University of Kentucky
UKnowledge

Theses and Dissertations--Animal and Food Sciences

Animal and Food Sciences

2020

Effect of Different Fat Sources and Vitamin E Isoforms/ Levels on Carcass Characteristics, Meat Quality, and Belly/Bacon Characteristics of Pigs Grown to Heavy Slaughter Weights (>150kg)

Marlee Kelley
University of Kentucky, marleekelley@uky.edu
Author ORCID Identifier:
https://orcid.org/0000-0002-4303-8709
Digital Object Identifier: https://doi.org/10.13023/etd.2020.110

Right click to open a feedback form in a new tab to let us know how this document benefits you.

Recommended Citation

Kelley, Marlee, "Effect of Different Fat Sources and Vitamin E Isoforms/ Levels on Carcass Characteristics, Meat Quality, and Belly/Bacon Characteristics of Pigs Grown to Heavy Slaughter Weights (>150kg)" (2020). *Theses and Dissertations--Animal and Food Sciences*. 118.
https://uknowledge.uky.edu/animalsci_etds/118

This Master's Thesis is brought to you for free and open access by the Animal and Food Sciences at UKnowledge. It has been accepted for inclusion in Theses and Dissertations--Animal and Food Sciences by an authorized administrator of UKnowledge. For more information, please contact UKnowledge@lsv.uky.edu.

STUDENT AGREEMENT:

I represent that my thesis or dissertation and abstract are my original work. Proper attribution has been given to all outside sources. I understand that I am solely responsible for obtaining any needed copyright permissions. I have obtained needed written permission statement(s) from the owner(s) of each third-party copyrighted matter to be included in my work, allowing electronic distribution (if such use is not permitted by the fair use doctrine) which will be submitted to UKnowledge as Additional File.

I hereby grant to The University of Kentucky and its agents the irrevocable, non-exclusive, and royalty-free license to archive and make accessible my work in whole or in part in all forms of media, now or hereafter known. I agree that the document mentioned above may be made available immediately for worldwide access unless an embargo applies.

I retain all other ownership rights to the copyright of my work. I also retain the right to use in future works (such as articles or books) all or part of my work. I understand that I am free to register the copyright to my work.

REVIEW, APPROVAL AND ACCEPTANCE

The document mentioned above has been reviewed and accepted by the student's advisor, on behalf of the advisory committee, and by the Director of Graduate Studies (DGS), on behalf of the program; we verify that this is the final, approved version of the student's thesis including all changes required by the advisory committee. The undersigned agree to abide by the statements above.

Marlee Kelley, Student

Dr. Gregg Rentfrow, Major Professor

Dr. David Harmon, Director of Graduate Studies

Effect of Different Fat Sources and Vitamin E Isoforms/ Levels on Carcass Characteristics, Meat Quality, and Belly/Bacon Characteristics of Pigs Grown to Heavy Slaughter Weights (>150kg)

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture, Food ad Environment
at the University of Kentucky

By

Marlee Kelley

Lexington, Kentucky

Director: Dr. Gregg Rentfrow, Professor of Animal and Food Sciences

Lexington, Kentucky

2020

Copyright © Marlee Kelley 2020
https://orcid.org/0000-0002-4303-8709

ABSTRACT OF THESIS

Effect of Different Fat Sources and Vitamin E Isoforms/ Levels on Carcass Characteristics, Meat Quality, and Belly/Bacon Characteristics of Pigs Grown to Heavy Slaughter Weights (>150kg)

Two separate studies were conducted to evaluate the potential interaction of fat sources and vitamin E (VE) on heavy slaughter weights. In Study 1, a total of 64 individually-fed pigs (28.41 ± 0.83 kg) were randomly assigned to 8 dietary treatments in a 4×2 factorial arrangement. Fat treatments included cornstarch (CS), tallow (TW), corn oil (CO), and coconut-oil (CN). VE treatments were dietary alpha-tocopheryl-acetate (ATA) at 11 and 200 ppm. In Study 2, a total of 72 individually fed pigs (28.55 ± 1.16 kg) were randomly assigned to 12 dietary treatments in a 2 × 6 factorial arrangement. Fat treatments were TW and CO. VE treatments included four levels of ATA (11, 40, 100, and 200 ppm) and two levels of mixed tocopherols (primarily gamma-tocopherol (γ-T); 40 and 100 ppm). For Study 2, slaughter weight ($P = 0.04$) and pork sensory attributes such as tenderness ($P < 0.01$), juiciness ($P < 0.01$) and overall approval ($P < 0.01$) increased with increasing dietary ATA VE. Feeding γ-T at 40 ppm, resulted in a higher L^* and hue as well as a lower a^*, a/b, and chroma. Furthermore, feeding γ-T at 100 ppm resulted in a lower L^* and hue ($P < 0.05$) as well as a higher a^*, a/b, and chroma ($P < 0.05$). During extended shelf life measurements, TW tended to have a higher L^* ($P < 0.05$) and b^* ($P < 0.05$). γ-T VE chops exhibited less of an off-flavor ($P = 0.05$). Bellies from pigs fed higher saturated fat acids displayed a greater belly depth ($P < 0.05$), a larger belly angle ($P < 0.05$), and a lower bacon fat shatter score ($P < 0.05$). Overall, feeding a higher percentage of statured fatty acids leads to a more desirable pork belly and supplementing higher levels of γ-T could improve shelf life color and consumer sensory analysis.

KEYWORDS: vitamin E, isoforms, fat, pigs, heavy slaughter weight

Marlee Kelley
(Name of Student)

05/01/2020
Date

Effect of Different Fat Sources and Vitamin E Isoforms/ Levels on Carcass Characteristics, Meat Quality, and Belly/Bacon Characteristics of Pigs Grown to Heavy Slaughter Weights (>150kg)

By
Marlee Kelley

Dr. Gregg Rentfrow
Director of Thesis

Dr. David L. Harmon
Director of Graduate Studies

05/01/2020
Date

ACKNOWLEDGMENTS

Thank you, thank you, thank you! To all the faculty, staff, meat lab crew, farm crew and students who provided support during my time at the University of Kentucky. I appreciate everything everyone has done for me. I would also like to thank the National Pork Board, Fats and Proteins Research Foundation, and DSM for their financial funding for this project.

A special thank you to my advisor Dr. Gregg K. Rentfrow for his support throughout my time in graduate school, from starting my research project my third week in Lexington to finishing it after leaving Lexington and taking a job as an Extension Agent. Thank you to Dr. Merlin Lindemann and Dr. Surendranath Suman for serving on my advisory committee, to Dr. David Harmon, Director of Graduate Studies, and to Dr. Richard Coffey, Chair of the Department of Animal and Food Sciences. Also, thank you Dr. Ding Wang for your guidance throughout this process and helping with samples. Thank you again to Dr. Merlin Lindemann for your patience with all my nutrition and statistic questions. Also, thank you to every single person in Dr. Lindemann's lab helped during slaughter and cut-out days.

I cannot say thank you enough to Brock Billingsley for his guidance, patience and assistance during everything. Thank you for teaching me everything about slaughter, fabrication and retail cuts. I could not have finished graduate school without you… literally. I also appreciate the generous help of the meat lab student workers including Emma Shelton, Emma Horney, Noah Cartwright, Abby Phillips, Luke Wilson, Ethan Ellis, and Justin Smith. I'm sure none of them will ever forget the Bacon Project!

Last but not least, thank you to my parents for supporting me no matter what from over 700 miles away. I would not be where I am today without your loving support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Chapter 1 LITERATURE REVIEW

1.1. Introduction

Overall meat consumption has continued to rise globally. According to the USDA (2016), commercial red meat production has increased by 25 percent in the past 25 years, with most of the increase being in pork production. The increasing demand for pork can only be met either by increasing the number of pigs produced or by increasing slaughter weight (SLW). Given the pressure of total food supply on a finite land mass, environmental impact and the dilution effect of fixed production cost, it is obvious that increased market weights will be a large part in meeting the pork demand.

The increasing demand for pork globally has provided the swine industry both opportunities and challenges in providing more and more high-quality products. The market weight of pigs has risen continuously over the past decades from 113 kg (1990) to 127 kg (2017). Based on a projection using slaughter weight data from the USDA National Agricultural Statistics Service, the estimated slaughter weight in 2032 will be over 150 kg. As one of the promising solutions, increasing slaughter weight up to 150 kg might come into practice in the near future. Previous research suggested that slaughter weights over 124 kg decreased live pig performance and carcass leanness without any additional benefits to pork quality (Latorre et al., 2004). However, the improvements in genetics over the past 15 years may overcome this problem.

Another rising challenge for the industry is the cost pressure caused by the increasing price of corn which has driven the producer to explore feeding more by-products, such as dried distillers grains with solubles (DDGS), that are higher in

unsaturated fatty acids (Seman et al., 2013). Additionally, the American Heart Association recommends limiting saturated fats because they can raise LDL-Cholesterol which can cause a higher risk for heart disease (AHA, 2015). The swine industry has responded to these challenges by developing leaner genotype pigs by supplementing swine diets with unsaturated fat sources which leads to higher polyunsaturated fatty acids (PUFA) in pork because the changes of the dietary fatty acid profile are able to be expressed in pork (Gatlin et al., 2002). The increase of unsaturated fatty acids results in soft pork fat, which is associated with greater potential for oxidative problems and poor belly quality. Pork processors consider soft belly fat undesirable because it leads to poor bacon slicing due to an oily appearance, poor slice definition in retail packaging, fat and lean separation, reduced slicing efficiency and problems with processing. If longer periods of feeding high polyunsaturated oils happens when growing pigs to heavy slaughter weights, a reduction in pork quality and product value may occur.

Many attempts have been made to solve meat quality problems caused by over consumption of highly unsaturated fat that can lead to peroxidation of pork fat. One attempt is using different fat sources that have a high saturated fatty acid content (such as beef tallow) (Wood and Enser, 1997; Wood et al., 2004; Mitchaothai et al., 2007). Another attempt is dietary antioxidants supplementation with Vitamin E (VE). Dietary vitamin E supplementation improves the oxidative stability of pork and prolongs shelf life of fresh pork (Boler et al., 2009). Among many VE forms, α- and γ-tocopherols are two possible forms for the swine diets as acetate or alcoholic forms. Although the absorption rate of RRR-α-tocopherol and RRR-γ-tocopherol is similar, the elimination of RRR-γ-tocopherol from plasma is faster (Jiang et al., 2001), which might imply either

faster excretion or faster incorporation into tissue; more rapid incorporation into tissue could be extremely positive in improving meat quality, especially in preventing lipid oxidation in meat. The interaction between VE and fat sources are rarely reported, especially under a long-term dietary treatment at heavy SLW beyond 150 kg.

1.2. Measurements for Market Pigs, Pork Carcasses and Pork Quality

1.2.1 Measurements for Pork Quality

Pork quality affects both consumer acceptance and value-added opportunities for pork. The quality of pork results from the combination of genetic and environmental factors, for example, breed, gender, nutrition, pre- and post-slaughter conditions. There are five major indicators used in measuring pork quality: color, marbling, water-holding capacity, firmness and ultimate pH.

1.2.2 Meat Color

Meat purchasing decisions are influenced by color more than any other quality factor. Consumers use discoloration as an indicator of freshness and wholesomeness (Mancini and Hunt, 2005). Meat color is dependent on the ratio of red to white muscle fibers. Red, Type 1, fibers have a higher myoglobin content compared to white, Type 2, muscle fibers. Pork color can be measured by three different methods: subjective assessment, computer vision and instrumental color (Mancini and Hunt, 2005).

Subjective assessment of meat color is closely related to consumer evaluations and is the benchmark for instrumental measurement comparison (Hunt et al, 1991). Subjective color is measured by an experienced grader using the National Pork Board Color Standards (NPB, 2011). The scale ranges from one to six. A color score of one appears pale, grayish

pink to white in its appearance. While a color score of six appears dark, purplish. Wright et al. (2005) determined an average mean color score of boneless loin chops was 3.52.

Visual-color appraisals are difficult to conduct because human judgement may not be repeatable from day to day and are often influenced. The use of instrumental color evaluation is of significant interest to the industry because of its speed, consistency of measures, and potential for use as the basis of sorting (Brewer et al., 2001). Objective analysis can be performed with instrumental color (colorimeters or spectrophotometers) or computer vision, however this can be a costly instrument. Computer vision measures the entire sample surface, it is more representative of sensory descriptors than the colorimeter, which is only based on point-to-point measurements (Mancini and Hunt, 2005).

For instrumental color, the Hunter color solid system, or HunterLab, is the most widely used system for the measurement of meat color. The Hunter L^*, a^*, and b^* values represent a three-dimensional specification of color location within a three-dimensional color solid as shown in Figure 1.1 (Hunt et al., 1991). L^*, a^* and b^* measure lightness, redness and yellowness, respectively (AMSA, 2012). Color may also be observed using calculations from the a^* and b^* values. Larger ratios of a^*/b^* (or decreases in b^*/a^*) indicates more redness and less discoloration (Hunt et al., 1991; Mancini and Hunt, 2005). Hue angle ($\tan{-}1(b^*/a^*)$ is the development of color from red to yellow and larger angle values indicate a less red product. Chroma ($\sqrt{a}*2 + b*2$) is used to indicate the saturation of color with larger values indicating more saturation of the color (Tapp et al., 2011). Minolta and Hunter colorimeters are the most popular colorimeters used in recent published papers.

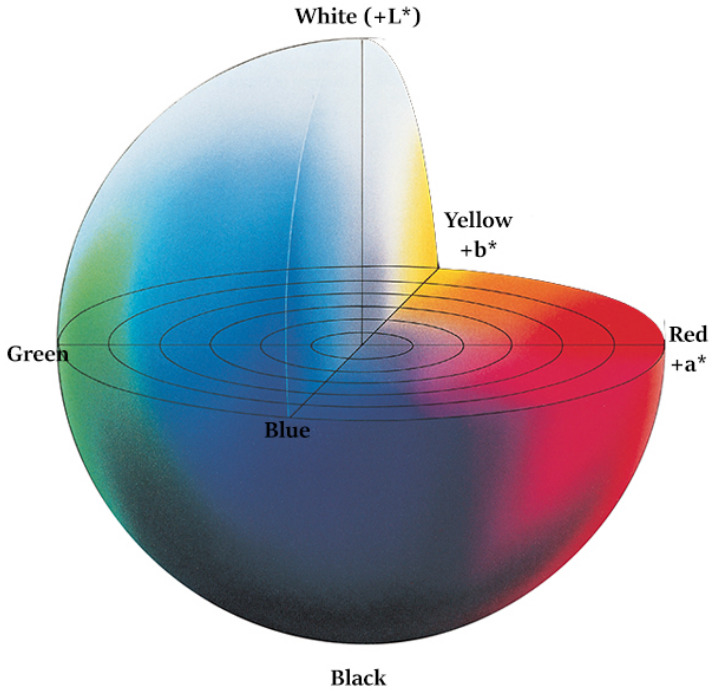

Figure 1.1 Representation of Color Solid for *L* a* b** Color Space.
AMSA (2012)

1.2.3 Intramuscular Fat

Intramuscular fat is located between and within muscle fibers (cells) and its greatest deposition is in the later stages of the growth process. Intramuscular fat is called marbling in the meat industry and marbling has a significant impact on marketing fresh meat, particularly pork loin cuts (Gerrard and Grant, 2003). Pork is given a subjective marbling score based on the percentage of intramuscular lipid content. The recommended intramuscular fat content to meet consumer demand ranges from 2.0 to 4.0% (Verbeke et al., 1999). Fernandez (1999) concluded that lower sensory quality traits were associated with intramuscular fat content below 2.5%.

1.2.4 Firmness

Firmness can be measured both subjectively and objectively for the loin and belly. Subjective firmness measurement, for the loin, is conducted with either trained or consumer panels according to a certain standard, such as the NPPC (1999) 1 to 3 scale or the NPPC (1991) 1 to 5 scale. A texture analyzer can be used to measure objective firmness for a fresh pork loin (Rincker et al., 2007). The following methods that have been employed in assessing subjective belly firmness: visual appraisal using either 4, 5, or 6 point scales (Weber et al., 2006) and finger testing (Maw et al., 2003). The belly-flop test using either a suspended round bar (Uttaro and Zawadski, 2010) or a v-shaped smokehouse stick (Whitney et al., 2006) and the belly-flex method (Rentfrow et al., 2003) are used to objectively assess fresh pork belly firmness. Firm pork is usually associated with other quality measurements indicating better quality such as darker color and greater water holding capacity. Additionally, appropriate firmness allows for better meat processing for bacon and sausage (McClelland et al., 2012).

1.2.5 Water Holding Capacity

The water holding capacity, or ability to retain inherent water, is an important property of fresh meat as it affects both the yield and the quality of the end product. Water accounts for approximately 75% of the weight of meat. This water can be found in the three forms within the muscle; bound, immobilized, or free. The portion of bound water is the smallest (1-2%) and the sturdiest of the three. This portion is very tightly associated with proteins by hydrogen bonds and is nearly impossible to remove from meat. Meat processing has little effect on the bound component of water. Immobilized water (80%) is held together by steric effects and/or by attraction to the bound water. The more water that

is immobilized, the greater the water holding capacity. Free water that flows from the tissue is unimpeded (Huff-Lonergan and Lonergan, 2005) and is likely to be lost as purge.

Unacceptable water holding capacity costs the meat industry millions of dollars annually (Huff-Lonergan and Lonergan, 2004). For fresh products, drip loss and purge loss are the two measurements commonly used to determine water holding capacity. The mechanism by which drip or purge is lost from meat is influenced both by the pH of the tissue and by the amount of space between proteins in the muscle cell. Numerous factors can affect both the rate and the amount of drip or purge lost from the product.

The number of cuts made, size of resulting meat pieces and orientation of the cuts with respect to the axis of the muscle cell can influence the immobilized and free water. When increasing the number of cuts and cutting perpendicular to the muscle fibers some of the immobilized water may move into the free category and more free water can be lost as purge. The rate of temperature decline after harvest, temperature during storage and even the rate of freezing and temperature of frozen storage can cause immobilized water to shift into the free water category due to protein denaturation. This can lead to a decrease in water holding capacity (Huff-Lonergran and Sosnicki, 2002).

1.2.6 pH

Normal muscle pH drops from 7.2 (physiological) to between 5.5 and 5.8 during the immediate 24-hour post-slaughter. The ultimate pH is determined by the extent of the pH decline at 24-hours after slaughter. If pork reaches an ultimate pH of below 5.4 within approximately 3 to 5 hours after slaughter the pork is classified as PSE (pale, soft, and exudative) (Bendall and Swatland, 1988). PSE pork is caused by a very rapid drop in pH immediately after slaughter while muscle temperatures are still high. This combination of

relatively low pH and high temperatures results in proteins being denatured, which reduces WHC and results in a pale color (Brewer et al., 2001). PSE can be triggered by a combination of factors, such as genetics, pre-slaughter stress and post-slaughter handling. Pork classified as PSE loses its value for further meat processing, such as juiciness, solubility and gelation due to the lack of functional proteins (Schilling et al., 2003).

If the ultimate pH is above 6.0 the meat will have DFD (dark, firm, and dry) characteristics which appears darker in color, firmer texture, and has a high-water holding capacity. The DFD condition results from low glycogen levels in the muscle at slaughter due to glycogen depletion that occurs from a combination of chronic stress and activity levels before slaughter. DFD fresh meat is usually more palatable; however, it can cause bacteriological spoilage in fresh meat and problems in dry-cured products (Guardia et al., 2005).

1.3. Role of Fat in Swine Diet, on Carcass Characteristics and on Meat Quality

1.3.1 Role of Supplementing Fat in Swine Diets

Most of the lipid in swine diets is in the form of triacylglycerol which consist of three fatty acid molecules attached by ester bonds to a single glycerol moiety. The three fatty acids, which are hydrocarbon structures formed by four or more carbons attached to a carboxyl group, may differ in chain length and/or degree of saturation. Other types of lipids in swine diets include diacylglycerides (two fatty acids on a glycerol), monoacylglycerides (one fatty acid on a glycerol) and phospholipids, which are like a triacylglycerol except one fatty acid is replaced by orthophosphate and a nitrogenous base (Pettigrew, 1991). A fat is defined as a mixture of triacylglycerides which is solid or pasty at room temperature

(usually 20º C). Conversely, the term oil corresponds to a mixture of triglycerides which is a liquid at room temperature. The increase of double bonds in fatty acids significantly reduces its melting point. Thus, for a structure of the same number of carbon atoms, if it is saturated may give rise to a solid or semisolid product at room temperature, but if the same structure is unsaturated, it may originate a liquid or less solid product at room temperature (Valenzuela and Valenzuela, 2013).

Fatty acids are classified as short-chain fatty acids with four to six carbons; as medium-chain with eight to fourteen carbons; as long-chain with sixteen to eighteen carbons; and as very long-chain with twenty or more carbons. The longer the fatty acid chain the higher the melting point of the fatty acid. Carbons in fatty acids are linked by a covalent bond which may be single (saturated bond) or double (unsaturated bond). The simpler classification of fatty acids divides them into saturated fatty acids (SFA) which have no double bonds, monounsaturated fatty acid (MUFA) which have one double bond, and polyunsaturated fatty acids (PUFAs) which have two to six double bonds. Furthermore, each unsaturated fatty acid can be classified as cis- or trans- based on the configuration of the double bonds. Different forms of fatty acids function differently in animal metabolic reactions (Rossi et al., 2010; Valenzuela and Valenzuela, 2013).

There are physical effects of fat in swine diets that are of practical importance. Inclusion of supplemental fat reduces the amount of airborne dust in the pig building (Chiba et al., 1985). Added fat can also be used to reduce wear on feed processing equipment and increase the uniformity of feed mixes. Additionally, good quality supplemental fat increases the diet palatability for animal feed. Fat plays a key role in the growth and development of pigs and the requirements for these molecules changes with

age and individual physiological state. Biological attributes of dietary fat include: 1) provide a dense source of energy; 2) provides essential fatty acids; 3) facilitates absorption and transportation of fat-soluble vitamins; 4) affects meat quality; 5) provides bioactive lipid molecules; and 6) acts as important signal compounds (Rossi et al., 2010).

1.3.2 Meat Quality

According to the Swine NRC (2012), growing-finishing pigs require a metabolizable energy (ME) content of 3.34 Mcal ME/kg to maximize growth. Animal fats, vegetable oils and restaurant greases are common supplemental fat sources used in swine diets and they differ largely in their fatty acid composition. The addition of fats to grow-finish diets have been shown to reduce feed intake and enhance overall feed conversion thus making pigs more efficient. The goal is to provide just enough fat in the diet to maximize protein accretion (Pettigrew & Esnaola, 2001). Also, the inclusion of fats in pig finishing diets seem to have no significant effects on estimated carcass yield and pork quality (Eggert, Grant, & Schinckel, 2007). It is well-documented that pig growth, carcass composition and pork color quality are affected by genetics (Gu et al., 1992; Lo et al., 1992), gender (Mahan and Gerber, 1985; Shipp et al., 1996), BW (Martin et al., 1980; Cisneros et al., 1996), and the interactions among these effects (Fortin et al., 1987; Ellis et al., 1996; Unruh et al., 1996).

Typically, pork fat contains high concentrations of saturated fatty acids and lower concentrations of mono- and poly-unsaturated fatty acids (Miller, Shackelford, Hayden, & Reagan, 1990). The consumption of saturated fatty acids by humans may increase LDL-cholesterol, resulting in an increased risk of coronary heart disease (Rivellese et al., 2003). For pigs, there's been a drive to manipulate the fatty acid composition of meat. One way

to achieve this is by increasing n-3 PUFAs (formed from alpha-linolenic acid 18:3) by feeding oils/oilseeds that are high in unsaturated fatty acids (Wood et al., 2004). The swine industry has responded to the consumer preferences by developing leaner pigs with more unsaturated fatty acids. However, increases in linolenic acid and other PUFAs are undesirable to pork meat because increased PUFA content results in soft belly fat, which leads to poor bacon slicing, and may result in poor meat color due to oxidation (Gatlin et al., 2002). A greater amount of unsaturated fatty acids in meat lipids is more likely to cause fat oxidation when catalyzed by heme pigments. Thus, the interaction between pigment and lipid oxidation results in discoloration of meat due to pigment damage from oxidation (Gray and Pearson, 1994). Gatlin et al. (2003) showed that an increasing saturation of fat reduced the color or redness of pork due to lipid oxidation denaturing heme pigments. Oxidation can also result in the loss of nutritional value of meat, especially losses of vitamins (A, E, and C), and production of toxic molecules from cholesterol oxidation (Xiong, 2000). One method of interest to slow down oxidation is supplementing diets of livestock animals, or increasing amounts of, with antioxidants such as Vitamin E.

1.4. Dietary Vitamin E and Pork Quality

Vitamin E refers to a family of 8 structurally related fat-soluble compound isoforms, including four tocopherols (α, β, γ, and δ) and four tocotrienols (α, β, γ, and δ). These compounds contain a chromanol ring attached to a saturated (tocopherols) or unsaturated (tocotrienols) phytyl chain and vary as to the number of methyl groups on the chromanol ring as shown in Figure 1.2 (Jiang et al., 2001; Gril et al., 2014). All isoforms of vitamin E

are potent membrane-soluble antioxidants, however, α- tocopherol is the most potent form and is the most widely studied by meat scientists (Burton & Traber, 1990).

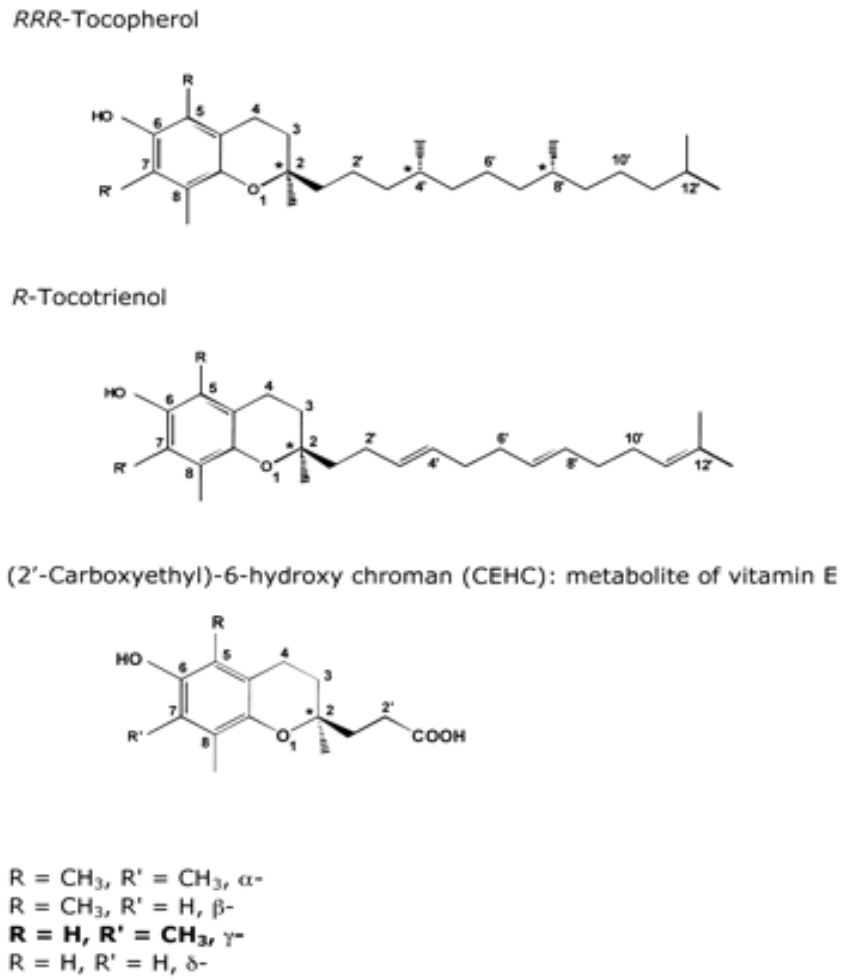

Figure 1.2 Chemical Structures of Vitamin E.
Jiang et al. (2001)

The supplementation of natural and synthetic Vitamin E, as an antioxidant, in livestock feed has gained popularity since the early 1990s. The requirements of Vitamin E and Se for grow-finishing pigs, from the NRC (2012), is shown in Table 1.2. The supplemental use of Vitamin E at supernatural levels in the swine diet has shown a dose-

dependent increase in tissue tocopherol concentration (Cannon et al., 1996). This accumulation is associated with several meat quality improvements.

Table 1.1 Requirement of Vitamin E and Selenium for Grow-Finishing Pigs

	BW, kg	5-7	7-11	11-25	25-50	50-75	75-100	100-135
NRC[1] (2012)	Vitamin E							
	Dietary[2]	16	16	11	11	11	11	11
	Daily need[3]	4.3	7.5	10.0	16.5	23.3	27.6	30.7
	Se							
	Dietary[4]	0.3	0.3	0.25	0.2	0.15	0.15	0.15
	Daily need[5]	0.08	0.14	0.23	0.30	0.32	0.38	0.42
DSM[6] (2016)	BW, kg	5-30		30-70		70-market		
	Dietary[2]	100-150		60-100		60-100		

[1] Assuming diets meet the energy requirement recommended by NRC (2012)
[2] Unit, IU/kg of diet. 1 IU vitamin E = 0.67 mg of D-α-tocopherol or 1 mg of DL-α-tocopheryl acetate.
[3] Unit, IU/day.
[4] Unit, %.
[5] Unit, mg/day.
[6] When dietary fat is higher than 3%, then add 5 ppm vitamin E for each 1% dietary fat.

1.4.1 Vitamin E and Meat Color

Myoglobin is the sarcoplasmic protein primarily responsible for the color of meat obtained from a well-bled livestock carcass (Livingston and Brown, 1981). In live muscle, myoglobin functions as the oxygen binder and delivers oxygen to the mitochondria, enabling the tissue to maintain its physiological functions, while in meat myoglobin serves as the major pigment responsible for the red color (Suman and Poulson, 2013). Myoglobin is a monomeric heme protein with a heme prosthetic group and a globin (protein) moiety. The globin chain, as shown in Figure 1.3, consists of eight helical segments (blue) forming a coiled structure enwrapping the heme (red), and the ability of myoglobin to bind oxygen is due to the presence of heme located within the heme crevice.

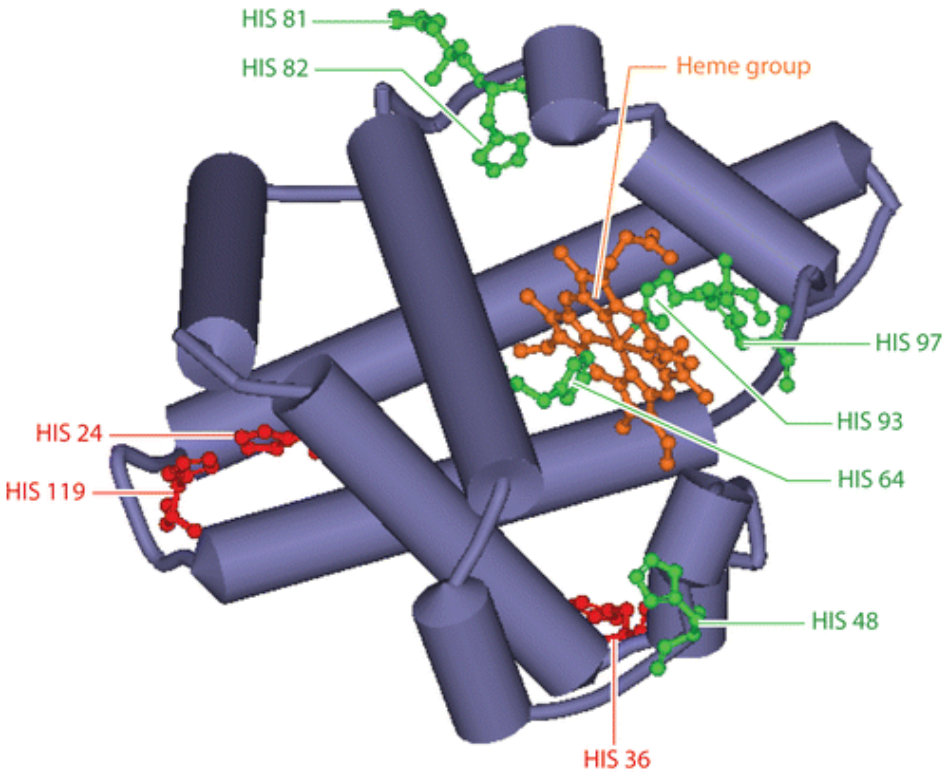

Figure 1.3 The three-dimensional structure of pork myoglobin.
Adapted from Suman and Joseph (2013)

Pigments oxidation, oxygen consumption and the effectiveness of the metmyoglobin enzymatic reducing systems affect the rate of discoloration in fresh meat. A consistent effect of dietary vitmain E supplementation on meat color has been extensively reported in ruminant animals including cattle, goat and lamb; however, this effect has been inconsistent in pork (Phillips et al., 2001). Ashgar et al. (1991) showed that the pork from pigs receiving the highest level of vitamin E (200 IU kg^{-1} feed) exhibited the smallest increase in thiobarbituric acid reactive substances. Similar results were reported by Lanari et al. (1995) where pigs were fed with either 13 ppm or 200 ppm VE, VE improved bone color stability regardless of the package atmosphere, and muscle color

stability was improved during display in air or modified atmosphere, although the beneficial effect was only detectable for illuminated storage. Jensen et al (1997) reported that a diet supplemented with 100 mg of a- tocopherol/kg feed from weaning to slaughter was sufficient to ensure optimum color stability of porcine M. *Longissimus dorsi a*nd M. *Psoas major*. Higher supplementation levels of 200 and 700 mg α-tocopheryl acetate/kg feed provided no additional benefit for pork meat quality color, marbling or firmness. Hoving-Bolink et al. (1998) also found that extra dietary vitmain E, or higher supplementation, had no effect on meat quality traits such as color, marbling and firmness. More recent studies using up to 326 ppm dietary VE did not detect significant effects in delaying discoloration (Ohene-Adjei et al., 2004 and Guo et al., 2006).

The inconsistent result might be due to the structural differences of myoglobin from pigs and cattle. When myoglobin was incubated with 4-hydroxy-2-nonenal (HNE), only mono-adducts of HNE with porcine myoglobin were detected and three histidine (HIS 24, 36 and 119) residues in porcine Mb that were readily adducted by HNE, whereas in bovine Mb seven histidine residues (HIS 24, 36, 81, 88, 93, 119 and 152) were detected (Suman et al., 2007).

1.4.2 Vitamin E and Water Holding Capacity

The term water-holding capacity refers to the ability of meat to hold moisture and it affects the appearance, cooking quality and eating quality. Past research has indicated that VE's antioxidant action can increase water holding capacity by measurements of drip loss and purge loss, although results are inconsistent. Cheah et al. (1995) reported an increase in water-holding capacity and Dirinck showed an increase in juiciness (Dirinck et al, 1996) as a result of dietary vitamin E supplementation. Ashgar et al. (1991) showed cell

membrane integrity is believed to play a role in drip loss and membrane lipids are thought to be protected from lipid oxidation by endogenous a-tocopherol. In a similar study, pork *Longissimus dorsi* samples from pigs fed increased α-tocopheryl acetate (200 mg/kg feed) showed reduced drip loss and lipid oxidation (TBARS) than a diet of 10 mg/kg (Monahan et al, 1994). However, other studies showed that dietary supplementation of VE up to 200 ppm has no significant effect on water holding capacity as measured by drip loss in pigs compared to those fed with control diets of less than 20 ppm dietary VE (Cannon et al., 1995; Cannon et al., 1996; Hoving-Bolink et al., 1998). Further studies need to be done for us to better understand the role of dietary VE on the water holding capacity.

1.4.3 γ-Tocopherol

Humans and animals do not synthesize vitamin E, they primarily acquire tocopherols from plants or chemically synthesized sources. α-tocopheryl acetate (ATA) is the most commonly used isoform in swine diets, however, γ-tocopherol represents ~70% of the VE consumed in the typical human diet in the United States (Jiang et al., 2001). γ-tocopherol is often the most prevalent form of VE in many plant seeds (Grilo et al., 2014). In contrast, α-tocopherol is the predominant form of VE in most human and animal tissues, blood plasma and the primary form in supplements. However, Burton et al. (1998) reported γ-tocopherol may constitute as much as 30–50% of the total VE in human skin, muscle, vein, and adipose tissue. Additionally, recent studies indicate that γ-tocopherol may be important to human health and that it possesses unique features that distinguish it from α-tocopherol. γ-Tocopherol appears to be a more effective trap for lipophilic electrophiles than is α-tocopherol (Jiang et al., 2001).

1.4.4 Shelf-Life

Shelf-life is defined as the period between packaging of a product and its end use when product properties remain acceptable to the product user. Shelf-life properties may include appearance, texture, flavor, color and nutritive value. Simply put, shelf-life is the amount of time that passes before meat becomes unpalatable or unfit for human consumption because of the growth of spoilage organisms (Delmore, 2009).

Meat color is an important attribute for consumers because it is the primary standard by which consumers assess freshness and acceptability. Consumers prefer bright-red fresh meats, brown or gray-colored cooked meats and pink cured meats. Any deviations may result in reduced price, consumer complaints and returned products. The relatively short shelf-life of fresh meats is the single greatest concern to retail meat markets (Cornforth, 1994). The rate of discoloration of meat is believed to be related to the effectiveness of oxidation processes and enzymic reducing systems in controlling metmyoglobin levels in meat (Gray, Gomaa and Buckley, 1996).

Fresh meats are stored under a variety of packaging systems for retail display. In packaged fresh meat, myoglobin can exist in any of the four redox states (Figure 1.4): deoxymyoglobin, oxymyoglobin, carboxymyoglobin and metmyoglobin (Mancini and Hunt, 2005). The heme iron of the porphyrin ring can exist either in a reduced ferrous (+2) or oxidized ferric (+3) state. If molecular oxygen complexes with myoglobin, oxygenation occurs by the formation of oxymyoglobin, which is a desirable bright red color. CO can attach to myoglobin and produce carboxymyoglobin. When oxygen is made unavailable, reducing enzymes convert myoglobin to a purplish-red myoglobin molecule known as deoxymyoglobin. Oxymyoglobin, carboxymyoglobin and deoxymyoglobin are susceptible

to oxidation when the state of iron changes from ferrous to ferric. Formation of brown metmyoglobin results from the oxidation of the three ferrous forms to ferric state and is associated with meat discoloration (Suman and Poulson, 2013).

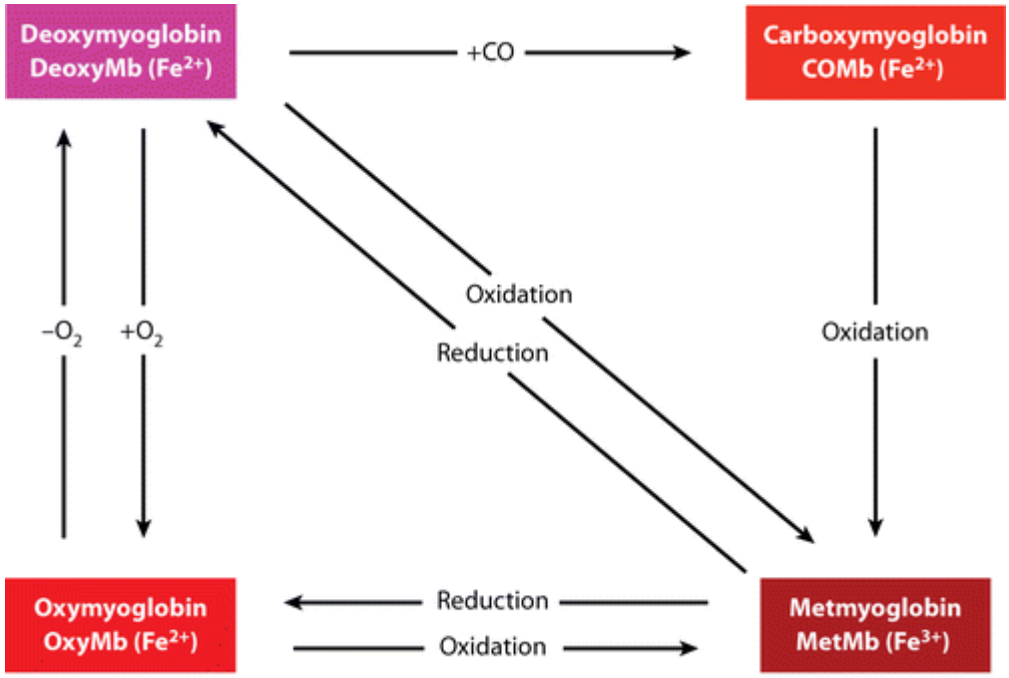

Figure 1.4 Myoglobin redox forms in fresh meat.
Adapted from Suman and Poulson (2013)

1.4.5 Oxidative Stability

One of the major factors affecting the shelf-life of meat products is rancidity or lipid oxidation, a chemical reaction that occurs when fatty acids found in meat react to a source of oxygen in the environment (Gerrard and Grant, 2003). Lipids are especially prone to oxidation during post-mortem handling and storage. Oxidation of lipids is a three-step radical chain reaction, which consists of initiation, propagation, and termination with the production of free radicals (Frankel, 2014) as shown in Figure 1.5. Initiation reaction produces the fatty acid (alkyl) radical (R•) which in turn reacts with oxygen to form peroxy

radicals (ROO•) in the propagation reaction. The peroxy radicals react with UFAs and form hydro-peroxides (ROOH), which later decompose to produce the volatile aromatic compounds that give meat its perceived off-flavors and rancid odor. The rate and extent of lipid oxidation are influenced by several factors, which include iron content, distribution of unsaturated fatty acids, pH and antioxidant levels (Falowo et al., 2014).

The thiobarbituric acid reacting substances (TBARS) test is the most commonly used method to measure lipid oxidative stability in foods, particularly meat and fish (Tarladgis, 1960). Malondialdehyde (MDA) is a decomposition product of lipid peroxides formed in meats which reacts with the TBA reagent to form a colored complex with maximum absorbance at 532 nm (Fernández et al., 1997).

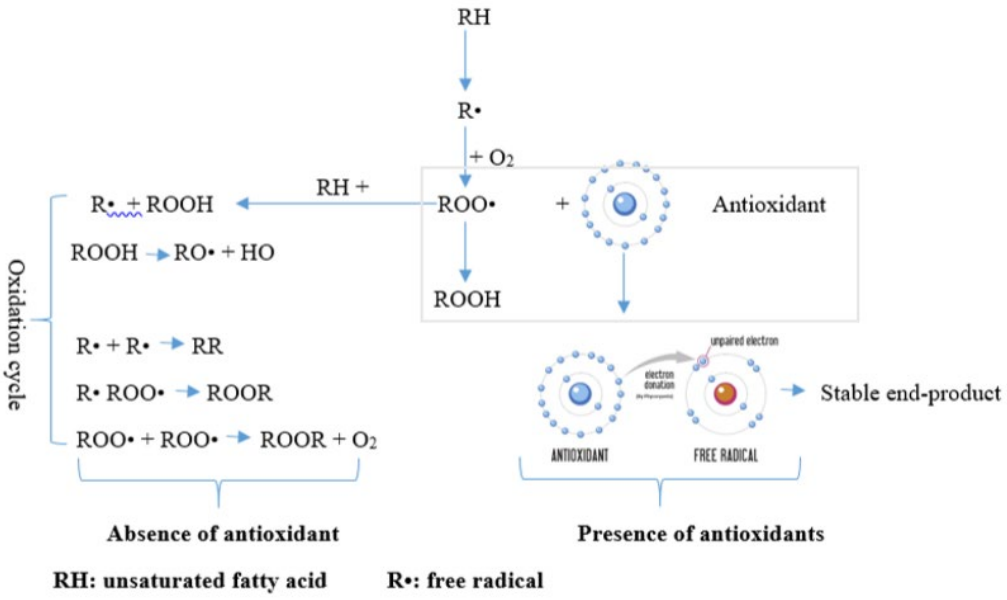

Figure 1.5 Antioxidant reaction with lipid oxidation from the propagation stage to terminate the oxidation cycle.

Adapted from Falowo et al. (2014)

1.5. Sensory Evaluation

The main objective of sensory evaluation is to provide valid and reliable information to production, research and development, marketing and quality control to make profitable decisions about the perceived sensory properties of the food products (Meilgaard, 1991). Sensory evaluation can be divided into two categories: consumer testing and objective quality measurements.

The current sensory evaluation methods comprise a set of measurement techniques with established track records of use in industry and academic research. The primary concern of any sensory evaluation is to ensure that the test method is appropriate to answer the questions being asked about the product in the test. Three types of sensory testing are commonly used, each with a different goal and each using participants selected using different criteria. A summary of the three main types of testing from Lawless and Heymann (2013) is given in Table 1.2.

Table 1.2 Classification of Test Methods in Sensory Evaluation.

Class	Question of Interest	Type of Test	Panelist Characteristics
Discrimination	Are products different in any way?	"Analytic"	Screened for sensory acuity, oriented to test method, sometimes trained
Descriptive	How do products differ in specific sensory characteristics?	"Analytic"	Screened for sensory acuity and motivation, trained or highly trained
Affective	How well are products liked or which products are preferred?	"Hedonic"	Screened for product use, untrained or trained

1.5.1 Hedonic Scale

The hedonic scale was developed in the U.S. Army Food and Container Institute in the late 1940s by Jones et al. (1955). In the hedonic scale method, the samples are presented singly and are rated on a scale where the 9 categories range from “dislike extremely” to “like extremely” with a neutral category “neither like or dislike” at the center of the scale (Peryam and Pilgrim, 1957). The test relies on people’s ability to communicate their feelings of like or dislike. Hedonic is popular because it may be used with untrained people as well as with experienced panel members. In hedonic testing, samples are presented in succession and the subject is able to make their own inferences about the meaning of the scale categories and determine for their self how they will apply them to the samples (Peryam and Pilgrim, 1957). A separate scale is provided for each sample in a test session. The scales may be grouped together on a page or be on separate pages. The like or dislike phrases are placed on a line-graphic scale either horizontally or vertically.

1.5.2 Sensory Attributes in Meat Quality

The most important aspect of meat quality is eating quality, usually defined as scores given by taste panelists for tenderness, juiciness, and flavor. These characteristics are affected by several factors in production, such as breed and diet and by intrinsic factors in the animal such as muscle type as determined by the proportions of the different muscle fibers (Wood et al., 2004). The sensory properties that are important to consumers may differ among different meat products.

For pork, tenderness is arguably the most important quality attribute to consumers (Steenkamp and Trijp, 1988). Tenderness can be attributed to a perception of meat, such as: softness to tongue and cheek, resistance to tooth pressure, fragmentation of the food

particles, adhesion, and residual after chewing (Breene, 1978). Juiciness depends on the amount of water retained in a cooked meat product. It helps in softening meat to make it easier to chew while fat stimulates saliva production in the mouth. Water retention and lipid content can impact the perception of tenderness and can determine juiciness (Blumer, 1963). Flavor is an important sensory attribute in pork, but this characteristic cannot be explained by consumers given their vocabulary is inadequate to explain the complex flavors found in most meat products (Chambers and Bowers, 1993). Thus, flavor intensity and off-flavor are typically the only flavor attributes evaluated in consumer sensory studies.

1.6. Belly/ Bacon Production and Quality

The pork belly is currently one of the most valuable primal cuts on the pork carcass (USDA, 2018). Despite the continued increase in bacon prices in recent years, consumer demand has not waned. This is partly because the consumption of bacon has transformed over the years from the traditional breakfast entrée to condiment for different dishes, including sandwiches, bacon bits, combination dishes and salads, among others, which has triggered the recent growth trend in the bacon market (Scramlin et al., 2008). The belly is one of the primal sections obtained from pig carcasses, usually cut from between the 2nd and 3rd ribs to just a few inches above the hip bone. About 55–60% of a pork belly is adipose tissue, although this percentage has decreased over the years (Person et al. 2005). Bacon processing generally follows the same basic steps with slight variations with spices and curing ingredient mixtures, as well as curing methods. The following briefly describe the basic operations in commercial bacon processing.

1.6.1 Raw Material Selection and Sorting

The composition of pork bellies is 55-60% fat; however, this varies depending on sex, genetics of the animal or dietary treatments, among other factors (Mandigo, 2002). Based on technological requirements and consumer demands for leaner meat, pork processors would prefer to sort pork bellies based on thickness and fat percentages but, currently, weight seems to take precedence. Proper sorting is essential because the bellies are pumped with curing solution at fixed percentage and poor sorting will lead to inconsistent product and poor product quality (The National Provisioner, 2008). Following sorting, pork bellies are skinned. Then adequate trimming of bellies to individual industrial specifications is done to get rid of spareribs and flank ends, which leaves about 65 to 85% of the original pork belly weight for curing (Knipe and Beld, 2014).

1.6.2 Curing Methods

There are basically three methods of curing bacon: pump/ injection, dry, and immersion curing. Pump/ injection curing is widely used for mass production of bacon because it allows the liquid curing ingredients to be injected directly into the pork belly to accelerate the curing process. This is done by a stitch or spray needle type machine (Mandigo, 2009). Dry curing involves applying premeasured dry cure mixture onto the belly surface and allowing it to cure for a few days. For immersion cure, bellies are immersed in a curing solution for two to three days.

For pump curing, the pork belly is injected with a liquid brine mixture (pickle) usually made up of water, salt, sugar, nitrite, sodium erythorbate and/ or ascorbate, and phosphate. Each of the ingredients in the brine mixture has a specific function. Water serves as the carrier for all the ingredients. Salt helps as a flavor enhancer and as a microbial inhibitor,

while the sugar helps to moderate the taste intensity of the salt in the product (Mandigo, 2009). Nitrite, with a permitted limit (FSIS, 2011) of not more than 120ppm, helps with inhibiting bacteria, flavor and color enhancement. Sodium erythorbate and/ or ascorbate is a cure accelerator and color stabilizer with a limit of 550ppm according to the United States Department of Agriculture (FSIS, 2011). Sodium phosphate cannot exceed 5000ppm in the United States (FSIS, 2011) and it helps with moisture retention during bacon processing and cooking (Mandigo, 2009). The order to which ingredients are added to water and dissolved is crucial in pickle formation. Necessarily, phosphate is adequately dissolved first followed by ascorbates, then salt, sugar and other flavorings, and nitrites come last. The pumping level of bellies is usually around 112 to 115% (FSIS, 2011) of the belly's green weight (fresh, pre-pumped). The belly is then allowed to equalize for a few hours before heating to prevent inconsistent color and streak marks.

1.6.3 Smoking and Pressing

Mass-produced bacon is heat processed in large convection ovens. It is much faster to mass produce bacon using a convection oven (as little as 6 hours) than by traditional smoking (many days). Bacon receives its smoke flavor and color from natural smoke obtained by smoldering wood chips or by spraying the bacon with a liquid smoke extract (FSIS, 2011). Aside from the flavor that smoke impacts to bacon, it also adds aroma and color and serves as a means of preservation, resulting from the heating, drying and the chemical components of the smoke, for example acetic acid, formaldehyde and creosote, among others (Young, 2008). Proper hanging of the bellies on bacon combs prior to transfer for smoking is also an important step to ensure a more regular belly shape that will subsequently aid high slicing yield. The target core temperature for bacon during smoking

ranges between 46 and 53°C, while the smokehouse schedule may be dependent on belly size, smokehouse air velocity, facility and internal temperature (Young, 2008). After smoking, bacon slabs are chilled and tempered. Bacon slabs are rapidly cooled to 4 to 5°C, within 24 hours, and then slowly chilled to -12°C to allow for proper fat setting (FSIS, 2011). Then they will be tempered in another refrigerated area, -5.5 to -3.3°C, in preparation for pressing. The chilled bacon is then pressed hydraulically into rectangular shaped bacon with width between 24 to 28 cm and varying length depending on the extent of trim. During pressing, bacon slabs should be at a temperature ranging from -2 to -1°C. This will facilitate a better shape that eventually results in better slicing and increased slicing yields (Rocha, 2011).

1.6.4 Slicing and Packaging

During slicing, bacon slabs should be at a temperature between -5 and -4°C. Slice breakage or fat smearing can occur if bacon slabs are too cold or too warm, respectively (Rocha, 2011). Usually bacon is sliced, and vacuum packaged as thin (> 17 strips per pound), regular (7 to 16 slices per pound) or thick (4 to 6 slices per pound) slices (Knipe and Beld, 2014).

1.6.5 Bacon Quality

The majority of the highest quality slices of bacon originate from the center slice or the slices nearest to the center on the posterior end (Mandigo, 2002). Bacon is evaluated according to lean content and slice thickness to identify premium quality slices. The bacon ranking system described by Person et al. (2005) is divided into three classifications: type #1, #2, and #3 slices. Type #1 bacon slices (Figure 1.6) will have the M. cutaneous trunci extending greater than 50% the length of bacon slice and its profile is no less than 1.9 cm

in thickness. Type #2 bacon slices would have a profile thickness no less than 1.9 cm or would have the M. cutaneous trunci not extending greater than 50% of the length of the bacon slice. Type #3 bacon slices are slices that do not meet any of the previously mentioned characteristics. Pieces falling into the type #3 category generally come from the shoulder or ham ends and are generally described as "ends and pieces" (Person et al., 2005). Outside of this grading system, there has been an increasing amount of research on belly firmness to evaluate bacon quality.

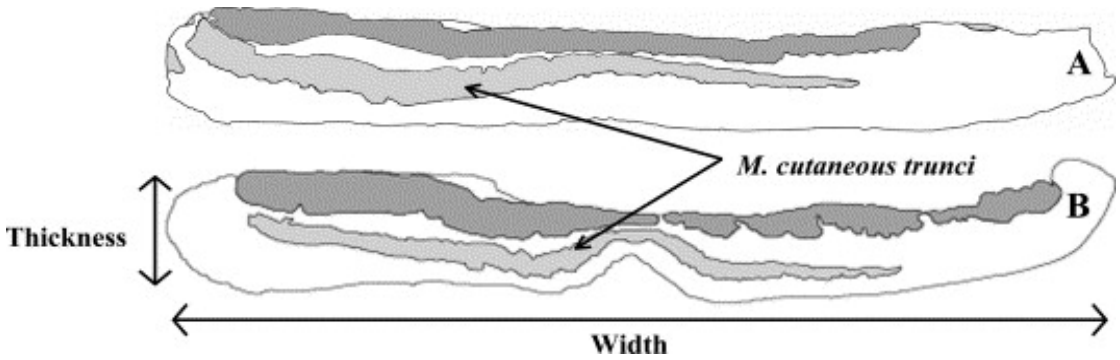

Figure 1.6 Diagram and nomenclature for dimensions and musculature used to characterize slices of bacon.

A) Type #1 Bacon. B) Type #2 Bacon.
(Person et al. 2005)

1.6.6 Belly Firmness

Consumers' desire for leaner meat has driven the reduction in the fat content of pork belly from 74% (Smith et al., 1975) to today's 45 to 55% (Scramlin et al., 2008), with a corresponding increase in the percentage of unsaturated fatty acids (Trusell et al., 2011). Pork belly softness is a major quality defect that has been reported to reduce processors' and packers' profitability because of its overall effect on fabrication efficiency, bacon shelf stability, sensory quality and bacon slicing yield. Generally, softer bellies may lead to oily

appearance and poor slice definition in bacon retail package, fat and lean separation, reduced slicing efficiency and yield of bacon slabs, and reduced product shelf life due to poor oxidative stability (Benz et al., 2010; Correa et al., 2008; Larsen et al., 2009).

Iodine value (IV) is an important quality factor used in studies of fat sources focusing on pork quality (Kellner et al., 2016). Iodine value refers to the grams of iodine taken up by 100 grams of fat. This measurement can reflect the degree of saturation of a fat source by indication of the relative content of double bonds within the constituent fatty acids (AOAC, 1990). The higher IV indicates that fat is more unsaturated and softer. Although IV has been widely used as an indication of belly firmness, the appropriateness of this measurement has been criticized due to its destructive and time-consuming nature, as well as the difficulty in deciding on a unique site of sampling for analysis on pig carcasses (Trusell et al., 2011). Furthermore, fat samples may have the same IV but are structurally different (Gatlin et al., 2005).

To quantify belly firmness, the following methods have been employed among different research groups: visual firmness scoring (Weber et al., 2006), finger pressure testing (Maw et al., 2003), compression and puncture test using texture analyzers (Apple at al., 2011), iodine value (Seman et al., 2013), and belly-flop testing. For the belly-flop test, the belly is centered over a bar at the midpoint of the length of the belly. Rentfrow et al. (2003) affixed a 7.6 cm diameter polyvinyl chloride pipe perpendicular to a board that had a 2.54 cm grid matrix drawn on it. Firmness was quantified by counting the boxes between the ham and shoulder ends. A larger distance between ends represented a firmer belly while a smaller distance signified a softer belly (Figure 1.7).

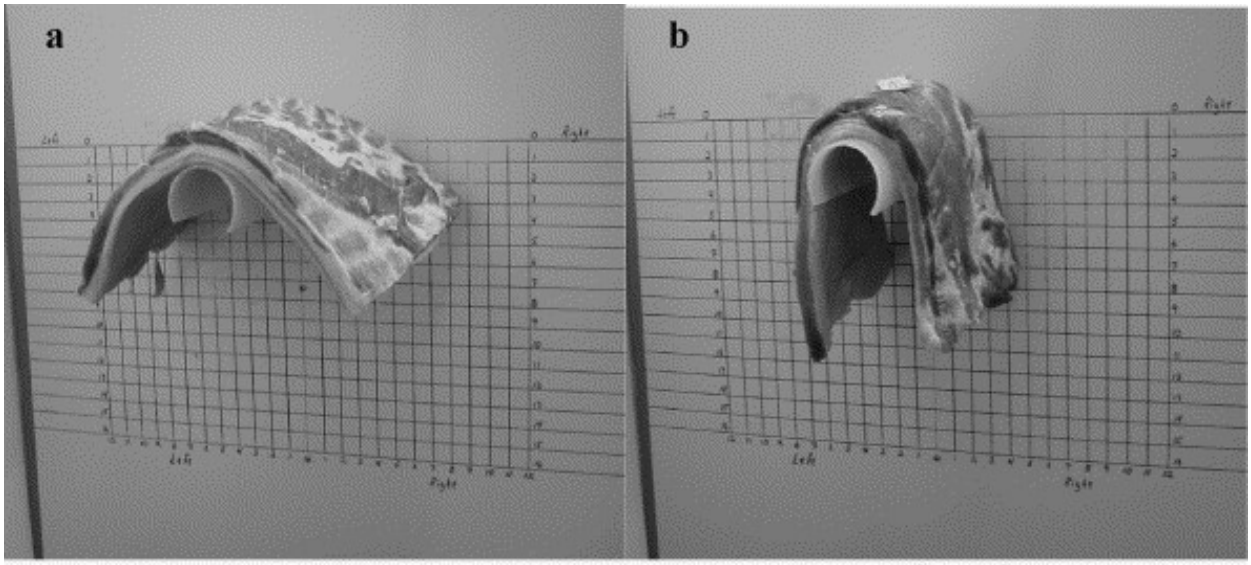

Figure 1.7 Measuring lateral and vertical belly flex.

(a) Illustrates a lower lateral, higher vertical flex; firmer belly. (b) Illustrates a higher lateral, lower vertical flex; softer belly. (Rentfrow et al., 2003)

1.6.7 Bacon Shattering

Bacon shattering, or fracture analysis, is defined as the incidence of breaks in the fat of a slice of bacon perpendicular to the length of the slice (Mandingo, 1998). Shatter marks do not include the natural separation of fat tissue or the separation between fat and lean tissue. Mandingo (1998) classified shatter marks into five categories depending on their length: 5mm, (1-10 mm), 15mm (11-20 mm), 25mm (21-30 mm), 35mm (31-40 mm), 41 and up mm. In another study, Rentfrow et al. (2002) divided a bacon slab, containing only commercially acceptable slices, into five separate sections and labeled as A, B, C, D and E. The first two slices from the cranial end are evaluated for fracture analysis. A trained person evaluates the bacon slice by rolling it over the forefinger. Subjective fracture analysis is found by dividing the slice into four quadrants along the length of the bacon slice and averaging the number of shatters. A score of 0 indicated that no visual cracks or

shattering could be detected, the scoring increased in severity with 2, 3, 4, 5 and a score of 6 indicative of a “spider-web” consistency of shattering within the fat of the bacon slice (Mandigo, 1998).

1.7 Conclusion

The market weight of pigs has continuously risen over the past decade and will continue to increase to an estimated 150 kg in 2032. To reduce the challenges associated with an increased market weight, research evaluating the potential outcomes of the heavier SLW including the size of primal cuts, meat quality, shelf life and bacon quality would be necessary. Furthermore, the cost pressure from the increasing ingredient price is causing producers to explore by-products, such as DDGS, which can result in soft pork with potential for oxidative problems. Using different fat sources that have a high saturated fatty acid contents (such as beef tallow) and supplementing diets with vitmain E could reduce peroxidation of pork fat. Additionally, supplementing different isoforms of VE (such as γ-tocopherol) could impact the rate of oxidation.

Therefore, the objective of the study was to evaluate the effect of two fat sources that differed in FA profile on carcass characteristics, meat quality, and belly/ bacon attributes of pigs grown to heavy slaughter weights and its potential interaction with the form and level of vitamin E.

Chapter 2 CARCASS CHARACTERISTICS AND FRESH MEAT QUALITY OF HEAVY WEIGHT (>150KG) PIGS FED DIFFERENT FAT SOURCES AND SUPPLEMENTATION OF VITAMIN E

2.1 Abstract

The objective of this study was to evaluate the effect of supplementing alpha-tocopheryl-acetate (ATA) and gamma-tocopherol (γ-T) vitamin E (VE) isoforms with corn oil (CO) and tallow (TW) on carcass characteristics, meat quality and sensory characteristics of pigs grown to heavier weights (>150kg). Individually fed pigs (n=72; 36 barrows, 36 gilts; 28.55 ± 1.16 kg) were randomly assigned to 12 dietary treatments in a 2 × 6 factorial arrangement. Fat treatments were TW and CO. The VE treatments included four levels of ATA (11, 40, 100, and 200 ppm) and two levels of mixed tocopherols (primarily γ-T; 40 and 100 ppm). Pigs were humanely slaughtered at approximately 150 kg. Carcass characteristics, pH, primal cuts, meat quality measurements and sensory characteristics were collected. Data analysis were performed by PROC GLM in SAS. There were no differences in dressing percentage, 45 min pH, 24 h pH, backfat depth, loin muscle area, primal cuts, purge loss, drip loss, objective color, TBARS and sensory analysis between the VE isoforms. Fat treatments did not affect 45-min and 24-h pH, backfat depth, loin muscle area, primal cuts, purge loss, drip loss, objective and subjective color, and sensory analysis. Slaughter weight ($P = 0.04$) increased with increasing dietary ATA VE. Dressing percentage was lower ($P = 0.04$) for pigs fed corn oil. Increasing dietary ATA VE had a quadratic effect on 45 min pH ($P = 0.02$) and 24-hour pH ($P = 0.02$). Fresh bellies from pigs fed fat sources with higher saturated fat acids displayed a greater belly depth ($P = 0.04$), a larger belly angle ($P < 0.01$), a higher lateral ($P < 0.05$) and a lower vertical ($P < 0.05$) belly flex. Pigs fed γ-T VE supplementation tended to have a higher L^* value ($P < 0.05$) and a higher a/b ratio ($P < 0.05$) during shelf life. The shelf life of loin

muscle measured as TBARS content was also improved ($P < 0.01$) when dietary ATA increased over 40 ppm. During extended shelf life measurements, TW supplemented pigs tended to have a higher L^* ($P < 0.05$) and b^* ($P < 0.05$). Pork sensory attributes such as tenderness ($P < 0.01$), juiciness ($P < 0.01$) and overall approval ($P < 0.01$) increased with increasing dietary ATA VE. Also, γ-T VE chops exhibited less of an off-flavor ($P = 0.05$) during sensory analysis.

Keywords: fat, vitmain E, heavy slaughter weight pigs, tocopherol, isoforms

2.2 Introduction

A question that arises in almost all discussions about the future of agriculture is – "How will we feed a growing population in the future?" According to the Food and Agricultural Organization (2014), the meat of choice worldwide is pork except for those countries that do not eat pork for religious reasons. The increasing demand for pork can only be met by increasing the number of pigs produced or by increasing slaughter weight (SLW). Given the pressure of total food supple on finite land mass, it is obvious that increased market weights will be a large part of meeting demand. While it is relatively easy to slaughter at a heaver weight, there has been very little research on the pork quality.

The increasing price of feed ingredients has driven producers to explore more and more by-products. This has led to the increasing use of dried distillers grains with solubles (DDGS). Some producers have added as much as 30% of DDGS in the diet, which has created some pork quality issues. The main quality concern is soft pork fat due to the high content of unsaturated fatty acids (UFA) present in DDGS. Ellis and Hankins (1925) first reported the relationship between dietary FA composition and pork carcass firmness, and it is now widely accepted that pork carcass fat is closely related to dietary FA profile (Kellner et al., 2014; Kellner et al., 2017). Reduction in pork quality and product value may occur when increasing pig SLW due to the longer feeding periods of high polyunsaturated oils.

Vitamin E is an antioxidant that may contribute to reducing oxidative stress and improve the oxidative stability of pork while prolonging fresh pork shelf life (Bolar et al., 2009). Wang et al. (2012) found that supplementation with high levels of vitamin E decreased the TBARS value of meat produced with high DDGS diet (30% highest) on d 4,

7, 10 and 13 post slaughter. Therefore, improving dietary vitamin E levels could increase lipid stability of pork produced with increasing unsaturated FAs caused by the change in dietary FAs (Guo et al., 2006). Additionally, recent studies indicate that γ-tocopherol may be important to human health and that it possesses unique features that distinguish it from α-tocopherol. Although the absorption rate α-tocopherol and γ-tocopherol is similar, the elimination of γ-tocopherol from plasma is faster, which might imply either faster excretion or faster incorporation into tissue; more rapid incorporation into tissue could be extremely positive in improving meat quality, especially in preventing lipid oxidation in meat. However, the interaction between VE and fat sources are rarely reported.

Therefore, the objective of the study was to evaluate the effect of two fat sources that differed in FA profile on carcass characteristics and meat quality of pigs grown to heavy slaughter weights and its potential interaction with the form and level of vitamin E.

2.3 Materials and Methods

The growth and feeding phase of the experiment was carried out in environmentally controlled rooms at the University of Kentucky Swine Research Center. The slaughter and sample collection were performed at the University of Kentucky Meats Science Laboratory. The experiment was conducted under protocols approved by the Institutional Animal Care and Use Committee of the University of Kentucky. The study was a collaborative research project evaluating meat quality from the same set of pigs by Wang (2019).

2.3.1 Animals, Diet and Experimental Design

A total of 72 individually fed pigs (half barrows and gilts; initial BW ~24-30 kg) were blocked by sire, body weight, and sex, and then randomly assigned to individual pens.

Pens were randomly assigned to 1 of 12 dietary treatments in a 2 x 6 factorial arrangement. Fat treatments included Tallow and Corn Oil. Vitamin E treatments included four levels α-tocopheryl-acetate (11, 40, 100 and 200 ppm) and two levels of mixed tocopherols (primarily γ-tocopherol; 40 and 100 ppm). The diets were corn-soybean meal (SBM) based diets in mash form and fed for five weight phases including 25-50 kg, 50-75 kg, 75-100 kg, 100-125 kg, and 125-150 kg, respectively. All experimental diets were formulated to meet or exceed NRC (2012) nutrient requirement estimates for grow-finishing pigs. Formulas for each phase are listed in Table 2.1. Treatment diets were fed to pigs up until slaughter, and slaughter weight was ~150 kg.

The ATA was suppled in the form of DL (all-rac)-α-tocopheryl acetate (ROVIMIX E 50 ADS, DSM Nutritional Products, Inc., GA US) in a dry form. The mixed tocopherols were supplied as Mixed Tocopherols 95 (DSM Nutritional Products, Inc., NJ US) in liquid form, which contained 0-15% α-tocopherol, less than 5% β-tocopherol, 55-75% γ-tocopherol, and 20-30% δ-tocopherol.

Table 2.1 Basal diet composition of diets with different fat sources[1] and VE isoform/levels[2] from Phase 1 to Phase 5 (as-fed basis)

Ingredient, %	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Corn	62.85	69.55	73.81	77.04	80.17
Soybean meal, 48% CP	28.50	22.00	18.00	15.00	12.00
Fat (tallow or corn oil)	5.00	5.00	5.00	5.00	5.00
L-Lysine HCL	0.22	0.24	0.21	0.17	0.22
DL-Methionine	0.12	0.09	0.04	0.01	0.01
L-Threonine	0.09	0.09	0.06	0.04	0.05
Limestone	1.08	0.99	0.88	0.77	0.68
Dicalcium phosphate	0.92	0.82	0.78	0.75	0.65
Salt	0.50	0.50	0.50	0.50	0.50
Vitamin premix[3]	0.02	0.02	0.02	0.02	0.02
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15
Choline[5]	0.03	0.03	0.03	0.03	0.03
Santoquin[6]	0.02	0.02	0.02	0.02	0.02
AB-20[7]	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00

Calculated nutrient level, %	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
ME, Mcal/kg	3.47	3.49	3.50	3.50	3.51
CP, %	19.13	16.58	14.94	13.70	12.59
SID Lys	1.04	0.90	0.78	0.67	0.64
SID Lys/ME	2.99	2.58	2.22	1.92	1.82
SID Met	0.38	0.32	0.26	0.21	0.20
SID Cys	0.26	0.24	0.22	0.21	0.19
SID M+C	0.65	0.55	0.47	0.42	0.39
SID Arg	1.13	0.94	0.82	0.73	0.65
SID His	0.45	0.39	0.35	0.33	0.30
SID Ile	0.69	0.58	0.51	0.46	0.41
SID Leu	1.43	1.28	1.19	1.12	1.05
SID Phe	0.81	0.70	0.62	0.57	0.52
SID Tyr	0.53	0.45	0.40	0.37	0.33
SID P+T	1.34	1.15	1.03	0.94	0.85
SID Thr	0.67	0.58	0.50	0.44	0.41
SID Trp	0.20	0.17	0.14	0.13	0.11
SID Val	0.75	0.64	0.58	0.53	0.48
SID Ca	0.7	0.62	0.56	0.51	0.44
Total P	0.54	0.49	0.46	0.45	0.41
STTD P	0.32	0.29	0.27	0.26	0.23

[1] Fat treatment included corn oil and tallow

[2] Dietary VE treatments including four levels of ATA (11, 40, 100, and 200 ppm) and two levels of mixed tocopherols (40 and 100 ppm) were applied to each basal diet.

[3] Supplied the following per kg of diet: 7,000 IU of vitamin A; 1,500 IU of vitamin D3; 2.0 mg of vitamin K; 0.03 mg of vitamin B12; 7.0 mg of riboflavin; 25.0 mg of pantothenic acid; 20.0 mg of niacin; 1.0 mg of folic acid; 2.5 mg of vitamin B6; 2.0 mg of thiamin; and 0.15 mg of biotin.
[4] Supplied the following per kg of added fat diet: 50 mg of Mn as manganese hydroxychloride; 100 mg of Fe as ferrous sulfate monohydrate; 125 mg of Zn as zinc hydroxychloride; 20 of Cu as tribasic copper chloride; 0.35 mg of I as calcium iodate; and 0.30 mg of Se as sodium selenite.
[5] Provided 150 mg per kg of choline to the final diet.
[6] Santoquin (Monsanto, St. Louis MO) supplied 130 mg/kg ethoxyquin to the final diet.
[7] Clay product from Prince Agri Products, Inc., Quincy IL.

2.3.2 Slaughter and Carcass Fabrication

Pigs were humanely slaughtered at ~150 kg live weight at the University of Kentucky (UK) Meat Lab under USDA inspection according to standard industry practice. Pigs to be slaughtered were weighed (BW) and then loaded and transported to the UK Meat Lab (~20km, ~ 40 minutes). Pigs were then slaughtered after resting for at least 30 minutes. Pigs were slaughtered under the supervision of the Food Safety and Inspection Service of the United States Department of Agriculture (USDA). At 45 min, pH between the 10th and 11th rib was recorded with an Accumet 50 pH meter (Fisher Scientific, Fairlawn, NJ, USA) and hot carcass weights were taken to calculate dressing percentage [(HCW/BW) × 100)].

All carcass measurements were performed according to the methods described by McClelland et al. (2012). Following a 24-h chill (4°C), cold carcass weight, fat depth at the 10th rib, 1st rib, last rib, and last lumbar were measured on the left side of each carcass. Carcass length was measured from the anterior edge of the symphysis pubic to the recess of the first rib. The Boston butt (IMPS #406), shoulder picnic (IMPS #405), loin (IMPS #412), and belly (IMPS #408; squared at each end) and spareribs were removed and weighed individually according to Institutional Meat Purchasing Specifications (North

American Meat Processors Association, 2010). Primal cuts were recorded in absolute weight (weight in kg of the primal) and relative weight ((primal cut, kg/HCW) × 100). After weighing the loin, it was deboned, and chops were cut anterior to the 10th rib location for further analysis. The first chop at the 10th rib (~2.54cm) was used for subjective and objective color, the second (~2.54cm) was used for drip loss, the third (~2.54cm) for sensory evaluation, and the remaining loin section was used to measure purge loss. Belly depth was measured in 6 locations that were evenly divided into rectangles from the shoulder to flank end before being measured for belly flex. *Longissimus dorsi* muscle area (LMA) and 24-hour pH (Accumet 50 pH meter Fisher Scientific, Fairlawn, NJ, USA); were also measured from the left side of each carcass according to methods described by NPPC (2000).

Belly flex was measured to determine belly firmness using an objective test developed by Rentfrow et al. (2003). The detailed procedure for this measurement was previously described by Cromwell et al. (2011). The spareribs, related cartilage and remaining leaf fat were removed, and the bellies were squared. The fresh bellies with the skin on were then centered, skin side down, on a 7.5-cm diameter polyvinyl chloride pipe mounted perpendicular to a board marked with a 2.54-cm grid matrix. Lateral and vertical flexes were determined from the degree of belly flex relative to the grid matrix. A vertical belly flex of zero meant the belly was parallel to the floor and completely stiff. A lateral belly flex of 10 cm meant that the belly flexed to a point where there was 10 cm between the end of the squared belly and a vertical line directly below the center of the supporting polyvinyl chloride pipe. Thus, a lower lateral flex and a higher vertical flex indicated a

softer, more flexible, belly. The belly flex measurements were determined in a room maintained at 7°C. The bellies were boxed, and then frozen (-22°C) until further analyses.

2.3.3 Meat Quality Measurements

2.3.3.1 48-hr Drip Loss and Purge Loss

A chop (~1.3cm) from the *Longissimus thoracis* was obtained that was anterior to the 10th rib. Drip loss was determined by suspending the sample from a hook covered by a plastic bag and stored at 4°C for 48 hours. The samples were weighed before and after hanging, drip loss percentage was determined by the following equation:

Drip loss (48 hr, %) = (Initial weight – 48 hr weight) / Initial weight × 100

For purge loss, a 10cm section of *Longissimus thoracis*, anterior to the 10th rib, was obtained and weighed prior to being vacuum packaged, boxed and stored under refrigeration (4°C) for 30 days to simulate the period between the packing plant and the retail grocery store. Loin samples were reweighed at day 7, 14, and 30 to determine purge loss at each stage to help determine when the majority of weight is lost during storage. Before reweighing the samples, they were taken out of the vacuum package and surface water was removed with a paper towel. The samples were vacuum packaged, reweighed and stored in the same conditions. All sample handling was conducted at 4°C.

2.3.3.2 Subjective and Objective Meat Color Evaluation

For subjective color measurements, a 2.54 cm chop was cut from the *Longissimus thoracis* immediately after the 24 hr primal weight and placed on foam trays which were then overwrapped in Polyvinyl Chloride (PVC) film. Subjective color, marbling score, and firmness (NPPC, 1999) were evaluated by a single trained individual. National Pork

Producers Council (NPPC) color scale (1-5, 1= pale pinkish to white; 5= dark purplish), NPPC marbling scale (1-5, percentage of fat in the loin muscle), and NPPC firmness scale (1-5; 1=very soft; 5= very firm) were used.

The overwrapped chops were also analyzed for objective color using a HunterLab LabScan XE colorimeter (Hunter Associated Laboratory, Reston, VA) with a 2.54cm diameter aperture, illuminant A, and 10° standard observer was used to measure CIE lightness (L^*), redness (a^*) and yellowness (b^*) values from 3 random locations on the light-exposed surfaces (American Meat Science Association, 2012). The instrument was standardized before the analysis with black and white tilers that had been overwrapped with PVC film to adjust for the PVC over the chop. Spectral reflectance was determined every 10 nm over the 400-700nm range. Observations were made at retail display days (1, 3, 5, and 7; 1300 Lax) to determine shelf-life. The a^*/b^* ratio, hue angle ($\tan{-1}(b^*/a^*)$) and chroma ($\sqrt{a*2 + b*2}$) were calculated to help indicate shifts in color over time toward discoloration. Additionally, after the loin sections underwent the 30-day purge loss period, a 2.54cm chop was taken to examine the shelf-life after the period between the packing plant and the retail grocery store. The chop was overwrapped with PVC film and objective color measurements were taken at 30, 32, 34 and 37 days post-slaughter.

2.3.3.3 Oxidative Stability

Lipid oxidation was determined utilizing the distillation method to analyze TBARS as described by Yin et al. (1993). Samples (5g) from the *Longissimus thoracis* were homogenized with 22.5mL of 11% trichloroacetic acid solution (TCA) and filtered through Whatman no. 1 paper. Two mL filtrate was mixed with two mL of aqueous solution of thiobarbituric acid (20 mM), and incubated at room temperature for 20 hr. The absorbance

values at 532 nm were then measured utilizing a UV-1800 spectrophotometer (Shimadzu Corporation, Kyoto, Japan). The value of concentration of TBARS was calculated from a standard line based on known concentration of a standard malondialdehyde (Cayman, Ann Arbor, MI).

2.3.3.4 Hedonic Sensory Analysis

A trained 8-member panel of University of Kentucky students/staff (male and female) agreed to participate in the sensory evaluation for the entire length of the study. The evaluation was split into multiple day sessions and was conducted in the University of Kentucky sensory lab using American Meat Science Association Guidelines (2015). The panelists evaluated five sensory attributes and ranked them on the following scale: tenderness 1-6 (1= extremely tough; 6= extremely tender), juiciness 1-6 (1= extremely dry; 6= extremely juicy), off-flavor 1-6 (1=none; 6=intense off-flavor), pork intensity 1-6 (1=none; 6= extremely intense), and overall liking 1-6 (1=extremely dislike; 6=extremely like).

The previously cut ~2.54cm chops for sensory evaluation were taken out of the freezer and thawed at 4°C for 24 hr. Each individual chop was assigned at three-digit number that was written on the plates served to the panelist and each plate contained six samples. The chops were cooked on George Foreman Basic Plate grills (George Foreman, Spectrum Brands, Inc., Madison, WI). Internal temperature of each chop was monitored using a thermocouple positioned in the geometric center of each chop. Chops were removed from the grills at 69.5°C in order to reach a target endpoint temperature of 71°C. Samples were immediately cut into ~1.27cm × 1.27cm cubes and served warm to the panel for evaluation.

2.3.4 Statistical Analysis

Prior to analyses, all data was evaluated to identify any potential statistical outliers according to the test published by Barnett and Lewis (1974). To summarize, outliers can be tested by the following procedure. First, calculate the statistic T: T = (XH -Mean)/s for a high value, or T = (XL – Mean)/s for the low value (XH, high value; XL, low value; s, standard deviation). Second, compare the value of T with the value from critical values for 95% confidence interval (under condition of this study, the critical value is 2.03.) If the calculated T is larger than the critical value for the measurement, then the XL or XH is an outlier at the level of 5% significance. Potential outliers are listed in Appendix 1.

Data analysis was performed in SAS (SAS Inst. Inc., Gary, NC) by least squares analysis of variance using the generalized linear model (GLM) as a randomized complete block design. The individual pig served as the experimental unit. When interaction between main effect and other factors was significant, further contrasts between each two treatments were performed to analyze the treatment effects. In addition, shelf life data was also analyzed as repeated measures to determine the response trends over time. Regression and contrasts were also performed as necessary when interactions between time and main effect were observed.

Statistical differences were established at $P \leq 0.05$, tendencies were established at $P \leq 0.10$. Sex effect was expected but is not discussed in the results in this chapter. *P*-values for sex and related interactions are listed in Appendix 2 (values greater than 0.10 are replaced as "-"). In the results table, all *P*-values greater than 0.20 were replaced as "-". For evaluation of ATA levels and fat sources, *P*-values for main effects are provided, significant interactions ($P \leq 0.05$) between levels of dietary ATA and fat sources are

superscripted in the table. For evaluation of isoforms, because *P*-values for effects of dietary VE level and fat sources and their interactions have been provided previously, only *P*-values for effects of isoform and its interaction with main effects including levels of dietary VE and fat sources are provided in the tables.

2.4 Results and Discussion

2.4.1 Carcass Traits and Primal Cuts

The results of carcass traits are listed in Table 2.2. There were no differences in HCW, CCW, shrink loss, carcass length, back fat depth and loin muscle area among different treatments. Increasing dietary levels of ATA from 11 to 200 ppm affected the SLW (linear, $P = 0.04$), 45-min pH (quadratic, $P = 0.02$) and 24-hour pH (quadratic, $P = 0.02$). Interactions between isoforms of VE and fat sources was observed for the difference in pH ($P = 0.03$) between 45-min and 24-hr. γ-T increased in ΔpH from 40 ppm to 100 while ATA decreased between the levels, additionally, corn oil appeared to cause a larger difference between the levels. Pigs fed TW had higher dressing percentages ($P = 0.04$) and greater belly depth ($P = 0.04$) than pigs fed CO.

Results of primal cut weights are provided in Table 2.3. There were no differences in ATA level for absolute weight (primal cut, kg) and relative weight (primal cut, percentage of HCW). Pigs fed γ-T had a lower belly weight (IMPS #408; squared at each end) in relative weight ($P = 0.02$) than pigs fed ATA. Interactions between fat and dietary ATA VE level were observed for absolute and relative weight for picnic shoulder (IMPS #405) ($P < 0.05$). No other effects of dietary treatment were observed on primal cuts.

Table 2.2 Effect of different fat sources and VE supplementation on carcass traits of pigs[1]

		Isoforms						*P*-value					
		ATA, ppm				γ-T, ppm		ATA[2] Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
SLW, kg	TW	146.24	148.23	147.49	147.87	145.23	147.51	0.04	-	-	-	-	-
	CO	146.06	148.21	148.02	151.12	149.08	147.24						
HCW, kg	TW	113.17	114.44	114.53	113.62	111.17	112.81	0.09	-	-	-	-	0.14
	CO	111.87	112.77	113.89	115.44	114.19	112.35						
CCW[4], kg	TW	110.54	111.58	111.13	110.62	109.09	109.27	0.14	-	-	0.17	-	-
	CO	109.15	109.54	111.36	112.79	110.03	109.72						
Dressing[5], %	TW	77.41	77.21	77.65	76.99	77.21	76.62	-	-	0.04	-	-	-
	CO	76.29	76.09	76.36	76.42	76.61	76.30						
Shrink loss[6], %	TW	2.33	2.48	2.30	2.60	1.87	2.38	-	-	0.07	-	-	0.11
	CO	2.36	1.66	2.23	1.49	2.40	2.34						
45-min pH	TW	5.90	6.13	6.09	5.91	6.02	5.99	-	0.02	-	0.15	-	-
	CO	5.87	6.19	6.10	6.10	6.12	6.00						
24-hour pH	TW	5.59	5.71	5.66	5.53	5.64	5.65	-	0.02	-	-	-	-
	CO	5.49	5.65	5.70	5.72	5.75	5.57						
ΔpH[7]	TW	0.31	0.42	0.41	0.42	0.30	0.35	-	-	-	0.19	-	0.03
	CO	0.33	0.54	0.32	0.38	0.34	0.43						
C. Length, cm[8]	TW	82.07	84.14	83.71	83.82	82.55	82.44	-	-	-	-	-	-
	CO	82.42	85.25	82.80	84.24	85.09	82.02						
Back fat depth, cm													
First Rib	TW	4.17	4.93	5.13	4.88	4.85	4.61	-	-	-	-	-	-
	CO	4.93	4.51	4.62	4.78	4.74	5.03						
Last Rib	TW	3.35	3.71	3.43	3.24	3.60	3.77	-	-	-	-	-	-
	CO	3.33	3.40	3.43	3.43	3.26	3.56						

Table 2.2 Continued.

10th Rib	TW	2.69	2.90	3.01	2.60	3.05	3.22	-	-	-	-	-	-
	CO	3.15	2.86	3.22	2.90	2.67	2.69						
Last Lumbar	TW	2.34	2.72	2.12	1.73	2.29	2.18	0.11	-	-	-	-	-
	CO	2.29	2.48	2.46	2.41	2.58	1.98						
Belly Depth, cm	TW	5.15	5.23	5.13	4.94	5.21	5.05	-	-	0.04	-	-	-
	CO	4.63	4.95	4.81	4.83	4.85	4.42						
Loin Muscle Dimension[9], cm													
Vertical	TW	7.37	7.01	7.75	7.21	7.62	7.28	-	-	-	-	-	-
	CO	7.16	7.18	6.86	7.58	7.26	7.57						
Horizontal	TW	10.82	10.57	10.58	10.41	10.29	10.80	-	-	-	-	-	-
	CO	10.21	10.61	10.46	11.01	10.29	10.26						
Area[10], cm^2	TW	61.04	58.84	58.52	59.49	62.05	61.40	-	-	0.17	-	-	-
	CO	56.39	57.64	56.00	58.58	54.30	57.87						

[1] Values are average of 6 replicates. SLW, slaughter weight; HCW, hot carcass weight; CCW, cold carcass weight; C. Length, carcass length. *P*-values for sex interactions are listed in Appendix Table A 2.1

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. No interaction between fat sources and dietary ATA levels was observed.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] Cold Carcass Weight (CCW) was recorded 24 hours post slaughter.

[5] Dressing Percentage was calculated by ((HCW/BW) × 100).

[6] Shrink Loss was calculated by (((HCW-CCW)/ HCW) × 100).

[7] ΔpH was calculated by (45 min pH-24 hr pH).

[8] Carcass Length was measured from the anterior edge of the symphysis pubic to the recess of the first rib.

[9] Vertical distance refers to depth vertical to the 10^{th} rib; Horizontal distance refers to width horizontal to the 10^{th} rib.

[10] Area was measured with a plastic standard grid as described by NPPC (2000).

Table 2.3 Effect of different fat sources and VE supplementation on primal cuts of pigs[1]

								P-value					
		Isoforms						ATA[2]					
		ATA, ppm				γ-T, ppm		Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
Primal cuts[4], kg													
Boston Butt	TW	5.15	4.68	4.88	4.93	4.91	4.96	-	-	-	-	-	-
	CO	5.14	4.63	5.07	4.58	5.08	4.98						
Picnic Shoulder	TW	5.11	5.60	5.44	4.83	5.63	4.85	-	-	I	-	-	0.17
	CO	4.93	5.17	5.08	5.57	5.22	5.08						
Loin	TW	12.96	12.37	12.71	12.41	12.27	12.58	-	-	-	-	-	-
	CO	12.07	11.83	12.51	12.51	12.69	12.59						
Spare Ribs	TW	2.20	2.04	1.99	1.91	2.10	2.07	0.14	-	-	-	-	-
	CO	1.89	2.15	1.95	1.93	1.97	1.91						
Ham	TW	12.49	12.87	12.68	12.84	12.40	12.36	-	-	-	-	-	-
	CO	12.54	12.37	12.76	13.06	12.69	12.73						
Belly	TW	9.75	9.52	9.41	9.36	8.88	9.53	-	-	-	0.11	0.14	-
	CO	10.03	9.95	9.36	9.49	9.49	9.12						
Primal cuts[5], % hot carcass weight													
Boston Butt	TW	4.57	4.26	4.33	4.37	4.24	4.37	-	-	-	-	-	-
	CO	4.51	4.07	4.69	4.02	4.50	4.38						
Picnic Shoulder	TW	4.51	5.06	4.83	4.28	4.86	4.29	-	0.06	I	0.07	-	-
	CO	4.32	4.55	4.72	4.88	4.60	4.46						
Loin	TW	11.45	11.22	11.24	11.00	10.53	11.13	-	-	-	-	-	-
	CO	10.57	10.40	11.60	10.99	11.20	11.08						
Spare Ribs	TW	1.87	1.85	1.77	1.69	1.82	1.84	-	-	-	-	-	0.17
	CO	1.65	1.89	1.89	1.70	1.73	1.68						
Ham	TW	11.03	11.66	10.87	11.44	10.71	10.94	-	-	-	-	-	-
	CO	10.98	11.39	11.46	11.68	11.19	11.21						

Table 2.3 Continued

Belly	TW	8.61	8.63	8.34	7.99	7.67	8.06	0.11	-	-	0.02	-	-
	CO	8.80	8.74	8.68	8.34	8.36	8.08						

[1] Values are average of 6 replicates. *P*-values for sex interactions are listed in Appendix Table A 2.1

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. [I] Interaction between fat and dietary VE level, $P < 0.05$.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] Primal cuts were made according to Institutional Meat Purchasing Specifications (NAMPA, 2010).

[5] Primal cuts percentage of hot carcass weight (HCW) was measured by ((primal cut weight/ HCW) × 100).

2.4.2 Meat Quality

The water holding capacity was not affected by dietary treatments when measured by drip loss and purge loss in Table 2.4, however, an increase in purge loss (linear and quadratic, $P < 0.01$) was observed with increasing retail display. Subjective meat quality measurements were not affected by dietary treatments. The γ-tocopherol supplementation tended to have a lighter subjective color (P=0.06). As expected, belly flex was affected by dietary fat sources but not dietary vitamin E supplementation. Pigs fed tallow diets had a higher lateral distance ($P < 0.05$) and a lower vertical distance ($P < 0.05$) then pigs fed corn oil diets. Pigs fed tallow diets also had a greater belly flex than pigs fed corn oil diets ($P < 0.01$). Bellies from pigs fed TW fat sources tended to have firmer bellies, as anticipated since TW is higher in saturated fatty acids.

Shelf life samples were measured at retail times of 1, 3, 5, 7 days (Table 2.5 and 2.6), vacuum packaged and then measured again at 30, 32, 34, and 36 days (Table 2.7 and 2.8). No interactions between levels of dietary ATA supplementation and fat sources were observed on meat color. Increases in L^* (lighter; linear and quadratic, $P < 0.01$), a^* (redder, linear and quadratic, $P < 0.01$), b^* (more yellow; linear and quadratic, $P < 0.01$), a/b (more red; linear and quadratic, $P < 0.01$), and chroma (more saturated; linear and quadratic, $P < 0.01$) were observed with increasing retail display. Hue angle decreased (more red; linear and quadratic; $P < 0.01$) with time. No interaction between time and level of ATA or fat sources were observed, which reflected the lack of effect of dietary ATA on the developing of the color loss with time under retail display.

Interactions between isoforms and level of VE were observed on L^* (Day 1, $P = 0.04$; Day 3, $P < 0.01$; Day 5, $P < 0.01$; Day 7, $P < 0.01$), a^* (Day 3, $P = 0.06$; Day 3, $P =$

0.01; Day 7, $P = 0.05$), b^* (Day 3, $P = 0.04$), a/b (Day 1, $P = 0.08$; Day 3, $P = 0.02$; Day 5, $P = 0.02$; Day 7, $P = 0.05$), hue angle (Day 1, $P = 0.08$; Day 3, $P = 0.02$; Day 5, $P = 0.02$; Day 7, $P = 0.05$) and chroma (Day 3, $P < 0.01$; Day 5, $P = 0.03$; Day 7, $P = 0.06$). Additionally, differences between the two isoforms were detected on L^* (Day 1, $P = 0.02$; Day 3, $P = 0.07$), b^* (Day 1, $P < 0.01$), a/b (Day 1, $P = 0.03$), hue angle (Day 1, $P = 0.03$), and chroma (Day 1, $P = 0.02$). Interactions between time and isoforms of VE ($P < 0.01$) was observed for b^* and chroma. No interactions between isoforms of VE and fat sources were observed on meat color during the first shelf life period.

Decreases in L^* (darker; quadratic, $P < 0.01$), a^* (less red; linear and quadratic, $P < 0.01$), a/b (less red; linear and quadratic, $P < 0.01$), and chroma (less saturated; linear and quadratic, $P < 0.01$) were observed with increasing retail time after 30 days vacuum packaged. However, b^* (less yellow; quadratic, $P < 0.01$) and hue angle (less red; linear, $P < 0.01$) increased with time. Pigs fed tallow had a higher L^* value (Day 1, $P = 0.01$; Day 32, $P = 0.06$; Day 34, $P = 0.03$; Day 26, $P = 0.06$), higher b^* value (Day 30, $P = 0.05$; Day 32, $P = 0.04$; Day 34, $P = 0.02$), lower a/b ratio (Day 32, $P = 0.02$; Day 34, $P = 0.08$), and higher hue angle (Day 32, $P = 0.07$; Day 34, $P = 0.08$). However, further comparison of the slopes of color development with time showed no interactions between time and fat sources or dietary VE treatments (isoforms and levels). No interactions between isoforms of VE and dietary level or fat sources were observed on meat color during the second shelf life period.

TBAR results, adapted from Wang (2019) in a collaborative study, were also measured to assess oxidative stability and the results are provided in Table 2.9. No interactions between fat sources and levels of dietary VE treatments (isoforms or levels)

were observed in this measurement. While numerical effects of increasing dietary ATA were present, levels of ATA did not affect lipid oxidation from day 1 to day 5 as measured by TBARS, however increasing dietary ATA decreased TBARS at day 7 (linear, $P < 0.01$). TBARS content in the loin muscle increased with time (linear and quadratic, $P < 0.01$), interaction between time and levels of ATA was observed ($P < 0.05$). Further comparison of the slopes for the development of TBARS along with time indicated that the TBARS in the loin muscle from pigs fed 11 ppm increased in a greater ($P < 0.05$) slope compared to that from pigs fed 40, 100 and 200 ppm ATA.

No effect of isoform was observed on the lipid oxidation in this study. Dietary fat sources affected ($P < 0.05$) lipid oxidation from day 1 to day 7. When measured as TBARS content, the lipid oxidation development with time was affected by fat sources as indicated by the interaction between time and fat sources ($P < 0.01$). Further comparison of the slopes for the development of TBARS along with time also confirmed this effect, where the TBARS content from pigs fed CO diets increased in a greater ($P < 0.05$) slope compared to those from pigs fed TW diets.

Table 2.4 Effect of different fat sources and VE supplementation on meat quality of pork[1]

								P-value					
		Isoforms						ATA[2]					
		ATA, ppm				γ-T, ppm		Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
Drip Loss[4], %	TW	5.99	4.56	7.40	5.21	5.85	7.19	-	-	-	-	-	-
	CO	7.38	5.20	5.20	5.36	6.62	8.97						
Purge Loss[5], %													
Day 7	TW	3.60	4.50	4.12	4.43	3.03	4.40	-	-	-	-	-	-
	CO	4.65	3.88	4.34	4.51	3.92	5.30						
Day 14	TW	8.13	9.14	8.94	8.90	8.42	9.71	-	-	-	-	-	-
	CO	9.22	9.73	9.43	9.36	9.85	7.98						
Day 30	TW	12.02	12.89	10.98	11.71	13.43	13.60	-	-	-	0.14	-	-
	CO	11.42	13.54	12.00	13.82	12.78	13.55						
Subjective Meat Color[6]													
Color	TW	2.60	3.20	2.67	2.40	2.67	2.17	-	-	-	0.06	-	-
	CO	3.00	3.00	2.50	2.83	2.67	2.20						
Marbling	TW	1.40	2.00	2.00	2.20	1.83	1.50	-	0.18	-	0.12	-	-
	CO	1.80	2.00	2.17	1.33	1.50	1.40						
Firmness	TW	2.40	2.80	2.50	2.20	2.17	2.33	0.10	-	-	0.15	-	-
	CO	2.60	2.75	2.17	1.83	2.33	1.60						
Belly Flex[7], cm													
Left Side													
Lateral	TW	18.03	14.29	16.09	17.15	15.49	15.75	-	-	<0.01	-	-	-
	CO	11.68	10.48	11.01	11.26	10.16	9.14						
Vertical	TW	29.53	27.94	27.73	27.94	28.36	27.18	-	-	0.04	-	-	-
	CO	31.50	31.05	29.85	29.13	32.17	31.24						

Table 2.4 Continued.

Right Side													
Lateral	TW	16.51	13.97	13.34	15.24	15.49	13.46	-	0.17	<0.01	-	-	-
	CO	10.41	10.41	11.01	11.18	10.37	9.40						
Vertical	TW	29.85	29.46	30.23	29.72	30.48	28.15	-	-	0.15	-	-	-
	CO	32.26	30.16	31.33	31.88	30.48	31.24						
Belly Angle[8], °	TW	52.75	44.31	47.18	48.28	50.69	44.45	-	-	<0.01	-	-	-
	CO	31.65	34.26	34.94	34.08	33.48	29.52						

[1] Values are average of 6 replicates. *P*-values for sex interactions are listed in Appendix Table A 2.2

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. No interaction between fat sources and dietary ATA levels was observed.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] Drip loss = ((Initial weight – 48 hr weight) / Initial weight) × 100.

[5] Purge loss = ((Initial weight – Day 7, 14, 30) / Initial weight) × 100. Time effect, linear and quadratic, $P < 0.01$; no interaction between time and fat sources or time and dietary VE treatments was observed.

[6] Subjective National Pork Producers Council; color scale 1-6 (1 = light, 6 = dark); marbling scale (estimated % intramuscular fat); firmness 1-5 (1 = soft, 5 = firm).

[7] Belly flex was measured as the summation of each lateral and vertical from right and left ends of the belly. A zero lateral would be a complete folding of the belly and a zero vertical would be flat. A higher lateral flex would be a firmer belly. A lower vertical would be a firmer belly.

[8] Belly angle was calculated as: arctangent (left side lateral distance/ left side vertical distance) + arctangent (right side lateral distance/ right side vertical distance).

Table 2.5 Effect of different fat sources and VE supplementation on *L*a*b** objective color of Longissimus thoracis in simulated retail display[1]

		Isoforms						*P*-value					
		ATA, ppm				γ-T, ppm		ATA[2] Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
*L**[4]													
Day 1	TW	59.10	53.89	60.60	58.12	58.99	59.34	-	-	0.13	0.02	0.04	-
	CO	57.01	55.10	57.31	56.01	58.96	59.58						
Day 3	TW	60.32	54.74	61.67	61.47	57.77	58.59	-	-	-	-	<0.01	-
	CO	60.44	55.73	58.96	58.00	60.05	57.98						
Day 5	TW	61.08	54.68	61.90	61.29	59.37	58.85	-	-	-	0.07	<0.01	-
	CO	61.10	55.74	58.64	59.89	60.67	58.24						
Day 7	TW	60.53	55.16	62.32	61.38	59.90	59.23	0.06	-	-	0.15	<0.01	-
	CO	58.41	56.89	59.45	60.18	61.23	58.18						
*a**[5]													
Day 1	TW	8.71	9.57	8.62	8.86	9.11	9.15	-	-	-	-	-	-
	CO	10.20	8.58	9.36	9.33	8.92	9.86						
Day 3	TW	11.67	14.68	12.53	12.15	13.03	13.52	-	-	0.17	-	0.06	-
	CO	13.51	13.96	13.21	13.10	12.99	13.53						
Day 5	TW	10.97	14.63	11.65	11.60	12.56	12.67	-	-	-	0.15	0.01	-
	CO	12.17	13.41	12.47	12.60	12.07	12.68						
Day 7	TW	10.63	13.82	11.57	10.70	12.05	11.81	-	-	-	0.08	0.05	-
	CO	11.48	12.55	11.55	11.54	11.45	11.71						
*b**[6]													
Day 1	TW	16.26	14.47	15.72	15.68	16.14	16.57	-	-	-	<0.01	-	-
	CO	16.74	14.14	15.62	15.62	16.18	16.71						
Day 3	TW	17.92	18.46	17.86	17.66	18.19	18.30	-	-	-	-	0.04	-
	CO	18.03	18.59	17.57	18.17	17.88	18.10						

Table 2.5 Continued.

Day 5	TW	17.58	18.05	17.35	17.39	17.42	17.81	-	-	-	-	-	-
	CO	17.67	18.05	17.67	17.99	18.11	17.74						
Day 7	TW	17.08	17.79	17.18	16.80	17.12	17.29	-	-	-	-	-	0.17
	CO	17.10	17.47	17.03	17.24	17.74	17.42						

[1] Values are average of 6 replicates. *P*-values for sex interactions are listed in Appendix Table A 2.2

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. No interaction between fat sources and dietary ATA levels was observed.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] L^* values are a measure of lightness (higher value indicated a lighter color). Time effect, linear and quadratic, $P < 0.01$. No interaction between time and fat sources or time and dietary VE treatments (isoforms and levels) was observed.

[5] a^* values are a measure of redness (higher values indicated a redder color). Time effect, linear and quadratic, $P < 0.01$; No interaction between time and fat sources or time and dietary VE treatments (isoforms and levels) was observed.

[6] b^* values are a measure of yellowness (higher value indicated a more yellow color); Time effect, linear and quadratic, $P < 0.01$; interaction between time and isoforms of VE, $P < 0.01$. No interaction between time and fat sources or time and dietary VE level was observed.

Table 2.6 Effect of different fat sources and VE supplementation on derivatives of *L*a*b** objective color of Longissimus Thoracis in simulated retail display[1]

								P-value					
		Isoforms						ATA[2]					
		ATA, ppm				γ-T, ppm		Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
a/b[4]													
Day 1	TW	0.56	0.66	0.57	0.57	0.62	0.55	-	-	0.16	0.03	0.08	-
	CO	0.61	0.61	0.59	0.59	0.55	0.59						
Day 3	TW	0.65	0.82	0.69	0.69	0.73	0.74	-	-	-	-	0.02	-
	CO	0.73	0.75	0.73	0.72	0.70	0.75						
Day 5	TW	0.63	0.80	0.67	0.67	0.72	0.71	-	-	-	-	0.02	-
	CO	0.69	0.74	0.70	0.70	0.68	0.71						
Day 7	TW	0.62	0.77	0.63	0.64	0.71	0.68	-	-	-	-	0.05	-
	CO	0.67	0.72	0.68	0.67	0.64	0.68						
Hue Angle[5]													
Day 1	TW	1.06	0.99	1.05	1.06	1.02	1.07	-	-	0.15	0.03	0.08	-
	CO	1.02	1.03	1.04	1.04	1.07	1.04						
Day 3	TW	0.99	0.89	0.97	0.97	0.94	0.94	-	-	-	-	0.02	-
	CO	0.94	0.93	0.94	0.97	0.96	0.93						
Day 5	TW	1.01	0.90	0.98	0.98	0.95	0.95	-	-	-	-	0.02	-
	CO	0.97	0.93	0.96	0.96	0.98	0.95						
Day 7	TW	1.02	0.92	1.01	1.01	0.96	0.97	-	-	-	-	0.05	-
	CO	0.98	0.95	0.98	0.98	1.00	0.98						
Chroma[6]													
Day 1	TW	18.48	17.35	17.95	18.03	18.19	18.93	-	-	-	0.02	-	-
	CO	19.62	16.54	18.22	17.59	18.48	19.41						
Day 3	TW	21.40	23.86	21.99	21.46	22.07	22.77	-	-	-	-	<0.01	-
	CO	22.84	23.26	21.67	22.42	21.76	22.61						

Table 2.6 Continued.

Day 5	TW	21.02	23.00	20.63	20.93	21.49	21.88	-	-	-	-	0.03	-
	CO	20.98	22.49	21.65	21.99	21.51	21.83						
Day 7	TW	20.15	22.43	20.32	19.95	20.97	20.97	-	-	-	-	0.06	-
	CO	20.12	21.51	20.60	20.77	21.13	21.10						

[1] Values are average of 6 replicates. *P*-values for sex interactions are listed in Appendix Table A 2.2

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. No interaction between fat sources and dietary ATA levels was observed.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] a/b is calculated as a^*/b^* (larger ratios indicated more redness and less discoloration). Time effect, linear and quadratic, $P < 0.01$. No interaction between time and fat sources or time and dietary VE treatments (isoforms and levels) was observed.

[5] Hue angle represents the change from the true red axis (larger number indicated shift from red to yellow). Time effect, linear and quadratic, $P < 0.01$. No interaction between time and fat sources or time and dietary VE treatments (isoforms and levels) was observed.

[6] Chroma is a measure of total color (larger number indicated a more vivid color). Time effect, linear and quadratic, $P < 0.01$; interaction between time and isoforms of VE, $P < 0.01$. No interaction between time and fat sources or time and dietary VE ATA treatment level

Table 2.7 Effect of different fat sources and VE supplementation on *L*a*b** objective color of Longissimus Thoracis in extended simulated retail display[1]

								P-value					
		Isoforms						ATA[2]					
		ATA, ppm				γ-T, ppm		Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
*L**[4]													
Day 30	TW	60.44	58.10	59.33	59.09	57.54	60.15	-	-	0.01	-	-	-
	CO	55.64	57.68	57.12	57.26	58.55	58.21						
Day 32	TW	59.37	60.27	60.06	59.16	57.51	61.36	-	-	0.06	-	0.17	-
	CO	57.92	58.14	57.67	57.33	58.83	57.56						
Day 34	TW	59.09	59.78	59.48	59.52	57.60	60.53	-	-	0.03	-	0.19	-
	CO	55.98	58.47	57.81	57.80	59.63	59.46						
Day 36	TW	58.35	59.56	59.75	59.27	57.77	60.77	-	-	0.06	-	-	0.16
	CO	57.15	56.55	58.03	56.98	58.82	60.89						
*a**[5]													
Day 30	TW	10.58	11.45	11.56	11.37	10.14	10.95	-	-	-	0.08	-	-
	CO	10.85	10.05	11.47	10.32	11.08	9.98						
Day 32	TW	11.08	11.72	11.24	11.46	11.49	11.12	-	-	-	-	-	-
	CO	12.09	11.86	12.42	11.66	11.83	11.18						
Day 34	TW	9.80	10.18	9.77	9.78	10.22	9.80	-	-	-	-	-	-
	CO	10.44	10.62	10.56	10.15	10.12	9.85						
Day 36	TW	8.72	9.06	8.90	8.60	9.07	9.35	-	-	-	-	-	-
	CO	8.08	9.83	9.31	8.77	9.41	8.87						
*b**[6]													
Day 30	TW	15.72	16.27	16.09	16.03	15.49	16.02	-	0.17	0.05	0.19	-	-
	CO	15.43	15.44	15.88	15.13	15.75	14.98						
Day 32	TW	16.36	16.85	16.61	16.70	16.14	16.49	-	-	0.04	0.18	-	-
	CO	16.19	16.26	16.30	16.11	16.62	15.97						

Table 2.7 Continued.

Day 34	TW	16.04	16.39	16.39	15.92	15.97	16.06	-	0.03	0.02	0.06	0.05	0.09
	CO	15.66	15.71	16.07	15.97	16.39	15.65						
Day 36	TW	15.73	15.82	15.94	15.92	15.35	15.95	-	-	-	-	-	-
	CO	15.59	15.75	15.62	15.56	15.60	15.59						

[1] Values are average of 6 replicates. *P*-values for sex interactions are listed in Appendix Table A 2.2

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. No interaction between fat sources and dietary ATA levels was observed.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] L^* values are a measure of lightness (higher value indicated a lighter color). Time effect, quadratic, $P < 0.01$. No interaction between time and fat sources or time and dietary VE treatments (isoforms and levels) was observed.

[5] a^* values are a measure of redness (higher values indicated a redder color). Time effect, linear and quadratic, $P < 0.01$. No interaction between time and fat sources or time and dietary VE treatments (isoforms and levels) was observed.

[6] b^* values are a measure of yellowness (higher value indicated a more yellow color). Time effect, quadratic, $P < 0.01$. No interaction between time and fat sources or time and dietary VE treatments (isoforms and levels) was observed.

Table 2.8 Effect of different fat sources and VE supplementation on derivatives of *L*a*b** objective color of Longissimus Thoracis in extended simulated retail display[1]

								P-value					
		Isoforms						ATA[2]					
		ATA, ppm				γ-T, ppm		Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
a/b[4]													
Day 30	TW	0.67	0.72	0.71	0.71	0.66	0.67	-	-	-	0.03	-	-
	CO	0.72	0.71	0.72	0.68	0.70	0.67						
Day 32	TW	0.68	0.70	0.68	0.69	0.73	0.66	-	-	0.04	0.10		0.18
	CO	0.75	0.73	0.76	0.72	0.72	0.70						
Day 34	TW	0.61	0.62	0.60	0.62	0.65	0.59	-	-	0.08	-	-	-
	CO	0.67	0.68	0.66	0.63	0.62	0.63						
Day 36	TW	0.56	0.58	0.54	0.54	0.59	0.59	-	-	-	-	-	-
	CO	0.52	0.62	0.60	0.57	0.60	0.57						
Hue Angle[5]													
Day 30	TW	0.98	0.95	0.96	0.96	0.97	0.98	-	-	-	0.04	-	-
	CO	0.95	0.95	0.95	0.98	0.96	0.98						
Day 32	TW	0.98	0.93	0.98	0.97	0.94	0.99	-	-	0.07	0.18	-	-
	CO	0.93	0.94	0.92	0.95	0.93	0.96						
Day 34	TW	1.02	1.01	1.03	1.02	0.99	1.04	-	-	0.08	-	-	-
	CO	0.98	0.98	0.99	1.01	1.02	1.01						
Day 36	TW	1.07	1.01	1.08	1.08	1.04	1.04	-	-	-	-	-	-
	CO	1.10	1.01	1.04	1.06	1.03	1.05						
Chroma[6]													
Day 30	TW	18.98	19.53	19.45	19.66	18.53	19.70	-	-	-	-	-	-
	CO	18.90	17.92	19.61	18.35	19.28	18.02						
Day 32	TW	19.80	20.44	20.08	20.26	20.05	20.13	-	-	-	-	-	-
	CO	19.84	20.13	20.51	19.90	20.28	19.51						

Table 2.8 Continued.

Day 34	TW	18.83	19.24	19.09	18.70	19.13	19.26	-	0.16	-	-	-	-
	CO	18.52	18.97	18.88	18.93	19.29	18.50						
Day 36	TW	18.05	18.18	18.13	18.14	17.84	18.50	-	-	-	-	-	-
	CO	17.64	18.58	18.24	17.89	18.33	17.94						

[1] Values are average of 6 replicates. *P*-values for sex interactions are listed in Appendix Table A 2.2

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. No interaction between fat sources and dietary ATA levels was observed.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] a/b is calculated as a^*/b^* (larger ratios indicated more redness and less discoloration). Time effect, linear and quadratic, $P < 0.01$. No interaction between time and fat sources or time and dietary VE treatments (isoforms and levels) was observed.

[5] Hue angle represents the change from the true red axis (larger number indicated shift from red to yellow). Time effect, linear, $P < 0.01$. No interaction between time and fat sources or time and dietary VE treatments (isoforms and levels) was observed.

[6] Chroma is a measure of total color (larger number indicated a more vivid color). Time effect, linear and quadratic, $P < 0.01$. No interaction between time and fat sources or time and dietary VE treatments (isoforms and levels) was observed.

Table 2.9 Effect of different fat sources and VE supplementation on shelf life of Longissimus Thoracis measured as TBARS (μg MDA/kg wet meat)[1]

		Isoforms						*P*-value					
		ATA, ppm				γ-T, ppm		ATA[2]					
								Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
Day 1	TW	0.28	0.23	0.22	0.22	0.26	0.25	-	-	0.02	-	-	0.18
	CO	0.26	0.29	0.29	0.29	0.27	0.28						
Day 3	TW	0.32	0.31	0.29	0.30	0.32	0.30	-	-	<0.01	0.18	0.17	-
	CO	0.37	0.33	0.36	0.34	0.39	0.35						
Day 5	TW	0.41	0.35	0.33	0.39	0.34	0.33	0.15	0.12	0.09	-	-	-
	CO	0.44	0.39	0.43	0.37	0.41	0.46						
Day 7	TW	0.74	0.59	0.53	0.56	0.63	0.64	<0.01	0.15	<0.01	-	-	0.07
	CO	0.87	0.75	0.78	0.65	0.61	0.73						

[1] Adapted from Wang et al. (2019). Values are average of 6 replicates. Time effect, linear and quadratic, $P < 0.01$; interaction between time and dietary ATA levels, $P < 0.05$; interaction between time and fat sources, $P < 0.01$. No interaction between time and isoforms of VE was observed. *P*-values for sex and other interactions are listed in Appendix Table A. 2.2.

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. No interaction between fat sources and dietary ATA was observed.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] Time effect on TBARS, linear and quadratic, $P < 0.0001$, with interaction with both fat sources and levels of ATA ($P < 0.05$).

2.4.3 Sensory Analysis

Five sensory attributes were evaluated and ranked on the following scale: tenderness 1-6 (1= extremely tough; 6= extremely tender), juiciness 1-6 (1= extremely dry; 6= extremely juicy), off-flavor 1-6 (1=none; 6=intense off-flavor), pork intensity 1-6 (1=none; 6= extremely intense), and overall liking 1-6 (1=extremely dislike; 6=extremely like) the results are provided in Table 2.10. Increasing dietary levels of ATA from 11 to 200 ppm increased Tenderness ($P < 0.01$), Juiciness ($P < 0.01$), and Overall approval ($P < 0.01$). There were no differences in dietary VE levels for off-flavor and flavor intensity. An interaction between fat and dietary ATA VE level for juiciness ($P < 0.05$) was observed, juiciness increased more for CO across ATA levels. The γ-T isoform displayed a less intense off-flavor (good flavor; $P = 0.05$) and less flavor intensity ($P = 0.06$) compared to ATA. No other effects of dietary treatment were observed on sensory analysis.

Table 2.10 Effect of different fat sources and VE supplementation on sensory characteristics of the Longissimus Thoracis[1]

		Isoforms						*P*-value					
								ATA[2]					
		ATA, ppm				γ-T, ppm		Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
Tenderness[4]	TW	3.23	3.65	3.71	4.00	3.85	3.70	<0.01	-	-	-	-	-
	CO	3.00	3.53	3.88	4.00	3.90	3.83						
Juiciness[5]	TW	3.30	2.58	3.10	3.40	3.19	3.00	<0.01	-	[1]	-	-	0.09
	CO	2.22	3.34	3.25	3.73	2.75	2.88						
Off-Flavor[6]	TW	2.00	1.91	1.88	1.70	1.81	1.68	-	-	-	0.05	-	-
	CO	1.70	1.81	1.75	1.75	1.77	1.55						
Flavor Intensity[6]	TW	3.30	3.20	3.33	3.25	3.17	2.98	-	-	-	0.06	-	-
	CO	3.31	3.25	3.33	3.30	3.00	3.13						
Overall Approval[7]	TW	3.13	2.93	3.15	3.48	3.31	3.10	<0.01	-	-	-	-	-
	CO	2.56	3.44	3.40	3.65	3.33	3.33						

[1] Values are average of 6 replicates. *P*-values for sex interactions are listed in Appendix Table A 2.3.

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. [I] Interaction between fat and dietary VE level, $P < 0.05$.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] Evaluated on a 6-point hedonic scale with 1 = "extremely tough" and 6 = "extremely tender" used as anchors.

[5] Evaluated on a 6-point hedonic scale with 1 = "extremely dry" and 6= "extremely juicy" used as anchors.

[6] Evaluated on a 6-point hedonic scale with 1 = "none" and 6 = "intense" used as anchors.

[7] Evaluated on a 6-point hedonic scale with 1 = "extremely dislike" and 6 = "extremely like" used as anchors.

2.5 Conclusion

The results of the study demonstrated the interaction of dietary fat sources and VE supplementation on carcass characteristics, primal cuts, meat quality, oxidative stability and sensory characteristics of pigs grown to 150kg. Increasing dietary levels of ATA had beneficial impacts on carcass traits and sensory characteristics. Compared to dietary CO, pigs fed dietary TW had a greater belly depth and belly angle which could lead to poor bacon slicing yield. Feeding γ-T at 40 ppm, compared to ATA, resulted in a higher L^*, lower a^*, lower a/b, higher hue and lower chroma (paler less red color) while feeding at 100 ppm resulted in a lower L^*, higher a^*, higher a/b, lower hue and higher chroma (darker redder color) for the first 7 days of retail display. Compared to CO, pigs fed TW displayed higher L^* and b^* values (Darker yellow color) for extended retail display. Tenderness, juiciness and overall approval increased with the increasing level of dietary vitamin E. Pigs fed γ-T had less of an off-flavor than pigs fed ATA. Overall, feeding a higher percentage of statured fatty acids leads to a more desirable pork belly. Also, supplementing higher levels of γ-T could improve shelf life color and improve consumer sensory analysis.

Chapter 3 BELLY/ BACON CHARACTERISTICS OF HEAVY WEIGHT (>150KG) PIGS FED DIFFERENT FAT SOURCES AND SUPPLEMENTATION OF VITAMIN E

3.1 Abstract

Two separate studies were conducted to evaluate the effect of dietary fat source and vitamin E supplementation on belly/bacon characteristics and quality of pigs grown to heavier weights (>150kg). For the first study, 64 individually fed pigs (half barrows and gilts; initial BW ~24-30 kg) were blocked by body weight and sex, and then randomly assigned to individual pens, pens were randomly assigned to 1 of the 8 dietary treatments in a 4 × 2 factorial arrangement. Fat treatments included cornstarch (CS), tallow (TW), corn oil (CO) and coconut oil (CN). Vitamin E (VE) supplementation was at 11 IU/kg (NRC, 2012) and 200 IU/kg in the form of DL (all-rac)-α-tocopheryl acetate. For the second study, individually fed pigs (n=72; 36 barrows, 36 gilts; 28.55 ± 1.16 kg) were randomly assigned to 12 dietary treatments in a 2 × 6 factorial arrangement. Fat treatments were tallow and corn oil. The vitamin E treatments included four levels of α-tocopheryl-acetate (ATA; 11, 40, 100, and 200 ppm) and two levels of mixed tocopherols (primarily γ-tocopherol; 40 and 100 ppm). Pigs were humanely slaughtered at approximately 150 kg for both studies. Fresh belly characteristics were recorded 24 hrs post-slaughter. Bellies were then frozen and stored until commercial processing for bacon characteristics and quality measurements. Data analysis was performed by using PROC GLM in SAS. Pigs fed fat diets higher in saturated fatty acids (SFA) had a greater belly angle ($P < 0.01$) than pigs fed higher unsaturated fatty acid due to a higher lateral distance ($P < 0.05$) and a lower vertical distance ($P < 0.05$). Also, the shatter score was higher ($P < 0.05$) for pigs fed diets

higher in saturated fatty acids. For study 1, slicing yield decreased ($P = 0.04$) when dietary VE level was increased from 11 to 200ppm.

For study 2, pigs fed ATA vitamin E had increased belly green weight ($P = 0.04$), pump weight ($P = 0.02$), pump percentage ($P = 0.05$), smoke weight ($P = 0.02$), chill weight ($P = 0.02$), and bacon slice weight ($P = 0.04$). CO had a higher slice shrink than TW ($P = 0.02$)

Keywords: vitamin E, isoforms, bacon, fat, heavy slaughter weight, pig

3.2 Introduction

Due to the rising cost of feed ingredients, producers are considering alternative feedstuffs, such as dried distillers' grains with solubles (DDGS) that are higher in unsaturated fatty acids. Additionally, the American Heart Association recommends limiting saturated fats because they can raise LDL-Cholesterol which can cause a higher risk for heart disease (AHA, 2015). The swine industry has responded to these challenges by developing leaner genotype pigs by supplementing swine diets with unsaturated fat sources which leads to higher polyunsaturated fatty acids (PUFA) in pork because the changes of the dietary fatty acid profile are able to be expressed in pork (Gatlin et al., 2002). The increase of unsaturated fatty acids results in soft pork, which is associated with greater potential for oxidative problems and poor belly quality. The meats industry considers soft belly fat undesirable because it leads to poor bacon slicing.

Several vitamins and minerals have been evaluated as dietary ingredients to enhance the growth of pigs and the quality of pork. Dietary inclusion of vitamin E has been reported to reduce lipid oxidation in pork and improve meat color (Guo et al., 2006; Lahucky et al., 2007). Even with an observed trend of increased fatty acid unsaturation in pork with α-tocopherol acetate inclusion in swine diets, lipid oxidation is still observed to be reduced (Guo et al., 2006). The effects of vitamin E supplementation on bacon are less pronounced, probably due to the presence of nitrite which can also act as an antioxidant (Bucklet and Connolly, 1980).

Therefore, the objective of the two separate studies was to evaluate the effect of different dietary fat sources and variable vitamin E supplementation on belly/ bacon characteristics and quality of pigs grown to heavy slaughter weights.

3.3 Materials and Methods

The growth and feeding phase of these experiments were carried out in environmentally controlled rooms at the University of Kentucky Swine Research Center. The slaughter and sample collection were performed at the University of Kentucky Meats Science Laboratory. The experiments were conducted under protocols approved by the Institutional Animal Care and Use Committee of the University of Kentucky.

3.3.1 Animals, Diet and Experimental Design

In study 1, a total of 64 individually fed pigs (half barrows and gilts; initial BW ~24-30 kg) were blocked by body weight and sex, and then randomly assigned to individual pens, pens were randomly assigned to 1 of the 8 dietary treatments in a 4 × 2 factorial arrangement. Fat treatments included cornstarch (CS), tallow (TW), corn oil (CO) and coconut oil (CN). Vitamin E (VE) supplementation was at 11 IU/kg (NRC, 2012) and 200 IU/kg in the form of DL (all-rac)-α-tocopheryl acetate (PROVIMIX D 50 SD, DSM Nutritional Products Inc., NJ). As defined in NRC (2012), one IU VE equals to 1 mg of DL- α-tocopheryl acetate.

In study 2, which was a result of study 1, a total of 72 individually fed pigs (half barrows and gilts; initial BW ~24-30 kg) were blocked by sire, body weight, and sex, and then randomly assigned to individual pens. Pens were randomly assigned to 1 of the 12 dietary treatments in a 2 x 6 factorial arrangement. Fat treatments included TW and CO. Vitamin E treatments included four levels α-tocopheryl-acetate (11, 40, 100 and 200 ppm) and two levels of mixed tocopherols (primarily γ-tocopherol; 40 and 100 ppm). The ATA

was suppled in the form of DL (all-rac)-α-tocopheryl acetate (ROVIMIX E 50 ADS, DSM Nutritional Products, Inc., GA US) in a dry form. The mixed tocopherols were supplied as Mixed Tocopherols 95 (DSM Nutritional Products, Inc., NJ US) in liquid form, which contained 0-15% α-tocopherol, less than 5% β-tocopherol, 55-75% γ-tocopherol, and 20-30% δ-tocopherol.

For both studies, the diets were corn-soybean meal (SBM) based diets in mash form and all experimental diets were formulated to meet or exceed NRC (2012) nutrient requirement estimates for grow-finishing pigs (Table 3.1 and 3.2). Treatment diets were fed to pigs up until slaughter, and slaughter weight was ~150 kg.

Table 3.1 Study 1 diet composition of diets with different fat sources and VE levels1 from Phase 1 to Phase 5 (as-fed basis)

	Phase 1		Phase 2		Phase 3		Phase 4		Phase 5	
Ingredient, %	CS	Fat	CS	Fat	CS	Fat	CS	Fat	CS	Fat
Corn	60.08	62.85	66.48	69.55	70.55	73.81	73.64	77.04	76.75	80.30
Soybean meal, 48% CP	27.24	28.50	21.03	22.00	17.21	18.00	14.34	15.00	11.47	12.00
Fats[2]	-	5.00	-	5.00	-	5.00	-	5.00	-	5.00
Corn starch	9.19	-	9.19	-	9.19	-	9.19	-	9.19	-
L-Lysine HCl	0.21	0.22	0.23	0.24	0.20	0.21	0.16	0.17	0.12	0.13
DL-Methionine	0.11	0.12	0.08	0.09	0.04	0.04	0.01	0.01	0.00	0.00
L-Threonine	0.09	0.09	0.08	0.09	0.06	0.06	0.03	0.04	0.02	0.03
Limestone	1.03	1.08	0.95	0.99	0.84	0.88	0.74	0.77	0.65	0.68
Dicalcium phosphate	0.88	0.92	0.79	0.82	0.75	0.78	0.72	0.75	0.62	0.65
Salt	0.48	0.50	0.48	0.50	0.48	0.50	0.48	0.50	0.48	0.50
Vitamin premix[3]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mineral premix [4]	0.14	0.15	0.14	0.15	0.14	0.15	0.14	0.15	0.14	0.15
Choline[5]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Santoquin[6]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
AB-20[7]	0.48	0.50	0.48	0.50	0.48	0.50	0.48	0.50	0.48	0.50
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated nutrient level, %										
ME, Mcal/kg	3.32	3.47	3.33	3.49	3.34	3.50	3.35	3.50	3.36	3.51
CP	18.31	19.13	15.87	16.58	14.31	14.94	13.12	13.70	11.96	12.48
SID Lys	0.99	1.04	0.86	0.90	0.74	0.78	0.64	0.67	0.54	0.56
SID Lys/ME	2.99	2.99	2.58	2.58	2.22	2.22	1.92	1.92	1.61	1.61
SID Met	0.37	0.38	0.30	0.32	0.25	0.26	0.20	0.21	0.18	0.19
SID Cys	0.25	0.26	0.22	0.24	0.21	0.22	0.20	0.21	0.18	0.19
SID M+C	0.62	0.65	0.53	0.55	0.45	0.47	0.40	0.42	0.37	0.38
SID Thr	0.64	0.67	0.56	0.58	0.48	0.50	0.42	0.44	0.37	0.39
SID Trp	0.19	0.20	0.16	0.17	0.14	0.14	0.12	0.13	0.11	0.11

Table 3.1 continued

SID Arg	1.08	1.13	0.90	0.94	0.79	0.82	0.70	0.73	0.62	0.65
SID His	0.43	0.45	0.37	0.39	0.34	0.35	0.31	0.33	0.29	0.30
SID Ile	0.66	0.69	0.55	0.58	0.49	0.51	0.44	0.46	0.39	0.41
SID Leu	1.37	1.43	1.23	1.28	1.14	1.19	1.07	1.12	1.01	1.05
SID Phe	0.77	0.81	0.66	0.70	0.60	0.62	0.55	0.57	0.50	0.52
SID Tyr	0.50	0.53	0.43	0.45	0.39	0.40	0.35	0.37	0.32	0.33
SID P+T	1.28	1.34	1.10	1.15	0.98	1.03	0.90	0.94	0.81	0.85
SID Val	0.72	0.75	0.62	0.64	0.55	0.58	0.51	0.53	0.46	0.48
Ca	0.67	0.70	0.59	0.62	0.54	0.56	0.48	0.51	0.42	0.44
STTD P	0.31	0.32	0.28	0.29	0.26	0.27	0.25	0.26	0.22	0.23
Total P	0.52	0.54	0.47	0.49	0.45	0.46	0.43	0.45	0.40	0.41

[1] Dietary VE levels (11 and 200 ppm) were applied to each basal diet.

[2] Fat treatment included corn starch, corn oil, tallow and coconut oil.

[3] Supplied the following per kg of diet: 7,000 IU of vitamin A; 1,500 IU of vitamin D_3; 2.0 mg of vitamin K; 0.03 mg of vitamin B_{12}. 7.0 mg of riboflavin; 25.0 mg of pantothenic acid; 20.0 mg of niacin; 1.0 mg of folic acid; 2.5 mg of vitamin B_6; 2.0 mg of thiamin; and 0.15 mg of biotin.

[4] Supplied the following per kg of added fat diet: 50 mg of Mn as manganese hydroxychloride; 100 mg of Fe as ferrous sulfate monohydrate; 125 mg of Zn as zinc hydroxychloride; 20 of Cu as tribasic copper chloride; 0.35 mg of I as calcium iodate; and 0.30mg of Se as sodium selenite.

[5] Provided 150 mg per kg of choline to the final diet.

[6] Santoquin (Monsanto, St. Louis, MO) supplied 130 mg/kg ethoxyquin to the final diet.

Table 3.2 Study 2 Basal diet composition of diets with different fat sources[1] and VE isoform/levels[2] from Phase 1 to Phase 5 (as-fed basis)

Ingredient, %	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Corn	62.85	69.55	73.81	77.04	80.17
Soybean meal, 48% CP	28.50	22.00	18.00	15.00	12.00
Fat (tallow or corn oil)	5.00	5.00	5.00	5.00	5.00
L-Lysine HCL	0.22	0.24	0.21	0.17	0.22
DL-Methionine	0.12	0.09	0.04	0.01	0.01
L-Threonine	0.09	0.09	0.06	0.04	0.05
Limestone	1.08	0.99	0.88	0.77	0.68
Dicalcium phosphate	0.92	0.82	0.78	0.75	0.65
Salt	0.50	0.50	0.50	0.50	0.50
Vitamin premix[3]	0.02	0.02	0.02	0.02	0.02
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15
Choline[5]	0.03	0.03	0.03	0.03	0.03
Santoquin[6]	0.02	0.02	0.02	0.02	0.02
AB-20[7]	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00

Calculated nutrient level, %	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
ME, Mcal/kg	3.47	3.49	3.50	3.50	3.51
CP, %	19.13	16.58	14.94	13.70	12.59
SID Lys	1.04	0.90	0.78	0.67	0.64
SID Lys/ME	2.99	2.58	2.22	1.92	1.82
SID Met	0.38	0.32	0.26	0.21	0.20
SID Cys	0.26	0.24	0.22	0.21	0.19
SID M+C	0.65	0.55	0.47	0.42	0.39
SID Arg	1.13	0.94	0.82	0.73	0.65
SID His	0.45	0.39	0.35	0.33	0.30
SID Ile	0.69	0.58	0.51	0.46	0.41
SID Leu	1.43	1.28	1.19	1.12	1.05
SID Phe	0.81	0.70	0.62	0.57	0.52
SID Tyr	0.53	0.45	0.40	0.37	0.33
SID P+T	1.34	1.15	1.03	0.94	0.85
SID Thr	0.67	0.58	0.50	0.44	0.41
SID Trp	0.20	0.17	0.14	0.13	0.11
SID Val	0.75	0.64	0.58	0.53	0.48
SID Ca	0.7	0.62	0.56	0.51	0.44
Total P	0.54	0.49	0.46	0.45	0.41
STTD P	0.32	0.29	0.27	0.26	0.23

[1] Fat treatment included corn oil and tallow

[2] Dietary VE treatments including four levels of ATA (11, 40, 100, and 200 ppm) and two levels of mixed tocopherols (40 and 100 ppm) were applied to each basal diet.
[3] Supplied the following per kg of diet: 7,000 IU of vitamin A; 1,500 IU of vitamin D3; 2.0 mg of vitamin K; 0.03 mg of vitamin B12; 7.0 mg of riboflavin; 25.0 mg of pantothenic acid; 20.0 mg of niacin; 1.0 mg of folic acid; 2.5 mg of vitamin B6; 2.0 mg of thiamin; and 0.15 mg of biotin.
[4] Supplied the following per kg of added fat diet: 50 mg of Mn as manganese hydroxychloride; 100 mg of Fe as ferrous sulfate monohydrate; 125 mg of Zn as zinc hydroxychloride; 20 of Cu as tribasic copper chloride; 0.35 mg of I as calcium iodate; and 0.30 mg of Se as sodium selenite.
[5] Provided 150 mg per kg of choline to the final diet.
[6] Santoquin (Monsanto, St. Louis MO) supplied 130 mg/kg ethoxyquin to the final diet.
[7] Clay product from Prince Agri Products, Inc., Quincy IL.

3.3.2 Slaughter and Fresh Belly Measurements

Pigs were humanely slaughtered at ~150 kg live weight at the University of Kentucky (UK) Meat Lab under USDA inspection. Pigs to be slaughtered were weighed (BW) then loaded onto a transport vehicle and transferred to the UK Meat Lab following a trip of 20km which was around 40 minutes. Pigs were then slaughtered after a resting period of at least 30 minutes. The slaughter process used humane normal commercial processing procedures including electrical stunning, exsanguination, dehairing, evisceration and carcass washing.

The bellies (IMPS #408; squared at each end) were removed and weighed individually according to Institutional Meat Purchasing Specifications (North American Meat Processors Association, 2010). Bellies were divided into six sections then belly depth was measured in the geographic middle of each section. Belly flex was measured to determine belly firmness using an objective test developed by Rentfrow et al. (2003). The detailed procedure for this measurement was previously described by Cromwell et al. (2011). The spareribs, related cartilage and remaining leaf fat were removed, and the bellies

were squared. The fresh bellies with the skin on were then centered, fat side down, on a 7.5-cm diameter polyvinyl chloride pipe mounted perpendicular to a board marked with a 2.54-cm grid matrix. Lateral and vertical flexes were determined from the degree of belly flex relative to the grid matrix. A vertical belly flex of zero meant the belly was parallel to the floor and completely stiff. A lateral belly flex of 10 cm meant that the belly flexed to a point where there was 10 cm between the end of the squared belly and a vertical line directly below the center of the supporting polyvinyl chloride pipe. Thus, a lower lateral flex and a higher vertical flex indicated a softer, more flexible, belly. The belly flex measurements were determined in a room maintained at 7°C. The bellies were boxed, and then frozen (-22°C) until further analyses.

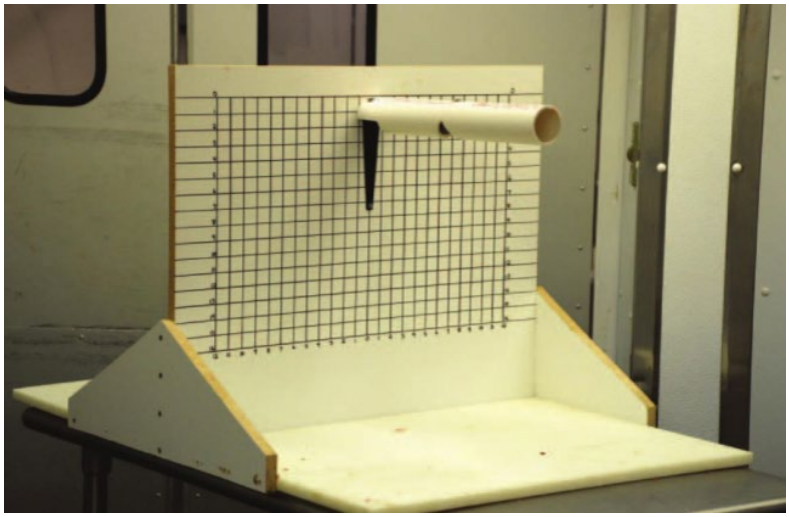

Figure 3.1 Apparatus used to quantify belly flex measurements.

3.3.3 Bacon Processing

Bellies were thawed (4°C) for 24hr and skinned at the University of Kentucky Meat Science Laboratory. Due to temperature abuse and freezer burn some of the bellies were excluded from the study (Appendix Table A. 3.1). The bellies were then transported 420km to a commercial packing plant where they were weighed before (green weight) and after

injection (pumped weight). The bellies were pumped fat side down using a Townsend multi-needle bacon injection pump (Townsend INC., Des Monies, IA). The proprietary commercial brine was injected to 117% of the bellies green weight and allowed to drain to 110% of the green weight. Bellies were hung on a bacon tree by a bacon comb attached at the flank end and heat processed according to the plants proprietary commercial protocol. Following heat processing, bacons were removed from the smokehouse, chilled overnight at 4°C, and then placed in a tempering cooler (-4°C) to facilitate optimal pressing and slicing. The weights of the bacon trees were taken after injection, after smoking and after chill. Smokehouse yield was calculated as (Individual pump weights × (bacon tree smokehouse weight/bacon tree injection weight)). The individual chill weights of each belly were calculated as (Individual pump weights × (bacon tree chill weight/bacon tree injection weight)). Full bacon slabs were pressed using a commercial bacon press (Hoegger, Provisur Technologies, Inc, Chicago, IL) and then sliced by a high-speed slicer (IBS 2000 Vision, Marel, Norwich, UK) at 12 slices/cm. An average of 24 slices of bacon were placed on slip-sheets (complete with all ends and pieces) and placed in boxes. Boxes were sealed and properly labeled for delivery to the University of Kentucky Meat Science Laboratory.

3.3.4 Bacon Measurements

Slicing yield was determined by weighing the center portions of the bacon slab after the removal of comb marks and all incomplete slices. The remaining bacon slab, containing only commercially acceptable slices, was divided into five separate sections and labeled as A, B, C, D, and E (Rentfrow et al., 2002; Mandigo, 1998). A slice from each section was

removed and evaluated for fracture analysis. A trained person evaluated fracture analysis by rolling the bacon slice and assigning a score for each quadrant. The scores were then averaged for each slice. A score of 0 indicated that no visual cracks in the fat or shattering could be detected, the scoring increased in severity with 2, 3, 4, 5 and a score of 6 being indicative of a "spider-web" consistency of shattering within the fat of the bacon slice (Mandigo, 1998).

3.3.5 Cooking and Shelf-Life Measurements

The five slices of bacon, representing one slice from each section, were cooked on a George Foreman Basic Plate Grill (George Foreman, Spectrum Brands, Inc., Madison, WI) to determine cooking loss and shrink. Preliminary testing was conducted to verify the degree of doneness (golden brown; not crisp). Each slice was weighed (Carolina Compact Balance, Burlington, NC) before and after cooking to the nearest 0.1g. After cooking, slices cooled for 10 min at room temperature on absorbent paper towels. Cooking loss was calculated as ((raw weight-cooked weight)/raw weight) ×100. Bacon slice length was measured to the nearest 0.5 cm before and after cooking. Bacon slice cooking shrink was calculated as ((raw length-cooked length)/raw length) ×100. Subjective evaluation of cooked slice visual distortion was evaluated using a 5-point distortion scale where 1 represented a mostly flat slice, and as severity of curling increased samples were rated 2, 3, 4, and 5, where 5 (Figure 3.2) indicated a slice that completely curled with no flat areas on the slice (Rentfrow et al., 2002).

For a shelf-life study, seven slices from the same section of the bacon slab were taken and measured to the nearest 0.5 cm. The slices were vacuum sealed for seven days then

placed on a foam tray and overwrapped with PVC film. The trays were kept at 4 °C for an additional seven days. The slices were then removed from the trays and measured (cm) again. The shelf-life stretch was calculated from the difference between day seven and day one.

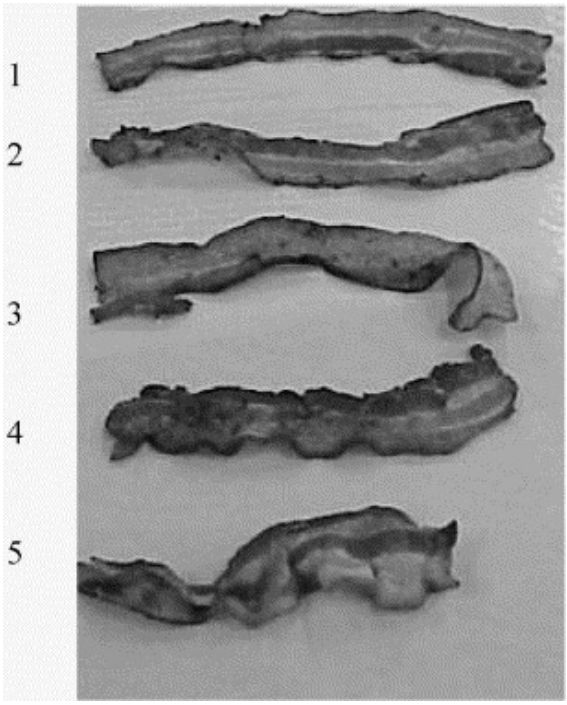

Figure 3.2 Numeric scale and examples for subjective visual evaluation of cooked bacon slice distortion.
(Rentfrow, 2002)

3.3.6 Statistical Analysis

Prior to analyses, all data were evaluated to identify any potential statistical outliers according to the test published by Barnett and Lewis (1974). To summarize, outliers can be tested by the following procedure. First, calculate the statistic T: T = (XH -Mean)/s for a high value, or T = (XL – Mean)/s for the low value (XH, high value; XL, low value; s, standard deviation). Second, compare the value of T with the value from critical values for 95% confidence interval (under condition of this study, the critical value is 2.03.) If the

calculated T is larger than the critical value for the measurement, then the XL or XH is an outlier at the level of 5% significance. Potential outliers are listed in Appendix 3. Data analysis was performed in SAS (SAS Inst. Inc., Gary, NC) by least squares analysis of variance using the generalized linear model (GLM) as a randomized complete block design. The individual pig served as the experimental.

Statistical differences were established at $P \leq 0.05$, tendencies were established at $P \leq 0.10$. Sex effect was expected but is not discussed in the results in this chapter. *P*-values for sex and related interactions are listed in Appendix 4 (values greater than 0.10 are replaced as "-"). In the results table, all *P*-values greater than 0.20 were replaced as "-". For evaluation of ATA levels and fat sources, *P*-values for main effects are provided, significant interactions ($P \leq 0.05$) between levels of dietary ATA and fat sources are superscripted in the table. For evaluation of isoforms, because *P*-values for effects of dietary VE level and fat sources and their interactions have been provided previously, only *P*-values for effects of isoform and its interaction with main effects including levels of dietary VE and fat sources are provided in the tables.

3.4 Results and Discussion

3.4.1 Fresh Belly Quality

For Study 1 (Table 3.3), belly depth differed ($P < 0.01$) among pigs from different fat treatments but not different VE treatments. Belly flex was significantly affected by dietary fat sources, as expected, but not by dietary VE supplementation. Pigs fed CO diet had the lowest lateral distance ($P < 0.01$), highest vertical distance ($P < 0.01$), and smallest belly angle making it the softest belly. Pigs fed CN had the highest lateral

distance ($P < 0.01$), lowest vertical distance ($P < 0.01$), and largest belly angle compared to the other groups ($P < 0.01$), making it the firmest belly. As anticipated, firmness increased with the increasing content of SFA in the diet.

For Study 2 (Table 3.4), pigs fed γ-T had a lower belly weight (IMPS #408; squared at each end) in relative weight ($P = 0.02$) than pigs fed ATA. Pigs fed TW had a greater belly depth ($P = 0.04$) than pigs fed CO. As expected, belly flex was affected by dietary fat sources but not dietary vitamin E supplementation. Pigs fed tallow diets had a higher lateral distance ($P < 0.05$) and a lower vertical distance ($P < 0.05$) then pigs fed corn oil diets. Pigs fed tallow diets had a greater belly angle than pigs fed corn oil diets ($P < 0.01$) due to the larger percentage of SFA.

Table 3.3 Effect of different fat sources and VE supplementation on Study 1 bacon processing[1]

VE, ppm:	11				200				SE	*P*-value		
Fat Source:	CS	TW	CO	CN	CS	TW	CO	CN		VE	Fat	VE*Fat
Belly depth, cm	5.49	5.44	5.16	5.94	5.21	4.88	4.93	5.79	0.17	0.03	<0.01	-
Absolute primal cut[4], kg												
Belly	8.46	8.55	9.77	8.65	8.85	9.05	9.16	9.01	0.30	-	0.08	-
Relative primal cut, % live weight												
Belly	5.77	5.78	6.46	5.84	5.93	6.06	6.07	6.04	0.18	-	0.16	-
Belly Flex[5], cm												
Left side												
Lateral	21.29	21.41	13.03	32.66	19.69	20.32	11.43	32.72	1.51	0.19	<0.01	-
Vertical	25.1	24.31	29.85	13.79	25.4	23.7	32.23	16.51	1.70	-	<0.01	-
Right side												
Lateral	21.29	19.96	10.31	30.84	15.88	19.05	10.16	31.12	1.76	0.13	<0.01	-
Vertical	27.31	25.76	33.17	16.69	28.91	27.51	33.81	18.11	1.88	-	<0.01	-
Belly angle[6], °	79.05	79.66	40.70	130.64	70.00	66.97	36.53	122.49	6.72	0.10	<0.01	-

[1] Values are an average of 8 replicated; *P*-values for sex interactions are listed in Appendix Table A 4.1. CS, corn starch; TW, tallow; CO, corn oil; CN, coconut oil. *P*-values for sex interactions are listed in Appendix Table A 1.2

[2] Pump percentage = ((pump weight – green weight)/green weight) × 100.

[3] Slice yield = (slice weight/final weight) × 100.

[4] Primal cuts were made according to Institutional Meat Purchasing Specifications (NAMPA, 2010).

[5] Belly flex was measured as the summation of each lateral and vertical from right and left ends of the belly. A zero lateral would be a complete folding of the belly and a zero vertical would be flat. A higher lateral flex would be a firmer belly. A lower vertical would be a firmer belly.

[6] Belly angle was calculated as: arctangent (left side lateral distance/ left side vertical distance) + arctangent (right side lateral distance/ right side vertical distance).

Table 3.4 Effect of different fat sources and VE supplementation on study 2 belly characteristics[1]

								P-value					
		Isoforms						ATA[2]					
		ATA, ppm				γ-T, ppm		Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
Belly Depth, cm	TW	5.15	5.23	5.13	4.94	5.21	5.05	-	-	0.04	-	-	-
	CO	4.63	4.95	4.81	4.83	4.85	4.42						
Primal cuts[4], kg													
Belly	TW	9.75	9.52	9.41	9.36	8.88	9.53	-	-	-	0.11	0.14	-
	CO	10.03	9.95	9.36	9.49	9.49	9.12						
Primal cuts, % hot carcass weight													
Belly	TW	8.61	8.63	8.34	7.99	7.67	8.06	0.11	-	-	0.02	-	-
	CO	8.80	8.74	8.68	8.34	8.36	8.08						
Belly Flex[5], cm													
Left Side													
Lateral	TW	18.03	14.29	16.09	17.15	15.49	15.75	-	-	<0.01	-	-	-
	CO	11.68	10.48	11.01	11.26	10.16	9.14						
Vertical	TW	29.53	27.94	27.73	27.94	28.36	27.18	-	-	0.04	-	-	-
	CO	31.50	31.05	29.85	29.13	32.17	31.24						
Right Side													
Lateral	TW	16.51	13.97	13.34	15.24	15.49	13.46	-	0.17	<0.01	-	-	-
	CO	10.41	10.41	11.01	11.18	10.37	9.40						
Vertical	TW	29.85	29.46	30.23	29.72	30.48	28.15	-	-	0.15	-	-	-
	CO	32.26	30.16	31.33	31.88	30.48	31.24						
Belly Angle[6], °	TW	52.75	44.31	47.18	48.28	50.69	44.45	-	-	<0.01	-	-	-
	CO	31.65	34.26	34.94	34.08	33.48	29.52						

[1] Values are average of 6 replicates. *P*-values for sex interactions are listed in Appendix Table A 4.2

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. No interaction between fat sources and dietary ATA levels was observed.

Table 3.4 Continued.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] Primal cuts were made according to Institutional Meat Purchasing Specifications (NAMPA, 2010).

[5] Belly flex was measured as the summation of each lateral and vertical from right and left ends of the belly. A zero lateral would be a complete folding of the belly and a zero vertical would be flat. A higher lateral flex would be a firmer belly. A lower vertical would be a firmer belly.

[6] Belly angle was calculated as: arctangent (left side lateral distance/ left side vertical distance) + arctangent (right side lateral distance/ right side vertical distance).

3.4.2 Bacon Processing

For study 1, no differences were observed across treatments for green weight, pump weight, pump percentage, smoke weight, chill weight, final weight and slice weight as shown in Table 3.5. Slicing yield decreased ($P = 0.04$) for every fat source when dietary VE level was increased from 11 to 200 ppm. No interactions between dietary levels of VE and fat sources were observed for bacon processing.

For study 2, bacon processing characteristics were not affected by dietary ATA level or fat sources. The results are provided in Table 3.6. Differences between the two isoforms were observed for green weight ($P =0.04$), pump weight ($P = 0.02$), pump percentage ($P = 0.05$), smoke weight ($P = 0.02$), chill weight ($P = 0.07$), and slice weight ($P = 0.04$). The bellies with ATA isoform were heavier than the γ-T bellies, however, there was no difference in slicing yield between the two isoforms. No interaction between isoforms of VE and dietary level or isoforms of VE and fat source was detected for bacon processing.

Table 3.5 Effect of different fat sources and VE supplementation on study 1 bacon processing[1]

VE, ppm:	11				200				SE	*P*-value		
Fat Source:	CS	TW	CO	CN	CS	TW	CO	CN		VE	Fat	VE*Fat
Green Weight, kg	5.64	5.60	6.11	5.86	6.05	6.00	5.96	6.25	0.79	-	-	-
Pump Weight, kg	6.55	6.54	7.23	7.13	6.90	7.01	7.05	7.06	0.85	-	-	-
Pump[2], %	16.07	15.86	18.18	16.42	16.19	16.95	18.25	14.84	2.53	-	0.18	-
Smoke Weight, kg	5.93	5.92	6.54	6.45	6.24	6.34	6.38	6.39	0.77	-	-	-
Chill Weight, kg	5.24	5.15	5.77	5.47	5.80	5.97	5.58	5.73	0.77	-	-	-
Final Weight, kg	5.81	5.71	6.40	6.07	6.43	6.62	6.19	6.36	0.86	-	-	-
Slice Weight, kg	5.53	5.08	5.65	5.55	5.75	5.52	5.47	5.77	0.90	-	-	-
Slicing Yield[3], %	94.98	95.68	93.27	91.70	89.62	89.18	88.69	91.53	5.52	0.04	-	-

[1] Values are an average of 8 replicated; *P*-values for sex interactions are listed in Appendix Table A 4.1. CS, corn starch; TW, tallow; CO, corn oil; CN, coconut oil.

[2] Pump percentage = ((pump weight – green weight)/green weight) × 100.

[3] Slice yield = (slice weight/final weight) × 100.

Table 3.6 Effect of different fat sources and VE supplementation on study 2 bacon processing[1]

		Isoforms						*P*-value					
		ATA, ppm				γ-T, ppm		ATA[2] Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
Green Weight, kg	TW	6.09	6.31	6.28	5.82	5.77	5.82	0.15	-	-	0.04	-	-
	CO	6.33	6.21	6.09	5.58	6.00	5.50						
Pump Weight, kg	TW	7.17	7.41	7.28	6.83	6.72	6.78	-	-	-	0.02	-	-
	CO	7.36	7.31	7.30	6.62	7.13	6.04						
Pump[4], %	TW	17.59	17.51	17.46	17.17	14.38	16.21	0.15	-	-	0.05	-	-
	CO	18.88	17.87	18.43	16.57	18.74	15.10						
Smoke Weight, kg	TW	6.67	6.90	6.77	6.35	6.25	6.30	-	-	-	0.02	-	-
	CO	6.84	6.80	6.79	6.16	6.63	5.62						
Chill Weight, kg	TW	6.64	6.86	6.74	6.32	6.22	6.28	-	-	-	0.02	-	-
	CO	6.81	6.77	6.76	6.13	6.60	5.59						
Final Weight, kg	TW	6.25	6.48	6.38	5.98	5.92	5.90	-	-	-	0.07	0.14	-
	CO	6.48	5.67	6.41	5.79	6.28	5.33						
Slice Weight, kg	TW	5.95	6.14	5.98	5.45	5.53	5.31	0.08	-	-	0.04	-	-
	CO	6.38	5.93	5.79	5.40	5.80	5.25						
Slicing Yield[5], %	TW	95.41	94.75	93.76	94.20	93.37	94.89	-	-	-	-	-	-
	CO	94.23	91.73	92.57	92.94	92.65	93.73						

[1] Values are average of 6 replicates. *P*-values for sex interactions are listed in Appendix Table A 4.2

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. No interaction between fat sources and dietary ATA levels was observed.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

[4] Pump percentage = ((pump weight – green weight)/green weight) × 100.

[5] Slice yield = (slice weight/final weight) × 100.

3.4.3 Bacon Quality

For experiment 1, no differences between dietary level of VE or interactions between dietary VE level and fat sources were observed for bacon quality as shown in Table 3.7. No differences were observed between fat sources for raw weight, cooked weight, slice cook loss, raw length, cooked length, slice shrink, distortion or stretch. As expected, shatter ($P < 0.01$) was different between fat sources. Corn starch displayed a higher shatter score for both dietary levels of VE, coconut oil had the lowest shatter for 11 ppm dietary VE and tallow had the lowest shatter for 200 ppm dietary VE.

For experiment 2, there were no differences among dietary levels of VE for bacon quality as shown in Table 3.8. Tallow had a higher shatter ($P = 0.02$) score than corn oil across the dietary VE treatments. Bacon slice raw length ($P = 0.02$) was longer for corn oil than for tallow. Bacon slice shrink ($P = 0.02$) was higher for corn oil than for tallow. No other difference in fat sources was detected. Differences between the two isoforms were observed for raw weight ($P = 0.03$) and cooked weight ($P = 0.01$). Bacon slices from the ATA isoform weighed more for raw and cooked weight than γ-T slices, however, there was no difference between the isoforms for slice cook loss. No interactions were observed between dietary levels of VE and isoforms of VE and between isoforms of VE and fat sources for bacon quality.

Table 3.7 Effect of different fat sources and VE supplementation on study 1 bacon quality[1]

VE, ppm:	11				200				SE	*P*-value		
Fat Source:	CS	TW	CO	CN	CS	TW	CO	CN		VE	Fat	VE*Fat
Shatter[2]	4.00	3.63	3.78	3.24	3.80	3.37	3.53	3.66	0.31	0.07	<0.01	0.09
Raw Weight, kg	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.00	-	0.11	0.15
Cooked Weight, kg	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	-	-	-
Slice Cook Loss[3]	59.96	62.51	63.97	58.73	60.86	65.67	62.96	60.40	5.69	-	-	-
Raw Length, cm	23.64	23.95	25.85	24.50	24.40	24.53	25.50	24.17	1.14	-	0.05	-
Cooked Length, cm	14.28	14.04	13.44	15.03	14.53	14.07	14.28	14.73	1.21	-	-	-
Slice Shrink[4]	39.60	42.18	45.80	36.67	40.53	42.74	44.21	39.98	5.53	-	0.12	-
Distortion[5]	2.90	2.60	2.79	2.30	2.67	2.67	2.13	1.88	0.84	-	0.09	-
Stretch[6], cm	0.47	0.48	0.90	0.81	0.43	0.36	0.90	0.28	0.55	-	-	-

[1] Values are an average of 8 replicated; *P*-values for sex interactions are listed in Appendix Table A 4.1. CS, corn starch; TW, tallow; CO, corn oil; CN, coconut oil. *P*-values for sex interactions are listed in Appendix Table A 1.2

[2] Subjective evaluation of slice integrity (fracture) from 0 to 6 where 0=intact slice possessing no shatter and 6= "spider-web" fracture.

[3] Bacon slice cooking loss = ((raw weight – cooked weight) / raw weight) × 100.

[4] Bacon slice cooking shrink = ((raw length – cooked length) / raw length) × 100.

[5] Subjective evaluation of slice appearance (curling, cooked distortion) from 0 to 5 where 0 = flat slice with no distortion and 5 = extreme curling and distortion.

[6] Bacon slice stretch = (shelf life day 7 length – shelf life day 1 length)

Table 3.8 Effect of different fat sources and VE supplementation on study 2 bacon quality[1]

								P-value					
		Isoforms						ATA[2]					
		ATA, ppm				γ-T, ppm		Level			Isoforms[3]		
Items	Fat	11	40	100	200	40	100	L	Q	Fat	IF	IF*Level	IF*Fat
Shatter[4]	TW	2.93	3.58	3.26	3.41	3.33	3.23	-	-	0.02	-	-	-
	CO	2.64	3.01	3.03	2.97	2.98	3.23						
Raw Weight, kg	TW	0.04	0.04	0.04	0.04	0.03	0.04	0.13	-	-	0.03	-	-
	CO	0.04	0.04	0.04	0.03	0.04	0.03						
Cooked Weight, kg	TW	0.02	0.02	0.02	0.02	0.02	0.02	-	-	0.10	0.01	-	-
	CO	0.02	0.02	0.01	0.02	0.02	0.01						
Slice Cook Loss[5]	TW	54.76	49.33	50.42	50.86	51.98	49.22	-	-	-	-	-	-
	CO	57.08	48.99	58.75	52.43	56.22	57.76						
Raw Length, cm	TW	24.70	25.56	24.63	24.84	23.82	25.85	-	-	0.02	-	0.09	-
	CO	26.18	26.45	26.33	25.58	25.98	25.54						
Cooked Length, cm	TW	15.48	15.38	17.07	16.24	15.57	17.72	-	-	-	-	-	-
	CO	15.64	16.03	14.32	16.36	16.78	14.90						
Slice Shrink[6]	TW	37.47	35.58	30.87	34.89	34.73	31.32	-	-	0.02	-	-	-
	CO	41.89	40.06	45.78	39.29	36.00	41.80						
Distortion[7]	TW	2.20	2.40	2.67	2.40	2.17	3.17	-	-	-	-	-	0.12
	CO	2.20	2.50	2.50	2.50	2.00	2.00						
Stretch[8], cm	TW	0.09	0.16	0.27	0.24	0.06	0.19	-	-	0.15	-	-	-
	CO	0.71	0.50	0.52	0.11	0.74	0.19						

[1] Values are average of 6 replicates. *P*-values for sex interactions are listed in Appendix Table A 4.2

[2] Statistical analysis used 8 treatments with a 4×2 factorial arrangement of four levels of ATA and two fat sources (data columns 1, 2, 3 and 4). L, linear; Q, quadratic. No interaction between fat sources and dietary ATA levels was observed.

[3] Statistical analysis used 8 treatments with a 2×2×2 factorial arrangement of two isoforms of VE, two levels of VE and two fat sources (data columns 2, 3, 5, and 6).

Table 3.8 Continued

[4] Subjective evaluation of slice integrity (fracture) from 0 to 6 where 0=intact slice possessing no shatter and 6= “spider-web” fracture.

[5] Bacon slice cooking loss = ((raw weight – cooked weight) / raw weight) × 100.

[6] Bacon slice cooking shrink = ((raw length – cooked length) / raw length) × 100.

[7] Subjective evaluation of slice appearance (curling, cooked distortion) from 0 to 5 where 0 = flat slice with no distortion and 5 = extreme curling and distortion.

[8] Bacon slice stretch = (shelf life day 7 length – shelf life day 1 length)

3.5 Conclusion

The results of these studies demonstrated the importance of dietary fat sources and vitamin E supplementation on belly and bacon quality in pigs grown up to 150 kg. These results showed that dietary fat sources with more saturated fatty acids could improve the firmness of bellies and quality of bacon compared to those fats with higher poly-unsaturated fatty acids. Additionally, bellies from pigs fed ATA weighed more before and after bacon processing compared to gamma-tocopherol bellies. Dietary supplementation in the form of ATA also showed an increase in raw and cooked weight for individual bacon slices. However, there were no interactions between vitamin E isoforms and dietary fat sources or vitamin E isoforms and level of vitamin E.

APPENDICES

Appendix 1. Number of excluded outliers and missing values in Chapter 2

Table A. 1.1 Number of excluded outliers and missing values for carcass traits and primal cuts

Fat sources	Tallow						Corn oil					
Isoform	ATA				γ-T		ATA				γ-T	
Level, ppm	11	40	100	200	40	100	11	40	100	200	40	100
Carcass traits												
SLW, kg	0	0	0	1	0	1	1	0	0	0	0	0
HCW, kg	0	0	0	1	0	1	1	0	0	0	0	0
CCW, kg	0	0	0	1	0	1	1	0	0	0	0	0
Dressing, %	0	0	0	0	1	0	0	0	1	0	0	0
Shrink loss, %	0	0	1	0	0	1	0	1	0	1	2	0
45-min pH	0	0	1	0	0	0	1	0	0	0	0	0
24-hr pH	0	0	0	1	0	0	0	0	0	0	1	0
ΔpH	0	0	1	0	1	0	0	0	1	0	0	0
C.Length	1	1	0	0	0	0	0	0	1	0	0	0
First rib	0	0	1	0	0	0	0	0	1	1	0	0
Last rib	0	0	0	1	0	0	0	0	0	1	0	1
10th rib	0	0	0	1	0	0	0	0	0	0	0	0
Last lumbar	0	0	0	0	1	1	0	0	0	0	0	0
Belly depth, cm	0	0	1	1	0	0	0	0	0	0	0	1
Vertical	0	0	0	0	1	0	0	0	0	0	1	1
Horizontal	0	0	0	0	0	0	0	0	1	0	0	0
Area, cm2	0	0	1	1	0	0	0	1	1	1	0	0
Primal cuts, kg												
Boston butt	1	0	0	0	0	1	1	0	0	0	1	0

Table A. 1.1 Continued												
Picnic Shoulder	0	0	0	0	0	0	0	1	0	1	0	0
Loin	0	0	1	0	1	0	0	0	0	0	0	0
Spare ribs	2	0	0	0	1	0	0	0	1	0	0	0
Ham	0	0	0	1	0	1	0	1	0	1	0	0
Belly	0	0	0	1	0	1	0	0	0	0	0	1
Primal cuts, %												
Boston butt	1	0	0	0	0	1	1	0	0	0	1	0
Picnic Shoulder	0	0	0	0	0	0	0	1	0	1	0	0
Loin	0	0	1	0	1	0	0	0	0	0	0	0
Spare ribs	0	0	0	0	1	0	0	0	0	0	0	0
Ham	0	0	1	1	0	1	0	0	1	0	0	0
Belly	0	0	0	0	0	0	0	0	0	0	1	0

Table A. 1.2 Number of excluded outliers and missing values for meat quality

Fat sources	Tallow						Corn oil					
Isoform	ATA				γ-T		ATA				γ-T	
Level, ppm	11	40	100	200	40	100	11	40	100	200	40	100
Meat Quality												
Drip Loss	1	0	0	0	1	1	0	0	0	0	0	1
Purge loss D7	0	0	0	0	1	1	0	0	0	0	0	1
Purge loss D14	0	0	0	0	0	0	0	0	0	0	0	0
Purge loss D30	0	0	1	0	1	0	0	0	0	0	0	0
Left-Lateral	0	1	0	1	1	1	0	0	0	0	0	0
Left-Vertical	1	0	0	1	0	1	0	0	0	0	0	0
Right-Lateral	1	1	2	0	1	1	0	0	0	0	0	0
Right-Vertical	1	0	1	0	2	0	0	0	0	0	0	0
Belly angle	1	1	1	0	1	1	0	0	0	0	0	0
Shelf life												
*L**	0	0	0	0	3	1	2	0	0	2	0	0
*a**	0	2	3	0	1	0	3	0	1	0	0	0
*b**	1	3	0	0	2	0	0	0	2	2	2	1
a/b	1	0	4	0	0	0	3	0	0	1	0	1
Hue	1	0	4	0	0	0	3	0	0	2	0	1
Chroma	1	3	2	0	0	0	1	0	2	0	1	1
Extended shelf life												
*L**	3	0	1	0	0	0	2	4	0	0	0	3
*a**	0	3	1	0	0	0	3	1	0	0	1	0
*b**	0	1	1	0	2	4	1	0	0	0	0	0
a/b	0	3	2	0	0	0	2	0	0	0	1	0
Hue	0	1	2	0	1	0	2	0	0	0	0	0
Chroma	0	3	1	0	2	0	1	1	1	0	1	0

Appendix 2. P-values of sex effect and their interactions for Chapter 2

Table A. 2.1 P-values of sex effect and their interactions for carcass traits and primal cuts

	ATA levels × Fat (4×2)			Isoforms × levels × fat (2×2×2)			
Items	sex	sex*level	sex*fat	sex	sex*isoform	sex*level	sex*fat
Carcass traits							
SLW, kg	-	-	0.04	-	-	-	-
HCW, kg	-	-	-	-	-	-	-
CCW, kg	-	-	-	-	-	-	-
Dressing, %	-	-	-	-	-	-	-
Shrink loss, %	-	-	-	0.04	-	-	-
45-min pH	-	-	-	-	-	-	-
24-hr pH	-	-	-	-	-	-	-
ΔpH	-	-	-	-	-	-	-
C.Length	-	-	-	-	-	-	-
First rib	-	-	-	-	-	-	-
Last rib	-	-	-	-	-	-	-
10th rib	-	-	0.04	-	-	-	-
Last lumbar	-	-	-	-	-	-	-
Belly depth, cm	-	-	-	0.08	-	-	-
Vertical	0.04	-	0.03	-	-	-	-
Horizontal	-	-	0.02	-	-	0.03	0.09
Area, cm2	-	-	-	-	-	-	-
Primal cuts, kg							
Boston butt	-	-	-	-	-	-	-
Picnic Shoulder	-	-	-	-	-	-	-
Loin	-	-	-	0.07	0.10	-	-
Spare ribs	-	-	-	0.08	-	-	-
Ham	-	-	-	-	-	-	-
Belly	-	0.10	-	-	-	<0.01	-
Primal cuts, %							
Boston butt	-	-	-	-	-	-	-
Picnic Shoulder	-	-	-	-	-	-	-
Loin	-	-	-	-	0.04	-	-
Spare ribs	-	-	-	-	-	-	-
Ham	-	-	-	-	-	-	-
Belly	-	-	-	-	-	<0.01	-

Appendix 2.2 P-values of sex effect and their interactions for meat quality

	ATA levels × Fat (4×2)			Isoforms × levels × fat (2×2×2)			
Items	sex	sex*level	sex*fat	sex	sex*isoform	sex*level	sex*fat
Meat Quality							
Drip Loss	-	0.05	-	-	-	<0.01	-
Purge loss D7	-	-	-	-	-	-	-
Purge loss D14	0.03	-	-	-	0.04	-	-
Purge loss D30	0.06	-	-	-	0.07	-	-
Color	-	0.04	-	0.05	-	-	-
Marbling	-	-	-	-	-	-	-
Firmness	-	-	-	-	-	-	-
Left-Lateral	-	-	0.09	0.03	-	-	0.02
Left-Vertical	-	-	-	0.09	-	-	0.04
Right-Lateral	-	-	-	-	-	-	-
Right-Vertical	-	-	-	-	-	-	-
Belly angle	-	-	-	-	-	-	-
Shelf Life							
*L** Day 1	-	0.04	-	-	-	0.07	-
*L** Day 3	0.06	<0.01	-	-	-	-	-
*L** Day 5	0.06	0.02	0.07	-	-	-	-
*L** Day 7	0.02	<0.01	-	-	-	-	-
*a** Day 1	-	-	-	-	-	0.07	-
*a** Day 3	-	-	-	-	-	-	-
*a** Day 5	-	-	-	-	-	-	-
*a** Day 7	0.09	-	-	-	-	-	-
*b** Day 1	-	0.05	-	-	-	-	-
*b** Day 3	-	-	-	-	-	-	-
*b** Day 5	-	-	-	-	-	-	-
*b** Day 7	-	-	-	-	-	-	-
a/b Day 1	0.04	-	-	-	-	<0.01	-
a/b Day 3	-	-	-	-	-	-	-
a/b Day 5	0.10	-	-	-	-	-	-
a/b Day 7	0.04	-	-	-	-	-	-
Hue Day 1	0.03	-	-	-	-	<0.01	-
Hue Day 3	-	-	-	-	-	-	-
Hue Day 5	0.10	-	-	-	-	-	-
Hue Day 7	0.04	-	-	-	-	-	-
Chroma Day 1	-	0.06	-	-	-	-	-
Chroma Day 3	-	-	-	-	-	-	-
Chroma Day 5	-	-	-	-	-	-	-
Chroma Day 7	-	-	-	-	-	-	-
Extended Shelf Life							
*L** Day 30	-	-	-	-	-	-	-

Table A. 2.2 Continued

*L** Day 32	-	0.05	-	-	-	0.05	-
*L** Day 34	-	0.03	-	-	-	-	-
*L** Day 36	-	0.03	-	-	-	-	0.08
*a** Day 30	-	-	-	-	-	-	-
*a** Day 32	-	0.06	-	-	0.06	0.02	-
*a** Day 34	-	0.04	-	-	0.02	<0.01	-
*a** Day 36	-	-	-	-	-	0.03	-
*b** Day 30	-	-	-	-	0.06	-	-
*b** Day 32	-	-	-	-	-	0.06	-
*b** Day 34	0.05	-	-	-	-	0.01	-
*b** Day 36	-	-	-	-	-	-	-
a/b Day 30	-	-	-	0.09	-	-	-
a/b Day 32	-	0.04	-	-	<0.01	<0.01	0.01
a/b Day 34	-	0.05	-	-	<0.01	0.03	-
a/b Day 36	-	0.04	-	-	0.06	0.03	-
Hue Day 30	-	-	-	-	-	-	-
Hue Day 32	-	0.04	-	-	-	<0.01	-
Hue Day 34	-	0.06	-	-	0.01	0.04	-
Hue Day 36	-	0.08	-	-	-	0.02	-
Chroma Day 30	-	-	-	-	-	-	-
Chroma Day 32	-	-	-	-	-	0.07	-
Chroma Day 34	0.06	0.02	-	-	-	0.03	-
Chroma Day 36	-	-	-	-	-	0.02	-

Table A. 2.3 P-values of sex effect and their interactions for sensory characteristics

	ATA levels × Fat (4×2)			Isoforms × levels × fat (2×2×2)			
Items	sex	sex*level	sex*fat	sex	sex*isoform	sex*level	sex*fat
Tenderness	-	-	-	-	-	-	-
Juiciness	-	-	-	-	-	-	-
Off-Flavor	0.02	-	-	<0.01	-	0.01	0.10
Flavor Intensity	-	-	0.07	-	0.10	-	-
Overall Approval	-	-	-	0.04	-	-	-

Appendix 3. Number of excluded outliers and missing values in Chapter 3

Table A. 3.1 Numbers of excluded outliers and missing values for bacon processing and quality (Study 1)

VE, ppm:	11				200			
Fat Source:	CS	TW	CO	CN	CS	TW	CO	CN
Excluded Bellies	3	2	1	2	2	3	4	0
Green Weight, kg	0	1	1	0	0	0	0	2
Pump Weight, kg	0	1	1	0	0	0	0	2
Pump, %	0	0	0	1	1	0	0	1
Smoke Weight, kg	0	1	1	0	0	0	0	2
Chill Weight, kg	0	1	1	0	0	0	0	2
Final Weight, kg	0	1	1	0	0	0	0	2
Slice Weight, kg	0	0	1	0	0	0	0	2
Slicing Yield, %	0	1	1	0	0	1	0	0
Shatter	1	0	1	0	0	0	0	2
Raw Weight, kg	0	0	0	0	0	0	0	0
Cooked Weight, kg	0	0	0	0	0	0	0	0
Slice Cook Loss	0	0	2	0	0	0	0	0
Raw Length, cm	0	1	1	0	0	0	0	1
Cooked Length, cm	0	0	0	1	0	0	0	1
Slice Shrink	0	1	2	0	0	0	0	0
Distortion	0	0	0	0	0	0	0	0
Stretch, cm	0	1	1	0	0	0	1	0

Table A. 3.2 Number of excluded outliers and missing values for bacon processing and quality (Study 2)

Fat sources	Tallow						Corn oil					
Isoform	ATA				γ-T		ATA				γ-T	
Level, ppm	11	40	100	200	40	100	11	40	100	200	40	100
Green Weight, kg	0	0	0	0	0	1	0	1	0	0	0	1
Pump Weight, kg	0	0	0	0	0	1	1	1	0	0	0	0
Pump, %	0	0	1	0	1	0	1	0	1	1	0	0
Smoke Weight, kg	0	0	0	0	0	1	1	1	0	0	0	0
Chill Weight, kg	0	0	0	0	0	1	2	1	0	0	0	0
Final Weight, kg	0	0	0	0	0	1	2	2	0	0	0	0
Slice Weight, kg	0	0	0	0	0	0	1	1	0	0	0	1
Slicing Yield, %	0	0	0	1	0	0	0	0	1	0	0	1
Shatter	1	0	0	0	0	0	1	0	0	0	0	0
Raw Weight, kg	0	0	0	0	0	1	0	0	0	0	0	1
Cooked Weight, kg	0	1	0	0	0	0	0	1	0	0	1	0
Slice Cook Loss	0	0	0	0	0	0	0	0	0	0	1	0
Raw Length, cm	0	0	0	0	0	0	1	0	0	0	0	0
Cooked Length, cm	0	0	0	0	0	0	0	1	0	1	1	0
Slice Shrink	0	0	0	0	0	0	0	0	0	0	1	0
Distortion	0	0	0	0	0	0	0	0	0	0	0	0
Stretch, cm	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4. P-values of sex effect and their interactions for Chapter 3

Table A. 4.1 P-values of sex effect and their interactions for bacon processing and quality (Study 1)

	P-value		
Items	sex	sex*VE	sex*fat
Green Weight, kg	-	-	-
Pump Weight, kg	-	-	-
Pump, %	-	-	-
Smoke Weight, kg	-	-	-
Chill Weight, kg	-	-	-
Final Weight, kg	-	-	-
Slice Weight, kg	-	-	-
Slicing Yield, %	-	-	-
Shatter	<0.01	-	0.05
Raw Weight, kg	-	-	-
Cooked Weight, kg	-	-	-
Slice Cook Loss	-	-	-
Raw Length, cm	-	-	-
Cooked Length, cm	-	-	-
Slice Shrink	-	-	-
Distortion	-	-	-
Stretch, cm	0.10	-	-

Table A. 4.2 P-values of sex effect and their interactions for bacon processing and quality (Study 2)

	ATA levels × Fat (4×2)			Isoforms × levels × fat (2×2×2)			
Items	sex	sex*level	sex*fat	sex	sex*isoform	sex*level	sex*fat
Green Weight, kg	-	0.03	-	<0.01	-	-	-
Pump Weight, kg	-	0.04	-	<0.01	-	-	-
Pump, %	-	-	-	-	-	0.04	-
Smoke Weight, kg	-	0.04	-	<0.01	-	-	-
Chill Weight, kg	-	0.04	-	<0.01	-	-	-
Final Weight, kg	-	0.02	-	<0.01	-	-	-
Slice Weight, kg	-	0.01	-	<0.01	-	-	-
Slicing Yield, %	-	-	-	-	-	-	-
Shatter	-	-	-	-	-	0.09	-
Raw Weight, kg	-	-	-	0.01	-	-	-
Cooked Weight, kg	-	-	-	-	-	-	-
Slice Cook Loss	-	-	-	-	-	-	-
Raw Length, cm	-	0.04	-	-	-	0.05	0.02
Cooked Length, cm	-	-	-	-	-	0.05	-
Slice Shrink	-	-	-	-	-	-	-
Distortion	-	-	0.02	-	-	-	-
Stretch, cm	-	-	-	0.05	-	-	-

REFERENCES

AHA (2015). Saturated Fat. American Heart Association, Dallas, TX

AMS (1985). United States Standards for Grades of Pork Carcasses, United States Department of Agriculture, Agricultural Marketing Service.

AMSA. (2012) AMSA Meat Color Measurement Guidelines: American Meat Science Association, Champaign, IL

Apple, J. K., Sawyer, J. T., Maxwell, C. V., Yancey, J. W. S., Frank, J. W., Woodworth, J. C., & Musser, R. E. (2011). Effects of L-carnitine supplementation on quality characteristics of fresh pork bellies from pigs fed 3 levels of corn oil. Journal of animal science, 89(9), 2878-2891.

Asghar, A., Gray, J. I., Booren, A. M., Gomaa, E. A., Abouzied, M. M., Miller, E. R., & Buckley, D. J. (1991). Effects of supranutritional dietary vitamin E levels on subcellular deposition of α-tocopherol in the muscle and on pork quality. Journal of the Science of Food and Agriculture, 57(1), 31-41.

Bendall, J. R., & Swatland, H. J. (1988). A review of the relationships of pH with physical aspects of pork quality. Meat science, 24(2), 85-126.

Benz, J. M., Linneen, S. K., Tokach, M. D., Dritz, S. S., Nelssen, J. L., DeRouchey, J. M., & Prusa, K. J. (2010). Effects of dried distillers grains with solubles on carcass fat quality of finishing pigs. Journal of animal science, 88(11), 3666-3682.

Blumer, T. N. (1963). Relationship of marbling to the palatability of beef. Journal of animal science, 22(3), 771-778.

Boler, D. D., S. Gabriel, H. Yang, R. Balsbaugh, D. Mahan, M. Brewer, F. McKeith, and J. Killefer. 2009. Effect of different dietary levels of natural-source vitamin E in grow-finish pigs on pork quality and shelf life. Meat Science 83(4):723-730.

BREENE, W. M. (1978). TEXTURAL CHARACTERIZATION OF TEXTURIZED PROTEINS 1. Journal of Texture Studies, 9(1-2), 77-107.

Brewer, M.S., L.G Zhu, B Bidner, D.J Meisinger, F.K McKeith. (2001) Measuring pork color: effects of bloom time, muscle, pH and relationship to instrumental parameters. Meat Science 57 (2): 169-176

Buckley, D. J., Morrissey, P. A., & Gray, J. I. (1995). Influence of dietary vitamin E on the oxidative stability and quality of pig meat. Journal of Animal Science, 73(10), 3122-3130.

Buckley, J., & Connolly, F. (1980). Influence of alpha-tocopherol (vitamin E) on storage stability of raw pork and bacon. Journal of Food Protection, 43(4), 265-267.

Burton, Graham W., and Maret G. Traber. "Vitamin E: antioxidant activity, biokinetics, and bioavailability." Annual review of nutrition 10.1 (1990): 357-382.

Cannon, J. E., Morgan, J. B., Heavner, J., McKeith, F. K., Smith, G. C., & Meeker, D. L. (1995). PORK QUALITY AUDIT: A REVIEW OF THE FACTORS INFLUENCING PORK QUALITY 1. Journal of muscle foods, 6(4), 369-402.

Cannon, J. E., Morgan, J. B., Schmidt, G. R., Tatum, J. D., Sofos, J. N., Smith, G. C., ... & Williams, S. N. (1996). Growth and fresh meat quality characteristics of pigs supplemented with vitamin E. Journal of Animal Science, 74(1), 98-105.

Chambers, E., & Bowers, J. R. (1993). Consumer perception of sensory qualities in muscle foods. Food technology (USA).

Chemists, A. A., & Horwitz, W. (1990). Official methods of analysis. Vol. I. 15th ed. AOAC, Arlington, VA, 489.

Chiba, L. I., Peo Jr, E. R., Lewis, A. J., Brumm, M. C., Fritschen, R. D., & Crenshaw, J. D. (1985). Effect of dietary fat on pig performance and dust levels in modified-open-front and environmentally regulated confinement buildings. Journal of Animal Science, 61(4), 763-781.

Cisneros, F., M. Ellis, F. K. McKeith, J. McCaw, and R. L. Fernando. 1996. Influence of slaughter weight on growth and carcass characteristics, commercial cutting and curing yields, and meat quality of barrows and gilts from two genetic populations. J. Anim. Sei.

Cornforth, D. (1994). Color—its basis and importance. In Quality attributes and their measurement in meat, poultry and fish products (pp. 34-78). Springer, Boston, MA.

Correa, J. A., Gariepy, C., Marcoux, M., & Faucitano, L. (2008). Effects of growth rate, sex and slaughter weight on fat characteristics of pork bellies. Meat science, 80(2), 550-554.

Cromwell, G. L., M. J. Azain, O. Adeola, S. K. Baidoo, S. D. Carter, T. D. Crenshaw, S.W. Kim, D. C. Mahan, P. S. Miller, M. C. Shannon, and North Central Coordinating Committee on Swine Nutrition. 2011. Corn distillers dried grains

with solubles in diets for growing finishing pigs: A cooperative study. J. Anim. Sci. 89:2801–2811.

Delmore, R. J. (2009). Beef shelf-life. National Cattlemen's Beef Association.

Eggert, J. M., Grant, A. L., & Schinckel, A. P. (2007). Factors affecting fat distribution in pork carcasses. The Professional Animal Scientist, 23(1), 42-53.

Ellis, M., A. J. Webb, P. J. Avery, and I. Brown. 1996. The influence of terminal sire genetic population, gender, slaughter weight, feeding regime and slaughter house on growth performance and carcass and meat quality in pigs and on the organoleptic properties of fresh pork. J. Anim. Sci.

Ellis, N., and O. Hankins. 1925. Soft pork studies I. Formation of fat in the pig on a ration moderately low in fat. Journal of Biological Chemistry 66(1):101-122.

Falowo, A. B., Fayemi, P. O., & Muchenje, V. (2014). Natural antioxidants against lipid–protein oxidative deterioration in meat and meat products: A review. Food Research International, 64, 171-181.

Fernández, J., Pérez-Álvarez, J. A., & Fernández-López, J. A. (1997). Thiobarbituric acid test for monitoring lipid oxidation in meat. Food chemistry, 59(3), 345-353.

Fernandez, X., et al. "Influence of intramuscular fat content on the quality of pig meat—1. Composition of the lipid fraction and sensory characteristics of m. longissimus lumborum." Meat Science 53.1 (1999): 59-65.

Food and Agricultural Organization of the United Nations (2014). Meat Consumption, Animal Production and Health. Rome, Italy

Forrest, J. C., Kuei, C. H., Orcutt, M. W., Schinckel, A. P., Stouffer, J. R., & Judge, M. D. (1989). A review of potential new methods of on-line pork carcass evaluation. Journal of Animal Science, 67(8), 2164-2170.

Fortin, A., J. D. Wood, and O. P. Whelehan. 1987. Breed and sex effects on the development and proportions of muscle, fat and bone in pigs. The Journal of Agricultural Science, 108(1), 39-45.

Fox Jr, J. B. (1966). Chemistry of meat pigments. Journal of Agricultural and Food Chemistry, 14(3), 207-210.

Frankel, E. N. (2014). Lipid oxidation. Elsevier.

FSIS. (2011). Bacon and food safety. Food Safety and Inspection Service, United State Department of Agriculture.

Gatlin, L. A., See, M. T., Larick, D. K., Lin, X., & Odle, J. (2002). Conjugated linoleic acid in combination with supplemental dietary fat alters pork fat quality. The Journal of nutrition, 132(10), 3105-3112.

Gatlin, L. A., See, M. T., Hansen, J. A., & Odle, J. (2003). Hydrogenated dietary fat improves pork quality of pigs from two lean genotypes. Journal of animal science, 81(8), 1989-1997.

Gerrard, D. E., & Grant, A. L. (2003). Principles of Animal Growth and Development (1st ed.). Dubuque, IA: Kendall/Hunt Publishing Co.

Gray, J. I., & Pearson, A. M. (1994). Lipid-derived off-flavours in meat—formation and inhibition. In Flavor of meat and meat products (pp. 116-143). Springer, Boston, MA.

Gray, J. I., Gomaa, E. A., & Buckley, D. J. (1996). Oxidative quality and shelf life of meats. Meat science, 43, 111-123.

Grilo, Evellyn Câmara, et al. "Alpha-tocopherol and gamma-tocopherol concentration in vegetable oils." Food Science and Technology 34.2 (2014): 379-385.

Gu, Y., A. P. Schinckel, and T. G. Martin. 1992. Growth, development, and carcass composition in five genetic populations of swine. J. Anim.

Guàrdia, M.D., J. Estany, S. Balasch, M.A. Oliver, M. Gispert, A. Diestre. (2005) Risk assessment of DFD meat due to pre-slaughter conditions in pigs. Meat Science 70 (4): 709-716

Guo, Q., B. Richert, J. Burgess, D. Webel, D. Orr, M. Blair, A. Grant, and D. Gerrard. 2006. Effect of dietary vitamin E supplementation and feeding period on pork quality. Journal of Animal Science 84(11):3071-3078.

Hoving-Bolink, A. H., Eikelenboom, G., Van Diepen, J. T. M., Jongbloed, A. W., & Houben, J. H. (1998). Effect of dietary vitamin E supplementation on pork quality. Meat Science, 49(2), 205-212.

Huff-Lonergan, E., & Sosnicki, A. (2002). Water-holding capacity of fresh meat. Fact Sheet, 4669.

Huff-Lonergan, E., & Lonergan, S. M. (2005). Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat science, 71(1), 194-204.

Hunt, M. C., Acton, J. C., Benedict, R. C., Calkins, C. R., Cornforth, D. P., Jeremiah, L. E., ... & Shivas, S. D. (1991). Guidelines for meat color evaluation. American Meat Science Association, Kansas State University: Manhattan, KS, 1-17.

Jensen, C., Lauridsen, C., & Bertelsen, G. (1998). Dietary vitamin E: quality and storage stability of pork and poultry. Trends in food science & technology, 9(2), 62-72.

Jiang, Qing, et al. "γ-Tocopherol, the major form of vitamin E in the US diet, deserves more attention." The American journal of clinical nutrition 74.6 (2001): 714-722.

Jones, L. V., Peryam, D. R., & Thurstone, L. L. (1955). DEVELOPMENT OF A SCALE FOR MEASURING SOLDIERS'FOOD PREFERENCES ab. Journal of Food Science, 20(5), 512-520.

Kellner, T., N. Gabler, and J. Patience. 2017. The composition of dietary fat alters the transcriptional profile of pathways associated with lipid metabolism in the liver and adipose tissue in the pig. Journal of Animal Science 95(8):3609-3619.

Kellner, T. A., Gourley, G. G., Wisdom, S., & Patience, J. F. (2016). Prediction of porcine carcass iodine value based on diet composition and fatty acid intake. Journal of animal science, 94(12), 5248-5261.

Kellner, T., K. Prusa, and J. Patience. 2014. Impact of dietary fat source and concentration and daily fatty acid intake on the composition of carcass fat and iodine value sampled in three regions of the pork carcass. Journal of Animal Science 92(12):5485-5495.

Knipe, C. L., & Beld, J. (2014). Bacon Production| Bacon.

Lahucky, R., Bahelka, I., Kuechenmeister, U., Vasickova, K., Nuernberg, K., Ender, K., & Nuernberg, G. (2007). Effects of dietary supplementation of vitamins D3 and E on quality characteristics of pigs and longissimus muscle antioxidative capacity. Meat science, 77(2), 264-268.

Lanari, M. C., Schaefer, D. M., & Scheller, K. K. (1995). Dietary vitamin E supplementation and discoloration of pork bone and muscle following modified atmosphere packaging. Meat Science, 41(3), 237-250.

Larsen, S. T., Wiegand, B. R., Parrish Jr, F. C., Swan, J. E., & Sparks, J. C. (2009). Dietary conjugated linoleic acid changes belly and bacon quality from pigs fed varied lipid sources. Journal of animal science, 87(1), 285-295.

Lawless, H. T., & Heymann, H. (2013). Sensory evaluation of food: principles and practices. Springer Science & Business Media. New York, NY 10013

1. Livingston, D. J., & Brown, W. D. (1981). The chemistry of myoglobin and its reactions Food Technol. 35:244–252.

Lo, L. L., D. G. McLaren, F. K. McKeith, R. L. Fernando, and J. Novakofski. 1992. Genetic analyses of growth, real-time ultrasound, carcass, and pork quality traits in Duroc and Landrace pigs: I. Breed effects. J. Anim.

Mahan, D. C., and D. B. Gerber. 1985. Gilt and barrow performance measurements from 60 to 135 kg body weight. Nutr. Rep. Int.

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

Mandigo, R. (1998). Belly and bacon quality. Pork Qual. Saf. Summit. Natl. Pork Producers, Washington, DC, 239-249.

Mandigo, R. W. (2002). A new look at belly and bacon values. National Hog Farmer. Available: http://nationalhogfarmer. com/ar/farming_new_look_belly/index.

Mandigo, Roger. (2009) "Bacon Processing Today." American Meat Science Association. Lincoln, NE 68583

Martin, A. H., A. P. Sather, H. T. Fredeen, and R. W. Jolly. 1980. Alternative market weights for swine. II. Carcass composition and meat quality. Journal of Animal Science, 50(4), 699-705.

Maw, S. J., Fowler, V. R., Hamilton, M., & Petchey, A. M. (2003). Physical characteristics of pig fat and their relation to fatty acid composition. Meat Science, 63(2), 185-190.

McClelland, K., G. Rentfrow, G. Cromwell, M. Lindemann, and M. Azain. 2012. Effects of corn distillers dried grains with solubles on quality traits of pork. Journal of Animal Science 90(11):4148-4156.

Meilgaard, M. C. (1991). Testing for sensory threshold of added substances. Journal of the American Society of Brewing Chemists, 49(3), 128-135.

Miller, M. F., Shackelford, S. D., Hayden, K. D., & Reagan, J. O. (1990). Determination of the alteration in fatty acid profiles, sensory characteristics and carcass traits of swine fed elevated levels of monounsaturated fats in the diet. Journal of Animal Science, 68(6), 1624-1631.

Mitchaothai, J., Yuangklang, C., Wittayakun, S., Vasupen, K., Wongsutthavas, S., Srenanul, P., & Beynen, A. C. (2007). Effect of dietary fat type on meat quality and fatty acid composition of various tissues in growing–finishing swine. Meat Science, 76(1), 95-101.

Monahan, F. J., Asghar, A., Gray, J. I., Buckley, D. J., & Morrissey, P. A. (1994). Effect of oxidized dietary lipid and vitamin E on the colour stability of pork chops. Meat Science, 37(2), 205-215.

National Pork Producers Council. 2000. Pork Composition & Quality Assessment Procedures. National Pork Producers Council, Des Moines, IA.

North American Meat Processors Association. 2010. The Meat Buyers Guide. 6th ed. North American Processors Association, Reston, VA.

Ohene-Adjei, S., Bertol, T., Hyun, Y., Ellis, M., McKeith, F. K., & Brewer, M. S. (2004). Effect of vitamin E, low dose irradiation, and display time on the quality of pork. Meat science, 68(1), 19-26.

Person, R. C., McKenna, D. R., Griffin, D. B., McKeith, F. K., Scanga, J. A., Belk, K. E., ... & Savell, J. W. (2005). Benchmarking value in the pork supply chain: Processing characteristics and consumer evaluations of pork bellies of different thicknesses when manufactured into bacon. Meat science, 70(1), 121-131.

Peryam, D. R., & Pilgrim, F. J. (1957). Hedonic scale method of measuring food preferences. Food technology.

Pettigrew, J. E., Moser, R. L., Miller, E. R., Ullrey, D. E., & Lewis, A. J. (1991). Fat in swine nutrition. Swine nutrition, 133-145.

Pettigrew, J. E., & Esnaola, M. A. (2001). Swine nutrition and pork quality: A review. Journal of Animal Science, 79(suppl_E), E316-E342.

Phillips, A. L., Faustman, C., Lynch, M. P., Govoni, K. E., Hoagland, T. A., & Zinn, S. A. (2001). Effect of dietary α-tocopherol supplementation on color and lipid stability in pork. Meat Science, 58(4), 389-393.

Piggott, J. R., & MacleodJohn, S. (2010). Sensory quality control of distilled beverages. In Sensory Analysis for Food and Beverage Quality Control (pp. 262-275). Woodhead Publishing.

Rentfrow, G., Sauber, T. E., Allee, G. L., & Berg, E. P. (2003). The influence of diets containing either conventional corn, conventional corn with choice white grease, high oil corn, or high oil high oleic corn on belly/bacon quality. Meat Science, 64(4), 459-466.

Rincker, P. J., Killefer, J., & McKeith, F. K. (2007). Evaluating an objective method to measure fresh pork loin firmness. Meat science, 77(2), 213-219.

Rivellese, A. A., Maffettone, A., Vessby, B., Uusitupa, M., Hermansen, K., Berglund, L., & Riccardi, G. (2003). Effects of dietary saturated, monounsaturated and n-3 fatty acids on fasting lipoproteins, LDL size and post-prandial lipid metabolism in healthy subjects. Atherosclerosis, 167(1), 149-158.

Rocha, A. E. (2011). Basic Manufacturing of Bacon.

Rossi, R., Pastorelli, G., Cannata, S., & Corino, C. (2010). Recent advances in the use of fatty acids as supplements in pig diets: a review. Animal Feed Science and Technology, 162(1-2), 1-11.

Schilling, M. W., Mink, L. E., Gochenour, P. S., Marriott, N. G., & Alvarado, C. Z. (2003). Utilization of pork collagen for functionality improvement of boneless cured ham manufactured from pale, soft, and exudative pork. Meat Science, 65(1), 547-553.

Scramlin, S. M., Carr, S. N., Parks, C. W., Fernandez-Dueñas, D. M., Leick, C. M., McKeith, F. K., & Killefer, J. (2008). Effect of ractopamine level, gender, and duration of ractopamine on belly and bacon quality traits. Meat science, 80(4), 1218-1221.

Seman, D. L., Barron, W. N. G., & Matzinger, M. (2013). Evaluating the ability to measure pork fat quality for the production of commercial bacon. Meat science, 94(2), 262-266.

Shackelford, S. D., Miller, M. F., Haydon, K. D., Lovegren, N. V., Lyon, C. E., & Reagan, J. O. (1990). Acceptability of bacon as influenced by the feeding of elevated levels of monounsaturated fats to growing-finishing swine. Journal of Food Science, 55(3), 621-624.

Shipp, T. E., H. W. Miller, and T. G. Althen. 1996. Effects of supplemental dietary fat on growth and carcass characteristics of growing-finishing swine. Prof. Anim.

Smith, G. C., West, R. L., & Carpenter, Z. L. (1975). Factors affecting desirability of bacon and commercially-processed pork bellies. Journal of Animal Science, 41(1), 54-65.

Steenkamp, J. E. B. M., & van Trijp, J. C. M. (1988). Free choice profiling in food acceptance research. In Food acceptability (pp. 363-375).

Suman, S. P., & Joseph, P. (2013). Myoglobin chemistry and meat color. Annual review of food science and technology, 4, 79-99.

Suman, S. P., Faustman, C., Stamer, S. L., & Liebler, D. C. (2007). Proteomics of lipid oxidation-induced oxidation of porcine and bovine oxymyoglobins. Proteomics, 7(4), 628-640.

SWINE–NRC, N. R. O. (2012). National academic of sciences.

Tapp Iii, W. N., Yancey, J. W. S., & Apple, J. K. (2011). How is the instrumental color of meat measured?. Meat Science, 89(1), 1-5.

Tarladgis, B. G., Watts, B. M., Younathan, M. T., & Dugan Jr, L. (1960). A distillation method for the quantitative determination of malonaldehyde in rancid foods. Journal of the American Oil Chemists' Society, 37(1), 44-48.

The National Provisioner, (2008). Bacon Technology 101. Bacon Technology Journal.

Trusell, K. A., Apple, J. K., Yancey, J. W., Johnson, T. M., Galloway, D. L., & Stackhouse, R. J. (2011). Compositional and instrumental firmness variations within fresh pork bellies. Meat science, 88(3), 472-480.

Unruh, J. A., K. G. Griesen, S. R. Stuewe, B. L. Dunn, J. L. Nelssen, R. D. Goodband, and M. D. Tokach. 1996. The influence of genetic population, sex and dietary lysine on pork subprimai cut yield and carcass quality of pigs fed to either 104 or 127 kilograms. J. Anim.

USDA. (2016) Overview of the United States Slaughter Industry. National Agricultural Statistics Service

USDA. (2018) A User's guide to USDA's pork carcass cutout. Agricultural Marketing Service

Uttaro, B., & Zawadski, S. (2010). Prediction of pork belly fatness from the intact primal cut. Food Control, 21(10), 1394-1401.

Valenzuela, R., & Valenzuela, A. (2013). Overview About Lipid Structure. In Lipid Metabolism. IntechOpen.

Wang, H., L.-S. Wang, B.-M. Shi, and A.-S. Shan. 2012. Effects of dietary corn dried distiller's grains with solubles and vitamin E on growth performance, meat quality, fatty acid profiles, and pork shelf life of finishing pigs. Livestock Science 149(1):155-166.

Weber, T. E., Richert, B. T., Belury, M. A., Gu, Y., Enright, K., & Schinckel, A. P. (2006). Evaluation of the effects of dietary fat, conjugated linoleic acid, and ractopamine on growth performance, pork quality, and fatty acid profiles in genetically lean gilts. Journal of Animal Science, 84(3), 720-732.

Whitney, M. H., Shurson, G. C., Johnston, L. J., Wulf, D. M., & Shanks, B. C. (2006). Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. Journal of animal science, 84(12), 3356-3363.

Wood, J. D., Richardson, R. I., Nute, G. R., Fisher, A. V., Campo, M. M., Kasapidou, E., ... & Enser, M. (2004). Effects of fatty acids on meat quality: a review. Meat science, 66(1), 21-32.

Wood, J. D., et al. "Effects of breed, diet and muscle on fat deposition and eating quality in pigs." Meat Science 67.4 (2004): 651-667.

Wright, L. I., Scanga, J. A., Belk, K. E., Engle, T. E., Tatum, J. D., Person, R. C., ... & Smith, G. C. (2005). Benchmarking value in the pork supply chain: Characterization of US pork in the retail marketplace. Meat Science, 71(3), 451-463.

Xiong, Y. L. (2000). Protein oxidation and implications for muscIe food quaIity. Antioxidants in Muscle Foods: Nutritional Strategies to Improve Quality. New York: Wiley and Sons, 85-90.

Young, B. (ed.) 2008. Bacon technology. Bacon Technology Journal Feb. 2008.

VITA

Marlee M. Kelley

EDUCATION

Bachelor of Science in Animal Science (2017) at the University of Florida, Gainesville, FL

PROFESSIONAL POSITIONS AND HONORS

Graduate Teaching Assistantship, Animal and Food Science, University of Kentucky, January 2018- December 2019

East Region Director, American Meat Science Association Student Board 2018-2019

Undergraduate Research Assistant, Animal Science, University of Florida 2015-2017