SORGHUM BRAN IN MEAT AND POULTRY

A Thesis

by

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ABSTRACT

Pre-cooked pork and poultry products contribute more than $6 billion to the meat industry in the US, and are traditionally manufactured and stored as frozen products. One of the major concerns by meat processors about pre-cooked products is their high susceptibility to lipid oxidation. The development of off-flavors, such as warmed-over flavor (WOF), from lipid oxidation limits the shelf-life of these products to less than 6 mo. To retard lipid oxidation, synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) are added to increase shelf-life. With the increasing demand for more natural products, recent research has shown that sorghum bran is a quality inhibitor of lipid oxidation. We analyzed sorghum bran as an antioxidant by adding 0.25%, 0.5% and 0.75% of either Sumac or Black, high tannin sorghum bran to pre-cooked sausage patties, bratwurst and pre-cooked turkey patties, and 0.25% and 0.5% to dark meat chicken nuggets. A negative control (no antioxidants added) and two positive controls (0.02% BHA/BHT and 0.2% rosemary extract) were added to the study. Products were manufactured and stored on Styrofoam trays over-wrapped with polyvinyl chloride film at 4°C for 0, 1, 3 and 5 d of storage and re-heated to 70°C and served to a trained sensory panel on d 1 and d 3 to test descriptive flavor attributes. Thiobarbituric acid reactive substances (TBARS) were used to evaluate lipid oxidation. Descriptive sensory traits were not affected ($P > 0.05$) by antioxidant treatments. No antioxidant treatment effects ($P > 0.05$) were found in chicken nuggets, bratwurst or pre-cooked sausage patties for TBARS, but the addition of sorghum bran to turkey patties yielded similar or lower ($P < 0.05$) TBARS values than BHA/BHT. These results suggest that high tannin sorghum bran can be used as an effective antioxidant without negatively affecting sensory flavor attributes.

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NOMENCLATURE

AMSA	American Meat Science Association
AOAC	Association of Official Analytical Chemists
BHA	Butylated hydroxyanisole
BHT	Butylated hydroxytoluene
DxyMb	Deoxymyoglobin
EDTA	Ethylenediaminetetraacetic acid
FSIS	Food Safety and Inspection Service
GC	Gas Chromatography
GRAS	Generally recognized as safe
H_2O_2	Hydrogen Peroxide
MS	Mass Spectrometry
Mb	Myoglobin
NADH	Nicotinamide Adenine Dinucleotide plus Hydrogen
OxyMb	Oxymyoblobin
PG	Propyl gallate
PUFA	Polyunsaturated fatty acid
PVC	Polyvinyl chloride
ROS	Reactive Oxygen Species
SPME	Solid Phase Microextraction
TBARS	Thiobarbituric acid reactive substances

TBHQ	Tert-butylhydroquinone
USDA	United States Department of Agriculture
WOF	Warmed-over Flavor

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1. INTRODUCTION

The meat industry strives to produce products that meet the ever changing demand of consumers. As life-styles have become more fast-paced, recent trends have seen an increase in consumer demand for more shelf-stable products that are quick to consume. Consumers are also becoming more health-conscious and are more stringent on the quality of food they are letting into their bodies. As a result of this, there has been an increase in demand for natural additives in meat products. In order to meet these demands, the meat industry is faced with the challenge of finding new methods to improve quality and pro-long the shelf-life of meat products, without sacrificing cost, to meet the needs of consumers for a more natural label.

Modern trends toward convenience foods have resulted in an increase in production of pre-cooked and restructured meat products (Gray et al., 1996). Pre-cooked pork and poultry products represent a greater than $6 billion industry in the United States. These products are traditionally manufactured and stored as frozen product. One of the major concerns by meat processors about these types of products is their high susceptibility to lipid oxidation. Ramanathan and Das (1992) defined lipid oxidation as a free radical mediated phenomenon that deteriorates polyunsaturated fatty acids (PUFAs). These highly unstable free radicals also react with amino acids, heme groups in pigments, and vitamins with conjugated double bonds, forming more free radicals as well as other undesirable compounds (McMillin, 1996). Lipid oxidation in meats causes a loss in nutritional value, and functionality, safety and a change in flavor (Frankel, 1984). Products most susceptible to lipid oxidation are comminuted or restructured products with high levels of fat. When products are ground or chopped, muscle tissues are broken down and phospholipids are more exposed to oxygen and other catalysts of lipid oxidation (Pearson et al., 1977). The development of off-flavors from lipid oxidation limits the shelf-life of these products to less than 6 months. To retard lipid oxidation, commercial antioxidants are added to increase shelf-life, but many consumers want "natural" ingredients added to their pork and poultry products, not ingredients they perceive negatively, such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), propyl gallate (PG), and tert-butylhydroquinone (TBHQ). Consumers are becoming weary of consuming products containing these synthetic additives due to the perception that they possess potential toxic and carcinogenic effects on the body. These concerns, along with the desire to consume products with more natural ingredients, are pushing technologists in the meat industry to find a suitable, natural antioxidant replacement.

In recent years, there has been a vast amount of research on naturally-derived antioxidants. It has been found that plant-based, phenolic compounds are inhibitors of oxidation. One of the primary natural antioxidants used in the meat industry is derived from rosemary. Extracts of sage and oregano have also been utilized, as well as tocopherol supplementation in animal rations. Recent research has shown that sorghum bran is a quality inhibitor of lipid oxidation. Awika (2003, 2000) found that sorghum bran is a rich source of phytochemicals and has a high antioxidant activity compared to other fruits and cereals due to high polyflavan content found in the tannins of the sorghum. It is believed that the tannin component of sorghum could possibly inhibit the lipid oxidation of fat-soluble or phospholipid compounds in meat (Jenschke, 2004).

There has been a series of five research projects conducted prior to this one that used powdered high-tannin sorghum bran as a “natural” antioxidant in beef products. Results have shown that high-tannin sorghum bran has stronger antioxidant properties than BHA/BHT. However, high-tannin sorghum bran has not been tested in pre-cooked pork sausage, fresh pork sausage, bratwurst, or turkey. These products are more susceptible to lipid oxidation than pre-cooked beef patties because of inherently higher levels of unsaturated fatty acids. Meat and poultry processors are very interested in a “natural” antioxidant for these products, but further understanding of ingredient addition levels, stage of addition during processing, effect of addition on color and flavor, and further evidence of antioxidant efficacy are needed to ensure adaptation by the meat and poultry industries.

2. LITERATURE REVIEW

2.1 Consumer Perception of Meat and Meat Products

The profitability of meat and meat products is directly impacted by consumer perception (Troy and Kerry, 2010). It must be pointed out that consumer demands are driven by their perception of a given product. Perception is not only affected by sense, such as vision or taste, but it can also be altered by learning or previous experience with a similar product. Consumers typically have preconceived expectations of the quality of a meat product they are looking to purchase. For a consumer to willingly purchase a particular food item, they must first have a positive perception of that product. In the case of meat, consumer perception is most often related to its quality, which in this case can include color or external appearance, flavor, nutritional value, and shelf life (Grunert et al., 2004; Troy and Kerry, 2010).

2.2 Importance of a Natural and Healthy Product

Consumers are becoming more health conscious and recent trends have shown that consumers are increasing their purchases of natural products, due to the preconceived notion that natural products are healthier than products containing manufactured ingredients and additives. A natural product in the meat and poultry industry 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). Health-conscious consumers associate diet with the probability of experiencing health problems or diseases such as high blood pressure, cancer, and heart disease (Resurreccion, 2004). In other words, the more healthy the diet, the less likely the chance will be for the aforementioned health problems to occur. This has significantly increased the demand for natural meat products as consumers are more aware of what ingredients are going into their food.

Troy and Kerry (2010) explained that red meat can have an image of both positive and negative effects on human health, with respect to composition and nutrition. In a positive sense, Aberle et al. (2001) reported that meat is one of the most nutritious foods to consume, as it is a rich source of protein, iron, and essential vitamins of the Vitamin B complex, especially B_{12}. On the other hand, meat has a negative image due to its presumed high fat content and the consequent link of its consumption with specific health issues pertaining to cancer, heart disease and obesity (Troy and Kerry, 2010). Accompanied with a low level of carbohydrates, red meat contributes to a low glycemic index, which is assumed to have positive effects on preventing obesity and the development of diabetes and cancer (Biesalski et al., 2009). However, more emphasis is usually placed on the negative attributes of consuming meat due to misconceptions about meat and a general lack of knowledge of product quality and composition. While a sound diet may not be the only factor that affects human well-being and health, it is highly important. As consumer concern for a healthier diet grows, the demand for leaner, healthier, and more natural meat products should also rise.

Like any other food, meat and meat products contain elements which, in certain circumstances and in inappropriate proportions, have a negative effect on human health

(Jiménez-Colmenero et al., 2001). Dietary fatty acid composition is an extremely important part of the fatty acid profiles of monogastric animals (pigs, poultry) and is less important in ruminants (cattle) where desirable combinations of fatty acids are to be obtained for human consumption (Byers et al., 1993) with less saturated and more mono- and poly-unsaturated fatty acids (Jiménez-Colmenero et al., 2001). However, with the increase in the amount of unsaturated fatty acids, there is a greater possibility for lipid oxidation to occur. There are several ways to minimize lipid oxidation, some of which involve animal feeding (Decker and Xu, 1998; Morrissey et al., 1998). The ratio of fat to lean in pork carcasses is affected by the diet composition and feeding levels, particularly the energy and protein intake (Jiménez-Colmenero et al., 2001). In pigs, restricting the energy intake will reduce carcass fat, and feeding excess protein will result in a higher proportion of lean to fat (Hays and Preston, 1994). However, to manipulate an animal's diet, certain dietary supplements, such as vitamin E and growth hormones, have to be added in order to alter the way the animal's body would normally function or metabolize a typical feed ration. Most of these additives are synthetic, and consumers are beginning to shy away from meat and food products with such additives as they are seeking a more "natural" source of nutrition.

2.3 Meat Color and Pigment Oxidation

2.3.1 Consumer Perception of Meat Color

Consumers have an expectation of what raw, fresh meat should typically look like in terms of color and product conformation. Grunert et al. (2004) described meat color as an intrinsic quality cue. Other intrinsic quality cues are fat content, marbling and conformation, as these are cues that can be measured objectively and include the physical characteristics of the product. Color is what consumers see upon initial contact with fresh meat and meat products at a grocery store or on their plate prior to consumption in a foodservice establishment. This is a critical factor because color most often is the primary indicator (if not the only indicator) of meat quality and freshness. This is called an expected quality cue. According to research conducted by Grunert et al. (2004), it can be implied that consumers develop expectations from past experiences in the supermarket or from foodservice providers and the quality of the eating experiences that came from those products. Hence, consumers typically assume that by purchasing a product that looks similar to what they have had and enjoyed in the past, they will have a similar experience. According to Faustman and Cassens (1990), meat discoloration is easily defined as a change in meat color from the consumer-defined ideal to something less desirable, for instance, cherry red to brown. Kropf et al. (1986) explained that consumers discriminated against meat cuts which lacked a fresh appearance. It could be concluded that when consumers see products with a dark or off color, they would deem that as a defect or product of poor quality.

Meat purchasing decisions are influenced by color more than any other quality factor because consumers use discoloration as an indicator of freshness and wholesomeness (Mancini and Hunt, 2005). Fresh, raw beef is bright cherry red in color, while chicken and pork are typically pink or grayish-pink in color, respectively. Fresh meat, whether whole muscle or restructured, is typically packaged in trays overwrapped with polyvinyl chloride (PVC) film and displayed in a climate-controlled, open-topped, retail display case. Regardless of how meat is displayed, over time it is inevitably exposed to oxygen, and goes through a series of color changes due to myoglobin oxidation, as explained by Faustman and Cassens (1990). Inexperienced or uneducated consumers automatically assume that meat displaying an objectionable color is defective or spoiled, thus leaving them with a negative impression, which may reduce the overall value and marketability of meat products. Therefore it is important to understand how and why meat changes color.

2.3.2 Pigment Oxidation

Myoglobin (Mb) is the principle protein responsible for meat color. In the living cell, it functions in both oxygen storage and oxygen delivery in muscle (Livingston et al., 1983). Myoglobin is a sarcoplasmic, water-soluble protein that determines meat color via its centrally-located heme iron which can form six bonds (Mancini and Hunt, 2005). Using pyrrole nitrogens, four of these bonds connect iron to protoporphyrins, which then interact with histidines to aid in protein structure, functionality and meat color stability (Mancini, 2013). The heme group is attached to the apoprotein at the fifth binding site by a bond between the iron atom and the proximal histidine 93 (Faustman and Cassens, 1990). The sixth coordination site on iron is able to reversibly as well as preferentially bind ligands such as oxygen, carbon monoxide and nitric oxide (Mancini, 2013). The presence or absence of a ligand, such as oxygen, at the sixth binding site, as well as the addition or removal of an electron of the central iron atom plays a prominent role in the state of myoglobin. The different states of myoglobin give meat a different color, starting from the external surface where myoglobin initially reacts with oxygen or other mentioned compounds, working its way toward the internal portions of the meat. For the purpose of this study, the focus will be placed on the three main forms of myoglobin and the cycle between the three forms.

The first form of myoglobin is its oxygen-free form. Deoxymyoglobin (DxyMb) causes muscle to exhibit a dark-purple color, and the heme iron is in the ferrous (Fe^{2+}) state. Here, no ligand is present at the sixth binding site, resulting in the absence of oxygen (Mancini, 2013). This form of myoglobin is most often found in fresh, vacuum-packaged products or in the center of a freshly cut muscle. The next step, oxygenation, occurs when myoglobin is exposed to oxygen at the sixth binding site, which yields oxymyoglobin (OxyMb). Oxymyoglobin exhibits a bright, cherry-red color in beef, pink to light pink color in pork and grayish-pink color in poultry, and is the most desired color of fresh meat by consumers. The difference in color of oxymyoglobin among species is due to beef having higher levels of haemoprotein than pork or chicken (Millar et al., 1994). In other words, beef has a greater concentration of muscle myoglobin than pork or poultry.

Although oxygen is introduced and oxymyoglobin is formed, there is no change in the heme iron as it remains in the ferrous (Fe^{2+}) state (Mancini and Hunt, 2005). Consumers assume that this color is associated with a fresh product, and is therefore safe to consume. Consumers base this judgment of assumed freshness from pre-formed learning and previous experiences as discussed by Troy and Kerry (2010) and referenced in the previous section regarding consumer perception of meat color. Finally, oxymyoglobin can be oxidized (further exposed to oxygen) to form metmyoglobin

(MetMb). In this instance, the heme iron is oxidized to the ferric (Fe^{3+}) state, where an oxygen atom and an electron are lost, and water is bound as the sixth ligand (Faustman and Cassens, 1990; Kanner, 1994). Troy and Kerry (2010) also point out that, at this stage, metmyoglobin is incapable of binding oxygen and is, therefore, inactive. Metmyoglobin causes a brown appearance in muscle and typically gives consumers the impression that the meat is spoiled and unsafe to consume (Hood and Riordan, 1973).

Mancini and Hunt (2005) point out that metmyoglobin can be converted back to deoxymyoglobin, but only under metmyoglobin-reducing conditions. The existence of natural metmyoglobin-reducing systems in meat was recognized by Dean and Ball (1960). This process is called metmyoglobin reducing activity (Mancini, 2013). Metmyoglobin can be reduced enzymatically by metmyoglobin reductase to ferrous Mb, subject to the availability of cofactors and substrates such as NADH (Bekhit and Faustman, 2005; Mancini, 2013). Meat color, and furthermore, pigment oxidation, is positively correlated with lipid oxidation (Liu et al., 1995). As quantified by Hutchins et al. (1967), the relationship between lipid oxidation and metmyoglobin formation was found to be moderately correlated ($r = 0.73$). It has been suggested that radical species produced during lipid oxidation either act directly to promote pigment oxidation and (or) indirectly by damaging pigment-reducing systems (Gray et al., 1996). Lipid and pigment oxidation are a major problem in the fresh and processed meat industries. Although there are additives used today to retard the oxidation process and prolong shelf-life of meat products, lipid oxidation still occurs and poses a problem for the industry. Further research needs to be conducted in order to find a suitable antioxidant replacement that not only further prolongs or eliminates lipid oxidation, but meets consumers' demands of a natural, high quality, wholesome product. This would result in an increase of profit as more product would be able to be sold before it is deemed unacceptable by the consumer.

2.4 Meat Flavor

Aside from meat color, flavor is also one of the most important factors regarding consumer perception. Flavor is a very important component of the eating quality of meat, and there has been a considerable amount of research conducted to improve the understanding of the chemistry of meat flavor. Raw, fresh meat typically does not have a strong odor and has been most often described to be bland, or have a metallic or serum-like in taste (Troy and Kerry, 2010). It is only upon cooking that a series of thermally-induced, complex reactions take place between many different non-volatile compounds of the lean and fatty tissues (Calkins and Hodgen, 2007). With this in mind, it is safe to say that at the point of purchase, meat flavor is not as important as meat color in influencing consumer purchase. It would not be ideal to allow consumers to taste the product before taking it home to prepare it, not to mention unsafe and uneconomical.

Meat flavor is still an important "quality experience" within the Total Food Quality Model as described by Grunert et al. (2004). This model was constructed to analyze consumer quality perception and decision-making in an organized, step-wise manner and includes an in-depth ideology behind the factors that influence consumer purchases and experiences with meat products. A quality experience in flavor is only reached upon consumption of a product. Grunert et al. (2004) explained that the relationship between quality expectation (which would most likely be derived from color prior to purchase) and quality experience was commonly believed to determine product satisfaction, and consequently, the probability of purchasing the product again. Therefore, it can be concluded that flavor is of high importance to a consumer with the likelihood that consumers base their purchasing decisions, at least partially, on previous eating experiences.

2.5 Chemistry of Oxidation

2.5.1 Lipid Oxidation

There have been many cases where consumers report an off-odor or a rancid or “warmed-over” flavor in fresh and pre-cooked meats, respectively. The term “warmed-over” was introduced by Tims and Watts (1958) to explain the rapid development of an oxidized flavor in refrigerated cooked meats. The rancid taste is derived from the same processes as the warmed-over taste, yet it is commonly found in raw meats or fatty tissues that have been stored weeks or months prior to preparation (Pearson et al., 1977). However, these two terms are commonly used interchangeably and are both products of lipid oxidation.

Lipid oxidation (otherwise known as autoxidation) is a primary concern in the meat industry as it causes deterioration in the quality of meat and meat products (Hemphill, 2006). Buckley et al. (1995) stated that, apart from microbial spoilage, lipid oxidation is the primary process by which quality loss of muscle foods occurs. According to Nuñez de Gonzalez et al. (2008), lipid oxidation can negatively affect sensory attributes such as color, texture, and flavor as well as the nutritional quality of the product. There are many factors that can cause, initiate or influence lipid oxidation in meat. Buckley et al. (1995) stated that the propensity of meat and meat products to undergo oxidation depends on several factors including pre-slaughter stress and post-slaughter conditions in the meat such as early postmortem pH, carcass temperature, cold shortening, and processing techniques such as electrical stimulation. Also, any disruption of the integrity of muscle membranes by mechanical deboning, grinding, restructuring or cooking alters cellular compartmentalization (Gray et al., 1996). Understanding the effects of lipid oxidation and the factors that affect this phenomenon in meat and meat products is important. However, what is more important is to understand the chemistry of lipid oxidation to help the meat industry in its pursuit of decreasing the occurrences and (or) the extent of lipid oxidation in the future.

The actual function of lipid oxidation is a vast topic. For simplicity purposes, the three main stages of oxidation will be discussed, and include initiation, propagation and termination. Lipid oxidation is initiated when a labile hydrogen atom, which comes from a hydrocarbon, is abstracted from a site on the fatty acyl chain (Hemphill, 2006). Willian (2013) stated that the most common type of initiator is a hydroxyl radical. Upon abstraction, a free lipid radical is then produced which reacts rapidly with oxygen to form a peroxyradical (Ladikos and Lougovois, 1990). In this step, free radicals can also react with oxygen to form alkoxyradicals and alkylradicals (Roybal, 2010). Lipid oxidation can be initiated by various factors such as light, metals such as copper and iron, heat, sodium chloride, oxygen and various others (Cruzen, 2010; Ladikos and Lougovois, 1990; Morrissey et al., 1998).

The free radicals produced during initiation can react with oxygen or remove hydrogen molecules from other hydrocarbons to form hydroperoxides and new free radicals. The fatty acid peroxide is relatively stable and it is referred to as a primary oxidation product (Willian, 2013). This perpetuates the autocatalytic chain reaction which is referred to as the propagation phase of lipid oxidation. At this point, branching of the hydroperoxide may occur into peroxy radicals or alkoxyl radicals. Morrissey et al. (1998) gave a detailed explanation of this split stating that hydroperoxides formed in the propagation phase are both products of oxidation and substrates subject to possible further reaction with Fe^{2+} and Cu^{+}, which yield either the peroxy radical or the alkoxyl radical. Lipid oxidation then enters the termination phase where the free radicals and their electrons continuously pair to form non-radical compounds such as aldehydes, alcohols and hydrocarbons (Hemphill, 2006). When there are no radicals available to react with oxygen, initiation of lipid oxidation ceases. The by-products of the termination phase (aldehydes, alcohols, hydrocarbons, etc.) have distinct aromas and can affect flavor properties of meat and poultry at levels well below 1ppm (Ladikos and Lougovois, 1990).

It should also be noted that comminuted meats are more susceptible to lipid oxidation and the resulting effects because processing meat disrupts the tissue and exposes phospholipids to oxygen and other catalysts of lipid oxidation (Pearson et al., 1977). Therefore, processed meats are especially susceptible to rancidity and other effects of lipid oxidation. It is essential that a better understanding is obtained of lipid oxidation to enhance the quality of processed meat products. Not only does oxidation occur in lipid, which affects meat flavor, but it also occurs in myoglobin as well, which can impart an off-color or spoiled appearance.

2.5.2 Differences in Lipid Composition among Species

Lipid oxidation differs among species primarily due to the type and amount of each fatty acid found in each species. Lipid oxidation occurs in both triacylglycerols and phospholipids; however, it is the degree of unsaturation that influences the oxidative quality (Roybal, 2010). Triacylglycerols are largely composed of straight-chain, even-numbered-carbon fatty acids (Hemphill, 2006). Triacylglycerols are mainly stored in specialized cells called adipocytes, and are the main storage form in adipose tissue (Willian, 2013). Phospholipids contain a much larger portion of 20- and 22-carbon unsaturated fatty acids (Hemphill, 2006). They are the main components of the membrane of the cell and cellular organelles and thus they contribute greatly to the total lipid extract in muscle tissue (Willian, 2013).

One of the main factors affecting lipid oxidation as a whole and also providing differences among species is the amount of phospholipids in each species. Phospholipids within muscle cells contain about 15 times more polyunsaturated fatty acids (PUFAs) than triacylglycerides in muscle tissue, and are therefore more rapidly oxidized (Allen and Foegeding, 1981; Pearson et al., 1977). Because free radicals attack double bonds of fatty acids to steal hydrogen, unsaturated fatty acids are most susceptible to oxidation (Cruzen, 2010). Pearson et al. (1977) explained that, based on the degree of PUFAs, oxidation occurs more regularly in fish, followed by poultry, pork, beef and lamb. The configuration of double bonds plays a role in fatty acid stability as well, because *cis* double bonds oxidize more easily than *trans* double bonds (Morrissey et al., 1998). Also, the amount of phospholipids in the muscle stays relatively constant as the animal ages but the amount of triacylglycerol can increase dramatically (Willian, 2013). Although oxidation is inevitable, the delay of one or two days is considered substantial. With this in mind, producers are looking for economical ways to provide consumers with products that are desirable and shelf-stable.

2.6 Enhancing Shelf-life with Antioxidants

With the change in consumer demand for convenience foods, the meat industry has seen a drastic increase in the production of pre-cooked and shelf-stable products. Pearson and Gillett (1996) stated that the production of pre-cooked and shelf-stable products would increase in the years to follow, as in years prior to their publication. According to Sheely (2008), the market for convenience food products in the United States reached 7.2 billion pounds in 2007, and also in 2007, the global consumption of chilled convenience products (which included meat and meat products) reached a capita of 45.2 billion pounds. With the increase in production, meat processors and technologists have been challenged with finding techniques to extend the shelf-life of these products, due to the susceptibility that precooked and restructured products have to lipid oxidation. Lipid oxidation and its development of warmed-over flavor (WOF) during storage of pre-cooked meat have been of increasing interest in relation to product quality improvement of ready-to-eat meals and other convenience foods (Nielsen et al., 1997). Cooked meats held in a refrigerator develop rancid odors and flavors which usually become apparent within 48 h at 4°C (Ladikos and Lougovois, 1990). These flavors are particularly noticeable after reheating the meat and are referred to as WOF (Tims and Watts, 1958). Numerous studies have been conducted utilizing packaging techniques and other nonconventional methods in meat processing to retard lipid oxidation in both fresh and precooked meat products (Buckley et al., 1995; Greene et al., 1971; Morrissey et al., 1998; Nuñez de Gonzalez et al., 2008; Tims and Watts, 1958). One of the most common solutions found to slow lipid oxidation and extend shelf-life has been the use of antioxidants, whether man-made or natural. Many studies have shown that the use of antioxidants can control, or at least minimize, lipid oxidation.

2.6.1 Function of Antioxidants in Meat and Meat Products

Because antioxidants are an important ingredient in processed meat products, it is important to understand the function or chemistry behind how antioxidants actually retard oxidation. Antioxidants are chemical compounds that can delay the onset, or slow the rate of, lipid oxidation protecting the lipid components in meat by limiting or inhibiting exposure of free radicals and reactive oxygen species (Hemphill, 2006; Roybal, 2010). According to Cruzen (2010), there are two main types of antioxidants: those that terminate free radicals (primary) and those that prevent them (secondary). These two types of antioxidants can be further broken down by their specific functions. Antioxidants can: 1) remove oxygen or decrease local O_2 concentrations; 2) remove catalytic metal ions; 3) remove key reactive oxygen species (ROS) such as H_2O_2; 4) scavenge initiating radicals such as OH; 5) break the chain of an initiated sequence; and 6) quench or scavenge singlet oxygen (Gutteridge, 1994). The three most common reactions of antioxidants are: 1) neutralizing free radicals by either sharing or donating an electron: 2) reducing the peroxide concentrations and repairing oxidized membranes; or 3) acting as a metal chelator to quench iron and decreasing free radical production (Hemphill, 2006).

2.6.2 Types of Antioxidants

Two main types of antioxidants are used in the meat industry today; synthetic and naturally-derived, plant-based antioxidants. Synthetic antioxidants are man-made compounds that are formed in lab-type settings and are usually found in crystalline form. Synthetic compounds such as butylated hydroanisol (BHA), butylated hydrotoluene (BHT), tertiary-butylhydroquinone (TBHQ), and propyl gallate (PG) are all phenolic compounds and are standard primary antioxidants used in the meat industry today (Ladikos and Lougovois, 1990). The compounds BHA and BHT are typically used in combination with one another and are the most common type of synthetic antioxidant used in the meat industry. Propyl gallate is also used in some processing facilities as a primary antioxidant. These compounds are effective in their own right, however, the effects are much stronger when coupled with secondary antioxidants such as ethylenediamine tetraacetic acid (EDTA), citric acid, ascorbic acid and phosphates (Haworth, 2003). These secondary antioxidants trap radicals, chelate metal ions, regenerate primary antioxidants or act as emulsifying agents (Haworth, 2003).

The BHA/BHT complex is recognized as one of the most common synthetic antioxidants used in the meat industry to date. Both substances are generally recognized as safe (GRAS) by USDA/FSIS for use as preservatives in foods (USDA, 2000). The USDA regulations permit up to 0.01% each of BHA and BHT in fresh sausage and up to

0.003% each in dry sausage (Sebranek et al., 2005; USDA, 2000). Compounds BHA, BHT, TBHQ and tocopherol all act as free radical terminators by donating a hydrogen atom to the free radical which stops the chain reaction of the propagation phase of oxidation (Ladikos and Lougovois, 1990). In a study conducted by Greene et al. (1971) using ground beef patties, it was reported that the use of PG or BHA combined with ascorbic acid was effective in retarding lipid and pigment oxidation for up to 8 d of refrigerated storage. As for TBHQ, it is an approved antioxidant in certain meat and poultry products in the USA and is allowed at 0.02% in combination only with BHA and (or) BHT (Ladikos and Lougovois, 1990).

Many non-meat ingredients used as processing aids serve specific purposes in a particular product. However, some ingredients such as nitrates, nitrites and phosphates possess certain properties that allow them to serve a secondary purpose in meat products as well. For example, sodium nitrite is used as a curing agent in some processed meat products, but it can also have antioxidant effects on meat and meat products. Morrissey and Tichivangana (1985) found that the addition of low levels of nitrite (20 mg/kg) significantly inhibited lipid oxidation and the addition of 50 mg/kg showed a significant reduction in lipid oxidation. However, in a study using pre-cooked ground pork, Yun et al. (1987) found that TBHQ and BHA were the most effective antioxidants among various other compounds tested to find a suitable replacement for nitrite as an antioxidant.

Tims and Watts (1958) showed that phosphates were able to suppress lipid oxidation through metal chelation. When combined with ascorbic acid, phosphates or

EDTA had a synergistic effect in preventing oxidation (Lehmann and Watts, 1951). However, using ascorbic acid alone could yield prooxidant activity. Tims and Watts (1958) also found that phosphates, especially pyro-, tripoly-, and hexameta-phosphate, were important for preventing rancidity in cured meat products. Finally, erythorbates can be added to processed products as a cure accelerator. Lambrecht (1995) stated that the family of erythorbates, erythorbic acid and sodium erythorbate, are stereoisomers of ascorbates and function in a similar manner as antioxidants. These compounds are reducing agents and are preferentially oxidized in foods, thus preventing or minimizing oxidative flavor and color deterioration. Erythorbates also break down nitrite to nitric oxide to help set the cured color in cured and smoked meats.

Natural antioxidants are becoming popular for prevention and inhibition of oxidation in meat products (Shahidi, 2000). Natural antioxidants are gaining attention due to health concerns, such as cancer, heart disease and obesity, by human health professionals and consumers regarding synthetic antioxidants (Decker and Mei, 1996). Natural antioxidants typically have a high phenolic content and are products derived directly from plant rinds, seeds, pulp or skins, and are typically used as any other ingredient in a processed meat product in terms of actual application. The ability of phenolic compounds to serve as antioxidants was first recognized by Decker (1995). The antioxidant activity of phenolic compounds is mainly due to their redox properties, which allow them to act as reducing agents, hydrogen donators, and singlet oxygen quenchers (Kähkönen et al., 1999). In addition, they also have the potential to chelate metals such as iron (Rice-evans et al., 1995). Examples of plants that possess antioxidant compounds are rosemary, oregano, sage, grape seed, and tannins as well as other smaller varieties. In a study conducted by Cruzen (2010), cherry seed flour, CitruSmart citrous extract, chardonnay grape seed flour and Norton grape seed flour were tested for their antioxidant capacity in pre-cooked beef patties. Results from this study showed that 0.5% addition of chardonnay grape seed and both 0.25% and 0.5% of Norton grape seed greatly suppressed lipid oxidation in pre-cooked ground beef patties throughout 5 days of storage, compared to the other non-meat additives and especially the control patties. The addition of these three different treatments yielded TBARS values that were lower than those of the BHA/BHT treated patties. Even more interesting is the fact that, with the addition of 0.5% Norton grape seed flour, TBARS values did not change throughout the study. This, along with other findings from other non-meat ingredients in the study, confirmed that these grape seed extracts could be used as effective natural antioxidant replacements.

Another notable natural phenolic compound is tocopherol or vitamin E (Ladikos and Lougovois, 1990). However, tocopherol is different from other natural antioxidants in that it is administered to the live animal as a feed supplement, which is then absorbed into cell walls upon digestion where it reacts with phospholipids. Natural antioxidants also exhibit a wide range of biological effects including antibacterial, antiviral, anti-inflammatory, antithrombotic, and vasodilatory actions (Cook and Samman, 1996). Most natural antioxidants are ortho-disusbstituted phenolic compounds while synthetic antioxidants are mostly para-disubstituted phenolic compounds. Ortho-disubstituted compounds have low activation energy which allows them to readily donate a hydrogen molecule to free radicals, thus resulting in a stabilized free radical which is no longer able to oxidize or produce other free radicals (Roybal, 2010).

Of the known natural antioxidants, rosemary extract is the most commonly used in the meat industry. Before its antioxidant capabilities were discovered, rosemary was used as a flavoring ingredient in processed meat products; however, now it can be used as a dual purpose ingredient. Wu et al. (1982) discovered that carnosol, an odorless and tasteless phenolic diterpenic lactone, and carnosic acid were the two main compounds responsible for rosemary's antioxidant capabilities. Aruoma et al. (1992) found that carnosol and carnosic acid were both good scavengers of peroxyl radicals, and were more effective than PG at inhibiting the peroxidation of membrane lipids. Two major diterpenes were further derived from these compounds as well, rosmaridiphenol and rosmariquinone (Houlihan et al., 1984, 1985).

The oleoresins of rosemary, sage, and oregano have been classified generally recognized as safe (GRAS), and are commonly used as antioxidants (Cruzen, 2010). The results of numerous research projects on the effectiveness of rosemary as an antioxidant have been conflicting. As is evident in the studies discussed below, there has been a great deal of variation in results regarding rosemary extracts of different origins used in various food systems, thus requiring the need for further research to obtain more consistent results. Most of the variation in rosemary is because data were collected from both raw and cooked samples, and more importantly, the difference in consistency of levels of phenolic compounds that exist among different plants. Haworth (2003) reported, however, that rosemary extract producers have tried to control the inconsistency in rosemary extracts by certifying their products based on phenolic activity. Rosemary's effect as an antioxidant is lower in cooked products than it is in raw products, but it is still an effective antioxidant (Sebranek et al., 2005). For instance, rosmaridiphenol and rosmariquinone were measured for antioxidant activity in lard, and were found to surpass the effects of BHA and were similar to that of BHT (Houlihan et al., 1984, 1985). Lawrence et al. (2004) found that beef loins injected with rosemary extracts showed improved color stability. Formanek et al. (2003) also studied rosemary extracts in irradiated ground beef and found that both lipid oxidation and color change were inhibited by the addition of rosemary. However, Ahn et al. (2002) reported that rosemary was significantly less effective than BHA/BHT for suppression of oxidative changes in cooked ground beef. Although there is conflicting evidence on the extent of rosemary's effectiveness as an antioxidant, it can be concluded that rosemary is, in fact, a viable natural antioxidant source.

Numerous other natural, plant-derived substances have been found to possess antioxidant capabilities as well. Sage has been shown to have similarities in structure and antioxidant capabilities as rosemary, as carnosol and carnosic acid were found in both sources (Wu et al., 1982). Thymol and carvacrol have been isolated from essential oils of oregano and have antioxidant properties as reported by Deighton et al. (1993). This, along with their similarity in structure to that of BHA and BHT, would suggest that they hold promising antioxidant capabilities. Deighton et al. (1993) also noted that compounds such as thymol and carvacrol may supplement α-tocopherol in plant membranes, thus aiding in lipid peroxidation.

A form of vitamin E, α-tocopherol, is another natural antioxidant of interest because of its potent chain-breaking capabilities. This type of antioxidant readily donates a hydrogen atom to more reactive free radicals, while at the same time, forming a very stable phenoxy radical for itself (Deighton et al., 1993). The most effective way to introduce α-tocopherol into the muscle is by way of ingestion, where it is then metabolized by the body and carried to the muscle cell membrane. In a study conducted by Buckley et al. (1989), it was found that pork chops from pigs fed α-tocopherol (200 mg/kg of feed) were more stable for longer periods of time compared to chops from pigs fed control diets. Vitamin E can be applied to meat after postmortem aging; however, it has been found that results from this method are more variable and not as prominent as dietary supplementation (Benedict et al., 1975; Chen et al., 1984). All of these natural antioxidants possess positive lipid anti-oxidation properties, but in some cases, further research needs to be conducted in order to verify the extent of their capabilities as an antioxidant replacement. Also, it must be taken into consideration the level that some of these aforementioned potential antioxidants must be used in order to reach significant results. By using too much of any of these ingredients discussed above, it could impart an undesirable or overpowering flavor in the product, which would offset any benefit that might come from suppressing lipid oxidation.

2.6.3 Sorghum Bran

Sorghum is the fifth-leading cereal crop in the world, and is used as a primary source of food in Asia and Africa and is a primary feed grain in the United States (Rooney and Waniska, 2000). The use of sorghum bran as an antioxidant is relatively new, so little research on sorghum bran and its antioxidant activity and capacity exists. However, there has been a significant amount of research about certain properties within sorghum. Awika (2003) found that sumac sorghum bran had higher oxygen radical absorbance capacity values compared to common fruits that humans consume on a regular basis. In a recent study conducted by Shin (2006), sumac sorghum bran was used at three different level (0.25%, 0.5% and 1%) in beef patties consisting of 10 and 27% fat. Although oxidation was higher in the patties with the higher fat content, the addition of sumac sorghum bran significantly decreased oxidation levels compared to control patties and patties with rosemary extract added. Also, when sumac sorghum bran was added at 0.5% and 1%, oxidation levels were low and comparable to patties with BHA/BHT added (Shin, 2006). These results showed that the sorghum bran can effectively be used as an antioxidant replacement.

According to Dykes et al. (2005), all sorghum cultivars contain phenolic compounds, but the amount present in any particular cultivar is influenced by its genotype and the environment in which it is grown. These factors affect the sorghum's color, appearance, and nutritional quality (Hahn et al., 1984). Sorghum bran is a source of phenols with varying antioxidant potentials because there are different varieties of sorghum. Compounds found within sorghum bran are both hydrophilic and lipophilic, acting together to inhibit lipid oxidation more than conventional antioxidants (Hemphill, 2006). The fact that sorghum is readily available and contains by-products that can be used for human consumption and for the enhancement of product shelf life, is both an economic and an agronomic advantage that, with further research, could greatly influence the meat industry. Also, sorghum bran contains tannins which are lipophilic compounds that donate electrons to free radicals and are 15 – 30 times more powerful than simple phenolics according to Hagerman et al. (1998).

Roybal (2010) tested the antioxidant capacity of several different sorghum types in beef patties. In this study, all treatments except for control and 0.25% white sorghum bran yielded lower TBARS values in beef patties than patties treated with rosemary extract, which showed that these treatments could possibly be used as suitable natural antioxidant replacements in processed meat products. Among these treatments, 0.5% tannin sorghum bran, 0.5% black sorghum bran, 0.5% black tannin sorghum bran, both 0.1 and 0.25% chestnut wood, and 0.5% chardonnay grape seed yielded lower TBARS values than BHA/BHT treated patties, thus showing that these were as good as, or better, at suppressing lipid oxidation than the standard synthetic antioxidant used in the meat industry today. Also notable was the fact that, within this particular study and studies prior to this one, products that contained sorghum brans with tannins typically yielded lower TBARS values than other treatments within their respective studies. These results have led to further research on sorghum varieties that contain tannins. With these facts in mind, it is important to note that the use of tannins as a natural antioxidant replacement is one of the newer interests in the meat industry.

2.6.4 Tannins

According to Hagerman et al. (1998) tannins are natural phenolic antioxidants and are present in a wide variety of foods including cereals, fruits, vegetables and a wide variety of foods humans consume on a daily basis. Tannins are also found in a wide variety of grains such as sorghum, barley, dry beans, peas, and others. Three main classifications of tannins exist: condensed tannins which are called proanthocyanidins, hydrolysable tannins, and the phlorotannins (Hagerman et al., 1998). According to Ragan and Glombitza (1986) phlorotannins are only present in brown algae and are not typically consumed by humans. Proanthocyanidins, or condensed tannins, such as those found in grape seed have also been found to possess strong antioxidant properties. Ahn et al. (2002) found that, with the addition of 0.02% grape seed extract, TBARS values were reduced to half that of control samples in beef patties. Furthermore, Carpenter et al. (2007) reported that grape seed used in raw, minced pork patties reduced oxidation throughout 12 d of storage compared to the control using levels as low as 0.005%. It was also found that lipid oxidative stability increased with the increase in concentration of grape seed extract up to 0.1%. In cooked pork patties, it was shown that 0.1% inclusion of grape seed extract decreased TBARS values 9-fold compared to control patties (Carpenter et al., 2007).

In a study conducted by Awika et al. (2003), it was discovered that high-tannin sorghum bran had high oxygen radical absorbance capacity values compared to common fruits, thus indicating that they function well as antioxidants. Other researchers have attributed tannins' high antioxidant capacity to being strong metal chelators in addition to free radical scavengers (Bors et al., 1990; Carbonaro et al., 1996). Jenschke (2004) also found that the addition of brown tannin sorghum bran significantly decreased TBARS values in beef patties compared to control patties and patties with sodium phosphate and salt added over the course of 9 d. The addition of 0.25% brown tannin sorghum bran resulted in lower TBARS values compared to control patties and patties with sodium phosphate and salt added. With the increased addition of sorghum bran to 2.0%, TBARS values were lowered even more at 3, 6, and 9 d of storage. Even greater results were found in retarding lipid oxidation when sodium phosphate, salt and 2.0% sorghum bran were added together in beef patties, yielding the lowest TBARS values in the study.

There is a need for an alternative natural additive for retarding lipid oxidation. There is also a need to build upon results from previous studies in order to find more consistent and positive results regarding the efficacy of sorghum bran as a possible natural antioxidant. We have proposed the addition of 0, 0.25, 0.50 and 0.75% of powdered high-tannin sorghum and sumac sorghum bran to pre-cooked pork patties, pre-cooked ground turkey patties, and bratwurst sausage. In addition, treatments containing BHA/BHT and rosemary were included to compare the results to the two industry-standard antioxidants. This model has been effective in inducing high levels of lipid oxidation in controls and provides a strong test of the antioxidant properties of the added ingredients.

Therefore, we hypothesized that natural, tannin-based sorghum bran had greater antioxidant properties in meat and poultry products than BHA/BHT and rosemary extract. Our objectives for this study were to evaluate the antioxidant, color and flavor effects of powdered high-tannin sorghum bran in pre-cooked pork sausage patties, bratwurst sausage, and pre-cooked turkey patties.

3. MATERIALS AND METHODS

3.1 Fully-Cooked Dark Meat Chicken Nuggets

Non-emulsified dark meat chicken nuggets were produced separately based on treatments defined in Table 1. The basic ingredients of the nuggets were boneless skinless breast meat (white meat), boneless skinless thigh meat (dark meat; 50:50 w/w), antioxidant and marinade and each treatment was manufactured in 4.54 kg batches. For each treatment, 453.6 g (10% of total weight) of marinade was prepared by dissolving of 27.22 g of salt and 21.77 g of sodium tri-phosphate in 404.61 g of tap water. Treatments were: 1) no antioxidants added (control); 2) 0.2% rosemary extract (Herbalox® Type HT-25; Kalsec Inc. Kalamazoo, MI); 3) 0.01% each of food-grade butylated hydroxyanisole (BHA; Sigma-Aldrich, W218208) and butylated hydroxytoluene (BHT; Sigma-Aldrich, W218405, 0.5% ViniferOX™); 4) 0.25% black sorghum bran with tannins (equivalent mixture of B.05020, B.05029, and B.05023); 5) 0.5% black sorghum bran with tannins (equivalent mixture of B.05020, B.05029, and B.05023); 6) 0.25% high-tannin-containing sorghum bran (sumac); and 7) 0.5% high-tannin-containing sorghum bran (sumac).

At 24 h postmortem, boneless, skinless breast meat and boneless, skinless thigh meat were obtained from a commercial facility (Sanderson Farms Inc., Texas, USA). Connective tissue and visible fat was removed using a knife. The meats were ground through a 4.8 mm plate using a meat grinder (Butcher boy, Toledo, Ohio) and placed in a cooler (4°C) until the production of all nugget treatments were completed. Following the recipe given in Table 1, the required amount of ground breast meat, ground thigh meat, and antioxidant were weighed and placed into a bowl. Then, 0.454 kg of the marinade was poured into the bowl and the ingredients were mixed using a KitchenAid mixer (Model: K45SSWH, St. Joseph, Michigan) at number 2 speed for 2 min. The mixture was shaped into nuggets (14g, 34.2 mm x 47.3 mm x 8 mm) using a plate former machine (Bridge rotary machine, S-93, Palmyra, New Jersey). Each nugget was directly placed on a tray and the tray was kept in the blast freezer (-21^{o}C) until the nuggets became hard (approximately 1 h). The hard, frozen structure simplified coating of nuggets with batter and breading.

After freezing, nuggets were immediately dipped in batter (Kerry Ingredients-G411349) and coated with breading (Kerry Ingredients-G3684) using an automatic batter-breading system (Model:ABB, Bettcher Industries, Vermilion, Ohio) with a batter and breading pick up level of 28%. Coated nuggets were par-fried for 30 s in 190°C canola oil using a deep fat fryer (Star-Max, Model 515D, St. Louis, MO). Then, the nuggets were fully cooked in the oven (Blodgett/Zephaire, Model Zephaire-G-L, Burlington, VT) at 177°C until the internal temperature of the nuggets reached 80°C. After the cooking process was completed, the nuggets were frozen in the blast freezer (Hobart, Model W, Troy, Ohio) at -21^{o}C for 2 h. They were packaged in polyethylene Ziplock brand storage bags (S.C. Johnson & Son Inc., Racine, WI) and stored in the regular freezer (-9.4°C).

All treatments were taken out of the freezer after 3 mo of storage and prepared for refrigerated storage. Six nuggets per treatment were placed in one small Styrofoam tray in one layer and covered with polyvinyl chloride (PVC) film in an air-tight package using a heat sealing machine (104-A, Heat Sealing Equipment Company, Cleveland, Ohio) to simulate commercial sale of nuggets in the market place. Trays were randomly assigned locations in a 4°C cooler under 1600 lx, fluorescent lighting (Lithonia Lighting, Aculty Lighting Group, Inc., Conyers, GA, 1614 lux) using cool white bulbs.

Color, pH, and lipid oxidation (TBARS) were determined at 0, 1, 3 and 5 d of storage and sensory characteristics of nuggets were determined at 1 and 3 d of storage. Prior to testing, nuggets were reheated in a Hobart convection oven (Model No. DN09, Troy, OH) for 10 min at 204.4°C. Objective color was determined using a Minolta Chroma Meter (model CR-400, Minolta Co. Ltd., Ramsey, NJ) D_{65}: pulsed xenon lamp with diffuse illumination and 0° viewing angle calibrated daily, using a white tile ($Y = 94.3$, $x = 0.3130$, $y = 0.3199$) through the same polyvinyl chloride (PVC) over wrap film used for packaging. Each reading consisted of CIE L*, a*, and b* (lightness, redness, and yellowness, respectively) color space values. Three color readings were taken from random locations on one nugget from each of the seven treatment groups. For this reading, the Minolta Chroma Meter was placed in three random locations on either side of the selected nugget, and those three readings were averaged across the nugget in order to provide a value for each treatment. Also, the lens portion of the Minolta was covered with PVC to imitate the view through a packaged product. On each of the 4 d of tested storage (0, 1, 3, and 5), Thiobarbituric acid reactive substances (TBARS) analyses were conducted on two nuggets within each treatment using the procedures described by Tarladgis et al. (1960) and modified by Rhee (1978).

Six nuggets from each treatment group were used for expert, trained meat descriptive flavor and texture attribute evaluation to determine the effect of ingredient addition on flavor and texture after 1 and 3 d of storage. Four panelists were trained using the lexicon described in Tables 2 & 3 for 10 d prior to the study. Chicken nugget flavor and texture attributes were measured using a 16-point universal scale, where 0 = none and 15 = extremely intense. After training was complete, panelists evaluated seven nuggets per day (d 1 & 3 of storage). At the beginning of each evaluation day, panelists were calibrated using an orientation (control) or "warm-up" sample that was evaluated and discussed orally amongst panel members. Following the orientation sample, panelists were then served one sample per treatment, each assigned in a random order pre-determined at the beginning of each panel session.

For chicken nugget evaluation, each panelist was served one nugget apiece. Each nugget was cut into approximate halves and served in clear, plastic soufflé cups tested to assure that they did not impart flavors on the samples. Each soufflé cup was labeled with a 3-digit random number for data collection purposes. Panelists were seated in individual breadbox-style booths separated from the preparation area, and samples were evaluated under red light in order to prevent sample identification prior to evaluation. In order to prevent taste fatigue, each evaluation day was divided into two sessions, with a ten-minute break between sessions and samples were served 4 min apart. Double distilled water, unsalted saltine crackers and ricotta cheese were available for cleansing the palette between samples. Nuggets were reheated in a Hobart convection oven

(Model No. DN09, Troy, OH) for 10 min at 204.4°C, and placed in a food warmer (Alto-Shaam, Model 750-TH-II, Milwaukee, WI) set at 40°C until served.

3.2 Pre-cooked Pork Sausage Patties

On three different days (defined as replicates), 40.8 kg of hot-boned, pre-mixed and seasoned fresh, coarse ground pork sausage (approximately 25% lipid) was obtained from a large, commercial whole-hog processor. Within 3 d of pickup, the pork sausage was fine ground through a 4.8 mm plate using a grinder (Hollymatic, Countryside, Illinois), and divided into nine 3.175 kg batches assigned to a specific treatment. Treatments were as follows: 1) no antioxidants added (control); 2) 0.2% rosemary extract (Herbalox® Type HT-25, Kalsec Inc., Kalamazoo, MI); 3) 0.01% each of food-grade butylated hydroxyanisole (BHA; Sigma-Aldrich, W218208) and butylated hydroxytoluene (BHT; Sigma-Aldrich, W218405, 0.5% ViniferOX™); 4) 0.25% black sorghum bran with tannins (equivalent mixture of B.05020, B.05029, and B.05023); 5) 0.5% black sorghum bran with tannins (equivalent mixture of B.05020, B.05029, and B.05023); 6) 0.75% black sorghum bran with tannins (equivalent mixture of B.05020, B.05029, and B.05023); 7) 0.25% high-tannin-containing sorghum bran (sumac); 8) 0.5% high-tannin-containing sorghum bran (sumac); and 9) 0.75% high-tannin-containing sorghum bran (sumac). Pork sausage patties were produced by treatment group following the recipe defined in Table 7. After treatment groups were assigned and the meat block was divided accordingly, each treatment and water was added to the meat block. Each batch was mixed using a small, batch-type paddle mixer (Gander Mountain, Saint Paul, Minnesota) for 2 min. All treatments contained the commercial processor's formulated spice blend and 3% water added as a mixing aid.

After mixing, pork sausage patties (155 g, 10.8-cm diameter x 1.6-cm thick; n = 20) within each treatment were formed using a cast-iron manual patty press (Gander Mountain, Saint Paul, Minnesota). Meat for each patty was weighed (155 g) and then placed in the patty maker between two pieces of dry waxed patty paper (Weston Products, Strongville, Ohio) and pressed. Raw patty moisture, lipid, color and pH were obtained from one patty per treatment within each of three replications. Moisture content was determined using the oven dry method, while lipid was determined using ether extraction as described by AOAC (2000). Objective color was determined using a Minolta Chroma Meter (model CR-400, Minolta Co. Ltd., Ramsey, NJ) D_{65}: pulsed xenon lamp with diffuse illumination and 0° viewing angle calibrated daily, using a white tile (Y = 94.3, x = 0.3130, y = 0.3199) through the same PVC film used for patty packaging.

Each reading consisted of CIE L*, a*, and b* (lightness, redness, and yellowness, respectively) color space values. Three color readings were taken from three random locations on a patty from each of the nine treatment groups and averaged across patty. Subjective color was measured by two pre-trained descriptive attribute color sensory panelists as defined by AMSA (1991, 1995). Patties were cooked using a convection conveyor oven (XLT 1832E-TS, Wolfe Electric, Inc., Wichita, KS) to an internal temperature of 70°C monitored by threading an iron thermocouple (Omega Engineering, Stamford, CT) through each patty to the geometric center, attached to an

Omega HH501BT Type T thermometer (Omega Engineering, Inc., Stamford, CT). Pre- and post-cook weights were obtained and cook yield was calculated. After cooking, patties were cooled to 4°C and placed on Styrofoam trays and over-wrapped with PVC film (AEP Industries; Matthews, NC). Packages were randomly assigned locations in a 4°C cooler under 1600 lx, fluorescent lighting (Lithonia Lighting, Aculty Lighting Group, Inc., Conyers, GA; 1614 lux) using cool white bulbs, simulating a retail meat case. Each package was also assigned to one of four days-of-storage treatments: 0, 1, 3 or 5 d.

Two patties from each treatment group were used for expert, trained meat descriptive flavor attribute evaluation to determine the effect of ingredient addition on flavor after 1 and 3 d of storage. Prior to the study, panelists were trained for 10 d using the lexicon described in Table 8. Sausage patty flavor attributes were measured using a 16-point universal scale, where 0 = none and 15 = extremely intense. Patties were reheated using a Hobart convection oven (Model No. DN09, Troy, OH) set at 162.8°C and cooked to an internal temperature of 70°C. Internal temperature was monitored by threading an iron thermocouple (Omega Engineering, Stamford, CT) through each patty to the geometric center, using an Omega HH501BT Type T thermometer (Omega Engineering, Inc., Stamford, CT). Upon reheating, patties were placed in a food warmer (Alto-Shaam, Model 750-TH-II, Milwaukee, WI) set at 40°C until served. Up to four panelists, seated in individual booths with red lights, evaluated nine patties per day (d 1 & 3 of storage). At the beginning of each evaluation day, panelists were calibrated using an orientation (control) or “warm-up” sample that was evaluated and discussed orally amongst panel members. Following the orientation sample, panelists were then served one sample per treatment, each assigned in a random order pre-determined at the beginning of each panel session. Each panelist was served two wedge pieces of a patty in a plastic soufflé cup tested to assure that they did not impart flavors on the samples. Each soufflé cup was labeled with a three-digit random number for data collection purposes. In order to prevent taste fatigue, each evaluation day was divided into two sessions, with a ten-minute break between sessions and samples were served four minutes apart. Double distilled water, unsalted saltine crackers and ricotta cheese were available for cleansing the palette between samples.

On each of the 4 d of storage (0, 1, 3, and 5 d), cooked patties were evaluated for pH, objective color, and TBARS determinations. For TBARS analysis, two patties within each treatment were tested using the procedures described by Tarladgis et al. (1960) and modified by Rhee (1978). One patty per treatment was subject to pH and objective color evaluation after cooking or reheating. One patty per treatment was also evaluated for chemical flavor volatile determinations using AromaTrax analysis (GC/MS/Olfactory) on d 1 and 3 of storage. Once samples were cooked or reheated, they were placed in a glass jar (473 mL) with a Teflon piece under the metal lid and then placed in a water bath at 60°C, where the headspace was collected with a solid-phase micro-extraction (SPME) Portable Field Sampler (Supelco 504831, 75 µm Carboxen/ polydimethylsiloxane, Sigma-Aldrich, St. Louis, Mo). Upon first receiving the SPME fibers, each fiber was conditioned for one hour at 280°C in the GC injection port. The headspace above each meat sample in the glass jar was collected for 2 h on the SPME.

Upon completion of collection, the SPME was injected in the injection port, where the sample was desorbed at 280°C. The sample was then loaded onto the multi-dimensional gas chromatograph into the first column (30 m x 0.53 mm ID/ BPX5 [5% phenyl polysilphenylene-siloxane] x 0.5 μm, SGE Analytical Sciences, Austin, TX), which is non-polar and separates compounds based on boiling point. Through the first column, the temperature started at 40°C and increased at a rate of 7°C/min until reaching 260°C. Upon passing through the first column, the sample passed to a second column (30 m x 0.53 mm ID [BP20- polyethylene glycol] x 0.50 μm, SGE Analytical Sciences), which separates compounds based on polarity. The gas chromatography column was then split at a three-way valve with one column going to the mass spectrometer (Agilient Technologies 5975 series MSD, Santa Clara, CA) and one column going to each of the two sniff ports, which were heated to a temperature of 115° C, and fitted with glass nose pieces. The sniff ports and software for determining flavor and aroma are a part of the AromaTrax program (MicroAnalytics-Aromatrax, Round Rock, Tx). Two panelists were trained to accurately use the Aromatrax software after they had also been trained according to the beef lexicon aromas (Adhikari, 2011).

3.3 Bratwurst

On three separate days (defined as replicate), approximately 31.725 kg of fresh pork (approximately 17% lipid) was obtained from a local processor. On each of those 3 d, whole product was coarse ground once using a 12.7 mm plate. The coarse ground product was then fine ground once using a 4.8 mm plate. Upon grinding, product was weighed out into nine separate batches, one for each of the nine treatments in this study, each weighing 3.175 kg. From these nine batches, each group was assigned to a treatment and formulated accordingly. Bratwurst sausage was produced by treatment group following the recipe defined in Table 13. Each batch of fine ground product was then mixed with a pre-mixed spice blend (T.A.M.U. Bratwurst Seasoning; Reo Spice & Seasoning, Inc., Huntsville, Tx), 95.3 g (3%) water, and its designated treatment (or lack of treatment) for 2 min using a paddle mixer (Gander Mountain, Saint Paul, Minnesota) and stuffed into natural hog casings (DeWied International, San Antonio, TX) approximately 32-34 mm in diameter. Once the product was stuffed, 18 links were formed measuring approximately 140 mm in length. Uncooked bratwurst links (number varied due to different tests on each storage day) were stored immediately after manufacture at 4°C for 0, 1, 3, and 5 d and evaluated accordingly.

Raw lipid and moisture and pH, and cooked chemical and color analyses were conducted using the methods previously described for sausage patties. Note that for objective color analysis of cooked bratwursts, three individual slices (approximately 12.7 mm thick) of one link per treatment were evaluated to get a proper average across the entire link. Also, objective color was not evaluated on raw product due to the product being encased. On each of the 4 d of storage (0, 1, 3, and 5 d), bratwursts were cooked to an internal temperature of 70ºC using a Hamilton Beach HealthSmart grill (Hamilton Beach/ Proctor-Silex, Inc., Southern Pines, NC) set and maintained at approximately 177°C. Internal temperature was monitored by an iron thermocouple probe (Omega Engineering, Stamford, CT) placed in the geometric center of each link, attached to an Omega HH501BT Type T thermometer (Omega Engineering, Inc., Stamford, CT). Pre- and post-cook weights were obtained and cook yield was calculated. After cooking, links were cooled to 4°C and two links, each, were placed on a Styrofoam tray and over-wrapped with PVC film (AEP Industries; Matthews, NC).

Sensory and AromaTrax were evaluated after 1 and 3 d of storage. Sensory evaluation of bratwurst sausages was conducted in the same manner as that of the previous products described in this study. Note that panelists were trained for 10 d prior to the study using the lexicon described in Table 14. For Spice Complex, special attention was paid to the difference in taste of the spice blend used in the bratwurst, as it was different than the spice blend found in the sausage patties. Also, instead of wedges or halves, panelists were given two 12.7 mm thick slices of a link from each of the nine treatments. All other sensory evaluation practices were conducted as previously described in sausage patties and chicken nuggets. For AromaTrax analysis, one link was evaluated per treatment following the same sample preparation procedures as previously described.

3.4 Cooked Turkey Patties

On three different days (defined as replicate), 36.3 kg of raw ground, dark turkey meat (approximately 7% lipid) was obtained from a commercial turkey processor (Jennie-O's, Austin, MN). Within a day, the ground turkey was divided into nine batches weighing 3.175 kg apiece for each of the nine treatments in this study. Turkey patties were produced by treatment group following the recipe defined in Table 18. After division, product was mixed, 18 patties (155 g; 10.8-cm diameter x 1.6-cm thick; n = 20) were formed and stored as described for sausage patties. Patties were cooked, packaged, evaluated and raw and cooked chemical data were collected as discussed for pork sausage patties. The process of sensory analysis was carried out as described for sausage patties. However, panelists were trained on a separate lexicon for turkey patties as described in Table 19. Note the main difference in this lexicon as opposed to the other lexicons was the absence of spice blend and the change from pork flavor to turkey flavor. Raw color for turkey patties was evaluated using AMSA's Guidelines for Meat Color Evaluation (AMSA, 1991), where 1 = very bright reddish pink and 8 = tan to brown; as this was the closest representative, on a scale basis, to the color of the turkey product. Most color score values analyzed were 3 (dull reddish pink), 4 (slightly grayish pink), 5 (grayish pink), and 6 (slightly tannish gray).

3.5 Statistical Analysis

Data were analyzed using analysis of variance with alpha < 0.05 using SAS (v9.3, SAS Institute, Inc., Cary, NC). The model included replicate as a block, antioxidant treatment, storage day and the antioxidant treatment by storage day interaction in a factorial arrangement of a randomized block design. Least squares means were calculated where F-test significance ($P < 0.05$) was reported in the analysis of variance (ANOVA) table. Least squares means were separated by Fisher's protected least significant differences (pair-wise t-tests) using the pdiff function of SAS. Interaction least squares means were presented when significant ($P < 0.05$) F-test effects were reported in the analysis of variance table. Simple correlation coefficients were generated using the CORR procedure of SAS. Partial least squares regressions were calculated and created using the XLSTAT component of Microsoft Excel.

4. RESULTS AND DISCUSSION

4.1 Fully Cooked Dark Meat Chicken Nuggets

Chemical and color data for chicken nuggets with antioxidant and storage day treatments are presented in Table 4. Antioxidant treatments affected ($P < 0.001$) L*, a* and b* color space values. Chicken nuggets containing black tannin sorghum bran were darker (lower L* values) and more red (higher a* values) with less yellow color (lower b* values) than all other chicken nugget treatments ($P < 0.05$). Within sorghum bran treatment, chicken nuggets were darker, more red and less yellow as level increased from 0.25% to 0.50% sorghum bran ($P < 0.05$). Control cooked nuggets (control, BHA/BHT and rosemary treatments) were lighter ($P < 0.001$) than sorghum-treated nuggets. This is most likely due to the sorghum bran being darker in color and in a solid, non- dissolvable form, unlike BHA/BHT and rosemary treatments which are in crystalline and liquid form, respectively. Neither antioxidant treatment ($P = 0.28$) nor storage day ($P = 0.99$) affected TBARS. As storage day increased, cooked chicken nuggets were lighter, with less red and higher levels of yellow color ($P < 0.05$). There was an antioxidant treatment by storage day interaction ($P < 0.05$; Figure 1) for pH of chicken nuggets. On d 0 of storage, cooked chicken nuggets containing rosemary had the highest pH. Control and BHA/BHT-treated cooked chicken nuggets had slightly lower pH ($P < 0.05$) values and cooked chicken nuggets with sorghum bran treatments had the lowest pH ($P < 0.05$) values. As storage time increased, pH decreased ($P < 0.05$), but pH did not significantly differ ($P > 0.05$) across treatments after 3 and 5 d of storage. Note that the pH for chicken nuggets was the highest (on average) when compared to the other three products in the study. This is most likely due to the addition of phosphate (PO_4) in the brine during chicken nugget preparation in order to increase water holding capacity of the nuggets. Knipe et al. (1985) found that, with the addition of various types of phosphate, pH increased as did water holding capacity.

Sensory texture attributes were not affected by the addition of sorghum bran or storage day ($P > 0.05$; Table 5). Flavor descriptive attributes were not affected ($P > 0.05$) by antioxidant treatment, except control cooked chicken nuggets, which were more sour than cooked chicken nugget treated with BHA/BHT, or either sorghum bran added at 0.5% ($P < 0.05$; Table 6). Storage days did not affect ($P > 0.05$) flavor descriptive attributes of cooked chicken nuggets.

These results indicate that sorghum bran addition did not negatively affect the texture or flavor of chicken nuggets. These findings agree with those of Roybal (2010), as the addition of antioxidant treatments did not negatively affect flavor of the product. The changes in color in this study were in the meat component and may slightly influence consumer perception. Interestingly, in this study, there was no oxidation occurring in the nuggets during refrigerated storage. The threshold of acceptability for lipid oxidation/ rancidity is a value of 1- 2 (Watts, 1962). In this particular study, the TBARS values were low (less than 2.00) for cooked chicken nuggets even after 5 d of storage in PVC overwrapped packaging under lights. This result was somewhat unexpected as poultry has a higher amount of phospholipids, which are more susceptible to lipid oxidation, especially when cooked, compared to other species (Pearson et al., 1977; Rhee et al., 1996). It seems that the breading may have protected the nuggets from oxidation within this system as the breading was not included in the chemical analyses. One explanation for this occurrence (or lack thereof) could possibly be explained by the findings of Lalam et al. (2012). Chicken nuggets for the aforementioned study were measured for fat uptake between the breading and the core of the product (the meat/lean portion) after being deep fat fried, similar to the methods used for the current study. It was found that fat uptake, across the entire study, was relatively higher in the crust portion of the nugget than the core (Lalam et al., 2012). Since the crust was not included in TBARS analyses for the current study, it could be suggested that the low level of oxidation found was due to the crust containing most of the fat content.

Also, as previously mentioned, the chicken nuggets in this study had a high pH level, which could have also played a role in inhibiting lipid oxidation. Tichivangana and Morrissey (1985) found that there was an inverse relationship between pH and lipid oxidation in poultry products. The higher the pH value, the lower the occurrence of lipid oxidation. Mast et al. (1979) also found an inverse relationship in pH and lipid oxidation of poultry meat, where poultry with lower pH than the control group had higher amounts of lipid oxidation. Another possible scenario, cooked chicken nuggets are commonly frozen for up to 6 to 12 mo. In frozen storage, oxidation occurs within 6 mo (Dr. Cain Cavett, Tyson Foods, personal communication). It may be advisable to test the efficacy of sorghum bran addition on cooked chicken nuggets using a frozen storage system instead of a refrigerated system, or investigate a longer refrigerated storage period.

4.2 Pre-cooked Pork Sausage Patties

Chemical and color values for sausage patties are presented in Table 9. Antioxidant treatment did not affect raw or cooked pH ($P > 0.05$). The pH of the cooked sausage patties was higher ($P = 0.01$) at d 1 compared to d 3 of storage. There was no treatment affect ($P > 0.05$) for raw subjective color values in pork sausage patties, however; the addition of any of the sorghum bran treatments resulted in darker (lower L* values; $P < 0.05$) cooked sausage patties compared to those from control, BHA/BHT, or rosemary. The a* values were not affected ($P = 0.96$) by antioxidant treatment. Control and 0.25% black tannin sorghum bran cooked pork sausage patties had similar b* values, but differences in b* values of cooked pork sausage patties from other sorghum treatments, while slightly lower, were minimal ($P < 0.05$; Table 9). With increased storage, cooked pork sausage a* and b* values significantly decreased ($P < 0.001$), but antioxidant treatments did not affect this change in color with storage. Sausage patty TBARS values were not affected by antioxidant treatment ($P = 0.35$) or storage time ($P = 0.23$). This was surprising as storage of cooked pork sausage patties in aerobic storage under white lights at 4°C would be expected to result in lipid oxidation. Cooked pork sausage patties contained about 25% chemical lipid (Table 10) and 56% moisture. It would be expected that at this lipid level, lipid oxidation would occur.

However, control cooked pork sausage patties had very low levels of lipid oxidation (Table 9). It is apparent that ingredient addition, such as sage, in the spice blend that was inherent in the product formulation at the processing facility, may have contributed to the lack of lipid oxidation in these patties. The antioxidant capacity of sage has been of significant interest to researchers in recent years. Results from a study conducted by McCarthy et al. (2001) showed that sage was similar in effectiveness as rosemary and BHA/BHT at suppressing lipid oxidation over the course of 9 d of refrigerated storage. Also, El-Alim et al. (1999) found that sage significantly decreased oxidation during 6 mo of frozen storage in ground pork patties, as compared to other herbs in the study. Results from these studies suggest that sage possesses antioxidant properties, and the inclusion of sage in this product could possibly explain the lack of oxidation expressed in pork sausage patties in this study.

Additionally, pork sausage patties were formulated from pre-rigor, hot-boned pork sow meat. Consequently, lipid oxidation may have been limited due to the use of this type of meat, which has a higher pH value (approximately 6.2 in this study). In previous research, pH has been shown to have an influence on lipid oxidation (Chen and Waimaleongora-Ek, 1981; Judge and Aberle, 1980; Keskinel, 1962; Owen and Lawrie, 1975). In the study conducted by Owen and Lawrie (1975), lipid oxidation was thought to be inhibited by high pH (6.14) in raw, frozen ground pork. Judge and Aberle (1980) found similar results in ground pork stored at 2°C for 10 d. Also, Tichivangana and Morrissey (1985) conducted a study using ground lean from various species of the common meat producing animals. Samples from each species were cooked and stored at 4 °C for 0, 24 and 48 h, and were subject to four levels of pH (3, 5, 7 and 9). For ground pork samples, as pH increased from 3 to 7, TBA values for lipid oxidation decreased, reaching a minimum at a pH of 7 (Tichivangana and Morrissey, 1985). Results from these studies, along with the results from the current study indicate that lipid oxidation was most likely inhibited due to the higher pH level measured in the product.

The addition of antioxidant treatments did not significantly affect cook loss ($P > 0.05$) in pork sausage patties during initial cooking (Table 10). Additionally, upon re-heating patties for sensory evaluation, while pre-heat and re-heat patty weights differed and re-heat cook loss was affected by antioxidant treatment ($P < 0.05$), consistent treatment effects were not found (Table 11). Based on the inconsistency in weight differences between treatments, it cannot be concluded that antioxidant treatment was the primary cause of the difference in cook loss. However, it should be noted that pork sausage patties containing the higher levels of black tannin sorghum bran tended to be heavier (approximately 2-3 g heavier), but had slightly more ($P < 0.05$) re-heat cook loss than control patty treatments. Cook loss results from this study are similar to those found in the study conducted by (Lau and King, 2003). During that study, it was concluded that the excessive loss of moisture, compared to the control, was most likely due to the powdered texture of the grape seed used as the tested subject for the study. Conclusions were made that the powdery texture of the grape seed affected the cohesion of the product, thus making the product more susceptible to water loss due to lack of uniformity and increased surface area (Lau and King, 2003). Like the grape seed flour used in the aforementioned study, sumac and black tannin sorghum bran are also powdered substances. The texture of the potential antioxidant additives may have played a role in the amount of water loss found in the sorghum-added patties in this study.

Descriptive flavor sensory attributes across antioxidant and storage day treatments are presented in Table 12. The BHA/BHT treated patties were lower ($P < 0.05$) in pork flavor and overall sweet, and higher in sweet, bitter and BHA/BHT flavor than patties from the other treatments. Cooked pork sausage patties did not differ ($P > 0.05$) in salty, sour, sorghum, spice complex, brown/roasted, rosemary, and fat-like flavor attributes across antioxidant treatments. As storage day increased from 1 to 3 d of storage, cooked pork sausage patties decreased ($P < 0.05$) in pork, rosemary, and fat-like flavor, and increased ($P < 0.05$) in sour flavor, most likely due to microbial growth. As storage day increased, cooked pork sausage patties did not differ ($P > 0.05$) in salty, sweet, bitter, sorghum, spice complex, BHA/BHT, brown/roasted, or overall sweet flavors.

These results indicate that in refrigerated, aerobically-stored, cooked pork sausage patties, the addition of sorghum bran did not affect lipid oxidation, chemical, patty composition, color, or pork sausage patty flavor attributes. It was surprising that even control patties did not have appreciable levels of lipid oxidation. The results in this study regarding lipid oxidation disagree with the theory of Pearson et al. (1977), as it was pointed out that comminuted meat products should develop higher levels of lipid oxidation due to more exposed phospholipids. These findings also do not agree with Ladikos and Lougovois (1990), as they point out that cooked meats held in refrigerated storage should develop rancid odors and flavors within 48 h at 4°C. These results were most likely due to either the additional ingredients added to this product, such as sage, at the plant during formulation of the sausage, or the use of hot-boned, high-pH pork meat in the manufacture of this product.

Appropriate oxidation conditions were not created to test the efficacy of sorghum bran as an antioxidant; however, the addition of sorghum bran did not appreciably affect color, pH or flavor attributes. To test the efficacy of sorghum bran's antioxidant capabilities in cooked pork sausage patties, a study examining the effect of sorghum bran addition in pre-cooked, frozen pork sausage patties needs to be conducted. As pre-cooked pork sausage patties are traditionally packaged in aerobic atmospheres at frozen temperatures for up to 12 mo, these conditions should be emulated to test the efficacy of sorghum bran as an antioxidant. To stress this point, it was found that cooked samples, both control and antioxidant treated, stored for just 36 d at -18°C exhibited increased TBARS values (Keller and Kinsella, 1973), emphasizing that longer storage time would yield better results of the antioxidant treatment potential.

4.3 Bratwurst

Antioxidant addition did not affect ($P > 0.05$) raw or cooked pH of bratwursts nor raw subjective color, b* or TBARS values (Table 15). Bratwursts containing black tannin sorghum bran had lower ($P < 0.05$) L* values and lower ($P < 0.05$) a* values than other antioxidant treatments. Higher levels of black tannin sorghum bran addition increased ($P = 0.03$) the darkness and reduced ($P = 0.04$) the redness in bratwursts. TBARS values were extremely low across antioxidant treatments and storage days (less than 0.1 each); however, there was no significant difference among treatments ($P = 0.90$) or storage days ($P = 0.43$) in TBARS values. Days of storage significantly increased raw ($P = 0.001$) and cooked pH ($P < 0.001$) through d 0 through 3; however, it was interesting that both raw and cooked pH values were lower on d 5.

The occurrence of a low pH at d 5 could be due to high levels of lactic acid bacteria (LAB) build up during the storage process. Lactic acid bacteria are able to grow in a variety of conditions as they do not require oxygen for growth and can survive in low pH environments (Egan, 1983). Lactic acid bacteria are able to thrive in low oxygen environments and can survive in products that contain salt, such as the bratwursts in this study, and the presence of a carbohydrate source creates a favorable medium for LAB growth (Egan, 1983). Bratwursts were obviously encased in this study, and the casings could have potentially created a barrier, much like a sort of packaging, which was conducive to higher levels of LAB formation. Color values were significantly affected by days of storage as L* ($P < 0.001$) and a* ($P = 0.01$) values decreased with storage, and b* ($P > 0.05$) values were not affected. Bratwursts contained about 17% lipid and 61% moisture (Table 16). Bratwursts containing antioxidant ingredients were heavier prior to cooking ($P = 0.001$) and control bratwursts were the lightest weight ($P < 0.001$) after cooking. Cook loss was less in bratwursts containing sorghum bran treatments ($P < 0.001$); however, cook loss differences were about 1.5 to 1 %.

The effect of antioxidant treatment and storage days on descriptive flavor attributes for bratwursts are reported in Table 17. Bratwursts containing BHA/BHT had less ($P < 0.05$) pork, sweet, spice complex and overall sweet flavor attributes, and more ($P < 0.05$) sour, bitter, and BHA/BHT flavor attributes, compared to all other treatments. Salty, sour, sorghum, brown/roasted, rosemary, and fat-like were not affected ($P > 0.05$)

by antioxidant treatment. These results indicate that sorghum bran addition did not negatively affect bratwurst flavor attributes and, in fact, the use of sorghum bran instead of BHA/BHT as an antioxidant resulted in bratwurst with similar flavor as control bratwursts. The results of sorghum bran effect on flavor are similar to those found by Hemphill (2006).

The use of other non-meat ingredients and casings for bratwursts may have influenced the rate of lipid oxidation in bratwurst in this study. As no detectable level of lipid oxidation was reported, these results are inconclusive as to the effectiveness of sorghum bran as a natural antioxidant. The findings in this study were not in agreement with the theories of Taylor (1987) or Sato and Hegarty (1971) as they proposed that the addition of salts and other spices along with the grinding process should develop oxidation capabilities. However, these results indicate that the addition of sorghum bran to bratwursts did not affect the pH, color, and flavor attributes appreciably. To determine efficacy of sorghum bran as a natural antioxidant, studies using frozen bratwurst over a 6 to 12 mo storage time may be needed, as Pearson et al. (1977) proposed that lipid oxidation was more likely to occur in pre-cooked meat products that were stored for multiple weeks or months.

4.4 Pre-cooked Turkey Patties

Antioxidant treatments did not affect the raw or cooked pH of cooked turkey patties ($P > 0.05$; Table 20), or raw subjective color values ($P > 0.05$). Cooked turkey patties had lower L* and b* values ($P < 0.001$) with the addition of sorghum bran, and these values continued to decrease with higher levels of sorghum bran added. There was no significant antioxidant treatment effect on a* values ($P = 0.18$). Cooked pH values significantly decreased with the increase in 3 d of storage ($P < 0.001$); however, pH values exhibited on d 5 were higher than any other day, however, the reasoning behind this cannot be explained. As days of storage increased, L* ($P < 0.001$), a* and b* values ($P < 0.05$) decreased, but a* inexplicably exhibited higher values at d 5 than d 0. There was a significant antioxidant treatment effect ($P < 0.001$) on TBARS values in cooked turkey patties. Control patties had high TBARS values (greater than 7.0) indicating that lipid oxidation occurred in cooked turkey patties, given that the threshold of acceptability for lipid oxidation in poultry is 1- 2 (Watts, 1962). The addition of sumac and black tannin sorghum bran decreased or improved TBARS values and as level of sumac and black tannin sorghum bran addition increased, TBARS values decreased. Turkey patties containing black tannin sorghum bran had lower TBARS values than turkey patties containing sumac sorghum bran. As storage days increased, TBARS values increased ($P < 0.001$). There was an antioxidant treatment by storage day interaction ($P < 0.001$; Figure 2). Control patties increased in TBARS with increased storage day and well above those with antioxidant ingredients showing that lipid oxidation occurred. On d 0, cooked turkey patties containing antioxidants had lower TBARS values than control patties. After 1 d of storage, control patties increased in TBARS value and cooked turkey patties containing rosemary, and 0.25 sumac and black tannin sorghum bran increased ($P < 0.001$) in TBARS values. Patties from the other treatments had low TBARS values. After 3 d of storage, control patties continued to increase in TBARS values. Cooked turkey patties containing rosemary increased in

TBARS values, but did not have levels similar to control. Cooked turkey patties containing 0.5 and 0.75% sumac and black tannin sorghum bran and those with BHA/BHT had low TBARS values indicating that these ingredients were affective antioxidants. After 5 d of storage, control patties had the highest TBARS values followed by patties containing rosemary. Cooked turkey patties containing 0.25% sumac and black tannin sorghum bran had lower ($P < 0.001$) TBARS values than control and rosemary patties. Even after 5 d of storage, cooked turkey patties containing 0.5% and 0.75% sumac and black tannin sorghum bran had the lowest TBARS values. While storage TBARS values increased slightly for these patties, TBARS values indicated that both the sumac and black tannin sorghum bran were effective antioxidants. The antioxidant effectiveness of both sorghum brans are similar to results found by Awika (2003).

The addition of antioxidant treatments did not affect lipid percentage ($P = 0.63$; Table 21). Cooked turkey patties containing sorghum bran had lower moisture percentage ($P < 0.05$) than patties containing rosemary. The explanation for this occurrence could be explained as was for pork sausage patties. As described by Lau and King (2003), the powdered texture, of the sorghum bran in this case, may have altered the cohesiveness of the product, which allowed for more moisture to be lost during the heating process. Raw and cooked patty weights were higher in patties containing sorghum bran ($P < 0.001$) and cook loss was lowest in these same patties ($P < 0.001$). Reheat weights for cooked turkey patties are reported in Table 22. Patties containing sorghum bran treatments had higher pre-heat ($P < 0.001$) and reheat ($P = 0.01$) weights, but they did not have less cook loss during reheating compared to control patties ($P >$ 0.05). These results indicate that sorghum bran addition did not affect water retention in cooked turkey patties.

Descriptive sensory flavor attributes of cooked turkey patties are presented in Table 23. Cooked turkey patties containing BHA/BHT had less ($P < 0.05$) turkey, warmed-over, overall sweet, cardboard, sweet and salty flavor; and the highest level ($P < 0.05$) of sour, bitter and BHA/BHT flavor, compared to all other treatments. Control cooked turkey patties had higher ($P < 0.03$) refrigerator stale values compared to all other treatments. There was an antioxidant by storage day interaction ($P = 0.013$) on BHA/BHT sensory flavor attribute values (Figure 3). Brown/roasted, fat-like, and rosemary flavor attributes were not affected by antioxidant treatments ($P > 0.05$). Control patties had the highest level of warmed-over, refrigerator stale, and cardboardy flavor ($P < 0.05$) as would have been expected and is explained by Tims and Watts (1958), based on TBARS values for control patties. As storage day increased, turkey flavor and overall sweet values significantly decreased ($P < 0.05$), and warmed-over and sour flavors increased ($P < 0.05$).

4.5 Flavor Compounds

To understand what volatile flavor compounds affected flavor of cooked pork sausage patties, bratwursts and cooked turkey patties, 35 volatile flavor compounds were identified (Table 24). The simple correlations between the 35 volatile flavor compounds, and TBARS values and the descriptive flavor sensory attributes are presented in Tables 25, 26 and 27 for cooked pork sausage, bratwursts, and cooked turkey patties, respectively. As lipid oxidation was limited in cooked pork sausage patties and bratwursts, it was not surprising that simple correlation coefficients were low and most were not significant (*P* > 0.05) between TBARS and flavor volatile compounds. However, TBARS values and 2,4 decadienal, nonanal, 1-octanol, 2-decanone, heptane and nonenal were slightly correlated (*P* < 0.05). These compounds have been shown to be products of lipid oxidation and this relationship supports that lipid oxidation was occurring during storage in cooked turkey patties.

For cooked pork sausage patties, decanal, heptanal, 2,4-decadienal, benzaldehyde, octanal, 1-octanol, 2-decanone, butylated hydroxytoluene, and heptane were moderately related (*P* < 0.05) to pork flavor. Fat-like flavor was moderately related to 1-octen-3-ol, 2,4 decadienal, and 2-decenal, (E). Spice complex was moderately and negatively related to benzaldehyde and 2-decanone and positively related to alpha teripineol. Rosemary flavor was negatively and moderately related to 2, 4 decadienal and 2-decanal, (E). BHA/BHT, sorghum and metallic flavors were not moderately or highly related to the 35 volatile compounds. Overall sweet flavor was moderately and negatively related to butylated hydrooxytoluene and heptane. Butylated hydrooxytoluene was also negatively and moderately related to sweet taste and positively and moderately related to bitter taste. Heptanal was negatively and moderately related to sour and salty tastes. Green/hay-like flavor was not highly related to the 35 volatile compounds.

Similar relationships were reported for bratwursts and volatile chemical compounds; however, burnt flavor was identified in bratwursts. Butylated hydrooxyanisole was positively and highly correlated to burnt flavor. As higher levels of lipid oxidation were reported in cooked turkey patties, warmed-over flavor, refrigerator stale, cardboard, heated oil, smokey/wood and boar taint were reported even though these attributes were identified at somewhat low levels. Warmed-over flavor was moderately related to pentanal, 2-pentyl-furan, hexanal, 2-decenal, (E), 1-octanol, and nonenal. Refrigerator stale and cardboard flavors were similarly related to the same compounds plus additional compounds related to lipid oxidation. Heated oil flavor was moderately related to 2-ethyl-and 2-ethyl-3,5-dimethyl-pyrazine whereas green/hay-like was moderately related to 2,4 decadienal, 2-methyl- and 2-ethyl-3,5-dimethyl-pyrazine. Smokey/wood and boar taint were not highly related to the 35 volatile compounds. This was most likely due to the low level of these flavors in the cooked turkey patties.

These results indicate that flavors were related to lipid oxidation and that, in cooked turkey patties, where the highest level of oxidation occurred, volatile chemicals related to by-products of lipid oxidation. Specific flavor volatiles related to sorghum bran addition were not present, indicating that sorghum bran addition did not affect flavor. Rosemary and BHA/BHT addition to cooked pork patties, bratwursts and cooked turkey patties influenced flavor to a greater extent than sorghum bran addition.

5. CONCLUSIONS

Limited lipid oxidation occurred in the cooked chicken nuggets, cooked pork sausage patties, and bratwursts even though the system, aerobic storage for 5 d at 4°C has induced high levels of lipid oxidation with other products.   Due to the low level of lipid oxidation in these products, the efficacy of sorghum bran as an antioxidant was not sufficiently challenged. The batter and breading of the chicken nuggets, along with high pH levels due to the addition of phosphate as a water binding aid, most likely inhibited lipid oxidation in the product. The high pH of the hot-boned, pre-rigor pork used in the sausage patties most likely played the biggest role in the lack of oxidation. As stated earlier, there have been numerous studies where an inverse relationship has been found in high pH and low occurrences of lipid oxidation. The sage used in the cooked pork patties most likely protected the meat from oxidation as well, given the antioxidant properties that sage has been shown to possess. Also, the utilization of a casing, which created a sort of double barrier in conjunction with the PVC film used for packaging, along with insufficient storage time most likely helped to deter lipid oxidation in bratwurst. The efficacy of sorghum bran as an antioxidant needs to be tested in these products during frozen storage for up to 6 to 12 mo to induce lipid oxidation.

Lipid oxidation occurred in cooked turkey patties stored in PVC overwrapped packaging and stored for up to 5 d at 4°C under constant white lights. Control patties showed a high level of lipid oxidation. Patties containing rosemary, while not as high, had sufficient levels of lipid oxidation to show that while rosemary (the traditional natural antioxidant used in meat and poultry products) had limited ability to retard lipid oxidation. Additionally, rosemary resulted in flavor in cooked turkey patties. The addition of sumac and black tannin sorghum bran at 0.25% retarded lipid oxidation to a greater extent than rosemary, but after 5 d of storage, lipid oxidation occurred. However, the addition of 0.5% and 0.75% sumac and black tannin sorghum bran and BHA/BHT retarded lipid oxidation throughout the 5 d of storage. While the addition of black tannin sorghum bran impacted color slightly, flavor was not affected with the addition of either sumac or black tannin sorghum bran at these levels. These results indicate that either sumac or black tannin sorghum bran can be used at 0.5% or 0.75% levels as antioxidants.

The addition of sorghum bran did not negatively impact flavor, color, pH or water holding capacity in cooked chicken nuggets, cooked pork patties, bratwursts or cooked turkey patties. These results indicate that sorghum bran addition at the levels defined would not have functionality as a processing aid and would not affect flavor or color in the final product. Cooked turkey patties had the lowest level of total flavor as other non-meat ingredients were not added. The cooked turkey patties could be classified as bland in flavor. Even in the cooked turkey patties, sorghum bran addition did not affect flavor except flavors associated with lipid oxidation. The results from the turkey patties alone indicate that sorghum bran can be successfully used as a natural antioxidant to suppress lipid oxidation; however, further research needs to be conducted on products from other species in order to truly test its efficacy.

REFERENCES

Aberle, E. D., Forrest, J.C., Gerrard, D.E., and E.W. Mills. 2001. Principles of Meat Science. Kendall Hunt. Dubuque, IA.

Adhikari, K., Chambers, IV, E., Miller, R., Vázcuez-araújo, L., Bhumiratana, N., and C. Philip. 2011. Development of a lexicon for beef flavor in intact muscle. Journal of Sensory Science 26: 413-420.

Ahn, J., I. Grün, and L. Fernando. 2002. Antioxidant properties of natural plant extracts containing polyphenolic compounds in cooked ground beef. Journal of Food Science 67: 1364-1369.

Allen, C., and E. Foegeding. 1981. Some lipid characteristics and interactions in [avian, aquatic, and mammalian] muscle foods: a review. Food Technology 35.

AMSA. 1995. Research Guidelines for Cookery, Sensory Evaluation and Instrumental Tenderness Measurements of Fresh Meat. American Meat Science Association, Chicago, IL.

AMSA. 1991. Guidelines for Meat Color Evaluation. American Meat Science Association, Chicago, IL.

AOAC. 2000. Meat and Meat Products Official Methods of Analysis of AOAC International. p 1-23. AOAC International, Washington D.C.

Aruoma, O., B. Halliwell, R. Aeschbach, and J. Löligers. 1992. Antioxidant and pro-oxidant properties of active rosemary constituents: carnosol and carnosic acid. Xenobiotica 22: 257-268.

ASTM. 2011. Lexicon for Sensory Evaluation: Aroma, Flavor, Texture and Appearance. In: G. V. Civille, Lyon, B. G., Rutledge, K.P., Butkiewicz, N. (ed.). ASTM International, West Conshohocken, PA.

Awika, J. M. 2003. Antioxidant properties of sorghum. Doctoral Dissertation. Texas A&M University.

Awika, J. M. 2000. Sorghum phenols as antioxidants. Doctoral Dissertation. Texas A & M University.

Awika, J. M., L. W. Rooney, X. Wu, R. L. Prior, and L. Cisneros-Zevallos. 2003. Screening methods to measure antioxidant activity of sorghum (Sorghum bicolor) and sorghum products. Journal of Agricultural and Food Chemistry 51: 6657-6662.

Bekhit, A. E. D., and C. Faustman. 2005. Metmyoglobin reducing activity. Meat Science 71: 407-439.

Benedict, R. C., E. D. Strange, and C. E. Swift. 1975. Effect of lipid antioxidants on the stability of meat during storage. Journal of Agricultural and Food Chemistry 23: 167-173.

Biesalski, H., D. Nohr, J. Kerry, and D. Ledward. 2009. The Nutritional Quality of Meat. Improving the Sensory and Nutritional Quality of Fresh Meat: pg. 161-177.

Bors, W., W. Heller, C. Michel, and M. Saran. 1990. Radical Chemistry of Flavonoid Antioxidants. Antioxidants in Therapy and Preventive Medicine. pg. 165-170. Springer, New York, NY.

Buckley, D., J. Gray, A. Asghar, J. Price, R. Crackel, A. Booren, A. Pearson, and E. Miller. 1989. Effects of dietary antioxidants and oxidized oil on membranal lipid stability and pork product quality. Journal of Food Science 54: 1193-1197.

Buckley, D.J., P. Morrissey, and J. Gray. 1995. Influence of dietary vitamin E on the oxidative stability and quality of pig meat. Journal of Animal Science. 73: 3122-3130.

Byers, F. M., N. D. Turner, and H. Russell Cross. 1993. Meat Products in a Low-Fat Diet. Food Science and Technology. p 343. Marcel Dekker, New York.

Calkins, C., and J. Hodgen. 2007. A fresh look at meat flavor. Meat Science. 77: 63-80.

Carbonaro, M., F. Virgili, and E. Carnovale. 1996. Evidence for protein–tannin interaction in legumes: implications in the antioxidant properties of Faba bean tannins. Journal of Food Science and Technology 29: 743-750.

Carpenter, R., M. O’Grady, Y. O’Callaghan, N. O’Brien, and J. Kerry. 2007. Evaluation of the antioxidant potential of grape seed and bearberry extracts in raw and cooked pork. Meat Science. 76: 604-610.

Chen, C., A. Pearson, J. Gray, and R. Merkel. 1984. Effects of salt and some antioxidants upon the TBA numbers of meat. Food Chemistry 14: 167-172.

Chen, T. C., and C. Waimaleongora-Ek. 1981. Effect of pH on TBA values of ground raw poultry meat. Journal of Food Science 46: 1946-1947.

Cook, N., and S. Samman. 1996. Flavonoids—chemistry, metabolism, cardioprotective effects, and dietary sources. The Journal of Nutritional Biochemistry 7: 66-76.

Cruzen, S. M. 2010. Plant-Based Tannins as Antioxidants in Pre-Cooked Ground Beef Patties. Master Thesis. Texas A&M University.

Dean, R., and C. Ball. 1960. Analysis of the myoglobin fractions on the surfaces of beef cuts. Food Technology 14: 271.

Decker, E. A. 1995. The role of phenolics, conjugated linoleic acid, carnosine, and pyrroloquinoline quinone as nonessential dietary antioxidants. Nutrition Reviews 53: 49-58.

Decker, E.A., and L. Mei. 1996. Antioxidant mechanisms and applications in muscle foods. In: Reciprocal Meat Conference Proceedings. p 64-72.

Decker, E. A., and Z. Xu. 1998. Minimizing rancidity in muscle foods. Food Technology 52: 54-59.

Deighton, N., S. M. Glidewell, S. G. Deans, and B. A. Goodman. 1993. Identification by EPR spectroscopy of carvacrol and thymol as the major sources of free radicals in the oxidation of plant essential oils. Journal of the Science of Food and Agriculture 63: 221-225.

Dykes, L., L. W. Rooney, R. D. Waniska, and W. L. Rooney. 2005. Phenolic compounds and antioxidant activity of sorghum grains of varying genotypes. Journal of Agricultural and Food Chemistry 53: 6813-6818.

Egan, A. F. 1983. Lactic acid bacteria of meat and meat products. Antonie van Leeuwenhoek 49: 327-336.

El- Alim, S. S. L. A., A. Lugasi, J. Hóvári, and E. Dworschák. 1999. Culinary herbs inhibit lipid oxidation in raw and cooked minced meat patties during storage. Journal of the Science of Food and Agriculture 79: 277-285.

Faustman, C., and R. Cassens. 1990. The biochemical basis for discoloration in fresh meat: A review. Journal of Muscle Foods 1: 217-243.

Formanek, Z., A. Lynch, K. Galvin, J. Farkas, and J. Kerry. 2003. Combined effects of irradiation and the use of natural antioxidants on the shelf-life stability of overwrapped minced beef. Meat Science. 63: 433-440.

Frankel, E. 1984. Recent Advances in the Chemistry of Rancidity of Fats. Recent Advances in the Chemistry of Meat: pg. 87-118.

Gray, J., E. Gomaa, and D. Buckley. 1996. Oxidative quality and shelf life of meats. Meat Science. 43: 111-123.

Greene, B. E., I. M. Hsin, and M. Y. W. Zipser. 1971. Retardation of oxidative color changes in raw ground beef. Journal of Food Science 36: 940-942.

Grunert, K. G., L. Bredahl, and K. Brunsø. 2004. Consumer perception of meat quality and implications for product development in the meat sector—a review. Meat Science 66: 259-272.

Gutteridge, J. M. C. 1994. Biological origin of free radicals, and mechanisms of antioxidant protection. Chemico-Biological Interactions 91: 133-140.

Hagerman, A. E., K. M. Riedl, G. A. Jones, K. N. Sovik, N. T. Ritchard, P. W. Hartzfeld, and T. L. Riechel. 1998. High molecular weight plant polyphenolics (tannins) as biological antioxidants. Journal of Agricultural and Food Chemistry 46: 1887-1892.

Hahn, D., L. Rooney, and C. Earp. 1984. Tannins and phenols of sorghum. Cereal Foods World 29.

Haworth, J. E. 2003. Natural antioxidants review. RMC 2003: 95.

Hays, V. W., and R. L. Preston. 1994. Nutrition and feeding management to alter carcass composition of pigs and cattle: Low-fat meats design strategies and human implications. p 13-34. Academic Press, San Diego, CA.

Hemphill, S. P. 2006. Effect of Sorghum Bran Addition on Lipid Oxidation and Sensory Properties of Ground Beef Patties Differing in Fat Levels. Masters Thesis. Texas A&M University.

Hood, D., and E. Riordan. 1973. Discolouration in pre-packaged beef: measurement by reflectance spectrophotometry and shopper discrimination. International Journal of Food Science & Technology 8: 333-343.

Houlihan, C. M., C.-T. Ho, and S. S. Chang. 1985. The structure of rosmariquinone—A new antioxidant isolated from Rosmarinus officinalis L. Journal of the American Oil Chemists' Society 62: 96-98.

Houlihan, C. M., C.T. Ho, and S. S. Chang. 1984. Elucidation of the chemical structure of a novel antioxidant, rosmaridiphenol, isolated from rosemary. Journal of the American Oil Chemists Society 61: 1036-1039.

Hutchins, B. K., T. H. Liu, and B. M. Watts. 1967. Effect of additives and refrigeration on reducing activity, metmyoglobin and malonaldehyde of raw ground beef. Journal of Food Science 32: 214-217.

Jenschke, B. E. 2004. Chemical, Color, and Sensory Attributes of Sorghum Bran-enhanced Beef Patties in a High Oxygen Environment. Masters Thesis. Texas A&M University.

Jiménez-Colmenero, F., J. Carballo, and S. Cofrades. 2001. Healthier meat and meat products: their role as functional foods. Meat Science. 59: 5-13.

Judge, M., and E. Aberle. 1980. Effect of prerigor processing on the oxidative rancidity of ground light and dark porcine muscles. Journal of Food Science 45: 1736-1739.

Kähkönen, M. P., A. I. Hopia, H. J. Vuorela, J.-P. Rauha, K. Pihlaja, T. S. Kujala, and M. Heinonen. 1999. Antioxidant activity of plant extracts containing phenolic compounds. Journal of Agricultural and Food Chemistry 47: 3954-3962.

Kanner, J. 1994. Oxidative processes in meat and meat products: quality implications. Meat Science. 36: 169-189.

Keller, J. D., and J. E. Kinsella. 1973. Phospholipid changes and lipid oxidation during cooking and frozen storage of raw ground beef. Journal of Food Science 38: 1200-1204.

Keskinel, A. 1962. Determination of oxidative changes in raw meats by the 2-thiobarbituric acid method. Doctoral Dissertation. Iowa State University.

Knipe, C., D. Olson, and R. Rust. 1985. Effects of selected inorganic phosphates, phosphate levels and reduced sodium chloride levels on protein solubility, stability and pH of meat emulsions. Journal of Food Science 50: 1010-1013.

Kropf, D., M. Hunt, and D. Piske. 1986. Color formation and retention in fresh meat. In: Proccedings of Meat Industry Research Conference. p 62.

Ladikos, D., and V. Lougovois. 1990. Lipid oxidation in muscle foods: A review. Food Chemistry 35: 295-314.

Lalam, S., J. S. Sandhu, P. S. Takhar, L. D. Thompson, and C. Alvarado. 2012. Experimental study on transport mechanisms during deep fat frying of chicken nuggets. LWT-Food Science and Technology.

Lambrecht, H. S. 1995. Sulfite Substitutes for the Prevention of Enzymatic Browning in Foods. In: J. R. W. Chang, Y. Lee (ed.) Enzymatic Browning and Its Prevention. p 313–323.

Lau, D. W., and A. J. King. 2003. Pre-and post-mortem use of grape seed extract in dark poultry meat to inhibit development of thiobarbituric acid reactive substances. Journal of Agricultural and Food Chemistry 51: 1602-1607.

Lawrence, T., M. Dikeman, M. Hunt, C. Kastner, and D. Johnson. 2004. Effects of enhancing beef longissimus with phosphate plus salt, or calcium lactate plus non-phosphate water binders plus rosemary extract. Meat Science. 67: 129-137.

Lehmann, B. T., and B. M. Watts. 1951. Antioxidants in aqueous fat systems. Journal of the American Oil Chemists’ Society 28: 475-477.

Liu, Q., M. Lanari, and D. Schaefer. 1995. A review of dietary vitamin E supplementation for improvement of beef quality. Journal of Animal Science 73: 3131-3140.

Livingston, D. J., G. N. La Mar, and W. Brown. 1983. Myoglobin diffusion in bovine heart muscle. Science 220: 71-73.

Mancini, R.A. 2013. Meat Color. In: C. R. Kerth (ed.) The Science of Meat Quality. p. 177-198. Wiley-Blackwell, Ames, Iowa, United States.

Mancini, R. A., and M. C. Hunt. 2005. Current research in meat color. Meat Science 71: 100-121.

Mast, M. G., D. Jurdi, and J. H. MacNeil. 1979. Effects of CO2- snow on the quality and acceptance of mechanically deboned poultry meat. Journal of Food Science 44: 346-354.

McCarthy, T., J. Kerry, J. Kerry, P. Lynch, and D. Buckley. 2001. Evaluation of the antioxidant potential of natural food/plant extracts as compared with synthetic antioxidants and vitamin E in raw and cooked pork patties. Meat Science 58: 45-52.

McMillin, K. 1996. Initiation of oxidative processes in muscle foods. In: Reciprocal Meat Conferences Proceedings. p 53-64.

Millar, S., R. Wilson, B. Moss, and D. Ledward. 1994. Oxymyoglobin formation in meat and poultry. Meat Science 36: 397-406.

Morrissey, P. A., and J. Z. Tichivangana. 1985. The antioxidant activities of nitrite and nitrosylmyoglobin in cooked meats. Meat Science 14: 175-190.

Morrissey, P.A., Sheehy, P., Galvin, K., Kerry, J. and D. Buckley. 1998. Lipid stability in meat and meat products. Meat Science 49: S73-S86.

Nielsen, J. H., B. Sørensen, L. H. Skibsted, and G. Bertelsen. 1997. Oxidation in pre-cooked minced pork as influenced by chill storage of raw muscle. Meat Science 46: 191-197.

Nuñez de Gonzalez, M., R. Boleman, R. Miller, J. Keeton, and K. Rhee. 2008. Antioxidant properties of dried plum ingredients in raw and precooked pork sausage. Journal of Food Science 73: H63-H71.

Owen, J., and R. Lawrie. 1975. The effect of an artificially induced high pH on the susceptibility of minced porcine muscle to undergo oxidative rancidity under frozen storage. International Journal of Food Science & Technology 10: 169-180.

Pearson, A.M., J. D. Love, and F. Shorland. 1977. "Warmed-over" flavor in meat, poultry, and fish. Advances in Food Research 23: 1-74.

Pearson, A. M., and T. A. Gillett. 1996. Processed Meats. Springer. New York, NY

Ragan, M. A., and K.W. Glombitza. 1986. Phlorotannins, brown algal polyphenols. Progress in Phycological Research 4: 129-241.

Ramanathan, L., and N. Das. 1992. Studies on the control of lipid oxidation in ground fish by some polyphenolic natural products. Journal of Agricultural and Food Chemistry 40: 17-21.

Resurreccion, A. 2004. Sensory aspects of consumer choices for meat and meat products. Meat Science 66: 11-20.

Rhee, K. S. 1978. Factors affecting oxygen uptake in model systems used for investigating lipid peroxidation in meat. Journal of Food Science 43: 6-9.

Rhee, K.S., L. Anderson, and A. Sams. 1996. Lipid oxidation potential of beef, chicken, and pork. Journal of Food Science 61: 8-12.

Rice-evans, C. A., N. J. Miller, P. G. Bolwell, P. M. Bramley, and J. B. Pridham. 1995. The relative antioxidant activities of plant-derived polyphenolic flavonoids. Free Radical Research 22: 375-383.

Rooney, L. W., and R. D. Waniska. 2000. Sorghum Food and Industrial Utilization. In: C. W. Smith and R. A. Frederiksen (eds.) Sorghum: Origin, History, Technology, and Production. p 689-729. John Wiley and Sons, New York, NY.

Roybal, T. L. 2010. Sorghum Bran, Chestnut Wood Powder, and Chardonnay Grape Seed Flour Addition Effect on Lipid Oxidation and Color in Ground Beef Patties. Masters Thesis. Texas A&M University.

Sato, K., and G. R. Hegarty. 1971. Warmed-over flavor in cooked meats. Journal of Food Science 36: 1098-1102.

Sebranek, J., V. Sewalt, K. Robbins, and T. Houser. 2005. Comparison of a natural rosemary extract and BHA/BHT for relative antioxidant effectiveness in pork sausage. Meat Science 69: 289-296.

Shahidi, F. 2000. Antioxidants in food and food antioxidants. Food/Nahrung 44: 158-163.

Sheely, M. 2008. Global adoption of convenience foods. American Journal of Agricultural Economics 90: 1356-1365.

Tarladgis, B. G., B. M. Watts, M. T. Younathan, and L. Dugan Jr. 1960. A distillation method for the quantitative determination of malonaldehyde in rancid foods. Journal of the American Oil Chemists Society 37: 44-48.

Taylor, A. 1987. Effect of water quality on lipid oxidation. Food Science and Technology Today 1: 158-159.

Tims, M. J., and B. M. Watts. 1958. Protection of cooked meats with phosphates. Food Technology 12: 240-243.

Troy, D., and J. Kerry. 2010. Consumer perception and the role of science in the meat industry. Meat Science 86: 214-226.

USDA. 2000. Approval of substances for use in the preparation of products. http://www.gpo.gov/fdsys/pkg/CFR-1998-title9-vol2/pdf/CFR-1998-title9-vol2-sec318-7.pdf Accessed September 12, 2013.

USDA. 2005. Food standards and labeling policy book. http://www.fsis.usda.gov/OPPDE/larc/Policies/Labeling_Policy_Book_082005 Accessed July 9, 2013.

Willian, K. 2013. Lipids and Lipid Oxidation. In: C. R. Kerth (ed.) The Science of Meat Quality. Wiley-Blackwell, Ames, Iowa, USA

Wu, J. W., M.-H. Lee, C.-T. Ho, and S. S. Chang. 1982. Elucidation of the chemical structures of natural antioxidants isolated from rosemary. Journal of the American Oil Chemists' Society 59: 339-345.

Yun, J., F. Shahidi, L. J. Rubin, and L. L. Diosady. 1987. Oxidative stability and flavour acceptability of nitrite-free meat-curing systems. Canadian Institute of Food Science and Technology Journal 20: 246-251.

APPENDIX A

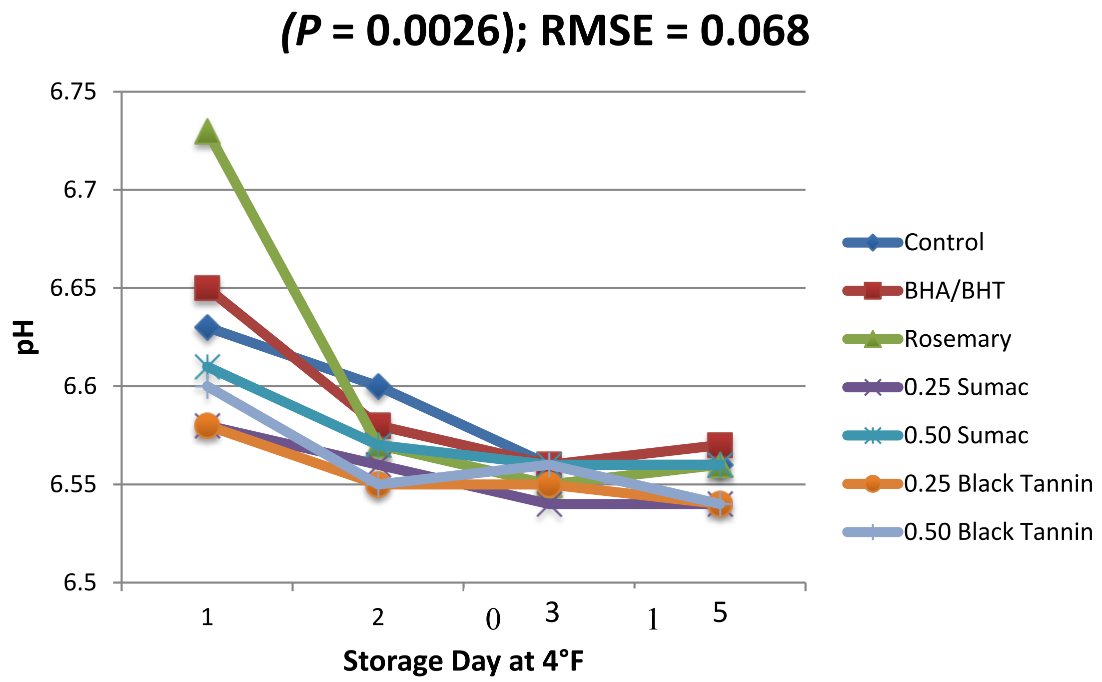

Figure 1. Interaction of antioxidant treatment and storage day on pH for chicken nuggets stored at 4°C in polyvinyl chloride (PVC) over-wrapped packaging.

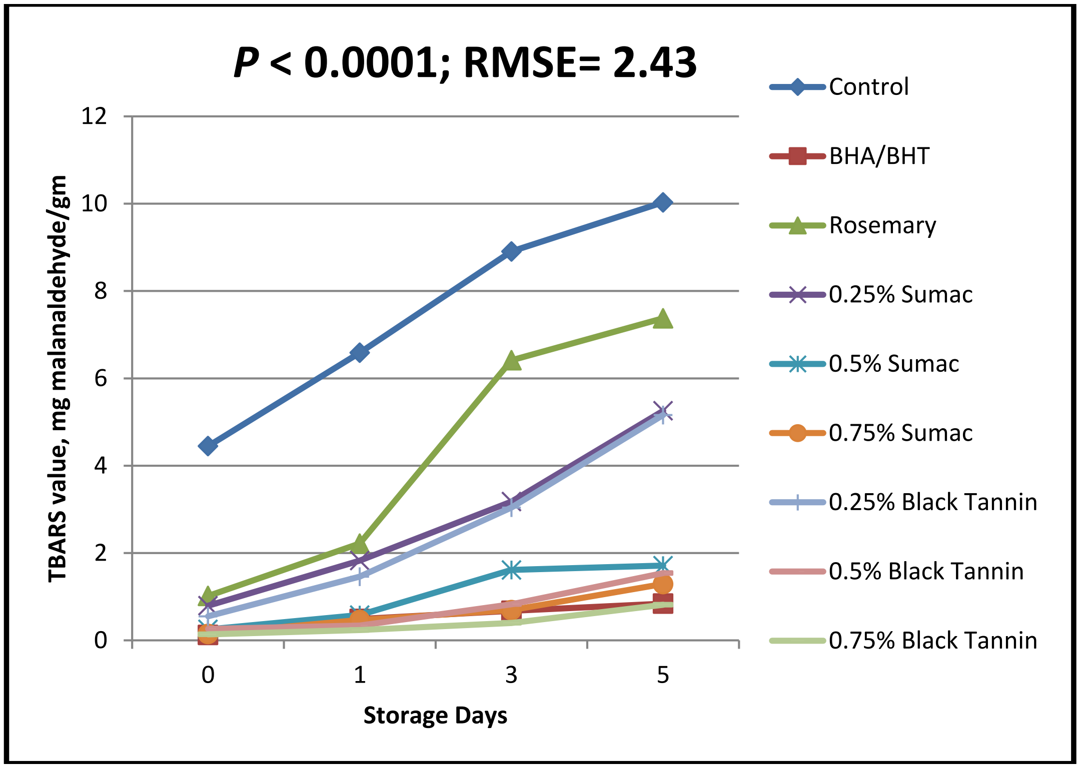

Figure 2. Interaction of antioxidant treatment and storage day on thiobarbituric acid reactive substances (TBARS) values for turkey patties stored at 4°C in polyvinyl chloride (PVC) over-wrapped packaging.

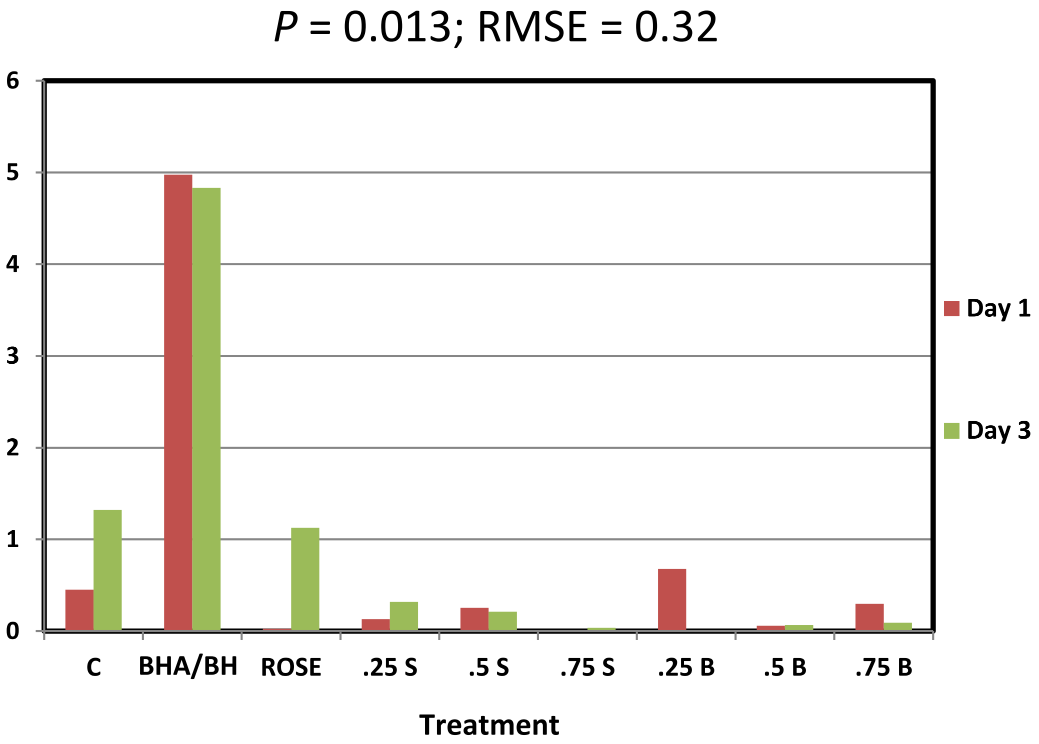

Figure 3. Interaction of antioxidant and storage day treatment on butylated hydroxyanisole (BHA)/butylated hydroxytoluene (BHT) flavor sensory attribute values for turkey patties stored at 4°C in polyvinyl chloride over-wrapped packaging.

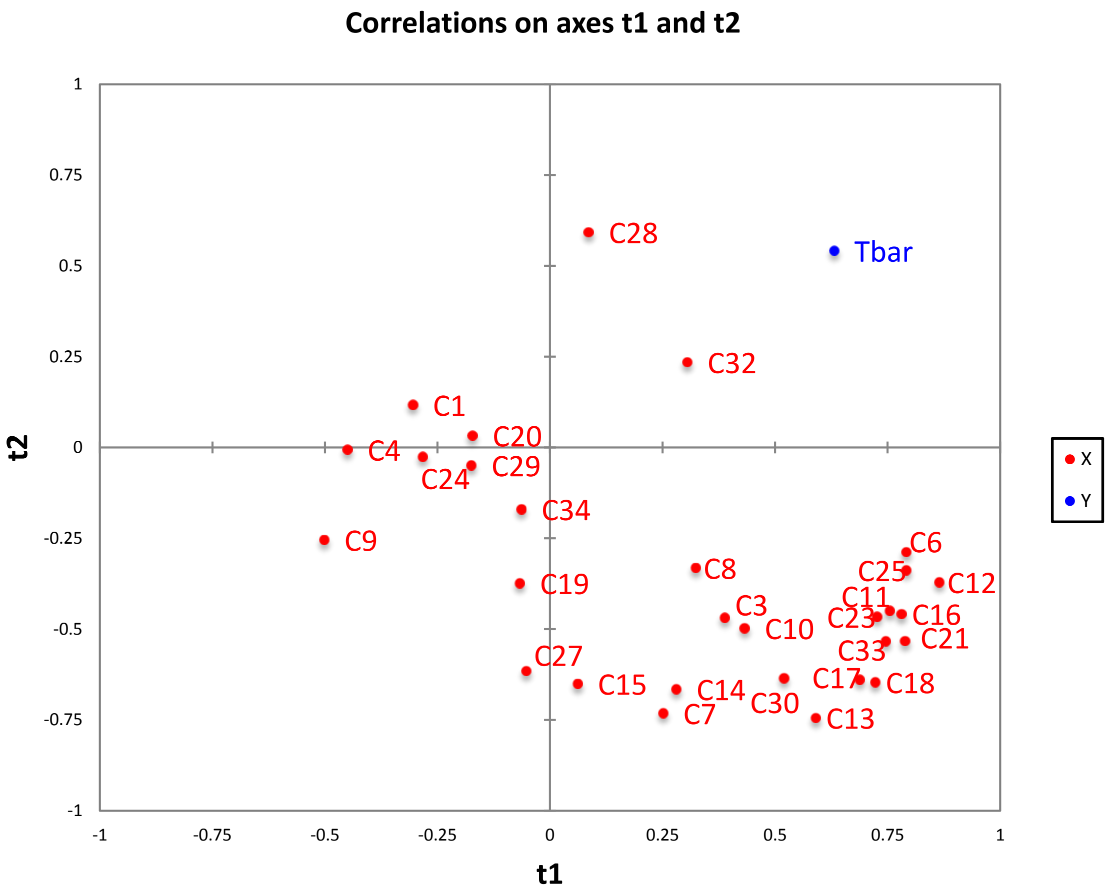

Figure 4. Partial least square regression analysis of volatile aroma compounds and thiobarbituric acid reactive substances (TBARS) for turkey patties. C1 = Trimethyl-Pyrazine, C2 = 2-Pentanone, C3 = 1-Pentanol, C4 = Styrene, C5 = Alpha, = Terpinene, C6 = Decanal, C7 = Pentanal, C8 = 1-Octen-3-ol, C9 = 2,5-dimethyl- Pyrazine, C10 = Octane, C11 = Heptanal, C12 = 2,4 Decadienal, C13 = 2-pentyl-Furan, C14 = Hexanal, C15 = Benzaldehyde, C16 = (E)-2-Decenal, C17 = Octanal, C18 = Nonanal, C19 = dl-Limonene, C20 = Alpha = Terpineol, C21 = 1-Octanol, C22 = 3-hydroxy-2-Butanone, C23 = 2-Decanone, C24 = (E)-2-Octenal, C25 = (E,E)-2,4-Nonadienal, C26 = Butanoic acid, C27 = Butyl Hydrooxy Anisole, C28 = Butylated Hydroxytoluene, C29 = E-2-decenal, C30 = 2-ethyl-Furan, C31 = 2-methyl-Furan, C32 = Heptane, C33 = Nonenal, C34 = 2-ethyl-3,5-dimethyl-Pyrazine, C35 = Trans-Anethole.

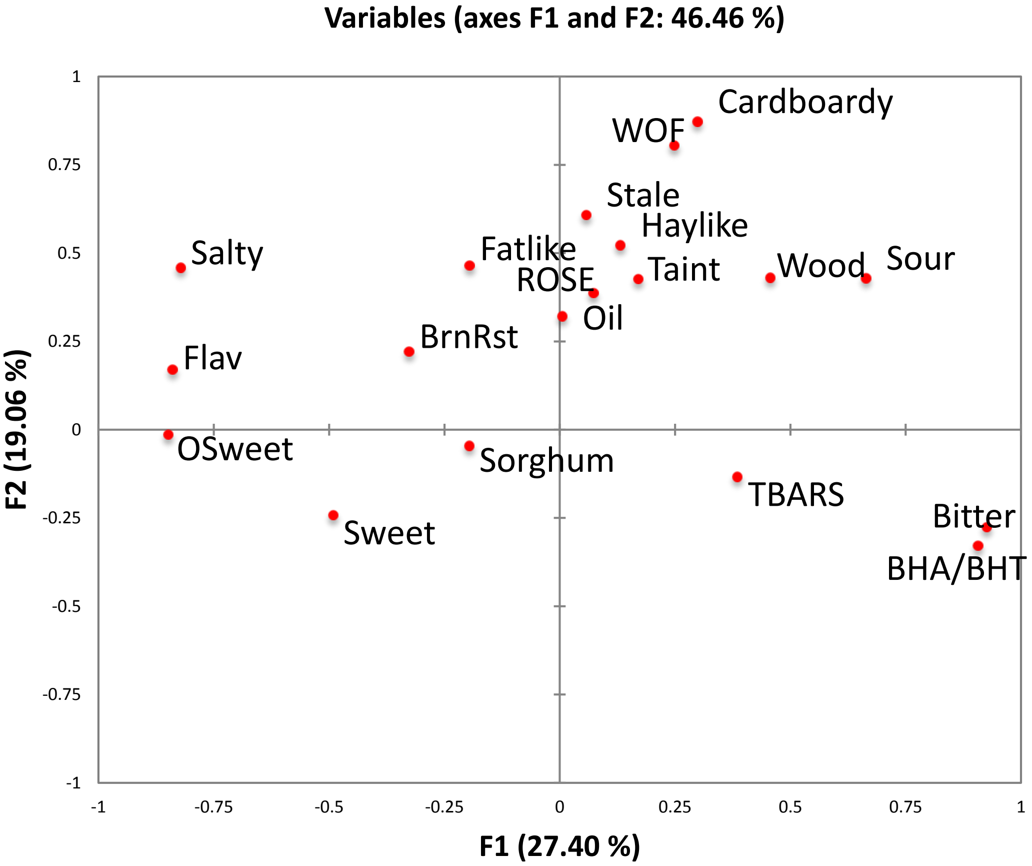

Figure 5. Partial least square regression analysis of descriptive sensory attributes and thiobarbituric acid reactive substances (TBARS) for turkey patties.

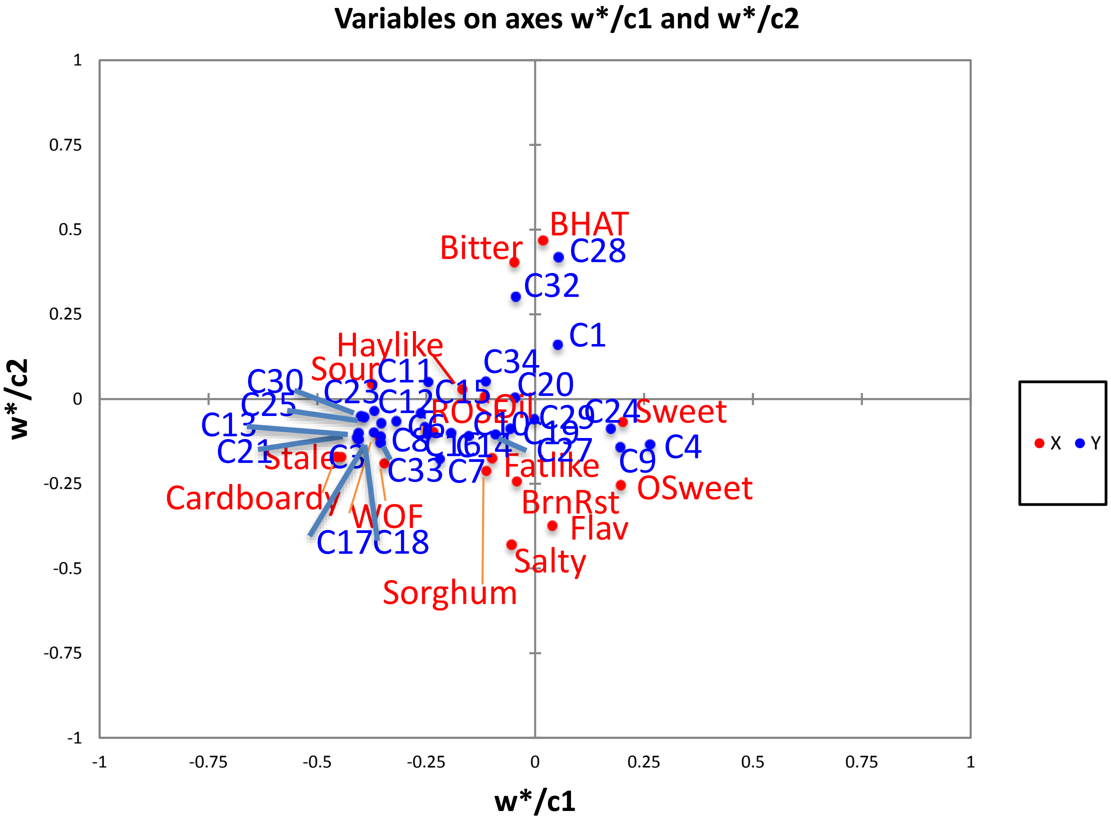

Figure 6. Partial least square regression analysis of descriptive sensory attributes and volatile aroma compounds for turkey patties. C1 = Trimethyl-Pyrazine, C2 = 2-Pentanone C3 = 1-Pentanol C4 = Styrene C5 = Alpha = Terpinene C6 = Decanal C7 = Pentanal C8 = 1-Octen-3-ol C9 = 2,5-dimethyl- Pyrazine C10 = Octane C11 = Heptanal C12 = 2,4 Decadienal C13 = 2-pentyl-Furan C14 = Hexanal C15 = Benzaldehyde C16 = (E)-2-Decenal C17 = Octanal C18 = Nonanal C19 = dl-Limonene C20 = Alpha = Terpineol C21 = 1-Octanol C22 = 3-hydroxy-2-Butanone C23 = 2-Decanone C24 = (E)-2-Octenal C25 = (E,E)-2,4-Nonadienal C26 = Butanoic acid C27 = Butyl Hydrooxy Anisole C28 = Butylated Hydroxytoluene C29 = E-2-decenal C30 = 2-ethyl-Furan C31 = 2-methyl-Furan C32 = Heptane C33 = Nonenal C34 = 2-ethyl-3,5 -dimethyl-Pyrazine C35 = Trans-Anethol.

APPENDIX B

Table 1. Recipe of dark meat chicken nuggets prepared based on seven different formulations.

Treatments	Boneless skinless breast meat, g (%)	Boneless skinless thigh meat, g (%)	Antioxidant g (%)	Marinade g (%)
Control	2041.00 (45%)	2041.00 (45%)	-	453.6 (10%)
0.02% BHA[y]/BHT[z]	2040.75 (44.99%)	2040.75 (44.99%)	0.907 (0.02%)	453.6 (10%)
0.2% Rosemary	2036.66 (44.9%)	2036.66 (44.9%)	9.07 (0.2%)	453.6 (10%)
0.25% Sumac	2035.53 (44.875%)	2035.53 (44.875%)	11.34 (0.25%)	453.6 (10%)
0.5% Sumac	2029.86 (44.75%)	2029.86 (44.75%)	22.68 (0.5%)	453.6 (10%)
0.25% Black tannin	2035.53 (44.875%)	2035.53 (44.875%)	11.34 (0.25%)	453.6 (10%)
0.5% Black tannin	2029.86 (44.75%)	2029.86 (44.75%)	22.68 (0.5%)	453.6 (10%)

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytolue

Table 2. Sensory flavor attributes and references for expert panel training for chicken nuggets. All definitions and references from Ceville (2007).

Attribute	Definition	Reference
Bitter	Taste on the tongue stimulated by solutions of caffeine, quinine, and certain other alkaloids	Caffeine (0.1% solution)
Brown Roasted	Aromatic associated with the outside of grilled or broiled meat	Grilled or broiled meat patty
Cardboardy	Aromatic associated with slightly oxidized fats and oils reminiscent of wet cardboard packaging	Cardboard (wet) = 6.0 (Aroma & Taste) Cardboard (dry) = 4.0 (Aroma); 5.0 (Taste)
Celery	Bitter aromatic, slightly astringent feeling factor, slightly salty taste, associated with celery	Chopped raw celery, butyl patholide
Chicken-like	Aromatic associated with cooked chicken white meat	Baked/broiled chicken breast meat
Feather-like/ Wet Poultry	Aroma reminiscent of wet poultry feathers found in products containing large amounts of mechanically deboned poultry meat	Processed poultry products (e.g. frankfurters)
Fishy	Aromatic associated with tri-methylamine and old fish	Tri-methylamine, cod liver oil
Grassy	Green, slightly sweet aromatic associated with fresh cut grass	Cis-3-hexenol (50 ppm in water)
Musky	An aroma associated with animals; musk aromas may be natural or synthetic	Tincture of civet

Table 2 continued. Sensory flavor attributes and references for expert panel training for chicken nuggets. All definitions and references from Ceville (2007).

Attribute	Definition	Reference
Onion	Aromatic associated with onion	Natural onion concentrate, onion powder
Painty	Aromatic associated with oxidized oil similar to the aromatic of linseed oil and oil-based paint	Linolenic acid, patenal, decatrienal, aged oil
Salty	Taste on the tongue stimulated by sodium salt especially sodium chloride	Solutions of sodium chloride 0.15% NaCl Solution = 1.5 (Taste) 0.25% NaCl Solution = 3.5 (Taste)
Sour	Basic taste on tongue stimulated by acids, aromatic caused by lactic acid bacteria	Citric acid, vinegar, lactic acid
Sweet	Taste on the tongue stimulated by sugars and high potency sweeteners	Sucrose (5% in water)

Table 3. Sensory texture attributes and references used for expert panel training for chicken nuggets.

Attribute	Definition	Scale Value	Reference	Brand/Type/ Manufacturer	Sample Size
Hardness	The force to attain a given deformation, such as: force to compress between molars, force to compress between tongue and palate, and force to bite through with incisors.	1.0	Cream cheese	Kraft Foods/ Philadelphia Light	12.7 mm cube
		2.5	Egg white	Hard cooked	12.7 mm cube
		4.5	Cheese	Yellow American pasteurized process-deli/Land O'Lakes	12.7 mm cube
		6.0	Olives	Goya Foods/queen-sized, stuffed	1 olive, pimento removed
		7.0	Frankfurter	Large, cooked 5 min/ Hebrew National	12.7 mm slice
		9.5	Peanuts	Cocktail type in vacuum tin/ Planters	1 nut, whole
		11.0	Carrots	Uncooked, fresh, Unpeeled	12.7 mm slice
		12.0	Almonds	Shelled/ Planters	1 nut
		14.5	Hard Candy	Life Savers	3 pieces, one color
Cohesiveness	The degree to which sample deforms rather than crumbles, cracks, or breaks.	1.0	Corn Muffin	Jiffy	12.7 mm cube
		5.0	Cheese	Yellow American pasteurized process-deli/Land O'Lakes	12.7 mm cube
		8.0	Pretzel	Soft pretzel	12.7 mm piece

Table 3 continued. Sensory texture attributes and references used for expert panel training for chicken nuggets.

Attribute	Definition	Scale Value	Reference	Brand/Type/ Manufacturer	Sample Size
		10.0	Dried fruit	Sun-dried seedless raisins/ Sun-Maid	1 tsp
		12.5	Candy chews	Starburst/ Mars	1 piece
		15.0	Chewing gum	Freedent/ Wrigley	1 stick
Cohesiveness of Mass	The degree to which chewed sample (10-15 chews) holds together in a mass.	0.0	Licorice	Shoestring	1 piece
		2.0	Carrots	Uncooked, fresh, unpeeled	12.7 mm slice
		4.0	Mushroom	Uncooked, fresh	12.7 mm slice
		7.5	Frankfurter	Large, cooked 5 min/ Hebrew National	12.7 mm slice
		9.0	Cheese	Yellow American pasteurized process-deli/Land O'Lakes	12.7 mm cube
		13.0	Soft brownie	Little Debbie (frosting removed)	12.7 mm cube
		15.0	Dough	Pillsbury/ Country Biscuit dough	1 tbsp
Springiness	The degree or rate at which a product returns to original shape.	0.0	Cream Cheese	Kraft Foods/ Philadelphia	12.7 mm cube
		5.0	Frankfurter	Large, cooked 10 min/ Hebrew National	12.7 mm slice

Table 3 continued. Sensory texture attributes and references used for expert panel training for chicken nuggets.

Attribute	Definition	Scale Value	Reference	Brand/Type/ Manufacturer	Sample Size
		9.5	Marshmallow	Miniature marshmallow/ Kraft Foods	3 pieces
		15.0	Gelatin	DessertJello, Knox gelatin	12.7 mm cube
Moisture Release	The amount of wetness or moistness felt in the mouth after 1 bite or chew.	1.0	Banana	Yellow banana	2 slices
		2.0	Carrot	HEB baby carrots	2 carrots
		4.0	Mushroom	HEB small mushrooms	2 slices
		7.0	Snap Beans	Fresh green beans	4 pieces
		8.0	Cucumber	Fresh cucumber	2 slices
		10.0	Apple	Red apple	1 slice
		15.0	Orange	Standard size orange	1 slice

All definitions and references from Meillgard (2007).

Table 4. Least squares means for objective color and thiobarbituric acid reactive substances (TBARS) values for chicken nuggets stored at 4^0C during 5 d of storage in polyvinyl chloride over-wrapped packaging.

	CIE Color Space Values			TBARS, mg MDA^x/g muscle
Treatments	L*	a*	b*	
Antioxidant Treatment				
P-values	<0.001	<0.001	<0.001	0.28
Control	72.89^{c}	2.08^{a}	15.54^{e}	1.91
BHA^y/BHT^z	72.71^{c}	2.28^{ab}	15.58^{e}	1.19
Rosemary	73.10^{c}	2.09^{a}	15.71^{e}	1.42
0.25% Sumac	68.13^{d}	2.20^{ab}	13.11^{d}	1.54
0.5% Sumac	66.04^{c}	2.35^{b}	11.76^{c}	1.68
0.25% Black tannin	64.34^{b}	2.85^{c}	11.07^{b}	1.43
0.5% Black tannin	59.26^{a}	3.50^{d}	8.92^{a}	1.88
Storage d *P*-values	<0.001	<0.001	<0.001	0.99
0	67.12^{a}	3.09^{d}	12.45^{a}	1.58
1	67.96^{b}	2.51^{c}	13.11^{b}	-
3	68.45^{bc}	2.32^{b}	13.23^{b}	-
5	68.74^{c}	2.01^{a}	13.61^{c}	1.58
Root Mean Square Error	1.267	0.256	0.430	0.805

[a,b,c,d] Different letters within each column of antioxidant or storage treatment are different ($P < 0.05$).

[x] MDA= malanaldehyde

[y] BHA= butylated hydroxyanisole

[z] BHT= butylated hydroxytoluene

Table 5. Descriptive sensory texture attributes for chicken nuggets stored at 4°C during 5 d in polyvinyl chloride (PVC) over-wrapped packaging.

Treatments	Initial Springiness Cohesiveness	Hardness	Moisture Release	Cohesiveness of Mass	
<u>Antioxidant Treatment</u>					
<u>*P*-values</u>	0.28	0.94	0.83	0.23	0.84
Control	11.7	5.6	2.7	6.2	6.3
BHA[y]/BHT[z]	11.5	5.7	2.6	6.2	6.4
Rosemary	11.7	5.5	2.7	6.1	6.3
0.25% Sumac	11.7	5.6	2.7	6.0	6.4
0.5% Sumac	11.5	5.5	2.7	6.1	6.4
0.25% Black tannin	11.8	5.6	2.5	6.1	6.5
0.5% Black tannin	11.8	5.6	2.6	6.2	6.5
<u>Storage d</u>					
<u>*P*-values</u>	0.67	0.36	0.51	0.65	0.74
1	11.7	5.6	2.7	6.1	6.4
3	11.7	5.6	2.6	6.1	6.4
Root Mean Square Error	0.357	0.401	0.345	0.217	0.268

[y] BHA= Butylated hydroxyanisole
[z] BHT= Butylated hydroxytoluene

Table 6. Descriptive sensory flavor attributes, where 0 = none and 15 = extremely intense, for chicken nuggets stored at 4^{0}C during 5 d in polyvinyl chloride (PVC) over-wrapped packaging.

Treatments	Chicken Flavor	Salty	Sweet	Sour	Bitter	Sorghum	Feather-like/ Wet Poultry	Cardboardy	Painty	Rosemary	Wet Dog	Medicinal
Antioxidant Treatment												
P-values	0.60	0.09	0.12	0.01	0.71	0.15	0.18	0.46	0.35	0.55	0.42	0.26
Control	3.4	2.2	0.6	0.2^{b}	0.6	0.1	0.0	0.3	0.0	0.0	0.0	0.0
BHA^{y}/BHT^{z}	3.5	2.3	0.5	0.0^{a}	0.4	0.3	0.0	0.2	0.0	0.0	0.0	0.0
Rosemary	3.4	2.3	0.6	0.1^{ab}	0.4	0.2	0.0	0.2	0.0	0.1	0.0	0.0
0.25% Sumac	3.6	2.3	0.6	0.1^{b}	0.4	0.2	0.0	0.1	0.0	0.0	0.0	0.0
0.5% Sumac	3.6	2.3	0.7	0.0^{a}	0.4	0.2	0.0	0.2	0.0	0.0	0.0	0.0
0.25% Black tannin	3.4	2.0	0.6	0.1^{ab}	0.5	0.2	0.0	0.2	0.0	0.0	0.0	0.0
0.5% Black tannin	3.4	2.0	0.7	0.0^{a}	0.3	0.4	0.1	0.2	0.0	0.0	0.0	0.0
Storage d												
P-values	0.08	0.80	0.30	0.85	0.31	0.28	0.51	0.95	0.46	0.18	0.34	0.24
1	3.6	2.2	0.6	0.1	0.5	0.2	0.0	0.2	0.0	0.0	0.0	0.0
3	3.4	2.2	0.6	0.1	0.4	0.2	0.0	0.2	0.0	0.0	0.0	0.0
Root Mean Square Error	0.36	0.29	0.18	0.12	0.33	0.27	0.06	0.22	0.05	0.07	0.02	0.02

^{a,b} Different letters within each column of antioxidant or storage treatment are different ($P < 0.05$).

^{y} BHA= Butylated hydroxyanisole

^{z} BHT= Butylated hydroxytoluene

Table 7. Recipe for pork sausage patties for nine different formulations.

Treatments	Pork Sausage blend, g (%)	Antioxidant, g (%)	Water, g (%)
Control	3079.94 (97%)	---	95.26 (3%)
0.02% BHA[y]/BHT[z]	3079.30 (96.98%)	0.64 (0.02%)	95.26 (3%)
0.2% Rosemary	3073.59 (96.8%)	6.35 (0.2%)	95.26 (3%)
0.25% Sumac	3072 (96.75%)	7.94 (0.25%)	95.26 (3%)
0.5% Sumac	3064.06 (96.5%)	15.88 (0.5%)	95.26 (3%)
0.75% Sumac	3056.13 (96.25%)	23.81 (0.75%)	95.26 (3%)
0.25% Black tannin	3072 (96.75%)	7.94 (0.25%)	95.26 (3%)
0.5% Black tannin	3064.06 (96.5%)	15.88 (0.5%)	95.26 (3%)
0.75% Black tannin	3056.13 (96.25%)	23.81 (0.75%)	95.26 (3%)

[y] BHA= Butylated hydroxyanisole
[z] BHT= Butylated hydroxytoluene

Table 8. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for pork sausage patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
BHA[y]/BHT[z]	The aromatics associated with the chemicals butylated hydroxyanisole and butylated hydroxytoluene.	0.01% BHA/ 0.01% BHT = 12.0 (Aroma)
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% caffeine solution = 2.0 (Taste) 0.02% caffeine solution = 3.5 (Taste)
Brown/Roasted	A round, full aromatic generally associated with pork suet that has been broiled.	Pork suet = 8.0 (Taste) Fresh ground pork = 10.0 (Taste)
Burnt	The sharp/acrid flavor note associate with over-roasted beef muscle, something over-baked or excessively browned in oil.	Alf's red wheat puffs = 5.0 (Taste)
Buttery	Sweet, dairy-like aromatics associated with natural butter.	Land O'Lakes Unsalted Butter = 7.0 (Aroma & Taste)

[y] BHA= Butylated hydroxyanisole
[z] BHT= Butylated hydroxytoluene

Table 8 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for pork sausage patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Cardboardy	The fundamental taste factor associated with cardboard.	Cardboard (wet) = 6.0 (Aroma & Taste) Cardboard (dry) =4.0 (Aroma); 5.0 (Taste)
Chemical	The aromatic associated with garden hose, hot Teflon pan, plastic packaging and petroleum based products such as charcoal liter fluid.	Zip-Loc sandwich bag = 13.0 (Aroma) Clorox in water = 6.5 (Taste)
Fat-like	The aromatic associated with cooked animal fat.	Hillshire Farms Lil' Beef Smokies = 7.0 (Taste) Pork suet = 12.0 (Taste)
Green/ Hay-like	Sharp, slightly pungent aromatics associated with green/plant/ vegetable matter such as parsley, spinach, pea pod, fresh cut grass, etc.	Hexanal in propylene glycol (5,000 ppm) = 6.5 (Aroma) Fresh parsley water = 9.0 (Taste)
Heated Oil	The aromatics associated with oil heated to a high temperature.	Lays potato chips = 4.0 (Aroma) Wesson Vegetable Oil = 7.0 (Taste)

Table 8 continued . Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for pork sausage patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Metallic	The impression of slightly oxidized metal, such as iron, copper and silver spoons.	0.10% potassium chloride solution = 1.5 (Taste)
Overall Sweet	The combination of sweet taste and sweet aromatics.	Post Shredded Wheat = 1.5 (Taste) Hillshire Farms Lil' Beef Smokies = 3.5 (Taste)
Petroleum-like	A specific chemical aromatic associated with crude oil and its refined products that have heavy oil characteristics.	Vaseline petroleum jelly =3.0 (Aroma)
Pork Flavor	Amount of pork flavor identity in the sample.	Fresh ground pork = 8.0 (Taste)
Rancid	An aromatic commonly associated with oxidized fat and oils. These aromatics may include cardboard, painty, varnish, and fishy.	Wesson Vegetable Oil (microwaved 3 min) = 7.0 (Taste) Wesson Vegetable Oil (microwaved 5 min) = 9.0 (Taste)

Table 8 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for pork sausage patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Refrigerator Stale	Aromatics associated with products left in refrigerator for an extended period of time and absorbing a combination of odors (lack of freshness/stale)	Ground pork (1 day old) = 5.5 (Aroma); 4.5 (Taste)
Rosemary	The aromatics associated with rosemary extract.	0.02% Rosemary Extract = 12.0 (Aroma)
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% NaCl Solution = 1.5 (Taste) 0.25% NaCl Solution = 3.5 (Taste)
Smokey Wood	Dry, dusty aromatic reminiscent of burning wood.	Wright's Natural Hickory seasoning in water = 7.5 (Aroma)
Sorghum	The fundamental aromatic and taste factor associated with sorghum bran.	Ground pork with sorghum bran added = 7.0 (Taste)
Sour Aromatics	The aromatics associated with a sucrose solution.	Dillon's Buttermilk = 5.0 (Aroma)

Table 8 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for pork sausage patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Sour Milk/Dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.	Laughing Cow Light Swiss Cheese = 3.0 (Aroma); 7.0 (Taste) Dillon's Buttermilk = 4.0 (Aroma); 9.0 (Taste)
Sour	The fundamental taste factor associated with a citric acid solution.	0.015% Citric Acid Solution = 1.5 (Taste) 0.05% Citric Acid Solution = 3.5 (Taste)
Spice Complex	The fundamental taste factor from a specific spice blend.	Spice Complex = 12.0 (Taste)
Spoiled	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates the product is starting to decay and putrefy.	Dimethyl disulfide in glycol (10,000 ppm) = 12.0 (Aroma)
Sweet	The fundamental taste factor associated with a sucrose solution.	SAFC Ethyl Maltol 99% = 4.5 (Aroma) 2.0% Sucrose solution = 2.0 (Taste)

Table 8 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for pork sausage patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Warmed-over	Perception of a product that has been previously cooked and reheated.	Ground pork = 6.0 (Aroma & Taste)

Table 9. Least squares means for pH, subjective and objective color and thiobarbituric acid reactive substances (TBARS) values for sausage patties stored at 4^{0}C during 5 d of storage in polyvinyl chloride over-wrapped packaging.

Treatments muscle	Raw pH	Raw Subjective Color	Cooked pH	Cooked CIE Color Space Values			TBARS, mg MDA^x/g
				L*	a*	b*	
Antioxidant Treatment							
P-values	0.59	0.33	0.65	0.03	0.96	0.01	0.35
Control	6.28	4.00	6.12	42.38^{cd}	4.28	10.48^{bcd}	0.07
BHA^y/BHT^z	6.30	4.00	6.06	42.36^{cd}	4.02	11.24^{cd}	0.09
Rosemary	6.30	4.00	6.05	42.79^{d}	4.45	11.77^{d}	0.09
0.25% Sumac	6.24	3.67	6.04	42.21^{bcd}	3.93	9.64^{abc}	0.07
0.5% Sumac	6.35	4.00	6.06	41.35^{abc}	4.22	8.95^{ab}	0.06
0.75% Sumac	6.28	3.67	6.11	40.89^{ab}	4.30	8.55^{a}	0.08
0.25% Black tannin	6.34	4.00	6.14	42.27^{bcd}	4.26	10.56^{bcd}	0.06
0.5% Black tannin	6.23	4.00	5.98	41.50^{abcd}	4.49	9.05^{ab}	0.08
0.75% Black tannin	6.24	4.00	6.07	40.54^{a}	4.73	9.14^{ab}	0.05
Storage d							
P-values	--	--	0.01	0.02	<0.001	<0.001	0.23
0	--	--	6.05^{ab}	41.94^{b}	5.50^{c}	12.91^{c}	0.06
1	--	--	6.09^{b}	42.00^{b}	4.47^{b}	8.26^{a}	0.07
3	--	--	5.98^{a}	40.90^{a}	4.70^{bc}	9.86^{b}	0.08
5	--	--	6.15^{b}	42.40^{b}	2.52^{a}	8.70^{ab}	0.08
Root Mean Square Error	0.079	0.255	0.186	1.724	1.485	2.228	0.064

[a,b,c,d] Different letters within each column of antioxidant or storage treatment are different ($P < 0.05$).

[x] MDA= Malanaldehyde [y]; BHA= Butylated hydroxyanisole; [z] BHT= Butylated hydroxytoluene

Table 10. Fat and moisture analysis of raw product and initial cook yield analysis of sausage patties.

Treatments	Lipid, %	Raw Moisture, %	Raw Weight, g	Cook Weight, g	Loss, %
Antioxidant Treatment					
P-values	0.30	0.82	<0.001	0.001	0.06
Control	25.90	56.09	147.04^{bc}	121.39^{a}	17.41
BHA^{y}/BHT^{z}	26.23	56.73	145.67^{a}	121.25^{a}	16.71
Rosemary	25.95	56.07	147.60^{bcd}	123.12^{bc}	16.51
0.25% Sumac	25.81	56.47	146.65^{b}	122.59^{ab}	16.35
0.5% Sumac	25.27	56.63	148.25^{d}	124.28^{c}	16.13
0.75% Sumac	25.13	56.18	147.04^{bc}	123.60^{bc}	15.87
0.25% Black tannin	25.45	56.98	147.23^{bc}	122.82^{abc}	16.52
0.5% Black tannin	23.99	56.60	147.56^{c}	123.39^{bc}	16.34
0.75% Black tannin	24.77	57.00	147.81^{cd}	123.9^{bc}	16.10
Root Mean Square Error	1.042	0.852	2.632	4.442	2.453

[a,b,c,d] Different letters within each column of treatment are different ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 11. Reheat yield data for sausage patties.

	Pre-Cooked Sausage Patties		
	Pre-Heat Weight, g	Reheat Weight, g	Reheat Loss, %
Antioxidant Treatment			
P-values	<0.001	0.01	0.03
Control	116.00^{ab}	109.62^{ab}	5.54^{ab}
BHA^{y}/BHT^{z}	114.88^{a}	108.58^{a}	5.49^{ab}
Rosemary	116.78^{bc}	110.55^{bc}	5.35^{a}
0.25% Sumac	116.77^{bc}	110.55^{bc}	5.34^{a}
0.5% Sumac	118.58^{d}	111.85^{c}	5.70^{ab}
0.75% Sumac	117.81^{cd}	110.88^{bc}	5.89^{b}
0.25% Black tannin	116.60^{abc}	109.73^{b}	5.93^{b}
0.5% Black tannin	118.01^{cd}	111.02^{bc}	5.95^{b}
0.75% Black tannin	118.75^{d}	111.82^{c}	5.70^{ab}
Root Mean Square Error	4.038	4.132	1.098

[a,b,c,d] Different letters within each column of treatment are different ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 12. Descriptive sensory flavor attributes, where 0 = none and 15 = extremely intense, for sausage patties stored at 4^{0}C during 5 d in polyvinyl chloride over-wrapped packaging.

Treatments	Pork Flavor	Salty	Sweet	Sour	Bitter	Sorghum	Spice Complex	BHA^{y}/BHT^{z}	Brown Roasted	Rosemary	Fat-Like	Overall Sweet
Antioxidant												
Treatment *P*-values	0.02	0.68	0.01	0.16	<0.001	0.27	0.34	<0.001	0.73	0.53	0.49	0.002
Control	5.7^{b}	6.0	0.8^{b}	0.8	0.7^{a}	0.0	8.9	0.2^{a}	2.5	6.6	2.8	1.3^{b}
BHA/BHT	5.2^{a}	5.4	0.3^{a}	1.1	2.9^{b}	0.0	8.4	4.0^{b}	2.4	6.1	2.6	0.4^{a}
Rosemary	5.6^{b}	6.5	0.8^{b}	0.6	0.9^{a}	0.1	8.7	0.2^{a}	2.7	6.2	2.7	1.3^{b}
0.5% Sumac	5.6^{b}	5.9	0.9^{b}	0.6	0.8^{a}	0.0	8.5	0.5^{a}	2.7	6.3	2.8	1.5^{b}
0.75% Sumac	5.7^{b}	6.0	0.8^{b}	0.8	0.9^{a}	0.0	8.7	0.5^{a}	2.9	6.0	2.9	1.2^{b}
0.25% Black Tannin	5.6^{b}	5.8	0.9^{b}	0.5	0.6^{a}	0.0	8.5	0.5^{a}	2.7	6.2	2.6	1.4^{b}
0.5% Black Tannin	5.7^{b}	6.1	0.9^{b}	0.6	0.5^{a}	0.0	8.8	0.3^{a}	2.8	6.5	2.8	1.5^{b}
0.75% Black Tannin	5.7^{b}	5.7	1.0^{b}	0.6	0.8^{a}	0.1	8.5	0.2^{a}	2.6	6.4	2.7	1.7^{b}
Storage d												
P-values	0.03	0.09	0.80	0.04	0.22	0.16	0.14	0.25	0.17	<0.001	0.02	0.50
1	5.7^{b}	6.2	0.8	0.6^{a}	0.9	0.0	8.8	0.7	2.6	6.6^{b}	2.8	1.2
3	5.5^{a}	5.8	0.8	0.8^{b}	1.0	0.0	8.6	0.9	2.7	6.0^{a}	2.7	1.3
Root Mean Square Error	0.24	0.73	0.26	0.32	0.42	0.09	0.38	0.56	0.41	0.53	0.17	0.40

[a,b] Different letters within each column of treatment and storage are different ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 13. Recipe for bratwurst sausage prepared for nine different formulations.

Treatments	Pork trim, g (%)	Spice Blend g (%)	Antioxidant, g (%)	Water, g (%)
Control	2929.44 (92.26%)	150.5 (4.74%)	---	95.26 (3%)
0.02% BHA[y]/BHT[z]	2928.80 (92.24%)	150.5 (4.74%)	0.64 (0.02%)	95.26 (3%)
0.2% Rosemary	2923.09 (92.06%)	150.5 (4.74%)	6.35 (0.2%)	95.26 (3%)
0.25% Sumac	2921.50 (92.01%)	150.5 (4.74%)	7.94 (0.25%)	95.26 (3%)
0.5% Sumac	2913.56 (91.76%)	150.5 (4.74%)	15.88 (0.5%)	95.26 (3%)
0.75% Sumac	2905.63 (91.51%)	150.5 (4.74%)	23.81 (0.75%)	95.26 (3%)
0.25% Black tannin	2921.50 (92.01%)	150.5 (4.74%)	7.94 (0.25%)	95.26 (3%)
0.5% Black tannin	2913.56 (91.76%)	150.5 (4.74%)	15.88 (0.5%)	95.26 (3%)
0.75% Black tannin	2905.63 (91.51%)	150.5 (4.74%)	23.81 (0.75%)	95.26 (3%)

[y] BHA= Butylated hydroxyanisole
[z] BHT= Butylated hydroxytoluene

Table 14. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for bratwurst sausages from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
BHA[y]/BHT[z]	The aromatics associated with the chemicals butylated hydroxyanisole and butylated hydroxytoluene.	0.01% BHA/ 0.01% BHT = 12.0 (Aroma)
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% caffeine solution = 2.0 (Taste) 0.02% caffeine solution = 3.5 (Taste)
Brown/Roasted	A round, full aromatic generally associated with pork suet that has been broiled.	Pork suet = 8.0 (Taste) Fresh ground pork = 10.0 (Taste)
Burnt	The sharp/acrid flavor note associate with over-roasted beef muscle, something over-baked or excessively browned in oil.	Alf's red wheat puffs = 5.0 (Taste)
Buttery	Sweet, dairy-like aromatics associated with natural butter.	Land O'Lakes Unsalted Butter = 7.0 (Aroma & Taste)

[y] BHA= Butylated hydroxyanisole
[z] BHT= Butylated hydroxytoluene

Table 14 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for bratwurst sausages from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Cardboardy	The fundamental taste factor associated with cardboard.	Cardboard (wet) = 6.0 (Aroma & Taste) Cardboard (dry) = 4.0 (Aroma); 5.0 (Taste)
Chemical	The aromatic associated with garden hose, hot Teflon pan, plastic packaging and petroleum based products such as charcoal liter fluid.	Zip-Loc sandwich bag = 13.0 (Aroma) Clorox in water = 6.5 (Taste)
Fat-like	The aromatic associated with cooked animal fat.	Hillshire Farms Lil' Beef Smokies = 7.0 (Taste) Pork suet = 12.0 (Taste)
Green/ Hay-like	Sharp, slightly pungent aromatics associated with green/plant/ vegetable matter such as parsley, spinach, pea pod, fresh cut grass, etc.	Hexanal in propylene glycol (5,000 ppm) = 6.5 (Aroma) Fresh parsley water = 9.0 (Taste)
Heated Oil	The aromatics associated with oil heated to a high temperature.	Lays potato chips = 4.0 (Aroma) Wesson Vegetable Oil = 7.0 (Taste)

Table 14 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for bratwurst sausages from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Metallic	The impression of slightly oxidized metal, such as iron, copper and silver spoons.	0.10% potassium chloride solution = 1.5 (Taste)
Overall Sweet	The combination of sweet taste and sweet aromatics.	Post Shredded Wheat = 1.5 (Taste) Hillshire Farms Lil' Beef Smokies = 3.5 (Taste)
Petroleum-like	A specific chemical aromatic associated with crude oil and its refined products that have heavy oil characteristics.	Vaseline petroleum jelly = 3.0 (Aroma)
Pork Flavor	Amount of pork flavor identity in the sample.	Fresh ground pork = 8.0 (Taste)
Rancid	An aromatic commonly associated with oxidized fat and oils. These aromatics may include cardboard, painty, varnish, and fishy.	Wesson Vegetable Oil (Microwaved 3 min) = 7.0 (Taste) Wesson Vegetable Oil (Microwaved 5 min) = 9.0 (Taste)

Table 14 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for bratwurst sausages from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Refrigerator Stale	Aromatics associated with products left in refrigerator for an extended period of time and absorbing a combination of odors (lack of freshness/stale)	Ground pork (1 day old) = 5.5 (Aroma); 4.5 (Taste)
Rosemary	The aromatics associated with rosemary extract.	0.02% Rosemary Extract = 12.0 (Aroma)
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% NaCl Solution = 1.5 (Taste) 0.25% NaCl Solution = 3.5 (Taste)
Smokey Wood	Dry, dusty aromatic reminiscent of burning wood.	Wright's Natural Hickory seasoning in water = 7.5 (Aroma)
Sorghum	The fundamental aromatic and taste factor associated with sorghum bran.	Ground pork with sorghum bran added = 7.0 (Taste)
Sour Aromatics	The aromatics associated with a sucrose solution.	Dillon's buttermilk = 5.0 (Aroma)

Table 14 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for bratwurst sausages from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Sour Milk/Dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.	Laughing Cow Light Swiss Cheese = 3.0 (Aroma); 7.0 (Taste) Dillon's buttermilk = 4.0 (Aroma); 9.0 (Taste)
Sour	The fundamental taste factor associated with a citric acid solution.	0.015% Citric Acid Solution = 1.5 (Taste) 0.05% Citric Acid Solution = 3.5 (Taste)
Spice Complex	The fundamental taste factor from a specific spice blend.	T.A.M.U. Bratwurst Seasoning = 12.0 (Taste)
Spoiled	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates the product is starting to decay and putrefy.	Dimethyl disulfide in propylene glycol (10,000 ppm) = 12.0 (Aroma)
Sweet	The fundamental taste factor associated with a sucrose solution.	SAFC Ethyl Maltol 99% = 4.5 (Aroma) 2.0% Sucrose solution = 2.0 (Taste)

Table 14 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for bratwurst sausages from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Warmed-over	Perception of a product that has been previously cooked and reheated.	Ground pork (1 day old) = 6.0 (Aroma & Taste)

Table 15. Least squares means for pH, subjective and objective color and thiobarbituric acid reactive substances (TBARS) values for bratwurst sausage stored at 4^{0}C during 5 d of storage in polyvinyl chloride over-wrapped packaging.

Treatments	Raw pH	Raw Subjective Color	Cooked pH	CIE Color Space Values			TBARS, mg MDA[x]/g muscle
				L*	a*	b*	
Antioxidant Treatments							
P-values	0.88	0.39	0.92	0.03	0.04	0.70	0.90
Control	6.08	4.75	6.04	58.37^{b}	7.23^{d}	13.96	0.07
BHA[y]/BHT[z]	6.02	4.67	6.00	58.22^{b}	6.92^{cd}	12.92	0.06
Rosemary	6.03	4.42	6.02	58.34^{b}	6.96^{cd}	13.52	0.09
0.25% Sumac	6.08	4.25	6.04	57.43^{ab}	6.69^{bcd}	13.46	0.04
0.5% Sumac	6.07	4.58	6.07	57.12^{ab}	6.41^{bcd}	12.99	0.09
0.75% Sumac	6.05	4.67	6.05	56.48^{ab}	6.33^{abc}	12.17	0.07
0.25% Black Tannin	6.08	4.33	6.02	57.39^{ab}	6.00^{ab}	12.67	0.06
0.5% Black Tannin	6.09	4.83	6.04	55.38^{a}	6.39^{abcd}	13.34	0.07
0.75% Black Tannin	6.08	4.67	6.02	55.62^{a}	5.78^{a}	12.63	0.05
Storage d							
P-values	0.001	--	<0.001	<0.001	0.01	0.06	0.43
0	6.00^{a}	--	5.96^{a}	54.95^{a}	6.02^{a}	13.55	0.06
1	6.11^{b}	--	6.10^{b}	57.70^{bc}	6.64^{bc}	12.80	0.07
3	6.12^{b}	--	6.09^{b}	57.03^{b}	6.35^{ab}	13.74	0.08
5	6.03^{a}	--	5.99^{a}	58.92^{c}	7.08^{c}	12.22	0.05
Root Mean Square Error	0.136	0.255	0.113	2.533	1.098	2.284	0.115

[a,b,c,d] Different letters within each column of treatment and storage are different ($P < 0.05$).

[x] MDA= Malanaldehyde

[y] BHA= Butylated hydroxyanisole; [z] BHT= Butylated hydroxytoluene

Table 16. Fat and moisture analysis of raw product and cook yield analysis of bratwursts.

Treatments	Lipid, %	Moisture, %	Raw Weight, g	Cook Weight, g	Cook Loss, %
<u>Antioxidant Treatment *P*-values</u>	0.57	0.69	0.001	<0.001	<0.001
Control	16.95	61.83	149.29^{a}	133.04^{a}	11.10^{c}
BHA[y]/BHT[z]	17.08	62.26	161.40^{bc}	142.99^{b}	11.45^{c}
Rosemary	16.47	62.02	157.03^{ab}	140.15^{ab}	10.78^{bc}
0.25% Sumac	17.76	61.17	162.06^{c}	145.90^{bc}	9.87^{ab}
0.5% Sumac	16.96	61.09	160.25^{b}	144.94^{b}	9.61^{a}
0.75% Sumac	17.04	60.95	168.29^{c}	152.36^{c}	9.44^{a}
0.25% Black tannin	17.71	61.52	155.82^{ab}	141.19^{b}	9.45^{a}
0.5% Black tannin	16.23	61.33	163.22^{bc}	146.91^{bc}	9.73^{ab}
0.75% Black tannin	18.43	60.23	158.88^{b}	144.00^{b}	9.35^{a}
Root Mean Square Error	1.274	1.275	18.313	16.853	2.616

[a,b,c] Different letters within each column of treatment and storage are different ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 17. Descriptive sensory flavor attributes, where 0 = none and 15 = extremely intense, for bratwursts stored at 4^{0}C during 5 d in polyvinyl chloride (PVC) over-wrapped packaging.

Treatments	Pork Flavor	Salty	Sweet	Sour	Bitter	Sorghum	Spice Complex	BHA^{y}/BHT^{z}	Brown Roasted	Rosemary	Fat-Like	Overall Sweet
Antioxidant Treatment												
P-values	<0.001	0.49	<0.001	0.46	<0.001	0.54	0.02	<0.001	0.59	0.35	0.97	0.002
Control	5.5^{b}	6.3	1.0^{b}	0.9	0.4^{ab}	0.1	6.3^{ab}	0.4^{ab}	1.8	0.0	2.8	1.5^{b}
BHA/BHT	5.0^{a}	6.8	0.1^{a}	1.7	3.8^{c}	0.1	6.1^{a}	4.9^{c}	1.8	0.0	2.7	0.4^{a}
Rosemary	5.7^{bcd}	6.8	1.1^{b}	0.8	0.5^{ab}	0.0	6.7^{bc}	0.1^{ab}	1.8	0.1	2.7	1.6^{b}
0.25% Sumac	5.7^{bcd}	7.0	1.0^{b}	0.9	0.6^{ab}	0.1	6.7^{bc}	0.3^{ab}	1.8	0.1	2.7	1.4^{b}
0.5% Sumac	5.9^{cd}	6.8	1.1^{b}	0.6	0.5^{ab}	0.1	6.8^{c}	0.2^{ab}	2.0	0.0	2.7	1.6^{b}
0.75% Sumac	5.8^{bcd}	6.7	1.0^{b}	0.8	0.3^{a}	0.0	7.0^{c}	0.2^{ab}	1.9	0.2	2.7	1.6^{b}
0.25% Black tannin	6.0^{d}	7.2	0.9^{b}	0.7	0.6^{ab}	0.1	6.6^{bc}	0.6^{b}	1.9	0.1	2.7	1.5^{b}
0.5% Black tannin	5.8^{bcd}	6.4	1.0^{b}	0.8	0.4^{ab}	0.0	6.6^{bc}	0.0^{a}	1.7	0.2	2.5	1.5^{b}
0.75% Black tannin	5.6^{bc}	7.6	0.9^{b}	0.8	0.8^{b}	0.1	6.8^{c}	0.6^{b}	1.8	0.1	2.7	1.2^{b}
Storage d												
P-values	0.08	0.32	0.03	0.18	0.11	0.41	0.80	0.92	0.01	0.75	0.06	0.14
1	5.7	6.7	0.8^{a}	0.8	1.0	0.0	6.6	0.8	1.7^{a}	0.1	2.6	1.3
3	5.6	7.0	1.0^{b}	1.0	0.8	0.1	6.6	0.8	1.9^{b}	0.1	2.8	1.4
Root Mean Square Error	0.21	0.89	0.23	0.65	0.35	0.13	0.33	0.38	0.20	0.17	0.36	0.37

[a,b,c,d] Different letters within each column of treatment and storage are different ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 18. Recipe for turkey patties for nine different formulations.

Treatments	Turkey trim, g (%)	Antioxidant, g (%)	Water, g (%)
Control	3079.94 (97%)	---	95.26 (3%)
0.02% BHA[y]/BHT[z]	3079.30 (96.98%)	0.64 (0.02%)	95.26 (3%)
0.2% Rosemary	3073.59 (96.8%)	6.35 (0.2%)	95.26 (3%)
0.25% Sumac	3072.00 (96.75%)	7.94 (0.25%)	95.26 (3%)
0.5% Sumac	3064.06 (96.5%)	15.88 (0.5%)	95.26 (3%)
0.75% Sumac	3056.13 (96.25%)	23.81 (0.75%)	95.26 (3%)
0.25% Black tannin	3072.00 (96.75%)	7.94 (0.25%)	95.26 (3%)
0.5% Black tannin	3064.06 (96.5%)	15.88 (0.5%)	95.26 (3%)
0.75% Black tannin	3056.13 (96.25%)	23.81 (0.75%)	95.26 (3%)

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 19. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for turkey patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
BHA[y]/BHT[z]	The aromatics associated with the chemicals butylated hydroxyanisole and butylated hydroxytoluene.	0.01% BHA/ 0.01% BHT = 12.0 (Aroma)
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% caffeine solution = 2.0 (Taste) 0.02% caffeine solution = 3.5 (Taste)
Brown/Roasted	A round, full aromatic generally associated with pork suet that has been broiled.	Pork suet = 8.0 (Taste) Fresh ground turkey = 10.0 (Taste)
Burnt	The sharp/acrid flavor note associate with over-roasted beef muscle, something over-baked or excessively browned in oil.	Alf's red wheat puffs = 5.0 (Taste)
Buttery	Sweet, dairy-like aromatics associated with natural butter.	Land O'Lakes Unsalted Butter = 7.0 (Aroma & Taste)

[y] BHA= Butylated hydroxyanisole
[z] BHT= Butylated hydroxytoluene

Table 19 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for turkey patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Cardboardy	The fundamental taste factor associated with cardboard.	Cardboard (wet) = 6.0 (Aroma & Taste) Cardboard (dry) = 4.0 (Aroma); 5.0 (Taste)
Chemical	The aromatic associated with garden hose, hot Teflon pan, plastic packaging and petroleum based products such as charcoal liter fluid.	Zip-Loc sandwich bag = 13.0 (Aroma) Clorox in water = 6.5 (Taste)
Fat-like	The aromatic associated with cooked animal fat.	Hillshire Farms Lil' Beef Smokies = 7.0 (Taste)
Green/ Hay-like	Sharp, slightly pungent aromatics associated with green/plant/ vegetable matter such as parsley, spinach, pea pod, fresh cut grass, etc.	Hexanal in propylene glycol (5,000 ppm) = 6.5 (Aroma) Fresh parsley water = 9.0 (Taste)
Heated Oil	The aromatics associated with oil heated to a high temperature.	Lays potato chips = 4.0 (Aroma) Wesson Vegetable Oil = 7.0 (Taste)

Table 19 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for turkey patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Metallic	The impression of slightly oxidized metal, such as iron, copper and silver spoons.	0.10% potassium chloride solution = 1.5 (Taste)
Overall Sweet	The combination of sweet taste and sweet aromatics.	Post Shredded Wheat = 1.5 (Taste) Hillshire Farms Lil' Beef Smokies = 3.5 (Taste)
Petroleum-like	A specific chemical aromatic associated with crude oil and its refined products that have heavy oil characteristics.	Vaseline petroleum jelly = 3.0 (Aroma)
Rancid	An aromatic commonly associated with oxidized fat and oils. These aromatics may include cardboard, painty, varnish, and fishy.	Wesson Vegetable Oil (Microwaved 3 min) = 7.0 (Taste) Wesson Vegetable Oil (Microwaved 5 min) = 9.0 (Taste)
Refrigerator Stale	Aromatics associated with products left in refrigerator for an extended period of time and absorbing a combination of odors (lack of freshness/stale)	Ground turkey (1 day old) = 5.5 (Aroma); 4.5 (Taste)

Table 19 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for turkey patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Rosemary	The aromatics associated with rosemary extract.	0.02% Rosemary Extract = 12.0 (Aroma)
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% NaCl Solution = 1.5 (Taste) 0.25% NaCl Solution = 3.5 (Taste)
Smokey Wood	Dry, dusty aromatic reminiscent of burning wood.	Wright's Natural Hickory seasoning in water = 7.5 (Aroma)
Sorghum	The fundamental aromatic and taste factor associated with sorghum bran.	Ground turkey with sorghum bran added = 7.0 (Taste)
Sour Aromatics	The aromatics associated with a sucrose solution.	Dillon's buttermilk = 5.0 (Aroma)

Table 19 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for turkey patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Sour Milk/Dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.	Laughing Cow Light Swiss Cheese = 3.0 (Aroma); 7.0 (Taste) Dillon's buttermilk = 4.0 (Aroma); 9.0 (Taste)
Sour	The fundamental taste factor associated with a citric acid solution.	0.015% Citric Acid Solution = 1.5 (Taste) 0.05% Citric Acid Solution = 3.5 (Taste)
Spoiled	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates the product is starting to decay and putrefy.	Dimethyl disulfide in propylene glycol (10,000 ppm) = 12.0 (Aroma)
Sweet	The fundamental taste factor associated with a sucrose solution.	SAFC Ethyl Maltol 99% = 4.5 (Aroma) 2.0% Sucrose solution = 2.0 (Taste)
Turkey Flavor	Amount of turkey flavor identity in the sample.	Fresh ground turkey = 12.0 (Taste)

Table 19 continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense for turkey patties from the ASTM (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Warmed-over	Perception of a product that has been previously cooked and reheated.	Ground turkey (1 day old) = 6.0 (Aroma & Taste)

Table 20. Least squares means for pH and subjective and objective color values for turkey patties storedat 4^{0}C during 5 d of storage in polyvinyl chloride over-wrapped packaging.

Treatments	Raw pH	Raw Subjective Color	Cooked pH	CIE Color Space Values		
				L*	a*	b*
Antioxidant Treatment						
P-values	0.22	0.89	0.67	<0.001	0.18	<0.001
Control	6.23	4.33	6.05	46.00^{d}	7.37	15.24^{c}
BHA[y]/BHT[z]	6.31	4.33	6.05	45.70^{cd}	7.53	15.31^{d}
Rosemary	6.26	4.67	6.03	45.59^{cd}	7.61	15.81^{d}
0.25% Sumac	6.24	4.33	6.02	44.90^{cd}	6.63	13.51^{c}
0.5% Sumac	6.18	4.33	5.96	42.10^{a}	7.01	12.57^{bc}
0.75% Sumac	6.19	4.33	5.99	43.07^{ab}	6.69	11.84^{ab}
0.25% Black tannin	6.14	4.33	5.99	44.23^{bc}	7.35	13.35^{c}
0.5% Black tannin	6.15	4.33	6.08	43.12^{ab}	7.37	12.89^{bc}
0.75% Black tannin	6.15	4.33	6.00	41.52^{a}	7.11	11.19^{a}
Storage d						
P-values	--	--	<0.001	<0.001	0.02	0.002
0	--	--	6.07^{b}	45.84^{c}	7.41^{b}	14.16^{b}
1	--	--	5.94^{a}	42.41^{a}	7.34^{b}	12.53^{a}
3	--	--	5.94^{a}	44.02^{b}	6.51^{a}	13.93^{b}
5	--	--	6.13^{b}	43.83^{b}	7.49^{b}	13.47^{b}
Root Mean Square Error	0.082	0.255	0.156	2.150	0.989	1.625

[a,b,c,d] Different letters within each column of treatment and storage are different ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluen

Table 21. Fat and moisture analysis of raw product and initial cook yield analysis of turkey patties.

Treatments	Lipid, %	Moisture, %	Raw Weight g	Cook Weight, g	Cook Loss, %
<u>Antioxidant Treatment</u>					
<u>*P*-values</u>	0.61	0.03	<0.001	<0.001	<0.001
Control	7.49	74.29^{ab}	150.02^{b}	103.56^{a}	30.97^{e}
BHA[y]/BHT[z]	7.36	74.13^{a}	150.46^{b}	106.68^{b}	29.11^{d}
Rosemary	7.25	74.81^{b}	148.95^{a}	105.57^{ab}	29.07^{d}
0.25% Sumac	7.20	73.95^{a}	151.51^{c}	110.21^{c}	27.26^{c}
0.5% Sumac	7.16	73.83^{a}	151.84^{c}	110.74^{cd}	27.09^{bc}
0.75% Sumac	7.46	73.74^{a}	151.95^{c}	114.74^{e}	24.49^{a}
0.25% Black tannin	7.03	73.81^{a}	151.70^{c}	111.28^{cd}	26.67^{bc}
0.5% Black tannin	7.31	73.83^{a}	152.12^{c}	114.77^{e}	24.56^{a}
0.75% Black tannin	7.30	73.87^{a}	151.86^{c}	113.02^{de}	25.58^{ab}
Root Mean Square Error	0.279	0.339	2.745	6.691	4.216

[a,b,c,d,e] Different letters within each column of treatment and storage are different ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 22. Reheat yield data for turkey patties.

	Pre-Cooked Turkey Patties		
	Pre-Heat Weight, g	Reheat Weight, g	Reheat Loss, %
Antioxidant Treatment			
P-values	<0.001	<0.001	0.001
Control	99.96^{a}	90.51^{a}	9.42^{bc}
BHA[y]/BHT[z]	102.29^{a}	93.71^{b}	8.37^{a}
Rosemary	101.75^{a}	91.09^{a}	10.39^{c}
0.25% Sumac	106.38^{bc}	95.43^{bc}	10.29^{c}
0.5% Sumac	105.20^{b}	94.82^{b}	9.81^{bc}
0.75% Sumac	108.51^{cd}	98.71^{d}	9.02^{ab}
0.25% Black tannin	106.12^{bc}	95.49^{bc}	10.02^{bc}
0.5% Black tannin	109.91^{d}	98.79^{d}	10.17^{c}
0.75% Black tannin	108.36^{cd}	97.82^{cd}	9.77^{bc}
Root Mean Square Error	5.792	5.775	2.328

[a,b,c,d] Different letters within each column of treatment are different ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 23. Descriptive sensory flavor attributes, where 0 = none and 15 = extremely intense, for turkey patties stored at 4^{0}C during 5 d in polyvinyl chloride over-wrapped packaging.

Treatments	Turkey Flavor	Warmed Over Flavor	Brown/ Roasted	Fat-Like	Overall Sweet	Refrigerator Stale	Cardboardy
Antioxidant Treatment							
P-values	<0.001	0.001	0.24	0.33	<0.001	0.02	0.004
Control	5.2^{b}	0.8^{c}	1.9	2.0	0.2^{ab}	0.3^{b}	0.6^{d}
BHA^{y}/BHT^{z}	3.9^{a}	0.0^{a}	1.8	1.8	0.1^{a}	0.0^{a}	0.0^{a}
Rosemary	5.1^{b}	0.5^{bc}	1.9	1.9	0.3^{bc}	0.0^{a}	0.4^{cd}
0.25% Sumac	5.4^{bc}	0.2^{a}	1.9	2.0	0.7^{de}	0.0^{a}	0.3^{bc}
0.5% Sumac	5.4^{bc}	0.1^{a}	1.9	1.8	0.8^{de}	0.0^{a}	0.0^{ab}
0.75% Sumac	5.5^{bc}	0.2^{ab}	1.9	1.9	0.6^{cd}	0.0^{a}	0.2^{abc}
0.25% Black tannin	5.3^{bc}	0.3^{ab}	2.0	2.0	0.6^{de}	0.0^{a}	0.2^{abc}
0.5% Black tannin	5.6^{c}	0.2^{a}	2.0	1.8	0.7^{de}	0.0^{a}	0.2^{abc}
0.75% Black tannin	5.4^{bc}	0.2^{a}	2.1	1.9	0.9^{e}	0.0^{a}	0.1^{ab}
Storage d							
P-values	<0.001	0.02	0.61	0.31	0.03	0.17	0.07
1	5.3	0.2	1.9	1.9	0.6	0.0	0.2
3	5.1	0.4	2.0	1.9	0.4	0.1	0.3
Root Mean Square Error	0.27	0.23	0.15	0.15	0.23	0.13	0.24

[a,b,c,d] Different letters within each column of treatment and storage are different ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 23 continued. Descriptive sensory flavor attributes, where 0 = none and 15 = extremely intense, for turkey patties stored at 4^0C during 5 d in polyvinyl chloride over-wrapped packaging.

Treatments	Salty	Sweet	Sour	Bitter	Sorghum	BHA^y/BHT^z	Rosemary
<u>Antioxidant Treatment</u>							
<u>*P*-values</u>	<0.001	0.002	0.001	<0.001	0.43	<0.001	0.14
Control	0.9^b	0.0^{ab}	0.3^b	1.1^c	0.1	0.9^c	0.1
BHA/BHT	0.6^a	0.0^a	0.5^c	4.4^d	0.0	4.9^d	0.0
Rosemary	0.9^{bc}	0.0^{ab}	0.2^b	0.6^{bc}	0.2	0.6^{bc}	0.1
0.25% Sumac	1.0^{bc}	0.1^{abc}	0.1^{ab}	0.3^{ab}	0.1	0.2^{ab}	0.1
0.5% Sumac	1.0^{bc}	0.3^{cd}	0.1^{ab}	0.0^a	0.2	0.0^a	0.1
0.75% Sumac	1.0^{bc}	0.3^{cd}	0.1^{ab}	0.1^{ab}	0.0	0.0^a	0.0
0.25% Black tannin	1.0^{bc}	0.0^{ab}	0.2^b	0.4^{ab}	0.0	0.3^{ab}	0.0
0.5% Black tannin	1.0^c	0.2^{bcd}	0.1^{ab}	0.1^{ab}	0.0	0.1^a	0.0
0.75% Black tannin	1.0^{bc}	0.4^d	0.0^a	0.0^a	0.1	0.1^a	0.1
<u>Storage d</u>							
<u>*P*-values</u>	0.72	0.96	0.04	0.15	0.45	0.53	0.26
1	0.9	0.1	0.1	0.7	0.0	0.8	0.1
3	0.9	0.1	0.2	0.9	0.1	0.8	0.0
Root Mean Square Error	0.08	0.15	0.15	0.42	0.16	0.32	0.11

[a,b,c] Different letters within each column of treatment and storage are different ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 24. Mean spectrometer total ion counts area under the curve indicating quantity with arbitrary units values for flavor compounds identified in cooked pork sausage patties, bratwursts and cooked turkey patties treated with antioxidants and stored from 0 to 5 d in polyvinyl chloride over-wrapped packaging at 4°C.

Volatile Compound	Cooked Sausage	Bratwurst	Cooked Turkey
1. Trimethyl-pyrazine	3590	10368	9378
2. 2-Pentanone	10888	8167	0
3. 1-Pentanol	26866	28828	160534
4. Styrene	20322	13083	6584
5. Alpha. Terpinene	8603	55988	0
6. Decanal	43588	48844	57038
7. Pentanal	117207	41756	193250
8. 1-Octen-3-ol	101250	2793	259039
9. 2,5-dimethyl-pyrazine	145828	43975	38757
10. Octane	421454	73861	49841
11. Heptanal	130992	122937	247645
12. 2,4 Decadienal	36762	17053	34021
13. 2-pentyl-furan	91086	32680	202439
14. Hexanal	315562	190040	5081313
15. Benzaldehyde	197567	87364	294113
16. (E)-2-Decenal	122360	63972	30667
17. Octanal	246242	175943	362543
18. Nonanal	630437	500430	926352
19. dl-Limonene	1284997	718337	5883
20. Alpha. Terpineol	2598	3215	1465
21. 1-Octanol	35484	68248	79478
22. 3-hydroxy-2-Butanone	13901	45905	0
23. 2-Decanone	7520	5181	7128
24. (E)-2-Octenal	7539	3599	10511
25. (E,E)-2,4-Nonadienal	210	531	12330
26. Butanoic acid	0	13999	0
27. Butyl Hydrooxy Anisole	1454	16381	1930
28. Butylated Hydroxytoluene	1508549	2797963	1935787
29. E-2-decenal	0	5249	2455
30. 2-ethyl-furan	79	102	2890
31. 2-methyl-furan	1971	9826	0
32. Heptane	6356	8043	13212

Table 24 continued. Mean spectrometer total ion counts area under the curve indicating quantity with arbitrary units values for flavor compounds identified in cooked pork sausage patties, bratwursts and cooked turkey patties treated with antioxidants and stored from 0 to 5 d in polyvinyl chloride over-wrapped packaging at 4°C.

Volatile Compound	Cooked Sausage	Bratwurst	Cooked Turkey
33. Nonenal	0	12047	46257
34. 2-ethyl-3,5-dimethyl-pyrazine	2075	8314	3785
35. Trans-Anethole	1481	1494	0

Table 25. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in cooked pork sausage patties.

Effect	TBARS, mg malanaldehye/g	Pork Flavor	Brown/ Roasted	Fat-like	Spice Complex	Rosemary	BHA[y]/ BHT[z]	Sorghum	Metallic
1. Trimethyl-Pyrazine,	0.04	0.26	0.11	0.14	0.02	0.10	-0.10	-0.08	-0.05
2. 2-Pentanone	-0.13	0.15	-0.31	-0.11	-0.33	-0.28	-0.10	0.08	-0.13
3. 1-Pentanol	-0.13	0.12	-0.08	0.06	-0.21	-0.08	-0.01	0.03	-0.18
4. Styrene	0.04	0.20	0.10	0.13	0.12	0.13	-0.11	-0.03	-0.12
5. Alpha. Terpinene	0.05	0.01	0.09	0.10	0.24	0.26	-0.02	-0.12	-0.08
6. Decanal	-0.01	0.38	0.26	0.15	-0.07	-0.20	-0.16	-0.09	-0.06
7. Pentanal	-0.16	0.07	-0.02	0.02	-0.26	-0.21	0.05	0.04	-0.11
8. 1-Octen-3-ol	-0.14	0.04	-0.27	-0.33	-0.23	-0.14	-0.01	-0.05	-0.14
9. 2,5-dimethyl- Pyrazine	-0.11	0.17	-0.27	0.13	-0.34	-0.03	-0.03	0.39	-0.04
10. Octane	-0.16	0.02	-0.26	-0.09	-0.28	-0.16	0.01	0.10	-0.11
11. Heptanal	-0.08	0.25	0.25	-0.03	-0.10	-0.18	0.00	-0.22	-0.09
12. 2,4 Decadienal	-0.12	0.30	0.21	-0.40	-0.36	-0.62	-0.22	-0.14	-0.21
13. 2-pentyl-Furan	0.16	-0.16	-0.04	0.32	0.10	0.20	0.04	-0.07	0.04
14. Hexanal	-0.15	0.06	-0.04	0.01	-0.15	-0.16	0.10	0.13	0.28
15. Benzaldehyde	-0.23	0.35	-0.19	0.02	-0.50	-0.27	-0.02	0.15	-0.01
16. (E)-2-Decenal	-0.09	0.21	0.24	-0.40	-0.31	-0.60	-0.22	-0.16	-0.18
17. Octanal	-0.16	0.43	0.19	0.08	-0.23	-0.36	-0.24	0.12	-0.01
18. Nonanal	0.06	0.21	0.10	0.01	0.01	0.08	-0.09	-0.05	-0.25
19. dl-Limonene	-0.05	0.05	-0.07	-0.01	-0.06	0.03	-0.01	-0.12	-0.06
20. Alpha. Terpineol	0.35	0.10	0.73	0.08	0.48	0.06	-0.01	-0.04	-0.02
21. 1-Octanol	-0.09	0.37	0.15	-0.08	-0.20	-0.34	-0.20	-0.19	-0.12
22. 3-hydroxy-2-Butanone	-0.02	0.00	-0.14	0.23	-0.06	0.07	0.09	0.01	-0.14
23. 2-Decanone	-0.18	0.37	0.08	-0.05	-0.40	-0.47	-0.18	0.23	-0.09

Table 25 continued. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in cooked pork sausage patties.

Effect	TBARS, mg malanaldehye/g	Pork Flavor	Brown/ Roasted	Fat-like	Spice Complex	Rosemary	BHA[y]/ BHT[z]	Sorghum	Metallic
24. (E)-2-Octenal	0.17	-0.13	0.19	0.16	0.24	0.13	-0.06	-0.08	-0.05
25. (E,E)-2,4-Nonadienal	0.22	-0.06	0.14	-0.16	0.12	0.06	-0.07	-0.04	-0.02
26. Butanoic acid	-	-	-	-	-	-	-	-	-
27. Butyl Hydrooxy Anisole	-0.05	0.35	-0.10	-0.02	-0.14	0.13	-0.20	-0.08	-0.05
28. Butylated Hydroxytoluene	0.15	-0.51	-0.12	-0.16	-0.07	-0.01	0.84	-0.07	0.11
29. E-2-decenal	-	-	-	-	-	-	-	-	-
30. 2-ethyl-Furan	-0.02	-0.17	0.04	-0.16	0.12	0.06	-0.07	-0.04	-0.02
31. 2-methyl-Furan	-0.06	0.14	0.28	-0.25	-0.21	-0.39	-0.12	-0.08	-0.05
32. Heptane	0.04	-0.37	-0.12	-0.11	-0.05	0.04	0.50	-0.08	-0.05
33. Nonenal	-	-	-	-	-	-	-	-	-
34. 2-ethyl-3,5 -dimethyl-Pyrazine	0.01	0.01	-0.23	0.16	-0.03	0.22	-0.03	-0.09	-0.06
35. Trans-Anethole	-0.04	0.29	0.06	-0.12	-0.04	0.14	-0.15	-0.10	-0.06

[a] Simple correlation coefficients > 0.20 are significant ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 25 continued. Simple correlation coefficients^{a} between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in cooked pork sausage patties.

Effect	Sweet	Overall Sweet	Sour	Salty	Bitter	Green/ Hay-like
1. Trimethyl-Pyrazine	-0.03	-0.10	-0.15	0.04	-0.12	0.35
2. 2-Pentanone	0.10	0.06	-0.20	-0.24	-0.20	-0.13
3. 1-Pentanol	0.05	0.03	-0.14	-0.16	-0.13	-0.17
4. Styrene	-0.03	-0.06	-0.10	0.15	-0.10	-0.11
5. Alpha. Terpinene	-0.05	-0.05	0.10	0.25	-0.03	0.41
6. Decanal	0.19	0.09	-0.30	-0.04	-0.25	-0.08
7. Pentanal	0.05	0.06	-0.11	-0.17	-0.06	-0.13
8. 1-Octen-3-ol	-0.01	-0.06	-0.20	-0.32	-0.16	-0.06
9. 2,5-dimethyl-Pyrazine	0.00	-0.01	-0.15	-0.25	-0.01	0.08
10. Octane	0.07	0.01	-0.11	-0.26	-0.11	-0.12
11. Heptanal	-0.10	-0.18	-0.24	-0.08	-0.14	0.02
12. 2,4 Decadienal	0.40	0.24	-0.36	-0.45	-0.27	-0.15
13. 2-pentyl-Furan	-0.13	-0.22	0.32	0.07	0.18	0.15
14. Hexanal	0.01	0.01	-0.05	-0.06	0.01	-0.04
15. Benzaldehyde	0.07	-0.01	-0.30	-0.43	-0.15	-0.01
16. (E)-2-Decenal	0.32	0.11	-0.29	-0.38	-0.24	-0.17
17. Octanal	0.28	0.19	-0.31	-0.12	-0.24	0.01
18. Nonanal	0.03	-0.05	-0.29	-0.02	-0.21	0.16
19. dl-Limonene	-0.13	-0.24	-0.08	-0.04	-0.14	-0.09
20. Alpha. Terpineol	0.00	-0.11	0.19	0.12	0.15	-0.03
21. 1-Octanol	0.13	-0.08	-0.39	-0.15	-0.26	0.05

Table 25 continued. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in cooked pork sausage patties.

Effect	Sweet	Overall Sweet	Sour	Salty	Bitter	Green/ Hay-like
22. 3-hydroxy-2-Butanone	-0.11	-0.07	0.06	0.02	0.02	-0.13
23. 2-Decanone	0.22	0.13	-0.30	-0.35	-0.25	-0.07
24. (E)-2-Octenal	0.01	0.04	0.15	0.27	-0.01	-0.07
25. (E,E)-2,4-Nonadienal	0.16	0.21	0.04	0.09	-0.08	-0.03
26. Butanoic acid	-	-	-	-	-	-
27. Butyl Hydrooxy Anisole	-0.00	-0.01	-0.23	-0.21	-0.27	-0.07
28. Butylated Hydroxytoluene	-0.66	-0.58	-0.21	-0.11	0.77	0.34
29. E-2-decenal	-	-	-	-	-	-
30. 2-ethyl- Furan	0.07	-0.00	0.04	0.09	0.01	-0.03
31. 2-methyl-Furan,	0.22	0.18	-0.28	-0.21	-0.20	-0.07
32. Heptane	-0.39	-0.33	0.11	-0.12	0.44	0.54
33. Nonenal	-	-	-	-	-	-
34. 2-ethyl-3, 5-dimethyl-Pyrazine	-0.11	0.00	0.00	-0.02	-0.01	0.15
35. Trans-Anethole	0.04	0.04	-0.26	-0.05	-0.12	0.44

[a] Simple correlation coefficients > 0.20 are significant ($P < 0.05$).

Table 26. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in Bratwursts.

Effect	TBARS, mg malanaldehye/g	Pork Flavor	Brown/ Roasted	Fat-like	Spice Complex	Rosemary	BHA[y]/ BHT[z]	Sorghum
1. Trimethyl-Pyrazine,	-0.04	-0.03	-0.05	0.13	0.01	-0.24	-0.06	-0.02
2. 2-Pentanone	-0.18	-0.11	0.03	0.09	0.06	-0.13	0.05	-0.12
3. 1-Pentanol	-0.16	0.27	-0.04	-0.05	0.39	0.14	-0.25	0.15
4. Styrene	-0.04	0.24	0.27	0.26	0.36	0.15	-0.11	-0.22
5. Alpha. Terpinene	-0.07	0.17	-0.08	0.08	0.17	0.12	-0.13	0.16
6. Decanal	-0.03	0.02	0.18	0.06	-0.02	0.09	0.10	-0.14
7. Pentanal	-0.03	-0.01	0.12	0.20	0.24	0.03	-0.09	0.01
8. 1-Octen-3-ol	0.02	-0.19	-0.09	-0.03	0.10	0.15	0.21	-0.10
9. 2,5-dimethyl-Pyrazine	0.06	0.14	0.03	0.06	-0.26	-0.11	-0.06	-0.16
10. Octane	-0.15	-0.06	-0.13	0.01	0.25	-0.07	-0.11	0.14
11. Heptanal	-0.08	0.01	0.01	-0.01	0.13	0.02	-0.05	0.10
12. 2,4 Decadienal	-0.05	0.05	0.11	0.04	0.02	-0.03	0.03	0.04
13. 2-pentyl-Furan	-0.10	0.15	0.11	0.01	-0.01	-0.01	0.10	0.14
14. Hexanal	-0.11	0.09	-0.11	0.01	0.32	0.10	-0.14	0.11
15. Benzaldehyde	0.08	-0.08	0.19	0.06	-0.22	-0.00	0.15	-0.12
16. (E)-2-Decenal	-0.11	0.22	0.16	0.15	0.16	0.12	-0.07	-0.05
17. Octanal	-0.16	0.07	-0.04	-0.10	0.06	-0.05	-0.14	0.11
18. Nonanal	-0.06	0.12	0.16	0.14	0.30	0.21	-0.07	-0.15
19. dl-Limonene	-0.11	0.09	-0.22	-0.04	0.42	0.10	-0.14	0.15
20. Alpha. Terpineol	-0.05	0.10	0.11	0.05	0.08	-0.08	-0.06	0.18
21. 1-Octanol	-0.10	0.04	0.01	-0.13	0.21	0.04	-0.13	0.05
22. 3-hydroxy-2-Butanone	0.25	-0.22	0.10	-0.02	-0.21	-0.16	0.21	-0.01

Table 26 continued. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in Bratwursts.

Effect	TBARS, mg malanaldehye/g	Pork Flavor	Brown/ Roasted	Fat-like	Spice Complex	Rosemary	BHA[y]/ BHT[z]	Sorghum
23. 2-Decanone	-0.04	-0.24	-0.01	-0.24	-0.21	-0.16	0.18	0.20
24. (E)-2-Octenal	0.02	-0.03	0.05	0.12	0.12	-0.13	-0.14	-0.12
25. (E,E)-2,4-Nonadienal	-0.11	0.11	0.05	0.05	0.17	0.21	-0.10	-0.10
26. Butanoic acid	0.06	-0.06	0.04	-0.09	0.12	-0.03	0.13	0.28
27. Butyl Hydrooxy Anisole	-0.03	0.08	0.20	-0.05	-0.13	-0.04	-0.03	-0.06
28. Butylated Hydroxytoluene	0.07	-0.68	-0.11	-0.10	-0.34	-0.15	0.89	-0.15
29. E-2-decenal	0.12	0.07	-0.12	-0.10	0.03	-0.04	-0.11	0.17
30. 2-ethyl-Furan	-0.00	0.20	0.18	0.06	-0.07	-0.08	-0.03	-0.08
31. 2-methyl- Furan	-0.09	-0.15	0.05	0.23	-0.09	-0.03	-0.13	-0.23
32. Heptane	0.07	-0.60	-0.00	-0.05	-0.30	0.03	0.80	-0.04
33. Nonenal	-0.02	-0.19	-0.01	-0.12	0.05	-0.17	0.08	-0.09
34. 2-ethyl-3, 5-dimethyl-Pyrazine	-0.03	-0/00	0.09	0.06	-0.02	-0.08	0.06	-0.04
35. Trans-Anethole	-0.09	-0.02	-0.15	-0.16	0.14	-0.07	-0.10	0.07

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[a] Simple correlation coefficients > 0.19 are significant (*P* < 0.05).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 26 continued. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in Bratwursts.

Effect	Overall Sweet	Sweet	Sour	Salty	Bitter	Burnt
1. Trimethyl-Pyrazine	0.08	0.14	0.06	-0.01	-0.10	-0.12
2. 2-Pentanone	-0.04	-0.00	0.05	0.02	0.20	-0.01
3. 1-Pentanol	0.21	0.22	0.04	-0.17	-0.10	0.00
4. Styrene	0.19	0.29	0.22	-0.26	0.04	0.05
5. Alpha. Terpinene	0.14	0.12	0.24	-0.04	-0.14	-0.09
6. Decanal	-0.05	-0.18	0.21	-0.26	0.24	0.29
7. Pentanal	0.21	0.02	0.17	-0.14	0.04	-0.00
8. 1-Octen-3-ol	-0.06	-0.09	0.11	-0.16	0.27	-0.05
9. 2,5-dimethyl-Pyrazine	-0.04	-0.14	-0.04	-0.03	-0.09	-0.00
10. Octane	0.07	0.14	0.16	0.07	-0.12	-0.06
11. Heptanal	0.03	0.01	0.13	-0.14	0.09	0.14
12. 2,4 Decadienal	0.08	-0.08	0.20	-0.12	0.06	-0.16
13. 2-pentyl-Furan	-0.10	-0.16	0.14	0.10	0.12	0.17
14. Hexanal	0.17	0.15	0.13	-0.21	-0.01	-0.04
15. Benzaldehyde	-0.04	-0.17	-0.01	-0.25	0.20	-0.04
16. (E)-2-Decenal	0.17	0.00	0.29	-0.20	0.05	-0.25
17. Octanal	0.08	0.02	0.06	0.02	-0.15	0.17
18. Nonanal	0.24	0.10	0.32	-0.34	0.06	0.06
19. dl-Limonene	0.15	0.12	0.23	-0.17	-0.03	-0.00
20. Alpha. Terpineol	0.04	0.31	-0.04	0.10	-0.05	-0.04
21. 1-Octanol	0.16	0.10	0.01	-0.13	-0.02	0.07
22. 3-hydroxy-2-Butanone	-0.10	-0.10	-0.14	0.09	0.19	-0.09

Table 26 continued. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in Bratwursts.

Effect	Overall Sweet	Sweet	Sour	Salty	Bitter	Burnt
23. 2-Decanone	-0.20	-0.20	-0.04	0.09	0.06	0.27
24. (E)-2-Octenal	0.23	0.08	0.19	-0.14	-0.12	-0.06
25. (E,E)-2,4-Nonadienal	0.14	0.09	0.21	-0.05	-0.05	-0.05
26. Butanoic acid	0.03	-0.03	0.14	-0.22	0.15	-0.10
27. Butyl Hydrooxy Anisole	-0.02	-0.07	-0.12	-0.04	-0.03	0.82
28. Butylated Hydroxytoluene	-0.63	-0.72	0.23	0.19	0.82	0.04
29. E-2-decenal	-0.06	0.05	-0.09	0.14	-0.08	0.12
30. 2-ethyl-Furan	-0.01	-0.02	-0.03	0.05	0.00	0.48
31. 2-methyl-Furan	-0.23	-0.22	0.14	-0.14	0.38	0.08
32. Heptane	-0.60	-0.60	0.28	0.19	0.80	-0.01
33. Nonenal	-0.00	-0.19	0.11	-0.08	0.07	0.20
34. 2-ethyl-3,5 -dimethyl-Pyrazine	-0.19	-0.18	0.18	0.07	0.07	0.37
35. Trans-Anethole	0.07	-0.02	0.19	-0.07	-0.15	-0.07

[a] Simple correlation coefficients > 0.19 are significant ($P < 0.05$).

Table 27. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in cooked turkey patties.

Effect	TBARS, mg malanaldehye/g	Pork Flavor	Brown/ Roasted	Fat-like	Rosemary	BHA[y]/ BHT[z]	Sorghum	Overall Sweet	Sweet
1. Trimethyl-Pyrazine	0.01	-0.04	0.18	0.05	-0.02	0.25	-0.05	-0.13	-0.12
2. 2-Pentanone	-	-	-	-	-	-	-	-	-
3. 1-Pentanol	0.10	-0.05	-0.07	0.05	-0.11	-0.01	0.11	-0.11	-0.27
4. Styrene	-0.08	0.32	0.35	0.07	0.01	-0.22	-0.09	0.26	0.05
5. Alpha. Terpinene	-	-	-	-	-	-	-	-	-
6. Decanal	0.22	0.07	0.13	0.01	-0.06	-0.12	0.33	0.09	0.03
7. Pentanal	0.08	-0.02	0.02	0.08	-0.01	-0.21	0.06	0.11	0.00
8. 1-Octen-3-ol	0.11	0.09	0.08	-0.12	0.15	-0.12	0.51	-0.09	-0.22
9. 2,5-dimethyl- Pyrazine	-0.16	0.30	0.35	0.04	-0.05	-0.26	0.05	0.28	0.13
10. Octane	0.04	-0.07	-0.12	-0.22	-0.13	-0.13	0.04	-0.03	-0.04
11. Heptanal	0.10	-0.07	0.14	-0.16	0.08	0.01	0.19	-0.04	-0.11
12. 2,4 Decadienal	0.24	-0.11	0.02	-0.01	0.08	-0.02	0.33	-0.28	-0.11
13. 2-pentyl- Furan	0.07	-0.09	-0.09	0.05	0.08	-0.06	0.09	-0.25	-0.26
14. Hexanal	0.12	-0.15	-0.07	0.07	-0.12	-0.09	0.11	-0.05	-0.12
15. Benzaldehyde	-0.01	-0.12	0.08	0.06	0.01	0.16	-0.06	0.01	-0.15
16. (E)-2-Decenal	0.17	-0.06	0.15	0.09	0.06	-0.07	0.16	-0.17	-0.08
17. Octanal	0.16	-0.01	0.03	-0.01	-0.01	-0.13	0.10	-0.01	-0.16
18. Nonanal	0.18	-0.01	-0.00	-0.04	0.04	-0.12	0.22	-0.05	-0.12
19. dl-Limonene	-0.08	0.08	0.03	-0.12	-0.05	-0.14	-0.11	0.01	-0.11
20. Alpha. Terpineol	-0.08	0.05	0.01	0.06	-0.06	-0.07	-0.05	0.13	-0.09

Table 27 continued. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in cooked turkey patties.

Effect	TBARS, mg malanaldehye/g	Pork Flavor	Brown/ Roasted	Fat-like	Rosemary	BHA[y]/ BHT[z]	Sorghum	Overall Sweet	Sweet
21. 1-Octanol	0.22	0.03	-0.01	-0.05	0.03	-0.15	0.23	-0.12	-0.23
22. 3-hydroxy-2-Butanone	-	-	-	-	-	-	-	-	-
23. 2-Decanone	0.17	-0.17	0.02	0.16	0.05	0.05	0.07	-0.27	-0.20
24. (E)-2-Octenal	-0.06	-0.01	0.02	-0.16	-0.12	-0.11	0.13	0.12	0.25
25. (E,E)-2,4-Nonadienal	0.14	-0.04	0.16	0.06	0.04	-0.00	-.12	-0.19	-0.17
26. Butanoic acid	-	-	-	-	-	-	-	-	-
27. Butyl Hydrooxy Anisole	-0.07	-0.02	-0.29	0.02	-0.05	-0.05	0.20	-0.05	-0.11
28. Butylated Hydroxytoluene	0.16	-0.55	-0.30	-0.34	-0.13	0.78	-0.11	-0.38	-0.19
29. E-2-decenal	0.01	0.22	0.02	0.10	-0.10	-0.12	-0.08	0.05	-0.16
30. 2-ethyl- Furan	0.05	-0.14	-0.24	0.10	0.11	0.03	0.06	-0.34	-0.24
31. 2-methyl- Furan	-	-	-	-	-	-	-	-	-
32. Heptane	0.22	-0.56	-0.32	-0.34	-0.13	0.56	-0.01	-0.32	-0.11
33. Nonenal	0.18	-0.01	0.12	0.04	0.09	-0.08	0.15	-0.17	-0.15
34. 2-ethyl-3,5 -dimethyl-Pyrazine	-0.08	-0.18	-0.24	-0.11	0.03	0.13	-0.14	-0.34	-0.13
35. Trans-Anethole	-	-	-	-	-	-	-	-	-

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[a] Simple correlation coefficients > 0.18 are significant ($P < 0.05$).

[y] BHA= Butylated hydroxyanisole

[z] BHT= Butylated hydroxytoluene

Table 27 continued. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in cooked turkey patties.

Effect	Sour	Salty	Bitter	Warmed Over Flavor	Refrigerator Stale	Cardboardy	Heated Oil	Green/ Hay-like	Smokey/ Wood
1. Trimethyl-Pyrazine	-0.03	-0.31	0.22	-0.16	-0.07	-0.18	-0.07	0.08	-0.01
2. 2-Pentanone	-	-	-	-	-	-	-	-	-
3. 1-Pentanol	0.06	-0.07	0.06	0.12	0.32	0.21	0.14	0.02	-0.02
4. Styrene	-0.28	0.27	-0.24	-0.23	-0.09	-0.28	-0.21	-0.14	-0.14
5. Alpha. Terpinene	-	-	-	-	-	-	-	-	-
6. Decanal	0.24	0.00	-0.08	0.02	0.14	-0.02	-0.22	-0.18	-0.12
7. Pentanal	0.20	0.16	-0.18	0.36	0.30	0.31	0.10	0.08	0.01
8. 1-Octen-3-ol	-0.03	-0.10	-0.06	0.31	0.34	0.26	-0.07	0.28	-0.03
9. 2,5-dimethyl-Pyrazine,	-0.05	0.34	-0.32	-0.25	-0.13	-0.22	-0.09	-0.07	-0.18
10. Octane	0.03	0.05	-0.05	0.13	0.31	0.27	0.39	0.04	-0.04
11. Heptanal	0.30	-0.05	0.07	0.14	0.16	0.08	-0.05	0.17	0.07
12. 2,4 Decadienal	0.22	-0.07	0.06	0.28	0.31	0.30	0.06	0.37	-0.10
13. 2-pentyl-Furan	0.23	0.07	0.00	0.35	0.39	0.45	0.37	0.43	-0.05
14. Hexanal	0.20	0.00	-0.02	0.42	0.35	0.43	0.27	0.04	0.13
15. Benzaldehyde	0.28	-0.15	0.18	0.12	0.07	0.11	0.16	0.05	-0.02
16. (E)-2-Decenal	0.23	0.05	-0.01	0.33	0.44	0.29	0.01	0.30	-0.11
17. Octanal	0.27	0.05	-0.05	0.24	0.32	0.24	0.07	0.10	-0.08
18. Nonanal	0.20	0.06	-0.05	0.24	0.35	0.24	0.13	0.19	-0.10
19. dl-Limonene	0.06	0.10	-0.11	0.19	0.35	0.29	-0.07	-0.05	-0.05
20. Alpha. Terpineol	-0.07	0.05	-0.08	0.10	-0.05	-0.07	-0.03	-0.02	-0.02
21. 1-Octanol	0.18	-0.01	-0.06	0.36	0.41	0.34	0.10	0.20	-0.08
22. 3-hydroxy-2-Butanone	-	-	-	-	-	-	-	-	-

Table 27 continued. Simple correlation coefficients[a] between volatile flavor compounds and sensory and thiobarbituric acid reactive substances (TBARS) values identified in cooked turkey patties.

Effect	Sour	Salty	Bitter	Warmed Over Flavor	Refrigerator Stale	Cardboardy	Heated Oil	Green/ Hay-like	Smokey/ Wood
23. 2-Decanone	0.33	-0.02	0.12	0.23	0.19	0.27	0.23	0.33	-0.08
24. (E)-2-Octenal	-0.18	0.07	-0.13	-0.14	-0.15	-0.12	-0.09	-0.07	-0.07
25. (E,E)-2,4-Nonadienal	0.29	0.07	0.03	0.17	0.32	0.21	-0.05	0.21	-0.09
26. Butanoic acid	-	-	-	-	-	-	-	-	-
27. Butyl Hydrooxy Anisole	0.03	0.01	-0.02	0.06	0.29	0.18	0.40	-0.05	-0.05
28. Butylated Hydroxytoluene	0.20	-0.66	0.71	-0.17	-0.11	-0.16	-0.06	-0.05	-0.04
29. E-2-decenal	-0.13	0.09	-0.13	-0.14	-0.08	-0.13	-0.05	-0.04	-0.04
30. 2-ethyl- Furan	0.19	-0.02	0.07	0.30	0.38	0.36	0.47	0.38	-0.06
31. 2-methyl- Furan	-	-	-	-	-	-	-	-	-
32. Heptane	0.22	-0.46	0.56	-0.01	0.13	0.07	0.12	0.03	-0.07
33. Nonenal	0.25	0.06	-0.03	0.34	0.49	0.29	0.01	0.35	-0.12
34. 2-ethyl-3,5 -dimethyl-Pyrazine	0.07	-0.03	0.09	0.15	0.28	0.20	0.42	0.30	-0.06
35. Trans-Anethole	-	-	-	-	-	-	-	-	-

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[a] Simple correlation coefficients > 0.18 are significant (*P* < 0.05).