef (18% fat, fresh meat basis) when compared to the control. In this study, grape seed extract was added to ground beef, cooked to an internal temperature of 75 °C, packaged in sterile plastic bags, and held for 9 d in refrigerated storage at 4 °C. The TBARS value of the control sample was 9.45 ± 0.29 mg MDA/kg, and the grape seed extract treatment had a reduced ($p < 0.05$) TBARS value of 0.75 ± 0.18 mg MDA/kg.

Lower concentrations of grape seed extract (0.2% and less) had no adverse effects on sensory characteristics such as color, odor, and Warmed Over flavor (WOF) (Ahn and others 2002; Rojas and Brewer 2007). Concentrations above 1% affected color of finished products. Ahn and others (2007) found that cooked beef treated with 1% ActiVin significantly increased the a* value (9.1 ± 0.68) as compared to the control (4.55 ± 0.7), and decreased the yellow score (b*) by 20% (control 17.32 ± 0.98, treated 14.03 ± 0.97). Carpenter and others (2007) showed that a concentration of 1000 μg gallic acid equivalent phenolics/g meat of grape seed extract in raw pork patties stored at 4 °C for 12 d in modified atmospheric packaging increased ($p < 0.05$) a*. The control had an a* value of 7.04 ± 0.49, and the treated sample was 8.19 ± 0.24. However, this color difference was not perceived as a negative by a sensory panel.

Rojas and Brewer (2007) used grape seed extract (Gravinol Super, Kikkoman, Tokyo, Japan) at a concentration of 0.02% in cooked beef and pork, and found no difference ($p > 0.05$) in a* value between the treated and control samples after 8 d of refrigerated storage. Further investigation is needed to determine what concentration of grape seed extract begins to impact the color of various meat and poultry products.

A number of studies have shown the antioxidant power of grape seed extract in a variety of meat and poultry products. At some concentrations there are significant differences in color between products treated with grape seed extract and those that were not treated (Ahn and others 2002; Carpenter and others 2007). In some meat and poultry products, consumers may perceive that a more red color is a negative. A fully cooked product may appear to be undercooked because of the red color of grape seed extract, and this may be unacceptable to consumers. Further investigation is needed on the impact of grape seed extract on color of meat and poultry products, as well as on the functionality of grape seed extract under various processing conditions.

Cranberry

Cranberries have a high concentration of phenolic compounds (8.2 mg phenolics/g dry weight), which can inhibit lipid oxidation (Vinson and others 2001). Anthocyanins are the main constituent of the phenolic compounds in cranberries, which tend to accumulate during the maturation of red fruit (Kahkonen and others 2001).

The potential of cranberry press cake and cranberry juice powder to be used as antioxidants in meat and poultry products has been the topic of several studies (Larrain and others 2008; Raghavan and Richards 2007; Raghavan and Richards 2006). Cranberry juice powder extract (extracted with chloroform) was superior ($p < 0.05$) to cranberry press cake extract (extracted with either ethyl acetate or ethanol) at inhibiting lipid oxidation in vacuum-packaged mechanically separated turkey (Raghavan and Richards 2006).

Lee and others (2006) examined the potential of the different polyphenolic classes found in cranberries to inhibit lipid oxidation in mechanically separated turkey and cooked ground pork. In this study, mechanically separated turkey treated with cranberry juice powder (90-MX, Ocean Spray Cranberries, Inc., Lakeville-Middleboro, MA) at 0.32% showed equal inhibition of lipid oxidation (TBARS value of 5.1 μmol/kg tissue) to rosemary extract (StabilEnhance, Naturex, Mamaroneck, NY) used at 0.04% (TBARS value 3.6 μmol/kg tissue) in samples held for 14 d at 2 °C. Both treatments inhibited TBARS formation by almost 10-fold as compared to control (58.8 μmol/kg tissue).

Sensory evaluation was used to detect the degree of rancid odor. Trained panelists rated the degree of rancid odor by sniffing each sample and assigning it a score between 0 and 10 (10 = highly rancid). After 14 d, control mechanically-separated turkey was given a rancidity score of 5.90. The mechanically separated turkey treated with cranberry juice powder at 0.32% had a lower ($p < 0.05$) rancidity score of 1.23. However, no mention was made regarding other sensory attributes or the quality impact the cranberry juice powder had on the meat. Lee and others (2006) also demonstrated that in cooked pork (30% fat before cooking), crude cranberry extract exhibited 51% inhibition on TBARS formation in samples that were held for 9 d at 2 °C.

Cranberry products have antioxidant properties when used in poultry and pork products. Also, cranberry juice powder is a stronger inhibitor of lipid oxidation than cranberry press cake. Further investigation is needed to evaluate effectiveness of cranberry juice powder used as an antioxidant in a variety of meat and poultry products. This research should also include an examination of the impact of cranberry products on the sensory attributes of these products.

Pomegranate

Pomegranate fruit parts contain a high concentration of antioxidants. The peel and rind are good sources of tannins, anthocyanins and flavonoids (Naveena and others 2008a). Cam and others (2009) report that juice and extracts from many other common fruits show less antioxidant activity than the pomegranate. Gil and others (2000) found that commercial pomegranate juice possesses an antioxidant activity three times higher than that of green tea and red wine.

When pomegranate rind powder was used at 10 mg tannic acid equivalent phenolics/100 g in fresh chicken, and then prepared as cooked chicken patties, a reduction ($p < 0.05$) in TBARS values was observed when compared to control (Naveena and others 2008b). Kabul variety pomegranate fruits were obtained from a local supermarket, and pomegranate rind powder was prepared in the laboratory. In this study, chicken patties were treated with pomegranate, cooked to an internal temperature of 80 °C, and stored in low density polyethylene pouches for 15 d at 4 °C. The TBARS value for the control was reported as 1.272 ± 0.13 mg MDA/kg meat, and the pomegranate rind powder treatment had a TBARS value of 0.203 ± 0.04 mg MDA/kg. They also reported a 68% reduction ($p < 0.05$) in TBARS values when compared to samples treated with BHT (100 mg BHT/100 g meat) for the same product held under identical storage conditions. The TBARS value for the BHT sample was 0.896 ± 0.12 mg MDA/kg meat.

Pomegranate rind powder and pomegranate juice powder have little effect on sensory or quality attributes when used at concentrations of 5 to 20 mg tannic acid equivalent phenolics/100 g meat (Naveena and others 2008a; Naveena and others 2008b). Naveena and others (2008a) reported a decrease in L* values when compared to the control in cooked chicken patties with pomegranate rind powder at 20 mg equivalent phenolics/100g meat. The L* for the control was 63.8 ± 0.73, and the L* for the pomegranate rind powder treatment was 56.71 ± 0.74 (Naveena and others 2008a).

An 8- to 10-member semi-trained sensory panel used an 8-point descriptive scale to rate samples based on three characteristics: off-odor, sweet flavor, and chicken flavor. No significant difference ($p > 0.05$) was found between the pomegranate samples at any of the concentrations used in this study when compared to control (Naveena and others

2008a). However, there was a slight reduction in chicken flavor for the sample with 20 mg tannic acid equivalent phenolics/100 g meat.

These studies demonstrate the potential of pomegranate components to be used as antioxidants in refrigerated chicken patties. Pomegranate is effective at inhibiting lipid oxidation, and does not significantly impact the overall sensory attributes of the finished product. More investigation needs to be done for other varieties of meat products, with a focus on different storage conditions.

Bearberry

Bearberry is one of the lesser-studied natural antioxidants as compared to other natural antioxidants obtained from fruit or plant sources. Carpenter and others (2006) investigated the antioxidant activity of several plant extracts under oxidative stress in cells and found bearberry to be a strong antioxidant.

Several studies have been conducted on the antioxidant activity of bearberry at several concentrations in raw and cooked pork patties held under refrigerated conditions. Carpenter and others (2007) examined the effects of bearberry (obtained from Clonminam Industrial Estate, Portlaoise, Co. Laois, Ireland) in raw and cooked pork. Cooked pork patties were heated to an internal temperature of 72 °C and held for an additional 8 min at 180 °C. Both cooked and raw patties were packaged in polystyrene/ethylvinylalcohol/polyethylene trays with low oxygen permeable film and then flushed with a 75% O_2: 25% CO_2 mixture. The fat content of these patties was not provided. Carpenter and others (2007) found that lipid oxidation was significantly reduced when compared to the control in raw pork patties held for 12 d at 4 °C. The control patties had a TBARS value of 0.91 ± 0.01 mg MDA/kg muscle. Bearberry used at a concentration of 80 μg/g meat had a TBARS value of 0.21 ± 0.2 mg MDA/kg muscle. In the cooked pork patties stored for 4 d at 4 °C, lipid oxidation was also significantly reduced. The final TBARS value for the control was 0.90 ± 0.012 mg MDA/kg muscle, and bearberry used at 80 μg/g meat had a TBARS value of 0.54 ± 0.018 mg MDA/kg muscle (Carpenter and others 2007). These findings are in agreement with findings from Pegg and others (2001) that showed bearberry used at 80 μg/g meat and 1000 μg/g meat reduced ($p < 0.05$) lipid oxidation in cooked pork patties. Bearberry used at the 1000 μg/g meat concentration showed a 9-fold reduction in lipid oxidation in cooked pork after 4 d when stored at 4 °C.

Carpenter and others (2007) examined the impact of bearberry on sensory and quality properties of raw and cooked pork. They found that bearberry used at 80 μg/g meat, and 1000 μg/g meat did not result in color scores that were different ($p > 0.05$) from the control after 12 d storage. A trained sensory panel of 8 to 10 members was used to evaluate the samples after 0, 2, and 4 d of storage at 4 °C. Samples were evaluated for color, flavor, texture, juiciness, and off-flavors on a 10-point descriptive hedonic scale (1 = extremely desirable; 10 = undesirable). They found that bearberry used at 80 μg/g meat and 1000 μg/meat did not negatively affect these sensory attributes when compared to control.

These studies demonstrate the potential that bearberry has to work as a natural antioxidant in pork. Further research should be conducted in order to determine the functionality of bearberry on additional meat and poultry products, as well as different processing methods.

Plant Products

In plants, phenolic compounds serve many defense functions. Plants are a rich source of these compounds (Kahkonen and others 2001), which can function as antioxidants. This also makes plant products good candidates to be used as natural antioxidants in meat and poultry products. Many studies have looked into the use of a variety of plant materials as antioxidants in food products. A review of studies conducted on pine bark extract, rosemary, oregano, other spices, irradiated almond skins, and green tea used in various meat and poultry products will be discussed.

Pine Bark Extract

Pine bark extract is a good source of phenolic compounds, which possess antioxidant activity (Vuorela and others 2005). Pine bark extract, Pycnogenol, is a commercially available dietary supplement that has received considerable attention because of its antimutagenic, anticarcinogenic, and antioxidant activity (Ahn and others 2002).

The antioxidant effect of the pine bark extract Pycnogenol (Natural Health Sciences, Hillside, New Jersey) on cooked beef patties was evaluated by Ahn and others (2007). In Ahn and other's study (2002), 82% fresh lean beef was treated with 1% Pycnogenol; patties were formed from the treated beef and then cooked to an internal temperature of 75 °C. Cooked patties were stored individually in sterile plastic bags at 4 °C for 9 d. TBARS values for Pycnogenol samples (0.06 ± 0.06 mg MDA/kg) were reduced ($p \leq 0.05$) when compared to control (9.45 ± 0.29 mg MDA/kg). A reduction ($p < 0.05$) was shown in TBARS values for the pine bark extract treatments when compared to the 0.01% BHA/0.01% BHT treatment, which had a TBARS value of 2.32 mg MDA/kg. Hexanal content of Pycnogenol treated samples and control samples were 0.05 and 4.93 ppm respectively after 9 d of refrigerated storage.

Significant differences in color values were also observed between the control and treated samples (Table 2-3). After 3 d of storage, L* values were significantly increased for the control, BHA/BHT, and Herbalox (rosemary) treatments. The L* values did not significantly increase after 3 d storage in the ActiVin (grape seed extract) treatment and Pycnogenol (pine bark extract) treatments. The a* values of the control, BHA/BHT, and Herbalox treatments significantly decreased after 3 d of storage. With the exception of the BHA/BHT treatment, no significant changes were found in b* values at 3 d and 6 d of storage. After 9 d of storage, the L* score of the pine bark extract treatment decreased ($p \leq 0.05$) when compared to control. For the same storage period, the b* value also deceased ($p \leq 0.05$) in the pine bark extract treatment when compared to control, whereas the redness value (a*) was increased ($p \leq 0.05$) in the treated samples when compared to the control value. There was no sensory testing conducted in this study. These color differences may be a concern to consumers because a fully cooked product may appear to be undercooked due to the high redness value of the product.

Table 2-3 – Color changes of cooked ground beef treated with natural extracts stored at 4 °C (Ahn and others 2007).

Treatment[1]	L*, a* and b* color values during storage time (days)			
	0	3	6	9
L* value				
Control	$^{y}47.34 \pm 2.24^{b}$	$^{x}48.51 \pm 1.91^{b}$	$^{x}48.69 \pm 1.67^{b}$	$^{x}48.39 \pm 1.69^{c}$
BHA/BHT 0.02%	$^{z}48.46 \pm 2.23^{ab}$	$^{y}49.11 \pm 1.81^{b}$	$^{y}49.63 \pm 1.75^{b}$	$^{x}50.45 \pm 1.67^{b}$
ActiVin 1.0%	$^{x}40.29 \pm 2.09^{d}$	$^{x}41.20 \pm 3.15^{d}$	$^{x}41.73 \pm 2.25^{d}$	$^{x}39.95 \pm 1.66^{e}$
Pycnogenol 1.0%	$^{x}45.32 \pm 1.75^{c}$	$^{x}46.16 \pm 2.32^{c}$	$^{x}46.57 \pm 1.48^{c}$	$^{x}46.37 \pm 1.66^{d}$
Herbalox 1.0%	$^{z}49.33 \pm 1.79^{a}$	$^{y}51.12 \pm 1.98^{a}$	$^{x}51.77 \pm 1.57^{a}$	$^{x}51.72 \pm 1.70^{a}$
a* value				
Control	$^{x}6.28 \pm 0.81^{b}$	$^{y}5.00 \pm 0.69^{cd}$	$^{z}4.09 \pm 1.34^{d}$	$^{yz}4.55 \pm 0.70^{c}$
BHA/BHT 0.02%	$^{x}6.51 \pm 0.79^{b}$	$^{y}5.09 \pm 0.94^{c}$	$^{y}4.90 \pm 0.70^{c}$	$^{z}4.09 \pm 0.69^{d}$
ActiVin 1.0%	$^{x}9.20 \pm 0.57^{a}$	$^{x}9.09 \pm 0.59^{a}$	$^{x}8.98 \pm 0.81^{a}$	$^{x}9.10 \pm 0.68^{a}$
Pycnogenol 1.0%	$^{x}6.41 \pm 0.67^{b}$	$^{x}6.42 \pm 0.57^{b}$	$^{y}5.68 \pm 0.86^{b}$	$^{y}5.79 \pm 0.69^{b}$
Herbalox 1.0%	$^{x}6.73 \pm 2.02^{b}$	$^{y}4.60 \pm 0.97^{d}$	$^{yz}3.59 \pm 0.66^{d}$	$^{z}3.21 \pm 0.72^{e}$
b* value				
Control	$^{x}17.56 \pm 1.06^{a}$	$^{x}17.10 \pm 1.14^{bc}$	$^{x}15.51 \pm 2.77^{b}$	$^{x}17.32 \pm 0.98^{c}$
BHA/BHT 0.02%	$^{xy}18.52 \pm 1.18^{a}$	$^{y}17.74 \pm 0.81^{b}$	$^{x}19.07 \pm 1.05^{a}$	$^{xy}18.00 \pm 1.01^{a}$
ActiVin 1.0%	$^{x}13.95 \pm 1.27^{c}$	$^{x}13.95 \pm 1.31^{d}$	$^{x}14.08 \pm 1.03^{b}$	$^{x}14.03 \pm 0.97^{e}$
Pycnogenol 1.0%	$^{x}15.77 \pm 1.33^{b}$	$^{x}16.41 \pm 1.36^{c}$	$^{x}16.02 \pm 0.91^{b}$	$^{x}15.88 \pm 1.01^{d}$
Herbalox 1.0%	$^{xy}18.68 \pm 2.29^{a}$	$^{x}19.62 \pm 0.64^{a}$	$^{x}19.38 \pm 0.98^{a}$	$^{y}17.90 \pm 1.00^{b}$

[1]Control = untreated, BHA/BHT = butylated hydroxyanisole/butylated hydroxytoluene, ActiVin = grape seed extract, Pycnogenol = pine bark extract, Herbalox = rosemary.
$^{a-e}$ Means with different superscripts within a column are different ($p \leq 0.05$).
$^{x-z}$ Means with different superscripts within a row are different ($p \leq 0.05$).

Ahn and others (2002) also investigated the impact of Pycnogenol (Natural Health Sciences, Hillside, New Jersey) on cooked ground beef. In this study, ground beef (20% fat) was treated with Pycnogenol at 0.02%, 0.05%, and 0.1%. Patties were formed from the treated ground beef, cooked to an internal temperature of 75 °C, and held at 4 °C for 3 d. Pycnogenol® was effective ($p \leq 0.05$) at inhibiting TBARS formation (control sample TBARS value 5.77 MDA/kg, 0.1% treated sample TBARS value 1.58 mg MDA/kg).

Warmed Over Flavor (WOF) was also evaluated in this study by an 11-member trained sensory panel. Intensity of WOF was rated on an unstructured 15 cm line (0 = no WOF; 15 = extremely strong WOF). WOF development was inhibited ($p \leq 0.05$) by Pycnogenol at 0.02% when compared to control after 3 d storage at 4 °C. The treated sample had a score of 6.61 ± 0.69 and control was 10.25 ± 0.88.

Pine bark extract has antioxidant properties in cooked ground beef. It also increases the redness of cooked ground beef (Ahn and others 2007). Consumers may perceive this as a negative because the product may appear to be undercooked. Further consumer acceptability testing should be conducted on cooked ground beef treated with pine bark extract to determine whether consumers view the color differences as negative. Consumer acceptability of pine bark extract should also be examined. Consumers may find products made using pine bark extract unappealing and not purchase them because of this.

Despite the observations made regarding the color differences in ground beef, pine bark extract may be a viable option as a natural antioxidant in meat and poultry products. However, more investigation into other types of meat and poultry products and into various processing methods are needed to determine the full potential of pine bark extract.

Rosemary

Currently rosemary and rosemary extracts are some of the most studied natural antioxidants used in meat and poultry products (Rojas and Brewer 2007). In these studies, variation has been reported regarding the effectiveness of rosemary products used as antioxidants in meat and poultry products (Sebranek and others 2005). Rosemary products have been successful antioxidants in mechanically deboned turkey meat (Mielnik and others 2003), vacuum packaged raw ground beef and pork (Rojas and Brewer 2008), cooked pork patties (Nissen and others 2004), cooked ground beef (Ahn and others 2007), and more effective than a combination of BHA/BHT in raw frozen sausage (Sebranek and others 2005).

Rojas and Brewer (2007) examined the effect of the oleoresin rosemary Herbalox (Kalsec Inc., Kalamazoo, Michigan) in cooked beef and pork. Raw ground beef and pork (30% fat) was treated with Herbalox at 0.02%. Samples were cooked to an internal temperature of 71 °C, packaged in foam trays overwrapped with polyvinyl chloride film, and stored at 4 °C for 8 d. They reported that TBARS values for the treated samples were not different ($p > 0.05$) than the control samples. These findings are in agreement with those of Lee and others (2005) and Chen and others (1999), who reported that oleoresin rosemary (Ecom Manufacturing Corporation, Scarborough, Ont., Canada) used at 0.02% did not prevent lipid oxidation in ready-to-eat hamburgers or pork patties.

Nissen and others (2004) investigated the use of rosemary as a natural antioxidant in cooked pork patties. Ground pork (25% fat) was treated with 200 ppm rosemary extract, (Nestle Research Centre, Lausanne, Switzerland) and formed into patties. Patties were cooked to an internal temperature of 80 °C, and packaged in high barrier (OTR 2.0 cm^3/m^2d bar) vacuum bags. Samples were held at 4.5 ± 0.5 °C for 10 d. Nissen and others reported a decrease ($p < 0.05$) in both TBARS and hexanal values in the rosemary treatments when compared to the control sample. The TBARS value of the rosemary-treated cooked pork patty was 9.3 μmol MDA/kg, whereas control was 30.0 μmol

MDA/kg. Hexanal values were 21.6 and 4.9 ppm in control and rosemary-containing cooked pork patties, respectively.

Mielnik and others (2003) evaluated five commercially available rosemary products at three different usage levels in mechanically deboned turkey meat (MDTM) (Table 2-4). Fat content of the MDTM averaged 15.3%, with a range of 13.8% to 17.2%. Samples were divided into 200 g portions, treated with antioxidant, and vacuum packaged in transparent polyethylene cups. Samples were stored at -25 °C, and TBARS values were analyzed after 0, 2, 4.5, and 7 mo of storage.

Table 2-4 – Amount of antioxidant added to mechanically deboned turkey meat (g/kg) (Mielnik and others 2003).

	Level added (g/kg)		
Antioxidant	**Low Level**	**Middle Level**	**High Level**
Trolox C[a]	0.2	0.5	0.8
Guaridan Rosemary Extract GP[b]	0.2	0.5	0.8
Flavor Guard LO[c]	0.2	0.5	0.8
Biolox HT-W[d]	0.8	1.6	2.4
Herbalox W[e]	0.8	1.6	2.4
Stabiloton WS[f]	0.8	1.6	2.4
Ascorbic acid[g]	0.8	1.6	2.4

[a]Vitamin E (Trolox C, Sigma Aldrich, Ltd., England).
[b]Guaridan Rosemary Extract GP (Cultor Food Science, Inc. Ardslay, New York).
[c]Flavor Guard LO (Chr. Hansen GmbH, Holdorf, Germany).
[d]Biolox HT-W (Kalsec, Inc. Kalamazoo, Michigan).
[e]Herbalox W (Kalsec, Inc. Kalamazoo, Michigan).
[f]Stabiloton WS (RAPS & Co, Kulmbach, Germany).
[g]Ascorbic acid (Sigma Aldrich, Ltd., England).

Mielnik and others (2003) reported that after 7 mo of storage, TBARS values for the ascorbic acid treatments and all rosemary treatments were lower ($p < 0.05$) when compared to the control (Table 2-5). However, some treatments were more effective at reducing TBARS formation than others. The high concentration of Guardian Rosemary Extract GP showed the largest reduction in TBARS formation (0.244 mg MDA/kg), and the low concentration of Herbalox W showed the lowest reduction in TBARS formation (1.726 mg MDA/kg).

The initial TBARS for all treatments ranged from 0.099 mg/kg to 0.127 mg/kg whereas, the control and the ascorbic acid treatments had significantly higher values. After 2 mo of storage, no differences ($p > 0.05$) were observed among the rosemary treatments. TBARS values ranged from 0.137 mg/kg to 0.185 mg/kg. After 4.5 mo of storage, TBARS values of Trolox C, Guardian Rosemary Extract GP, Flavor Guard LO, and Biolox HT-W rosemary-treated samples at all levels ranged from 0.183 mg MDA/kg to 0.314 mg/kg. For the same time period, TBARS values for Herbalox W (low and medium), Stabiloton WS (low level), and control were all significantly higher. After 7 mo of storage, Trolox C (high level) (0.203 mg MDA/kg) showed the largest inhibition of TBARS formation compared to Guardian Rosemary Extract GP (low level) (1.890 mg MDA/kg), which expressed the least amount of TBARS inhibition as compared to all other treated samples. This study shows that the quality of the rosemary product and level used to inhibit lipid oxidation plays a significant role.

Table 2-5 – Effect of type and level of antioxidant on TBARS (mg MDA/kg sample) values of MDTM stored at -25 °C for seven months (Mielnik and others 2003).

Antioxidant and level	**TBARS values during storage time (mo)**			
	0	**2.0**	**4.5**	**7.0**
Trolox C[y]				
Low	0.125^{c}	0.175^{c}	0.197^{c}	0.346^{d}
Medium	0.112^{c}	0.171^{c}	0.178^{c}	0.224^{d}
High	0.108^{c}	0.159^{c}	0.157^{c}	0.203^{d}
Guardian Rosemary Extract				
Low	0.108^{c}	0.185^{c}	0.314^{c}	1.890^{b}
Medium	0.102^{c}	0.162^{c}	0.203^{c}	0.311^{d}
High	0.098^{c}	0.145^{c}	0.183^{c}	0.244^{d}
Flavor Guard LO[z]				
Low	0.119^{c}	0.167^{c}	0.285^{c}	0.882^{c}
Medium	0.103^{c}	0.169^{c}	0.207^{c}	0.432^{d}
High	0.127^{c}	0.137^{c}	0.195^{c}	0.303^{d}
Biolox HT-W[z]				
Low	0.111^{c}	0.173^{c}	0.253^{c}	0.428^{d}
Medium	0.120^{c}	0.147^{c}	0.205^{c}	0.269^{d}
High	0.117^{c}	0.140^{c}	0.195^{c}	0.221^{d}
Herbalox W[z]				
Low	0.105^{c}	0.167^{c}	0.595^{b}	1.726^{b}
Medium	0.115^{c}	0.171^{c}	0.457^{b}	1.479^{bc}
High	0.108^{c}	0.173^{c}	0.350^{bc}	1.170^{c}
Stabiloton WS[z]				
Low	0.107^{c}	0.176^{c}	0.570^{b}	1.614^{b}
Medium	0.107^{c}	0.170^{c}	0.365^{bc}	1.428^{bc}
High	0.099^{c}	0.144^{c}	0.395^{bc}	1.131^{c}
Ascorbic acid				
Low	0.168^{b}	0.212^{b}	0.296^{c}	0.381^{d}
Medium	0.191^{ab}	0.224^{b}	0.262^{c}	0.332^{d}
High	0.208^{a}	0.250^{b}	0.269^{c}	0.334^{d}
Control –no antioxidant added	0.127^{c}	0.582^{a}	2.571^{a}	2.662^{a}
F-value	43.03***	65.86***	120.66***	49.62***
Pooled SEM	0.0063	0.0159	0.0645	0.1417

[a-c] Mean values within each column, which are different according to Tukey's test ($p < 0.05$), are marked with different letters.

[y-z] Commercially available vitamin E and rosemary product.

Ahn and others (2007) investigated the effects of oleoresin rosemary on lipid oxidation in cooked beef. Oleoresin rosemary, Herbalox® (Natural Health Science, Hillside, New Jersey), was added at 1% to raw ground beef (18% fat), patties were formed, and were cooked to an internal temperature of 75 °C. Samples were stored in sterile plastic bags and held at 4 °C for 9 d. TBARS values were reduced ($p < 0.05$) with the treatment of oleoresin rosemary (0.72 ± 0.03 mg MDA/kg) when compared to the control (9.45 ± 0.29 mg MDA/kg). The hexanal value of the treated product (0.09 ± 0.01 ppm) was also reduced ($p < 0.05$) when compared to the control (4.93 ± 0.64 ppm).

Ahn and others (2007) found that a*, L*, and b* values in samples treated with Herbalox® were different ($p < 0.05$) when compared to control (Table 2-3). The redness value (a*) decreased, while the lightness (L*) and yellow value (b*) increased when compared to control. These significant color variations may be a concern to consumers. If a product is different in color from what a consumer is expecting to see, the consumer may think the product is unacceptable.

Numerous studies have demonstrated the ability of rosemary products to act as natural antioxidants in various meat and poultry products. There are also studies that are not in agreement with these findings. As Mielnik and others (2003) demonstrated, differences in rosemary products may impact their performance on inhibiting lipid oxidation. It is possible that the inconsistencies in the literature can be attributed to the quality of the oleoresins and extracts used in these studies. Further investigation should be conducted regarding the quality of various rosemary products and how that impacts their functionality as a natural antioxidant.

Oregano

Oregano has been shown to inhibit lipid oxidation in cooked ground beef and pork (30% fat, fresh meat basis) (Rojas and Brewer 2007; Rojas and Brewer 2008), and in 85% lean raw beef (Sanchez-Escalante and others 2003). Rojas and Brewer (2008) studied the effects of water-soluble oregano extract (Oreganox WS, RAD Natural Tech LTD., Barrington Chemical Corp, New York) in cooked beef and pork. They found that Oreganox WS added at 0.02% was effective ($p < 0.05$) at reducing lipid oxidation in vacuum packaged cooked beef samples held at -18 °C for 4 mo. They also reported a reduction in TBARS values, although the difference was not found to be significant ($p > 0.05$), with oregano extract added at 0.02% (Oreganox) in cooked pork stored under the same conditions. No off color or aroma was reported.

Oregano may be used as a natural antioxidant in meat products. However, current research shows that that there are more powerful natural antioxidants available such as grape seed extract, cranberry, sage extract, and thyme extract, all of which exhibit a more significant reduction in TBARS values in a variety of products.

Other Spices

Spices in general have antioxidant properties due to the presence of compounds such as polyphenolics, flavanoids, lignans, and terpenoids (Craig 1999). Spices have demonstrated their antioxidant effect in raw and cooked pork (El-Alim and others 1999; Park and others 2008; Jayathilakan and others 2007), raw chicken (El-Alim and others 1999), raw and cooked beef (Jayathilakan and others 2007; Du and Li 2008; Vasavada and others 2006; Dwivedi and others 2006), and cooked mutton (Jayathilakan and others 2007).

El-Alim and others (1999) investigated the use of ground spices and spice extracts as antioxidants in raw ground chicken, and ground pork (fat contents not reported). Ground chicken was treated with 10 g/kg of the following dried spices: marjoram, wild marjoram, caraway, clove, peppermint, nutmeg, curry, cinnamon, basil, sage, thyme, and ginger (obtained from a local supermarket). Samples were wrapped in aluminum foil and placed in polyethylene sacks. Samples were stored at 4 °C for 7 d, or at -18 °C for 6 mo. El-Alim and others (1999) reported that TBARS formation was inhibited ($p < 0.05$) in refrigerated and frozen samples that were treated with spices (Table 2-6). During refrigerated storage, cloves showed the largest reduction in TBARS values when compared to the control. Peppermint and caraway were not shown to be significantly different from the control sample.

After 7 d frozen storage at -18 °C, only marjoram and cinnamon had reduced ($p < 0.05$) TBARS values; all other treatments were not different ($p > 0.05$) from the control. After 180 d of frozen storage, the sample treated with marjoram was shown be the most effective at inhibiting TBARS formation. All other treatments showed a significant reduction in TBARS formation except for curry and cinnamon.

Table 2-6 – Effect of dried natural spices on TBARS (ng MDA/100 g)[1] content[2] of minced chicken meat during storage (El-Alim and others 1999).

	TBARS values during refrigerated storage at 4 °C		TBARS values during frozen storage at -18 °C	
Sample	**0 d**	**7 d**	**7 d**	**180 d**
Control	55.9 ± 0.1	72.1 ± 2.3[a]	63.1 ± 6.7[a]	319.1 ± 86.5[a]
Marjoram	---	66.5 ± 0.1[b]	45.7 ± 0.1[b]	102.9 ± 0.1[b]
Wild Marjoram	---	96.9 ± 1.3[c]	68.2 ± 0.7[a]	113.4 ± 51.2[c]
Caraway	---	82.4 ± 9.9[a,c]	69.2 ± 0.7[a]	132.3 ± 0.7[d]
Peppermint	---	74.8 ± 1.9[a,c]	69.2 ± 4.7[a]	164.7 ± 1.3[e]
Clove	---	32.5 ± 0.1[d]	---	173.2 ± 0.1[f]
Nutmeg	---	42.4 ± 0.1[e]	---	185.2 ± 0.1[g]
Curry	---	56.1 ± 0.1[f]	---	232.4 ± 0.8[a,h]
Cinnamon	---	54.9 ± 0.4[g]	50.9 ± 0.11[c]	267.2 ± 0.1[a,i]

[1]To convert values to mg MDA/kg sample multiply each value by 0.00001.
[2]Each value is the mean ± SD of four determinations (of two different experiments).
[a-h]Mean values within a column with a different letter are different ($p < 0.05$).

El-Alim and others (1999) also evaluated the use of spice extracts of basil, sage, thyme, and ginger (prepared in the laboratory) as antioxidants in ground pork. Spices were extracted with ethanol and the extract was used to treat ground pork at a concentration of 1 ml/10 g meat. Samples were wrapped in aluminum foil, placed in polyethylene sacks, and stored at either 4 °C for 7 d, or -18 °C for 6 mo. After 0 d of refrigerated storage, all treatments were not found to be significantly different from control I (meat only) (Table 2-7). However, control II (meat + 1 mL ethanol (500 mL/L) was found to have a significantly lower TBARS values than control I and all other treatments. After 7 d of refrigerated storage, TBARS values for sage, basil, and thyme were found to be lower than they were at 0 d, and all treatments were significantly lower than control I and control II. Sage, thyme, and basil were also more effective ($p < 0.05$) at inhibiting TBARS values than ginger.

After 1 mo frozen storage, TBARS values for all treatments were lower ($p < 0.05$) than control I and control II, with basil and thyme having the lowest values. After 3 mo storage, TBARS values increased for basil, thyme, and ginger, and all treatments had lower TBARS values than control I and control II. All treatments stored under frozen conditions reduced ($p < 0.05$) TBARS formation after 6 mo storage when compared to control I or control II. Sage and basil were significantly more effective at reducing TBARS values than thyme, and sage was significantly more effective than ginger at reducing TBARS formation.

Table 2-7 – TBARS (ng MDA/kg sample)[1] content of raw pork patties treated with ethanolic extract (El-Alim and others 1999).

	TBARS values during refrigerated storage at 4 °C		TBARS values during frozen storage at -18 °C		
Sample	**0 (d)**	**7 (d)**	**1 (mo)**	**3 (mo)**	**6 (mo)**
Control I	64.8 ± 8.9[a]	579.7 ± 86.6[a]	179.6 ± 32.6[a]	436.4 ± 114.6[a]	405.7 ± 52.6[a]
Control II	50.4 ± 4.7[b]	64.6 ± 7.3[b]	172.5 ± 0.1[a]	419.9 ± 4.7[a]	311.9 ± 1.3[b]
Sage	68.8 ± 4.0[a]	44.8 ± 0.6[c]	29.7 ± 1.9[b]	28.3 ± 2.7[b]	35.4 ± 6.0[c]
Basil	58.2 ± 0.3[a]	45.3 ± 2.6[c]	39.1 ± 0.7[c]	46.7 ± 6.0[c]	52.3 ± 17.9[c,d,e]
Thyme	60.4 ± 5.3[a]	46.7 ± 4.6[c]	41.0 ± 3.4[c]	43.4 ± 1.3[c]	48.5 ± 0.7[d]
Ginger	67.8 ± 1.7[a]	70.6 ± 3.3[b]	62.1 ± 0.3[d]	54.7 ± 0.6[d]	55.1 ± 1.6[e]

[1]To convert values to mg MDA/kg sample multiple each value by 0.00001.
[a,b,c,d,e]Mean values within a column with a different letter are different ($p < 0.05$).
[x]Each value is the mean ± SD of four determinations (of two different experiments).
[y]Control I = meat only, Control II – 10 g meat + 1 mL ethanol (500 mL/L).

Park and others (2008) examined the antioxidant effects of garlic and onion powder in fresh pork belly and pork loin. In this study, pork belly (36.9% fat) and pork loin (4.41% fat) were injected to 110% of their original weight with a solution containing either 5% garlic powder or 5% onion powder (garlic and onion powder from Dong Bang Food Co. Seoul, Korea). Samples were vacuum packaged and held at 8 °C for 28 d. Park and others (2008) found that garlic and onion powder were effective at reducing

($p < 0.05$) TBARS values when compared to control in fresh pork belly (Table 2-8). However, no significant reduction ($p > 0.05$) in TBARS values was found in the pork loin treated with garlic (0.05 mg MDA/kg) or onion powder (0.05 mg MDA/kg) when compared to the control (0.08 mg MDA/kg).

In this study, Park and others (2008) measured the color values of the lean and fat portion of the pork belly separately because of the color differences that naturally occur between lean and fat. They reported an increase ($p < 0.05$) in the fat b* value, the lean b* value, and the lean a* values of fresh pork belly for samples treated with garlic or onion powder when compared to the corresponding lean or fat control.

Table 2-8 – Effect of garlic and onion powder on fresh pork belly during storage at 8 °C for 28 d (Park and others 2008).

Parameter	Control	5% Garlic	5% Onion
TBARS[1]	0.23^{a}	0.15^{b}	0.15^{b}
Fat L*	80.50	79.90	79.50
Fat a*	2.98	2.46	2.92
Fat b*	4.41^{b}	5.50^{a}	5.76^{a}
Lean L*	54.10^{a}	53.70^{a}	53.60^{a}
Lean a*	6.55^{b}	7.72^{a}	7.66^{a}
Lean b*	3.60^{bc}	4.71^{a}	4.25^{ab}

[1]Values reported as mg MDA/kg sample
[a,b]Means having same superscript within same row are not different ($p > 0.05$).
Fat L* = fat lightness, Fat a* = fat redness, Fat b* = fat yellowness, Lean L* = lean lightness, Lean a* = lean redness, Lean b* = Lean yellowness.

Pork loin samples showed an increase ($p < 0.05$) in the a* value of the garlic powder treatments and in the b* values of both the garlic powder and onion powder treatment (Park and others 2008). The a* of the control was 3.85, and was found to be 4.21 for the garlic powder treatment. The b* of garlic powder was 4.08, 3.57 for onion powder, and 2.87 for control.

Jayathilakan and others (2007) showed that cinnamon and cloves were more effective ($p < 0.05$) at inhibiting TBARS formation in cooked ground beef, cooked ground pork and cooked ground mutton (fat contents not reported), than samples treated with TBHQ at 0.02%. In this study, ground meats of the various species were treated with 250 mg/100g meat (2,500 ppm) of either ground cinnamon or ground cloves (obtained from a local supermarket), packed in polypropylene pouches, and cooked in a boiling water bath under atmospheric pressure for 35 min. These samples were stored at 5 °C for 6 d. TBARS values were measured and the antioxidant potential was reported. The percentage antioxidant activity potential was calculated using the following equation: (Equation 1)

$$\% \text{ AOA} = \frac{[\text{TBARS value of the control} - \text{TBARS value of the test sample}] \times 100}{[\text{TBARS value of control}]}$$

Antioxidant activity decreased in all treatments throughout the 6 d of storage in all meat species tested (Tables 2-9, 2-10, 2-11). There were no differences ($p > 0.05$) found between samples treated with clove, samples treated with BHA, or samples treated with propyl gallate at 0.02% in mutton, ground beef, and pork. Cinnamon was not significantly different from BHA or PG at 2, 4, or 6 d in all tested products. TBHQ demonstrated the highest antioxidant activity of all tested antioxidants in all three species of meat.

Table 2-9 – Antioxidant activity (% AOA) of natural and synthetic antioxidants in mutton during storage at 5 °C (Jayathilakan and others 2007).

	Antioxidant activity during storage time (d)			
Treatment[1]	**0**	**2**	**4**	**6**
Cloves	80.5[c] ± 2.98	78.2[c] ± 3.69	73.9[c] ± 3.36	68.2[c] ± 3.85
Cinnamon	58.4[b] ± 2.94	52.5[b] ± 4.26	45.7[b] ± 3.91	37.2[b] ± 4.16
Ascorbic Acid	73.8[c] ± 5.05	71.9[c] ± 3.91	70.9[c] ± 2.90	67.4[c] ± 3.81
TBHQ	98.2[a] ± 1.51	95.1[a] ± 2.98	93.2[a] ± 4.26	91.0[a] ± 4.36
BHA	71.2[c] ± 3.60	60.6[b] ± 3.16	51.5[b] ± 2.61	42.9[b] ± 4.15
PG	68.3[c] ± 4.98	57.9[b] ± 3.86	49.9[b] ± 3.26	40.6[b] ± 2.16

[1]Treatments: TBHQ = *tert*-butylhydroquinone, BHA = butylated hydroxyanisole, PG = propyl gallate.

[a-c]Within the column, values superscripted with different letters are different, ab ($p < 0.01$), ac and bc ($p < 0.05$).

[a-c]Within the rows, cinnamon and PG at 4 and 6 d were different ($p < 0.01$) from initial values. Other treatments were not different ($p > 0.01$) during storage.

Table 2-10 – Antioxidant activity (% AOA) of natural and synthetic antioxidants in beef during storage at 5 °C (Jayathilakan and others 2007).

	Antioxidant activity during storage time (d)			
Treatment[1]	**0**	**2**	**4**	**6**
Cloves	78.3[c] ± 3.86	75.2[c] ± 3.15	70.7[c] ± 3.69	64.4[c] ± 2.89
Cinnamon	58.3[b] ± 3.15	49.4[b] ± 2.91	42.4[b] ± 3.16	33.2[b] ± 1.89
Ascorbic Acid	72.3[c] ± 3.61	69.5[c] ± 3.86	65.1[c] ± 3.10	57.7[c] ± 2.16
TBHQ	96.3[a] ± 2.08	93.5[a] ± 3.16	91.6[a] ± 2.98	88.6[a] ± 4.19
BHA	65.3[b] ± 4.10	55.2[b] ± 2.16	47.4[b] ± 2.05	39.4[b] ± 3.89
PG	63.6[b] ± 2.09	54.1[b] ± 4.09	46.4[b] ± 1.98	38.7[b] ± 1.98

[1]Treatments: TBHQ = *tert*-butylhydroquinone, BHA = butylated hydroxyanisole, PG = propyl gallate.

[a-c] Within the column, values superscripted with different letters are different, ab ($p < 0.01$), ac and bc ($p < 0.05$).

[a-c] Within the rows, BHA at 4 and 6 d were different ($p < 0.01$) from initial values. Ascorbic acid, after 6 d storage is different ($p < 0.01$) from initial values. Other treatments were not different ($p > 0.01$) during storage.

Table 2-11 – Antioxidant activity (% AOA) of natural and synthetic antioxidants in pork during storage at 5 °C (Jayathilakan and others 2007).

	Antioxidant activity during storage time (d)			
Treatment[1]	**0**	**2**	**4**	**6**
Cloves	$72.2^{c} \pm 4.28$	$68.2^{c} \pm 2.23$	$65.3^{c} \pm 2.86$	$62.5^{c} \pm 3.16$
Cinnamon	$54.8^{b} \pm 1.89$	$43.9^{b} \pm 2.98$	$36.0^{b} \pm 1.98$	$31.4^{b} \pm 3.61$
Ascorbic Acid	$62.5^{c} \pm 4.61$	$65.2^{c} \pm 3.11$	$59.4^{c} \pm 2.98$	$55.4^{c} \pm 3.16$
TBHQ	$94.1^{a} \pm 3.10$	$90.5^{a} \pm 2.11$	$90.3^{a} \pm 3.19$	$86.4^{a} \pm 3.19$
BHA	$60.3^{b} \pm 2.85$	$51.3^{b} \pm 1.98$	$43.7^{b} \pm 3.98$	$35.4^{b} \pm 4.18$
PG	$58.5^{b} \pm 2.63$	$50.1^{b} \pm 3.09$	$42.8^{b} \pm 2.63$	$34.2^{b} \pm 1.98$

[1] Treatments: TBHQ = *tert*-butylhydroquinone, BHA = butylated hydroxyanisole, PG = propyl gallate.

[a-c] Within the column, values superscripted with different letters are different, ab ($p < 0.01$), ac and bc ($p < 0.05$).

[a-c] Within the rows, BHA at 4 and 6 d were different ($p < 0.01$) from initial values. Other treatments were not different ($p > 0.01$) during storage.

Dwivedi and others (2006) evaluated the antioxidant effects of Chinese 5-spice blend, and the components of this blend (obtained from a local supermarket), on cooked ground beef. Ground beef (15% fat) was treated with a retail 5-spice blend and with its individual components: cinnamon, clove, fennel, pepper, and star anise at 0.1%, 0.5%, and 1%. These samples were cooked to an internal temperature of 82 – 85 °C and stored in plastic bags for 15 d at 2 °C. Dwivedi and others (2006) identified the optimum level of each spice, which they defined as the lowest spice concentration that resulted in TBARS values lower ($p < 0.05$) than the control (Table 2-12). They found that the optimum level of clove was 0.1%, fennel was 0.5%, cinnamon was 0.5%, pepper was 0.5%, star anise was 0.5%, and the retail 5-spice blend optimum level was 0.5%.

Table 2-12 – Mean thiobarbituric acid (TBA) values for cooked ground beef formulated with the individual spices of Chinese 5-spice, at use levels of 0.1%, 0.5%, and 1.0% of raw meat weight (Dwivedi and others 2006).

Treatment	Spice level (% meat wt)	TBA (ppm MDA)
Control	0.0	3.41[a]
Cinnamon	0.1	1.66[c,d]
Cinnamon	0.5	0.76[e]
Cinnamon	1.0	0.78[e]
Cloves	0.1	0.76[e]
Cloves	0.5	0.96[d,e]
Cloves	1.0	0.88[e]
Fennel	0.1	2.32[b,c]
Fennel	0.5	1.39[d,e]
Fennel	1.0	0.99[d,e]
Pepper	0.1	2.87[a,b]
Pepper	0.5	1.28[d,e]
Pepper	1.0	1.26[d,e]
Star anise	0.1	2.55[b]
Star anise	0.5	0.97[d,e]
Star anise	1.0	0.71[e]
Retail 5-spice	0.1	0.99[d,e]
Retail 5-spice	0.5	0.73[e]
Retail 5-spice	1.0	1.00[d,e]
LSD	0.05	0.76

[a-e] Mean TBA values without a common letter differ ($p < 0.05$).
Means were pooled for storage time (1, 8 and 15 d) after cooking (n = 18).

In the second part of this study (Dwivedi and others 2006), a 13-member trained panel evaluated the sensory impact of the identified optimum levels of spice in cooked ground beef. A 5-spice blend with reduced clove was also used in this evaluation because cloves have a strong flavor and odor, which may be a concern to consumers. Three samples served as controls: rancid control, 0.5% sodium tripolyphosphate (STP) control, and fresh control. The rancid control was cooked ground beef without any added antioxidants held at 2 °C for 15 d. The fresh control was cooked ground beef without any added antioxidants cooked the day of sensory evaluations.

Rancid flavor, rancid odor, and spice flavor intensity were rated using a 5-point scale. A reduction ($p < 0.05$) was observed in rancid odor for the various spice treatments as compared to the control (Table 2-13). Rancid flavor was also decreased in the spice treatments as compared to the control. However, there was a significant increase reported in spice flavor of the treatments as compared to the control. The 5-spice blend with reduced clove had the lowest spice flavor score of 2.4, cinnamon had a score of 2.9, and the rest of the treatments ranged from 3.1 – 3.3. The reduction in rancid odor and flavor may be a result of the spice treatments masking the rancid odor and rancid flavor.

Table 2-13 – Mean trained panel sensory scores and thiobarbituric acid (TBA) values of spice-treated, cooked ground beef after 15 d storage at 2 °C. Lowest effective spice levels were used as determined in Table 2-12 (Dwivedi and others 2006).

Treatment[g]	Use level (% meat wt)	Rancid odor	Rancid flavor	Beef flavor	Spice flavor	TBA value (ppm)	Qualitative Comments
Rancid Control	0.0	3.3[a]	3.4[a]	2.0[b]	1.0[d]	7.4[a]	Rancid, painty, stale
STP Control	0.5	1.4[b]	1.4[b]	3.0[a]	1.1[d]	0.3[f]	Beefy, salty
Fresh Control	0.0	1.5[b]	1.5[b]	3.2[a]	1.1[d]	1.0[d,e]	Steak-like, oily, beefy
Cinnamon	0.5	1.1[b]	1.1[b]	1.7[b]	2.9[b,c]	1.6[c,d]	Cinnamon flavor, spicy
Cloves	0.1	1.0[b]	1.1[b]	2.2[b]	3.1[b,c]	0.4[e]	Strong clove flavor, smells like dentist's office
Fennel	0.5	1.5[b]	1.6[b]	1.9[b]	3.1[b,c]	5.5[b]	Licorice flavor, spicy
Pepper	0.5	1.4[b]	1.2[b]	2.1[b]	3.2[a,b]	1.6[c,d]	Peppery, hot
Star anise	0.5	1.2[b]	1.1[b]	1.8[b]	3.9[a]	1.9[c]	Licorice flavor, spicy
Retail 5-spice blend	0.5	1.0[b]	1.2[b]	1.9[b]	3.3[a,b]	0.7[e,f]	Strong spicy, black licorice
Low clove-spice blend	0.5	1.3[b]	1.2[b]	2.1[b]	2.4[c]	1.0[d,e]	Spicy
LSD	0.5	0.52	0.52	0.68	0.74	0.66	

[a-f]Mean values within a column without a common letter are different ($p < 0.05$).
[g]Rancid control = untreated sample cooked and held at 2 °C for 15 d, STP control = treated with 0.5% sodium tripolyphosphate cooked and held at 2 °C for 15 d, Fresh control = untreated and cooked the day of evaluation.

Vasavada and others (2006) studied the effects of garam masala spices as antioxidants in cooked ground beef. Lean ground beef (20% fat) was treated with black pepper[2], caraway[5], cardamom[1], chili powder[1], cinnamon[1], cloves[1], coriander[3], cumin[1], fennel[1], ginger[1], nutmeg[4], star anise[1], or retail garam masala[6] at 0.1%, 0.5%, and 1% ([1] products from McCormick & Co., Inc., Hunt Valley, MD, [2] product from Inter-American Foods, Inc., Cincinnati, OH, [3] Spice Islands Trading Co., San Francisco, CA, [4] Pacific Foods, Kent, WA, [5] Philips Foods, Inc. San Francisco, CA, [6] MDH garam masala blend, Mahashian Di Hatti Ltd., New Delhi, India). After treatment, the beef was cooked to an internal temperature of 82 – 85 °C and stored in Ziploc bags for 15 d at 2 °C. The lowest effective level for cinnamon, cloves, and retail garam masala spice blend was found to be 0.1% (Table 2-14). For the black pepper, chili, coriander, cumin, fennel, ginger, nutmeg, and star anise, the lowest effective level was 0.5%. Caraway and cardamom had the lowest effective level of 1.0%.

Table 2-14 – Mean TBA ± standard deviation value pooled over storage time, for the 2-way interaction of treatment x spice level (0, 0.1, 0.5, or 1.0% of raw meat weight) (Vasavada and others 2006).

	TBA values (ppm)			
Spice	**0.0% level**	**0.1% level**	**0.5% level**	**1.0% level**
Black pepper	3.43 ± 1.32^{a}	2.87 ± 1.37^{a}	1.28 ± 0.42^{b}	1.26 ± 0.41^{b}
Caraway	3.58 ± 1.69^{a}	2.40 ± 0.99^{b}	2.66 ± 1.25^{ab}	1.26 ± 0.74^{c}
Cardamom	3.43 ± 1.32^{a}	2.70 ± 1.46^{ab}	2.21 ± 1.02^{b}	1.11 ± 0.21^{c}
Chili Powder	3.58 ± 1.69^{a}	2.33 ± 0.92^{b}	1.13 ± 0.58^{c}	1.08 ± 0.26^{c}
Cinnamon	4.15 ± 2.29^{a}	1.66 ± 1.30^{b}	0.76 ± 0.44^{b}	0.78 ± 0.40^{b}
Cloves	3.58 ± 1.69^{a}	0.76 ± 0.22^{b}	0.97 ± 0.32^{b}	0.88 ± 0.28^{b}
Coriander	3.45 ± 1.41^{a}	2.39 ± 1.20^{b}	1.61 ± 0.63^{b,c}	1.03 ± 0.19^{c}
Cumin	3.45 ± 1.41^{a}	2.75 ± 1.20^{a}	1.08 ± 0.33^{b}	1.04 ± 0.21^{b}
Fennel	2.84 ± 1.59^{a}	2.32 ± 1.40^{a,b}	1.40 ± 1.70^{b,c}	0.99 ± 0.74^{c}
Ginger	4.29 ± 2.25^{a}	2.51 ± 2.19^{b}	0.88 ± 0.25^{c}	1.33 ± 0.99^{c}
Nutmeg	3.43 ± 1.32^{a}	2.16 ± 0.81^{b}	0.97 ± 0.24^{c}	1.04 ± 0.19^{c}
Retail garam masala	3.15 ± 1.34^{a}	1.73 ± 0.83^{b}	1.29 ± 0.51^{b}	0.82 ± 0.13^{b}
Salt	3.45 ± 1.41^{a}	2.89 ± 1.39^{a,b}	1.92 ± 0.9^{b}	2.27 ± 1.00^{b}
Star anise	3.18 ± 1.76^{a}	2.55 ± 1.42^{a}	0.97 ± 0.55^{b}	0.71 ± 0.38^{b}

$^{a-c}$Means without a common letter within a row are different ($p < 0.05$).

In the second part of Vasavada and others' (2006) study, a 13-member trained sensory panel evaluated cooked ground beef treated with spices at their lowest identified effective level for rancid odor/flavor, beef flavor, and spice flavor on a 5-point scale. They reported that both rancid odor and rancid flavor were reduced ($p < 0.05$) when compared to an untreated control sample (Table 2-15). Treated samples had scores ranging from 1.0 to 1.8 for rancid odor, and 1.0 to 1.7 for rancid flavor. Product treated with 0.1% cloves had the lowest rancid odor score, and product treated with star anise at 0.5% had the lowest rancid flavor score. As expected, spice flavor was increased ($p < 0.05$) for almost all treated samples with the exception of chili powder and ginger.

Table 2-15 – Mean trained panel sensory scores and thiobarbituric acid (TBA) values of spice-treated, cooked ground beef after 15 d storage at 2 °C (Vasavada and others 2006).

Treatment[1]	Use level (% meat wt)[2]	Rancid odor	Rancid flavor	Beef flavor	Spice flavor	TBA value (ppm)	Qualitative comments
Black pepper	0.5	1.4^{b}	1.2^{b}	$2.1^{b,c}$	$3.2^{a,b}$	$1.6^{f,g}$	Peppery, hot
Caraway	1.0	1.8^{b}	1.6^{b}	$2.1^{b,c}$	$2.6^{b,c,d}$	3.9^{c}	Spicy, dill-like flavor
Cardamom	1.0	1.4^{b}	1.1^{b}	$2.1^{b,c}$	$2.6^{b,c,d}$	$3.2^{c,d}$	Spicy, Mexican spice flavor
Chili powder	0.5	1.4^{b}	1.4^{b}	2.0^{c}	$1.9^{e,f,g}$	$1.7^{e,f,g}$	Bland, pizza-spice-like flavor
Cinnamon	0.1	1.1^{b}	1.1^{b}	1.7^{c}	$2.9^{a,b,c}$	$1.6^{f,g}$	Cinnamon flavor, spicy
Cloves	0.1	1.0^{b}	1.1^{b}	$2.2^{b,c}$	$3.1^{a,b}$	$0.4^{f,g}$	Strong clove flavor, smells like dentist's office
Coriander	0.5	1.4^{b}	1.3^{b}	2.0^{c}	$2.2^{b\text{-}f}$	3.4^{c}	Spicy
Cumin	0.5	1.6^{b}	1.7^{b}	1.9^{c}	$2.5^{b\text{-}e}$	$4.4^{b,c}$	Spicy, taco style spice, licorice flavor
Fennel	0.5	1.5^{b}	1.6^{b}	1.9^{c}	$3.1^{a,b}$	5.5^{b}	Licorice flavor, spicy
Ginger	0.5	1.4^{b}	1.4^{b}	$2.6^{a,b,c}$	$1.6^{d\text{-}g}$	$1.0^{f,g}$	Weak spice flavor and odor
Nutmeg	0.5	1.3^{b}	1.2^{b}	1.6^{c}	$2.5^{b\text{-}e}$	$3.1^{c,d,e}$	Spicy, nutmeg-like flavor
RGM	0.1	1.1^{b}	1.1^{b}	1.9^{c}	$3.1^{a,b}$	$0.7^{f,g}$	Spicy flavor
Salt	0.1	2.7^{a}	$2.6^{a,b}$	$2.2^{b,c}$	$1.4^{e,f,g}$	7.1^{a}	Salty flavor
Star anise	0.5	1.2^{b}	1.0^{b}	1.8^{c}	3.9^{a}	$1.9^{d,e,f}$	Licorice flavor, spicy
Fresh beef	0.0	1.5^{b}	1.5^{b}	3.2^{a}	$1.1^{f,g}$	$1.1^{f,g}$	Steak like, oily, beefy
15 d RBC	0.0	3.3^{a}	3.4^{a}	2.0^{c}	1.0^{g}	7.2^{a}	Rancid, painty, stale
Rosemary	0.4	1.1^{b}	1.1^{b}	$2.1^{b,c}$	$3.1^{a,b}$	$0.8^{f,g}$	Rosemary-like flavor
STP	0.5	1.4^{b}	1.4^{b}	$3.0^{a,b}$	$1.1^{f,g}$	0.3^{g}	Beefy, salty

[1] Treatments: RGM = retail garam masala, RBC = 15 d rancid beef control,
STP = sodium tripolyphosphate control.
[2] Recommended spice levels were used as determined from Table 2-14.
[a-g] Means with the same letters in a column are not different ($p > 0.05$).

Numerous spices are effective antioxidants in a variety of meat and poultry products. Cloves and marjoram were shown to function as antioxidants in ground chicken and ground pork. Sage extract, basil extract, thyme extract, and ginger extract were powerful antioxidants in ground pork. Garlic and onion powder showed inhibition of lipid oxidation in high fat cuts of pork stored in vacuum packaging. Cinnamon and clove retarded TBARS formation in ground beef, pork, and mutton. Of all spices studied thus far, extracts of sage, basil, thyme, and ginger were the most effective at inhibiting lipid oxidation.

Spices are a very practical choice as a natural antioxidant because they are already widely used in meat and poultry products today. However, there may be instances where a spice is used as a natural antioxidant, but the flavor of the spice may be desired in the finished product. Further investigation should be conducted to determine how the antioxidant power of spices may be may be used without providing their characteristic flavors.

Irradiated Almond Skin

Almond skins contain high levels of flavonoids and phenolic compounds (Teets and others 2008) and act as antioxidants in ground beef (Prasetyo and others 2008) and ground chicken (Teets and Were 2008; Teets and others 2008).

Phenolic compounds in almond skins and in other plants are normally glycosylated. Processing methods such as heat treatment or irradiation can liberate the phenolics from their glycoside components (Prasetyo and others 2008).

Prasetyo and others (2008) found that increasing the electron beam irradiation dose increased the total phenolics in almond skin powder obtained from the Carmel variety of almonds (Almond Board of California). However, Teets and others (2008) as well as Teets and Were (2008) have shown that electron beam irradiation had no effect on the total phenols in almond skin powder obtained from the Non-pareil variety of almonds (Almond Board of California). This discrepancy may be attributed to the differences in types of almonds, the type of irradiation, or the actual dosage of irradiation absorbed.

Prasetyo and others (2008) examined the use of electron beam irradiated almond skin powder as an antioxidant in raw ground beef. Almond skin powder extract irradiated at 0, 10, 20, and 30 kGy was added at 0.5% to raw ground beef (3% fat). Meat samples containing almond skin powder were stored in amber glass jars for 14 d at 4 °C. A reduction ($p < 0.05$) in TBARS values was found for all treatments (non-irradiated and irradiated) of almond skin powder when compared to control after 11 d of refrigerated storage (Prasetyo and others 2008). It was noted that the TBARS values were lower than the control by 82, 73, 53, and 55% for the samples with 30, 20, 10, and 0 kGy almond skin powder.

Prasetyo and others (2008) also evaluated the effects of almond skin powder on the color of ground beef. An untreated sample served as a negative control, and a sample treated with 0.01% BHT served as a positive control. It was observed that after 1 d, only the negative control and non-irradiated samples had higher ($p < 0.05$) L* values than ground beef containing irradiated almond skin powder (Table 2-16). After 4 d storage, the treatment containing non-irradiated almond skin powder had a lower ($p < 0.05$) a* value than all other treatments. All a* values were decreased after 8 d storage, and the BHT treatment and negative control had significantly lower values than all almond skin powder treated samples. It is expected that product treated with BHT would have a significantly higher a* value than the negative control. The low a* value found in this study for the BHT treated samples after 8 and 11 d of storage may be attributed to the 2 tert-butyl groups found in BHT. The tert-butyl groups cause steric hindrance and may be why the a* value was low for the BHT treated samples (Prasetyo and others 2008).

After 11 d storage, a decrease ($p < 0.05$) in the L* value, and an increase in the a* value was observed in all non-irradiated and irradiated samples treated with almond skin powder when compared to the control. The L* value for the 10 and 30 kGy treatments were reported as 30.73, and control was 31.86. The a* value was increased from 3.28 in control to 4.10 in the 30 kGy treatment. This larger a* value may be a result of the almond skin powder inhibiting the formation of metmyoglobin, which gives meat a brown color (Prasetyo and others 2008).

Table 2-16 – Lightness color values (L*) and red color values (a*) of refrigerated ground beef samples containing almond skin powder treated with or without irradiation (Prasetyo and others 2008).

	Color values			
L* values				
Treatment	**1 (d)**	**4 (d)**	**8 (d)**	**11 (d)**
0 kGy	31.30 ± 1.2[a,b]	29.13 ± 0.21[e]	31.0 ± 0.75[a,b,c]	30.8 ± 0.35[b]
10 kGy	29.63 ± 0.90[c]	29.4 ± 0.43[d,e]	30.53 ± 0.92[b,c]	30.73 ± 0.25[b]
20 kGy	30.23 ± 0.76[b,c]	29.80 ± 0.46[c,d]	31.7 ± 1.08[a,b]	30.87 ± 0.11[b]
30 kGy	30.13 ± 0.81[b,c]	30.03 ± 0.31[c]	29.93 ± 0.30[c]	30.73 ± 0.25[b]
BHT Control	30.10 ± 0.3[b,c]	30.8 ± 0.15[b]	32.1 ± 0.30[a]	31.6 ± 0.76[a]
Negative Control	32.00 ± 0.34[a]	31.57 ± 0.40[a]	32.1 ± 1.35[a]	31.86 ± 0.76[a]
a* values				
0 kGy	17.70 ± 0.96[c]	14.50 ± 0.1[c]	4.63 ± 0.21[c]	4.50 ± 0.15[a]
10 kGy	20.17 ± 0.40[b]	16.5 ± 0.15[b]	4.83 ± 0.10[b]	4.17 ± 0.21[b]
20 kGy	20.10 ± 1.0[b]	16.57 ± 0.31[b]	4.9 ± 0.06[a]	3.90 ± 0.52[c]
30 kGy	19.37 ± 0.96[b]	12.47 ± 0.11[d]	4.57 ± 0.21[d]	4.10 ± 0.06[b]
BHT Control	22.33 ± 0.72[a]	18.87 ± 0.17[a]	3.44 ± 0.11[e]	3.28 ± 0.15[d]
Negative Control	21.83 ± 0.86[a]	18.87 ± 0.15[a]	3.40 ± 0.10[e]	3.28 ± 0.21[d]

[a-e]Mean from different treatments with different superscripts are different ($p \leq 0.05$).

Teets and others (2008) studied the effects of electron beam irradiated almond skin powder in cooked ground chicken breasts. Almond skin powder was electron beam irradiated at 0, 10, 20, and 30 kGy. Extracts were made with each of almond skin powder treatments and used to treat ground chicken breast at 0.5% (fresh meat basis). Samples were put into polypropylene bags, spread to a thickness of 1 cm, vacuum packaged, and cooked in a water bath to an internal temperature of 80 °C. These samples were stored at 4 °C for 8 d. The average fat content of the samples after cooking was found to be 2.26 ± 0.07%.

Teets and others (2008) found that the 10 kGy irradiated almond skin powder treatment was the most effective at inhibiting TBARS formation when compared to the control. The 10 kGy sample had a TBARS value of 166.74 ± 9.90 µg MDA/kg meat, which is a reduction ($p < 0.05$) from the control value of 1042.46 ± 23.42 µg MDA/kg meat. Hexanal formation was also most effectively inhibited by the 10 kGy treatment. The 10 kGy treatment was reported to have a hexanal value of 13.19 ± 0.38 ppm, which is a reduction ($p < 0.05$) from the control value of 104.92 ± 0.33 ppm. There was no difference ($p > 0.05$) reported for the a* or b* values of any of the samples. However, the L* value of the almond skin powder treated samples were found to be significantly reduced by an average of 7.4%.

Teets and Were (2008) also examined the use of electron beam irradiated almond skin powder in raw chicken breasts. Samples of ground chicken breast (fat content not available) were treated with 0.5% almond skin powder extract after irradiation at 0, 10, 20, and 30 kGy. Samples were stored in Ziploc freezer bags for 12 d at 4 °C, or 7 mo at -20 °C. This research further confirmed that almond skin powder was effective at reducing lipid oxidation in poultry.

Teets and Were (2008) reported no difference ($p \geq 0.05$) in a* or b* values for the treatments with irradiated almond skin stored refrigerated (1 d and 12 d) or frozen (1 d and 12 d) when compared to controls for all (Table 2-17). They did report lower ($p \leq 0.05$) L* values of the refrigerated (1 d and 12 d) and frozen (1 d and 12 d) treatments with irradiated almond skin when compared to the controls. After 12 d, almond skin irradiated at 30 kGy held at 4 °C had an L* value of 49.74 whereas, control was 52.40. The L* value for the control sample held at -20°C was 46.88 ± 0.93, and the 30 kGy irradiated treatment was 39.88 ± 0.84.

Table 2-17 – L*, a*, and b* values for raw minced chicken breasts containing non-irradiated and irradiated almond skin powder (Teets and Were 2008).

	Color values during refrigerated storage (4 °C)		Color values during frozen storage (-18 °C)	
Treatment[1]	**1 (d)**	**12 (d)**	**14 (d)**	**194 (d)**
L* values				
Control -	52.41 ± 0.25[a]	52.40 ± 0.41[a]	45.20 ± 0.92[a]	46.88 ± 0.93[a]
Control +	52.82 ± 0.24[a]	52.88 ± 0.91[a]	46.83 ± 0.93[a]	46.01 ± 0.98[a]
0 kGy	50.25 ± 0.18[b]	50.46 ± 0.66[b]	41.37 ± 0.45[b]	41.06 ± 0.86[b]
10 kGy	49.99 ± 0.36[b]	49.87 ± 0.86[b]	41.73 ± 0.12[b]	39.75 ± 0.79[b]
20 kGy	49.99 ± 0.39[b]	49.56 ± 0.77[b]	40.47 ± 0.59[b]	40.65 ± 0.95[b]
30 kGy	50.09 ± 0.15[b]	49.74 ± 0.54[b]	41.23 ± 0.75[b]	39.88 ± 0.84[b]
a* values				
Control -	2.34 ± 0.21[a]	2.18 ± 0.16[a]	3.60 ± 0.75[a]	3.05 ± 0.66[a]
Control +	2.55 ± 0.26[a]	2.48 ± 0.19[a]	3.03 ± 0.21[a]	2.99 ± 0.94[a]
0 kGy	2.62 ± 0.11[a]	2.51 ± 0.33[a]	3.90 ± 0.82[a]	3.65 ± 0.81[a]
10 kGy	2.45 ± 0.18[a]	2.36 ± 0.46[a]	4.13 ± 0.45[a]	3.84 ± 0.99[a]
20 kGy	2.61 ± 0.38[a]	2.57 ± 0.06[a]	3.97 ± 0.42[a]	3.14 ± 0.56[a]
30 kGy	2.84 ± 0.27[a]	2.18 ± 0.11[a]	4.20 ± 0.56[a]	3.00 ± 0.43[a]
b* values				
Control -	8.74 ± 0.97[a]	8.93 ± 0.95[a]	11.53 ± 0.15[a]	11.85 ± 0195[a]
Control +	9.06 ± 0.59[a]	9.27 ± 0.42[a]	11.70 ± 0.36[a]	11.43 ± 0.15[a]
0 kGy	9.13 ± 0.71[a]	9.26 ± 0.41[a]	11.57 ± 0.46[a]	11.55 ± 0.24[a]
10 kGy	8.94 ± 0.98[a]	8.59 ± 0.61[a]	11.40 ± 0.35[a]	11.94 ± 0.30[a]
20 kGy	9.32 ± 0.71[a]	9.37 ± 0.86[a]	11.60 ± 0.20[a]	12.02 ± 0.33[a]
30 kGy	9.06 ± 0.98[a]	8.67 ± 0.78[a]	11.83 ± 0.25[a]	11.54 ± 0.20[a]

[1] Treatments: Control - = meat without almond skin powder or BHT,
Control + = meat incorporated with 0.01% BHT.
[a,b]Means with different superscript letters within columns for the same analysis are different ($p \leq 0.05$).

Various studies have shown that electron beam irradiated almond skin powder and non-irradiated almond skin powder are effective at inhibiting lipid oxidation in meat and poultry products. Further investigation is needed to examine the impact of irradiation on the phenolic compound concentration of almond skin powder because the information in the literature is inconclusive thus far. Further research should also include an investigation into the effectiveness of using almond skin powder at varying concentrations, its impact on sensory characteristics of finished meat and poultry products, and the functionality of almond skin powder under other types of processing conditions for meat and poultry products.

Green Tea Extract

Tea is one of the most widely consumed beverages in the world (Martinez and others 2006). Many consume tea because of its perceived health benefits. Teas have anticarcinogenic and antimutagenic activity, inhibit the effects of arteriosclerosis, decrease the risk of diabetes, as well as possess antibacterial and antiviral agents (Jo and others 2003a; Bozkurt 2006). Teas also have antioxidant properties (Nanjo and others 1996). It is because of these properties that green tea is a good candidate for use as an antioxidant in meat and poultry products.

Green tea leaves are naturally dark in color and generally have an off-flavor associated with them. This dark color and off-odor can make green tea difficult to use in food products (Jo and others 2003a). Irradiation and ethanol extraction can change the color of green tea leaves from dark red to yellow in color, and freeze-drying prevents color reversion (Jo and others 2003b).

Jo and others (2003a) examined the use of irradiated and non-irradiated green tea leaf extract in raw and cooked pork patties. Pork patties were treated with irradiated green tea extract (20 kGy) and non-irradiated green tea extract at 0.1%. Samples were stored in oxygen permeable polyethylene packaging and held for 15 d at 4 °C. Cooked samples were heated to an internal temperature of 78 °C and held under the same conditions. Jo and others (2003a) report that TBARS values were reduced ($p < 0.05$) for both the irradiated and non-irradiated green tea extracts (Table 2-18).

In raw pork patties after 15 d storage, TBARS values for the irradiated green tea extract was 0.39 mg MDA/kg sample, and the non-irradiated green tea extract sample was 0.48 mg MDA/kg sample. The TBARS value of the raw pork control was 0.69 mg MDA/kg sample. For all storage times (0, 5, 10, and 15 d) when compared to control, cooked treated samples exhibited a reduction in TBARS values. For 15 d of storage, control was 1.21 mg MDA/kg sample, and irradiated and non-irradiated green tea extract treatments were 0.31 and 0.44 mg MDA/kg meat, respectively. The irradiated and non-irradiated green tea extract samples were not different ($p > 0.05$) after the 15 d (Jo and others 2003a).

Table 2-18 – TBARS values (mg MDA/kg meat) of raw and cooked pork patties with added non-irradiated or irradiated freeze-dried green tea leaf extract powder (0.1%) (Jo and others 2003a).

	TBARS values during storage time (d)				SEM
Treatment[1]	**0**	**5**	**10**	**15**	
Raw pork patties					
Trt A	$0.38^{c,x}$	$0.56^{b,x}$	$0.56^{b,x}$	$0.69^{a,x}$	0.029
Trt B	$0.28^{b,y}$	$0.42^{a,y}$	$0.43^{a,y}$	$0.48^{a,y}$	0.024
Trt C	$0.30^{b,y}$	$0.36^{a,z}$	$0.35^{a,y}$	$0.39^{a,y}$	0.016
SEM	0.021	0.016	0.025	0.028	
Cooked pork patties					
Trt A	$1.13^{b,x}$	$1.22^{a,b,x}$	$1.38^{a,x}$	$1.21^{a,b,x}$	0.044
Trt B	0.48^{z}	0.42^{y}	0.42^{y}	0.44^{y}	0.042
Trt C	$0.58^{a.,y}$	$0.36^{b,y}$	$0.44^{b,y}$	$0.31^{b,y}$	0.042
SEM	0.027	0.048	0.043	0.048	

[1] Treatments: Trt A = only pork patties, Trt B = patties with non-irradiated, freeze-dried green tea leaf extract powder (0.1%), Trt C = patties with irradiated at 10 kGy, freeze-dried green tea leaf extract powder (0.1%).
[a-c]Means within the same row with different superscripts differ ($p < 0.05$).
[x-z]Means within the same column with raw and cooked pork patties with different superscripts differ ($p < 0.05$).

In the raw pork samples after 10 d of storage, color values (L*, a*, and b*) were all different ($p < 0.05$) for the non-irradiated and irradiated (10 kGy) freeze-dried green tea leaf extract (Table 2-19). After 5 d storage, the L* value was significantly higher in the irradiated treatment than in the non-irradiated treatment and control. The L* value was increased from the control value of 54.16, whereas non-irradiated and irradiated green tea extract values were 56.03 and 57.10, respectively. The a* values decreased throughout storage. After 10 d storage, the a* values were higher ($p < 0.05$) in the irradiated and non-irradiated green tea treatments than the control. This is in agreement with findings from Martinez and others (2006), who showed that a* values were significantly increased in pork sausage (fat content not reported) when treated with green tea powder. The b* value for the control sample was found to be lower ($p < 0.05$) than both green tea extract treatments. The irradiated green tea extract sample was also lower than the non-irradiated green tea extract sample.

Table 2-19 – Color changes of raw pork patties added with non-irradiated or irradiated green tea leaf extract powder (0.1%) (Jo and others 2003a).

	Color values during storage time (d)			
Treatment[1]	**0**	**5**	**10**	**SEM**
L* value				
Trt A	53.13^{y}	55.37^{y}	54.16^{y}	0.591
Trt B	56.04^{x}	$56.42^{a,y}$	56.03^{x}	0.710
Trt C	$54.44^{b,x,y}$	$57.96^{a,x}$	$57.10^{a,x}$	0.530
SEM	0.684	0.666	0.473	
a* value				
Trt A	$4.84^{a,x}$	4.15^{b}	$3.08^{c,y}$	0.242
Trt B	$4.39^{a,x}$	4.24^{a}	$3.68^{b,x}$	0.277
Trt C	$4.34^{a,y}$	4.36^{a}	$3.89^{b,x}$	0.159
SEM	0.280	0.289	0.179	
b* value				
Trt A	$13.33^{a,x}$	$12.22^{b,y}$	$11.59^{c,z}$	0.220
Trt B	13.03^{x}	13.62^{x}	13.50^{x}	0.189
Trt C	$12.04^{c,y}$	$13.26^{a,x}$	$12.56^{b,y}$	0.159
SEM	0.127	0.216	0.217	

[1] Treatments: Trt A = only pork patties, Trt B = patties with non-irradiated, freeze-dried green tea leaf extract powder (0.1%), Trt C = patties with irradiated at 10 kGy, freeze-dried green tea leaf extract powder (0.1%).
[a,b,c] Means within the same row with different superscripts differ ($p < 0.05$).
[x,y,z] Means within the same column with raw and cooked pork patties with different superscripts differ ($p < 0.05$).

A 10-member trained sensory panel evaluated raw samples for color and odor, and cooked samples for color, odor, taste and tenderness. They used a 15 cm line scale (0 = mild; 15 = extreme) to rate the samples. In the raw samples, no color preference was found ($p < 0.05$) between the control and treated samples. The panelists preferred ($p < 0.05$) the odor in the raw patties treated with irradiated green tea extract (9.0) over control (6.9), and the raw patties treated with non-irradiated green tea extract (5.4). In the cooked product, green tea extract treatments scored higher ($p < 0.05$) than control. No difference was found between taste and tenderness of the treatments.

Bozkurt (2006) evaluated the use of green tea extract as an antioxidant in sucuk, which is a Turkish dry-fermented sausage. Sucuk (~5.5% fat) was treated with 300 ppm green tea extract, filled into artificial collagen casings, and allowed to ripen. Bozkurt (2006) reported that TBARS formation was reduced ($p < 0.05$) when compared to both the negative control and the treatment with 300 ppm BHT (Merck, Darmstadt, Germany).

Bozkurt's (2006) study used a 10-member trained panel to evaluate the color, flavor, and ease of cutting of the samples. Samples were given a score from 1 to 10 (1 = worst; 10 = best) in each sensory category. These scores were converted to an overall sensory quality score given by the equation: (Equation 2)

$$\text{Overall Sensory Quality} = (\text{flavor} \times 0.5) + (\text{color} \times 0.25) + (\text{cutting} \times 0.25)$$

Bozkurt (2006) reported that the overall sensory quality score was higher ($p < 0.05$) for the sample treated by the green tea extract (4.75 ± 0.39) than the control sample (4.25 ± 0.51).

Green tea products have exhibited powerful antioxidant activity. They also impact the color of some meat products. There have been solutions found (such as irradiation) to address some of the color issues involved when using green tea extract in meat products. However, consumers may view irradiated antioxidant products as being no better than synthetic antioxidants. An investigation should be conducted to determine consumers' acceptance of these products. Further studies should also be carried out to examine the ideal concentrations of green tea powders and extracts to use in meat products, as well as their effectiveness as an antioxidant in poultry products.

CHAPTER 3 - CONCLUSION

The meat and poultry industry has been seeking sources of natural antioxidants to replace currently used synthetic antioxidants. Due to their high phenolic compound content, fruits and other plant materials provide a good alternative to currently used conventional antioxidants. Plum, grape seed extract, cranberry, pomegranate, bearberry, pine bark extract, rosemary, oregano, other spices, irradiated almond skins, and green tea have potential as antioxidants in meat and poultry products. Pomegranate, pine bark extract, cinnamon, and cloves have all exhibited stronger antioxidant properties than some of the synthetic antioxidants currently used by the meat and poultry industry.

In order to compare the data from the discussed studies and to determine the most effective of the natural antioxidants, the TBARS or hexanal values from these studies were converted to the percentage antioxidant activity (% AOA) using Equation 1

$$\% \text{ AOA} = \frac{[\text{TBARS value of the control} - \text{TBARS value of the test sample}] \times 100}{[\text{TBARS value of control}]}$$

The larger the % AOA value obtained, the more effective that antioxidant was at reducing lipid oxidation.

From the discussed studies, plum was the only natural antioxidant tested in precooked frozen meat or poultry. The % AOA of plum in precooked frozen meat was found to be 58.6% (Table 3-1). In precooked refrigerated samples, grape seed extract, pine bark extract, and 5-spice blend had high % AOA values, which ranged from 80 to 95%. Coriander and fennel had the lowest % AOA values of the precooked refrigerated treatments. Values for these treatments were < 35%.

Wild marjoram and extracts of sage, thyme, basil, and ginger had the highest

% AOA values, which ranged from 85 to 95% in raw frozen meat or poultry products (Table 3-2). Curry and cinnamon had the lowest values, which were in the 15 to 25% range. Cranberry and extracts of sage, basil, thyme, and ginger had % AOA values in the 80 to 90% range in raw meat or poultry products stored at refrigerated temperatures. Clove, plum, caraway, and wild marjoram had the lowest % AOA values of raw refrigerated treatments. Values for these antioxidants were actually negative.

The % AOA values were also determined for the overall antioxidant activity of these natural antioxidants in meat and poultry products. Grape seed extract, cranberry, sage extract, thyme extract, basil extract, ginger extract, pine bark extract, and Chinese 5-spice blend all had % AOA values between 85% and 95% (Table 3-3). Coriander, fennel, caraway, wild marjoram, and curry had the lowest % AOA values. Values for these antioxidants were < 35%.

When looking at the overall antioxidant activity across treatments and storage, the majority of the top performing natural antioxidants were extracts. The solvent extraction process extracts the phenolic compounds, which makes these extracts more concentrated than using them without extracting them first. Concentrating the phenolic components of these antioxidants makes them more powerful.

When selecting a natural antioxidant to use in a meat or poultry product, the sensory and quality impact on the product should be considered in order to achieve a product with the desired traits. Some of these natural antioxidants have exhibited potentially negative consequences on finished meat and poultry products. Table 3-4 summarizes research findings related to the addition of fruit and plant materials to provide antioxidant properties when added to various meat and poultry products.

Some of these ingredients may impact product quality and ultimately consumer acceptability of the product. Plum, grape seed extract, pine bark extract, rosemary, almond skin powder, and green tea extract have all caused color changes when used in some meat or poultry products. Consumers may view these changes as negative. For example, if grape seed extract is used as an antioxidant in a fully-cooked chicken product, consumers may find the product unacceptable because grape seed extract has been shown to increase the redness of the product, and the product may be mistaken as undercooked.

The use of natural antioxidants in meat and poultry products is an emerging area of study. More consumer research is needed to understand if documented sensory changes to products are viewed as negative, and if these natural antioxidants are acceptable to consumers. There is also the potential issue that consumers will not want products with pine bark extract, bearberry, or other ingredients used as natural antioxidants because they do not understand what these ingredients are, or these ingredients do not sound appealing to them.

There are many sources of natural antioxidants. Some of them are just beginning to be studied such as rapeseed, blueberry, potato peel extract, or tomato. As demand for natural products and products with consumer-friendly labels continues to increase, there will be an increased need to identify new sources of natural antioxidants. Therefore, further research is important in this area to determine optimal levels and sensory and quality properties of various fruit and plant material antioxidants and how they can potentially be incorporated into meat and poultry products.

Table 3-1 – Percentage antioxidant activity (% AOA) of the discussed natural antioxidants tested in precooked meat or poultry products, and stored refrigerated or frozen.

Treatment	% AOA[1]
Precooked Frozen	
Plum	58.6 ± 16
Precooked Refrigerated	
Grape Seed Extract	94.5 ± 3
Pine Bark Extract	86.6 ± 15
5-Spice Blend	85.2 ± 6
Irradiated Almond Skin	79.2 ± 6
Clove	76.5 ± 13
Ginger	70.1 ± 23
Green Tea Extract	69.0 ± 8
Rosemary	69.0 ± 23
Star Anise	67.2 ± 12
Retail Garam Masala	65.6 ± 35
Oregano	64.2
Pepper	63.0 ± 21
Chili Powder	58.8 ± 25
Bearberry	58.5 ± 26
Pomegranate	56.7 ± 39
Cinnamon	54.0 ± 23
Plum	53.8 ± 25
Cardamom	53.3 ± 3
Nutmeg	53.2 ± 5
Caraway	45.2 ± 1
Cumin	41.3 ± 3
Coriander	34.5 ± 26
Fennel	33.9 ± 17

[1] Values are calculated from various studies cited in this report. Therefore, not all standard deviations were available.

Table 3-2 – Percentage antioxidant activity (% AOA) of the discussed natural antioxidants tested in raw meat or poultry products, and stored refrigerated or frozen.

Treatment	% AOA[1]
Raw Frozen	
Wild Marjoram	96.5
Sage Extract	91.3
Thyme Extract	88.1
Basil Extract	87.1
Ginger Extract	86.4
Marjoram	67.8
Caraway	58.5
Clove	48.4
Peppermint	45.7
Nutmeg	42.0
Curry	27.1
Cinnamon	16.3
Raw Refrigerated	
Cranberry	92.6 ± 2
Sage Extract	92.3
Basil Extract	92.2
Thyme Extract	91.9
Ginger Extract	87.8
Peppermint	54.9
Nutmeg	41.2
Green Tea Extract	37.0 ± 9
Garlic Powder	36.1 ± 2
Onion Powder	36.1 ± 2
Cinnamon	23.9
Curry	22.2
Marjoram	7.8
Clove	-3.7
Plum	-6.0 ± 4
Caraway	-14.3
Wild Marjoram	-34.4

[1] Values are calculated from various studies cited in this report. Therefore, not all standard deviations were available.

Table 3-3 – Overall percentage antioxidant activity (% AOA) of the discussed natural antioxidants tested in meat or poultry products.

Treatment	% AOA[1]
Grape Seed Extract	94.7 ± 3
Cranberry	92.6 ± 2
Sage Extract	91.8 ± 1
Thyme Extract	90.0 ± 3
Basil Extract	89.7 ± 4
Ginger Extract	87.1 ± 1
Pine Bark Extract	86.6 ± 15
5-Spice Blend	85.2 ± 6
Irradiated Almond Skin	79.2 ± 6
Ginger	70.1 ± 23
Rosemary	69.0 ± 23
Star Anise	67.2 ± 12
Retail Garam Masala	65.5 ± 35
Clove	64.5 ± 30
Oregano	64.2
Pepper	63.00 ± 21
Chili Pepper	58.8 ± 25
Bearberry	58.5 ± 26
Pomegranate	56.7 ± 39
Cardamom	53.3 ± 3
Green Tea Extract	53.0 ± 20
Peppermint	50.3 ± 7
Nutmeg	47.4 ± 7
Cinnamon	46.5 ± 25
Plum	43.0 ± 34
Cumin	41.3 ± 3
Marjoram	37.8 ± 42
Garlic Powder	36.1 ± 2
Onion Powder	36.1 ± 2
Coriander	34.5 ± 26
Fennel	33.9 ± 17
Caraway	33.7 ± 33
Wild Marjoram	31.0 ± 93
Curry	24.7 ± 4

[1] Values are calculated from various studies cited in this report. Therefore, not all standard deviations were available.

Table 3-4 – Summary of various natural antioxidant studies that have been conducted in meat and poultry products, and their findings.

Antioxidant	**Usage Level**	**Company**	**Product**	**Summary**
Dried Plum Puree (Nunez de Gonzalez and others 2008a)	3%, 6% (% of precooked meat weight)	CA Plum Board, Sunsweet Growers, Inc.	Cooked Pork Sausage Patties	▪ Significant reduction in TBARS[a] values from 1.00 to 0.34 in refrigerated samples, and from 1.98 to 0.46 in frozen samples ▪ Decrease in redness (a*) value from 12.59 to 10.63 ▪ Masking of pork and spicy flavors ▪ 3% treated sample overall liking score not significantly different from control ▪ 6% dried plum had the lowest overall flavor liking score of all treatments, however the sample was still found to be acceptable by a sensory panel
Plum Extract (Lee and Ahn 2005)	3% (% of precooked meat weight)	CA Plum Board, Sunsweet Growers, Inc.	Irradiated Turkey Breast Rolls	▪ Significant reduction in TBARS values from 1.59 to 1.14 ▪ Increase in a* value from 6.17 to $\geq$ 8.01 ▪ No flavor difference observed by a sensory panel ▪ Humectant properties observed
▪ Fresh Plum Juice Concentrate ▪ Dried Plum Juice Concentrate ▪ Spray Dried Plum Powder (Nunez de Gonzalez and others 2008b)	2.5% and 5% of brine injected at 20% weight of raw product	CA Plum Board, Sunsweet Growers, Inc.	Precooked Roast Beef	▪ Significant reduction in TBARS values from 0.62 to $\leq$ 0.40 ▪ Marginally detectable difference in sweet taste when compared to control ▪ 5% fresh plum juice concentrate was found to decrease a* values from 10.2 to 9.4

Grape Seed Extract (Ahn and others 2002)	0.1% (% of precooked meat weight)	ActiVin	Cooked Ground Beef	▪ Significant reduction in TBARS values from 5.77 to 1.35 ▪ Significant reduction in hexanal[b] values from 2.90 to 0.08
Grape Seed Extract (Ahn and others 2007)	1% (% of precooked meat weight)	ActiVin	Cooked Ground Beef	▪ Significant reduction in TBARS values from 9.45 to 0.75 ▪ Increase in a* value from 4.55 to 9.10 ▪ Decrease in yellowness (b*) value from 17.32 to 14.03
Grape Seed Extract (Carpenter and others 2007)	1000 µg gallic acid equivalent phenolics/g meat, precooked meat weight	Guinness Chemical Ltd., Ireland	Raw Pork Patties	▪ a* value increased from 3.47 to 4.15, but sensory panel did not find this as a negative attribute
Grape Seed Extract (Rojas and Brewer 2007)	0.02% % of precooked meat weight	Gravinol Super	Cooked Beef and Pork	▪ No significant color differences were observed
Cranberry Juice Powder (Lee and others 2006)	0.32% (% of precooked meat weight)	90-MX Ocean Spray Cranberry	Mechanically Separated Turkey	▪ Reduction in lipid oxidation equal to that of rosemary ▪ Inhibited TBARS formation 10 times when compared to control (values from 58.8 to 5.1 µmol MDA/kg sample) ▪ Significantly lowered rancidity score as determined by a sensory panel

Pomegranate Rind Powder (Naveena and others 2008b)	10 mg tannic acid equivalents/100 g meat (precooked meat weight)	Kabul variety, from local supermarket	Cooked Chicken Patties	▪ Significant reduction in TBARS values from 1.272 to 0.203 ▪ 68% reduction in TBARS values when compared to BHT treatment
Pomegranate Rind Powder (Naveena and others 2008a)	20 mg tannic acid equivalents/100 g meat (precooked meat weight)	From local supermarket	Cooked Chicken Patties	▪ Decrease in lightness (L*) value from 63.80 to 56.71 ▪ No off odors or sweet flavors detected by a sensory panel ▪ Slight reduction in chicken flavor as observed by a sensory panel
Bearberry (Carpenter and others 2007)	80 µg/g meat (precooked meat weight)	Industrial Estate, Portlaoise, Co.	Cooked and Raw Pork Patties	▪ Significant reduction in TBARS values from 0.90 to 0.54 ▪ No change in L*, a* or b* color values ▪ No negative sensory attributes
Bearberry (Pegg and others 2001)	1000 µg/g meat (precooked meat weight)	Extract prepared in laboratory	Cooked Pork	▪ 9-fold reduction in lipid oxidation
Pine Bark Extract (Ahn and others 2007)	1% (% of precooked meat weight)	Pycnogenol	Cooked Beef	▪ Significant reduction in TBARS values when compared to control from 9.45 to 0.06 ▪ Significant reduction in TBARS values when compared to samples treated with BHT or BHA at 0.01% ▪ Significant reduction in hexanal values from 4.93 to 0.05 ▪ Decreased L* value from 48.39 to 46.37 ▪ Decreased b* value from 17.32 to 15.88 ▪ Increased a* values from 4.55 to 5.79
Pine Bark Extract (Ahn and others 2002)	0.02% 0.05%	Pycnogenol Natural Health	Cooked Beef	▪ Significant reduction in TBARS values from 5.77 to 1.58

	0.1% (% of precooked meat weight)	Sciences, Hillside, NJ		▪ 0.02% inhibited development of warmed over flavor (WOF), sensory scores from 10.25 to 6.61
Rosemary (Rojas and Brewer 2007)	0.2% (% of precooked meat weight)	Herbalox Kalsec, Inc., Kalamazoo, MI	Cooked Beef and Pork	▪ No significant reduction in TBARS values was observed
Rosemary (Nissen and others 2004)	200 ppm (precooked meat weight)	Nestle Research Centre, Lausanne, Switzerland	Cooked Pork	▪ Significant reduction in TBARS values from 30 to 9.3 µmol MDA/kg ▪ Significant reduction in hexanal values from 21.6 to 4.9
Rosemary (Mielnik and others 2003)	0.2g/kg 0.5g/kg 0.8g/kg 0.8g/kg 1.6g/kg 2.4g/kg (precooked meat weight)	Guardian Rosemary Extract GP and Flavor Guard LO Biolox HT-W, Herbalox W, and Stabiloton WS	Mechanically Deboned Turkey	▪ Significant reduction in TBARS values for all treatments from 2.662 to ≤ 1.890 ▪ Guardian Rosemary Extract GP at 0.8g/kg largest reduction in TBARS value (0.244) ▪ Guardian Rosemary Extract GP at 0.2g/kg least reduction in TBARS value (1.890) ▪ The quality of the rosemary extract plays a role in its effectiveness to inhibit lipid oxidation
Rosemary (Ahn and others 2007)	1% (% of precooked meat weight)	Herbalox	Cooked Ground Beef	▪ Significant reduction in TBARS values from 9.45 to 0.72 ▪ Significant reduction in hexanal values from

				4.93 to 0.09 ▪ Increase in L* value from 48.39 to 51.72 ▪ Increase b* value from 17.32 to 17.90 ▪ Decrease in a* value from 4.55 to 3.21
Oregano (Rojas and Brewer 2008)	0.2% (% of precooked meat weight)	Oreganox WS	Cooked Beef	▪ Significant reduction in TBARS values from approx. 1.25 to approx. 1.10
Marjoram, Wild Marjoram, Caraway, Clove, Peppermint, Nutmeg, Curry, Cinnamon, Basil, Sage, Thyme, Ginger (El-Alim and others 1999)	10g/kg meat (precooked meat weight)	From local supermarket	Raw Ground Chicken stored refrigerated and frozen	▪ Refrigerated storage – all treatments with the exception of peppermint and caraway showed a significant reduction in TBARS (values from 72.1 to ≤ 66.5 ng MDA/kg sample); clove exhibited the largest reduction ▪ Frozen storage - all treatments with the exception of curry and cinnamon showed a significant reduction in TBARS (values from 319.1 to ≤ 173.2 ng MDA/kg sample); marjoram exhibited the largest reduction
Extracts of Basil, Sage, Thyme and Ginger (extracted with ethanol) (El-Alim and others 1999)	1 ml/10 g meat (precooked meat weight)	Extracts prepared in laboratory	Ground Pork stored refrigerated and frozen	▪ Significant reduction in TBARS values for all treatments ▪ Refrigerated storage - sage, thyme, basil most effective at reducing TBARS (values from 579.7 to 70.6 ng MDA/kg sample) ▪ Frozen storage - sage and basil most effective at reducing TBARS (values from 405.7 to 55.1 ng MDA/kg sample)
Garlic and Onion Powder (Park and others 2008)	5% of brine injected at 110% of original weight	Dong Bang Food Co.	Pork Loin and Pork Belly	▪ Significant reduction in TBARS formation in pork belly (from 0.23 to 0.15), not in pork loin

				▪ Significant increase in pork belly fat b* (from 4.41 to 5.50), lean b* (from 3.60 to 4.25), and lean a* (from 6.55 to 7.66) ▪ Significant increase in pork loin garlic treatment a* value from 3.85 to 4.21 ▪ Significant increase in pork loin b* values from 2.87 to 3.57
Cinnamon and Cloves (Jayathilakan and others 2007)	250 mg/100 g (precooked meat weight)	From local supermarket	Cooked Beef, Cooked Pork, Cooked Mutton	▪ Cinnamon and clove treated samples were more effective at reducing TBARS values than with 0.02% TBHQ ▪ No significant difference between samples treated with cinnamon or cloves and samples treated with BHA or propyl gallate at 0.02%
Chinese 5-Spice Blend, Cinnamon, Clove, Fennel, Pepper, Star Anise, Chinese 5-Spice Blend with Reduced Clove (Dwivedi and others 2006)	0.1% 0.5% 1% (% of precooked meat weight)	From local super market	Cooked Beef	▪ Optimum usage level for clove found to be 0.1%, all other spices was found to be 0.5% ▪ All treatments significantly reduced rancid odor (from 3.3 to 1.5), and flavor (from 3.4 to 1.6) as determined by a sensory panel ▪ 5-spice blend with reduced clove had the lowest spice flavor as determined by a sensory panel
Black Pepper[2], Caraway[5], Cardamom[1], Chili Pepper[1], Cinnamon[1], Clove[1], Coriander[3], Cumin[1],	0.1% 0.5% 1% (% of precooked	1. McCormick & Co. 2. Inter-American Foods, Inc.	Cooked Ground Beef	▪ Significant reduction in TBARS values for all treatments from 3.5 to ≤ approx. 1.75 ▪ 0.1% - lowest effective level for cinnamon, clove, and retail garam masala blend

Fennel[1], Ginger[1], Nutmeg[4], Star Anise[1], Garam Masala[6] (Vasavada and others 2006)	meat weight)	3. Spice Islands Trading Co. 4. Pacific Foods 5. Philips Foods, Inc. 6. MDH Garam Masala Blend, Mahashian Di Hatti Ltd.		▪ 0.5% - lowest effective level for black pepper, chili pepper, coriander, cumin, fennel, ginger, nutmeg, and star anise ▪ 1% - lowest effective level for caraway, cardamom ▪ As determined by a sensory panel, rancid odor (from 3.3 to 1.5), and flavor (from 3.4 to 1.6) reduced significantly when spices used at lowest effective usage level ▪ Star anise had the lowest rancid flavor ▪ Clove had the lowest rancid odor ▪ All treatments had significantly higher spice flavors when compared to the control, with the exception of chili pepper and ginger
Almond Skin Powder Irradiated at 0 kGy, 10 kGy, 20 kGy, 30 kGy (Prasetyo and others 2008)	0.5% (% meat weight)	Carmel variety almonds, Almond Board of California	Raw Ground Beef	▪ Significant reduction in TBARS values – 30 kGy exhibited the largest reduction ▪ Increase in a* values from 3.28 to 4.1 ▪ Decrease in L* values from 31.86 to 30.7
Almond Skin Powder irradiated at 0 kGy, 10 kGy, 20 kGy, 30 kGy (Teets and others 2008)	0.5% (% of precooked meat weight)	Non-pareil variety almonds, Almond Board of California	Cooked Chicken Breasts	▪ Significant reduction in TBARS values – 10 kGy exhibited the largest reduction ▪ Decrease in L* values, no change in a* and b* values
Almond Skin Powder irradiated at 0 kGy, 10 kGy, 20 kGy, 30 kGy (Teest and Were 2008)	0.5% (% meat weight)	Non-pareil variety almonds, Almond Board of California	Raw Chicken	▪ Significant reduction in lipid oxidation from 1042.46 to ≤ 299.39 μg MDA/kg sample ▪ Decrease in L* values ▪ No change in a* and b* values
Green Tea Extract – irradiated and non-irradiated (Jo and others 2003a)	0.1% (% of precooked meat weight)	Green tea purchased at local supermarket, extract prepared in	Raw and Cooked Pork	▪ Significant reduction in TBARS values demonstrated for irradiated and non-irradiated extract from 0.69 to 0.39 ▪ Increase in L* values (from 54.16 to 56.03),

		laboratory		and a* values (from 3.08 to 3.68) ▪ Decrease in b* values from 11.59 to 12.56 ▪ A sensory panel found no color preference between the control and treated samples ▪ No taste or tenderness differences were observed by a sensory panel ▪ Prefer the odor of the sample treated with irradiated extract
Green Tea Extract (Bozkurt 2006)	300 ppm (precooked meat weight)	Green tea from tea garden in Rize, Turkey, extract prepared in laboratory	Sucuk	▪ Significant reduction in TBARS values ▪ Higher overall sensory quality score

[a] Thiobarbituric acid-reactive substances (TBARS) is a measure of lipid oxidation. The lower the measured TBARS value, the less oxidation has occurred. Values measured in mg MDA/kg sample unless otherwise noted. Values are from different storage times, and the most noted changes.

[b] Hexanal content is a measurement of lipid oxidation. The lower the measured hexanal value, the less lipid oxidation has occurred. Values measured in ppm unless otherwise noted. Values are from different storage times, and the most noted changes.

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