SORGHUM BRAN AS AN ANTIOXIDANT IN FROZEN MEAT AND POULTRY PRODUCTS

A Dissertation

by

CRYSTAL MICHELLE WATERS

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Chair of Committee,	Rhonda K. Miller
Co-chair of Committee,	Jeffrey W. Savell
Committee Members,	L. Cain Cavitt
	Davey B. Griffin
	Wesley N. Osburn
Head of Department,	H. Russell Cross

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ABSTRACT

Synthetic antioxidants, butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT), or natural antioxidants such as rosemary extract, are common antioxidants used in meat products to retard lipid oxidation. Research has shown that sorghum bran has antioxidant properties in meat. The objective was to evaluate antioxidant development, pH, color, and sensory attributes of High Tannin and Onyx sorghum brans in fresh (Phase 1) and frozen (Phase 2) ground pork and ground chicken products. In Phase 1, ground pork and dark meat chicken thighs, were ground, mixed, and equally divided into one of 11 treatments: 1) Control-no added ingredients; 2) BHA and BHT at 0.01% of the meat weight; 3) Rosemary at 0.2%; 4, 5, 6 and 7) 0.125%, 0.25%, 0.50% and 0.75% Onyx sorghum bran, respectively; and 8, 9, 10 and 11) 0.125%, 0.25%, 0.5% and 0.75% high tannin sorghum (HTS), respectively. Patties and crumbles were cooked, packaged aerobically and stored at 4°C for 0, 1, 3 and 5 days under fluorescent lighting. Products were re-heated (day 1 and 3) and served to an expert, trained meat descriptive flavor and texture descriptive attribute panel, and TBARS, pH, instrumental color, and subjective color (days 0, 1, 3 and 5). In Phase 2, ground pork (20% lipid) and dark meat chicken leg and thigh meat, respectively, were ground and mixed into four treatments: 1) Control – no added antioxidant; 2) 0.20% Rosemary plus green tea extract (Kemin Fortium™, RGT12 Plus Dry Natural Plant Extract, Des Moines, IA); 3) 0.5 % of HTS bran; and 4) 0.5 % of Onyx sorghum bran. Pork pizza toppings and ground chicken were cooked, frozen, packaged aerobically and stored for 0, 3, 6, 9 and 12 months at Tyson Foods at -23^{0}C. On 0, 3, 6, 9 and 12 mo of storage, frozen cooked pork pizza toppings and ground chicken was evaluated as defined in Phase I.

In Phase 1, TBARS values increased ($P < 0.0001$) in control pork crumbles and chicken patties, but samples with higher levels of HTS or Onyx sorghum bran, and BHA/BHT did not increase. Treatments affected CIE L^* and b^* color space values. The higher sorghum bran addition resulted in darker colored products. Sorghum, brown roasted, bitter, umami, heated oil, refrigerator stale, and sweet sensory attributes differed ($P < 0.05$) across treatments in the chicken patties. In Phase 2, control pizza toppings had higher TBARS values with increased storage; however, rosemary and sorghum bran addition resulted in similar TBARS at each storage time ($P < 0.0001$). TBARS values were highest ($P < 0.01$) for control fully cooked dark meat ground chicken compared to treated product. As storage time increased, TBARS values did not change. Sorghum bran addition resulted in darker, redder products, but subjective color did not change with storage. Control products had slightly higher refrigerator stale and warmed over flavor than treated products ($P < 0.001$). Products containing rosemary had more off-flavors associated with rosemary than either the control or the sorghum bran addition. The addition of antioxidants provided much more protection against lipid oxidation than controls. However, the addition of sorghum bran, especially Onyx sorghum bran, resulted in slightly darker, less red and yellow meat products.

DEDICATION

This work is dedicated to the one and only, Dr. Rhonda Miller. Dr. Miller has been working with sorghum bran as an antioxidant in meat products for over 10 years, through numerous research projects and graduate students. I was fortunate enough to be in the right place at the right time to receive this assignment. With this project I was privileged to introduce her research with sorghum bran to industry via Tyson Foods Inc., working in their Discovery Center in Springdale, AR. Dr. Miller, this project, and the opportunity to work with Tyson Foods has forever shaped me as a person and has shown me glimpse of the career path I now wish to follow.

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Part 1, Faculty Committee Recognition

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Part 2, Student/Collaborator Contributions

The data analyzed for Phase I in Chapter 3 was provided by Dr. Rhonda K. Miller. Table 3 depicted in the appendix was adapted by Sarah Chu and Hannah Laird of the Department of Animal Science.

All other work conducted for the dissertation was completed by the student independently.

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TABLE OF CONTENTS

Page

ABSTRACT ii

DEDICATION iv

ACKNOWLEDGEMENTS v

CONTRIBUTORS AND FUNDING SOURCES vii

LIST OF TABLES x

LIST OF FIGURES xiii

CHAPTER I INTRODUCTION 1

CHAPTER II LITERATURE REVIEW 5

- Lipid Oxidation 5
- Oxidation Products and TBARS 12
- Gas Chromatography and Mass Spectrometry 16
- Antioxidants 17
- Natural Antioxidants 19
- Rosemary 21
- Tannins 21
- Anthocyanins 23
- Sorghum 23
- Sorghum as an Antioxidant in Meat Products 27

CHAPTER III MATERIALS AND METHODS 29

- Phase I: Aerobic, Refrigerated Study to Define Levels of Use 29
  - Pre-cooked Pork Crumbles 29
    - Product Collection, Treatments, and Manufacture 29
    - Pork Crumbles Fresh Color Analysis 30
    - Raw Pork pH and Cooking 31
    - Pork Crumbles Cooked color, pH, and Storage 31
    - Expert, Trained Descriptive Pork Flavor Analysis 32
    - Reheating 32
    - TBARS Analysis 34
    - Cooked Pork Crumbles Volatile Evaluation 35
  - Fully Cooked Dark Meat Chicken Patties 36
- Phase II: Aerobic, Frozen Storage Study in Cooperation with Tyson Foods 37
  - Pre-cooked Pork Pizza Toppings 37

Product Collection, Manufacture and Analysis 37
Fully Cooked Dark Meat Ground Chicken 38
Product Collection and Manufacture 38
Chemical and Sensory Analysis 39
Statistical Analysis...40

CHAPTER IV RESULTS AND DISCUSSION 41

Phase I: Aerobic, Refrigerated Study to Define Levels of Use 41
Pre-cooked Pork Crumbles 41
Raw Chemical and Color Evaluation..41
Cooked pH 42
Cooked Color...42
TBARS Determinations 43
Expert, Trained Descriptive Meat Sensory Analysis 44
Cooked Meat Volatile Evaluation..46
Fully Cooked Dark Meat Chicken Patties 47
Raw Chemical and Color Evaluation..47
Cooked pH and Color 48
TBARS Determinations 49
Expert, Trained Descriptive Meat Sensory Analysis 49
Cooked Meat Volatile Evaluation..50
Phase II: Aerobic, Frozen Storage Study in Cooperation with Tyson Foods 52
Pre-cooked Pork Pizza Toppings 52
Raw Chemical, Cooked pH, and Color Evaluation 52
TBARS Determinations 53
Expert, Trained Descriptive Meat Sensory Analysis 54
Cooked Meat Volatile Evaluation..57
Fully Cooked Dark Meat Ground Chicken 60
Raw Chemical, Cooked pH, and Color Evaluation 60
TBARS Determinations 61
Expert, Trained Descriptive Meat Sensory Analysis 62
Cooked Meat Volatile Evaluation..64

CHAPTER V CONCLUSIONS...66

LITERATURE CITED 69

APPENDIX A TABLES 80

APPENDIX B FIGURES...143

LIST OF TABLES

Page

Table 1. Raw color reference 80

Table 2. Cooked color reference using Sherwin-Williams paint color cards. 80

Table 3. Definitions and references for pork flavor attributes, where 0 = none and 15 = extremely intense adapted from Chu (2015); Laird (2015). 81

Table 4. Definitions and references for chicken flavor attributes, where 0 = none and 15 = extremely intense adapted by Lyon (1987); Laird (2015). 85

Table 5. Volatile, aromatic chemical compound classification identified by the GC/MS for pork and chicken in both Phases 1 & 2. 89

Table 6. Raw pork crumbles least squares means by treatment for raw percent lipid and moisture for Phase I. 94

Table 7. Pork crumbles least squares means for raw pH, objective color, subjective color attributes and cooking yield for Phase I. 95

Table 8. Pork crumbles least squares means for cooked pH, objective color, subjective color attributes and TBARS values for Phase I. 96

Table 9. Pork crumbles flavor and basic tastes attributes least squares means by treatments for Phase I. 97

Table 10. Pork crumbles least squares means values for volatile, aromatic chemicals identified by the GC/MS for each treatment for Phase I. 99

Table 11. Pork crumbles least squares means values for volatile, aromatic compounds identified by the GC/MS for each treatment for Phase I. 104

Table 12. Chicken patties least squares means by treatment for raw lipid and moisture for Phase I. 105

Table 13. Chicken patties least square means for raw pH, objective and subjective color attributes for Phase I. 106

Table 14. Chicken patties least squares means for cooked pH, objective color, subjective color attributes and TBARS values for Phase I. 107

Table 15. Chicken patties flavor and basic taste attributes least squares means by treatments for Phase I. 108

Table 16. Chicken patties least squares means values for volatile, aromatic chemicals identified by the GC/MS for each treatment for Phase I 110

Table 17. Chicken patties least squares means values for volatile, aromatic compounds identified by the GC/MS for each treatment for Phase I. 114

Table 18. Pre-cooked pork pizza toppings product formulation for Phase II. 115

Table 19. Ground chicken product formulation for Phase II. 115

Table 20. Pre-cooked pork pizza toppings least squares means by treatment for raw percent moisture, lipid and cooking yield for Phase II. 116

Table 21. Pre-cooked pork pizza toppings least squares means by treatment and storage time for cooked pH, objective color and subjective color attributes and TBARS values for Phase II. 117

Table 22. Flavor and basic taste descriptive attribute least squares means for pre-cooked pork pizza toppings by treatment and frozen storage time for Phase II. 118

Table 23. Least squares means values for volatile, aromatic chemicals identified by the GC/MS for pre-cooked pork pizza toppings by each treatment for Phase II. 121

Table 24. Least squares means values for volatile, aromatic chemicals identified by the GC/MS for pre-cooked pork pizza toppings by each frozen storage month for Phase II. 125

Table 25. Least squares means values for volatile, aromatic compounds identified by the GC/MS for pre-cooked pork pizza toppings by each frozen storage month for Phase II. 129

Table 26. Fully cooked dark meat ground chicken least square means for raw cook yield, percent moisture and lipid attributes for Phase II. 130

Table 27. Fully cooked dark meat ground chicken least square means for Phase II cooked TBARS values, pH, objective and subjective color attributes for Phase II. 131

Table 28. Flavor and basic taste descriptive attribute least squares means for fully cooked dark meat ground chicken by treatment and frozen storage time for Phase II. 132

Table 29. Least squares means values for volatile, aromatic chemicals identified by the GC/MS for fully cooked dark meat ground chicken by each treatment for Phase II. 134

Table 30. Least squares means values for volatile, aromatic chemicals identified by the GC/MS for fully cooked dark meat ground chicken by each frozen storage month for Phase II. 138

Table 31. Least squares means values for volatile, aromatic compounds identified by the GC/MS for fully cooked dark meat ground chicken by each frozen storage month for Phase II. 142

LIST OF FIGURES

Page

Figure 1. TBARS values least squares means for pork crumbles across treatments by storage time (*P* < 0.0001) for Phase I. 143

Figure 2. TBARS values least squares means for chicken patties across treatments by storage time (*P* < 0.0001) for Phase I. 144

Figure 3. CIE Color Space *a** Values least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* = 0.02) for Phase II. 145

Figure 4. CIE Color Space *b** Values least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* = 0.03) for Phase II. 145

Figure 5. TBARS values least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P*< 0.0001) for Phase II. 146

Figure 6. Pork Identity sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* = 0.01) for Phase II. 146

Figure 7. Bitter sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* = 0.04) for Phase II..147

Figure 8. Sorghum sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* = 0.01) for Phase II..147

Figure 9. Cardboard sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* = 0.002) for Phase II. 148

Figure 10. Floral sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* < 0.0001) for Phase II. 148

Figure 11. Green sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* = 0.005) for Phase II..149

Figure 12. Rosemary sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* = 0.0001) for Phase II. 149

Figure 13. Painty sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* < 0.0001) for Phase II. 150

Figure 14. Rancid sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* < 0.0001) for Phase II. 150

Figure 15. Refrigerator stale sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* < 0.0001) for Phase II. 151

Figure 16. pH values least squares means for fully cooked dark meat ground chicken across treatments by frozen storage time (*P* = 0.008) for Phase II. 152

Figure 17. CIE Color Space *L** Values least squares means for fully cooked dark meat ground chicken across treatments and frozen storage time (*P* = 0.01) for Phase II. 152

Figure 18. CIE Color Space *a** Values least squares means for fully cooked dark meat ground chicken across treatments and frozen storage time (*P* = 0.01) for Phase II. 153

Figure 19. TBARS values least squares means for fully cooked dark meat ground chicken across treatments by frozen storage time (*P* = 0.21) for Phase II. 153

CHAPTER I

INTRODUCTION

In today's market, consumers are becoming more health-conscious, and many truly care about how their food is made and where it comes from. Consumers are following the trend of buying natural, organic, hormone, and antibiotic free, etc., and with their food purchases, they are becoming more stringent with the quality of food they are eating and feeding their families. For processed meat producers, this has resulted in an increase in demand for natural additives available in replacement for traditional processing ingredients in meat products. To achieve the needs of consumers for a more natural, "clean label," finding new methods that make quality products and increase shelf life without sacrificing production cost will be a challenge to the meat industry.

In addition to health-conscious and "feel good" claims, consumers are faced with living in a fast paced, "no time to cook world." Convenience foods have become a quick, viable option for many consumers which has increased the 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. High susceptibility to lipid oxidation is one of the primary concerns of meat processors when producing pre-cooked, unsaturated meat products for end users (Hesteande, 2014). These products are traditionally manufactured and stored frozen, so most of these products contain antioxidants. Antioxidants that are found in nature, and can be labeled "natural" have potential in a variety of meat and poultry products. Major food companies continually evaluate new functional ingredients to replace "chemicals" such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT). This research will be used to assist in the adaptation of sorghum bran as a "natural" antioxidant.

Meat and poultry processors are continually looking for new and improved non-meat ingredients with increased functionality. Antioxidants are used extensively in the meat and poultry industry especially for pre-cooked ground beef, pork, turkey, and chicken, value-added products. While these products offer convenience, they have limited shelf life due to changes in flavor from lipid oxidation during frozen storage. Most of these products have a 3 to 4 month shelf life in frozen storage with current antioxidant usage. Antioxidants provide increased shelf life by stabilizing flavor or limiting off-flavor development. Antioxidants that control lipid oxidation during frozen and refrigerated storage also can stabilize color deterioration. The most common antioxidants are BHA and BHT. Consumers are making a shift in awareness of added ingredients, and many consumers are demanding the use of "natural" ingredients. Ingredients BHA/BHT are considered by many consumers as added chemicals. Meat and poultry processors, along with USDA, are addressing these consumer issues through labeling that allows for "natural" label claims. Natural label claims show a positive move by the meat and poultry industries to align and answer consumer demands, but meat and poultry processors are limited in options for ingredients to replace BHA/BHT. Extracts of rosemary are a natural replacement, but rosemary extract does not have the same antioxidant power as BHA/BHT. Meat and poultry processors can meet consumer demands for “natural” ingredients, but now are in a dilemma as “natural” replacement ingredients do not achieve the shelf life and flavor stability that equals BHA/BHT.

There are many different kinds of natural antioxidants on the market. Sorghum is a genus of grasses, and it is the fifth most important cereal crop grown in the world. High tannin sorghum varieties were developed for their drought, disease and insect resistance. Sorghum varieties containing tannins possess natural antioxidants that can be used in food products. However, tannins create a bitter taste in sorghum and limit human and animal consumption. Millers can remove the bran component and utilize the remaining seed for typical sorghum grain applications. The bran then becomes a by-product of production. This tannin-containing bran has functional ingredients (Awika et al., 2003), which are mainly antioxidants, that can be utilized in food products. Antioxidant usage in pre-cooked beef, pork, and chicken products is common and better antioxidants are continually being evaluated. Initial research showed significant efficacy for powdered high tannin sorghum bran as a "natural" antioxidant and recent studies have already shown the effectiveness of sorghum bran in pre-cooked beef patties and pre-cooked turkey patties (Roybal, 2010; Hesteande, 2014).

Tannin and anthocyanin-containing sorghum bran were evaluated as a natural antioxidant in meat and poultry products. Preliminary and published research has shown similar, and in some cases, stronger antioxidant properties than BHA/BHT. In fact, pre-cooked ground beef patties containing 0.5% tannin sorghum bran and 0.5% black sorghum bran had lower TBARS values than pre-cooked patties containing BHA/BHT after five days of aerobic storage. More recently, research has presented similar results in pre-cooked turkey patties. Therefore, this study is prepared to show evidence that natural, commercially available sorghum bran either high in tannins or anthocyanins (High Tannin and Onyx, respectively) will have greater antioxidant properties in meat and poultry products then BHA/BHT and rosemary extract. Antioxidant capability was measured using TBARS values, color and flavor effects of powdered High Tannin and Onyx sorghum brans. The sorghum brans were evaluated in pre-cooked dark meat chicken patties and pork crumbles stored in aerobic, refrigerated conditions (*P*hase I); and pre-cooked ground dark meat chicken and pork pizza topping crumbles in aerobic, frozen conditions (*P*hase II).

CHAPTER II

LITERATURE REVIEW

Lipid Oxidation

Lipid oxidation is the primary cause of deterioration in the quality of meat and meat products. Degradation and spoilage caused by lipid oxidation produce off-flavors and odors, discoloration, loss of nutritional value, and deterioration of texture. Development of rancid flavors or odors during storage is a major problem with the increased demand for pre-cooked items (Cross et al., 1987; Kanner, 1994; Morrissey et al., 1998). Fatty acid composition affects the susceptibility of meat to lipid oxidation. Oxidative stability in meats is related to the degree of saturation of the lipid fraction. The higher level of unsaturation, the faster oxidation will proceed. Fatty acids esterified to triacylglycerols and phospholipids will decompose during lipid oxidation and form small, volatile molecules that will produce off-aromas known as oxidative rancidity (McClements and Decker, 2008). Additionally, species, the location of the fat in the carcass, muscle fiber type and fatty acid content determine the susceptibility of the fat to lipid oxidation. Meat from non-ruminant animals contain a greater amount unsaturated fatty acids within triacylglycerols and usually display more rapid lipid oxidation than meat from ruminants (Love and Pearson, 1971; Love, 1987). Muscles that possess higher proportions of red muscle fibers are also more susceptible to lipid oxidation because red fibers contain more phospholipids, myoglobin, and have a higher iron concentration than muscles containing predominantly white fibers (Faustman et al., 2010).

Lipids in meat can either be found in intermuscular or intramuscular tissues. Intermuscular lipids are stored in connective tissues in large lipid deposits, while intermuscular lipids are integrated throughout the muscle tissues. Intramuscular lipids develop in the perimysium and close approximation to muscle fibers and contain a large percentage of phospholipids. The triacylglyceride portion of lipid within meat is about five times greater than the phospholipid faction. The phospholipid portion contributes about 1% of the weight of muscle. However, phospholipids are more susceptible to oxidation than triacylglycerides even though phospholipids are present at very low levels. Phospholipids are high in unsaturated fatty acid content and are close to tissue catalysts within the muscle compared to triacylglycerides (Love and Pearson, 1971).

Lipid composition differences among species may contribute to the susceptibility and severity of oxidative rancidity development and may influence the differences in flavor between species (Lillard, 1987). Nineteen percent of fatty acids in beef phospholipids have four or more double bonds whereas to only 0.1% of the triacylglyceride fatty acids have this same degree of unsaturation (Love and Pearson, 1971). Dietary fats contribute to the fatty acid composition of meat from non-ruminant species. Pork and chicken meat possess even a greater amount of cis double bonds in their unsaturated lipids. In chicken meat, 31% of the phospholipid faction fatty acids have three or more double bonds, while only 3.5% of the triacylglyceride fatty acids showed this degree of unsaturation (Lillard, 1987). There is a higher degree of

unsaturation in lipids from pork and chicken than beef and lamb. Pork and chicken fat tend to be physically softer, have lower melting points, is more susceptible to lipid oxidation and can potentially develop undesirable warmed-over flavor (WOF). Beef and lamb fats, depending on the location on the carcass, are generally more saturated that pork and chicken fats. The higher degree of saturation makes beef and lamb fat less susceptible to lipid oxidation than pork and chicken (Cross et al., 1987).
Comminuted meats are even more sensitive to lipid oxidation than whole muscle products. Processing meat and the separation of muscle and fat from bone results in tissue rupture, an increase of surface area, exposure to oxygen, temperature variation and microbial or debris contamination that can also contribute to increased lipid oxidation (Cross et al., 1987; Gray et al., 1996). Further processed meat products contain salt for preservation and flavor enhancement. Curing meats with the addition of salt and nitrite/nitrate stabilizes the chemical structure of the heme pigment of myoglobin that acts as a preservative. Non-heme iron in the porphyrin ring of myoglobin is a major lipid prooxidant (Faustman et al., 2010). When combined with heat, nitrite bound to the iron ligand-binding site will inhibit oxidation by stabilizing the porphyrin ring through preventing cleavage and release of iron from the porphyrin ring (Chen et al., 1984). Nitrite addition to cured meat products will eliminate WOF at 220 ppm (Sato and Hegarty, 1971).

Flavor is a key quality characteristic of muscle foods. Both intrinsic and extrinsic factors cause variability in meat flavor. Flavor factors are of primary concern in food science because of the consumer influence they possess (Shahidi, 2002; Jayathilakan et al., 2007). Meat flavor deterioration (MFD) is a sensory hurdle that food scientists strive to overcome. Meat flavor deterioration is the decrease in desirable flavor attributes and increasing off-flavors (Spanier et al., 1992).

Warmed-over flavor is the rapid onset of rancidity in cooked meats after only a few hours of refrigerated storage (Cross et al., 1987). During short periods of refrigeration, development of "old, stale, rancid, and painty" odor and flavor is detectable when refrigerated precooked meats are reheated and eaten (St. Angelo and Bailey, 1987). Consumers do recognize this "warmed-over" flavor with their dissatisfaction of reheated "leftovers" of steaks, roasts, chops and other precooked meat products. Oxidized flavors are detectable after 48 hrs in cooked meats, and after prolonged frozen storage, rancidity slowly develops in raw and fatty tissues (Cross et al., 1987). Warmed-over flavor was first recognized by Tims and Watts (1958) and is produced by lipid oxidation. Lipid oxidation is the chemical process that results in the formation of hydroperoxides, the primary initial products of lipid oxidation. Hydroperoxides are essentially odorless but will decompose to various volatile compounds (Gray et al., 1996). These volatile compounds include carbonyl compounds, hydrocarbons, furans, hexanes, and others that are the primary cause of rancid off-flavors and off-odors (Love, 1987; Kanner, 1994; Gray et al., 1996; Jayathilakan et al., 2007). The development of these off-flavor volatile compounds that cause WOF can be analyzed by gas chromatography-olfactory (GC-O) (Frankel et al., 1981; Dupuy et al., 1987; Tamura and Shibamoto, 1991; Gray and Monahan, 1992).

Many uncured, processed meat products contain salt in the formulation. Salt by itself is a prooxidant when there is greater than 60 percent water in the meat system (Chang and Watts, 1950). The higher the moisture content, the more rapid oxidation occurs because the higher moisture content will enable hemeproteins to acts as prooxidants (Cross et al., 1987). Rhee et al. (1983) reported that the addition of NaCl and $MgCl_2$ salts increased the rancidity of meat regardless of refrigerated or frozen storage. Saeed and Howell (2002) indicated that the rate of lipid oxidation increased with increased frozen storage time and temperature. Freezing facilitated lipid oxidation especially if salt was present in the frozen meat (Chaijan, 2008; Strasburg et al., 2008). Therefore, processed meats without added nitrite or nitrate as a preservative were particularly susceptible to rancidity and other effects of lipid oxidation. Understanding and controlling lipid oxidation continues to be a concern for food scientists especially in the study of quality enhancement of processed meat products.

Oxidative stability in meats is related to the degree of saturation of the lipid fraction. The greater the degree of unsaturation, the faster oxidation will proceed. In general, the more double bonds present in a fatty acid, the more susceptible it is to lipid oxidation. Mono- or poly-unsaturated fatty acids possess one or more double bonds. Double bonds weaken the strength of the bonds within structures, especially the bond between the hydrogen and the α-methyl carbon adjacent to double bonds. Lipid oxidation takes place in two different fractions: 1) triacylglycerols, which are the main components of the lipid, and 2) phospholipids, a constant one percent of the lipid and muscle tissue factions. Phospholipids are generally more unsaturated than triacylglycerols and are more of a concern in lipid oxidation. Lipids that contain more unsaturated fatty acids, more double bonds present, are more susceptible to lipid oxidation (Love and Pearson, 1971). Therefore, softer fats, or the polyunsaturated fatty acids (*P*UFA), are more easily oxidized than monounsaturated fatty acids, which are in turn more easily oxidized than saturated fatty acids.

The configuration of the double bonds also plays a role in fatty acid stability. Cis double bonds create kinks in the fatty acid chains causing the hydrophobic forces among subcells to be weaker. Trans double bonds do not create kinks in the fatty acid chains, and their melting points are similar to saturated or monounsaturated fatty acids. The kinks created by the cis double bonds are weaker and more susceptible to oxidation, thus oxidizing faster than trans double bonds (Morrissey et al., 1998).

Oxidative rancidity occurs when lipids are susceptible to oxidation when exposed to molecular oxygen in the air and may or may not be influenced by an initiator catalyst. The hydrogen at the α-methyl carbon adjacent to the double bonds in an unsaturated fatty acid is vulnerable to free radical attack. The nature and exact mechanism of initiation still are not fully elucidated (Gray et al., 1996; Hamilton et al., 1997). After many studies and years of research, it is believed that the presence of iron and the decomposition of hydroperoxides into a singlet oxygen radical plus a hydrogen peroxide is the leading cause for initiation. However, there are other theories and factors involved, but at present, the evidence in support of the proposed initiators seems more suggestive than conclusive (Gray et al., 1996). The presence of oxygen and/or the initiator catalyst, a singlet oxygen, or decomposed hydroperoxide creates free radicals

(Hamilton et al., 1997). An initiator acts as a catalyst to oxidation providing ions to speed up the oxidation process. Such initiators include exposure to light, heat, or metals, such as heme iron in hemoglobin or myoglobin. Reactive oxygen species (ROS) are free radicals having one or more paired electrons that exist independently. The ROS are responsible for the degradation of lipid membranes resulting in a decrease in membrane fluidity, cell damage and formation of toxic products (Morrissey et al., 1998; Jayathilakan et al., 2007). The free radicals produced then attacks the hydrogen at the α-methyl carbon adjacent to the double bond and steals the hydrogen leaving the now acyl radical (R•) in its place. The removal of the hydrogen could cause a conformational shift of the fatty acid to make a conjugated diene. The double bond could shift, and the acyl radical could take its place. The conformational shift causes more kinks in the fatty acid (McClements and Decker, 2008).

The free radicals produced during the initiation step can then react with oxygen or remove hydrogen molecules from other hydrocarbons to form hydroperoxides and new free radicals. The formation of new free radicals and hydroperoxides perpetuates the chain reaction, which is now autocatalytic and is referred to as the propagation phase of lipid oxidation (Lillard, 1987; Hamilton et al., 1997). Propagation will continue through to termination unless it is inhibited by a preventative antioxidant or mediated by an enzyme system. During propagation with the continuous exposure to oxygen, the oxygen binds to the acyl radical (R•) attached to unsaturated fatty acid and produces a peroxyl radical. Peroxyl radicals (ROO•) are more highly oxidized that acyl radicals and will oxidize and attack other unsaturated fatty acids one after another in a chain reaction

(Morrissey et al., 1998). Once a new fatty acid trades its hydrogen at the α-methyl carbon for a radical, a rancid aroma and flavor producing hydroperoxide (ROOH) is formed. Hydroperoxides are the primary initial products of lipid oxidation; they are very unstable, and they will quickly begin to decompose as soon as they are formed (Lillard, 1987). This decomposition will develop hydroperoxides into aldehydes, ketones, alkanes, acids, malonaldehyde (MDA), 4-hydroxynonanal (4-HNE), etc., and others that are responsible for the rancid odors and flavors found in meat (Morrissey et al., 1998; Faustman et al., 2010).

This oxidation cycle continues until there is no more oxygen or double bonds available to continue the chain reaction. Termination ensues after considerable oxidation has occurred. The only products that are left to react are the radicals with one another. The reaction is terminated when the free radicals react with each other, and their electrons come together in pairs yielding non-free radicals (*P*earson et al., 1977; Hamilton et al., 1997). When two radicals react, the production of more nonreactive products or hydroperoxides will then develop (McClements and Decker, 2008).

Oxidation Products and TBARS

Malonaldehyde (MDA) is a compound released from unsaturated fatty acids during oxidation that is used to measure thiobarbituric acid reactive substances (TBARS) and has long been used in meat as a measure of the extent of lipid oxidation (Frankel and Neff, 1983; Gray and Pearson, 1987). Even though the chemistry of the reaction is still not fully understood, MDA is still thought to be the major thiobarbituric acid reactive substance (Hoyland and Taylor, 1991). The TBARS values are the most widely used to measure oxidation in meat products by measuring mg MDA/kg. A reddish-pink chromogen results from condensation of two molecules of thiobarbituric acid (TBA) with one molecule of MDA, the active color-producing compound. The TBA reacts with MDA to produce a reddish-pink pigment at 530-537 nm (Hoyland and Taylor, 1991; Gray and Monahan, 1992).

It is theorized that TBARS are formed in substantial amounts primarily from PUFAs with three or more double bonds, such as α-linolenic acid (18:3) or arachidonic acid (20:4) (Rhee, 1978; Hoyland and Taylor, 1991). Particularly high levels of these fatty acids are found in phospholipids (Love and Pearson, 1971). Radicals with a double bond β to the carbon bearing the peroxy groups (acids containing more than two double bonds) cyclize to form peroxides with five-membered rings. Dahle et al. (1962) concluded that only peroxides unsaturated β to the peroxide group were capable of undergoing cyclization to form MDA. Once formed, the rings then decompose to form the compound MDA. The TBARS values provide a number associated with the extent of oxidation; they do not quantify the MDA that is present in the sample (Gray and Monahan, 1992).

The TBARS method as described by Tarladgis et al. (1960) and modified by Rhee (1978) tests the reaction of TBA and oxidative products of unsaturated fatty acids. The TBARS tests are performed on whole foods to measure the oxidation products of protein bound lipids and phospholipids (Tarladgis et al., 1960). After this method had become an established process, researchers wanted to minimize further any oxidation that was occurring in the sample during the distillation process to get a true TBARS value of the actual product. Vyncke (1975) was the first to add propyl gallate (*P*G), a phenolic antioxidant, and ethylene diamine tetra-acetic acid (EDTA), a metal chelator, in the distillation and extraction phase of the TBARS tests. The TBARS procedure was further modified by Rhee (1978). Rhee (1978) recommended adding PG and EDTA to the meat blending process to reduce any further oxidation that may occur during the process. Heat applied from the distillation unit is necessary for liberation and distillation of MDA. Hydrochloric acid is also added to the solution to lower the meat pH to 1.5-1.7 to aid in the release of MDA from the lipids and muscle cells. This process allows for approximately 66-70 percent of MDA recovery from the sample. High heat during a short time period increases the amount of MDA available for measurement. After distillation, the TBA reagent is added to the distillate, heated and color formation occurs. The TBA number is the absorbency of the sample multiplied by the constant (K).

$$K = \frac{\text{conc. moles/5mL distillate}}{\text{optical density}} \times \text{wt. MDA} \times \frac{10^7}{\text{wt. sample}} \times \frac{100}{\text{\% recovery}}$$

K (distillation) = 7.8 (68% recovery)

The correlation coefficient of TBARS values or mg MDA/kg when compared to trained panel sensory scores is highly significant at 0.89 (Tarladgis et al., 1960). Distillation method has been found to give lower recoveries compared to the solvent extraction method, but distillation is found to be more sensitive and more suitable to high fat samples (Hoyland and Taylor, 1991).

The compound 4-hydroxynonenal (4-HNE) is a well-documented secondary product of linoleic oxidation that also has an effect on the oxidation of myoglobin and color stability (Faustman et al., 2010). During oxidation, long chain fatty acids will produce aldehydes, hexanals, nonenals, and other compounds. These secondary products are responsible for covalently attaching to oxymyoglobin, making it more susceptible to oxidation and increasing metmyoglobin formation. A secondary nonenal, 4-HNE, is an important compound that affects the instability of myoglobin. It does this by changing the tertiary structure of the histidine present on the molecule allowing for greater accessibility and thus an increase of oxidation and metmyoglobin formation (Chaijan, 2008). The process of lipid oxidation is reported to enhance meat discoloration.

The instrumental measurement guidelines of American Meat Science Association's (AMSA) recommends using CIE *L*, a*, b**color space values for meat color measurement over the older Hunter-Lab values due to the formula's emphasis on the red part of the color spectrum (American Meat Science Association, 1991). The *L** component denotes color lightness, which measures the brightness or darkness of the color; the value is represented numerically, where 100 in white, and 0 is black. The *a** component measures the hue and chroma of color between green (-a) to red (+a); with higher values resultant in a redder color. The *b** component measures color between blue (-b) and yellow (+b) with higher values corresponding to a yellower color (American Meat Science Association, 2012).

Lipid oxidation is shown to drive changes in oxymyoglobin, *a** values and is correlated strongly with TBARS. Researchers also have reported that increased storage time will not only increase TBARS values, but concentrations of 4-HNE as well (Faustman et al., 2010). Products produced during lipid oxidation encourage oxidation of myoglobin, while the heme iron catalyzes and initiates lipid oxidation. Both lipid oxidation and color discoloration occur synergistically in the development of off odors, flavors, and color degradation.

Gas Chromatography and Mass Spectrometry

Warmed-over flavor is produced by lipid oxidation causing the formation of hydroperoxides. Hydroperoxides are the primary initial products of lipid oxidation and are essentially odorless, but will decompose to various volatile compounds (Gray et al., 1996). Gas chromatography (GC) and mass spectrometry (MS) systems, are used in flavor research to identify flavor and aroma compounds, can be used to identify compounds of products formed during lipid oxidation. The GC/MS determines these compounds through the collection of volatiles, separation of volatile compounds, identification of each compound, and quantification of each compound (Chambers & Koppel, 2013). Volatiles are collected with a solid phase microextraction (SPME) in the headspace of a container; they are injected into the GC/MS and then desorbed. The GC can separate the volatiles into individual compounds, while the MS identifies the compounds. Through the olfactory port (GC-O), the GC/MS can identify thousands of compounds and determine which compounds have aromas (Laird, 2015). The GC-O helps identify volatiles that are odor-active, and as the odor-active volatiles flow through the column, a panelist can record the smell and its intensity creating an aromagram, whereas the MS records the same compounds creating a chromatogram. The aromagram and chromatogram are compared to determine which compounds produce an odor. Data collected in a trained descriptive flavor attribute panel can be used to correlate with the volatile compounds identified and determine if the flavors and aromas present contribute to lipid oxidation. However, odors that have sensory significance and can occur at very low concentrations due to low threshold values. Therefore, the aromatic profile obtained by the GC-O might not reflect the human identified aroma profile of a compound (Laird, 2015).

Antioxidants

Controlling lipid oxidation is critical to preserving the shelf life of meat products. Antioxidants can be fed to the live animal, such as Vitamin E α-tocopherol, or can be added directly to product formulations of further processed meat products to delay onset, or slow the rate of lipid oxidation. Antioxidants offer a protective mechanism that limits or inhibits exposure of free radicals and reactive oxygen species. Antioxidants inhibit the chain reaction in the propagation phase of lipid oxidation by acting as free radical scavengers or excellent hydrogen donors that stop or inhibit the propagation of more free radicals (Nawar, 1996). A hydroxylated aromatic ring, or phenolic ring, (Haard and Chism, 1996) has a high affinity for free radicals and once attached, the free radical loses is destructive ability. Primary antioxidants are even more efficient when used in combination with a secondary antioxidant that acts as a synergist. Synergists are a mixture of antioxidants mixed with phenolic antioxidants as a free-radical acceptor or a combination of a free-radical acceptor and a metal chelator (Nawar, 1996). Once a synergist carries the radical, the primary antioxidant can continue working by collecting more radicals, thus inhibiting lipid oxidation.

All processed meat products use antioxidants to control lipid oxidation to some extent to inhibit the onset of lipid degradation and WOF. Synthetic antioxidants such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA), PG, nitrite and EDTA are common food preservatives that retard lipid oxidation and extend the shelf life of meat products (St Angelo and Bailey, 1987; Nunez de Gonzalez et al., 2008). Cured meats include sodium nitrite, whereas uncured meats typically depend on the addition of synthetic phenolic antioxidants (Sebranek et al., 2005). The most commonly added antioxidant in uncured meat products is the combination of BHA/BHT in fresh breakfast sausage and dried products, such as pepperoni (Sebranek et al., 2005). USDA regulations permit up to 0.01%, dependent on fat content, of each BHA and BHT in fresh sausage (CFR, 1999).

The use of antioxidants in food products is controlled by regulatory agencies within the country of use. Many compounds possess antioxidant properties to inhibit oxidative deterioration. However, few synthetic antioxidants are generally recognized as safe (GRAS) that can be added to food products. The use of antioxidants in food products in the United States is subject to regulation under the Federal Food, Drug and

Cosmetic Act, Meat Inspection Act, Poultry Inspection Act and other state laws (Karre et al., 2013).

Natural Antioxidants

Due to human health concerns for the synthetic antioxidants by some health professionals and consumers, meat processors are now seeking natural antioxidants as an alternative replacement to synthetic antioxidants (Sebranek et al., 2005; Karre et al., 2013). Natural antioxidants are the new wave of prevention and inhibition of oxidation in meat products; they are gaining scientific interest because of the safety and toxicity problems of synthetic antioxidants (Amarowicz et al., 2000; Shahidi, 2000; Jayathilakan et al., 2007; Karre et al., 2013). Consumer concern has favored plant or fruit-derived ingredients that contain naturally occurring antioxidants, mainly phenolic groups that have similar antioxidant properties of BHA/BHT (Nunez de Gonzalez et al., 2008).

Natural antioxidants are primarily plant phenolics that can occur in all parts of a plant. Phenolic compounds are among the most widely distributed plant secondary products and are found in many edible plants and feedstuffs (Hagerman et al., 1998). Polyphenols are partially responsible for color and astringency flavor in foods (Haard and Chism, 1996). There are two main categories of phenols, flavonoids, and phenolic acids. Flavonoids include the substantial antioxidant tannins and anthocyanins, while the phenolic acids are benzoic or cinnamic acid derivatives (Awika and Rooney, 2004). Antioxidant properties are also exhibited by polyphenols because they can inhibit lipid peroxidation and low-density lipoprotein oxidation by scavenging free radicals, acting as reducing agents, metal chelators and singlet oxygen quenchers (Sánchez-Moreno et al., 2000; Jayathilakan et al., 2007). Natural antioxidant compounds have a low activation energy that allows them to donate a hydrogen molecule to free radicals readily. The antioxidant that results after the donation of hydrogen is a free radical that is stabilized by the delocalization of the radical electron and, therefore, not subject to oxidation or initiation of other free radicals. The free radical antioxidants can react with other free radicals to form stable compounds, which in turn terminates the propagation phase of lipid oxidation. Several different types of antioxidants inhibit lipid oxidation. There are preventative antioxidants that inhibit free-radical formation, chain-breaking antioxidants or scavengers that interrupt the propagation of the autoxidation chain reaction, singlet oxygen quenchers, synergists of chain-breaking antioxidants, reducing agents, metal chelators, and inhibitors of pro-oxidant enzymes (Pokorný, 2007).

There is a direct relationship between the total amount of phenolic compounds and antioxidant capacity of plants (Robards et al., 1999). Such antioxidant phenols are found in fruits, vegetables, nuts, seeds, leaves, roots, and barks. Many natural antioxidants already have been isolated from different kinds of plants, such as oilseeds, cereal grains, vegetables, leaves, roots, spices, and herbs (Jayathilakan et al., 2007). Due to their high phenolic compound content and applicability in meat products, fruits, and other plant materials have been tested as a potential natural antioxidant alternative. These plant-derived ingredients include plum, grapeseed extract, cranberry, pomegranate, bearberry, pine bark extract, rosemary, oregano, and other spices. Some of these added ingredients may affect the quality, sensory, color, or ultimately consumer perception of the meat products (Karre et al., 2013).

Rosemary

Rosemary extracts and oleoresins have been found to be effective in slowing down lipid oxidation in meat systems by many researchers. Formanek et al. (2001) reported that the inclusion of a rosemary extract improved the stability of beef patties containing dietary alpha-tocopherol acetate similarly to BHA/BHT. Barbut et al. (1985) found that extracted rosemary oleoresin was comparable to BHA/BHT–citric acid blend in suppressing lipid oxidation in uncooked breakfast turkey sausages. Additionally, Sebranek et al. (2005) reported a rosemary extract was more effective than BHA/BHT in maintaining low TBARS values in raw frozen sausage. Contrary reports by Ahn et al. (2002) found even though rosemary extracts were effective antioxidants, they were considered less effective than BHA/BHT in cooked ground beef. Beltran et al. (2004) reported the same for rosemary extract used in cooked chicken samples.

Tannins

Tannins are naturally occurring phenolic compounds that precipitate proteins (Hagerman et al., 1998). Many plant derived tannins are natural phenolic antioxidants and are used as food additives to prevent or reduce lipid oxidation (Chung et al., 1998; Hagerman et al., 1998). Tannins are present in a wide variety of foods including cereals, herbs, fruits, vegetables, oilseeds, legumes, spices, cocoa products, wines and other beverages (Ivanov et al., 2001; Pokorný, 2007). Tannins are found in grains like sorghum, millet, barley, dry beans, fava beans, peas, carobs, pigeon peas, and winged beans. Other rich sources of tannins include different tea and wine beverages and forages such as crown vetch, lespedeza, lotus, sainfoin, and trefoil (Chung et al., 1998).

Hagerman et al. (1998) indicate that tannins possess higher antioxidant activities and are 15-30 times more potent at quenching peroxy radicals when compared to simple phenols. Tannins are polyphenols that are classified as hydrolyzable, contain a central core polyhydric alcohol and hydroxyl groups; or condensed, polymerized products of flavan-3-ols and/or flavan-3,4 diols (Haard and Chism, 1996; Awika, 2003). Antioxidant activity of tannins is binary as they can chelate transition metals, such as Cu and Fe, and they can inhibit free radical chain propagation reactions acting as scavenger antioxidants. Tannin polyphenols can donate an electron to highly reactive free radicals, and by delocalizing the unpaired electron on the phenolic ring can quench the reactivity of the radical (Hagerman et al., 1998; Awika, 2003).

There is hesitation associated with adding tannin-containing ingredients to meat products based on the known sensory attributes of tannins. Tannins range in color from yellowish-white to light brown, and they contribute to astringency in foods (von Elbe, 1996). Astringency can be perceived as a dry feeling in the mouth, a coarse puckering of oral tissue, and may often be described as a bitter taste. Because of its high tannin and polyphenol content, the consumption of a red wine leaves the consumer with a dry, or astringent, mouth feel. Tannin phenolic groups can cross-link chemically with proteins and have been suggested as a possible contributor to the astringency sensation (Lindsay, 1996). Increased astringency attributes in certain meat products may be undesirable, but astringency may be decreased or avoided by adding different tannins and adjusting concentrations (Roybal, 2010).

Anthocyanins

Anthocyanins are phenolic flavonoids that are responsible for color pigments in plants including blue, purple, violet, magenta, red and orange (von Elbe, 1996; Dykes et al., 2005). Anthocyanins are probably the most important group of visible plant pigments besides chlorophyll (Kong et al., 2003). Extensive studies on anthocyanins found in fruit and vegetables have been conducted to examine antioxidant properties, health benefits, and potential as natural food colorants (Awika and Rooney, 2004). Therapeutic health benefits found in anthocyanins include vasoprotective, anti-inflammatory, anti-cancer, and chemoprotective properties (Awika et al., 2004). Anthocyanins present in red wine were found to be effective in scavenging free radicals by inhibiting lipoprotein oxidation and platelet aggregation. Researchers suggest that anthocyanins could also be a key component in the protection against cardiovascular disease (Ghiselli et al., 1998), colon cancer and gastric cancer (Kamei et al., 1998).

Sorghum

Sorghum is an ancient old-world cereal grass that is the fifth most important cereal crop in the world after wheat, rice, corn, and barley (Rooney and Waniska, 2000; Awika and Rooney, 2004; Wu et al., 2012). Sorghum is grown in many parts of the world and is the dietary staple of over 500 million people in the tropics and semi-tropics (Wu et al., 2012). Sorghum is more economical to produce because it outperforms under various environmental stresses, greater drought resistance, and higher nutritional value than other cereal grains (Awika and Rooney, 2004; Wu et al., 2012). The majority of the sorghum grown in the world is used for animal feed, alcohol, and industrial products, while 35% is grown directly for human consumption. Twenty percent of the world production and almost 80% of global sorghum exports in 2001-2002 was produced and exported from the United States (Awika and Rooney, 2004).

Different sorghum varieties are in an assortment of food products. White food sorghum is processed into flour and can be a gluten-free substitute in bakery items for people allergic to wheat gluten. Whole sorghum grain can be used as partial or complete substitutes for cereal-based products directly in food and can be in baked and extruded products such as bread, beer, cookies, pasta, breakfast cereals, tortilla chips, and so forth. The addition of sorghum brans into food can increase dietary fiber, caramel coloring in baked items, as well as its high antioxidant properties in human health and product shelf life (Awika and Rooney, 2004; Dykes and Rooney, 2006).

In Africa, pigmented tannin-containing sorghum varieties are grown as a food staple, and the grain is mixed with making porridge and alcoholic beverages (Awika and Rooney, 2004; Dykes and Rooney, 2006). In some cultures, high tannin sorghums are preferred as they increase satiety, and the consumer will feel more “full” for longer. This phenomenon can also be beneficial to the obesity problem in America. Research has shown one of the most adverse effects of feeding animals and livestock the high tannin sorghum variety is reduced weight gain (Awika and Rooney, 2004; Wu et al., 2012). Tannins bind to carbohydrates, proteins, minerals, and digestive enzymes turning them into insoluble complexes, thus reducing the digestibility of those nutrients.

The inclusion of high tannin sorghum in the diet and feeling of satiety lowers the overall calorie intake in animals (Awika and Rooney, 2004; Dykes and Rooney, 2006). Because tannins in sorghum grains have been shown to decrease weight gain in animals and livestock, most of the feedstock production of sorghum in the United States is restricted to non-tannin containing sorghum varieties which have virtually the same energy profile as corn (Awika and Rooney, 2004). However, a niche market for the high tannin sorghum has emerged for the dietary fiber, high antioxidant, gluten free, and possible weight loss capabilities present in high tannin sorghum grains (Wu et al., 2012). Unfortunately, there is no reported work regarding weight loss on how high tannin attributes can be used to help lower calorie intake in humans (Awika and Rooney, 2004).

All sorghum contains phenolic compounds that assist in the natural defense of plants against pests and diseases, and most contain flavonoids (Awika and Rooney, 2004; Dykes and Rooney, 2006). Flavonoids in sorghum include the substantial antioxidant tannins and anthocyanins, whereas the phenolic acids are benzoic or cinnamic acid derivatives. Appearance and total extractable phenols classify sorghum into multiple varieties. White food-type sorghum has no detectable tannins or anthocyanins and low levels of extractable phenols. Red sorghum contains significant total extractable phenol levels, but does not have tannins. Black sorghum has a very high level of anthocyanins and a black pericarp, and brown sorghum has a pigmented testa and significant levels of tannins (Awika and Rooney, 2004). Only varieties with a pigmented testa, the layer that is made into a bran, possess tannins and are almost exclusively of the "condensed" type (Awika and Rooney, 2004). The phenolic compounds, found in the outer layers of the sorghum kernel, provide the antioxidant activity of interest in the food industry (Awika, 2003; Awika et al., 2003).

To measure the ability of antioxidants to protect protein from damage by free radicals, the oxygen radical absorbance capacity (ORAC) method was developed (Cao et al., 1993). The ORAC assays the antioxidant activity against different types of free radicals: peroxyl radicals, hydroxyl radicals, and transition metals. The brown tannin-containing sorghums, sumac and high tannin, and black sorghums, which do not contain tannins but have high levels of anthocyanins, were both found to have relatively high antioxidant activities. Most of the antioxidant activities were retained when sorghums were processed into foods, 57-78% for baked and 70-100% for extruded products (Awika et al., 2003).

Anthocyanins have been extensively studied in fruits and vegetables, but there is limited data regarding the anthocyanin levels in cereal grain because they have not been considered as a source for commercial antioxidant production. Sorghum contains a unique type of anthocyanin, 3-deoxyanthocyanadins, which are not found common in fruits, vegetables or other cereals. The 3-deoxyanthocyanadins were reported to be more stable in acidic solutions than the anthocyanins found in fruits, vegetables or other cereals (Awika and Rooney, 2004). Sorghum also has an advantage in storage stability relative to fruits and vegetables. Black sorghum varieties were reported to have higher anthocyanins than other sorghum, thus suggesting the potential advantage of black sorghum as a viable commercial source as an antioxidant. Any nutritional concerns related to tannins are eliminated as black sorghum does not have condensed tannins (Awika et al., 2004). Onyx sorghum bran is a commercially available black sorghum variety developed at Texas A&M University by Dr. William Rooney, and currently grown on the high plains of Kansas and West Texas. A cereal company, Silver Palate Kitchens, has contracted farmers to grow Onyx as they are introducing Onyx sorghum in combination with High Tannin Sorghum into their new high antioxidant cereals (Scott, 2016).

Sorghum as an Antioxidant in Meat Products

Using sorghum or sorghum bran in other food products, specifically processed meat, has been examined. Previous research has shown tannin-containing sorghum bran, Sumac and High Tannin, have been effective antioxidant additives to both raw and cooked ground meat systems. Jenschke (2004) reported the addition of brown HTS bran and Hemphill (2006) the addition of sumac sorghum bran both at low levels retarded oxidative rancidity in fresh ground beef patties without causing detrimental color changes and negatively affecting sensory attributes. Hesteande (2014) reported the addition of High Tannin sorghum bran to cooked turkey patties yielded similar or lower ($P < 0.05$) TBARS values than patties containing BHA/BHT and they suggested that HTS bran could be used as an effective antioxidant without negatively affecting sensory flavor attributes. Roybal (2010) reported HTS and black sorghum bran added to pre-cooked ground beef products would provide better antioxidant protection than BHA/BHT and rosemary extract. Shin (2006) reported Sumac sorghum bran delayed lipid oxidation by reducing TBARS values and cooked beef fat flavors when used at 0.25 and 0.5% levels and had minimal effects on color and sensory attributes were observed.

New High Tannin and Onyx sorghum brans are two commercially grown sorghum brans available currently on the market. Previous university research has shown the effectiveness of both tannin and anthocyanin containing sorghum in increasing the shelf-life and reducing lipid oxidation of fresh and cooked ground meat products. However, there is no data concerning applications of sorghum bran as an antioxidant in industrial meat applications or under frozen storage conditions.

Therefore, the hypothesis is that natural, commercially grown sorghum brans, the new High Tannin and Onyx, have greater antioxidant properties in meat and poultry products than BHA/BHT and rosemary extract. Objectives were to evaluate the antioxidant, color and flavor effects of powdered new High Tannin and Onyx sorghum bran in pre-cooked dark meat chicken patties and pre-cooked pork crumbles stored in aerobic, refrigerated conditions (*P*hase I) and in pre-cooked dark meat ground chicken and pre-cooked pork crumbles stored in aerobic, frozen conditions (*P*hase II).

CHAPTER III

MATERIALS AND METHODS

Phase I: Aerobic, Refrigerated Study to Define Levels of Use

Pre-cooked Pork Crumbles

Product Collection, Treatments, and Manufacture

At 10 d postmortem, coarse ground pork (20% lipid) was obtained from a meat distributor (Ruffino Meats and Food Service., Bryan, Texas via IBP Tyson Foods Inc., Dakota Dunes, South Dakota) at three different collection times. The pork then was further ground through a 4.8 mm plate using an electric bench top meat grinder (Guide Series #12 Electric Meat Grinder, 3/4 HP motor, Gander Mountain, St. Paul, MN). Each meat sample was weighed to 1610 g, vacuum packaged, and placed in a cooler (4°C) until the next day. On Day 0, the ground pork was divided into one of 11 treatments. Treatments were defined as: 1) Control - no added ingredients; 2) 0.2% rosemary extract (Herbalox® Type HT-25, Kalsec Inc., Kalamazoo, MI); 3) 0.01% of each food-grade butylated hydroxyanisole (BHA, Sigma-Aldrich, W218208) and butylated hydroxytoluene (BHT, Sigma-Aldrich, W218405); 4, 5, 6 and 7) 0.125%, 0.25%, 0.50% and 0.75% Onyx sorghum bran; and 8, 9, 10 and 11) 0.125%, 0.25%, 0.5% and 0.75% High Tannin sorghum (HTS). The sorghum brans were developed and supplied by Dr. William Rooney from Texas A&M's Department of Crop and Soil Science.

Each treatment received was mixed in a Hobart bench top mixer (Model: A-200 T, Troy, OH) at number 1 speed for exactly 1 min. The control treatment was mixed first, followed by the lowest level of HTS moving to the highest level. The same method was applied to the Onyx bran treatments. The bowl and mixing paddle were washed and dried between each treatment. After mixing, 150 g of each treatment was saved for fresh objective and subjective color measurements, pH and frozen to -62°C for chemical lipid and moisture determinations for each of the 11 treatments. Percent moisture was determined using the oven dry method, and percent lipid was determined using ether extraction.

Pork Crumbles Fresh Color Analysis

Objective color was obtained instrumentally on all raw pork crumbles using a Minolta Chroma Meter (model CR-400, Minolta Co. Ltd., Ramsey, NJ) to measure CIE color space values (*L**, *a**, *b**). The Minolta was calibrated daily using a white tile (values *L** = 98.13, *a** = -0.07, *b** = -0.39). The lens portion of the Minolta was covered with polyvinyl chloride (*P*VC) film to imitate the view through a packaged product, and the Minolta was calibrated to the PVC film. The CIE *L**, *a**, and *b** color space values were reported from three random locations and averaged. Subjective color was measured by at least three pre-trained descriptive attribute color sensory panelists as defined by American Meat Science Association (2012, 2014). Panelists became familiar with the twelve-point fresh lean color scale (1= very light; 12= dark grayish-brown) during training. Visual standards were provided for training and reference purposes. Color codes for each scale, fresh and cooked, were decided on by the panelists during training using the National Pork Producers Council Pork Quality Color Standard cards, combined with Sherwin-Williams Paint color cards, (Table 1 and 2).

Raw Pork pH and Cooking

Three internal pH readings were taken from random locations in the raw ground pork, using puncture needle probe and pH meter (Hach, H100, Loveland, CO) after subjective color evaluations were made. The three measurements were averaged to determine the representative pH value of each treatment. Standard buffers of 4.0 and 7.0 were used to calibrate the pH meter at the beginning of each day. The ground pork was cooked in aluminum electric skillets (Presto, 06852, 1500W, Eau Claire, WI.) at 177°C to an internal temperature of 70°C and cooked into crumbles. Internal temperatures were monitored using a copper-constantan thermocouple (Omega Engineering, Stanford, CT), inserted randomly in the ground meat and connected to a handheld Omega HH501BT Type T thermometer (T-Type, Omega Engineering, Inc., Stanford, CT) where the temperature was displayed. Initial time, initial internal temperature, final time, and final internal temperature were recorded for each treatment. Pre- and post-cook weights were obtained to calculate cook yield.

Pork Crumbles Cooked color, pH, and Storage

After cooking, ground pork crumbles were evaluated for objective and subjective cooked color, and internal pH was again measured following the same procedures as the fresh meat analysis. Each treatment of pork crumbles were then placed on individually labeled Styrofoam trays (Genpak®, W1002, #2 Westcoast Supermarket Tray, Glens Falls, NY) and over-wrapped (Heat Sealing Equip. Co., Cleveland, OH) with PVC film (Performance Plastic Meat Film, O_2 transmission rate = 1400cc/254cm^2 per 24 h @ 23°C, 1 atm, 57 Gauge, WP-MWL14, U.S. Packaging & Wrapping, Cabot, AR).

Packages were randomly selected for one of four storage days (0, 1, 3, and 5 d), for either trained sensory and color panel, or TBARS determinations. Packages were then randomly assigned locations in a 4°C cooler under 1600 lx fluorescent lighting, simulating a retail meat case. The crumbles remained under these conditions throughout the duration of the assigned storage period to stimulate lipid oxidation.

Expert, Trained Descriptive Pork Flavor Analysis

The stored pre-cooked pork crumbles were used for expert, trained meat descriptive flavor, and texture descriptive attribute evaluation to determine the effect of ingredient addition on flavor and texture (Table 4) after 1 and 3 d of storage. Panelists have over 200 h of training and had 12 h of specific training for pork crumbles and ground dark meat chicken. Each trained panelist was provided with room temperature ddH_2O (double distilled water), unsalted saltine crackers, expectorant cups, napkins, toothpicks, and a pencil. Trained panelists were asked to cleanse their palate before the first sample and between subsequent samples by taking a bite of an unsalted saltine cracker and a drink of ddH_2O. At the beginning of each evaluation day, panelists were calibrated using a control or "warm-up" sample that was evaluated and discussed orally amongst panel members. Each sample was assigned a three-digit random number and serve in a pre-randomized order.

Reheating

Crumbles were removed from the overwrap tray packaging, placed in the center of a Corelle (Corelle® Livingware™ Winter Frost White, World Kitchen, LLC., Rosemont, Il.) break and chip resistant plate, covered with a paper towel, and placed in the center of a household sensor microwave oven (General Electric Co., Louisville, KY, Model No. JES 1351WB 003). Crumbles were reheated until internal temperature of greater than 74°C was achieved. Crumbles were removed from the microwave and divided evenly to panelists into plastic 59 mL soufflé cups (translucent plastic 2 oz. portion cups, Georgia-Pacific, Asheboro, North Carolina) that are tested to assure they do not impart flavors on the samples. Crumbles were served to up to eight panelists seated in individual booths with red lights at 40-50 lx. Each sensory attribute was evaluated using a 16-point Universal scale where 0 = none and 15 = extremely intense. Attributes, definitions, and references for pork crumbles are reported in Table 4. Each soufflé cup was labeled with a 3-digit random number for data collection purposes. There were at least four min between samples to reduce the halo effect and minimize taste bud fatigue. Six samples were served per session, and a 10 m break was given between sessions. Two sessions were conducted on each sensory day, and samples assigned to sensory day were randomly assigned to a sensory session and order within a session.

Cooked and reheated pork crumbles on each storage day were evaluated for pH, objective and subjective color, and TBARS determinations. Objective and subjective color were performed following the same procedures as the fresh meat analysis. During training, color panelists became familiar with the twelve-point cooked color scale (1 = very light; 12 = dark grayish-brown) and the color cards were available for reference (Table 1 and 2).

TBARS Analysis

TBARS was conducted using the procedures described by Tarladgis et al. (1960) and modified by Rhee (1978). Two 10 g samples of each treatment were collected after reheating at the same time the samples were served to panelists. The reheated meat samples were added to a mixture of 50 mL of ddH2O with 5 mL of 0.5% propyl gallate (PG) and 0.5% ethylenediaminetetraacetic acid (EDTA) solution into 125 mL polypropylene bottles. Samples in solution were homogenized with a Polytron Homogenizer (System PT 3100, Kinematica Inc., Bohemia, NY) at 15,000 RPM for exactly 1 min. The homogenized mixture, boiling beads and 2.5 mL of 4*N* HCl was then added to 500 mL Kjeldahl distillation flasks. The polypropylene bottle was rinsed with 31.5 mL of ddH2O and then added to the flask. The inside neck of each Kjeldahl flask was coated with a 316 Silicone Release Spray (Molykote® 316 Silicone Release Fluid, DOW Corning Corp., Midland, MI) to reduce foaming. Flasks were placed on a distillation unit until 50 mL of distillate had been collected in graduated cylinders, and the distillate was then transferred to plastic screw cap vials.

In duplicate, 5 mL of distillate from each sample and 5mL of 0.02 M 2-Thiobarbituric Acid reagent (TBA) was pipetted into glass, screw cap test tubes and thoroughly mixed with a touch mixer. A blank reference test tube was prepared to contain 5mL of ddH2O and 5mL of the TBA reagent. Test tubes were added to 100°C water bath for 35 min, chilled in an ice water bath for 10 min and mixed again on a touch mixer. Each sample was loaded in triplicate in a 125 µL/well in a 96-well microplate and read at 532nm on an Epoch™ Spectrophotometer Microplate reader, controlled with the Gen5 Data Analysis software (BioTek U.S, Winooski, VT). TBARS values expressed as mg malonaldehyde/kg ground meat, were calculated using the following conversion factor: mg malonaldehyde/kg sample = absorbance x 7.8 (Tarladgis et al., 1960).

Cooked Pork Crumbles Volatile Evaluation

Chemical flavor volatile determinations using AromaTrax analysis (MicroAnalytics-Aromatrax, Round Rock, TX) were also conducted on the pork crumbles. This technology uses gas chromatography/mass spectrometry (GC/MS) coupled with a human sniff port to separate the volatile compounds in the air around the hot, pre-cooked meat. The same time samples were reheated and served to the panelists, 30 g of meat was frozen in liquid nitrogen and held at -62°C until ready to be read on the GC/MS. In preparation for reading on the GC/MS, the 30 g frozen sample was placed in a glass jar (473 mL) with a plastic lid and then placed in a water bath at 70°C for 1 h. The headspace above each meat sample in the glass jar then was collected for 2 h with a solid-phase micro-extraction (SPME) Portable Field Sampler (Supelco 504831, 75 μm Carboxen/ polydimethylsiloxane, Sigma-Aldrich, St. Louis, MO).

Upon completion of collection, the SPME was injected into the injection port, where the sample was desorbed at 280°C. The sample then was 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. 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 use the AromaTrax software, and they monitored the time when an aroma event took place.

This study was replicated three times with fresh product purchased on three different selection days with the same number of days aged. Data were analyzed, and the minimal usage level that had the highest amount of antioxidant capabilities and that was not detrimental to color, was used in Phase II for the HTS and Onyx sorghum brans. Data were analyzed using Proc General Linear Model of SAS (SAS Institute, Cary, NC) at $P < 0.05$. Antioxidant treatment and storage time were used as main effects, and their interactions were also included in the model. Each study was conducted in three replications, and replications were included as a block in the analyses.

Fully Cooked Dark Meat Chicken Patties

At 7 d postmortem boneless, skinless chicken thigh meat was obtained from a meat distributor (Ruffino Meats and Food Service., Bryan, Texas via Sanderson Farms Inc., Texas, USA), at three different collection times. Excess trimmable fat from the thighs was removed and ground through 4.8 mm plate and mixed using the same electric bench top meat grinder as previously defined. Ground chicken was mixed according to the same procedures as the ground pork. Treated chicken samples were divided and weighed to 113.5 g, placed on patty paper, and hand formed using a cast aluminum hamburger press (American Metalcraft, AHM485, Franklin Park, IL). Patties were selected randomly for one of four storage days (0, 1, 3, and 5 d) and for either trained sensory (Table 3) and color panel (Table 1 and 2), or TBARS determinations. Patties were cooked in electric skillets at 177°C to an internal temperature of 70°C as defined for pork. Pre- and post-cook weights were obtained to calculate cook yield. Patties were stored, reheated, and evaluated as defined for pork crumbles, and data were analyzed to determine minimal usage levels that had the highest amount of antioxidant properties, and that did not affect color for use in Phase II for the HTS and Onyx sorghum brans.

Phase II: Aerobic, Frozen Storage Study in Cooperation with Tyson Foods

Phase II utilized the optimal treatment levels defined from Phase I. Products were manufactured at the Tyson Foods Discovery Center pilot facility in Springdale, AR. Four treatments were defined, and three replicates were defined as different processing days. The treatments within each product were: 1) Control – no added antioxidant; 2) 0.20% Rosemary plus green tea extract (Kemin Fortium™, RGT12 Plus Dry Natural Plant Extract, Des Moines, IA); 3) 0.5 % of HTS bran; and 4) 0.5 % of Onyx sorghum bran.

Pre-cooked Pork Pizza Toppings

Product Collection, Manufacture and Analysis

Pork trimmings (35% lipid) obtained by Tyson Foods Inc., was ground to 4.8 mm in a meat grinder (Biro® Manufacturing Company, Marblehead, Ohio). Post grinding, meat, antioxidants, water, and salt were mixed in a vacuum paddle mixer (Food Processing Equipment Company, Model #814, Springdale, AR) for three min and chilled with CO_2 until the meat blend reached between -3 to -2°C. Raw data were collected after mixing as defined in Phase I, and the final raw product formula is presented in Table 18. Batches then were placed in the hopper of a Vemag vacuum filler (VEMAG Maschinenbau GmbH, Verden, Germany; Reiser, Canton, MA USA) and extruded into 2 g random shaped pieces defined as pizza toppings crumbles. The toppings were portioned directly into a ContinuTherm continuous food cooker (Model # OS-0906-J, Blentech Corp., Rohnert Park, CA) with a solid screw agitator that pushed the toppings through 81°C oil. Individual pieces were cooked to an internal temperature of 79°C. Internal temperature was determined on five random pieces throughout the duration of the cooking cycle using a probe thermometer (Atkins Econotemp Thermometer, Model #32311-K, Cooper-Atkins Corporation, Middlefield, CT). Raw data were collected after mixing as defined in Phase I. Ten weights of five raw crumbles were recorded, and cook yields were determined by recording ten weights of the five fully cooked crumbles randomly throughout the cook cycle. Fully cooked crumbles were water rinsed, and individually quick frozen (IQF) -68°C through a tunnel freezer (BOC, The Linde Group, UK) and boxed loose packed in aerobic plastic box liners. Boxes were stored at Tyson in -23°C freezer simulating industry storage conditions for up to 12 months.

Fully Cooked Dark Meat Ground Chicken

Product Collection and Manufacture

Boneless leg meat was ground to 4.8 mm and held overnight in covered plastic containers in a cooler at 4°C. The following day, antioxidants, water, salt, and rice starch, were added to a Versa Therm™ Blending Cooker (Blentech Corp., Rohnert Park, CA) where the product was mixed and steam jack cooked until the product reached an internal temperature of 74°C. Raw data were collected after mixing as defined in Phase I, and the final raw product formula is presented in Table 19. Temperature was monitored as previously defined. Cook yields were determined by weighing raw materials going in the blender, weighing the cooked meat, and straining out and weighing the broth produced in the cooker. The percentage of broth for each batch then was added back to each bag containing 1.8 kg and sealed with an Electric Bag Sealer (American International, 12" Hand Operated, Buford, GA). Bags (Cryovac® Barrier Bags, #B2470, O2 transmission rate cc@ 23°C 1 atm, m^2, 24 h, Sealed Air, Charlotte, NC) were sealed, blast frozen, and boxed. Boxes were stored at Tyson in -23°C freezer simulating industry storage conditions for up to 12 months.

Chemical and Sensory Analysis

On 0, 3, 6, 9 and 12 mo of storage, frozen cooked pork pizza toppings and ground chicken for each storage time was evaluated for pH, objective and subjective color, and TBARS determinations as defined in Phase I. To determine the effect of ingredient addition in frozen cooked pork pizza toppings and ground chicken, expert trained meat descriptive flavor attributes, texture evaluation, and AromaTrax chemical flavor and volatile determinations was used as defined in Phase I.

Statistical Analysis

Data were analyzed using PROC GLM of SAS (SAS Institute, Cary, NC) at $P < 0.05$. Antioxidant treatment and storage time was used as main effects, and their interactions also were included in the model. Each study was conducted in three replications, defined as separate weeks (Phase I), different processing days (Phase II), and replications were included as a block in the analyses. The model included replicate as a block, antioxidant treatment, storage day or month and the antioxidant treatment by storage day or month 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 STDERR 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 LINES function of SAS.

CHAPTER IV

RESULTS AND DISCUSSION

Phase I: Aerobic, Refrigerated Study to Define Levels of Use

Pre-cooked Pork Crumbles

Raw Chemical and Color Evaluation

In Phase I, raw pork crumbles treated with 11 treatments did not differ ($P \geq 0.05$) in percent moisture and lipid (Table 6) or cook yield, pH, and a* CIE color space values (Table 7). Raw pork crumbles containing BHA/BHT and rosemary antioxidants were lighter ($P < 0.05$) in subjective color than crumbles with Onyx sorghum and 0.75% HTS bran added. The greater amount of sorghum bran added to the crumbles increased the subjective score value, thus increasing the darkness of the crumbles. However, raw pork crumbles containing 0.75% Onyx were darkest in subjective color.

CIE *L*a*b** color space values indicated that the raw pork crumbles containing 0.50% HTS or Onyx, and 0.75% Onyx sorghum bran were darker ($P < 0.05$) than other treatments, whereas rosemary was the lightest among treatments. Raw pork crumbles with 0.75% HTS bran addition had more yellow color than other treatments, whereas 0.50% and 0.75% Onyx bran were the least yellow. These results indicate that higher levels of either HTS or Onyx sorghum bran in raw pork crumbles did not affect ($P > 0.05$) cook yield, pH or *a** color space values, but did have a slight effect on color of the final product. Hesteande (2014) suggested that meat products with added sorghum bran were darker in color than control, BHA/BHT, and rosemary treatments due to the darkness of the sorghum bran itself. The sorghum brans are added in a solid, nondissolvable form, which maintained their dark color in raw form, during cooking, and through storage, whereas BHA/BHT and rosemary treatments, which are in crystalline and liquid form, dissolve into the product at the raw phase.

Cooked pH

Pre-cooked pork crumbles did not differ ($P \geq 0.05$) in pH across 11 treatments, but as storage day increased, pH decreased ($P < 0.001$) in pre-cooked pork crumbles (Table 8). Shin (2006) also found with increased storage time, pH decreased in ground beef patties varying in fat content and treatment in general. Cruzen (2010) and Roybal (2010) observed over the first few days of storage pH values steadily and significantly increased then experienced a sudden drop during the remaining storage days. This pH decline with increased storage time was inconsistent with the findings of Jenschke (2004) and Hemphill (2006), whose data showed a steady pH increase over storage time.

Cooked Color

Subjective and objective color attributes were affected by treatment and storage day ($P < 0.001$) (Table 8). As the level of either HTS or Onyx sorghum bran increased in pre-cooked pork crumbles, subjective color and L^* color space values indicated that the subsequent pork crumbles were darker, redder and less yellow in color ($P < 0.0001$). Hesteande (2014) observed similar results within sorghum bran treatments, where fully cooked dark meat chicken nuggets also were darker, more red and less yellow as level increased from 0.25% to 0.50% sorghum bran ($P < 0.05$). L^* and a^* color space values showed that pre-cooked pork crumbles became darker and less red ($P < 0.0001$) as storage day increased. However, there was no treatment by storage day interaction ($P \geq 0.05$) in either subjective or objective color measurements.

TBARS Determinations

TBARS values, an indication of lipid oxidation, were affected by treatment, storage day and their two-way interaction ($P < 0.0001$). In general, as the level of either HTS or Onyx sorghum bran increased in pre-cooked pork crumbles, the TBARS values decreased showing that higher levels of sorghum bran prevented or reduced the amount of lipid oxidation present in the samples (Table 8). However, there was a significant ($P < 0.0001$) interaction between treatment and storage day (Figure 1). Control pre-cooked pork crumbles had the highest TBARS values at day 0, and TBARS values increased with each storage day showing the highest TBARS values across treatments at day 5 (11.39 TBARS value). Tarladgis et al. (1960) suggested that the detection of off-odor and oxidation was perceived with TBARS in the threshold range of approximately 0.5–1.0 in pork. At this recommended threshold, the pre-cooked pork crumbles' TBARS values suggest a very high amount of oxidation was present without the use of an antioxidant. Cruzen (2010) and Shin (2006) also had observed control cooked ground beef patty TBARS values increased at a rapid rate over the 5d storage period. The cooked ground beef patties in both studies were exposed to similar conditions that were favorable for lipid oxidation, including cooking, aerobic packaging, fluorescent lighting, and same length of storage. The control cooked ground beef patties had higher oxidation levels over the 5 d storage period than all other treated patties, indicating that the remaining treatments suppressed oxidation over time.

Pre-cooked pork crumbles containing either 0.50 or 0.75% HTS and Onyx or BHA/BHT had the lowest TBARS values, within 1.0-2.0 TBARS value across storage days. Recently, Hesteande (2014) also found that 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. Similarly, Jenschke (2004) observed the addition of sorghum bran at 0.25% in ground beef patties resulted in lower TBARS values when compared to controls at 3, 6, and 9 storage days. Treatments not previously defined were intermediate in TBARS values with increased storage time. These results indicated that 0.5 or 0.75% sorghum bran addition, either HTS or Onyx, limited the development of lipid oxidation similarly to BHA/BHT.

Expert, Trained Descriptive Meat Sensory Analysis

Pre-cooked pork crumbles were evaluated for flavor using an expert flavor descriptive attributes sensory panel (Table 9). Treatment did not affect pork identity, fat-like, metallic, salty, bitter, umami and rancid flavors. Pre-cooked pork crumbles with 0.50 or 0.75% HTS or Onyx sorghum bran were slightly higher ($P < 0.01$) in brown/roasted, sorghum, and gritty, while slightly lower ($P < 0.05$) in astringent, sweet, sour, cardboard, heated oil, painty, refrigerator stale, and warmed over flavor than control crumbles. These results indicate that sorghum bran addition at higher levels, retarded flavor ($P < 0.05$) associated with lipid oxidation (cardboard, heated oil, painty, refrigerator stale and warmed-over flavors) and slightly increased flavors associated with sorghum bran ($P < 0.0001$). As the level of sorghum bran was increased in the formulation, the overall sorghum flavor and grittiness also slightly increased ($P < 0.01$), whereas the astringency, sweetness, heated oil, refrigerator stale and warmed-over flavors decreased ($P < 0.05$). Onyx and high tannin sorghum also had slightly different effects on sensory attributes individually. As the level of HTS increased, painty slightly decreased, while the increased level of Onyx bran slightly decreased sour notes.

Storage day also had a slight effect on sensory attributes in pork crumbles. The increase from 1 d to 3 d of storage decreased the intensity ($P < 0.05$) of pork identity and sweet, while increasing the prevalence of brown/roasted, astringent, heated oil, nutty and painty flavor attributes. The difference in these attributes in storage day across all treatments shows how the day effect influenced attributes associated with lipid oxidation and changes with increased storage time. However, there were no treatment by storage day interactions ($P \geq 0.05$) for sensory attributes.

Whereas slight changes in sorghum bran-based flavors increased, the change in flavor was minimal when evaluated by a trained sensory attribute panel. Cruzen (2010) performed consumer sensory analysis comparing 0.5% Black Tannin Sorghum to control, BHA/BHT and rosemary extract in cooked ground beef patties stored for no more than 24 hrs. Consumers found black tannin sorghum to be equal to BHA/BHT and control in overall like, flavor, tenderness level and ground beef bite, while also showing greater approval for overall like, flavor and ground beef bite than rosemary extract. However, only trained sensory was performed in this study and flavor changes that were found were minimal. Further consumer panel testing would be needed to validate if the new Onyx and High Tannin sorghum bran-associated flavor would be negatively perceived by consumers.

Cooked Meat Volatile Evaluation

Volatile aromatic chemicals were identified for pork crumbles (Table 10), and 12 volatile aromatic chemicals differed across treatments ($P < 0.05$). 5-Pentyl-2(5H)furanone and nonenal differed across treatments ($P < 0.05$) and are considered products of lipid oxidation. Treatments containing BHA/BHT, rosemary, and 0.75% Onyx sorghum bran did not contain 5-pentyl-2(5H)furanone, whereas other treatments had increased levels. Pork crumbles with BHA/BHT did not have detectable levels of nonenal, but pork crumbles from other treatments had substantial levels of nonenal. Naphthalene and carbon disulfide tended to be present ($P < 0.05$) in pork crumbles with more limited lipid oxidation.

Other volatile aromatic compounds reported in pork crumbles were 1-octanol, 2,6-bis(1,1-dimethylethyl)-4-methyl-penol, 2-undecenal, 3,5-octadien-2-one, 3-ethyl-benzaldehyde, heptanoic and nonanoic acids. These volatile aromatic compounds are most closely associated with increased levels of lipid oxidation. There were significant amounts of 1-octanol present in pork crumbles containing 0.125% onyx sorghum, of 2-undecenal found in control, and of 3,5-octadien-2-one present in control, 0.125 and 0.25% HTS. Pork crumbles with BHA/BHT did not have detectable levels of 3-ethyl-benzaldehyde, but pork crumbles from other treatments had substantial levels of 3-ethyl-benzaldehyde with 0.25% onyx sorghum having the highest amount. As expected, pork crumbles with BHA/BHT did have significant levels of butyl hydroxyl toluene. Heptanoic and nonanoic acids were both only found in control and 0.125% onyx sorghum, crumble treatment with higher TBARS values and higher levels of oxidation.

Volatile, aromatic compounds revealed by the GC/MS also were divided into their chemical classifications. Of the compound classifications, only phenols ($P < 0.0001$) and sulfurs ($P < 0.05$) were found to differ across treatments. Substantial amounts of phenols were present in the pork crumbles treated with BHA/BHT, whereas phenol levels varied among remaining treatments. Interestingly, sulfurs tended to increase as sorghum levels increased, although they were not present in control and 0.125% HTS. These results support that sorghum bran addition reduced volatile aromatic compounds in pork crumbles associated with higher levels of lipid oxidation and that sorghum bran did not appreciably contribute unique volatile aromatic compounds to these products.

Fully Cooked Dark Meat Chicken Patties

Raw Chemical and Color Evaluation

Raw chicken patties treated with the 11 treatments did not differ ($P \geq 0.05$) in percent moisture and lipid (Table 12) as well as pH and a* CIE color space values (Table 13). However, cook yield was slightly higher ($P < 0.05$) for chicken patties containing sorghum bran compared to chicken patties containing BHA/BHT and rosemary. Subjective color was similar for raw chicken patties containing either no added ingredients, BHA/BHT, rosemary or 0.125 and 0.25% HTS. The addition of either Onyx sorghum bran at all levels or HTS sorghum bran at 0.50 and 0.75% resulted in darker ($P < 0.0001$) raw chicken patty color. Levels of L^* color space values showed similar results ($P < 0.0001$) to subjective color. As the level of sorghum bran added increased, the patties became darker, with lower *L** values. The Onyx bran *b** color space values were inversely related to either subjective and *L** color space values. As the level of onyx bran increased, the *b** values decreased ($P < 0.05$), and the less yellow the patties became.

Cooked pH and Color

The cooked chicken patties did not differ in pH, *a** color space values ($P \geq 0.05$) (Table 14), and exhibited similar trends as found in raw chicken patties (Table 13). Subjective color was darker, *L** and *b** values decreased ($P < 0.0001$) as levels of sorghum bran addition increased, showing higher sorghum bran levels made cooked chicken patties darker and less yellow. As storage time increased, cooked chicken patty pH ($P < 0.001$) and subjective color scores ($P < 0.05$) increased, while *L**($P < 0.05$), and a*($P < 0.0001$) color space values decreased. These results indicated that with increased storage, the cooked chicken patties grew darker and less red over time. Interactions between treatment and storage time were not significant ($P > 0.05$) for cooked chicken patty pH and color attributes. Jenschke (2004) and Hemphill (2006), whose data also revealed a steady pH increase over time in cooked ground beef patties, justified that aerobic bacterial growth and treatment solubilization was responsible for the pH increase. *Pseudomonas* and other aerobic bacteria are known to release ammonia as a by-product during metabolism which increases the pH of their host environment (Kakouri and Nychas, 1994). Additionally, Jenschke (2004) and Hemphill (2006) point to solubilization of sorghum bran treatments over time as a possible explanation for the significant pH increase with storage.

TBARS Determinations

TBARS values were affected by treatment, storage day (Table 14) and treatment by storage day interaction ($P < 0.0001$) (Figure 2). Similar results were reported for the effect of treatment on TBARS values as reported in Figure 1 for pre-cooked pork crumbles. Control cooked chicken patties had the highest TBARS values on day 0 and increased with storage time. Alternately, patties containing either 0.50 or 0.75% HTS and Onyx or BHA/BHT had the lowest TBARS values across storage days. Other treatments were intermediate in TBARS values with increased storage time. Similar to the pork crumbles, as sorghum bran treatment levels increased, TBARS values decrease in the cooked chicken patties. There was a rise in TBARS values across all treatments as storage day increased and treatment by storage day interaction is clearly visible in Figure 2. These results indicate that 0.5 or 0.75% sorghum bran addition, either HTS or Onyx, did suppress the development of lipid oxidation similarly to BHA/BHT in cooked chicken patties over storage days.

Expert, Trained Descriptive Meat Sensory Analysis

Flavor attributes for cooked chicken patties as affected by treatment and storage are reported in Table 15. Chicken identity, fat-like, metallic, astringent, sour, salty, gritty, burnt, cardboard, nutty, painty, rancid, sour dairy, spoiled putrid and warmed over flavor were not influenced by treatment ($P \geq 0.05$). Cooked chicken patties containing higher levels of 0.50 and 0.75% Onyx, and 0.75% HTS bran had slightly higher brown/roasted and sorghum flavors, were sweeter and had less heated oil and refrigerator stale flavors. Cooked chicken patties containing BHA/BHT were more bitter, and patties containing 0.75% Onyx sorghum bran were very slightly higher in umami than chicken patties from other treatments.

Chicken patty sensory attributes also were slightly affected by storage day. The increase from 1 d to 3 d of storage decreased the intensity ($P < 0.05$) of chicken identity, fat-like, sweet, salty, gritty, and burnt, while increased storage day resulted in higher levels of metallic, heated oil, and refrigerator stale. The difference indicated how storage day affected attributes associated with lipid. However, there were no treatment by storage day interactions ($P \geq 0.05$) for sensory attributes.

These results indicate that sorghum bran addition at higher levels inhibited flavors associated with lipid oxidation (cardboard, heated oil, refrigerator stale and warmed-over flavors) and slightly increased flavors associated with sorghum bran as previously reported for pre-cooked pork crumbles. While slight changes in sorghum bran-based flavors increased, the change in flavor was minimal, and testing with consumers would be needed to validate if sorghum bran-associated flavor would be negatively perceived by consumers.

Cooked Meat Volatile Evaluation

Volatile aromatic chemicals were identified for chicken patties (Table 16), and 8 volatile aromatic chemicals differed across treatments. 5-Pentyl-2(5H)furanone and nonenal differed across treatments ($P < 0.05$) for chicken products and are considered products of lipid oxidation. Chicken patties treatments containing BHA/BHT, rosemary, and 0.25, 0.50 and 0.75% Onyx sorghum bran did not contain 5-pentyl-2(5H)furanone. Similarly, nonenal, a lipid oxidation by-product, was lower ($P < 0.05$) in chicken patties where TBARS values indicated lower levels of lipid oxidation were reported. Naphthalene and carbon disulfide tended to be present in pork crumbles with more limited lipid oxidation, but interestingly neither chemical differed across treatments in the chicken patties.

Chicken patties differed ($P < 0.05$) in (E)-2-heptenal, 2-octen-1-ol, nonenal and undecenal, which are all compounds associated with increased levels of lipid oxidation. (E)-2-heptenal, nonenal, and undecenal appeared in higher concentrations in the control and at lower levels in chicken containing sorghum bran where the treatments had higher TBARS values. 2-Octen-1-ol was only observed at 0.125% HTS and Onyx sorghum levels. 2-Acetyl thiazole was present at higher levels ($P < 0.05$) in chicken patties with 0.50% and 0.75% Onyx or HTS sorghum bran indicating that this compound may have contributed to flavors associated with addition of higher levels of sorghum bran. Decanal, benzaldehyde, and hexadecane tended to vary across treatments ($P < 0.05$).

Chemical classifications divided volatile, aromatic compounds revealed by the GC/MS (Table 17). Of the compound classifications, only furans ($P < 0.05$) and phenols ($P < 0.0001$) were found to differ across treatments. The presence of furans decreased as the levels of HTS increased, and substantial amounts of phenols were present in the chicken patties treated with BHA/BHT. As storage day increased, the level of alkanes and furans decreased, even though there was not a treatment storage day interaction. These results also support that sorghum bran addition reduced volatile aromatic compounds in chicken patties associated with higher levels of lipid oxidation and that sorghum bran did not appreciably contribute unique volatile aromatic compounds to these products.

Based on results from Phase I, four treatments were selected for Phase II. A control treatment with no added ingredients, and a rosemary treatment to emulate the most common natural antioxidant. It was determined that addition of HTS and Onyx sorghum bran at 0.50% would be evaluated in Phase II to minimize color and flavor changes while maximizing lipid oxidation control.

Phase II: Aerobic, Frozen Storage Study in Cooperation with Tyson Foods

Pre-cooked Pork Pizza Toppings

Raw Chemical, Cooked pH, and Color Evaluation

Product formulations for pre-cooked pork pizza toppings for all treatments are shown in Table 18. Raw percentage moisture, lipid and cook yield for pre-cooked pork pizza toppings are reported in Table 20. Cook yield and raw moisture were not affected by treatment ($P > 0.05$); however, raw pork pizza toppings containing the sorghum-bran treatments had slightly higher ($P < 0.05$) lipid percentages than the other two treatments. Pre-cooked pork pizza toppings did not differ in pH ($P > 0.05$) across treatments (Table 21). However, pre-cooked pork pizza toppings with sorghum bran added were darker in subjective and objective color ($P < 0.0001$), with lower L^* color space values, and redder, higher a^* ($P < 0.0001$) color space values. Control pre-cooked pork pizza toppings exhibited the most yellow color and 0.50% Onyx sorghum bran treated pre-cooked pork pizza toppings had the least yellow color.

Increased frozen storage time from 0 to 12 months resulted in pre-cooked pork pizza toppings that were slightly lower in pH ($P < 0.0001$), were less red ($P < 0.0001$), and varied in lightness ($P < 0.001$) and yellow color ($P < 0.05$) (Table 21). Treatment by storage time interactions ($P < 0.05$) occurred in a^* and b^* color space values and are reported in Figures 3 and 4. Pre-cooked pork pizza toppings treated with sorghum bran slightly varied over the 12 months of storage, but were redder in color than rosemary and control, which decreased and became less red as storage time increased. Control pre-cooked pork pizza toppings lost most of the red color that was present at 0 months of storage. Over 12 months of frozen storage, pre-cooked pork pizza toppings varied in yellow color; however, control pre-cooked pork pizza toppings displayed the most yellow color and 0.50% onyx sorghum, and rosemary were the least yellow in color at month 12.

TBARS Determinations

Treatment and storage impacted TBARS values for pre-cooked pork pizza toppings (Table 21) and there was a significant ($P < 0.0001$) interaction for treatment by storage time (Figure 5). In general, rosemary treatment produced the lowest TBARS values, followed by 0.50% Onyx and HTS. Control pre-cooked pork pizza toppings displayed the highest amount of lipid oxidation with the highest TBARS values (Table 21). Also, as expected, as the storage months increased, the overall level of lipid oxidation increased across all treatments. Control pre-cooked pork pizza toppings had the highest TBARS at 0 months and TBARS values increased up to 12 months (Figure 5). Pre-cooked pork pizza toppings containing rosemary and sorghum bran were similar in TBARS values at 0 months, and TBARS values increased slightly during frozen storage for the rosemary treated pre-cooked pork pizza toppings. Pre-cooked pork pizza toppings containing sorghum bran treatments were slightly higher than rosemary treated pre-cooked pork pizza toppings at 6, 9 and 12 months of storage. However, the 0.50% Onyx bran pre-cooked pork pizza toppings had suppressed lipid oxidation and had slightly higher TBARS values than 0.50% HTS. Furthermore, much lower levels of lipid oxidation were reported in Phase II pre-cooked pork pizza toppings compared to Phase I pork crumbles.

Expert, Trained Descriptive Meat Sensory Analysis

Descriptive flavor and basic taste attributes for pre-cooked pork pizza toppings across treatments with storage time are reported in Table 22. Fat-like, metallic, astringent, sweet, sour, nutty, and vinegary flavors were not affected by treatment ($P \geq 0.05$). Pre-cooked pork pizza toppings containing sorghum bran had slightly higher brown/roasted, umami, sorghum, and gritty flavor attributes ($P < 0.05$) than control and rosemary pre-cooked pork pizza toppings. Pre-cooked pork pizza toppings containing rosemary were slightly less salty and bitter ($P < 0.05$), had lower levels of cardboard, fishy, heated oil, painty, and refrigerator stale flavors ($P < 0.0001$), and higher levels of floral, green, and rosemary flavors ($P < 0.001$) than control and sorghum treated pre-cooked pork pizza toppings. Control pre-cooked pork pizza toppings had slightly higher painty, rancid, refrigerator stale, and warmed over flavor ($P < 0.001$) than rosemary and sorghum treated pre-cooked pork pizza toppings. However, differences in flavor attributes between treatments were slight, with sorghum flavor differences between control and 0.50% Onyx treated pre-cooked pork pizza toppings differing to the greatest extent (0.6).

Storage time impacted pre-cooked pork pizza toppings flavor attributes. Pork identity, brown/roasted, astringent, sweet, bitter, sorghum, gritty, cardboard, fishy, green, nutty, warmed-over flavor, vinegary, and burning flavors varied (P < 0. 001) with increased storage time. Fat-like, metallic, salty, heated oil, rancid and refrigerator stale presence tended to increase (P < 0.0001), whereas umami and floral tended to decrease (P < 0.0001) in intensity with increased storage time.

Pre-cooked pork pizza toppings were affected by a treatment by storage month interaction (P < 0. 05) in the flavor attributes pork identity, bitter, sorghum, cardboard, floral, green, and rosemary. Pork identity varied over increased storage months with an evident drop in month 3, although at month 12, panelists found control pre-cooked pork pizza toppings to possess the least pork identity flavor (Figure 6). Similar to pork identity, bitter flavor varied over storage time with another apparent drop in month 3; however, at the end of the 12 months of storage, panelists observed control pre-cooked pork pizza toppings to be the most bitter, whereas rosemary treated pre-cooked pork pizza toppings were found to be the least bitter (Figure 7). Sorghum flavor varied throughout storage time, although an obvious increase in sorghum flavor occurred in 0.05% onyx treated pre-cooked pork pizza toppings at 6 months of storage. As expected, sorghum treated pre-cooked pork pizza toppings possessed a greater presence of sorghum flavors than found in control and rosemary treated pre-cooked pork pizza toppings (Figure 8). Even though the occurrence of cardboard flavor was slight in pre-cooked pork pizza toppings, cardboard flavor slightly increased from month 0 to month 6 across all treatments, then decreased as storage time continued to month 12 (Figure 9).

Floral notes were found at very low levels in control and sorghum bran treated pre-cooked pork pizza toppings over storage time; however, rosemary treated pre-cooked pork pizza toppings had the highest amount of floral notes at month 0 and floral notes slightly decrease over the 12 month frozen storage time. Similar to floral, green flavor was hardly noticeable, or absent in months 0, 3, and 9 in pre-cooked pork pizza toppings. At 6 months of storage, there was a slight sudden increase in across all treatments in green level (Figure 11). Nonetheless, at 12 months of storage, a slight presence of green flavor was found in control and rosemary treated pre-cooked pork pizza toppings, whereas green was completely absent in 0.50% HTS pre-cooked pork pizza toppings. Rosemary flavor was only found in minute amounts in control and sorghum treated pre-cooked pork pizza toppings over storage time. However, rosemary treated pre-cooked pork pizza toppings, had a very slight increase in rosemary flavor from month 0 to month 12 of frozen storage time.

Painty, rancid and refrigerator stale, all flavor indicators of lipid oxidation, had a treatment by storage interaction in pre-cooked pork pizza toppings. Across all treatments, painty flavor increased as storage time increased until month 9, where painty flavor then started to decreased at 12 months of frozen storage (Figure 13). Control pre-cooked pork pizza toppings during the entire 12 month storage period had the highest painty flavor levels, whereas rosemary treated pre-cooked pork pizza toppings had the lowest levels during the 12 months of storage. Rancid flavor across all treatments were minimally present until month 9 of storage, where rancidity flavors began to increase slightly (Figure 14). By month 12, control pre-cooked pork pizza toppings had the highest level of rancid flavor, with the incidence in rosemary and sorghum treated pre-cooked pork pizza toppings was low. Refrigerator stale flavor, although slight, varied across treatments in pre-cooked pork pizza toppings until month 9 of frozen storage. Refrigerator stale flavor increased with storage time through month 12 (Figure 15). At 12 months of storage control pre-cooked pork pizza toppings presented the highest occurrence of refrigerator stale flavor, whereas pre-cooked pork pizza toppings treated with rosemary had slightly suppressed levels of refrigerator stale flavor.

Cooked Meat Volatile Evaluation

Volatile aromatic chemicals were identified for pre-cooked pork pizza toppings (Table 23) and 14 volatile aromatic chemicals differed across treatments ($P < 0.05$). Chemical compounds 1-heptanol, 2,4-nonadienal, and heptanol, chemicals associated with lipid oxidation, were present in the highest amounts in control pre-cooked pork pizza toppings and paralleled increased TBARS values. Calkins and Hodgen (2007) described the flavor/aroma of 1-heptanol as fragrant, woody, oily, green, fatty, winey, sap and/or herb and is associated with increased levels of lipid oxidation.

High tannin sorghum bran in pre-cooked pork pizza toppings had the highest levels of (E,E)-2,4-heptadienal, 1-octen-3-ol, 1-pentanol, nonanal, and octadecanal. The compounds (E,E)-2,4-heptadienal, 1-octen-3-ol, and octadecanal are typically known as lipid oxidation products. Zhu et al. (2010) reported (E,E)-2,4-heptadienal as a widespread dienaldehyde, a lipid peroxidation product that has been detected in fish, chicken, meat, bread and heated oil and is known to have a nutty/fatty flavor and aroma (Calkins and Hodgen, 2007). Assaf et al. (1997) stated the unsaturated alcohol, 1-octen-3-ol is associated with as mushroom-like flavor and raw mushroom flavor. In combination with its oxidation product, 1-octen-3-ol has been identified in many mushroom species and is considered the major contributor to mushroom flavor in most species of edible mushrooms. The presence of 1-pentanol can produce a mild odor of fusel oil, fruit or balsamic flavors or aromas (Calkins and Hodgen, 2007). Nonanal can produce a variety of floral, citrus, fatty, grassy, waxy or green flavors or aromas, and octadecanal will have the aroma or flavor of oil (Calkins and Hodgen, 2007).

Onyx sorghum bran in pre-cooked pork pizza toppings had the highest levels of azulene and naphthalene, which are isomers of each other. Ohloff et al. (1985) stated that azulene was responsible for the formation of the blue color in essential oils and is extracted through steam distillation of blue chamomile (*Matricaria chamomilla* L.). The presence of the compound azulene in the onyx treated pre-cooked pork pizza toppings could partially be responsible for lower b^* color space values, as they were less yellow in color and closer to the blue spectrum. Snyder et al. (1996) reported that naphthalene was found in meat products exposed to fire. The presence and significance of naphthalene is interesting as none of the pre-cooked pork pizza toppings were ever exposed to fire neither in initial cooking, nor anytime during reheating.

Pre-cooked pork pizza toppings treated with the rosemary antioxidant had the highest levels of acetic acid, benzaldehyde, hexadecanal, and hexanoic acid. Acetic acid, the chemical responsible for vinegary flavor, was not found to differ across treatments in the descriptive sensory analysis, so it is interesting that acetic acid is found to be significant in rosemary in the GC/MS analyses. Presence of benzaldehyde can produce a volatile almond oil, bitter almond, or burning aromatic taste (Calkins and Hodgen, 2007). Hexadecanal is a lipid oxidation product originated by thermal degradation (Osorio et al., 2006). Anihouvi et al. (2009) reported the aldehyde (Z)-4-heptenal is responsible for the undesirable fishy and rancid odors in cooked alligator meat. Even though fishy and rancid flavors overall presence was very slight, the rosemary treated pre-cooked pork pizza toppings had the least amount of fishy flavor and minute rancid flavor when compared to the control in the descriptive sensory analysis.

Volatile aromatic chemicals in pre-cooked pork pizza toppings were also identified across storage time and of the 29 volatile aromatic chemicals that differed ($P <$ 0. 05), 26 of the aromatic chemicals were significantly at the highest level at three months of storage (Table 24). Three other compounds that were found significant during storage time were 2,6-bis(1,1-dimethylethyl)-4-methyl-phenol (a derivative od BHT), 1-pentanol, and azulene.

Chemical classifications for volatile, aromatic compounds pre-cooked pork pizza toppings found in the GC/MS are reported in Table 25. The compound classifications did not differ across treatments ($P >$ 0. 05). However, storage time ($P <$ 0. 05) impacted aldehydes, furans, phenols, and sulfurs. Aldehydes and furans were at their highest level at three months of storage, ketones were at their highest level at month 6, and sulfurs did not begin to appear until month 9 and significantly increased by 12 months of frozen storage. There was not a treatment storage day interaction ($P > 0.05$) in the classified volatile, aromatic compound in pre-cooked pork pizza toppings. These results also support that sorghum bran addition did not appreciably contribute unique volatile aromatic compounds to pre-cooked pork pizza toppings.

Fully Cooked Dark Meat Ground Chicken

Raw Chemical, Cooked pH, and Color Evaluation

Product formulations for dark meat ground chicken are shown in Table 19. The amount of broth added back to the meat package, raw moisture and lipid percentage (Table 26) and cooked pH (Table 27) for dark meat ground chicken were not affected by treatment ($P > 0.05$). However, fully cooked dark meat ground chicken with 0.50% Onyx sorghum bran was darker in subjective and objective color ($P < 0.0001$), redder ($P < 0.05$) and less yellow ($P < 0.0001$)in color than control or rosemary added product. Conversely, control dark meat ground chicken was the lightest in subjective and objective color, the least red and the most yellow in color. With increased storage time, cooked pH decreased slightly ($P < 0.0001$), and L^* and a^* color space values tended to decrease ($P < 0.0001$).

In general, across all treatments, subjective color did not change with storage ($P > 0.05$). There were, however, treatment storage day interactions ($P < 0.05$) for cooked pH, L^* and a^* color space values. Cooked pH values varied with increased storage, with an evident decline in pH in month 3 compared to the other months (Figure 6). Because across all treatments the pH values were the same, there may have been a malfunction with the pH meter during month 3 of storage. At 12 months of frozen storage, HTS and onyx sorghum treated dark meat ground chicken had the same L^* values and were the darkest compared to control and rosemary treated dark meat ground chicken (Figure 7). Control dark meat ground chicken was the lightest colored with the highest L^* color space values. Dark meat ground chicken treatment storage day interactions ($P < 0.05$) showed a general decrease in a^* values over time (Figure 8). Interestingly, at month 0, rosemary treated dark meat ground chicken was the most yellow, but by month 12, rosemary a^* color space values decreased significantly where they were less yellow compared to the other treatments.

TBARS Determinations

TBARS values were highest for control fully cooked dark meat ground chicken compared to treated product. As storage time increased, however, TBARS values did not appreciably change and there was not a treatment by storage time interaction ($P = 0.21$) (Figure 9). TBARS values were very low compared to values reported in other studies using sorghum bran as a natural antioxidant indicating that little lipid oxidation occurred in the aerobic, frozen fully cooked dark meat ground chicken. The way the dark meat ground chicken was packaged could have been the reason TBARS were not significant throughout storage time, or a treatment by storage time interaction. After straining and measuring the meat and broth weight after cooking, the calculated percentage of broth for each treatment was added back to the packaged chicken meat. Even though the packages were aerobic and not vacuumed packaged, the meat still had limited contact with the air in the package. Cross et al. (1987) suggested that products surrounded by water, sauce or gravy during cooking limits contact with air and may extend storage life of the product.

The pre-cooked pork pizza toppings were cooked submerged in oil, which helped limit the contact to air during cooking. However, the pre-cooked pork pizza toppings were rinsed and drained from any excess oil, and after freezing, were packaged in much more aerobic conditions than the dark meat ground chicken. The pre-cooked pork pizza toppings were loosely packed in a cardboard box lined with plastic, and every three months during collection, were stirred up, exposing more product to the air. The dark meat ground chicken was packaged with its broth, in individual sealed packages with limited exposure to air. Every three months, a random package of dark meat ground chicken from each treatment was selected for testing, removing the occurrence of the increased air exposure as in the pre-cooked pork pizza toppings. Even though the pre-cooked pork pizza toppings and dark meat ground chicken were stored in similar frozen conditions, the difference in packaging and increased exposure to air of the pre-cooked pork pizza toppings could be why there was more lipid oxidation present than in the dark meat ground chicken.

Expert, Trained Descriptive Meat Sensory Analysis

Treatment did not affect fat-like, metallic, salty, umami, nutty and burning flavor attributes for fully cooked dark meat ground chicken ($P > 0.05$) (Table 28). Control fully cooked dark meat ground chicken was slightly higher ($P < 0.05$) in chicken identity, heated oil, refrigerator stale and warmed over flavor than treated dark meat ground chicken. The changes in flavor are consistent with lipid oxidation associated flavor changes. Fully cooked dark meat ground chicken with added rosemary was higher ($P < 0.05$) in floral, green and rosemary flavors than fully cooked dark meat ground chicken from other treatments. Fully cooked dark meat ground chicken containing 0.50% Onyx sorghum bran was higher ($P < 0.05$) in sorghum flavor. Onyx and HTS were higher ($P < 0.05$) in brown/roasted, sweet, sorghum, and gritty than control and rosemary treated dark meat ground chicken.

All evaluated descriptive flavor attributes were affected across treatments by increased storage time in dark meat ground chicken ($P < 0.05$). However, as frozen storage time increased, astringency and heated oil flavors increased in intensity ($P < 0.05$), whereas grittiness and floral decreased ($P < 0.05$) and became less noticeable over storage time.

Sorghum, floral, green and rosemary flavors also had treatment storage day interactions ($P < 0.05$) in dark meat ground chicken. As expected, sorghum flavor during the 12 months of frozen storage was higher in Onyx- and HTS-treated dark meat ground chicken, than in control and rosemary dark meat ground chicken (Figure 10). Rosemary flavor was low in month 0, steadily increased by month 6, and declined by month 12. As expected, rosemary flavor in control and sorghum treated dark meat ground chicken was minimal during storage (Figure 11). Floral notes in rosemary-treated dark meat ground chicken was the highest at month 0 and slowly declined as storage time increase. There were minimal floral notes in control and sorghum treated dark meat ground chicken during storage (Figure 12). Lastly, panelists did not identify green flavor in any of the dark meat ground chicken samples at nine months of storage.

However, rosemary had the highest levels of green flavor during the remaining months of storage.

Cooked Meat Volatile Evaluation

Volatile aromatic compounds were also identified for dark meat ground chicken (Table 29) and 17 volatile aromatic chemicals differed across treatments ($P < 0.05$). Chemical compounds (E)-2-decenal, (E)-2-heptenal, 1-heptanol, 1-octen-3-ol, 2,4-nonadienal, 2-octenal, 3-ethyl-benzaldehyde, benzaldehyde, decanal, hexanal, nonenal, pentanal, and pentanol, compounds associated with lipid oxidation development, were present in the greatest amounts in control dark meat ground chicken. High tannin sorghum treatment in dark meat ground chicken displayed the highest levels of benzeneacetaldehyde and octadecanal, whereas Onyx sorghum bran treated product had the highest levels of acetic acid, 1-methylene-1H-indene and naphthalene. Rosemary-treated dark meat ground chicken did not have appreciably detectable aromatic volatile compounds.

Volatile aromatic chemicals in dark meat ground chicken were also identified across storage time and 13 volatile aromatic chemicals were found different during storage time ($P < 0.05$) (Table 30). The majority of aromatic chemicals that were significantly at the highest level were revealed at 6 months of storage, including: (E)-2 decenal, (E)-2-hetenal, 2,4-nonadienal, 2-octenal, decanal, and nonenal. Multiple compounds differed across treatments after 3 months storage, 2,5-octanedione, acetaldehyde, heptacosane, methanethiol, and octadecanal. Carbon disulfide and octadecane were compounds that at month 0 were not present or only minutely present, and during increased frozen storage, their values steadily increased. Compounds 2,4-nonadienal, 2-methyl-5-(4'methylphenyl)sulfinyl-4-nitroimidazole, 2-octenal, 3-ethyl-benzaldehyde, nonenal, octadecanal, and octadecane had treatment by storage day interactions in dark meat ground chicken.

Chemical classifications for volatile compounds in dark meat ground chicken are reported in Table 31. Alkenes and benzenes were highest in Onyx-treated dark meat ground chicken; however, ketones, usually associated with lipid oxidation products, were higher in the control product than the treated dark meat ground chicken product. There was not a treatment by storage day interaction ($P > 0.05$) for the classified volatile, aromatic compounds in dark meat ground chicken. These results also supported that sorghum bran addition did not appreciably contribute unique volatile aromatic compounds to dark meat ground chicken.

CHAPTER V

CONCLUSIONS

In Phase I, High Tannin and Onyx sorghum bran at 0.125%, 0.25%, 0.50% and 0.75% was added to cooked pork crumbles and cooked chicken dark meat patties. The other treatments included a control (no added ingredients), rosemary (the most common natural antioxidant), and BHA/BHT (the most common antioxidant). These treatments were added to determine if High Tannin or Onyx sorghum bran could be added to control lipid oxidation, the most common reaction in meat and poultry products that causes flavor deterioration. The products were stored in conditions that have been shown to result in high levels of lipid oxidation (aerobic storage under lights at refrigerated temperatures). The effect on flavor, cook yield, color, and pH also was examined. These attributes were evaluated to determine if High Tannin and Onyx addition changed any of these attributes. Ideally, the addition of any antioxidant ingredient should not affect flavor, color, pH or cook yield. Lipid oxidation occurred at a high level in control pre-cooked pork crumbles and chicken patties. The addition of these sorghum brans at levels of 0.50% and 0.75% had minimal effect on pH or cook yield in these products; however, slight changes in color and flavor were reported at the higher level of addition. Lipid oxidation was similar in products containing BHA/BHT, and 0.50 and 0.75% High Tannin and Onyx sorghum brans. The other treatments were intermediate for TBARS values, the measurement of lipid oxidation. These results indicate that High Tannin and Onyx sorghum bran addition did not negatively impact flavor and quality of pre-cooked pork crumbles and chicken patties.

For Phase II, control (no added antioxidants), 0.2% rosemary addition, and 0.50% High Tannin and Onyx sorghum bran were added to pre-cooked pork pizza toppings and fully cooked dark meat ground chicken. These products were stored aerobically at frozen temperatures and evaluated after 0, 3, 6, 9 and 12 months of storage. As in Phase I, lipid oxidation was measured using TBARS values, and pH, color, cook yield and flavor was evaluated. Similar results were reported for pre-cooked pork pizza toppings as found for pre-cooked pork crumbles in Phase I. While High Tannin and Onyx sorghum bran addition slightly affected color, the pH, cook yield and flavor were minimally affected. Lipid oxidation occurred in frozen pre-cooked pork pizza toppings over the 12 month storage time, but not to the same extent as reported in Phase I under refrigerated storage.

In aerobic, frozen pre-cooked meat systems for pork and chicken (*P*hase II), the addition of 0.50% higher tannin or Onyx sorghum bran limited lipid oxidation over a 12 storage period, but was not as effective as when rosemary was used as a natural antioxidant. In these systems, lipid oxidation was not as highly developed as in the aerobic, refrigerated pre-cooked meat systems used in Phase I indicating that when there are conditions conducive for extensive development of lipid oxidation, sorghum bran is a viable antioxidant alternative to rosemary in pre-cooked meats. Rosemary provided a slight advantage to limiting lipid oxidation compared to sorghum bran addition, but the addition of antioxidants provided much more protection against lipid oxidation than controls. In frozen fully cooked dark meat ground chicken, packaging the product in the chicken broth could have helped limit the lipid oxidation that occurred, even in control product, over 12 months of storage.

The addition of sorghum bran, especially Onyx sorghum bran, resulted in slightly darker, less red and yellow meat products. Fully cooked dark meat ground chicken containing rosemary had more off-flavors associated with rosemary addition than either the control or sorghum bran addition.

In conclusion, either high tannin sorghum or Onyx sorghum can be added to pre-cooked fresh, or frozen meat products as natural antioxidants. Their addition does not impact pH, water-holding capacity or flavor of pork and chicken products. It is recommended that 0.5% levels of either high tannin or Onyx sorghum bran be added for control of lipid oxidation. In products where color is not an issue, 0.75% addition of sorghum bran can be added to gain a slight advantage in retarding lipid oxidation.

The addition of HTS and Onyx sorghum bran at 0.50% and 0.75% reduced lipid oxidation in both pre-cooked pork crumbles and cooked chicken patties with minimal effects on flavor, pH and cook yield. Whereas higher levels of Onyx and HTS bran addition affected color, color effects may or may not be important depending on the final product.

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APPENDIX A

TABLES

Table 1. Raw Color Reference

Score	Source	Name	Card Number	Color Number
12	Sherwin-Williams	Emerging Taupe	7	SW 6044
11	Sherwin-Williams	Interface Tan	9	SW 6059
10	Sherwin-Williams	Likeable Sand	9	SW 6058
9	NPPC Pork Color Standards [a]	Dark Purplish Red	6.0	Min L^* 31[b]
8	NPPC Pork Color Standards [a]	Purplish Red	5.0	Min L^* 37[b]
7	NPPC Pork Color Standards [a]	Dark Reddish Pink	4.0	Min L^* 43[b]
6	NPPC Pork Color Standards [a]	Reddish Pink	3.0	Min L^* 49[b]
5	NPPC Pork Color Standards [a]	Grayish Pink	2.0	Min L^* 55[b]
4	NPPC Pork Color Standards [a]	Pale Pinkish Gray to White	1.0	Min L^* 61[b]
3	Sherwin-Williams	Soft Apricot	51	SW 6352
2	Sherwin-Williams	Warming Peach	49	SW 6338
1	Sherwin-Williams	Peach Fuzz	50	SW 6344

[a] National Pork Producers Council Pork Quality Color Standards
[b] Minolta L^* values use D65 daylight light source.

Table 2. Cooked Color Reference using Sherwin-Williams paint color cards.

Score	Source	Name	Card Number	Color Number
12	Sherwin-Williams	Grounded	13	SW 6089
11	Sherwin-Williams	Mocha	10	SW 6067
10	Sherwin-Williams	Moroccan Brown	9	SW 6060
9	Sherwin-Williams	Trusty Tan	13	SW 6087
8	Sherwin-Williams	Totally Tan	17	SW 6115
7	Sherwin-Williams	Camelback	18	SW 6122
6	Sherwin-Williams	Restrained Gold	19	SW 6129
5	Sherwin-Williams	Simplify Beige	13	SW 6085
4	Sherwin-Williams	Kilim Beige	16	SW 6106
3	Sherwin-Williams	Poplar Gray	11	SW 6071
2	Sherwin-Williams	Biscuit	17	SW 6112
1	Sherwin-Williams	Cachet Cream	53	SW 6365

Table 3. Definitions and references for pork flavor attributes, where 0 = none and 15 = extremely intense adapted from Chu (2015); Laird (2015).

Attribute	Definition	Reference
Basic Tastes		
Bitter	The fundamental taste factor associated with a caffeine solution	0.05% caffeine in 1000 mL water = 2.0 0.08% caffeine in 1000 mL water = 5.0
Salty	The fundamental taste factor of which sodium chloride is typical	0.2% Salt in 1000 mL water = 2.5 0.35% Salt in 1000 mL water = 5.0
Sour	The fundamental taste factor associated with citric acid solution	0.05% Citric Acid in 1000 mL water=2.0 0.08% Citric Acid in 1000 mL water=5.0
Sweet	The fundamental taste factor associated with a sucrose solution	0.05% Sugar in 1000 mL water = 2.0 0.08% Sugar in 1000 mL water = 5.0
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of aminoacids and other molecules called nucleotides.	0.035% Accent flavoring in 1000 mL water = 7.5 (F)
Flavor Aromatics		
Boar Taint	Aromatic associated with boar taint; hormone-like; sweat, animal urine.	0.1g 3-methylindole, sniffed = 13.0(A) Androstenone wafted directly from bottle = 15.0 (A)
Bloody/Serumy	An aromatic associated with blood on cooked meat products;	Boneless Pork Chop, 57°C = 2.0 closely related to metallic aromatic
Brown/Roasted	A round, full aromatic generally associated with broiled pork	Pork Fat, cooked and browned = 3.0 suet (F), 4.0 (A)
Burnt	The sharp/acrid flavor note associated with over roasted pork, muscle something over baked or excessively browned in oil	Arrowhead Barley Cereal, 7-10 puffs = 3.0

Table 3 Continued.

Attribute	Definition	Reference
Cardboardy	Aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging	Dry cardboard, 2.54 cm square = 5.0(F), 3.0 (A) Wet cardboard, 2.54 cm square steeped in 236.6 mL water for 30 min = 7.0(F), 6.0(A)
Chemical	Aromatic associated with garden hose, hot Teflon pan, plastic packaging and petroleum-based products such as charcoal lighter fluid	1 drop Clorox in 200 mL water = 6.5 Ziploc Bag in snifter = 2.0 (A)
Green	Sharp, slightly pungent aromatics associated with green/plant/ vegetable matter such as parsley, spinach, pea pod, fresh cut grass, etc.	Fresh parsley water = 9.0 (T)
Fat-Like	Aromatics associated with cooked animal fat	Pork Fat, cooked and browned = 10.0 (F); 7.0 (A)
Floral	Sweet, light, slightly perfume impression associated with flowers	3.5 mL Clorox Wipe Liquid in 118 mL water= 8.0 (A) Geraniol, 2 drops on cotton ball in sniffer = 7.5 (A) 1:1 White Grape Juice to Water = 5.0
Heated Oil	The aromatics associated with oil heated to a high temperature	Wesson Oil, microwaved 3 min = 7.0 Lay's Potato Chips = 4.0 (A)
Liver-Like	Aromatics associated with cooked organ meat/liver	Pork Liver, 71°C = 15.0 (F); 12.0 (A)
Metallic	The impression of slightly oxidized metal, such as iron, copper, and silver spoons	Dole Pineapple Juice = 6.0 (A&F) 0.10% KCl in 1L water = 1.5 (A&F)

Table 3 Continued.

Attribute	Definition	Reference
Nutty	Nutty characteristics are: sweet, oily, light brown, slightly musty and/or buttery, earthy, woody, astringent, bitter, etc.	Diamond Shelled Walnut, ground for 1 min = 6.5 (F)
Painty	Aromatic associated with oxidized oil similar to the aromatic of linseed oil and oil-based paint	Wesson Vegetable oil placed in covered glass container in 100°C oven for 14 days = 8 (F); 10 (A)
Pork Identity	Amount of pork flavor identity in the sample	Boneless Pork Chop, 79°C = 7.0(F), 5.0(A) 80/20 Ground Pork, 71°C = 6.0(F); 5.0(A)
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 (T) Wesson Vegetable Oil (microwaved 5 min) = 9.0 (T)
Refrigerator Stale	Aromatics associated with products left in the refrigerator for period time and absorbing a combination of odors (lack of freshness/flat)	80/20 Ground Pork, 71°C, left chilled overnight, served room temperature = 6.0 (F), 8.0 (A)
Rosemary	The aromatics associated with rosemary extract	1.0% Rosemary Extract = 12.0 (A)
Soapy	An aromatic commonly found in unscented hand soap	3.5 mL Clorox Wipe Liquid in 118 mL water = 3.0 (A) 0.5g Ivory Bar Soap in 100mL water = 6.5(A)
Sorghum	The fundamental aromatic and taste factor associated with sorghum bran	Onyx bran = 13.0 (F) High Tannin bran = 8.0 (F)

Table 3 Continued.

Attribute	Definition	Reference
Spoiled/Putrid	The presence of inappropriate aromatics and flavors that is commonly associated with spoiled products. It is a foul taste and/or smell that indicates product is starting to decay and putrefy	Boneless Pork Chop room temperature raw for 24 h, refrigerate for 6 days, 79°C, smelled only = 3.0 (A) 80/20 Ground Pork, same as above,
Vinegary	Aroma notes associated with vinegar	1.1g Vinegar in 200g water = 6.0 (F); 4.0 (A)
Warmed-Over	Perception of a product that has been previously cooked and reheated	80/20 Ground Pork, cooked to 71°C, left chilled overnight and microwaved for 1 min = 5.0 (F&A)
Mouthfeels		
Astringent	The chemical feeling factor on the tongue or other skin surfaces of the oral cavity described as a puckering/dry and associated with tannins or alum	Lipton Tea, 1 bag in 236.6 mL boiling water and steeped for 3 min = 6.0 (F) Lipton Tea, 3 bags in 236.6 mL boiling water and steeped for 3 min = 12.0 (F)
Gritty	The fundamental texture associated with grit or sand	Miracle Whip = 0.0 (F) Instant Cream of Wheat mixed in Sour Cream = 5.0 (F) Hellman's Mayonnaise mixed with Cornmeal = 10.0 (F)

Table 4. Definitions and references for chicken flavor attributes, where 0 = none and 15 = extremely intense adapted by Lyon (1987); Laird (2015).

Attribute	Definition	Reference
Basic Tastes		
Bitter	The fundamental taste factor associated with a caffeine solution	0.05% caffeine in 1000 mL water = 2.0 0.08% caffeine in 1000 mL water = 5.0
Salty	The fundamental taste factor of which sodium chloride is typical	0.2% Salt in 1000 mL water = 2.5 0.35% Salt in 1000 mL water = 5.0
Sour	The fundamental taste factor associated with citric acid solution	0.05% Citric Acid in 1000mL water= 2.0 0.08% Citric Acid in 1000mL water= 5.0
Sweet	The fundamental taste factor associated with a sucrose solution	0.05% Sugar in 1000mL water = 2.0 0.08% Sugar in 1000mL water = 5.0
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% Accent flavoring in 1000mL water = 7.5
Flavor Aromatics		
Brown/Roasted	A round, full aromatic generally associated with broiled	Pork Fat, cooked and browned = 3.0 (F), pork suet 4.0 (A)
Burnt	The sharp/acrid flavor note associated with over roasted chicken, muscle something over baked or excessively browned in oil	Arrowhead Barley Cereal, 7-10 puffs = 3.0
Cardboardy	Aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging	Dry cardboard, 2.54 cm square = 5.0 (F), 3.0 (A) Wet cardboard, 2.54 cm square steeped in 236.6 mL water for 30 min = 7.0(F),6.0(A)

Table 4 Continued.

Attribute	Definition	Reference
Chicken Identity	Amount of chicken flavor identity in the sample	Chicken breast grilled to 71°C = 4.0 Ground chicken cooked in skillet set at 177°C to 71°C internal temperature = 5.0 Swanson's chicken broth = 7.0 (F) Dark chicken baked thigh to 79°C Internal temperature = 6.0 (F) White chicken breast baked to 79°C Internal temperature = 4.0 (F)
Fat-like	Aromatics associated with cooked chicken fat	Chicken fat from the thigh, covered with water, cooked in pan with lid, boiled for 20 min, remove lid and cooked until the water evaporates = 8.0 (F) Grilled chicken skin in skillet set at 177°C until brown = 5.0 (F)
Fishy	Aromatics associated with fish	Canned Starkist tuna = 12 (F); 10 (A) Canned Chicken = 4 (F)
Floral	Sweet, light, slightly perfume impression associated with flowers	3.5 mL Clorox Wipe Liquid in 118 mL water= 8.0 (A) Geraniol, 2 drops on cotton ball in Snifter = 7.5 (A) 1:1 White Grape Juice to Water = 5.0
Green	Sharp, slightly pungent aromatics associated with green/plant/ vegetable matter such as parsley, spinach, pea pod, fresh cut grass, etc.	Fresh parsley water = 9.0 (T)

Table 4 Continued.

Attribute	Definition	Reference
Heated Oil	The aromatics associated with oil heated to a high temperature	Wesson Oil, microwaved 3 min = 7.0 Lay's Potato Chips = 4.0 (A)
Liver-Like	Aromatics associated with cooked organ meat/liver	Chicken liver 71°C = 9.0 (F)
Metallic	The impression of slightly oxidized metal, such as iron, copper, and silver spoons	Dole Pineapple Juice = 6.0 (A&F) 0.10% KCl in 1L water = 1.5 (A&F)
Nutty	Nutty characteristics are: sweet, oily, light brown, slightly musty and/or buttery, earthy, woody, astringent, bitter, etc.	Diamond Shelled Walnut, ground for 1 min= 6.5 (F)
Painty	Aromatic associated with oxidized oil similar to the aromatic of linseed oil and oil-based paint	Wesson Vegetable oil placed in covered glass container in 100°C oven for 14 days= 8 (F); 10 (A)
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 (T) Wesson Vegetable Oil (microwaved 5 min) = 9.0 (T)
Refrigerator Stale	Aromatics associated with products left in the refrigerator for period time and absorbing a combination of odors (lack of freshness/flat)	Ground dark meat chicken, 71°C, left chilled overnight, served room temperature = 6.0 (F), 8.0 (A)
Rosemary	The aromatics associated with rosemary extract	0.02% Rosemary Extract = 12.0 (A)
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 (T) Dillon's buttermilk = 4.0 (A); 9.0 (T)
Sorghum	The fundamental aromatic and taste factor associated with sorghum bran	Onyx bran = 13.0 (F) High Tannin bran = 8.0 (F)

Table 4 Continued.

Attribute	Definition	Reference
Spoiled/Putrid	The presence of inappropriate aromatics and flavors that is commonly associated with spoiled products. It is a foul taste and/or smell that indicates product is starting to decay and putrefy	Boneless Pork Chop room temperature raw for 24 h, refrigerate for 6 days, 79°C, smelled only = 3.0 (A) Ground dark meat chicken, same as above, 71°C = 5.0 (A)
Warmed-Over	Perception of a product that has been previously cooked and reheated	Ground dark meat chicken, cooked to 71°C, left chilled reheated overnight and microwaved for 1 min = 5.0
Wet Feathers	Aromatics associated with wet chicken feathers	Wet Chicken Feathers = 9 (A)
Mouthfeels		
Astringent	The chemical feeling factor on the tongue or other skin surfaces as a puckering/dry and associated	Lipton Tea, 1 bag in 236.6 mL boiling water and steeped of the oral cavity described with tannins or alum for 3 min = 6.0 (F) Lipton Tea, 3 bags in 236.6 mL boiling water and steeped for 3 min = 12.0 (F)
Gritty	The fundamental texture associated with grit or sand	Miracle Whip = 0.0 (F) Instant Cream of Wheat mixed in Sour Cream = 5.0 (F) Hellman's Mayonnaise mixed with Cornmeal = 10.0 (F)

Table 5. Volatile, aromatic chemical compound classification identified by the GC/MS for pork and chicken in both Phases 1 & 2.

Chemical Code	Volatile, Aromatic Chemical Compound	Classification
C1	(E)-2-Decenal	Aldehyde
C2	(E)-2-Heptenal	Aldehyde
C3	(E)-2-Hexenal	Aldehyde
C4	(E)-2-Nonenal	Aldehyde
C5	(E)-2-Octenal	Aldehyde
C6	(E,E)-2,4-Decadienal	Aldehyde
C7	(E,E)-2,4-Heptadienal	Aldehyde
C8	(E,Z)-2,4-Decadienal	Aldehyde
C9	1-(1-Cyclohexen-1-yl)Ethanone	Ketone
C10	1,2,3,4-Tetrahydro-Naphthalene	Benzene
C11	1,2,3,4-Tetramethyl-Benzene	Benzene
C12	1,2,3,5-Tetramethyl-Benzene	Benzene
C13	1,2,3-Trimethyl-Benzene	Benzene
C14	1,3-Bis(1,1-Dimethylethyl)-Benzene	Benzene
C15	1,3-Octadiene	Alkene
C16	1,3-Pentadiene	Alkene
C17	1,4-Bis(1,1-Dimethylethyl) Benzene	Benzene
C18	1,4-Dimethyl-Benzene	Benzene
C19	10-Methyl-Eicosane	Alkane
C20	10-Octadecenal	Aldehyde
C21	1-Decanol	Alcohol
C22	1-Docosanol	Alcohol
C23	1-Dodecanol	Alcohol
C24	1-Ethyl-3,5-Dimethyl-Benzene	Benzene
C25	1-Ethyl-3-Methyl-Benzene	Benzene
C26	1-Heptanol	Alcohol
C27	1-Hexanol	Alcohol
C28	1-Isocyano-2-Methyl-Benzene	Benzene
C29	1-Methoxy-4-(1-E-Propenyl)Benzene	Benzene
C30	1-Methoxy-4-(1-Propenyl)Benzene	Benzene
C31	1-Methoxy-4-(1-Z-Propenyl)Benzene	Benzene
C32	1-Methoxy-4-(2-Propenyl)Benzene	Benzene
C33	1-Methyl-2-(1-Methylethyl)Benzene	Benzene
C34	1-Methyl-3-(1-Methylethyl)Benzene	Benzene
C35	1-Methyl-4-(1-Methylethyl)Benzene	Benzene
C36	1-Methyl-4-(1-Methylpropyl)Benzene	Benzene
C37	1-Methylene-1H-Indene	Alkene

Table 5 Continued.

Chemical Code	Volatile, Aromatic Chemical Compound	Classification
C38	1-Octanol	Alcohol
C39	1-Octen-3-ol	Alcohol
C40	1-Pentanol	Alcohol
C41	1-Tetradecanol	Alcohol
C42	2-(Hexyloxy)Ethanol	Alcohol
C43	2,3-Dihydro-Benzofuran	Furan
C44	2,3-Octanedione	Ketone
C45	2,4-Decadienal	Aldehyde
C46	2,4-Diamino-N,N,5-Trimethyl-6-Quinolinesulfonamide	Sulfur
C47	2,4-Heptadienal	Aldehyde
C48	2,4-Hexadienal	Aldehyde
C49	2,4-Nonadienal	Aldehyde
C50	2,5-Hexanedione	Ketone
C51	2,5-Octanedione	Ketone
C52	2,6-Bis(1,1-Dimethylethyl)-4-Methyl-Phenol	Phenol
C53	2-Acetyl Thiazole	Sulfur
C54	2-Docecen-1-al	Aldehyde
C55	2-Dodecanone	Ketone
C56	2-Dodecenal	Aldehyde
C57	2-Ethyl-1,4-Dimethyl-Benzene	Benzene
C58	2-Furancarboxaldehyde	furan
C59	2-Heptanone	Ketone
C60	2-Hydroxy-Benzoic Acid Methyl Ester	Carboxylic Acid
C61	2-Methoxy-Phenol	Phenol
C62	2-Methyl-3-Octanone	Ketone
C63	2-Methyl-5-(4'-Methylphenyl)Sulfonyl-4-Nitroimidazole	Sulfur
C64	2-Methyl-Benzaldehyde	Aldehyde
C65	2-Methyl-Decane	Alkane
C66	2-Methyl-Dodecane	Alkane
C67	2-Methyl-Propanal	Aldehyde
C68	2-Octen-1-ol	Alcohol
C69	2-Octenal	Aldehyde
C70	2-Pentyl-Furan	Furan
C71	2-Undecenal	Aldehyde
C72	3,5-Octadien-2-one	Ketone
C73	3-Dodecen-1-al	Aldehyde
C74	3-Ethyl-2-Methyl-1,3-Hexadiene	Alkene

Table 5 Continued.

Chemical Code	Volatile, Aromatic Chemical Compound	Classification
C75	3-Ethyl-Benzaldehyde	Aldehyde
C76	3-Methyl-Butanal	Aldehyde
C77	3-Methyl-Phenol	Phenol
C78	3-Octanone	Ketone
C79	4-(1,1-Dimethylethyl) Benzenepropanal	Benzene
C80	4-Ethyl-1,2-Dimethyl-Benzene	Benzene
C81	4-Ethyl-Benzaldehyde	Aldehyde
C82	4-Hydroxy-Benzoic Acid	Carboxylic Acid
C83	4-Methyl-Benzaldehyde	Aldehyde
C84	4-Methyl-Phenol	Phenol
C85	4-Pentyl-Benzaldehyde	Aldehyde
C86	5-Pentyl-2(5H)Furanone	Furan
C87	6,7-Dodecanedione	Ketone
C88	6-Butyl-1,4-Cycloheptadiene	Alkene
C89	Acetaldehyde	Aldehyde
C90	Acetic Acid	Carboxylic Acid
C91	Aloxiprin	Phenol
C92	Alpha-Terpinene	Alkene
C93	Azulene	Carboxylic Acid
C94	Benzaldehyde	Aldehyde
C95	Benzene	Benzene
C96	Benzeneacetaldehyde	Benzene
C97	Benzeneacetonitrile	Benzene
C98	Benzenemethanol	Benzene
C99	Benzyl Alcohol	Benzene
C100	Benzyl Nitrile	Benzene
C101	Beta-Myrcene	Alkene
C102	Butanal	Aldehyde
C103	Butanoic Acid	Carboxylic Acid
C104	Butylated Hydroxy Anisole	Phenol
C105	Butylated Hydroxy Toluene	Phenol
C106	Carbon Disulfide	Sulfur
C107	Cyclooctane	Alkane
C108	Cyclooctanol	Alcohol
C109	Cyclooctene	Alkene
C110	Decadienal	Aldehyde
C111	Decanal	Aldehyde

Table 5 Continued.

Chemical Code	Volatile, Aromatic Chemical Compound	Classification
C112	Decane	Alkane
C113	Decanoic Acid	Carboxylic Acid
C114	Decyl Ester Acetic Acid	Carboxylic Acid
C115	Dihydro-2-Methyl-3(2H)-Furanone	Furan
C116	dl-Limonene	Alkene
C117	Dodecanal	Aldehyde
C118	Dodecane	Alkane
C119	Eicosane	Alkane
C120	Estragole	Phenol
C121	Ethanol	Alcohol
C122	Ethyl Ester Decanoic Acid	Carboxylic Acid
C123	Ethyl Ester Dodecanoic Acid	Carboxylic Acid
C124	Ethyl Ester Octanoic Acid	Carboxylic Acid
C125	Gamma-Terpinene	Alkene
C126	Heneicosane	Alkane
C127	Hentriacontane	Alkane
C128	Heptacosane	Alkane
C129	Heptadecane	Alkane
C130	Heptanal	Aldehyde
C131	Heptane	Alkane
C132	Heptanoic Acid	Carboxylic Acid
C133	Heptanol	Alcohol
C134	Heptenal	Aldehyde
C135	Heptyl Ester Formic Acid	Carboxylic Acid
C136	Hexadecanal	Aldehyde
C137	Hexadecane	Alkane
C138	Hexamethyl-Cyclotrisiloxane	Alkane
C139	Hexanal	Aldehyde
C140	Hexanoic Acid	Carboxylic Acid
C141	Hexyl Ester-Formic Acid	Carboxylic Acid
C142	Methanethiol	Sulfur
C143	Methyl Ester Nonahexacontanoic Acid	Carboxylic Acid
C144	Methyl(1-Methylethyl)Benzene	Benzene
C145	Methyl-Benzene	Benzene
C146	Naphthalene	Benzene
C147	N-Caproic Acid Vinyl Ester	Carboxylic Acid
C148	N-Heptanal	Aldehyde

Table 5 Continued.

Chemical Code	Volatile, Aromatic Chemical Compound	Classification
C149	Nonadienal	Aldehyde
C150	Nonacosane	Alkane
C151	Nonadecane	Alkane
C152	Nonanal	Aldehyde
C153	Nonanoic Acid	Carboxylic Acid
C154	Nonenal	Aldehyde
C155	Octacosane	Alkane
C156	Octadecanal	Aldehyde
C157	Octadecane	Alkane
C158	Octamethyl-Cyclotetrasiloxane	Alkane
C159	Octanal	Aldehyde
C160	Octane	Alkane
C161	Octanedione	Ketone
C162	Octenal	Aldehyde
C163	Octyl Ester Formic Acid	Carboxylic Acid
C164	Pentacosane	Alkane
C165	Pentadecane	Alkane
C166	Pentanal	Aldehyde
C167	Pentane	Alkane
C168	Pentanol	Alcohol
C169	Pentyl Ester-Formic Acid	Carboxylic Acid
C170	Pentyl-Benzene	Benzene
C171	Phenol	Phenol
C172	Phenyl Acetaldehyde	Aldehyde
C173	Phenyl-Oxirane	Alkane
C174	Propanal	Aldehyde
C175	Styrene	Benzene
C176	Sulfur Dioxide	Sulfur
C177	Tetradecanal	Aldehyde
C178	Tetradecane	Alkane
C179	Thiourea	Sulfur
C180	Toluene	Phenol
C181	Tridecanal	Aldehyde
C182	Tridecane	Alkane
C183	Undecanal	Aldehyde
C184	Undecane	Alkane
C185	Undecenal	Aldehyde

Table 6. Raw pork crumbles least squares means by treatment for raw percent lipid and moisture for Phase I.

Effect	% Lipid	% Moisture
RMSE	2.461	1.974
<u>Treatment</u>		
P-values	*0.82*	*0.83*
Control	17.97	63.22
Rosemary	17.72	63.68
BHA/BHT	19.64	62.84
0.125% High Tannin	19.42	63.15
0.25% High Tannin	18.21	63.09
0.50% High Tannin	18.95	62.37
0.75% High Tannin	17.06	63.91
0.125% Onyx	16.03	65.61
0.25% Onyx	17.41	62.84
0.50% Onyx	17.50	63.53
0.75% Onyx	17.33	63.04

Table 7. Pork crumbles least squares means for raw pH, objective color, subjective color attributes and cooking yield for Phase I.

Effect	Cook Yield %	pH	Subjective Color	CIE Color Space Values *L**	*a**	*b**
RMSE	2.793	0.250	0.581	1.442	0.904	0.654
Treatment						
P-values	*0.71*	*0.92*	*<0.0001*	*0.0002*	*0.18*	*0.02*
Control	75.70	6.05	6.1^{def}	60.45^{abcd}	12.82	9.89^{cd}
0.02% BHA/BHT	76.27	5.97	5.7^{ef}	61.99^{ab}	14.02	10.93^{abc}
0.20% Rosemary	75.77	6.04	5.5^{f}	62.69^{a}	13.50	10.98^{abc}
0.125% High Tannin	74.37	6.01	6.2^{def}	62.19^{ab}	13.27	11.04^{ab}
0.25% High Tannin	73.43	5.84	6.6^{cde}	61.45^{abc}	12.50	10.72^{abcd}
0.50% High Tannin	77.10	5.98	6.7^{cde}	58.54^{def}	13.19	10.70^{abcd}
0.75% High Tannin	76.47	5.88	7.2^{c}	59.95^{bcd}	12.74	11.49^{a}
0.125% Onyx	73.63	5.86	6.9^{cd}	59.05^{cde}	13.04	9.97^{bcd}
0.25% Onyx	73.57	5.88	7.3^{c}	62.03^{ab}	11.67	10.11^{bcd}
0.50% Onyx	76.47	6.11	9.6^{b}	57.31^{ef}	12.02	9.62^{d}
0.75% Onyx	76.17	6.07	11.5^{a}	56.21^{f}	12.93	9.79^{d}

^{abcdef} Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 8. Pork crumbles least squares means for cooked pH, objective color, subjective color attributes and TBARS values for Phase I.

Effect	pH	Subjective Color	CIE Color Space Values *L**	*a**	*b**	TBARS
RMSE	0.211	1.296	2.836	0.595	2.311	1.400
Treatment						
P-values	*0.57*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Control	6.29	5.9^{e}	59.97^{a}	2.61^{e}	15.76^{a}	11.39^{a}
0.02% BHA/BHT	6.30	6.6^{cde}	59.12^{a}	4.05^{a}	14.20^{ab}	1.43^{g}
0.20% Rosemary	6.31	6.1^{de}	59.77^{a}	3.73^{ab}	15.54^{a}	5.09^{e}
0.125% High Tannin	6.22	7.0^{cd}	57.75^{ab}	3.01^{cde}	14.13^{ab}	9.51^{b}
0.25% High Tannin	6.19	7.6^{c}	57.68^{ab}	3.32^{bc}	13.60^{bc}	6.44^{d}
0.50% High Tannin	6.19	8.7^{b}	55.15^{c}	3.86^{a}	11.81^{cde}	3.12^{f}
0.75% High Tannin	6.31	10.0^{a}	54.62^{c}	4.17^{a}	12.34^{bcd}	1.78^{g}
0.125% Onyx	6.27	7.2^{c}	58.12^{a}	2.82^{de}	13.18^{bc}	8.17^{c}
0.25% Onyx	6.20	8.8^{b}	55.53^{bc}	3.30^{bcd}	12.34^{bcd}	5.52^{ed}
0.50% Onyx	6.29	10.0^{a}	53.61^{c}	3.91^{a}	10.90^{de}	1.95^{g}
0.75% Onyx	6.35	10.9^{a}	51.29^{d}	3.96^{a}	10.16^{e}	1.62^{g}
Storage Day						
P-values	*0.001*	*0.01*	*<0.0001*	*<0.0001*	*0.39*	*<0.0001*
0	6.35^{a}	7.6^{b}	58.69^{ab}	4.27^{a}	12.59	2.53^{d}
1	6.32^{a}	8.7^{a}	57.35^{b}	3.57^{b}	12.99	4.36^{c}
3	6.21^{b}	8.0^{b}	58.86^{a}	3.07^{c}	13.23	6.05^{b}
5	6.18^{b}	8.0^{ab}	51.50^{c}	3.18^{c}	13.54	7.43^{a}
Treatment x Storage Day	*0.57*	*0.41*	*0.49*	*0.60*	*0.99*	*<0.0001*

^{abcdedfg} Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 9. Pork crumbles flavor and basic tastes attributes least squares means by treatments for Phase I.

Treatment	Pork Identity	Brown/ Roasted	Fat Like	Metallic	Astringent	Sweet	Sour	Salty	Bitter	Umami
RMSE	0.51	0.23	0.33	0.20	0.26	0.22	0.21	0.20	0.27	0.12
P-values	*0.27*	*0.009*	*0.52*	*0.05*	*0.002*	*0.02*	*0.002*	*0.12*	*0.17*	*0.25*
Treatment										
Control	4.6	0.5^{cd}	2.0	1.8	2.1^{a}	0.9^{c}	1.5^{a}	1.3	1.9	0.0
Rosemary	4.1	0.5^{d}	1.8	1.7	1.8^{b}	1.0^{bc}	1.3^{abc}	1.3	1.6	0.2
BHA/BHT	4.4	0.6^{bcd}	2.0	1.8	1.7^{bc}	1.3^{a}	1.2^{bcd}	1.5	1.6	0.1
0.125% High Tannin	4.5	0.6^{abcd}	1.8	1.8	1.8^{b}	1.0^{bc}	1.3^{abc}	1.1	1.6	0.1
0.25% High Tannin	4.4	0.8^{abc}	1.9	1.7	1.8^{b}	1.0^{bc}	1.4^{abc}	1.5	1.6	0.1
0.50% High Tannin	4.4	0.9^{a}	1.8	1.6	1.5^{bc}	1.1^{ab}	1.3^{bcd}	1.3	1.5	0.0
0.75% High Tannin	4.1	0.8^{abc}	1.8	1.5	1.4^{c}	1.2^{ab}	1.2^{acd}	1.3	1.4	0.1
0.125% Onyx	4.2	0.8^{abc}	1.7	1.8	1.8^{b}	1.0^{bc}	1.4^{ab}	1.3	1.7	0.1
0.25% Onyx	4.2	0.7^{abc}	2.0	1.8	1.7^{b}	1.1^{abc}	1.4^{abc}	1.4	1.6	0.0
0.50% Onyx	4.5	0.9^{a}	1.7	1.6	1.6^{bc}	1.2^{ab}	1.0^{d}	1.4	1.4	0.1
0.75% Onyx	3.8	0.9^{a}	1.7	1.4	1.5^{bc}	1.3^{a}	1.0^{d}	1.2	1.5	0.1
P-values	*0.02*	*0.01*	*0.72*	*0.67*	*0.02*	*<0.0001*	*0.12*	*0.21*	*0.22*	*0.01*
Storage d										
1	4.4^{a}	0.7^{b}	1.9	1.7	1.6^{b}	1.3^{a}	1.2	1.2	1.6	0.1^{a}
3	4.2^{b}	0.8^{a}	1.8	1.7	1.8^{a}	0.9^{b}	1.3	1.3	1.6	0.1^{b}

^{abcd} Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 9 Continued.

Treatment	Sorghum	Gritty	Cardboard	Heated Oil	Nutty	Painty	Rancid	Refrigerator Stale	WOF*
RMSE	0.53	0.45	0.31	0.35	0.14	0.22	0.06	0.31	0.39
P-values	*<0.0001*	*0.01*	*0.001*	*<0.0001*	*0.04*	*0.02*	*0.35*	*0.02*	*<0.0001*
<u>Treatment</u>									
Control	0.3^{e}	1.4^{c}	1.3^{a}	1.5^{a}	0.0^{d}	0.5^{a}	0.1	0.4^{abcd}	1.6^{a}
Rosemary	1.1^{bcd}	1.8^{abc}	0.9^{bc}	1.0^{bc}	0.2^{abc}	0.2^{a}	0.1	0.5^{ab}	1.1^{bcd}
BHA/BHT	0.6^{cde}	1.7^{bc}	0.5^{e}	0.3^{de}	0.3^{a}	0.1^{c}	0.1	0.3^{bcd}	0.8^{cde}
0.125% High Tannin	0.5^{de}	1.7^{bc}	0.8^{bcde}	1.2^{ab}	0.0^{cd}	0.4^{ab}	0.1	0.5^{abc}	1.1^{bc}
0.25% High Tannin	0.7^{bcde}	2.1^{ab}	0.9^{ab}	0.8^{bc}	0.1^{bcd}	0.2^{bc}	0.1	0.5^{abc}	1.2^{bc}
0.50% High Tannin	1.3^{ab}	2.3^{a}	0.6^{cde}	0.4^{de}	0.2^{abc}	0.2^{abc}	0.0	0.2^{bcd}	0.8^{cde}
0.75% High Tannin	1.8^{a}	2.3^{a}	0.9^{bcd}	0.2^{e}	0.2^{ab}	0.1^{bc}	0.0	0.1^{d}	0.6^{de}
0.125% Onyx	0.8^{bcde}	1.9^{abc}	1.0^{ab}	1.1^{ab}	0.1^{bcd}	0.1^{bc}	0.1	0.7^{a}	1.3^{ab}
0.25% Onyx	1.0^{bcd}	2.0^{ab}	0.7^{bcde}	0.6^{cd}	0.1^{bcd}	0.2^{bc}	0.0	0.3^{bcd}	1.0^{bcd}
0.50% Onyx	1.2^{bc}	2.2^{bc}	0.5^{de}	0.2^{e}	0.2^{abcd}	0.1^{c}	0.0	0.2^{bcd}	0.4^{e}
0.75% Onyx	1.8^{a}	2.2^{a}	0.7^{bcde}	0.4^{de}	0.1^{abcd}	0.0^{c}	0.0	0.1^{cd}	0.6^{de}
P-values	*0.53*	*0.49*	*0.44*	*<0.0001*	*0.01*	*0.0002*	*0.21*	*0.57*	*0.14*
<u>Storage d</u>									
1	1.0	2.0	0.1	0.5^{b}	0.1^{b}	0.1^{b}	0.0	0.3	0.9
3	0.9	1.9	0.0	0.9^{a}	0.3^{a}	0.3^{a}	0.1	0.4	1.0

^{abcde} Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

*Warmed-Over Flavor

Table 10. Pork crumbles least squares means values for volatile, aromatic chemicals identified by the GC/MS for each treatment for Phase I. *High Tannin Sorghum

Code**	RMSE	Trt *P-values*	Control	0.02% BHA/BHT	0.20% Rosemary	0.125% HTS*	0.25% HTS	0.50% HTS	0.75% HTS	0.125% Onyx	0.25% Onyx	0.50% Onyx	0.75% Onyx
C1	148496.0	*0.66*	246704	12604	197886	283504	242150	97002	338771	197410	270053	148582	172002
C2	245399.8	*0.06*	1065393	14275	300505	554938	234619	367210	333901	433684	705691	155179	259107
C3	90823.5	*0.57*	160692	0	8254	80385	0	0	79725	117705	61139	130755	0
C4	107476.5	*0.21*	35152	11298	0	162902	0	208766	0	74708	276513	30941	0
C5	75371.0	*0.55*	34877	5170	115937	0	0	108996	64455	65311	132867	71220	128157
C7	19696.8	*0.48*	41160	0	30175	35406	26578	53248	26813	34177	34161	36829	13408
C9	4353.8	*0.50*	0	0	0	4117	0	9290	1808	2097	0	5632	0
C15	90529.2	*0.58*	96850	0	0	0	0	37942	71426	183009	79935	0	0
C16	3091.8	*0.65*	0	5093	0	0	0	0	4190	0	1359	0	2831
C17	9417.9	*0.63*	0	0	2596	0	0	11836	0	17399	0	0	0
C20	5839.3	*0.50*	0	0	0	0	12065	7797	0	0	0	0	0
C21	9021.8	*0.64*	0	10865	0	0	0	0	2199	0	16876	1280	0
C26	75218.8	*0.67*	0	0	36595	86518	0	0	47518	138768	0	0	13081
C27	55540.5	*0.48*	30781	0	57084	75447	0	43135	51383	8486	14245	127723	0
C38	48950.4	*0.001*	87811^{b}	30200^{b}	73621^{b}	13239^{b}	39589^{b}	17598^{b}	58399^{b}	351876^{a}	47163^{b}	32538^{b}	10161^{b}
C39	186869.4	*0.25*	76393	86044	508767	26091	45229	176382	186687	44129	439706	102055	81653
C40	207769.2	*0.74*	417510	41171	63052	200697	5872	147027	159869	244678	127674	136767	13870
C42	67896.2	*0.52*	47388	72202	52000	0	0	58404	64507	68822	38953	61777	177940
C43	2956.4	*0.62*	0	0	0	0	2944	5658	0	0	0	2526	0
C45	77843.0	*0.41*	63868	0	8329	51162	71000	30974	22630	201790	59513	132130	27599
C46	1788.5	*0.24*	0	5146	0	0	0	0	0	1862	0	1580	1075
C47	34345.3	*0.79*	31648	0	0	26032	16621	0	4375	43203	53145	6017	18172
C48	2136.0	*0.66*	2873	0	0	0	0	1403	0	0	0	3555	0
C49	37762.0	*0.07*	124495	0	29818	90326	107907	126835	100781	91944	97857	74410	16578

Table 10 Continued.

Code**	RMSE	Trt *P-values*	Control	0.02% BHA/BHT	0.20% Rosemary	0.125% HTS	0.25% HTS	0.50% HTS	0.75% HTS	0.125% Onyx	0.25% Onyx	0.50% Onyx	0.75% Onyx
C50	12223.4	*0.12*	36807	0	0	0	24017	0	0	0	0	0	0
C52	394938.3	*0.003*	0	2380164	3820	0	0	0	0	2182	0	0	0
C53	7077.8	*0.19*	0	0	2627	0	2971	4855	21444	0	6037	1436	11876
C54	58758.2	*0.21*	0	0	70455	108254	0	0	0	0	147657	0	0
C59	75837.4	*0.14*	247593	0	120745	88161	0	50240	14782	80241	7189	101383	0
C62	89612.6	*0.66*	0	78484	0	0	0	0	86435	157659	0	82972	0
C63	2757.1	*0.50*	0	0	0	0	0	0	5736	0	0	3614	0
C69	64118.4	*0.50*	0	0	150371	0	0	0	0	0	0	0	0
C70	229483.7	*0.65*	134089	34347	365835	426821	46157	82162	101344	254234	247386	5211	53397
C71	57847.9	*0.03*	239577^{a}	0^{b}	0^{b}	36622^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	97296^{b}	0^{b}
C72	6790.2	*0.01*	31324^{a}	0^{c}	0^{c}	19714^{ab}	31386^{a}	7011^{bc}	15159^{b}	11591^{bc}	12418^{bc}	16055^{b}	9389^{bc}
C73	125860.2	*0.83*	50537	0	115814	124835	78276	168877	0	97496	37552	175279	0
C74	103853.6	*0.49*	186239	0	93971	178557	0	44192	0	117641	0	0	14277
C75	14771.2	*0.001*	73356^{bc}	0^{e}	48189^{cd}	27012^{cd}	83973^{ab}	63210^{bc}	55977^{bcd}	54775^{bcd}	108730^{a}	43357^{cd}	30290de
C76	1756.7	*0.69*	2746	0	0	544	0	0	0	0	2524	0	1134
C77	9487.7	*0.50*	0	0	0	0	0	0	0	0	19586	9334	11216
C78	374422.5	*0.10*	0	0	855014	0	0	0	210953	1115675	0	30443	0
C79	7983.6	*0.62*	12908	0	0	0	0	0	12334	0	0	0	0
C81	44121.8	*0.73*	56007	0	0	27608	0	0	44305	70896	21385	17682	0
C82	2713.9	*0.61*	0	0	5504	0	0	0	0	0	0	2325	1854
C83	9880.6	*0.50*	0	21086	0	0	0	10353	0	10196	0	1652	0
C84	15079.5	*0.30*	1520	7595	32287	4006	0	7578	27649	32665	4248	10172	3019
C85	4689.6	*0.61*	8275	0	0	0	6464	0	0	0	0	0	0
C86	14207.7	*0.04*	26459^{abcd}	0^{d}	0^{d}	13807^{bcd}	17584^{bcd}	41713^{ab}	2587^{cd}	50197^{a}	29654^{abcd}	33058^{abc}	0^{d}

Table 10 Continued.

Code**	RMSE	Trt *P-values*	Control	0.02% BHA/BHT	0.20% Rosemary	0.125% HTS	0.25% HTS	0.50% HTS	0.75% HTS	0.125% Onyx	0.25% Onyx	0.50% Onyx	0.75% Onyx
C87	8642.7	*0.64*	13603	0	0	11488	0	0	8954	0	0	0	0
C89	8459.8	*0.84*	6405	12021	15356	7184	6931	3733	5878	9443	0	2838	4610
C90	53444.0	*0.51*	68540	88424	19888	35392	54665	21491	53364	150651	49733	32338	38917
C91	8982.6	*0.66*	0	0	0	8813	0	0	0	18273	0	0	0
C94	172219.6	*0.21*	312173	432525	458317	459363	224672	301921	600473	290115	337522	178988	146236
C95	2900.7	*0.66*	4427	4384	1889	0	0	0	0	0	0	0	0
C96	15114.4	*0.10*	0	0	0	0	0	0	18454	0	0	0	52280
C98	12530.6	*0.67*	24875	10231	0	0	0	2260	0	6332	6572	0	0
C102	6061.4	*0.34*	11554	0	0	11678	820	0	0	9790	3245	2784	0
C103	9284.8	*0.09*	0	28552	20796	0	0	0	0	0	0	0	0
C104	490309.2	*0.50*	0	1149877	0	0	0	0	0	0	0	0	0
C105	579931.3	*<0.0001*	0^{b}	7146894^{a}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}
C106	29317.5	*0.04*	0^{c}	56458^{abc}	34088^{bc}	0^{c}	23070^{bc}	19791^{bc}	33724^{bc}	0^{c}	71799^{ab}	8187^{bc}	119243^{a}
C107	73904.0	*0.54*	0	0	129009	89958	0	89308	0	0	93836	0	44171
C108	18987.4	*0.57*	0	0	0	0	0	0	0	41130	13440	0	0
C109	73521.2	*0.50*	0	0	172423	0	0	0	0	0	0	0	0
C111	33581.5	*0.83*	20142	27722	63045	12824	20470	40022	68471	35534	32938	33935	29113
C116	5133.8	*0.71*	0	7706	780	0	0	0	4563	0	0	7049	1450
C117	8215.7	*0.62*	0	0	10541	0	14750	0	6210	0	0	5593	0
C126	184595.6	*0.50*	0	0	0	0	0	0	0	0	0	432915	0
C127	1999.2	*0.64*	0	0	637	0	0	3355	0	0	0	2904	0
C128	978.1	*0.64*	0	818	0	0	0	0	1092	0	1768	0	0
C130	96423.5	*0.50*	0	88734	107181	0	0	0	207885	0	0	24993	0
C131	22538.6	*0.17*	66457	0	17713	11707	0	0	0	0	36642	27531	0

Table 10 Continued.

Code**	RMSE	Trt *P-values*	Control	0.02% BHA/BHT	0.20% Rosemary	0.125% HTS	0.25% HTS	0.50% HTS	0.75% HTS	0.125% Onyx	0.25% Onyx	0.50% Onyx	0.75% Onyx
C132	6653.9	*0.005*	21384^{ab}	0^{c}	0^{c}	0^{c}	0^{c}	0^{c}	0^{c}	32311^{a}	0^{c}	10620^{bc}	0^{c}
C133	75218.8	*0.67*	0	0	36595	86518	0	0	47518	138768	0	0	13081
C134	84513.3	*0.50*	192758	0	0	0	52075	0	0	69467	0	0	0
C139	4740763.0	*0.83*	3583313	1388819	4515294	4270813	921613	359739	3331010	4706720	1995988	1435312	8953692
C140	107534.2	*0.27*	139348	22524	8089	51718	0	30596	61566	257218	77910	239578	0
C141	80498.8	*0.65*	136890	0	0	0	0	0	0	111310	35793	0	0
C142	13375.0	*0.63*	3200	7183	9481	0	2775	0	3850	2232	14885	14976	27714
C145	39687.2	*0.56*	0	0	0	0	0	0	8890	0	0	89363	14405
C146	33957.4	*0.008*	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	0^{b}	46797^{b}	178844^{a}
C147	496764.9	*0.58*	26512	70583	1019265	31517	0	23094	83344	551290	265390	504014	0
C148	939378.5	*0.39*	1397355	46455	493499	730890	25836	199397	729193	2139955	648269	1773096	91374
C150	1762.9	*0.27*	0	3667	0	0	0	0	0	2300	0	2135	3415
C152	676306.2	*0.71*	1554027	766737	816589	833958	245806	868540	1551707	1215965	932366	520032	1117082
C153	4168.4	*0.01*	9822^{b}	0^{c}	0^{c}	0^{c}	0^{c}	0^{c}	0^{c}	19733^{a}	0^{c}	0^{c}	0^{c}
C154	74485.1	*0.02*	373840^{a}	0^{d}	174966^{bc}	194564^{bc}	87869^{cd}	154900^{bcd}	290091^{ab}	247389^{abc}	123602^{cd}	240185^{abc}	212937^{abc}
C155	1180.1	*0.50*	0	0	0	0	0	2056	0	0	1972	1122	0
C159	726387.0	*0.13*	942569	123945	395479	788408	72726	279484	232285	2402737	204254	1534879	119830
C160	117457.9	*0.59*	61681	0	63155	0	0	0	143938	0	160638	203705	0
C161	122234.5	*0.90*	236470	34233	180993	144097	115338	136811	116450	67873	97713	157142	84281
C162	64118.4	*0.50*	0	0	150371	0	0	0	0	0	0	0	0
C163	110375.1	*0.53*	77202	0	47580	0	28411	10568	32832	62132	78068	270363	27450
C166	177947.0	*0.94*	232522	48641	133758	260117	0	167926	132872	172291	117743	183243	149511
C167	9936.8	*0.63*	0	0	0	9348	0	0	0	17540	11586	0	0
C169	7493.6	*0.50*	0	0	0	0	17574	0	0	0	0	0	0

Table 10 Continued.

Code**	RMSE	Trt *P-values*	Control	0.02% BHA/BHT	0.20% Rosemary	0.125% HTS	0.25% HTS	0.50% HTS	0.75% HTS	0.125% Onyx	0.25% Onyx	0.50% Onyx	0.75% Onyx
C171	10699.0	*0.09*	8623	0	2236	10518	9075	9314	31509	37633	16554	22571	9696
C172	3826.9	*0.32*	0	0	0	0	3156	9199	0	0	0	5014	4787
C174	5942.0	*0.76*	9799	0	0	0	6060	0	3678	3672	2705	6048	0
C175	80837.3	*0.69*	82596	121310	104128	131767	125081	123965	242780	217414	184379	147094	149555
C176	89271.8	*0.24*	0	0	32573	0	0	0	17547	9502	27403	186860	215914
C177	12719.0	*0.72*	16645	8767	14119	20530	0	0	11149	14226	3854	0	2868
C179	5134.7	*0.70*	0	0	1911	0	6657	0	0	8495	3423	0	0
C180	209759.9	*0.50*	0	0	0	0	0	0	491931	0	0	0	0
C181	12127.8	*0.27*	18064	0	16732	14227	32031	0	11026	3388	0	0	3736
C182	11162.7	*0.50*	21882	0	0	0	15007	0	0	11474	0	0	0
C185	95914.2	*0.55*	159807	0	0	87915	122341	109998	166175	160299	182769	49163	119817

[abcde] Least squares means within a row and treatment with the same letter are not different ($P \geq 0.05$).

*High Tannin Sorghum

**Code number represents the volatile, aromatic chemical compound name and classification identified by the GC/MS found in Table 5.

Table 11. Pork crumbles least squares means values for volatile, aromatic compounds identified by the GC/MS for each treatment for Phase I.

Treatment	Alcohols	Aldehydes	Alkanes	Alkenes	Benzenes	Carboxylic Acids	Furans	Ketones	Phenols	Sulfurs
RMSE	427870.1	5745075.0	318515.7	125224.8	99623.4	592393.2	235159.9	442370.1	388202.4	81010.0
P-values	*0.64*	*0.64*	*0.67*	*0.19*	*0.20*	*0.42*	*0.67*	*0.13*	*<0.0001*	*0.03*
Control	762798	11602983	153219	283089	124804	479696	160548	565796	1520^{b}	0^{c}
0.02% BHA/BHT	251371	3022010	11667	12798	135924	210082	34347	112717	10684530^{a}	61604^{bc}
0.20% Rosemary	819761	8445730	219994	267174	108612	1121120	365835	1156752	36107^{b}	71197^{bc}
0.125% HTS*	411860	9546570	111013	178557	131767	118626	440628	267575	12819^{b}	0^{c}
0.25% HTS	100054	2894293	20937	0	125081	100650	66684	170741	0^{b}	32697^{bc}
0.50% HTS	479068	3985457	103917	82134	138060	85749	129533	203352	7578^{b}	24645^{bc}
0.75% HTS	589874	8753418	148879	80178	282458	231105	103931	454540	519580^{b}	72715^{bc}
0.125% Onyx	974208	13503403	33546	300650	241144	1184643	304431	1435136	53120^{b}	19859^{bc}
0.25% Onyx	709963	6772438	321326	81293	190951	506893	277040	117320	23834^{b}	108662^{bc}
0.50% Onyx	693382	7622304	690300	7049	283253	1059236	40795	393625	19506^{b}	198062^{ab}
0.75% Onyx	310085	11684542	80086	18557	395083	68220	53397	93670	14235^{b}	348108^{a}
P-values	*0.66*	*0.39*	*0.35*	*0.26*	*0.32*	*0.48*	*0.92*	*0.27*	*0.89*	*0.09*
Storage d										
1	514252	6893522	106905	87963	218002	379110	175065	343068	1022595	117088
3	595279	9076141	237619	150487	174204	560166	184420	560790	1045191	53375

^{abc} Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

*High Tannin Sorghum

Table 12. Chicken patties least squares means by treatment for raw lipid and moisture for Phase I.

Effect	% Lipid	% Moisture
RMSE	0.967	1.038
Treatment		
P-values	*0.17*	*0.70*
Control	9.49	72.07
Rosemary	10.74	71.26
BHA/BHT	8.33	72.94
0.125% High Tannin	9.45	71.77
0.25% High Tannin	9.51	71.98
0.50% High Tannin	9.65	71.70
0.75% High Tannin	9.74	71.45
0.125% Onyx	8.53	72.73
0.25% Onyx	9.16	72.38
0.50% Onyx	8.46	72.10
0.75% Onyx	8.59	72.19

Table 13. Chicken patties least square means for raw pH, objective and subjective color attributes for Phase I.

Effect	Cook Yield %	pH	Subjective Color	CIE Color Space Values *L**	*a**	*b**
RMSE	2.238	0.078	0.854	1.044	0.658	0.783
Treatment						
P-values	*0.02*	*0.56*	*<0.0001*	*<0.0001*	*0.62*	*0.001*
Control	76.13[bcd]	6.25	4.4[f]	59.02[ab]	8.28	11.43[abc]
0.02% BHA/BHT	73.80[cd]	6.25	3.9[ef]	60.78[a]	7.66	12.17[a]
0.20% Rosemary	73.53[d]	6.26	4.1[ef]	60.32[ab]	8.17	11.61[ab]
0.125% High Tannin	77.67[ab]	6.25	3.6[f]	58.23[cde]	8.14	11.80[ab]
0.25% High Tannin	77.80[ab]	6.31	5.3[e]	58.87[bc]	7.96	11.95[ab]
0.50% High Tannin	80.63[a]	6.23	9.0[cd]	57.01[def]	8.40	11.96[ab]
0.75% High Tannin	77.57[abc]	6.22	10.3[bc]	56.33[f]	8.30	11.44[abc]
0.125% Onyx	78.17[ab]	6.28	7.5[d]	58.77[bcd]	7.40	10.81[bcd]
0.25% Onyx	77.13[abcd]	6.24	9.5[cd]	56.64[ef]	7.70	10.15[cde]
0.50% Onyx	76.53[bcd]	6.14	11.0[ab]	53.85[g]	7.66	9.64[de]
0.75% Onyx	79.77[ab]	6.26	12.0[a]	51.76[h]	8.32	9.47[e]

[abcdef] Least squares means within a column with the same letter are not different ($P \geq 0.05$).

Table 14. Chicken patties least squares means for cooked pH, objective color, subjective color attributes and TBARS values for Phase I.

Effect	pH	Subjective Color	CIE Color Space Values *L**	*a**	*b**	TBARS
RMSE	0.095	1.310	3.230	0.808	2.909	0.856
Treatment						
P-values	*0.82*	*<0.0001*	*<0.0001*	*0.15*	*<0.0001*	*<0.0001*
Control	6.46	5.8[e]	59.27[a]	6.23	19.73[a]	4.60[a]
0.02% BHA/BHT	6.46	6.4[de]	59.65[a]	6.27	19.68[a]	1.12[efg]
0.20% Rosemary	6.46	6.4[de]	59.16[a]	5.94	20.01[a]	2.30[c]
0.125% High Tannin	6.47	7.2[cd]	59.74[a]	6.01	18.23[ab]	3.29[b]
0.25% High Tannin	6.46	7.8[bc]	58.34[a]	5.59	16.82[bc]	2.28[c]
0.50% High Tannin	6.47	8.7[b]	57.88[a]	6.12	16.39[bc]	1.29[def]
0.75% High Tannin	6.42	9.9[a]	54.80[b]	6.15	15.32[cde]	0.70[fg]
0.125% Onyx	6.51	6.9[cd]	57.88[a]	5.55	18.12[ab]	1.98[cd]
0.25% Onyx	6.48	8.0[b]	57.62[a]	5.61	15.52[cd]	1.49[de]
0.50% Onyx	6.45	10.0[a]	52.59[bc]	5.61	13.76[de]	0.73[fg]
0.75% Onyx	6.47	10.8[a]	51.67[c]	6.15	13.07[e]	0.57[g]
Storage Day						
P-values	*0.0001*	*0.003*	*0.001*	*<0.0001*	*0.09*	*<0.0001*
0	6.42[b]	7.4[c]	58.96[a]	6.74[a]	17.45	0.78[d]
1	6.46[b]	7.9[bc]	55.75[b]	6.10[b]	17.75	1.29[c]
3	6.45[b]	8.5[a]	57.25[b]	5.59[c]	16.43	2.03[b]
5	6.53[a]	8.3[ab]	56.62[b]	5.28[c]	16.25	3.30[a]
Treatment x Storage Day	*0.90*	*0.82*	*0.61*	*0.79*	*0.97*	*<0.0001*

[abcdefg] Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 15. **C**hicken patties flavor and basic taste attributes least squares means by treatments for Phase I.

Treatment	Chicken Identity	Brown/ Roasted	Fat Like	Metallic	Astringent	Sweet	Sour	Salty	Bitter	Umami
RMSE	0.35	0.19	0.28	0.21	0.34	0.24	0.28	0.18	0.22	0.11
P-values	*0.26*	*0.003*	*0.33*	*0.62*	*0.64*	*0.004*	*0.22*	*0.84*	*0.003*	*0.04*
<u>Treatment</u>										
Control	4.0	0.3^{cd}	1.5	1.8	1.8	0.9^{bc}	1.4	1.0	1.9^{bc}	0.0^{bc}
Rosemary	4.0	0.3^{bcd}	1.7	1.9	2.0	0.8^{c}	1.7	1.1	2.0^{bc}	0.1^{bc}
BHA/BHT	3.8	0.2^{d}	1.5	1.8	1.8	0.8^{bc}	1.5	1.1	2.4^{a}	0.0^{bc}
0.125% High Tannin	3.9	0.3^{bcd}	1.4	1.9	1.6	0.9^{bc}	1.4	1.1	2.0^{bc}	0.0^{c}
0.25% High Tannin	3.7	0.4^{bc}	1.4	1.7	1.7	0.7^{c}	1.3	1.1	1.8^{c}	0.1^{bc}
0.50% High Tannin	4.5	0.3^{bcd}	1.6	2.0	1.9	0.9^{bc}	1.6	1.0	2.0^{bc}	0.0^{bc}
0.75% High Tannin	3.8	0.5^{abc}	1.3	1.8	1.9	1.1^{ab}	1.3	1.2	2.0^{b}	0.1^{ab}
0.125% Onyx	4.1	0.3^{bcd}	1.6	1.9	1.8	0.9^{bc}	1.5	1.1	2.0^{bc}	0.1^{bc}
0.25% Onyx	3.9	0.4^{bc}	1.5	1.8	1.7	0.9^{bc}	1.6	1.2	1.8^{bc}	0.1^{bc}
0.50% Onyx	3.7	0.5^{ab}	1.6	1.8	1.8	1.2^{a}	1.4	1.1	2.0^{bc}	0.1^{bc}
0.75% Onyx	3.8	0.7^{a}	1.3	1.7	2.0	1.3^{a}	1.3	1.2	1.8^{bc}	0.2^{a}
P-values	*<0.0001*	*0.14*	*0.02*	*0.008*	*0.68*	*<0.0001*	*0.14*	*0.009*	*0.83*	*0.24*
<u>Storage d</u>										
1	4.0^{a}	0.3	1.6^{a}	1.8^{b}	1.8	1.1^{a}	1.4	1.2^{a}	2.0	0.1
3	3.6^{b}	0.0	1.4^{b}	1.9^{a}	1.8	0.8^{b}	1.5	1.1^{b}	2.0	0.1

^{abcd} Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 15 Continued.

Treatment	Sorghum	Gritty	Burnt	Card board	Heated Oil	Nutty	Painty	Rancid	Refrigerator Stale	Sour Dairy	Spoiled Putrid	WOF*
RMSE	0.41	0.367	0.08	0.30	0.35	0.10	0.17	0.15	0.32	0.10	0.08	0.51
P-values	*<0.0001*	*0.12*	*0.96*	*0.53*	*0.0001*	*0.14*	*0.10*	*0.13*	*0.0007*	*0.20*	*0.58*	*0.14*
<u>Treatment</u>												
Control	0.7[d]	1.4	0.0	0.9	1.2[ab]	0.0	0.2	0.2	0.8[a]	0.0	0.0	1.4
Rosemary	0.7[d]	1.5	0.1	0.7	0.9[bcd]	0.0	0.3	0.3	0.7[ab]	0.1	0.1	0.9
BHA/BHT	1.2[bc]	1.6	0.0	1.0	0.5[def]	0.0	0.1	0.1	0.4[bc]	0.0	0.1	0.7
0.125% High Tannin	0.5[d]	1.4	0.1	0.8	1.0[abc]	0.0	0.2	0.0	0.9[a]	0.0	0.0	1.0
0.25% High Tannin	1.0[cd]	1.7	0.0	0.7	0.9[bcde]	0.0	0.1	0.1	0.6[ab]	0.0	0.0	0.8
0.50% High Tannin	1.0[cd]	1.5	0.0	1.0	0.7[cdef]	0.0	0.1	0.1	0.4[bc]	0.1	0.1	0.7
0.75% High Tannin	1.5[ab]	1.8	0.1	0.7	0.3[f]	0.1	0.1	0.1	0.2[c]	0.0	0.0	0.6
0.125% Onyx	0.6[d]	1.5	0.0	0.7	1.3[a]	0.1	0.2	0.1	0.6[ab]	0.0	0.0	1.0
0.25% Onyx	0.6[d]	1.4	0.0	0.7	0.7[cde]	0.1	0.0	0.1	0.4[bc]	0.0	0.0	0.7
0.50% Onyx	1.4[abc]	2.0	0.0	0.7	0.5[def]	0.1	0.2	0.1	0.2[c]	0.1	0.0	0.5
0.75% Onyx	1.8[a]	1.8	0.1	0.7	0.5[ef]	0.1	0.0	0.1	0.2[c]	0.1	0.0	0.6
P-values	*0.34*	*0.01*	*<0.0001*	*0.10*	*<0.0001*	*0.11*	*0.13*	*0.42*	*<0.0001*	*0.65*	*0.16*	*0.16*
<u>Storage d</u>												
1	1.1	1.7[a]	0.1[a]	0.7	0.5[b]	0.1	0.1	0.1	0.3[b]	0.0	0.0	0.9
3	1.0	1.5[b]	0.0[b]	0.9	1.0[a]	0.0	0.2	0.1	0.7[a]	0.0	0.0	0.7

[abcdef] Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).
*Warmed-Over Flavor

Table 16. Chicken patties least squares means values for volatile, aromatic chemicals identified by the GC/MS for each treatment for Phase I. *High Tannin Sorghum

Code**	RMSE	Trt *P-values*	Control	0.02% BHA/BHT	0.20% Rosemary	0.125% HTS*	0.25% HTS	0.50% HTS	0.75% HTS	0.125% Onyx	0.25% Onyx	0.50% Onyx	0.75% Onyx
C1	47612.5	*0.08*	113351	4945	105993	127214	74747	56511	41912	186170	121183	63570	19051
C2	20708.8	*0.01*	58240[ab]	0[c]	0[c]	45950[abc]	0[c]	2084[c]	0[c]	87486[a]	35263[bc]	7913[c]	0[c]
C4	28670.6	*0.70*	55559	2996	20254	22807	45831	20482	11686	9677	0	20590	10480
C5	41562.6	*0.74*	0	4862	57684	53715	53301	7955	0	21116	0	32158	4737
C7	2763.8	*0.62*	0	0	0	5340	0	0	0	2724	2061	0	0
C14	3723.2	*0.50*	0	0	0	0	0	0	5385	0	0	7433	0
C20	6641.9	*0.47*	8126	0	0	4838	0	0	4568	11233	0	12043	0
C21	900.6	*0.50*	0	1344	0	0	0	0	0	0	0	1518	1204
C23	7367.3	*0.67*	2665	0	0	8531	0	0	0	6208	0	0	13007
C26	21469.3	*0.56*	0	2149	0	26888	0	0	32132	3319	34325	0	0
C27	9052.8	*0.71*	0	0	0	7972	2275	0	12704	14541	8402	7178	3276
C38	29912.3	*0.34*	86369	4717	34616	66649	33689	31785	30022	32339	41176	13525	66092
C39	28973.7	*0.55*	60174	18802	57486	82018	54043	44775	20265	49912	33216	27745	29484
C40	22145.1	*0.09*	40927	0	33589	40984	41694	0	38354	65921	0	0	0
C41	11915.4	*0.46*	0	13693	3395	17798	21511	0	0	4224	17730	0	0
C42	12784.1	*0.24*	5457	8591	15674	2343	1259	31085	8238	11039	23901	35033	10510
C43	1261.3	*0.50*	2779	0	0	0	1330	0	0	0	0	0	0
C44	32599.1	*0.15*	58698	23561	16213	112388	53657	0	17383	16734	16801	58045	23010
C46	2397.0	*0.79*	0	0	3379	2357	0	2718	0	1545	0	1132	2183
C52	412350.3	*0.51*	3341	981061	24774	107403	1283	9071	55439	18356	9274	48079	4246
C53	6624.3	*0.02*	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]	16952[a]	0[b]	0[b]	18460[a]	23379[a]
C55	1664.5	*0.50*	0	0	0	2503	0	0	0	0	0	0	3257
C59	15879.0	*0.65*	8324	0	32406	5232	0	4480	0	12903	0	0	0

Table 16 Continued.

Code**	RMSE	Trt *P-values*	Control	0.02% BHA/BHT	0.20% Rosemary	0.125% HTS	0.25% HTS	0.50% HTS	0.75% HTS	0.125% Onyx	0.25% Onyx	0.50% Onyx	0.75% Onyx
C60	723.4	*0.50*	0	0	0	1103	0	0	0	1405	0	0	0
C62	49572.2	*0.61*	0	0	89770	0	65439	0	0	0	0	0	0
C66	3563.1	*0.14*	0	0	5581	10568	0	0	0	0	5133	0	0
C68	8177.3	*0.009*	0^{c}	0^{c}	0^{c}	40072^{a}	0^{c}	0^{c}	0^{c}	19039^{b}	0^{c}	0^{c}	0^{c}
C70	19366.8	*0.07*	17469	19532	31493	52768	76491	21951	5818	43205	9743	14123	9329
C72	8653.3	*0.38*	22929	0	0	3794	2492	0	991	1354	1492	0	0
C73	73631.0	*0.56*	0	0	69059	89576	29003	12412	0	148542	0	6295	4306
C75	22296.8	*0.07*	76307	0	25891	65613	32274	16055	21591	5360	23400	2138	1947
C76	12412.7	*0.52*	0	0	893	27516	0	0	12595	788	0	0	4828
C81	29638.9	*0.23*	30421	0	12944	80249	26201	0	15342	54868	44449	0	0
C85	4428.6	*0.50*	0	0	0	9393	0	0	0	5470	0	0	0
C86	6685.8	*0.02*	8762^{b}	0^{b}	0^{b}	29049^{a}	12856^{b}	2452^{b}	3597^{b}	12749^{b}	0^{b}	0^{b}	0^{b}
C87	6521.8	*0.49*	0	0	8243	0	0	11739	7385	6068	0	0	9137
C89	4530.7	*0.50*	0	0	4129	7920	2991	0	0	8204	3168	0	0
C90	79327.1	*0.46*	145451	0	12327	11723	62220	0	163695	18983	46736	50830	0
C94	110822.8	*0.03*	442631^{a}	209329^{abc}	445246^{a}	331610^{ab}	248067^{ab}	0^{c}	127720^{bc}	309345^{ab}	215659^{abc}	92028^{bc}	151784^{bc}
C96	39326.5	*0.59*	6610	7699	6845	3168	23401	24773	87846	17177	20083	54836	39943
C104	443693.1	*0.50*	0	1040553	0	0	0	0	0	0	0	0	0
C105	11011136.0	*0.50*	0	2370906	2008	0	0	0	0	0	0	2161	0
C106	38004.9	*0.34*	0	12465	44888	68610	44654	20263	58412	38619	20177	31067	110087
C108	13949.1	*0.50*	15232	0	28159	0	14913	0	0	15505	0	13121	0
C110	14215.5	*0.14*	35338	0	28616	23759	32103	6103	5366	30129	19320	0	0
C111	11209.0	*0.003*	45458^{bc}	14324^{d}	62780^{ab}	79556^{a}	50976^{b}	14510^{d}	59237^{ab}	43012^{bc}	48074^{bc}	25123^{cd}	40124^{bc}

Table 16 Continued.

Code**	RMSE	Trt *P-values*	Control	0.02% BHA/BHT	0.20% Rosemary	0.125% HTS	0.25% HTS	0.50% HTS	0.75% HTS	0.125% Onyx	0.25% Onyx	0.50% Onyx	0.75% Onyx
C116	7198.3	*0.50*	0	10773	4028	0	0	0	0	0	0	0	14270
C117	12099.3	*0.20*	25797	0	17909	14304	16333	1896	0	12892	1719	2707	32695
C118	24372.4	*0.56*	0	19812	34894	13006	0	3707	23624	41012	32001	0	38687
C121	14851.7	*0.69*	0	0	12342	16724	17766	0	0	21613	17936	0	9906
C127	4228.8	*0.97*	2913	2559	3040	3374	3702	1824	0	2592	2120	0	5318
C128	1742.3	*0.35*	1682	0	2654	0	2555	0	0	0	1686	0	3743
C133	21469.3	*0.56*	0	2149	0	26888	0	0	32132	3319	34325	0	0
C134	9876.8	*0.71*	12165	0	9642	0	15341	0	4258	0	0	0	0
C135	2427.9	*0.50*	0	0	4067	0	0	0	0	0	0	0	4413
C137	2867.9	*0.007*	3237^{b}	3110^{b}	0^{b}	15407^{a}	0^{b}	0^{b}	4552^{b}	0^{b}	0^{b}	0^{b}	0^{b}
C139	556257.7	*0.80*	1128393	529845	1185903	625479	1084606	608226	762477	565048	1051408	548380	317262
C140	8917.9	*0.56*	0	0	19742	0	0	0	0	0	0	5208	0
C142	1632.6	*0.26*	1149	3331	4593	1596	1684	1735	1780	0	984	3801	3585
C143	1133.8	*0.23*	581	2662	0	0	1851	1218	1273	1071	0	2597	0
C145	6113.0	*0.50*	0	0	0	0	0	0	0	4488	0	0	14072
C146	38147.2	*0.09*	0	0	0	0	0	0	11842	15322	47871	81623	122270
C147	81101.0	*0.70*	106985	0	162785	37264	34377	64418	55484	28020	26013	0	23871
C148	113447.7	*0.72*	59079	71466	180864	60826	74416	120336	148648	220561	51907	39372	0
C149	22959.5	*0.17*	12843	0	19238	41435	15014	2225	11734	70258	0	0	0
C152	277269.8	*0.08*	511296	234096	686557	930458	1195856	240475	688209	854916	369074	393913	850243
C154	19152.7	*0.002*	56383^{ab}	1785^{c}	11663^{c}	87168^{a}	57498^{ab}	22617^{bc}	32300^{bc}	91940^{a}	97404^{a}	10346^{c}	9503^{c}
C155	2407.9	*0.66*	4852	0	2637	1492	0	1648	1215	0	0	1980	900
C159	96216.2	*0.52*	179732	111068	173344	236301	137804	45062	282615	221491	121975	124429	191600

Table 16 Continued.

Code**	RMSE	Trt *P-values*	Control	0.02% BHA/BHT	0.20% Rosemary	0.125% HTS	0.25% HTS	0.50% HTS	0.75% HTS	0.125% Onyx	0.25% Onyx	0.50% Onyx	0.75% Onyx
C162	42851.3	*0.16*	90671	0	23570	119288	65298	43469	61511	94783	109948	16536	14696
C163	47647.5	*0.46*	58460	8121	0	106368	29801	39110	56709	31068	100927	39450	15868
C165	6161.9	*0.69*	0	0	9067	7459	7513	2915	0	0	0	0	0
C166	36313.4	*0.41*	66269	0	54197	76323	31432	12672	13172	19593	52688	1761	4993
C171	6851.3	*0.39*	2047	1897	9944	1068	11885	0	14065	8063	3453	13423	3369
C172	4924.6	*0.50*	609	0	0	0	0	11608	0	0	2311	0	0
C174	5774.4	*0.50*	0	0	0	10814	0	0	0	9305	0	0	0
C175	148919.7	*0.51*	145576	40685	310832	164361	325977	42972	67151	178890	57653	52911	84947
C176	4841.4	*0.80*	5328	0	1787	3797	5177	0	3619	6691	0	0	0
C177	20390.5	*0.49*	28659	14702	15791	28137	10635	5347	37691	47624	22452	5154	2846
C178	12373.5	*0.64*	0	0	0	15056	14915	0	0	14738	14145	5676	18149
C179	18905.2	*0.59*	0	0	0	0	0	0	0	0	38757	0	18004
C181	10515.4	*0.62*	4134	2414	16883	18047	0	2654	0	0	3113	0	0
C182	6406.3	*0.11*	19440	0	2723	13349	0	0	0	0	0	0	6806
C183	2962.9	*0.26*	4609	0	0	7293	3284	0	0	0	3662	0	0
C185	39093.1	*0.008*	182880^{a}	0^{d}	18604^{cd}	104430^{abc}	123749^{ab}	43758^{bcd}	58541^{bcd}	128408^{ab}	98431^{abc}	0^{d}	0^{d}

^{abcde} Least squares means within a row and treatment with the same letter are not different ($P \geq 0.05$).
*High Tannin Sorghum
**Code number represents the volatile, aromatic chemical compound name and classification identified by the GC/MS found in Table 5.

Table 17. Chicken patties least squares means values for volatile, aromatic compounds identified by the GC/MS for each treatment for Phase I.

Treatment	Alcohols	Aldehydes	Alkanes	Alkenes	Benzenes	Carboxylic Acids	Furans	Ketones	Phenols	Sulfurs
RMSE	90634.7	979817.1	31374.1	7198.3	166006.3	116353.1	21682.1	47163.2	166065.0	39402.8
Trt *P-values*	*0.21*	*0.20*	*0.36*	*0.50*	*0.74*	*0.35*	*0.02*	*0.12*	*<0.0001*	*0.12*
Control	241499	3228947	32123	0	152186	311476	29009[b]	89950	5388[b]	6477
0.02% BHA/BHT	55926	1201828	25481	10773	48383	10783	19532[b]	23561	4394415[a]	15796
0.20% Rosemary	218966	3247649	60596	4028	317676	198920	31493[b]	146631	36726[b]	54647
0.125% HTS*	340977	3335353	79708	0	167529	156458	81817[a]	123916	108471[b]	76359
0.25% HTS	236405	3426756	28685	0	349378	128248	90677[a]	121588	13168[b]	51515
0.50% HTS	121610	1296453	10093	0	67744	104745	24403[b]	16219	9071[b]	24715
0.75% HTS	153305	2401168	29391	0	172224	277161	9414[b]	25758	69504[b]	80762
0.125% Onyx	289365	3260935	58341	0	215876	80545	55954[ab]	37058	26419[b]	46855
0.25% Onyx	187931	2498665	55084	0	125607	173675	9743[b]	18293	12727[b]	59918
0.50% Onyx	117295	1404450	7656	0	196802	98084	14123[b]	58045	63663[b]	54459
0.75% Onyx	149170	1661091	73602	14270	261231	44151	9329[b]	35403	7615[b]	157236
P-values	*0.76*	*0.59*	*0.01*	*0.11*	*0.06*	*0.07*	*0.03*	*0.29*	*0.63*	*0.13*
Storage d										
1	185976	2335865	62969[a]	5286	116583	94051	45335[a]	52117	448779	43568
3	198105	2566552	20805[b]	0	260623	193993	22936[b]	74505	414341	70747

[ab] Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).
*High Tannin Sorghum

Table 18. Pre-cooked pork pizza toppings product formulation for Phase II.

Ingredients	Control	Rosemary	High Tannin	Onyx
Ground Pork 28% fat	72.81%	72.66%	72.43%	72.43%
Ground Pork 58% fat	22.16%	22.11%	22.04%	22.04%
Water	3.13%	3.13%	3.13%	3.13%
Salt	1.90%	1.90%	1.90%	1.90%
Antioxidant	0.00%	0.20%	0.50%	0.50%

Table 19. Ground chicken product formulation for Phase II.

Ingredients	Control	Rosemary	High Tannin	Onyx
Ground Dark Meat Chicken	94.20%	94.00%	94.00%	94.00%
Water	4.45%	4.45%	4.15%	4.15%
Salt	0.35%	0.35%	0.35%	0.35%
Antioxidant	0.00%	0.20%	0.50%	0.50%
Native Rice Starch	1.00%	1.00%	1.00%	1.00%

Table 20. Pre-cooked pork pizza toppings least squares means by treatment for raw percent moisture, lipid and cooking yield for Phase II.

Effect	Cook Yield %	Moisture, %	Lipid, %
RMSE	3.851	1.599	1.197
Treatment			
P-values	*0.63*	*0.36*	*0.02*
Control	47.71	52.24	30.98[b]
Rosemary	51.87	53.29	30.37[b]
0.50% High Tannin	49.27	51.75	33.89[a]
0.50% Onyx	50.03	50.84	33.87[a]

[ab]Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 21. Pre-cooked pork pizza toppings least squares means by treatment and frozen storage time for cooked pH, objective color and subjective color attributes and TBARS values for Phase II.

		Subjective	CIE Color Space Values			
Effect	pH	Color	*L**	*a**	*b**	TBARS
RMSE	0.086	1.864	3.782	0.656	1.998	0.303
Treatment						
P-values	*0.43*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Control	6.28	3.3	65.31[a]	1.14[c]	13.95[a]	3.84[a]
Rosemary	6.27	4.4	61.18[b]	2.38[b]	9.83[b]	0.68[d]
0.50% High Tannin	6.25	7.2	58.94[c]	3.22[a]	10.31[b]	1.27[b]
0.50% Onyx	6.28	9.1	55.40[d]	3.45[a]	8.55[c]	1.05[c]
Storage Month						
P-values	*<0.0001*	*0.09*	*0.0001*	*<0.0001*	*0.002*	*<0.0001*
0	6.35[a]	6.1	62.16[a]	3.12[a]	10.30[bc]	1.11[e]
3	6.19[c]	6.1	58.03[c]	2.71[b]	9.83[c]	1.38[d]
6	6.34[a]	5.4	60.29[ab]	2.32[c]	10.68[bc]	1.67[c]
9	6.27[b]	6.1	61.05[ab]	2.39[c]	11.72[a]	1.96[b]
12	6.20[c]	6.2	59.51[bc]	2.19[c]	10.77[b]	2.44[a]
Treatment x Storage Month	*0.33*	*0.49*	*0.28*	*0.02*	*0.03*	*<0.0001*

[abcde]Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 22. Flavor and basic taste descriptive attribute least squares means for pre-cooked pork pizza toppings by treatment and frozen storage time for Phase II.

Treatment	Pork Identity	Brown/ Roasted	Fat Like	Metallic	Astringent	Sweet	Sour	Salty	Bitter	Umami
RMSE	0.16	0.29	0.17	0.15	0.20	0.24	0.18	0.29	0.17	0.36
P-values	*0.03*	*<0.0001*	*0.08*	*0.11*	*0.22*	*0.08*	*0.09*	*0.04*	*0.01*	*0.002*
<u>Treatment</u>										
Control	5.3^{b}	1.1^{c}	3.1	2.2	1.9	1.9	2.1	3.5^{a}	2.1^{a}	1.4^{c}
Rosemary	5.4^{a}	1.2^{c}	3.0	2.1	1.9	2.0	1.9	3.3^{b}	1.9^{b}	1.5^{bc}
0.50% High Tannin	5.3^{a}	1.5^{b}	3.0	2.1	1.9	2.1	2.0	3.5^{a}	2.0^{a}	1.6^{ab}
0.50% Onyx	5.4^{a}	1.8^{a}	3.0	2.1	2.0	2.0	2.0	3.5^{a}	2.0^{a}	1.7^{a}
P-values	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.09*	*<0.0001*	*<0.0001*	*<0.0001*
<u>Storage Month</u>										
0	5.4^{c}	1.2^{c}	2.9^{d}	2.1^{b}	1.8^{b}	2.0^{c}	2.0	3.0^{d}	2.0^{b}	1.7^{a}
3	4.8^{e}	0.8^{d}	2.2^{e}	1.8^{c}	1.6^{c}	1.5^{d}	1.7	2.8^{e}	1.5^{c}	1.6^{a}
6	5.7^{a}	1.7^{ab}	3.0^{c}	2.1^{b}	2.1^{a}	2.3^{a}	2.1	3.8^{b}	2.2^{a}	1.7^{a}
9	5.6^{b}	1.7^{a}	3.2^{b}	2.3^{a}	1.9^{b}	2.2^{ab}	2.1	3.5^{c}	2.2^{a}	1.7^{a}
12	5.0^{d}	1.5^{b}	3.9^{a}	2.4^{a}	2.2^{a}	2.1^{bc}	2.0	4.1^{a}	2.2^{a}	1.1^{b}
Treatment x Storage Month	*0.01*	*0.14*	*0.37*	*0.55*	*0.77*	*0.90*	*0.10*	*0.10*	*0.04*	*0.21*

[abcde] Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 22 Continued.

Treatment	Sorghum	Gritty	Cardboard	Fishy	Floral	Green	Rosemary	Heated Oil
RMSE	0.30	0.17	0.17	0.15	0.11	0.19	0.23	0.31
P-values	*<0.0001*	*0.0001*	*<0.0001*	*0.0006*	*<0.0001*	*<0.0001*	*0.0001*	*<0.0001*
Treatment								
Control	0.5^{c}	0.4^{c}	0.8^{a}	0.2^{a}	0.0^{b}	0.1^{b}	0.0^{c}	2.2^{a}
Rosemary	0.5^{c}	0.4^{c}	0.6^{c}	0.0^{c}	0.3^{a}	0.4^{a}	0.1^{a}	1.8^{c}
0.50% High Tannin	1.1^{b}	0.7^{b}	0.7^{ab}	0.1^{bc}	0.0^{b}	0.1^{b}	0.0^{bc}	2.0^{b}
0.50% Onyx	1.8^{a}	0.8^{a}	0.7^{b}	0.1^{ab}	0.0^{b}	0.1^{b}	0.1^{b}	2.1^{a}
P-values	*<0.0001*	*<0.0001*	*<0.0001*	*0.0009*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Storage Month								
0	0.7^{c}	0.8^{a}	0.5^{c}	0.0^{c}	0.3^{a}	0.2^{b}	0.0^{b}	1.4^{d}
3	1.0^{b}	0.5^{c}	0.8^{b}	0.1^{bc}	0.1^{b}	0.2^{bc}	0.2^{a}	1.2^{d}
6	1.4^{a}	0.8^{a}	1.2^{a}	0.2^{a}	0.1^{b}	0.5^{a}	0.3^{a}	2.5^{b}
9	1.0^{b}	0.6^{b}	0.6^{c}	0.2^{a}	0.0^{c}	0.0^{d}	0.2^{a}	2.2^{c}
12	0.7^{c}	0.2^{d}	0.5^{c}	0.1^{ab}	0.0^{c}	0.1^{cd}	0.2^{a}	2.7^{a}
Treatment x Storage Month	*0.01*	*0.17*	*0.002*	*0.08*	*<0.0001*	*0.005*	*0.19*	*0.85*

[abc] Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 22 Continued.

Treatment	Painty	Rancid	Refrigerator Stale	Warmed Over Flavor	Nutty	Vinegary	Burning
RMSE	0.26	0.20	0.16	0.22	0.09	0.11	0.16
P-values	*<0.0001*	*<0.0001*	*<0.0001*	*0.0005*	*0.16*	*0.20*	*0.01*
<u>Treatment</u>							
Control	1.0[a]	0.4[a]	0.5[a]	1.0[a]	0.0	0.1	0.2[b]
Rosemary	0.2[c]	0.1[b]	0.2[c]	0.8[b]	0.1	0.6[a]	0.2[b]
0.50% High Tannin	0.4[b]	0.1[b]	0.4[b]	0.9[b]	0.1	0.1	0.2[ab]
0.50% Onyx	0.4[b]	0.1[b]	0.3[bc]	0.8[b]	0.1	0.1	0.3[a]
P-values	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0004*	*<0.0001*
<u>Storage Month</u>							
0	0.0[d]	0.1[c]	0.1[c]	0.5[c]	0.2[a]	0.0[b]	0.1[b]
3	0.1[d]	0.0[c]	0.2[c]	0.5[c]	0.0[bc]	0.1[b]	0.0[c]
6	0.7[b]	0.1[bc]	0.1[c]	1.7[a]	0.0[bc]	0.1[b]	0.2[b]
9	1.2[a]	0.2[c]	0.4[b]	0.5[c]	0.0[c]	0.4[a]	0.6[a]
12	0.5[c]	0.5[a]	0.9[a]	1.3[b]	0.1[b]	0.1[b]	0.2[b]
Treatment x Storage Month	*<0.0001*	*<0.0001*	*0.02*	*0.39*	*0.17*	*0.0001*	*0.18*

[abcd] Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 23. Least squares means values for volatile, aromatic chemicals identified by the GC/MS for pre-cooked pork pizza toppings by each treatment for Phase II.

Code*	Volatile, Aromatic Chemical	RMSE	Trt *P-values*	Control	Rosemary	0.50% HTS	0.50% Onyx
C1	(E)-2-Decenal	112089.1	*0.71*	106319	72900	77967	57393
C2	(E)-2-Heptenal	138796.8	*0.09*	98450	23912	162454	98962
C4	(E)-2-Nonenal	17641.3	*0.17*	2226	2125	15269	3849
C6	(E,E)-2,4-Decadienal	297847.0	*0.67*	155016	72792	205269	182842
C7	(E,E)-2,4-Heptadienal	30561.5	*0.03*	22321^{ab}	4677^{b}	32791^{a}	672^{b}
C8	(E,Z)-2,4-Decadienal	37281.1	*0.18*	9363	0	17398	31125
C10	1,2,3,4-Tetrahydro-Naphthalene	2908.9	*0.35*	0	784	1669	0
C11	1,2,3,4-Tetramethyl-Benzene	7668.0	*0.55*	0	3457	1710	0
C12	1,2,3,5-Tetramethyl-Benzene	7668.0	*0.55*	0	3457	1710	0
C13	1,2,3-Trimethyl-Benzene	10536.9	*0.51*	308	748	5455	308
C24	1-Ethyl-3,5-Dimethyl-Benzene	2544.3	*0.06*	0	0	2264	389
C25	1-Ethyl-3-Methyl-Benzene	2847.7	*0.08*	0	0	2303	0
C26	1-Heptanol	2211.0	*0.03*	2106^{a}	0^{b}	0^{b}	0^{b}
C29	1-Methoxy-4-(1-E-Propenyl)Benzene	1798.7	*0.50*	1012	603	0	298
C30	1-Methoxy-4-(1-Propenyl)-Benzene	53300.5	*0.46*	3092	3150	30033	2653
C31	1-Methoxy-4-(1-Z-Propenyl)Benzene	1081.3	*0.43*	575	0	66	0
C32	1-Methoxy-4-(2-Propenyl)-Benzene	53300.5	*0.46*	3092	3150	30033	2653
C34	1-Methyl-3-(1-Methylethyl)-Benzene	3561.8	*0.77*	0	784	1306	456
C35	1-Methyl-4-(1-Methylethyl)-Benzene	28224.4	*0.54*	0	12321	8247	0
C36	1-Methyl-4-(1-Methylpropyl)-Benzene	7826.3	*0.12*	113	113	6163	113
C38	1-Octanol	24806.7	*0.78*	8574	5055	14412	7255
C39	1-Octen-3-ol	72096.9	*0.05*	30618^{ab}	6454^{b}	82837^{a}	28085^{ab}

Table 23 Continued.

Code*	Volatile, Aromatic Chemical	RMSE	Trt *P-values*	Control	Rosemary	0.50% HTS	0.50% Onyx
C40	1-Pentanol	16622.1	*0.03*	13048[ab]	5125[b]	23288[a]	7579[b]
C42	2-(Hexyloxy)Ethanol	97075.9	*0.20*	0	0	66354	4129
C44	2,3-Octanedione	54932.9	*0.30*	18809	25398	54993	22204
C47	2,4-Heptadienal	6361.4	*0.09*	963	186	5602	186
C49	2,4-Nonadienal	75341.2	*0.02*	90062[a]	21064[b]	55734[ab]	2430[b]
C52	2,6-Bis(1,1-Dimethylethyl)-4-Methyl-Phenol	36452.8	*0.65*	19863	32856	15840	23106
C56	2-Dodecenal	47215.5	*0.06*	0	41450	0	0
C57	2-Ethyl-1,4-Dimethyl-Benzene	2544.3	*0.06*	0	0	2264	389
C59	2-Heptanone	6178.8	*0.29*	2351	2737	4699	59
C61	2-Methoxy-Phenol	18167.3	*0.59*	767	8111	9866	6372
C69	2-Octenal	133702.4	*0.45*	133096	62099	112013	68932
C70	2-Pentyl-Furan	31178.9	*0.09*	1801	28512	16080	2048
C72	3,5-Octadien-2-one	47240.7	*0.31*	17659	1725	26242	35133
C73	3-Dodecen-1-al	62862.4	*0.45*	15901	41777	5154	29834
C75	3-Ethyl-Benzaldehyde	49423.4	*0.58*	27327	8346	33979	22821
C76	3-Methyl-Butanal	7086.1	*0.63*	2341	2390	0	0
C80	4-Ethyl-1,2-Dimethyl-Benzene	2544.3	*0.06*	0	0	2264	389
C86	5-Pentyl-2(5H)Furanone	42574.0	*0.60*	28518	13746	23325	8280
C87	6,7-Dodecanedione	33173.5	*0.51*	1508	16422	0	734
C90	Acetic Acid	21161.8	*0.02*	3811[b]	26112[a]	9243[b]	3526[b]
C93	Azulene	7253.8	*<0.0001*	200[b]	200[b]	200[b]	14558[a]
C94	Benzaldehyde	151788.9	*0.006*	48704[b]	217677[a]	127452[ab]	13901[b]

Table 23 Continued.

Code*	Volatile, Aromatic Chemical	RMSE	Trt *P-values*	Control	Rosemary	0.50% HTS	0.50% Onyx
C96	Benzeneacetaldehyde	4685.6	*0.13*	112	1073	1090	4234
C98	Benzenemethanol	9840.9	*0.76*	2911	2333	4969	5777
C99	Benzyl Alcohol	31023.7	*0.44*	1098	4881	1098	17988
C101	Beta-Myrcene	10738.4	*0.52*	402	2706	6504	3552
C105	Butylated Hydroxy Toluene	22826.5	*0.33*	0	0	13031	0
C106	Carbon Disulfide	10803.8	*0.35*	206	2638	206	6786
C111	Decanal	12159.4	*0.41*	4400	6360	12038	8409
C112	Decane	17876.1	*0.33*	0	6532	10463	0
C116	dl-Limonene	229499.7	*0.22*	12733	118989	178077	35302
C117	Dodecanal	15187.7	*0.57*	597	2049	7611	393
C118	Dodecane	107623.9	*0.46*	4096	18671	64446	10494
C120	Estragole	23494.4	*0.11*	4517	23347	6813	19658
C122	Ethyl Ester Decanoic Acid	120577.9	*0.08*	23219	12535	115560	8408
C123	Ethyl Ester Dodecanoic Acid	30043.9	*0.11*	757	5440	25695	757
C124	Ethyl Ester Octanoic Acid	21792.5	*0.21*	2063	8841	16793	552
C125	Gamma-Terpinene	6406.8	*0.06*	0	0	5457	0
C127	Hentriacontane	1712.5	*0.87*	183	235	657	236
C130	Heptanal	45718.2	*0.19*	24156	25756	53709	17799
C133	Heptanol	2211.0	*0.03*	2106[a]	0[b]	0[b]	0[b]
C134	Heptenal	8610.0	*0.14*	92	1572	92	6918
C136	Hexadecanal	23881.8	*<0.0001*	0[b]	62245[a]	0[b]	0[b]
C137	Hexadecane	23659.2	*0.61*	2546	1237	11004	9962
C139	Hexanal	498586.6	*0.07*	825172	467445	671855	343285

Table 23 Continued.

Code*	Volatile, Aromatic Chemical	RMSE	Trt *P-values*	Control	Rosemary	0.50% HTS	0.50% Onyx
C140	Hexanoic Acid	11103.7	*<0.0001*	4248[bc]	35400[a]	11146[b]	548[c]
C145	Methyl-Benzene	27403.2	*0.60*	0	12355	2884	459
C146	Naphthalene	94270.1	*0.01*	2264[b]	2264[b]	2264[b]	103194[a]
C147	N-Caproic Acid Vinyl Ester	33646.7	*0.18*	27206	4369	20631	3088
C150	Nonacosane	794.2	*0.79*	319	164	10	167
C152	Nonanal	276831.6	*0.02*	164785[b]	334264[ab]	479622[a]	229516[b]
C154	Nonenal	86731.0	*0.64*	75990	37710	63685	44936
C156	Octadecanal	2920.8	*<0.0001*	0[b]	0[b]	5804[a]	0[b]
C158	Octamethyl-Cyclotetrasiloxane	11967.1	*0.43*	3648	3634	10292	6345
C159	Octanal	77362.5	*0.20*	54641	61052	108437	51175
C166	Pentanal	33027.3	*0.49*	16895	9977	18348	29433
C171	Phenol	25668.5	*0.50*	897	897	13833	2846
C172	Phenyl Acetaldehyde	2399.5	*0.29*	0	0	371	1498
C173	Phenyl-Oxirane	1213.8	*0.32*	0	0	0	698
C175	Styrene	69544.8	*0.12*	21466	81335	74400	56171
C177	Tetradecanal	11618.1	*0.19*	10605	5246	6613	731
C179	Thiourea	7856.9	*0.73*	714	3910	2392	1408
C184	Undecane	39460.1	*0.39*	0	22324	10264	0
C185	Undecenal	12572.2	*0.07*	10434	0	0	0

*Code number represents the volatile, aromatic chemical compound name and classification identified by the GC/MS found in Table 5.

Table 24. Least squares means values for volatile, aromatic chemicals identified by the GC/MS for pre-cooked pork pizza toppings by each frozen storage month for Phase II.

Code*	Volatile, Aromatic Chemical	RMSE	Month *P-values*	0	3	6	9	12	Month*Trt *P-values*
C1	(E)-2-Decenal	112089.1	*0.0001*	1184[b]	265504[a]	86846[b]	13676[b]	26014[b]	*0.51*
C2	(E)-2-Heptenal	138796.8	*0.01*	4844[b]	238641[a]	100242[b]	51143[b]	84852[b]	*0.92*
C4	(E)-2-Nonenal	17641.3	*0.17*	4383	19879	2499	2576	0	*0.11*
C6	(E,E)-2,4-Decadienal	297847.0	*0.002*	1706[b]	559679[a]	141568[b]	26942[b]	40005[b]	*0.79*
C7	(E,E)-2,4-Heptadienal	30561.5	*0.002*	0[b]	57478[a]	15203[b]	547[b]	2348[b]	*0.14*
C8	(E,Z)-2,4-Decadienal	37281.1	*0.01*	0[b]	58358[a]	1637[b]	3660[b]	8586[b]	*0.08*
C10	1,2,3,4-Tetrahydro-Naphthalene	2908.9	*0.24*	0	0	0	1094	2176	*0.78*
C11	1,2,3,4-Tetramethyl-Benzene	7668.0	*0.28*	0	0	0	1176	5713	*0.64*
C12	1,2,3,5-Tetramethyl-Benzene	7668.0	*0.28*	0	0	0	1176	5713	*0.64*
C13	1,2,3-Trimethyl-Benzene	10536.9	*0.53*	0	1540	6434	0	551	*0.55*
C24	1-Ethyl-3,5-Dimethyl-Benzene	2544.3	*0.08*	0	0	0	1152	2385	*0.35*
C25	1-Ethyl-3-Methyl-Benzene	2847.7	*0.17*	0	0	0	558	2414	*0.14*
C26	1-Heptanol	2211.0	*0.20*	0	2237	0	361	0	*0.10*
C29	1-Methoxy-4-(1-E-Propenyl)Benzene	1798.7	*0.47*	0	811	0	427	1144	*0.50*
C30	1-Methoxy-4-(1-Propenyl)-Benzene	53300.5	*0.54*	0	11237	32832	1169	3420	*0.56*
C31	1-Methoxy-4-(1-Z-Propenyl)Benzene	1081.3	*0.51*	0	0	0	185	649	*0.61*
C32	1-Methoxy-4-(2-Propenyl)-Benzene	53300.5	*0.54*	0	11237	32832	1169	3420	*0.56*
C34	1-Methyl-3-(1-Methylethyl)-Benzene	3561.8	*0.34*	1089	0	0	0	2423	*0.63*
C35	1-Methyl-4-(1-Methylethyl)-Benzene	28224.4	*0.24*	0	0	0	5418	21947	*0.66*
C36	1-Methyl-4-(1-Methylpropyl)-Benzene	7826.3	*0.77*	0	566	4030	1766	1766	*0.89*
C38	1-Octanol	24806.7	*0.21*	2443	19775	18720	1376	1806	*0.59*
C39	1-Octen-3-ol	72096.9	*0.32*	0	48670	52838	28428	55055	*0.93*
C40	1-Pentanol	16622.1	*0.04*	1773[b]	22830[a]	10167[ab]	7452[ab]	19077[a]	*0.73*

Table 24 Continued.

Code*	Volatile, Aromatic Chemical	RMSE	Month *P-values*	0	3	6	9	12	Month*Trt *P-values*
C42	2-(Hexyloxy)Ethanol	97075.9	*0.55*	0	0	4756	42788	45826	*0.76*
C44	2,3-Octanedione	54932.9	*0.22*	3099	36068	19553	38790	54245	*0.64*
C47	2,4-Heptadienal	6361.4	*0.68*	0	3161	3340	972	1198	*0.72*
C49	2,4-Nonadienal	75341.2	*0.001*	0^{b}	151872^{a}	37388^{b}	10003^{b}	12349^{b}	*0.09*
C52	2,6-Bis(1,1-Dimethylethyl)-4-Methyl-Phenol	36452.8	*0.05*	1165^{b}	25081^{ab}	46559^{a}	27277^{ab}	14499^{b}	*0.25*
C56	2-Dodecenal	47215.5	*0.16*	0	49738	0	0	1897	*0.07*
C57	2-Ethyl-1,4-Dimethyl-Benzene	2544.3	*0.08*	0	0	0	1152	2385	*0.35*
C59	2-Heptanone	6178.8	*0.16*	0	6507	2719	0	3081	*0.13*
C61	2-Methoxy-Phenol	18167.3	*0.10*	385	13936	16040	455	580	*0.45*
C69	2-Octenal	133702.4	*0.004*	4126^{c}	251013^{a}	119079^{b}	36331^{bc}	59627^{bc}	*0.51*
C70	2-Pentyl-Furan	31178.9	*0.03*	0^{b}	37664^{a}	22886^{ab}	0^{b}	0^{b}	*0.008*
C72	3,5-Octadien-2-one	47240.7	*0.02*	0^{b}	62477^{a}	34360^{ab}	1039^{b}	3073^{b}	*0.69*
C73	3-Dodecen-1-al	62862.4	*0.003*	0^{b}	110645^{a}	3717^{b}	0^{b}	1471^{b}	*0.65*
C75	3-Ethyl-Benzaldehyde	49423.4	*0.01*	500^{b}	70337^{a}	37422^{ab}	2716^{b}	4617^{b}	*0.81*
C76	3-Methyl-Butanal	7086.1	*0.55*	0	0	3124	0	3184	*0.45*
C80	4-Ethyl-1,2-Dimethyl-Benzene	2544.3	*0.08*	0	0	0	1152	2385	*0.35*
C86	5-Pentyl-2(5H)Furanone	42574.0	*0.008*	0^{b}	71078^{a}	16122^{b}	0^{b}	5136^{b}	*0.73*
C87	6,7-Dodecanedione	33173.5	*0.51*	0	0	0	5022	19913	*0.59*
C90	Acetic Acid	21161.8	*0.006*	450^{b}	37955^{a}	7942^{b}	4402^{b}	2616^{b}	*0.09*
C93	Azulene	7253.8	*<0.0001*	0^{b}	999^{b}	0^{b}	2757^{b}	15191^{a}	*<0.0001*
C94	Benzaldehyde	151788.9	*<0.0001*	0^{b}	377321^{a}	97814^{b}	24286^{b}	10248^{b}	*0.001*
C96	BenzeneAcetaldehyde	4685.6	*0.67*	523	1762	699	3020	2132	*0.17*

Table 24 Continued.

Code*	Volatile, Aromatic Chemical	RMSE	Month *P-values*	0	3	6	9	12	Month*Trt *P-values*
C98	Benzenemethanol	9840.9	*0.09*	3197	5566	0	750	10475	*0.81*
C99	Benzyl Alcohol	31023.7	*0.53*	851	9368	19002	2110	0	*0.55*
C101	Beta-Myrcene	10738.4	*0.28*	0	2010	9010	1120	4314	*0.80*
C105	Butylated Hydroxy Toluene	22826.5	*0.49*	0	0	3012	13802	0	*0.64*
C106	Carbon Disulfide	10803.8	*0.06*	0	1029	0	0	11265	*0.31*
C111	Decanal	12159.4	*0.01*	461[b]	19385[a]	8342[ab]	816[b]	10005[ab]	*0.81*
C112	Decane	17876.1	*0.12*	0	0	5055	0	16594	*0.68*
C116	dl-Limonene	229499.7	*0.14*	4036	23280	70823	96134	237104	*0.89*
C117	Dodecanal	15187.7	*0.59*	2069	1965	9023	255	0	*0.54*
C118	Dodecane	107623.9	*0.32*	4008	27015	83095	3020	4996	*0.72*
C120	Estragole	23494.4	*0.0007*	0[b]	47746[a]	16204[b]	1593[b]	2376[b]	*0.27*
C122	Ethyl Ester Decanoic Acid	120577.9	*0.34*	0	83543	76825	0	39283	*0.68*
C123	Ethyl Ester Dodecanoic Acid	30043.9	*0.37*	0	21142	16655	3016	0	*0.71*
C124	Ethyl Ester Octanoic Acid	21792.5	*0.10*	0	17805	17506	0	0	*0.75*
C125	Gamma-Terpinene	6406.8	*0.32*	0	0	0	3024	4017	*0.41*
C127	Hentriacontane	1712.5	*0.29*	0	0	1168	706	0	*0.64*
C130	Heptanal	45718.2	*0.01*	6296[b]	77218[a]	27900[b]	4087[b]	36275[ab]	*0.59*
C133	Heptanol	2211.0	*0.20*	0	2237	0	361	0	*0.10*
C134	Heptenal	8610.0	*0.17*	0	8994	1849	0	0	*0.07*
C136	Hexadecanal	23881.8	*<0.0001*	0[b]	77807[a]	0[b]	0[b]	0[b]	*<0.0001*
C137	Hexadecane	23659.2	*0.17*	0	6187	21504	1636	1610	*0.76*
C139	Hexanal	498586.6	*0.0005*	175305[c]	1170469[a]	462480[bc]	250014[c]	826427[ab]	*0.92*
C140	Hexanoic Acid	11103.7	*<0.0001*	4723[b]	47412[a]	0[b]	3045[b]	8998[b]	*<0.0001*

Table 24 Continued.

Code*	Volatile, Aromatic Chemical	RMSE	Month *P-values*	0	3	6	9	12	Month*Trt *P-values*
C145	Methyl-Benzene	27403.2	*0.28*	0	0	0	0	20318	*0.70*
C146	Naphthalene	94270.1	*0.25*	1910	78832	52407	4334	0	*0.33*
C147	N-Caproic Acid Vinyl Ester	33646.7	*0.13*	5128	34464	24699	4826	0	*0.66*
C150	Nonacosane	794.2	*0.35*	0	48	0	193	584	*0.71*
C152	Nonanal	276831.6	*0.03*	123847^{c}	495735^{a}	373859^{ab}	181153^{bc}	335640^{abc}	*0.94*
C154	Nonenal	86731.0	*0.01*	1589^{c}	138338^{a}	79014^{ab}	16373^{bc}	42586^{bc}	*0.63*
C156	Octadecanal	2920.8	*<0.0001*	0^{b}	7255^{a}	0^{b}	0^{b}	0^{b}	*<0.0001*
C158	Octamethyl-Cyclotetrasiloxane	11967.1	*0.29*	6349	11936	3207	543	7864	*0.14*
C159	Octanal	77362.5	*0.10*	27025	117879	82261	41669	75300	*0.89*
C166	Pentanal	33027.3	*0.05*	748^{b}	42742^{a}	18950^{ab}	4628^{b}	26249^{ab}	*0.73*
C171	Phenol	25668.5	*0.36*	0	4485	18163	0	443	*0.64*
C172	Phenyl Acetaldehyde	2399.5	*0.37*	0	0	1429	0	1063	*0.82*
C173	Phenyl-Oxirane	1213.8	*0.49*	733	0	0	168	0	*0.65*
C175	Styrene	69544.8	*0.002*	0^{c}	128717^{a}	86076^{ab}	21220^{c}	55703^{bc}	*0.62*
C177	Tetradecanal	11618.1	*0.001*	0^{b}	22537^{a}	6457^{b}	0^{b}	0^{b}	*0.02*
C179	Thiourea	7856.9	*0.29*	0	652	0	4531	5348	*0.88*
C184	Undecane	39460.1	*0.30*	0	1654	7775	0	30379	*0.84*
C185	Undecenal	12572.2	*0.36*	0	0	0	6407	7057	*0.48*

[abc] Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

*Code number represents the volatile, aromatic chemical compound name and classification identified by the GC/MS found in Table 5.

Table 25. Least squares means values for volatile, aromatic compounds identified by the GC/MS for pre-cooked pork pizza toppings by each treatment and frozen storage month for Phase II.

Treatment	Alcohols	Aldehydes	Alkanes	Alkenes	Benzenes	Carboxylic Acids	Furans	Ketones	Phenols	Sulfurs
RMSE	180783.0	1779758.0	191722.9	248158.6	217867.5	201434.8	68653.0	87040.8	64855.3	0.4
P-values	*0.06*	*0.46*	*0.41*	*0.26*	*0.25*	*0.12*	*0.61*	*0.54*	*0.38*	*0.40*
Treatment										
Control	56295	1857986	6942	17077	27673	56045	28677	40109	24846	584
Rosemary	15669	1526971	26843	122923	161082	87436	40615	46064	66366	6212
0.50% High Tannin	195890	2256482	120124	194852	133266	193806	37762	85289	35820	2262
0.50% Onyx	48265	1207234	23635	53289	186596	11618	8686	57911	49487	7857
P-values	*0.59*	*0.0006*	*0.37*	*0.16*	*0.08*	*0.12*	*0.01*	*0.12*	*0.01*	*0.009*
Storage Month										
0	6045	354082[b]	11089	4036	7570	10301	0[b]	3099	1549[c]	0[b]
3	92740	4148381[a]	21478	40748	252641	216018	100533[a]	101822	72765[ab]	0[b]
6	93013	1728183[b]	146860	73835	193050	143627	39007[ab]	56632	90937[a]	0[b]
9	80180	680968[b]	7435	113119	47084	15288	0[b]	44851	30444[bc]	4531[b]
12	123173	1649227[b]	35069	253440	135426	50897	5136[b]	80312	24954[bc]	16614[a]
Trt x Storage Month	*0.95*	*0.90*	*0.74*	*0.93*	*0.74*	*0.67*	*0.32*	*0.99*	*0.21*	*0.69*

[abc] Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 26. Fully cooked dark meat ground chicken least square means for raw cook yield, percent moisture and lipid attributes for Phase II.

Effect	Broth, %	Moisture, %	Lipid, %
RMSE	6.199	0.671	0.527
Treatment			
P-values	*0.85*	*0.11*	*0.83*
Control	15.38	73.93	7.86
Rosemary	13.40	73.49	7.98
0.50% High Tannin	16.39	72.24	8.04
0.50% Onyx	17.74	73.58	7.67

Table 27. Fully cooked dark meat ground chicken least square means for cooked TBARS values, pH, objective and subjective color attributes for Phase II.

Effect	pH	Subjective Color	CIE Color Space Values *L**	*a**	*b**	TBARS
RMSE	0.071	1.97	2.004	0.499	1.418	0.388
Treatment						
P-values	*0.09*	*<0.0001*	*<0.0001*	*0.02*	*<0.0001*	*<0.0001*
Control	6.53	5.4[d]	62.17[a]	2.88[b]	16.89[a]	2.06[a]
Rosemary	6.55	6.0[c]	60.22[b]	2.92[b]	14.56[b]	0.59[b]
0.50% High Tannin	6.53	8.6[b]	57.87[c]	3.07[ab]	13.71[c]	0.68[b]
0.50% Onyx	6.51	10.2[a]	54.97[d]	3.16[a]	11.47[d]	0.58[b]
Storage Month						
P-values	*<0.0001*	*0.47*	*<0.0001*	*<0.0001*	*<0.0001*	*0.01*
0	6.57[b]	7.9	59.30[ab]	3.48[a]	14.59[a]	1.01[ab]
3	6.34[d]	7.6	59.43[a]	3.05[b]	14.87[a]	0.87[b]
6	6.64[a]	7.4	58.43[b]	2.87[b]	13.40[c]	0.90[b]
9	6.56[b]	7.5	59.81[a]	2.94[bc]	14.22[ab]	0.99[ab]
12	6.51[c]	7.3	57.06[c]	2.67[c]	13.69[bc]	1.12[a]
Trt x Storage Month	*0.008*	*0.33*	*0.01*	*0.01*	*0.13*	*0.21*

[abcd] Least squares means within a column and followed by the same letter are not different ($P \geq 0.05$).

Table 28. Flavor and basic taste descriptive attribute least squares means for fully cooked dark meat ground chicken by treatment and frozen storage time for Phase II.

Treatment	Chicken Identity	Brown/ Roasted	Fat Like	Metallic	Astringent	Sweet	Sour	Salty	Bitter	Umami
RMSE	0.26	0.27	0.25	0.13	0.14	0.20	0.17	0.18	0.21	0.30
P-values	*0.01*	*<0.0001*	*0.49*	*0.16*	*0.001*	*0.02*	*0.003*	*0.25*	*0.003*	*0.44*
Treatment										
Control	5.1[a]	1.1[b]	1.8	2.0	1.8[b]	1.7[b]	1.7[b]	1.9	1.9[c]	1.3
Rosemary	4.9[b]	1.2[b]	1.7	2.0	1.9[ab]	1.7[b]	1.9[a]	1.9	2.0[bc]	1.4
0.50% High Tannin	4.9[b]	1.5[a]	1.7	2.0	1.9[a]	1.8[ab]	1.7[b]	1.9	2.1[a]	1.3
0.50% Onyx	4.9[b]	1.5[a]	1.8	2.0	2.0[a]	1.8[a]	1.7[b]	1.8	2.0[ab]	1.3
P-values	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Storage Month										
0	4.8[c]	1.1[c]	1.7[c]	1.9[d]	1.5[c]	1.3[c]	1.5[c]	1.8[c]	1.8[b]	1.2[c]
3	4.3[d]	0.4[d]	1.0[d]	1.8[e]	1.6[b]	1.2[c]	1.3[d]	1.5[d]	1.5[c]	0.9[d]
6	5.1[b]	1.4[b]	1.6[c]	2.0[c]	2.1[a]	2.2[a]	1.9[b]	1.9[b]	2.2[a]	1.4[b]
9	5.5[a]	2.4[a]	2.4[a]	2.3[a]	2.1[a]	2.0[b]	2.1[a]	2.1[a]	2.3[a]	2.1[a]
12	5.0[b]	1.4[b]	2.0[b]	2.2[b]	2.2[a]	2.0[b]	1.9[b]	2.0[b]	2.2[a]	0.9[d]
Trt x Storage Month	*0.17*	*0.82*	*0.94*	*0.44*	*0.13*	*0.30*	*0.90*	*0.52*	*0.43*	*0.48*

[abcde] Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 28 Continued.

Treatment	Sorghum	Gritty	Card board	Floral	Green	Heated Oil	Nutty	Refrigerator Stale	WOF	Burning	Rosemary
RMSE	0.32	0.23	0.24	0.13	0.15	0.28	0.12	0.22	0.25	0.25	0.29
P-values	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.01*	*0.18*	*<0.0001*	*<0.0001*	*0.08*	*<0.0001*
Treatment											
Control	0.5^{c}	0.8^{c}	1.0^{a}	0.0^{b}	0.1^{b}	1.3^{a}	0.1	0.7^{a}	1.3^{a}	0.2	0.1^{b}
Rosemary	0.7^{c}	0.9^{c}	0.7^{c}	0.6^{a}	0.6^{a}	1.1^{b}	0.2	0.3^{b}	0.8^{b}	0.3	1.5^{a}
0.50% High Tannin	1.6^{b}	1.2^{a}	0.9^{b}	0.1^{b}	0.1^{b}	1.1^{b}	0.2	0.4^{b}	0.8^{b}	0.3	0.2^{b}
0.50% Onyx	1.9^{a}	1.0^{b}	0.9^{ab}	0.0^{b}	0.1^{b}	1.1^{b}	0.2	0.3^{b}	0.7^{b}	0.3	0.1^{b}
P-values	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Storage Month											
0	1.0^{b}	1.3^{a}	0.6^{c}	0.4^{a}	0.3^{a}	0.7^{c}	0.2^{b}	0.3^{c}	0.8^{b}	0.0^{d}	0.1^{c}
3	1.0^{b}	1.3^{a}	0.9^{b}	0.2^{b}	0.3^{a}	0.4^{d}	0.0^{d}	0.3^{c}	0.6^{c}	0.4^{b}	0.5^{b}
6	1.5^{a}	1.0^{b}	1.3^{a}	0.2^{bc}	0.3^{a}	1.5^{b}	0.2^{b}	0.4^{b}	1.3^{a}	0.2^{c}	0.8^{a}
9	1.3^{a}	0.8^{c}	1.3^{a}	0.1^{c}	0.0^{c}	1.4^{b}	0.1^{c}	0.4^{b}	0.9^{b}	0.5^{a}	0.6^{b}
12	1.1^{b}	0.4^{d}	0.3^{d}	0.1^{cd}	0.1^{b}	1.7^{a}	0.3^{a}	0.6^{a}	0.9^{b}	0.5^{ab}	0.4^{b}
Trt x Storage Month	*0.003*	*0.51*	*0.45*	*<0.0001*	*<0.0001*	*0.26*	*0.51*	*0.59*	*0.50*	*0.39*	*<0.0001*

^{abcd} Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

Table 29. Least squares means values for volatile, aromatic chemicals identified by the GC/MS for fully cooked dark meat ground chicken by each treatment for Phase II.

Code:	Volatile, Aromatic Chemical	RMSE	Trt *P-values*	Control	Rosemary	0.50% HTS	0.50% Onyx
C1	(E)-2-Decenal	24187.0	*0.04*	25231^{a}	942^{b}	12696^{ab}	942^{b}
C2	(E)-2-Heptenal	14338.1	*0.02*	15842^{a}	206^{b}	2251^{b}	206^{b}
C4	(E)-2-Nonenal	5717.5	*0.97*	1234	1892	2204	2074
C6	(E,E)-2,4-Decadienal	43430.9	*0.20*	33910	2024	12306	2024
C19	10-Methyl-Eicosane	4409.7	*0.55*	2359	1035	188	175
C21	1-Decanol	3933.8	*0.55*	76	0	95	1822
C26	1-Heptanol	3223.3	*0.03*	3214^{a}	0^{b}	0^{b}	762^{ab}
C28	1-Isocyano-2-Methyl-Benzene	4886.9	*0.26*	3385	1613	248	0
C33	1-Methyl-2-(1-Methylethyl)-Benzene	11300.9	*0.62*	0	4748	32	1382
C37	1-Methylene-1H-Indene	16323.6	*0.05*	0^{b}	0^{b}	442^{b}	14899^{a}
C38	1-Octanol	12000.2	*0.99*	7174	6767	6511	7312
C39	1-Octen-3-ol	36687.5	*0.05*	48887^{a}	14722^{b}	12375^{b}	19569^{b}
C42	2-(Hexyloxy)Ethanol	14781.1	*0.64*	0	6363	4594	5194
C44	2,3-Octanedione	37444.1	*0.09*	42541	11884	11216	11084
C49	2,4-Nonadienal	4186.2	*0.006*	5027^{a}	5^{b}	0^{b}	5^{b}
C51	2,5-Octanedione	10155.0	*0.20*	7449	0	3086	0
C53	2-Acetyl Thiazole	4722.8	*0.79*	4282	3589	3257	2470
C58	2-Furancarboxaldehyde	41764.1	*0.53*	18702	0	0	0
C59	2-Heptanone	5565.7	*0.87*	1705	1140	0	798
C63	2-Methyl-5-(4'-Methylphenyl) Sulfonyl-4-Nitroimidazole	1916.3	*0.08*	1616	0	799	0
C69	2-Octenal	18214.4	*0.0002*	32872^{a}	2965^{b}	8090^{b}	200^{b}
C70	2-Pentyl-Furan	27832.5	*0.62*	20286	14634	7046	8570

Table 29 Continued.

Code:	Volatile, Aromatic Chemical	RMSE	Trt *P-values*	Control	Rosemary	0.50% HTS	0.50% Onyx
C73	3-Dodecen-1-al	9071.9	*0.08*	7822	0	0	757
C75	3-Ethyl-Benzaldehyde	4126.4	*<0.0001*	11867[a]	0[b]	1193[b]	0[b]
C76	3-Methyl-Butanal	2088.5	*0.51*	0	414	36	990
C89	Acetaldehyde	5216.9	*0.75*	3360	2942	1174	2968
C90	Acetic Acid	21988.3	*0.02*	0[b]	723[b]	4059[b]	24412[a]
C92	Alpha-Terpinene	2709.1	*0.66*	0	1031	0	552
C93	Azulene	33157.0	*0.24*	0	0	1005	21371
C94	Benzaldehyde	172920.4	*0.04*	330021[a]	160546[b]	195204[ab]	157376[b]
C96	BenzeneAcetaldehyde	11728.8	*0.0002*	0[c]	596[c]	22333[a]	10154[b]
C97	Benzeneacetonitrile	7304.5	*0.82*	4444	2073	2157	2804
C100	Benzyl Nitrile	7595.4	*0.30*	2504	4049	7693	2185
C106	Carbon Disulfide	20474.0	*0.20*	14095	22416	8273	6423
C111	Decanal	21836.8	*0.05*	34747[a]	13912[b]	17157[b]	19889[ab]
C112	Decane	4855.9	*0.45*	0	2678	194	1151
C116	dl-Limonene	7132.4	*0.32*	0	4493	120	2091
C117	Dodecanal	5909.2	*0.85*	1323	3032	1201	2021
C118	Dodecane	23977.9	*0.82*	6772	14806	9187	12949
C119	Eicosane	3240.6	*0.56*	0	1431	777	0
C122	Ethyl Ester Decanoic Acid	78120.1	*0.30*	51613	7296	0	8830
C123	Ethyl Ester Dodecanoic Acid	9807.3	*0.67*	1274	3961	0	0
C124	Ethyl Ester Octanoic Acid	62796.5	*0.48*	36376	3180	2168	10471
C127	Hentriacontane	2512.6	*0.45*	1554	628	1045	31

Table 29 Continued.

Code:	Volatile, Aromatic Chemical	RMSE	Trt *P-values*	Control	Rosemary	0.50% HTS	0.50% Onyx
C128	Heptacosane	1695.4	*0.34*	603	0	627	1194
C130	Heptanal	48376.2	*0.81*	36961	23374	19573	24243
C137	Hexadecane	3289.3	*0.68*	0	1065	922	0
C139	Hexanal	277530.9	*0.007*	526555[a]	204549[b]	206137[b]	169225[b]
C142	Methanethiol	2932.1	*0.44*	2334	3321	1505	1865
C146	Naphthalene	61099.4	*0.004*	4190[b]	2085[b]	13692[b]	82262[a]
C147	N-Caproic Acid Vinyl Ester	28246.7	*0.32*	16024	0	0	0
C150	Nonacosane	972.1	*0.16*	710	445	0	8
C151	Nonadecane	4035.0	*0.48*	2261	1005	173	30
C152	Nonanal	308494.4	*0.98*	394377	417167	414158	375338
C154	Nonenal	13089.9	*0.0003*	22351[a]	421[b]	5961[b]	1038[b]
C155	Octacosane	846.1	*0.95*	325	145	220	244
C156	Octadecanal	1749.2	*0.0001*	645[b]	0[b]	3350[a]	0[b]
C157	Octadecane	2657.5	*0.07*	0	11	123	2337
C158	Octamethyl-Cyclotetrasiloxane	27431.3	*0.30*	4470	15262	1802	20027
C159	Octanal	81420.6	*0.66*	102691	67854	68114	81302
C162	Octenal	9389.1	*0.31*	5584	0	3992	0
C165	Pentadecane	5307.0	*0.88*	1600	359	1769	1715
C166	Pentanal	15842.2	*0.03*	16678[a]	0[b]	975[b]	1933[b]
C168	Pentanol	6277.3	*0.04*	6999[a]	1199[b]	64[b]	1746[b]
C170	Pentyl-Benzene	1231.7	*0.51*	0	0	426	489
C172	Phenyl Acetaldehyde	8529.0	*0.11*	0	623	0	6837
C173	Phenyl-Oxirane	7283.2	*0.19*	636	275	6247	1124

Table 29 Continued.

Code:	Volatile, Aromatic Chemical	RMSE	Trt *P-values*	Control	Rosemary	0.50% HTS	0.50% Onyx
C175	Styrene	33650.5	*0.53*	15026	0	0	0
C176	Sulfur Dioxide	12009.6	*0.68*	5203	1459	0	1318
C177	Tetradecanal	9512.7	*0.52*	4490	311	4785	942
C178	Tetradecane	10950.6	*0.18*	2338	9356	0	4714
C179	Thiourea	18522.1	*0.62*	9474	4446	11429	2946
C181	Tridecanal	3695.4	*0.30*	2594	0	1066	1582
C185	Undecenal	4283.2	*0.35*	2504	0	128	0

[abcde] Least squares means within a row and treatment with the same letter are not different ($P \geq 0.05$).
*Code number represents the volatile, aromatic chemical compound name and classification identified by the GC/MS found in Table 5.

Table 30. Least squares means values for volatile, aromatic chemicals identified by the GC/MS for fully cooked dark meat ground chicken by each frozen storage month for Phase II.

Code:	Volatile, Aromatic Chemical	RMSE	Month *P-values*	0	3	6	9	12	Month*Trt *P-values*
C1	(E)-2-Decenal	24187.0	*0.01*	1178^{b}	9445^{b}	33584^{a}	6197^{b}	0^{b}	*0.16*
C2	(E)-2-Heptenal	14338.1	*0.03*	257^{b}	5473^{ab}	16748^{a}	12^{b}	640^{b}	*0.12*
C4	(E)-2-Nonenal	5717.5	*0.77*	2498	1950	2514	2501	0	*0.51*
C6	(E,E)-2,4-Decadienal	43430.9	*0.09*	2529	10118	45707	3263	1212	*0.42*
C19	10-Methyl-Eicosane	4409.7	*0.73*	219	877	2515	527	558	*0.59*
C21	1-Decanol	3933.8	*0.50*	0	0	395	0	2476	*0.64*
C26	1-Heptanol	3223.3	*0.22*	2361	0	836	0	2051	*0.28*
C28	1-Isocyano-2-Methyl-Benzene	4886.9	*0.14*	0	641	4581	1390	0	*0.69*
C33	1-Methyl-2-(1-Methylethyl)-Benzene	11300.9	*0.55*	0	0	0	1948	6597	*0.63*
C37	1-Methylene-1H-Indene	16323.6	*0.36*	3583	14380	1669	0	0	*0.19*
C38	1-Octanol	12000.2	*0.18*	10469	854	12583	2994	7805	*0.79*
C39	1-Octen-3-ol	36687.5	*0.49*	22360	19399	25677	11658	40348	*0.82*
C42	2-(Hexyloxy)Ethanol	14781.1	*0.09*	0	0	1652	4511	15616	*0.94*
C44	2,3-Octanedione	37444.1	*0.26*	4031	11097	36607	14836	29335	*0.92*
C49	2,4-Nonadienal	4186.2	*0.002*	6^{b}	25^{b}	6196^{a}	0^{b}	0^{b}	*0.0001*
C51	2,5-Octanedione	10155.0	*0.05*	0^{b}	12949^{a}	0^{b}	46^{b}	162^{b}	*0.25*
C53	2-Acetyl Thiazole	4722.8	*0.36*	4713	4822	3832	1078	2553	*0.95*
C58	2-Furancarboxaldehyde	41764.1	*0.56*	0	0	0	0	23899	*0.65*
C59	2-Heptanone	5565.7	*0.49*	2344	0	0	0	2941	*0.63*
C63	2-Methyl-5-(4'-Methylphenyl) Sulfonyl-4-Nitroimidazole	1916.3	*0.19*	341	284	1827	0	436	*0.02*
C69	2-Octenal	18214.4	*0.006*	9981^{b}	6022^{b}	30753^{a}	5314^{b}	3088^{b}	*0.003*
C70	2-Pentyl-Furan	27832.5	*0.80*	10081	13680	19453	5373	14583	*0.97*

Table 30 Continued.

Code:	Volatile, Aromatic Chemical	RMSE	Month *P-values*	0	3	6	9	12	Month*Trt *P-values*
C73	3-Dodecen-1-al	9071.9	*0.16*	0	0	8075	463	2563	*0.11*
C75	3-Ethyl-Benzaldehyde	4126.4	*0.06*	1838	3577	6314	2806	1516	*0.001*
C76	3-Methyl-Butanal	2088.5	*0.20*	0	0	236	0	1767	*0.91*
C89	Acetaldehyde	5216.9	*0.01*	75[b]	8181[a]	3296[ab]	1668[b]	0[b]	*0.70*
C90	Acetic Acid	21988.3	*0.30*	12	20861	9973	2518	3088	*0.25*
C92	Alpha-Terpinene	2709.1	*0.59*	0	0	0	740	1438	*0.61*
C93	Azulene	33157.0	*0.60*	2564	0	5637	0	19865	*0.84*
C94	Benzaldehyde	172920.4	*0.22*	158508	277110	287642	178911	151765	*0.11*
C96	BenzeneAcetaldehyde	11728.8	*0.34*	8934	14921	7931	3093	6370	*0.50*
C97	Benzeneacetonitrile	7304.5	*0.31*	0	3749	5503	615	4549	*0.96*
C100	Benzyl Nitrile	7595.4	*0.40*	103	5669	4248	4246	6273	*0.88*
C106	Carbon Disulfide	20474.0	*0.01*	0[c]	5411[bc]	7058[bc]	21942[ab]	30003[a]	*0.20*
C111	Decanal	21836.8	*0.01*	11379[b]	20931[b]	40374[a]	14368[b]	20079[b]	*0.74*
C112	Decane	4855.9	*0.36*	1333	0	0	28	3651	*0.92*
C116	dl-Limonene	7132.4	*0.65*	2017	212	805	595	4542	*0.92*
C117	Dodecanal	5909.2	*0.93*	3014	595	2233	1556	2073	*0.57*
C118	Dodecane	23977.9	*0.47*	10897	8094	6663	6006	22984	*0.89*
C119	Eicosane	3240.6	*0.55*	0	0	0	849	1940	*0.55*
C122	Ethyl Ester Decanoic Acid	78120.1	*0.41*	0	5505	12566	4176	58727	*0.43*
C123	Ethyl Ester Dodecanoic Acid	9807.3	*0.25*	0	0	0	0	7767	*0.86*
C124	Ethyl Ester Octanoic Acid	62796.5	*0.35*	0	2657	12523	1078	49465	*0.49*
C127	Hentriacontane	2512.6	*0.94*	331	900	851	733	1257	*0.39*

Table 30 Continued.

Code:	Volatile, Aromatic Chemical	RMSE	Month *P-values*	0	3	6	9	12	Month*Trt *P-values*
C128	Heptacosane	1695.4	*0.01*	0[b]	2640[a]	0[b]	0[b]	423[b]	*0.39*
C130	Heptanal	48376.2	*0.44*	16123	16458	39404	13499	44704	*0.96*
C137	Hexadecane	3289.3	*0.66*	1331	0	1258	0	47	*0.61*
C139	Hexanal	277530.9	*0.35*	237228	228924	396074	177659	343198	*0.90*
C142	Methanethiol	2932.1	*0.03*	863[b]	5171[a]	1254[b]	1512[b]	2483[ab]	*0.87*
C146	Naphthalene	61099.4	*0.41*	8002	25603	55744	19968	18470	*0.50*
C147	N-Caproic Acid Vinyl Ester	28246.7	*0.61*	15362	0	0	0	4400	*0.73*
C150	Nonacosane	972.1	*0.45*	164	39	0	514	657	*0.72*
C151	Nonadecane	4035.0	*0.46*	37	148	1257	2823	71	*0.92*
C152	Nonanal	308494.4	*0.12*	364534	342523	610009	269664	414569	*0.93*
C154	Nonenal	13089.9	*0.002*	2894[b]	8985[b]	22075[a]	2773[b]	487[b]	*0.007*
C155	Octacosane	846.1	*0.69*	312	0	138	493	291	*0.83*
C156	Octadecanal	1749.2	*0.0001*	0[b]	4057[a]	0[b]	0[b]	916[b]	*<0.0001*
C157	Octadecane	2657.5	*0.05*	14[b]	55[b]	0[b]	30[b]	2970[a]	*0.01*
C158	Octamethyl-Cyclotetrasiloxane	27431.3	*0.95*	9391	4002	12595	14092	11871	*0.79*
C159	Octanal	81420.6	*0.14*	69104	55170	128764	47609	99303	*0.95*
C162	Octenal	9389.1	*0.63*	653	1899	0	3867	5468	*0.85*
C165	Pentadecane	5307.0	*0.69*	2508	2421	1844	51	0	*0.47*
C166	Pentanal	15842.2	*0.32*	1203	0	11981	1848	9386	*0.80*
C168	Pentanol	6277.3	*0.13*	0	2763	3915	0	6045	*0.28*
C170	Pentyl-Benzene	1231.7	*0.47*	0	0	657	521	44	*0.34*
C172	Phenyl Acetaldehyde	8529.0	*0.78*	0	379	4092	2438	1924	*0.93*
C173	Phenyl-Oxirane	7283.2	*0.16*	1405	1535	0	198	7214	*0.09*

Table 30 Continued.

Code:	Volatile, Aromatic Chemical	RMSE	Month *P-values*	0	3	6	9	12	Month*Trt *P-values*
C175	Styrene	33650.5	*0.55*	0	0	0	0	19653	*0.66*
C176	Sulfur Dioxide	12009.6	*0.22*	10009	0	361	0	0	*0.89*
C177	Tetradecanal	9512.7	*0.32*	388	1553	7990	804	2424	*0.96*
C178	Tetradecane	10950.6	*0.38*	1081	6507	7779	5177	0	*0.85*
C179	Thiourea	18522.1	*0.32*	114	16813	9859	1541	7042	*0.37*
C181	Tridecanal	3695.4	*0.48*	235	2173	0	1968	2033	*0.48*
C185	Undecenal	4283.2	*0.67*	966	0	0	2288	125	*0.86*

[abcde] Least squares means within a row and treatment with the same letter are not different ($P \geq 0.05$).
*Code number represents the volatile, aromatic chemical compound name and classification identified by the GC/MS found in Table 5.

Table 31. Least squares means values for volatile, aromatic compounds identified by the GC/MS for fully cooked dark meat ground chicken by each frozen storage month for Phase II.

Treatment	Alcohols	Aldehydes	Alkanes	Alkenes	Benzenes	Carboxylic Acids	Furans	Ketones	Sulfurs
RMSE	58884.9	830858.6	57679.6	39521.5	72139.1	152506.5	54825.1	37071.5	30639.0
P-values	*0.30*	*0.07*	*0.57*	*0.04*	*0.02*	*0.34*	*0.41*	*0.01*	*0.22*
Treatment									
Control	64860	1624335	28846	0[b]	26567[b]	108135	39101	52839[a]	37610
Rosemary	30187	907191	48850	5644[b]	13598[b]	16967	14380	13488[b]	35558
0.50% High Tannin	23713	995305	21300	1335[b]	44596[ab]	8204	7433	14055[b]	25644
0.50% Onyx	37243	856361	46491	39745[a]	97903[a]	45291	8316	12346[b]	15348
P-values	*0.50*	*0.08*	*0.66*	*0.73*	*0.25*	*0.42*	*0.63*	*0.33*	*0.36*
Storage Month									
0	37779	889894	27746	9123	14503	16077	9763	6956	16127
3	30656	1027412	24987	15526	41467	36914	12411	25615	33711
6	41143	1704059	38816	8111	78663	35061	19453	36607	24190
9	20184	746361	30668	1364	30729	9709	5348	14961	26218
12	65243	1111265	59640	24281	62968	125487	39563	31773	42452
Trt x Storage Month	*0.95*	*0.82*	*0.97*	*0.96*	*0.62*	*0.51*	*0.94*	*0.94*	*0.47*

[abcde] Least squares means within a column and treatment with the same letter are not different ($P \geq 0.05$).

APPENDIX B

FIGURES

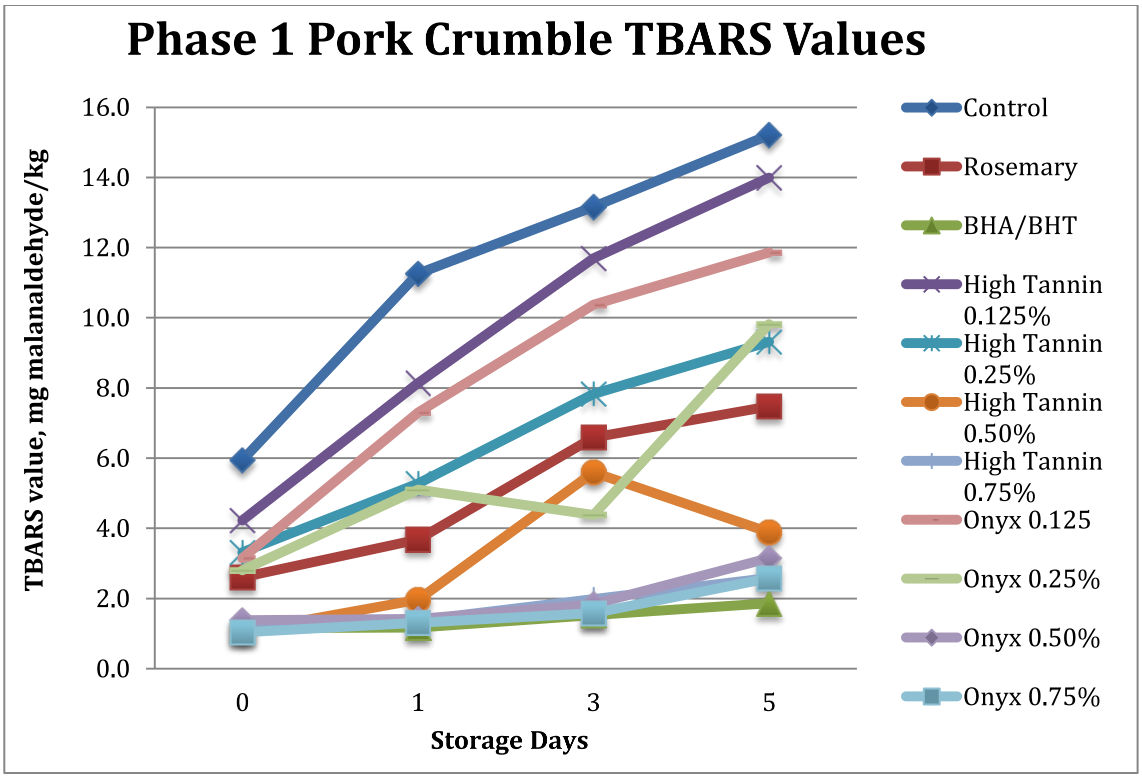

Figure 1. TBARS values least squares means for pork crumbles across treatments by storage time ($P < 0.0001$) for Phase I.

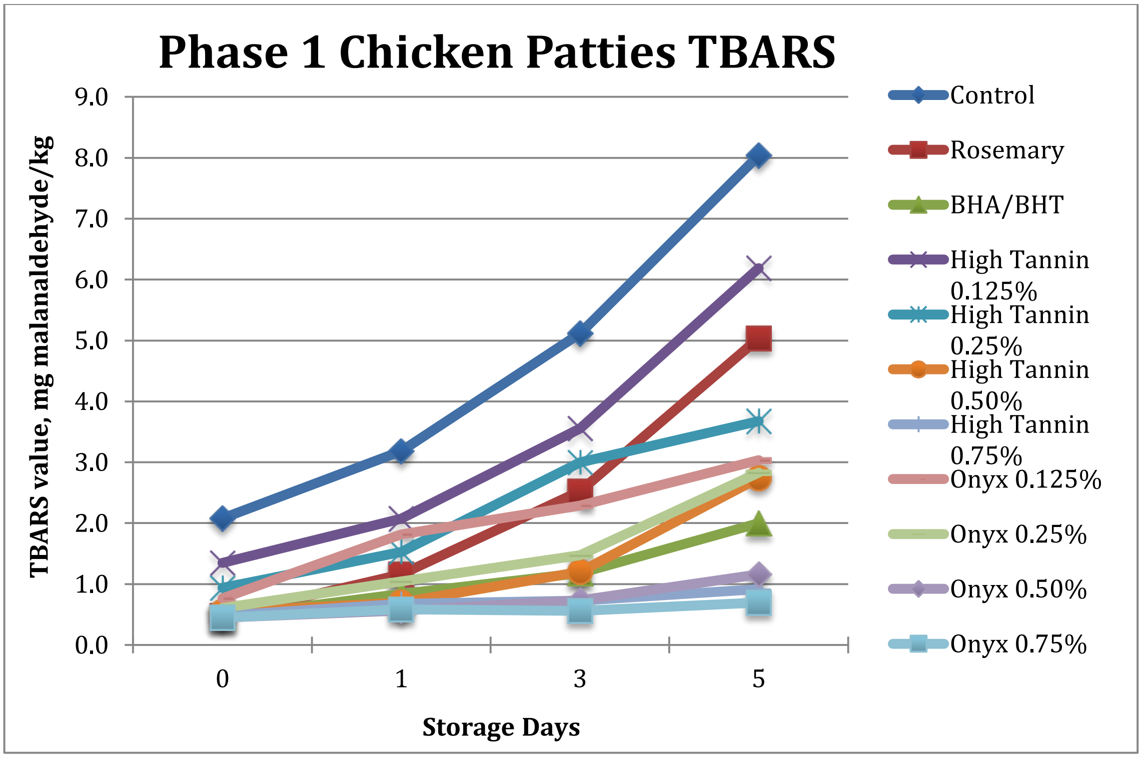

Figure 2. TBARS values least squares means for chicken patties across treatments by storage time (*P* < 0.0001) for Phase I.

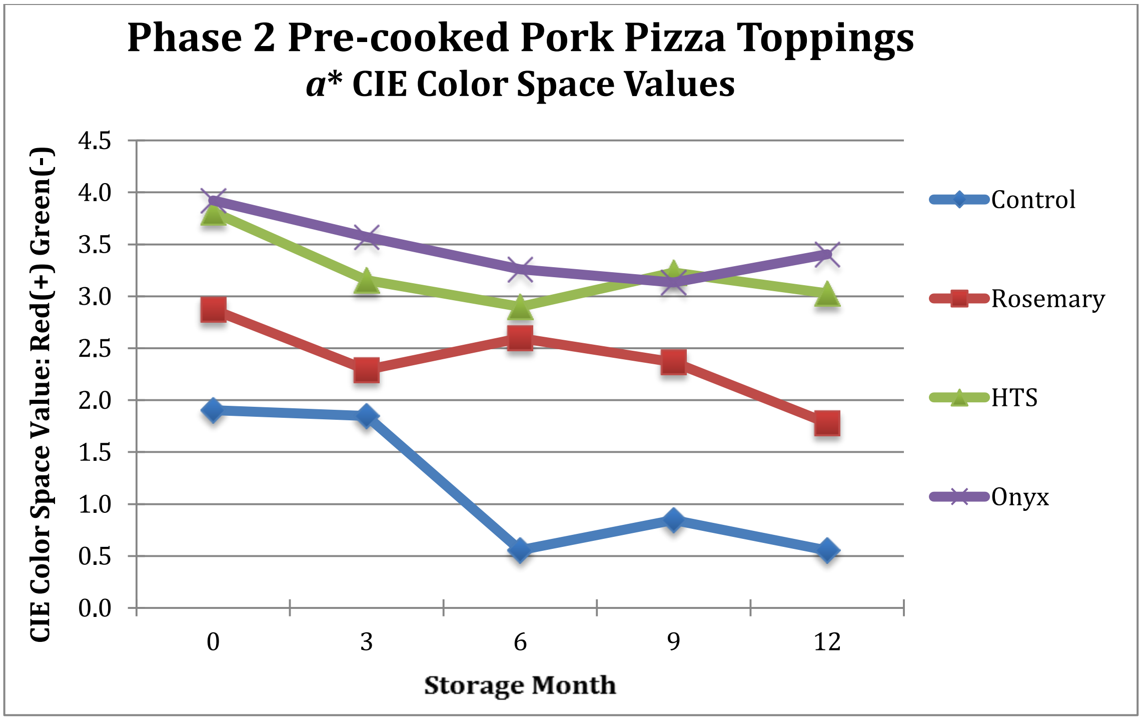

Figure 3. CIE Color Space *a** Values least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (P = 0.02) for Phase II.

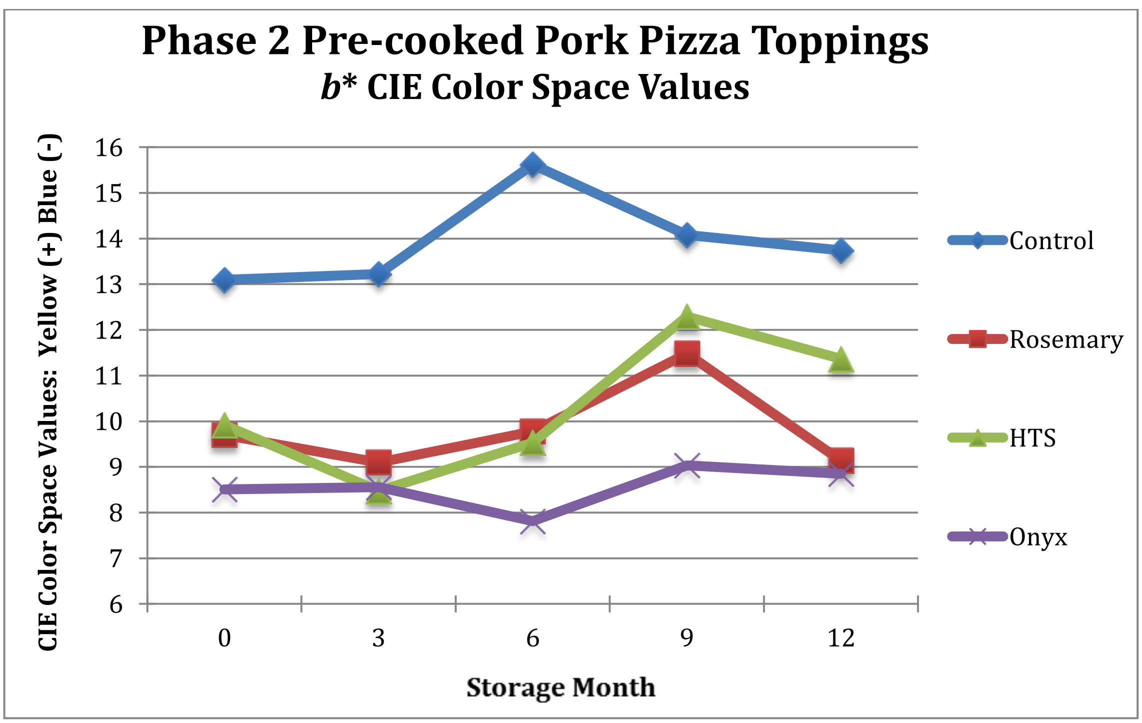

Figure 4. CIE Color Space *b** Values least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (P = 0.03) for Phase II.

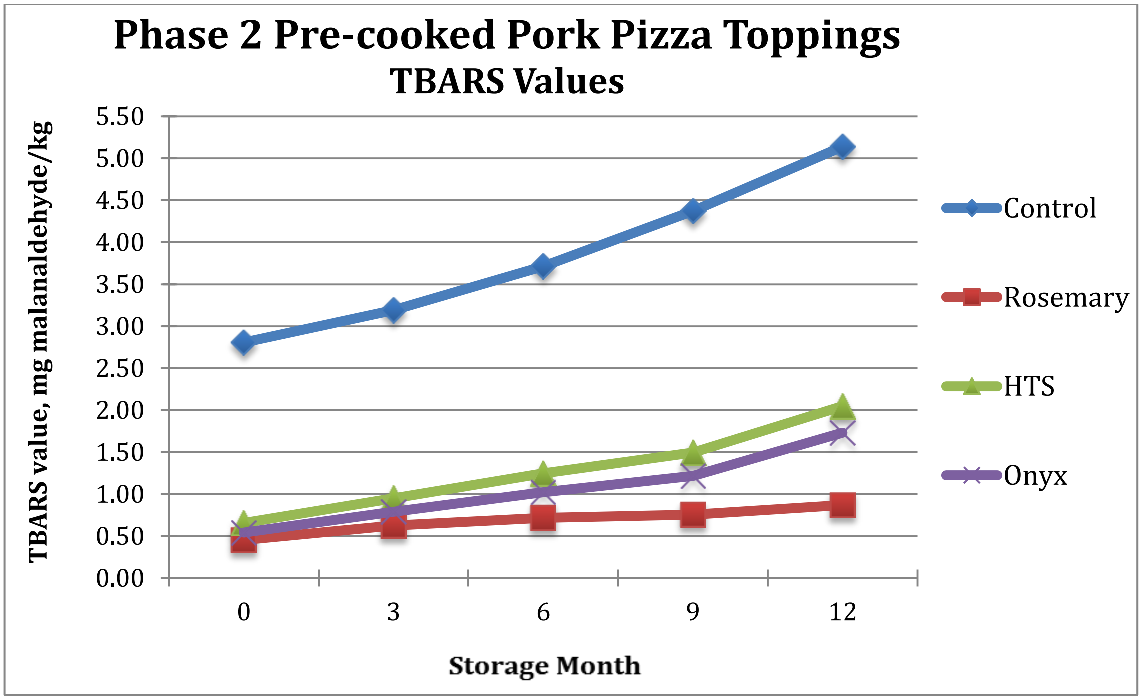

Figure 5. TBARS values least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time ($P < 0.0001$) for Phase II.

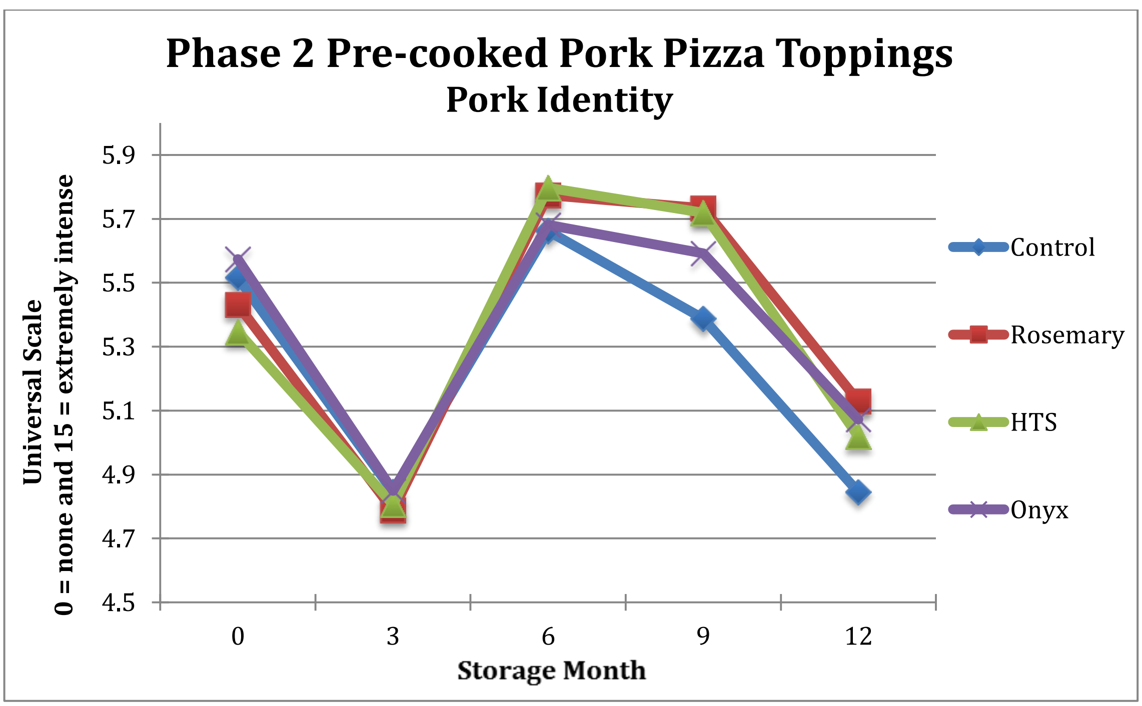

Figure 6. Pork Identity sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (P = 0.01) for Phase II.

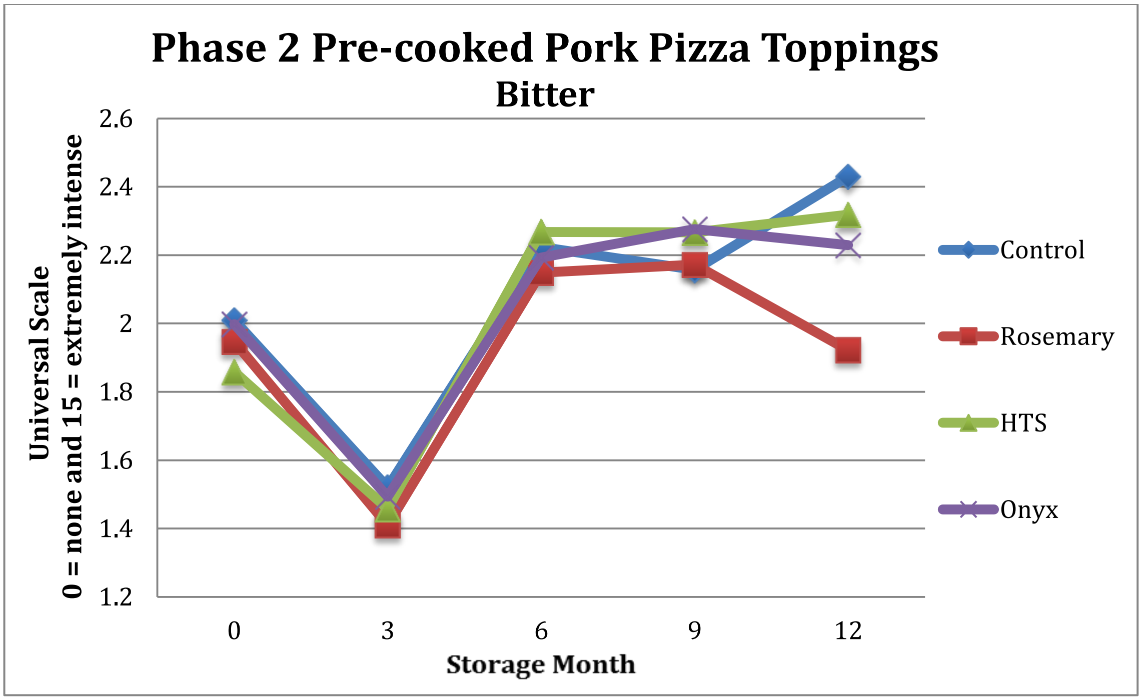

Figure 7. Bitter sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (P = 0.04) for Phase II.

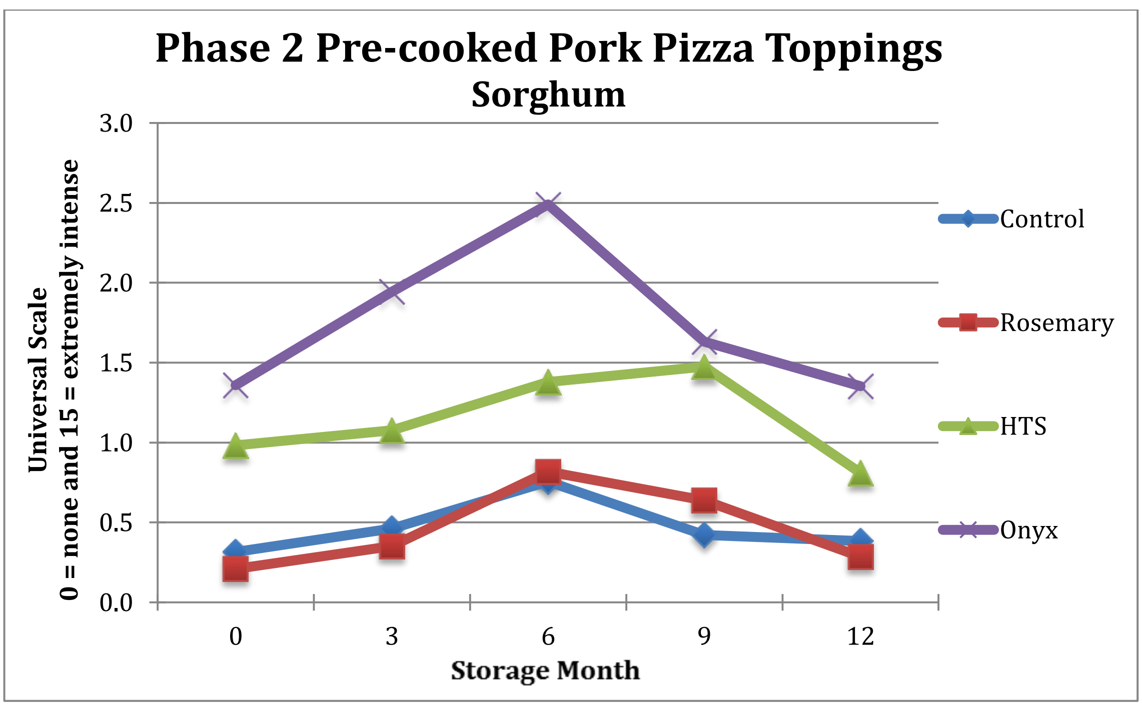

Figure 8. Sorghum sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (P = 0.01) for Phase II.

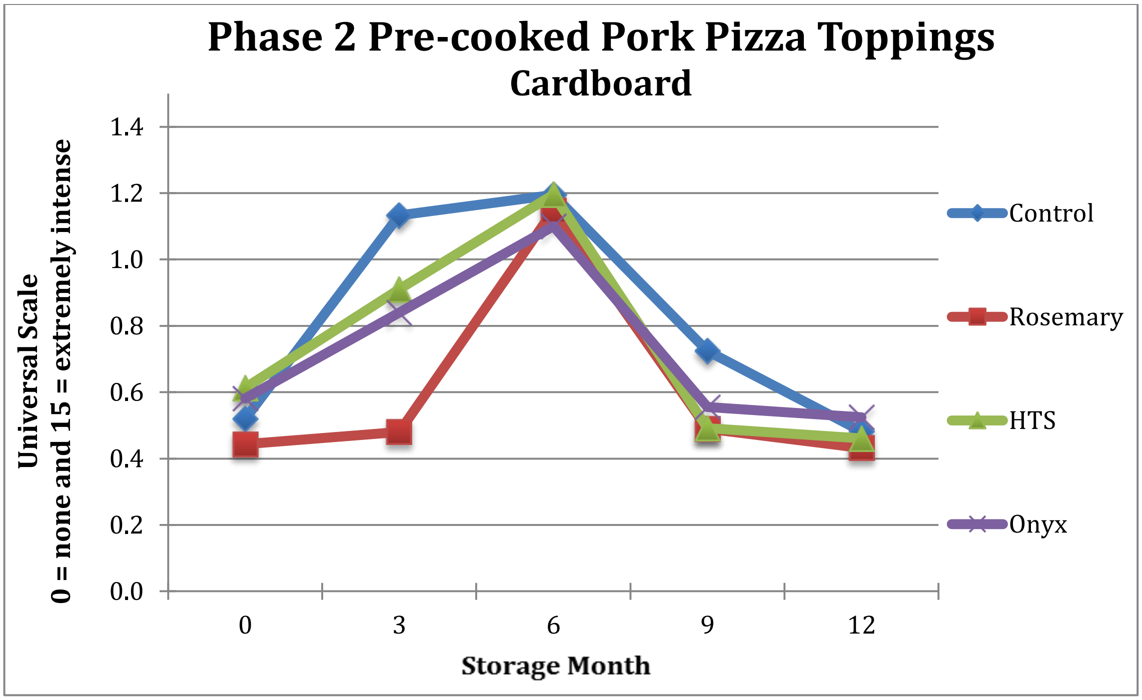

Figure 9. Cardboard sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time ($P = 0.002$) for Phase II.

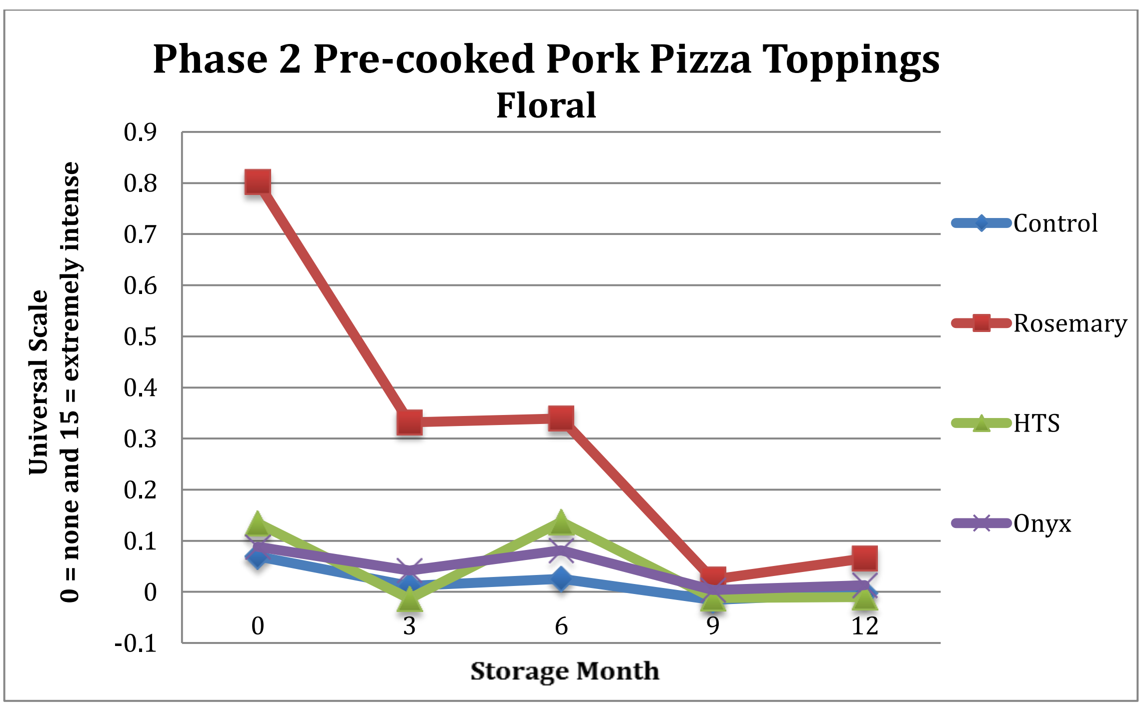

Figure 10. Floral sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time ($P < 0.0001$) for Phase II.

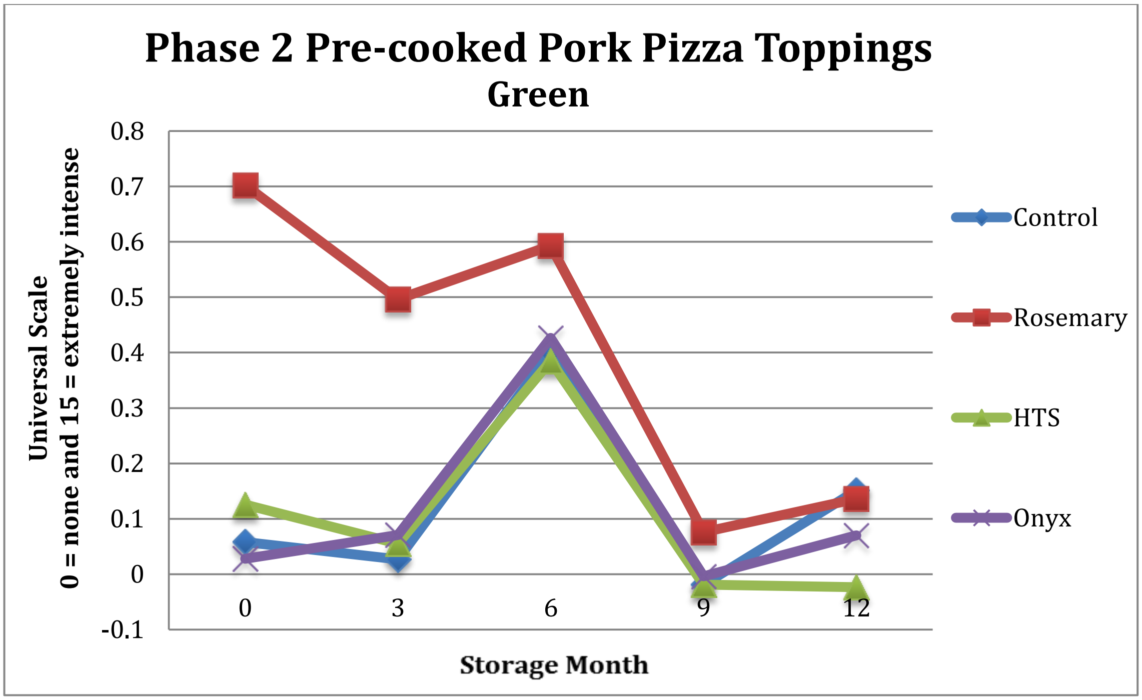

Figure 11. Green sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* = 0.005) for Phase II.

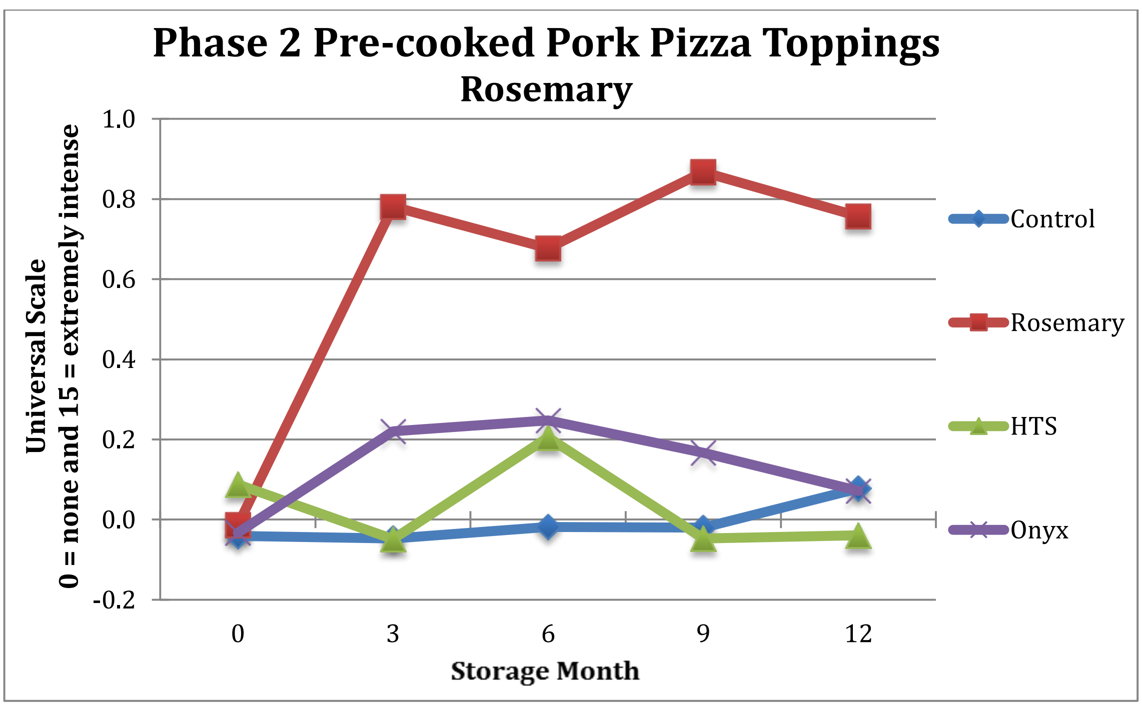

Figure 12. Rosemary sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time (*P* = 0.0001) for Phase II.

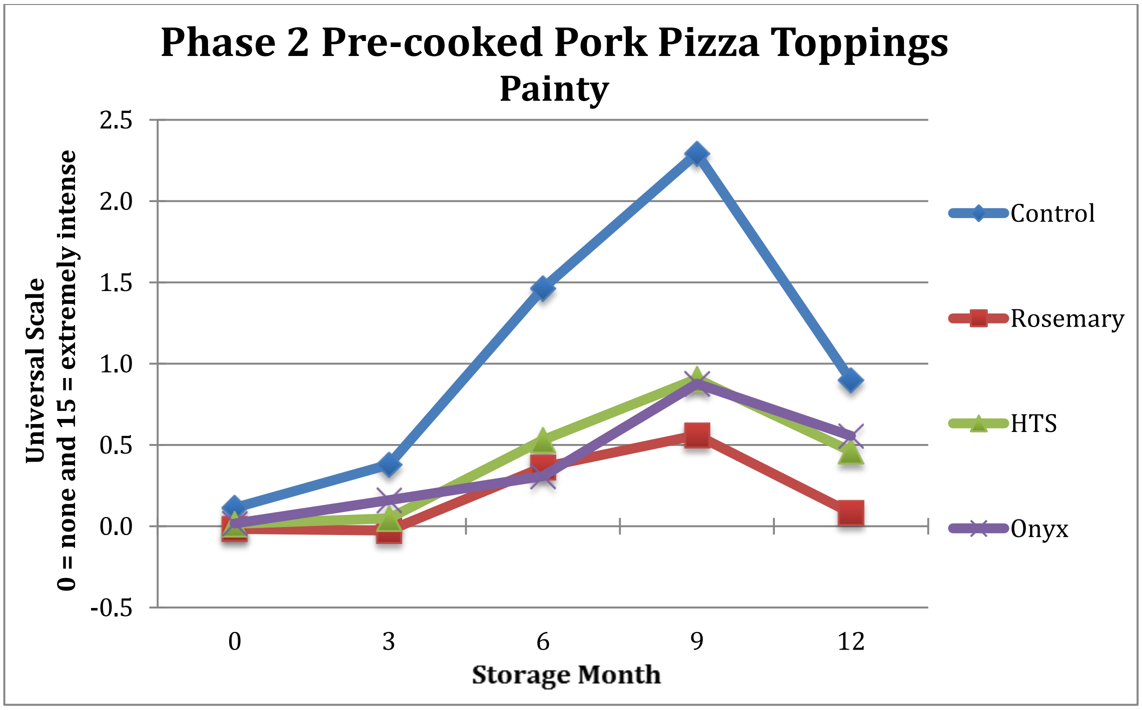

Figure 13. Painty sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time ($P < 0.0001$) for Phase II.

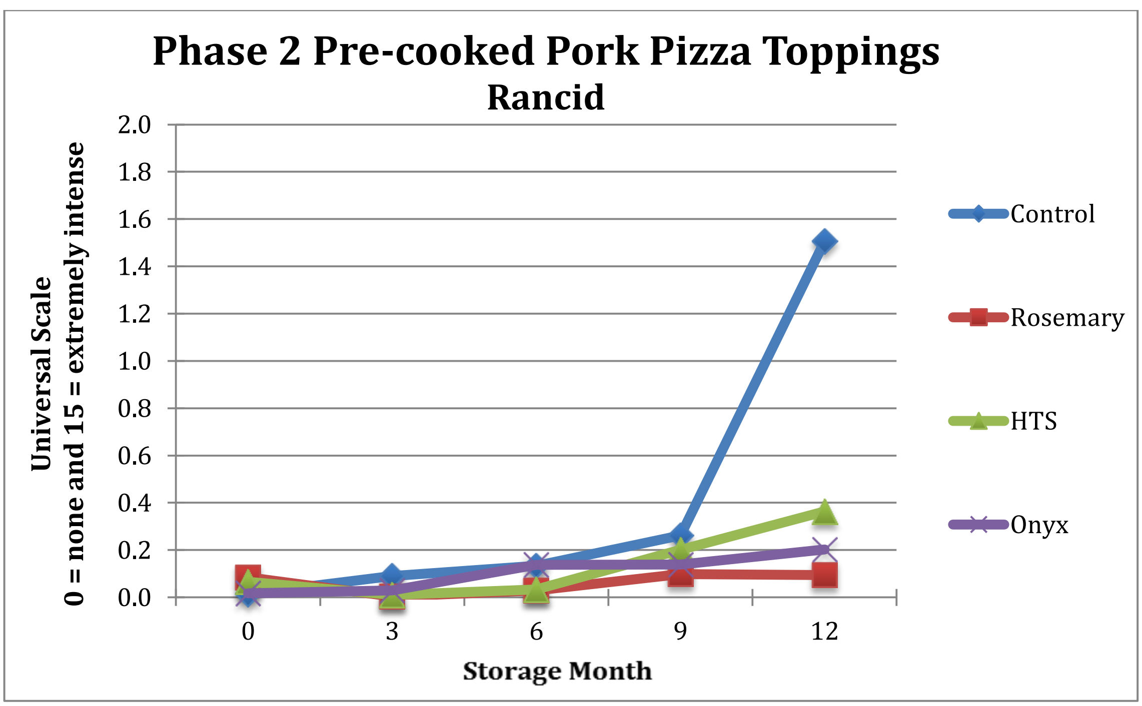

Figure 14. Rancid sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time ($P < 0.0001$) for Phase II.

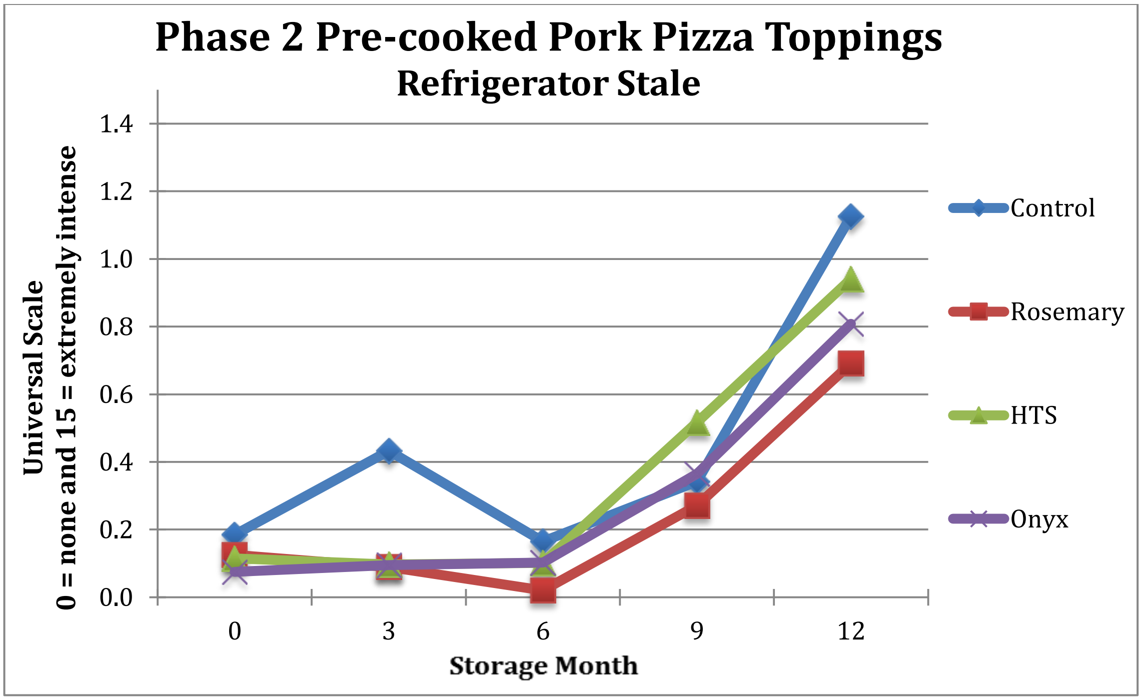

Figure 15. Refrigerator stale sensory attribute least squares means for pre-cooked pork pizza toppings across treatments and frozen storage time ($P < 0.0001$) for Phase II.

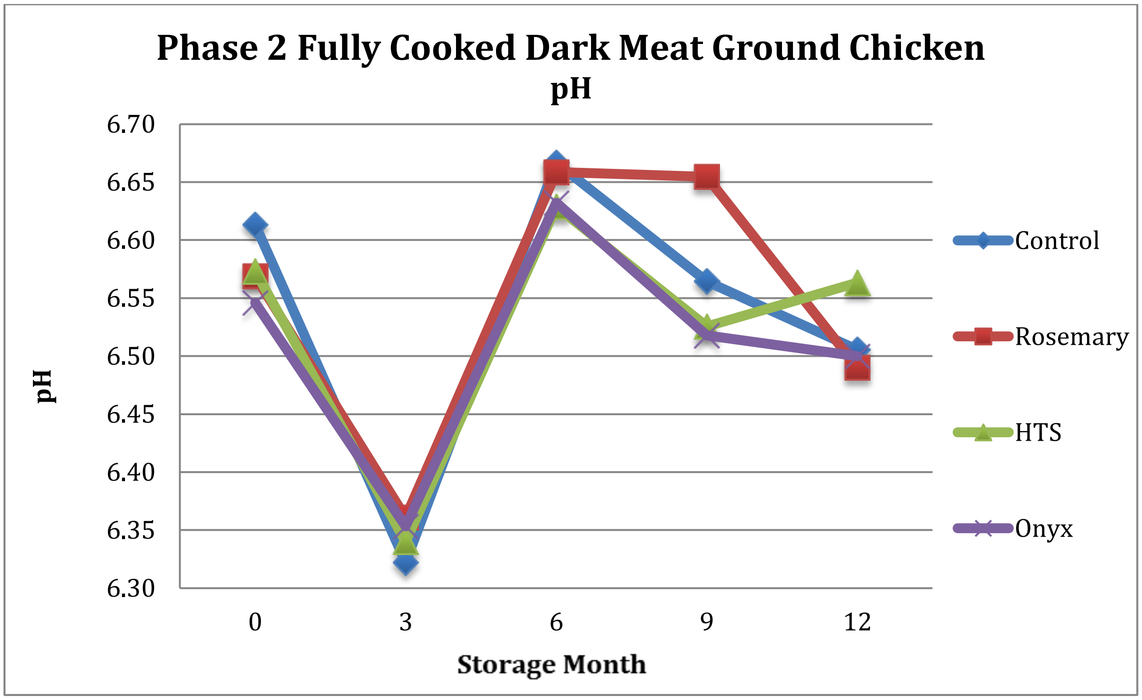

Figure 16. pH values least squares means for fully cooked dark meat ground chicken across treatments by frozen storage time (P = 0.008) for Phase II.

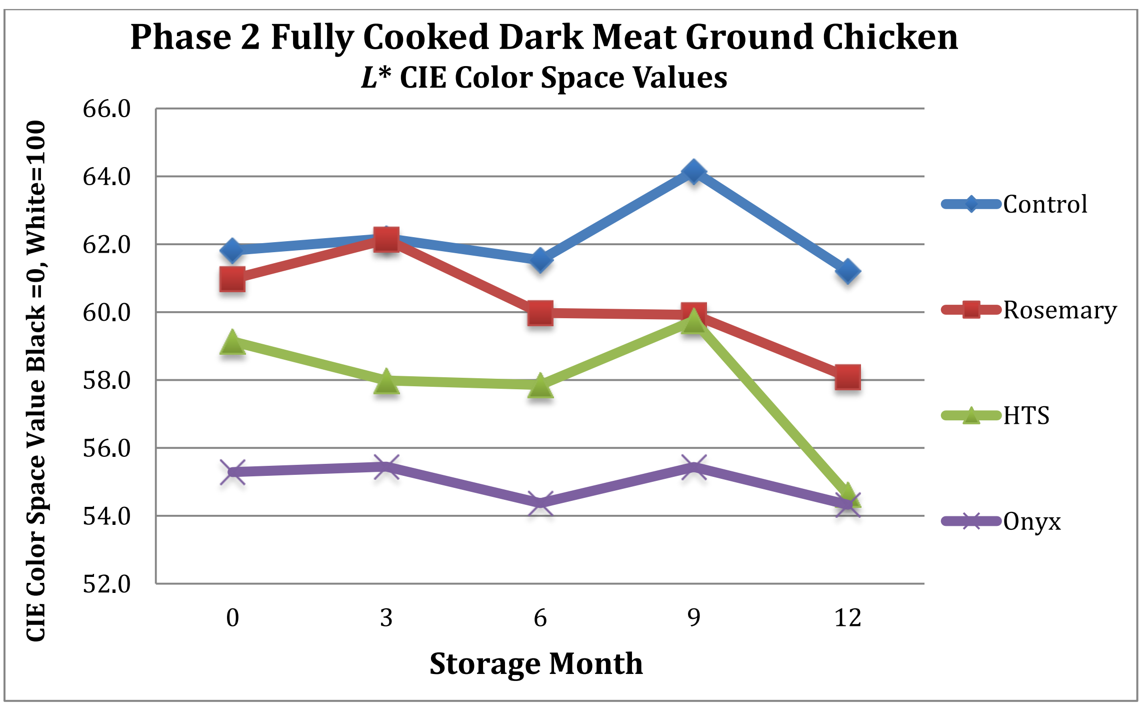

Figure 17. CIE Color Space L^* Values least squares means for fully cooked dark meat ground chicken across treatments and frozen storage time (P = 0.01) for Phase II.

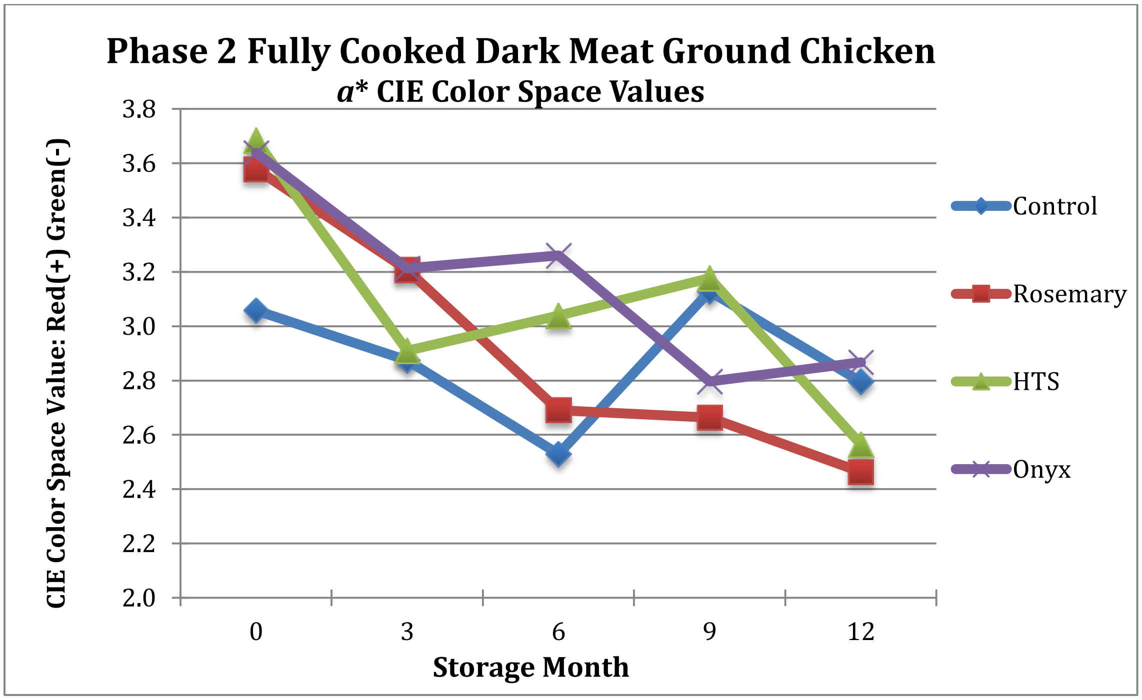

Figure 18. CIE Color Space *a** Values least squares means for fully cooked dark meat ground chicken across treatments and frozen storage time (P = 0.01) for Phase II.

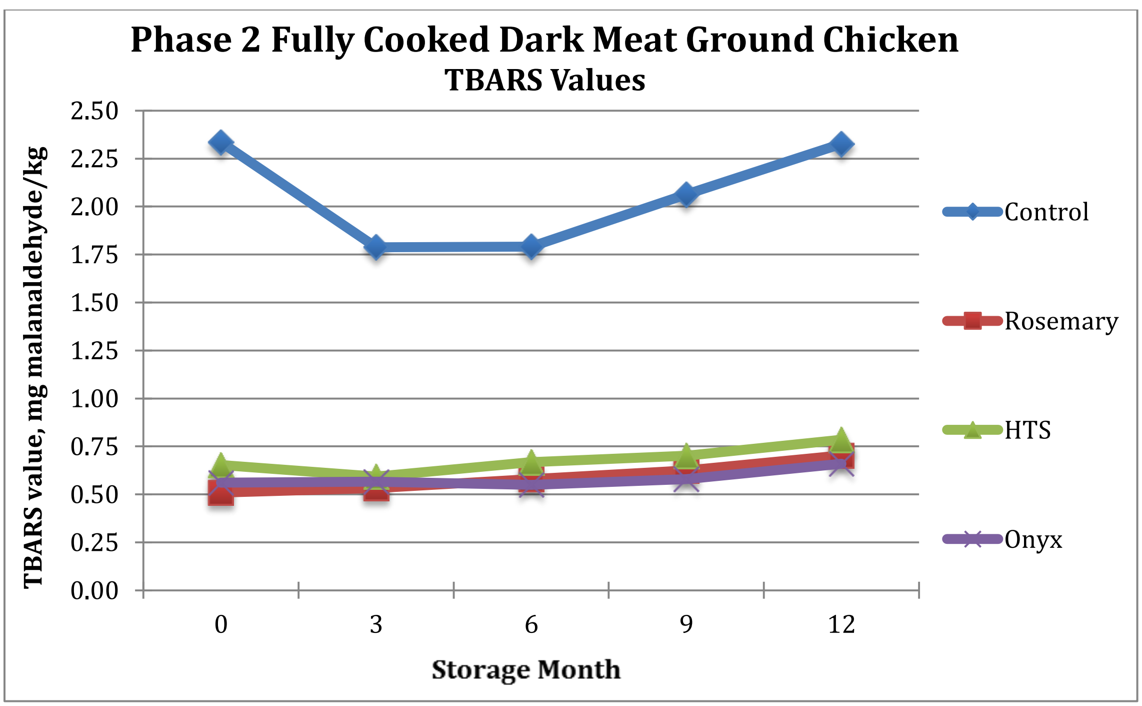

Figure 19. TBARS values least squares means for fully cooked dark meat ground chicken across treatments by frozen storage time (P = 0.21) for Phase II.