USE OF NATURAL ANTIOXIDANTS IN DAIRY AND MEAT PRODUCTS: A REVIEW OF SENSORY AND INSTRUMENTAL ANALYSES

by

ELYSE COTTONE

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Major Professor
Koushik Adhikari

Abstract

Oxidative deterioration is a significant contributing factor to the limited shelf life of foods containing lipids. The lipids in meats and dairy products make them susceptible to oxidation, limiting the amount of time that such products can be stored before a change in the sensory properties is evident. The use of rosemary oleoresin in meat products and fried foods has been extensively researched and used in commercialized foods. Since dry cheese and dairy products also contain lipids that are highly susceptible to oxidation, the use of a natural rosemary oleoresin may be beneficial in increasing the shelf life and sensory acceptability of these products as well. The overall objective of this report was to review the uses of a natural antioxidant, rosemary oleoresin, to inhibit oxidation and sensory changes in dairy and meat products and determine which areas need further study.

Keywords: oleoresin, rosemary, natural antioxidants, meats, dairy, sensory quality, chemical quality

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Dedication

In loving memory of my mother Teresa Parkinson, M.D.; her love and excitement for learning was contagious.

CHAPTER 1 - Significance

Today's consumers lead lifestyles that often require meals that are quick and convenient to prepare and do not require planning. This trend has sparked a multitude of prepackaged, easy-to-prepare side dishes, meal kits, and sauce mixes, many of which contain dairy products and dry cheese powders. These dairy ingredients and dry cheese powders are typically protected from oxidation through the use of synthetic antioxidants but a demand from consumers for natural ingredients has sparked the desire for natural antioxidant alternatives. Rosemary extracts have been extensively studied as natural antioxidants in meats and other foods that contain lipids and could potentially be used in dairy products.

Oxidative Deterioration in Foods

Oxidation is a process in which electrons are removed from an atom or group of atoms. During this reaction, a corresponding reduction reaction occurs involving the addition of these electrons to a different atom or group of atoms. Oxidation-reduction reactions are very common in biological systems and foods. Some oxidation reactions are beneficial in foods, while others lead to unfavorable effects such as the degradation of vitamins, pigments, and lipids. The degradation of lipids leads to the unwanted development of off flavors (Fennema 1999).

Meats and other food products containing fat with unsaturated fatty acids undergo deterioration during storage resulting in the auto-oxidation of these fatty acids (El-Alim and others 1999). Objectionable odors and flavors develop in oxidized products when subcomponents of the products recombine to form compounds such as hydrocarbons, aldehydes, and ketones, which are not found in the fresh product (Lee and Shibamoto 2002).

Lipids that contain polyunsaturated fatty acids and their esters are easily oxidized by molecular oxygen. The reaction with molecular oxygen via a self-catalytic mechanism is called auto-oxidation. Auto-oxidation proceeds by a free radical chain mechanism that is characterized by, but not limited to, the catalytic effects of light and free radicals producing substance and high yields of hydroperoxide but various free radical scavengers can contribute to chain termination in this process (Fennema 1999).

The initiation of auto-oxidation may begin by hydroperoxide decomposition, metal catalysis, exposure to light, or contact with singlet oxygen and tissue pigments such as chlorophyll and myoglobin which act as sensitizers (Fennema 1999). Oxidation is propagated by the removal of hydrogen atoms and the subsequent addition of oxygen at alpha positions to a fatty acid double bond, producing free radical species R and peroxy radicals (ROO·). The peroxy radicals then react with hydrogen from alpha-methylenic groups of other molecules, producing hydroperoxides (ROOH) and new free radicals (R·). The hydroperoxides produced are unstable compounds and they react in a number of reactions involving substrate degradation and interaction which results in many different compounds of varying flavor thresholds, molecular weights, and biological significance (Fennema 1999).

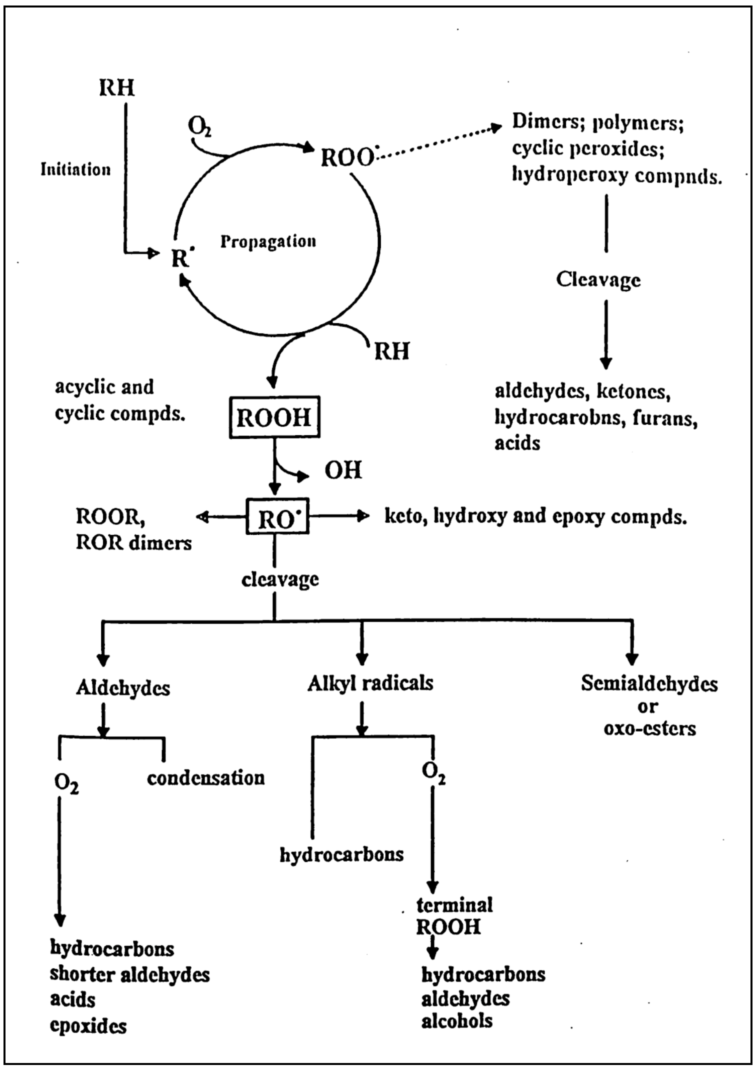

Figure 1.1 Lipid Oxidation Schematic (Fennema 1999)

Aldehydes are a significant result of fat oxidation. Saturated aldehydes can further oxidize to form the corresponding acids resulting in dimerization and condensation reactions.

Unsaturated aldehydes can go through oxidation resulting in short chain hydrocarbons, aldehydes, and dialdehydes. Malonaldehyde formation, a result of the oxidation of unsaturated aldehydes, is the basis for the Thiobarbituric Acid (TBA) method that is commonly used for measuring fat oxidation (Fennema 1999). Other components of foods also oxidize. The oxidation of cholesterol is of major concern because specific oxidation products have been found to create carcinogenic, angiotoxic, and cytotoxic effects. Cholesterol oxidation has been found in many processed foods including dried eggs, meat, dairy products, fried foods, and heated fats (Fennema 1999).

Lipolysis, the hydrolysis of ester bonds in lipids, has been shown by many studies to increase lipid oxidation. In deep fat frying, large amounts of water introduced into the oil and high temperatures cause a large amount of lipolysis and subsequently free fatty acids which are more susceptible to oxidation. Free-chain fatty acids are nearly nonexistent in the fat of living tissue but can form through the action of enzymes when the animal is slaughtered. Short chain fatty acids are released in raw milk by hydrolysis and can be responsible for an undesirable rancid flavor (Fennema 1999).

In food systems, lipid molecules are generally in a highly ordered state, have limited mobility, and are close to nonlipid material. In a membrane bilayer, phospholipids, proteins, cholesterol, tocopherols, trace metals, and enzymes neighbor one another and lipids have a very large surface area that is in contact with the aqueous phase. The mechanisms and results of oxidation in biological systems, including food, are very different than those in bulk-lipid models, and are affected by enzymes, mixed lipid systems, and the presence of nonlipid substances. Food lipids contain fatty acids which vary in chemical and physical properties, making the oxidation of lipids in foods a dynamic and multifaceted process that is greatly influenced by several factors including: fatty acid composition, free fatty acid to acylglycerol ratio, oxygen concentration, temperature, surface area, moisture, molecular orientation, physical state, emulsification, molecular mobility, prooxidants, radiant energy, and antioxidants (Fennema 1999).

Oxidative deterioration is a significant contributing factor to the limited shelf life of lipid-containing foods and is of great economic concern to the food industry. As lipid-containing foods are stored, oxidation causes the development of objectionable flavors and therefore, decreases the sensory acceptability of the products over time. These objectionable odors and flavors in oxidized food products are often described as unpleasant "stale" and "cardboard-like" flavors and rancid aromas. The sensory evaluation of foods is a crucial test for oxidized flavor in foods. The value of any chemical or physical test results is determined by how well it correlates with the sensory evaluation (Fennema 1999).

Before specific chemical technology was developed for the control of free radical mediated lipid oxidation, the term antioxidant was used as a blanket term for all substances that inhibited oxidation regardless of the mechanism. Ascorbic acid, which is commonly used to prevent enzymatic browning in cut fruit and vegetables, was considered an antioxidant. In its use to prevent browning in cut fruit and vegetables ascorbic acid actually acts as a reducing agent by transferring hydrogen atoms back to quinones that are formed by enzymatic oxidation of phenolic compounds but ascorbic acid acts as an oxygen scavenger in a closed system. The term "food antioxidants" have been more recently used to describe compounds that interrupt the free radical chain reaction involved in lipid oxidation and those that scavenge singlet oxygen (Fennema 1999).

Table 1.1 Commercial Use of Antioxidants to Increase Shelf Life of Lipid-Containing Foods

Antioxidant	Function	List of Food Products	References
Artificial			
Butylated Hydroxymethylphenol (BHT)	Free Radical Terminator	Chewing gum, potato flakes, sweet potato flakes, shortenings, enriched rice, dry breakfast cereals, meats, animal fats	Fennema 1996; Winters 1999.
Butylated hydroxyanisole (BHA)	Free Radical Terminator	Beverages, ice cream, ices, candy, baked goods, chewing gum, gelatin desserts, soup bases, potatoes, glaceed fruits, potato flakes, sweet potato flakes, dry breakfast cereals, dry yeast, dry mixes for desserts, lard, shortening, unsmoked dry sausage, shortening, fish cocoa, soup	Fennema 1996; Winters 1999.
Tertiary Butylhydroquinone (TBHQ)	Free Radical Terminator	Beverages, ice cream, ices, candy, baked goods, chewing gum, gelatin desserts, soup bases, potatoes, glaceed fruits, potato flakes, sweet potato flakes, dry breakfast cereals, dry yeast, dry mixes for desserts, lard, shortening,	Fennema 1996; Winters 1999.

		unsmoked dry sausage, shortening, fish cocoa, soup	
Propylgallate	Free Radical Terminator	Fats, oil, potato flakes, mashed potatoes, mayonnaise	Fennema 1996; Winters 1999.
Ascorbyl Palmitate	Reducing Agent	Meat, fruit	Fennema 1996; Winters 1999.
Thiodipropionic acid	Peracid Decomposer	Fats, oil, general food use	Fennema 1996; Winters 1999.
Natural			
Rosemary extract	Free Radical Terminator	Meat, fried foods, egg powder, mechanically deboned turkey meat	Houlihan and others 1984; Houlihan and others 1985; Nakatani and Intani 1984, Keokamnerd and others 2008; Mielnik and others 2003; Armitage and others 2002; Barbut and others1985; Barbut and others1988; Botsoglou and others 2007; Duxbury 1989; Han and Rhee 2004; Jaswir and others 1999; Murphy and others 1998; Sanchez-Escalante and others 2003; Tsen and others 2006; Coronado and others 2002; Sebranek and others 2005
Ascorbic Acid	Reducing Agent	Sliced peaches, frozen fish dip, dry milk, beer ale, flavoring oils, apple juice, soft drinks, fluid milk, candy, artificially sweetened jellies and preserves, canned mushrooms, meat, mechanically deboned turkey	Fennema 1996; Mielnik and others 2003
Sage Extract	Free Radical Terminator	Potato chips	Jaswir and others 1999;
Gum guaiac	Free Radical Terminator	Edible fats and oils, beverages, rendered animal fat	Fennema 1996; Namiki 1990
Coniferyl alcohol	Free Radical Terminator	General food use	Fennema 1996; Torres de Pinedoa and others 2007; Furukawa 1999.
Tocopherols	Free Radical Terminator	Rendered animal fats, oils, eggs; mechanically deboned turkey meat	Fennema 1996; Winters 1999; Chen and others 1998; Mielnik and others 2003; Namiki 1990

The shelf life of products can be potentially increased with the addition of antioxidants by reducing the rate of lipid oxidation and hydrolysis by sequestering and stabilizing free radicals (Armitage and others 2002). Antioxidants added to food products can delay lipid oxidation by causing a free radical reaction to occur with an added antioxidant compound rather than with the lipid portion of the foods. In order to combat such changes in lipid-containing foods, food manufacturers have routinely added synthetic antioxidants such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), tertiary butlyhydroquinone (TBHQ), and propyl gallate (Lee and Shibamoto 2002; Sato and Hegarty 1971; Igene and others 1979; Chastain and others 1982). Although they are effective in inhibiting oxidation, synthetic antioxidants have been linked to health concerns and have been banned in several countries. Most notably, several studies show that these synthetic antioxidants act as possible carcinogens (Hettiarachchy and others 1996; Schilderman and others 1995).

In this review our focus is natural antioxidants, their mechanistic efficacy in food products (fried foods, meats, and dairy products) in retarding auto-oxidation, their comparison with artificial antioxidants, and sensory properties of such foods.

Natural Antioxidants

The potential health hazards of synthetic antioxidants have prompted researchers to search for natural antioxidants occurring in plants (Lee and Shibamoto 2002). Additionally, recent trends in the marketplace have focused on natural and organic products that do not utilize synthetic additives which have further spurred this research. Food manufacturers have also been motivated to research the use of natural antioxidants because studies have shown that such compounds are not only beneficial to the shelf life of food products but also in preventive medicine (Anon 2000). Research has shown that natural antioxidants could play a vital role in fighting diseases caused by oxidative damage and even decrease the formation and mutagenicity of heterocyclic amines (HCAs) in cooked meat (Halliwell and Gutteridge 1992; Tsen and others 2006).

Natural antioxidants are generally classified as phenolic compounds such as flavonoids and phenolic acids, vitamins, and volatile compounds found in herbs and spices. Namiki (1990) discussed several common natural antioxidants that are used commercially in food: tocopherols, ascorbic acid, soybean products, oat products, components of crude vegetable oils, amino acids, peptides and proteins, guaiac gum, flavonoids, spices, and herbs. Since many plant-derived substances often have a strong, distinctive taste of their own, plant derived antioxidants must not only be tested for their ability to retard oxidation but also for any sensory characteristics they impart to the food product.

Several types of natural plant derived antioxidants have been studied, including extracts of grape seed, sage, thyme, rice bran, white peony, red peony, sappanwood, Moutan peony, rehmania or angelica, sedge, marjoram, wild marjoram, caraway, basil extract, ginger, plum concentrates, aloe vera, mustard, tea catechins, and rosemary extract (El-Alim and others 1999; Fiorentino and others 2008; Han and Rhee 2004, Namaki 1990; Nunez and others 2008). Much of the research devoted to natural plant derived antioxidants focuses on rosemary extract (Armitage and others 2002; Barbut and others1985; Barbut and others 1988; Botsoglou and others 2007; Duxbury 1989; Han and Rhee 2004; Jaswir and others 1999; Murphy and others 1998; Sanchez-Escalante and others 2003; Tsen and others 2006). Many spices such as rosemary and sage have strong anti-oxidant activity (Peterson and Johnson 1978; Chen and others 1992).

The active components of natural plant-derived antioxidants are polyphenolic compounds. The most effective antioxidants are those that contain two or more phenolic hydroxyl groups (Dziedzic and Hudson 1984; Shahidi and others 1992). Plant phenolics compounds can either act as reducing agents, free radical terminators, metal chelators, or singlet oxygen quenchers. Rosemary has been found to have the highest antioxidant activity of the spices tested and is one of a few spices used in the food industry mainly for its antioxidant property, while other spices are used primarily for their flavoring properties (Chipault and others 1956; Löliger 1983).

CHAPTER 2 - Use of Rosemary Extract in Foods

Rosemary oleoresin, a mixture of oil and resin that is extracted from the plant, is commonly used in meat and poultry products as an antioxidant and antimicrobial additive. Superheated water extraction produces higher yields of oxygenated rosemary flavor and fragrance compounds than steam distillation and a benefit of using rosemary extract as an antioxidant is that it readily forms aqueous solutions, common to many food products, whereas another common natural antioxidant, vitamin E, is only soluble in a hydrophobic environment (Armitage and others 2002; Basile 1998).

The compounds in the rosemary extract that act as antioxidants depend on the method of extraction. The volatile extract's major components are 1, 8-cineole and borneol, while a solvent extract's components are carnosol and carnosic acid. Carnosol and carnosic acid are found in commercially produced rosemary oleoresin and act as much more potent antioxidants than the volatile extract (Lee and Shibamoto 2002). Rosemary oleoresin has been reported to contain several components such as rosmanol, rosmariquinone, rosmaridiphenol, and carnosol, that may be up to four times as effective as BHA and equal to BHT as an antioxidant (Houlihan and others 1984; Houlihan and others 1985; Nakatani and Intani 1984).

Rosemary is a potent antioxidant due to its phenolic diterpene structure, which acts as a hydrogen donator to interfere with the free radical chain reaction (Hall and others 1998; Houlihan and others 1984; Schwarz and Ternes 1992). The phenolic diterpene structure donates a hydrogen, circumventing oxidation, without creating another reactive free radical species (Dugan 1980). Other plant phenolic compounds can also act as metal chelators and singlet oxygen quenchers (Keokamnerd and others 2008; Shahidi and others 1992; Cuppett and others 1997).

Extensive research has been performed on the uses of rosemary oleoresin in meat products and lipids, yet very few studies have focused on the use of oleoresins in dairy products. Dairy products, such as dry cheese blends, contain polyunsaturated fat and their esters and are therefore, very susceptible to oxidation over time. Such oxidation could be inhibited through the use of rosemary oleoresin, possibly extending the shelf life of such products (Al Zahal and others 2009; Van Nieuwenhove and others 2009). This literature review covers the research that has focused on meat products as well as other food lipid products in an effort to understand how to apply the use of rosemary oleoresin as an antioxidant to a dairy product.

Use of Rosemary Extract in Fried Foods

Deep fat frying is a popular method of food preparation. Fat or oil is highly susceptible to oxidation due to the lipid's exposure to air, light, and high temperatures (Jaswir and Man 1999). Such factors initiate a complex series of chemical and physical changes in the fat, lipolysis being the major reaction in fried foods. Lipolysis lead to high levels of free fatty acids in the foods therefore leading to increased lipid oxidation (Fennema 1999). BHA and BHT, antioxidants commonly added to many processed foods, are volatile compounds that are easily decomposed at high temperatures and, therefore, are not suitable for fried foods and potato chips (Chang and others 1977). In a study by Jaswir and Man (1999), a rosemary oleoresin, sage extract and citric acid were added individually to a refined, bleached, and deodorized palm olein that was used in the repeated deep-fat frying of potato chips. The purpose of the study was to determine whether the rosemary oleoresin and the other antioxidants inhibited the oxidation of the frying oil. A total of ten batches of potato chips were fried every day in palm olein containing rosemary oleoresin for ten consecutive days. A sensory panel analyzed the ninth and tenth batches of potato chips fried each day in order to determine the acceptability of the samples in terms of appearance, taste, odor, crispiness, and overall acceptability. A physiochemical analysis of the palm oil was also performed to determine the peroxide value, free fatty acid levels, iodine value, polymer content, color, and viscosity.

Jaswir and Man (1999) used response surface methodology to determine the acceptability of the potato chips fried in oils over several days containing different levels of each antioxidant. Response surface methodology is a statistical technique that uses quantitative data to determine and solve multivariate equations. This methodology is commonly used in product optimization in the field of sensory evaluation and it allowed the researchers to determine the optimal level of oleoresin extract to be added to the palm olein (Wada and Fang 1995).

The authors found a significant effect in the sensory acceptability of the product from the addition of the rosemary oleoresin to the potato chips. The effects of the addition of the rosemary oleoresin as an antioxidant were significant ($P < 0.05$) for taste, odor, crispiness, and overall acceptability. The authors also found that the rosemary oleoresin worked synergistically with sage oleoresin and citric acid on the second-order interactions (Jaswir and Man 1999). The results of the physiochemical analysis correlated with the results of the sensory analysis, showing that the frying oil deteriorated rapidly under the conditions of a high temperature, high moisture, and oxygen exposure. The authors saw changes in the peroxide value and the free fatty acid levels and concluded that this could have contributed to the decrease in some of the sensory parameters. The conclusion of this study showed that the use of a rosemary oleoresin at a range of 0.057-0.062% prevented oxidation in the palm olein (Jaswir and Man 1999).

In an alternate study (Lee and others 2006), rosemary extracts at concentrations of 100, 200, and 300 ppm were used to increase the oxidative stability of olive oil with synthesized structured lipids (SL). The major focus of the study was antioxidant evaluation and oxidative stability, with only physical analysis being performed on the samples. Olive oil refined to contain SL has a lower total antioxidant activity (TAA) and has less oxidative stability than extra virgin olive oil (EVOO) which naturally contains antioxidants such as tocopherols and phenolic compounds. Rosemary extract was added as a natural antioxidant to the SL olive oil and was evaluated by following the peroxide value (POV), p-anisidine value (AV), and 2-thiobarbituric acid reactive substances (TBARS) value during 20 days of storage at 60 °C. The rosemary extract added to improve oxidative stability contained approximately 24.6% (w/w) carnosic acid and 3.9% carnosol.

The results of the study showed that hydroperoxide and aldehyde formation was effectively inhibited by rosemary extracts in SL olive oil as well as in EVOO, showing significantly lower POV's and AV's than the oil without rosemary extracts. This study is an example of how rosemary extracts can be used as a natural antioxidant to stabilize lipids other than those found in meats. The levels used in this study could be a basis for understanding the usage levels to employ in testing rosemary oleoresin in dairy products (Lee and others 2006).

Use of Rosemary Extract in Meats

Rosemary extract has been extensively studied in poultry and meat applications as a natural antioxidant. Meat is very susceptible to oxidation due to factors intrinsic to the type of meat, to processing, and storage conditions. In a study by Rojas and Brewer (2007), the effects of several natural antioxidants, including rosemary oleoresin, were studied in cooked, refrigerated beef and pork. Cooked meats are highly susceptible to oxidative rancidity leading to quality degradation and warmed-over flavor (WOF). Before cooking, free-radical reactions cause auto-oxidation in meats, changing the meat's flavor, color, and aroma. During cooking, the lipids in meat can generate volatiles that oxidize, producing off-odors and flavors. The volatiles, such as aldehydes, alcohols, furans, and hydrocarbons, also form during oxidation at lower temperatures but cooking increases the concentrations of these compounds. After cooking, the emergence of WOF can be attributed to lipid oxidation and can be characterized by odors described as "stale," "wet," "cardboard," "painty," "grassy," or "rancid" (Rojas and Brewer 2007).

In an effort to minimize the quality degradation due to oxidation in beef and pork patties, Rojas and Brewer (2007) studied how the addition of natural antioxidants could inhibit such changes. Antioxidants that are intrinsic to meats, such as tocopherols and carnosine, and enzymes control oxidation in live animals but the effects of processing reduce their activity requiring the use of additional antioxidants in meat products. Synthetic antioxidants such as BHT, BHA, and TBHQ are very effective at inhibiting WOF but consumer concern regarding the safety of these synthetic additives has caused researchers to investigate alternative forms of natural antioxidants.

Extensive research in the past has found that rosemary and rosemary extracts at concentrations ranging from 0.02% to 1% are effective at retarding lipid oxidation and the development of WOF in meat products. The objective of the research by Rojas and Brewer (2007) was to compare the effectiveness of several natural antioxidants including rosemary oleoresin, grape seed extract, and oregano oleoresin. The researchers used a randomized complete block design with five antioxidant treatments, five storage times, and two meat types. The beef and pork patties were cooked and then stored for 0, 2, 4, 6, and 8 days and then were analyzed for thiobarbituric acid-reactive substances (TBARS), color, and pH. The samples were also subjected to sensory analysis for the aroma and color, in duplicate, by a panel of 10 trained panelists.

Rojas and Brewer (2007) concluded that grape seed extract functioned as the most effective antioxidant of the three antioxidants tested for both beef and pork. Grape seed extract did not affect instrumental color measurements and effectively inhibited oxidation measured by TBARS and sensory evaluation. The use of rosemary extract in this experiment did not inhibit lipid oxidation, although it has been seen to effectively retard lipid oxidation in pork in other studies. The authors concluded that a reason for this difference could be the quality of the rosemary extracts used in different experiments as well as the presence of salt in the meat in this study.

The concentration of rosemary extract in their study (Rojas and Brewer 2007) may have not been sufficient to inhibit the higher levels of oxidation induced by the salt. In other studies, research has found that salt can act as either a pro-oxidant or an antioxidant depending on its concentration and the level of moisture in the system (Chang and Watts 1950; Maybrouk and Dugan 1960). The interaction of salt in inducing oxidation must be considered while using rosemary extract in cheeses that have a high salt concentration.

In a study by Murphy and others (1998), the antioxidant properties of rosemary oleoresin in precooked roast beef slices were compared to a BHA/BHT combination, sodium tripolyphosphate and sodium citrate, during both refrigerated and frozen storage. In comparison to artificial antioxidants, rosemary oleoresin in combination with sodium tripolyphosphate was proven to be effective during storage, as determined by TBARS concentration and sensory scores (Murphy and others 1998).

The sensory analysis of the samples in the study entailed preference testing of trimmed beef slices. In this preference testing, the panelists were asked to rank the samples in the order of preference with regards to flavor as well as to determine the odd sample. There were an average of nine judges per session and although the study discussed the undesirable product of oxidation in meats being warmed over flavor (WOF), the panelists were not trained to detect WOF prior to the start of this study. The results of the sensory analysis showed that rosemary oleoresin in combination with sodium tripolyphosphate proved to be effective in refrigerated and frozen storage, although no overall significant correlation was found between the TBARS and the sensory scores (Murphy and others 1998).

Rosemary extract was also tested as a natural antioxidant in pre-cooked and raw frozen pork sausage and its effectiveness was compared to BHT and BHA in a study by Sebranek and others (2005). In the study, a commercial rosemary extract's effectiveness as an antioxidant was evaluated at concentrations of 1500 and 2500 ppm in frozen and precooked-frozen pork sausage, and from 500 to 3000 ppm in refrigerated, fresh pork sausage. Objective color values, TBARS, and sensory panel scores were evaluated.

The results of the study showed that the rosemary extract at 2500 ppm was equally effective as BHA/BHT in refrigerated pork sausage. In precooked-frozen sausage, the rosemary extract was as effective as BHA/BHT in maintaining low TBARS values. In raw frozen sausage the rosemary extract was more effective than BHA/BHT for preventing increased TBARS values or loss of red color (Sabranek and others 2005).

The addition of rosemary extract to pork wieners was also studied to determine if it was an effective natural antioxidant in a study by Coronado and others (2002). In the study, pigs were fed dietary vitamin E (10 or 200 mg/kg feed) and dietary fishmeal (0 or 5%). Wiener sausages were manufactured from the slaughtered pigs with or without antioxidants rosemary extract and sweet whey powder. The wieners were stored for 5 d at 4 °C and the oxidative stability of the wieners was examined over 10 mo of frozen storage. The TBARS values and fluorescence shift were measured to determine the lipid oxidation in the wieners. Sensory evaluation of the product was also carried out to detect oxidative changes. An untrained panel that consisted of ten panelists evaluated the wieners. Rancid odor was rated through the use of a 9-point scale questionnaire (1-no rancid odor to 9-extremely strong rancid odor). Panelists were asked to assess the sausages (heated to 60 °C) for rancid odor. A fresh sample and a rancid sample were presented as positive and negative controls.

The researchers (Coronado and others 2002) found that the fluorescence shift method was not appropriate for determining lipid oxidation in this study because the rosemary extract other contained compounds that fluoresced and interfered with the method. The results of the study showed that no lipid oxidation was evident in the wieners stored at -20° C for 10 months according to the TBARS values. The results of the study also showed that the oxidative stability of wieners was unaffected ($P > 0.05$) by the addition of antioxidants or by dietary treatments. The researchers concluded the study by determining that the high oxidative stability of the wieners, even in the absence of antioxidants, was possibly due to sodium erythorbate present in the formulation as an additional antioxidant (Coronado and others 2002).

The sensory analysis in the study by Coronado and others (2002) was not a major focus of the research. In reviewing other research on natural antioxidants in meat products and sensory analysis, a study by Nunez de Gonzalez and others (2008), is a better model to follow in designing a study for research on rosemary extract as an antioxidant in a dairy product. In the study by Nunez de Gonzalez and others (2008), sensory analysis, as well as chemical and physical analysis, was conducted on cooked beef roasts with brine-injected plum juice concentrates. Varying levels of fresh and dried plum ingredients were tested and samples were subjected to refrigerated storage over a 10-week period (Nunez de Gonzalez and others 2008).

For the sensory analysis, a seven member expert panel from Texas A&M University Sensory Testing Facility was used to evaluate roast samples for flavor, aromatics, feeling factors, basic tastes, and texture attributes. All the panelists had more than 5 years of experience in Spectrum descriptive flavor analysis and underwent ballot development and training sessions using beef roast control samples and beef roasts containing antioxidants. The panelists participated in six training sessions and underwent performance testing as specified in guidelines developed by AMSA (1995). The beef roasts were evaluated by the panelists for aromatics (cooked beef/brothy, cooked beef fat, chemical taste, serum/bloody, and plum/prune); feeling factors (astringent, metallic, and chemical burn); basic tastes (salt, sour, bitter, and sweet); and texture attributes (springiness, juiciness, hardness cohesiveness, and denseness). The roast beef samples were also scored using the 0–15 Spectrum TM Universal intensity scale (Nunez de Gonzalez and others 2008).

Samples of the roasts were evaluated at 2-week intervals, with seven samples evaluated per day. In addition to evaluating the samples for flavor and texture, the panelists also evaluated the roast samples for color intensity, greyness, off-color, and iridescence. A Minolta Colorimeter was also used to evaluate the lightness, redness, and yellowness of the samples. The roast beef samples were also subjected to TBARS analysis. Allo-Kramer shear force measurements and the moisture fat and protein content of the samples were determined as well.

The results of the study showed that all the added plum ingredients reduced TBARS values and had minimal effects on the sensory characteristics of tenderness, color, and appearance. The researchers also found small changes in color values, purge, TBARS, and some sensory properties during storage of the roast beef. They concluded that 2.5% fresh plum juice concentrate or dried plum juice concentrate could be incorporated into precooked beef roasts to reduce lipid oxidation and to potentially reduce WOF (Nunez de Gonzalez and others 2008).

Natural antioxidants, including rosemary extract, have been extensively studied in poultry applications to limit the oxidation of lipids. In a study by Armitage and others (2002), egg albumin coatings containing the natural antioxidants fenugreek, rosemary and vitamin E were evaluated on cooked and uncooked poultry breast meat. Whole, deboned, skinless chicken breasts were blast-frozen, cubed, and coated with a mixture of egg albumin and either alkaline water (control), rosemary solution (1000 ppm), fenugreek solution (2000 ppm), or vitamin E solution (1000 ppm) (Armitage and others 2002). TBA analysis was performed on the refrigerated samples on days 0, 3, and 7 of the study to examine the inhibitory effects of the natural antioxidants and coating on lipid oxidation. The frozen and freeze-dried samples were evaluated for their malondialdehyde content after 6, 30, 60, and 90 days.

Although the refrigerated, cooked samples that contained rosemary extract did not show improvement in retarding oxidation over the control sample, the frozen cooked samples showed lower thiobarbituric acid content after storage and the coated freeze dried samples showed lower malondialdehyde content after storage. The study concluded that rosemary extract, among other natural antioxidants, modified patterns of oxidation from the control preparations under similar trial conditions. This study presents the possibility of developing coated, frozen products designed for long periods of storage (Armitage and others 2002). This study's use of rosemary extract as an antioxidant in a coating solution is an example of a different application of natural antioxidants that could be applied toward studies using rosemary oleoresins in dairy products.

In another study on rosemary extract as an antioxidant in poultry, Mielnik and others (2003) studied the effects of commercial rosemary extract on the oxidative stability of mechanically deboned turkey meat (MDTM) compared with vitamin E, ascorbic acid, and a control without any antioxidants. The study focused on the changes that occur in meats during frozen storage, the MDTM meat being highlighted because of the high susceptibility to oxidation during processing and the compositional nature of the meat. The three types of antioxidants were added to the meat at three levels. TBA and dynamic headspace gas chromatography were used to assess the effects of commercial antioxidants on lipid stability of MDTM during 7 months of frozen storage. The results of the study showed increased levels of volatile carbonyl compounds and TBA-reactive substances in all turkey meat samples during storage. The highest levels were found in the meat without added antioxidants (Mielnik and others 2003).

Trolox C, a water soluble, synthetic derivative of vitamin E, showed the greatest antioxidative activity in the study as seen by the lowest values of TBARS and volatile compounds. Ascorbic acid was more potent than most rosemary extracts in suppressing lipid oxidation especially in the long term frozen storage MDTM. The results of this study could be used to aid in designing a study on incorporating rosemary extract in dairy products that are frozen but not vacuum packaged, such as ice cream and frozen dairy based sauces. (Mielnik and others 2003).

Rather than adding rosemary extracts directly to a meat product or in a coating solution, another method of utilizing rosemary as an antioxidant additive in food is through incorporating dehydrated rosemary leaves into the feed of animals. In a study by Botsoglou and others (2007), the malondialdehyde and α-tocopherol concentration was analyzed in turkey meat from animals that were fed a diet that included 0%, 0.5%, or 1.0% dehydrated rosemary leaves and α-tocopheryl acetate from 10 to 300 mg/kg. The results of the study's incorporation of rosemary in the diet of the turkeys led to a modest decrease in the formation of MDA in the meats compared with the respective mean control values. The findings of this study could be used to investigate whether rosemary incorporated in the diet of dairy cattle would have an inhibitory effect on oxidative rancidity, while the findings of the other studies assessing the use of rosemary as a natural antioxidant in meat could help in determining how to conduct sensory testing, the percentage of rosemary extract to add to a dairy product, and storage times and conditions for a study involving rosemary extract in a dairy product.

Use of Rosemary Extract in Dairy Products

Milk solids are components of many processed foods, including but not limited to ice cream, dressings, soups, sausage, baked goods, coffee creamers, beverages, batters, candy and condiments. Although there has not been any research done on the addition of rosemary extract to dairy products, the addition of this natural antioxidant could prove useful in preventing lipid oxidation and the development of off flavors and aromas.

Oxidation in Dairy Products

The development of off flavors in dairy products has been a topic of much research, from food science perspective, over the years. Early studies on off flavors in dairy products showed that air, light, contamination by metals, pH, salt content, and storage temperature were all factors related to the development of these flavors. One of the most common problems confronting the dairy industry for years was the occurrence of oxidized flavor (Corbett 1940).

Light and oxygen are very important factors leading to oxidative changes: oxidation takes place in the absence of light but at a much slower rate. Either free or the combined form of oxygen can participate in this reaction. Oxidative changes are also favored by both strong acid and alkaline reactions. Both salt and moisture also appear to play a role in the development of oxidative changes but to a lesser extent than the influences due to metallic contamination. Low temperature storage favors a slow rate of oxidative change but temperature is only important as a regulator of the rate of oxidative change; as the temperature increases the rate of oxidative change increases too (Krukovsky 1951).

Off flavors in stored butters, identified as “tallowy,” “oily,” and “fishy” flavors, are considered to be caused by oxidation (Carson Brown and Thurston, 1940). It has long been established by research that metals have a role in oxidation of dairy products (Thurston 1940; Hunziker and others 1929b). Early research on this topic by Hunziker and others (1929a) established that certain metals, such as copper and iron, dissolve in the milk brought into contact with their surfaces and cause undesirable flavors. Research by Rice (1926) and Thurston and others (1940) showed that copper contamination, resulting from contact of the milk with copper in vacuum pans or bottle caps, may cause tallowiness in sweetened condensed milk. Tallowy or oxidized flavor in ice cream has also been greatly researched and has been found to be the result of oxidation of either the phospholipid fraction or the butterfat or both (Dahle and Carson 1933; Carson Brown and Thurston 1940).

Other studies have shown that ascorbic acid plays an important part in reactions that produce the oxidized flavors and that oxidized flavors in fresh milk are not associated with the deterioration of fat but with unstable lipids in the fat-globule membrane (Chilson and others 1949; Krukovsky and Gutheie, 1945; Krukovsky, 1948; Krukovsky, 1949; Swanson, and Sommer, 1940; Thurston, 1935). As seen in studies on the stability of fat in cream and butter, after a while the fat itself may undergo deterioration in the presence of ascorbic acid, resulting in the development of oxidized flavors and losses in the fat-soluble vitamins.

A study by Krukovsky (1951) showed that the oxidized flavors in fresh milk, such as chalky and chalky-to-soapy-tallowy, are associated with the deterioration of milk plasma and that metallic and metallic-to-fishy flavors are associated with the deterioration of the fat-globule membrane and oxidation-sensitive fat, respectively. The data from the study indicated that the antioxidant activity of fat as determined by tocopherol content and extension of this activity to the body of milk by redistribution of fat plays an important part in the prevention of retardation oxidation.

In another study, Tamsma and others (1962) researched the storage stability of vacuum foam-dried whole milk powder containing antioxidants through sensory analysis. The whole milk powder was prepared from standardized milk, which had been pasteurized by holding at 62.8 °C for 30 min. The milk was then concentrated to 50% solids, homogenized, injected with nitrogen, and then dried in the form of a foam under a high vacuum. The powder was then produced by breaking the dried foam through a 20-mesh screen.

Antioxidants were added to the dry milk powder at a concentration of 0.01% in the dry product. The exceptions were ascorbic acid (added at 0.3%) and ascorbyl palmitate added at 0.5%. The antioxidants were dissolved in alcohol, propylene glycol, or water as a solvent and then stirred into the concentrate just before homogenization. A panel of 10 trained judges determined the type and intensity of the flavors in the reconstituted samples. The judges converted their sensory perception into flavor scores by use of a standard score-card and the significance of the scores was evaluated by use of statistical methods based on the analysis of variance (Tamsma 1962).

The study found that the relative effectiveness of antioxidants in reducing flavor deterioration in stored samples decreased in the following order: lauryl gallate, propyl gallate, nordihydroguaiaretic acid, ascorbyl palmitate, butylated hydroxy anisole, ascorbic acid, dihydroquercetin, sodium diethyldithioearbamate, thiodipropionic acid, quercetin, and dilaurylthiodipropionate. But statistical analysis of the data showed that only dihydroquercetin, ascorbic acid, ascorbyl palmitate, and sodium diethyldithio carbamate produced significant improvement ($P < 0.05$) of the flavor scores (Tamsma 1962). Lauryl gallate was found to be the most effective antioxidant tested but it produced an astringent flavor in the milk. The use of a deodorized rosemary extract could prove useful in a similar application and may be an alternative to antioxidants that impart flavor to the milk (Tamsma 1962; Chang and others 1977).

A study by Corbett (1940) researched the effectiveness of several antioxidants in milk, butter, and ice cream. Some of the antioxidants tested were found to be very effective when added to dairy products; tyrosine and the more soluble esters of tyrosine were found to be very effective antioxidants when used in milk in concentrations of .02% to .04%. The n-amyl ester of leucine was also found to be an effective antioxidant in dairy products but was not suitable for the application because it imparted an objectionable off-flavor to the milk. The di-ethyl ester of glutamic acid did not work effectively as an antioxidant and it also added an objectionable off-flavor to the milk (Corbett and others 1940).

The study showed conflicting results for the addition of ascorbic acid in milk. In metal-free milk, the addition of ascorbic acid retarded the development of oxidized flavors but did not prevent the development of the off-flavor. In copper-contaminated milk the ascorbic acid first retarded the development of the oxidized flavor but then accelerated the oxidized flavor once a threshold was reached. The addition of concentrated water extracts of the cereal grains was also found to delay the development of an oxidized flavor in milk. The final antioxidant, pancreatic extract effectively prevented the development of an oxidized flavor. The most effective application of an antioxidant was found to be drying a mixture of a water extract of cereal flour and concentrated skim milk on a roller drier (Corbett and others 1940). The results of this study could prove useful in designing a study involving rosemary as a natural antioxidant in a dairy product.

The stabilization of the preliminary flavor of whole milk powders produced by the spray and vacuum drying processes has been the objective of many studies. Although many antioxidants work well in a single component foods, such as cooking oil, they perform poorly in heterogeneous systems such as whole milk powder (Cornell 1979). The antioxidant should reside either in the fat or at the fat globule surface for adequate protection of the milk powder.

Although many antioxidants favor the oil phase, binding to the proteins of milk also occurs; this would cause some degree of retention of the antioxidant in the aqueous phase. The antioxidant distribution in whole milk would need to be determined to allow prediction of the division of added antioxidant between the oil and water phases and the amount bound to the proteins of milk (Cornell 1979). These findings show that in using rosemary extract as an antioxidant in a dairy product, the effectiveness of rosemary extract to disperse in the dairy product and inhibit oxidation would need to be considered.

Off-flavors in light exposed milk, a subject of many studies, have often been described as having cabbage, burnt protein, or "activated" characteristics. The cause of the off flavors in milk exposed to light are sulfur-containing volatiles such as dimethyl sulfide, methional, methanethiol, and dimethyl disulfide. These compounds are likely caused by the breakdown of sulfur-containing amino acids of whey proteins. Other off flavors, often described as metallic and tallowy, are due to carbonyl compounds such as 2-alkenals, 2-alkanones, acetaldehyde, and alkanals formed by the light-induced lipid oxidation in milk.

A study by Ueno and others (2007) identified the potent off-odorants formed during exposure of milk to light. They verified the analytical results through flavor reconstitution using reference substances, and tested the effects of added antioxidants on the formation of off-odorants during light exposure of milk. Although some recent studies have focused on using C-sniffing techniques to detect potent odorants formed in milk exposed to light and identified major contributors of light induced off-flavor, they have not clarified whether the mixture of these odorants actually represents the flavor character of the light-exposed milk (Cadwallader and Howard 1998). A small number of studies have reported the effects of added antioxidants on the formation of off-flavors in milk during light exposure. Jung and others (1998) found that the addition of L-ascorbic acid reduced the formation of dimethyl disulfide and subsequently improved the sensory quality of light-exposed skim milk. The study by Ueno and others (2007) used gas chromatography-olfactometry and gas chromatography-mass spectrometry to detect the odorants and verified the presence of the odorants through sensory analysis, a step previously not undertaken in studies identifying these odorants in light-exposed milk.

In the study by Ueno and others (2007), ultra- high temperature milk was stored under florescent light for 16 hours at 10 °C and compared to milk stored in the dark for the same time/ temperature combination. The results of the study showed that the flavor dilution (FD) chromatograms of nine odorants increased with light exposure, indicating that the off-flavor formation in the light-exposed milk can be attributed to the increase in these nine odorants. The flavor differences between the light-exposed and non- exposed milk were monitored by aroma extract dilution analysis by using aroma extracts prepared from the milk. A panel composed of by 14 trained assessors evaluated the milk samples and rated the intensities of the five odor attributes ("freshness," "fatty," "metallic," "dusty," and “overall off-odor”) using a linear scale ranging from 1 (= absent) to 7 (= very strong).

A second panel of 20 untrained panelists also ranked a series of six samples in the increasing order of off-flavor intensities. The statistical significance of the rankings was evaluated by Friedman's test. The sensory panels found differences between the light-exposed milk and non-exposed milk, indicating that the "freshness" of the milk almost totally deteriorated and "fatty," "metallic," and "dusty" off-odors developed with light exposure. The results of the study showed that off-flavor formation in milk upon light exposure can be attributed to the formation of nine potent odorants: hexanal, (Z)-4-heptenal, 1-octen-3-one, methional, (E)- and (Z)-2-nonenal, (E,Z)-2,6-nonadienal, (E,E)-2,4-nonadienal, and (E,E)-2,4-decadienal (Ueno and others 2007). The results of study by van Aardt and others (2005) were similar to the results found by Ueno and others (2007): weekly additions of BHT and BHA to extended shelf life milk prevented the development of increased concentrations of hexanal, pentanal, and 1-octen-3-ol, compounds used to monitor the oxidation of ESL milk (van Aardt and others 2005).

The contribution of these odorants to the light-induced off-flavor was further confirmed by flavor reconstitution experiments using the reference compounds. The results of the study also showed that the antioxidants (-)-epicatechin and chlorogenic acid were the most effective inhibitors of the formation of the identified off-odorants during light exposure of milk and subsequently most effective for reducing off-flavor intensities of light-exposed milk (Ueno and others 2007).

The antioxidants tested in the study by Ueno and others (2007) are well-known radical scavengers that inhibit lipid oxidation proceeding via a free-radical chain mechanism. The inhibitory effects of the antioxidants on the off odor formation is explained by the fact that several of the identified odorants were lipid-derived, such as (E,E)-2,4-nonadienal, (E)-2-nonenal, and (E,E)-2,4-decadienal (Ueno and others 2007).

Milk lipids contribute unique characteristics to the appearance, texture, and flavor of dairy products. These same components also make dairy products susceptible to oxidative rancidity (Fennema 1996). Lipid auto-oxidation in milk is affected by a complex interaction between pro- and antioxidants. Vitamin E, carotenoids, and vitamin C naturally occur in milk and their concentrations are affected by the cow's diet and milk storage conditions. In milk, antioxidants function by a number of different mechanisms: several non-enzymatic antioxidants act as free radical scavengers in the lipid and/or water phase. The specific function of each antioxidant naturally present in milk can not be easily defined because of the large number present and the possibility of many different types of reactions (Lindmark-Mansson 2000). A study by Butler and others (2008) found that milk fatty acid and naturally occurring antioxidant composition are also greatly affected by the cow's diet composition and the length of grazing period.

The occurrence of spontaneous oxidized flavor (SOF) is also tied to the ratio of antioxidants and fatty acid unsaturation. A study by Granelli and others (1996) analyzed the milk samples from five commercial dairy herds that had severe problems with spontaneous oxidized flavors in their milk, influenced by feeding. The milk was analyzed for the fatty acid compositions of both neutral lipids and phospholipids and the concentrations of α-tocopherol, β-carotene and copper in the milk. The samples were also analyzed by dynamic headspace gas chromatography to determine the volatile oxidation products (Granelli and others 1996). The results of the study found that the ratio between antioxidants and fatty acid unsaturation was lower in milk with spontaneous oxidized flavor and that the milk from herds with an oxidized flavor had a higher proportion of trans oleic acid. One of the herds with spontaneous oxidized flavor was found to have an extremely high proportion of linoleic acid, in the phospholipids. The study also found a higher copper content in milk with SOF, differences in importance of α-tocopherol and β-carotene between herds, and that the unsaturation in fatty acids of both neutral lipids and phospholipids have different importances for the flavor stability in different herds.

Based on the studies by Lindmark-Mansson (2000), Butler and others 2007, and Granelli and others 1996, the composition and concentration of naturally occurring antioxidants and fatty acids present in different batches of milk needs to be considered in determining the quantity of a supplemental natural antioxidant addition. A more thorough understanding of the mechanisms of lipid auto-oxidation in milk may lead to a better understanding of how added natural antioxidants, such as rosemary oleoresin, can help inhibit such oxidation and sensory changes in milk and dairy products.

Cheese Shelf Life and Sensory Analysis

Although there is no research currently available on the use of rosemary oleoresins in cheese or dairy products, there is a large amount of research done on the shelf life and subsequent sensory analysis of cheese. A study by Kilcawley and others (2007) showed that the extent of lipolysis in Cheddar cheeses has a major impact on its sensory characteristics; cheeses aged longer were associated with rancidity. The study concluded that longer ripened cheeses were associated with more negative attributes. The negative sensory attributes appeared to be due to excessive lipolysis and/or β-casein breakdown. Both proteolysis and lipolysis appear to be age dependent. Since excessive lipolysis in Cheddar cheese is widely associated with downgrading due to oxidative rancidity, this study shows a potential use of rosemary oleoresin as an antioxidant to inhibit oxidation in aged cheese (Deeth 2006). The use of rosemary extract as a natural antioxidant could be used to increase the shelf life of Cheddar cheese or cheese powder by inhibiting oxidation.

In another study on the shelf life and subsequent sensory analysis of cheese, Kristoffersen and others (1964) found that Cheddar and Swiss cheese deteriorated fairly rapidly in flavor, whether or not they were exposed to fluorescent light. Kristoffersen and others (1964) attempted to hinder flavor deterioration through the use of 11 different film materials, antioxidants, gas packaging, and coating of the cheese surfaces. They found that the type of deterioration was different between light-exposed and light-protected cheeses. The light exposed cheeses tended to deteriorate quicker and had an oxidized flavor.

To test the effect of antioxidants, the cheese slices or their polyethylene film packaging were sprayed with a solution of antioxidants to prevent light-induced changes in the cheese. The solution was made up of 1% solutions of cysteine HC1, tyrosine, ascorbic acid, or NDGA (nordihydroguaiaretie acid) which was sprayed on film and permitted to dry before packaging the cheese. Sensory analysis was conducted on the cheese samples. The flavor quality and intensity were evaluated by a panel of three or more judges on random packages of cheese that had been stored for regular intervals. Evaluation of the flavor quality was on the following numerical basis: 5-very good; 4-good; 3-fair; 2-low; 1-poor (Kristoffersen and others 1964).

Processed Cheddar cheese was found to be relatively more resistant to flavor change than natural cheese, particularly when protected from light. The researchers found that the rate and extent of flavor deterioration was directly related to the size of the cheese section and individual cheese properties. The results of the study also showed that none of the antioxidant treatments improved the flavor stability of either the light-exposed or the light-protected cheeses during the 10 d of storage. In several cases, the antioxidant treated cheese was considered of lower quality than the untreated sample due to taste of the antioxidant itself or because of apparent breakdown products resulting from light exposure. In an effort to minimize the direct contact between the antioxidants and the cheese, the antioxidants were also applied between two layers of polyethylene film used to package the cheese. Although this method prevented the transfer of the antioxidant flavor this method did not improve the flavor stability of the cheese (Kristoffersen and others 1964).

The study showed that aluminum-laminated film and a film containing an ultraviolet light screening material best inhibited the development of light-activated flavors, whereas coating the cheese surface with distilled acetylated monoglycerides retarded flavor deterioration in light-protected cheese. None of the other films or treatments provided useful protection against flavor changes in either light-exposed or light-protected cheese (Kristoffersen and others 1964). Although the use of specific antioxidants as a coating material for the cheese or the packaging material did not prove to be effective in this study, further research could prove useful in testing rosemary extract in a similar application.

CHAPTER 3 - Conclusion

The objectionable odors and flavors that develop in oxidized products are a significant contributing factor to the limited shelf life of foods containing lipids. These objectionable odors and flavors in an oxidized food products, however, can be limited through the use of antioxidant additives. Natural alternatives to the traditional synthetic antioxidant additives are preferred by consumers in the marketplace and may be used as an additive that is beneficial to human health in the future.

The use of rosemary oleoresin in meat products and fried foods has been extensively researched and used in commercialized foods. Since dairy products, especially dry cheese powders, also contain lipids that are highly susceptible to oxidation, the use of a natural rosemary oleoresin may be beneficial in increasing the shelf life and sensory acceptability of such products. The percentage of rosemary oleoresin added directly to the food would be crucial in effectively retarding lipid oxidation; the percentage used being highly tied to the lipid and salt concentration of the cheese powder.

Based on studies of meat products, the effectiveness of other methods of utilizing rosemary as a natural antioxidant in dairy products could be determined, including incorporating rosemary extract into cattle feed and coating solutions. Further research on the effectiveness of using rosemary oleoresin in a cheese powder should include both a sensory evaluation of the cheese powder over time in addition to physiochemical analyses. Products such as dry cheese powders and shelf stable products containing dairy components would most greatly benefit from research involving dairy products and rosemary extract.

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