EVALUATING PIG PERFORMANCE, CARCASS MERIT AND PROCESSED PORK

QUALITY WHEN CHESTNUTS AND ACORNS ARE FED TO DUROC-INFLUENCED PIG

GENETICS DURING LATE FINISHING

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by

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis titled

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presented by Katelyn Burdick,

a candidate for the degree of Master of Science,

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ABSTRACT

The objective of this study was to determine effects of feeding chestnuts and acorns on growth performance, carcass quality and further processed products of Duroc/Duroc crossbred finishing barrows. Barrows ($n = 30$) were individually housed in pens, blocked by body weight and randomly assigned to one of three treatments: control ($n = 10$), inclusion of acorns at 15% of the diet ($n = 7$), inclusion of chestnuts at 15% of the diet ($n = 13$). Pigs were fed *ad libitum* for 28 d prior to harvest. Feed refusal and individual pig weights were collected every 7 d to determine growth performance. Following harvest, carcass quality was determined by objective color, fat composition and marbling scores. Fat samples were removed from four fat depots (backfat, seam, jowl, kidney and pelvic) and analyzed for fatty acid composition. Sample chops were analyzed for fatty acid composition, moisture and fat content. Bellies were processed into bacon slabs and analyzed for slice quality, fatty acid composition, moisture and fat content. Carcass characteristics, particle size and bacon quality were analyzed using GLM procedure of SAS. Growth performance and fatty acid composition were analyzed using MIXED procedure of SAS. Significance was determined at P-value < 0.05. Dietary treatments did not impact ($P > 0.05$) growth performance, carcass characteristics or carcass quality. Moreover, feeding acorns tended to similar concentrations ($P = 0.079$) of oleic acid (18:1n9c) and linoleic acid (18:2n6c) when compared to the control

diet. However, feeding diets containing chestnuts tended to greater proportions ($P = 0.079$) of oleic acid and lower proportions ($P = 0.079$) of linoleic acid when compared to the control and acorn treatments. Acorns tended to increase ($P < 0.0001$) the total concentration of omega-6 fatty acids (n-6) when compared to chestnut diets, but no differences ($P > 0.05$) were observed between acorn and control diets. Inclusion of acorns and chestnuts did not negatively impact carcass characteristics, carcass quality or bacon quality, nevertheless, including acorns and chestnuts tended to alter oleic acid (18:1n9c), linoleic acid (18:2n6c) and total n-6 fatty acids.

Chapter I

REVIEW OF LITERATURE

Introduction

Consumer preference for a healthier product has risen in demand for leaner, more efficient hogs. As consistency of pork and pork quality have evolved, consumer preference for a novel, healthy and added value product is increasing in popularity (Ward, 1997). A large majority of pork products sold in the United States are in the form of further processed meat products specifically cured ham, and bacon (Davis and Lin, 2005; Wright et al., 2005).

Management practices and selective breeding of pig genetics has led to an expansion in utilizing natural feedstuffs to reduce the cost of feed while altering the profile of dry-cured products. Through the utilization of chestnuts and acorns in the finishing stage of pigs, producers are able to alter the fatty acid profile to reflect a healthier niche market for dry-cured products.

U. S. Pork Industry

Over the past century, the pork industry has evolved and integrated to larger producers and processors instead of small, family farms (Barkema and Cook, 1993). This evolution has led the pork industry to consist of largescale producers to meet pork consumption demand. A direct result of this industry evolution has led to a dramatic decrease

in the total number of farms needed to meet consumer demand. These changes have allowed producers to become more specialized in areas such as i.e. farrow-to-wean, wean-to-feeder or feeder-to-finish (Barkema and Cook, 1993). Even though the total number of large farms continue to decrease, the number of hogs produced is steadily increasing. A census conducted by McBride and Key (2013) found number of hog farms has decreased by 70 percent while the average herd size increased from 985 head in 1992 to 8,389 head in 2009. Due to integration seen in animal agriculture, processors and/or firms possess the ability to produce a more uniform herd which contributes to the production of a high quality and consistent pork (Martinez, 2002).

There are numerous factors associated with the integration of the pork industry such as technology and a more health conscious consumer (Barkema and Cook, 1993). Growth performance, production risk and efficiency of operations have evolved due to technology innovations such as genetic improvements, nutrition, veterinary services and operational facilities (McBride and Key, 2013). Implementing genetic technologies to produce a lean, more productive animal has been shown to increase the overall profitability of the producer while still meeting consumer needs and demands (Barkema and Cook, 1993). Through genetic and nutritional improvements, the number of sows needed to feed the population has decreased along with the amount of feed needed for efficiency of gain (Key and McBride, 2007; Lusk, 2013). According to USDA ERS (2018), consumption of pork is expected to steadily increase through 2019 but plateau to 52 pounds per year. However, pork exports are estimated to increase, ultimately exceeding beef exports due to improvements in hog performance and efficiency (USDA ERS, 2018).

The consistency of hogs produced and pork quality continues to grow and develop over time. With these developments, consumer preferences for a novel, healthy, affordable and consistent product continues to arise (Ward, 1997). A large majority of pork products sold in the United States are in the form of further processed meat products specifically cured ham, and bacon (Davis and Lin, 2005; Wright et al., 2005). Further processed meat products provide the ability to improve the overall quality and palatability of the product (Shan et al., 2017b). Popularity of further processed pork is on the rise followed by public health concerns by consumers. In response to public concerns, new nutritional and health properties have been introduced; whether through natural curing ingredients or supplying animals with alternative feedstuffs to improve the overall profile of the product (Shan et al., 2017b). Addition of alternative feedstuffs in animal diets, allows producers to alter the overall quality and stability of the end product without additional additives postmortem (Bermudez et al., 2012; Jesus et al., 2016b). By altering the nutritional composition of meat products through additives or feeding management practices, an underlining issue of consumers' willingness to pay a premium price for a desired, convenient further processed meat product has evolved (Decker and Park, 2010; Troy and Kerry, 2010).

Specialty Market

Specialty markets, otherwise known as "niche" markets, have emerged since the late 1990's as a competitive measure for small hog producers who incorporate alternative production systems (Honeyman et al., 2005). Alternative production systems may consist of but are not limited to free of antibiotics or growth promoters; natural, organic, local family operations; free-range rearing systems and incorporating alternative feedstuffs into the diet to promote a "healthier" end product (Honeyman et al., 2005). By constructing this novel,

underdeveloped market, consumers are able to make purchasing decisions based on certain attributes which are desired. A study conducted by National Pork Board (2019), determined the willingness of consumers to purchase niche marketed pork. National Pork Board (2019) concluded 69% to 74% of consumers are willing to purchase locally or alterative raised pork. Within this market, consumers tend to focus on production palatability attributes pertaining to the animal and flavor profile i.e. breed of pig, taste, flavor, and tenderness (Honeyman et al., 2005). As consumers become more intuitive to animal production and quality of the end product, producer willingness is needed to produce dry-cured products targeting these niche markets (Honeyman et al., 2005).

European Dry Cured Markets. According to USDA FAS (2019), Europe is ranked second in pork production and lead the work in pork exports. Unlike the United States, the consumption of pork in Europe is substantially higher, 30 kg/person vs. 44 kg/person, respectively (Backus and Dijikhuizen, 2002; Resano et al., 2011b). Similar to those in United States, European consumers are favoring pork produced from outdoor or more extensive rearing systems which utilize the natural environment (Pugliese and Sirtori, 2012). European producers use a multitude of breeds such as Celta, Iberian, and Cinta in production practices due to their fat production and quality of meat and dry cured meat products (Pugliese and Sirtori, 2012). During the fattening stage of pigs, Europe has developed a "*Montanera*" system where Iberian or Portuguese pigs are free-ranged and consume a rich-acorn diet (Carrapiso et al., 2003; Benito et al., 2006; Tejerina et al., 2012). Another common European extensive rearing and grazing practice is *dehesa*, which is a natural farming practice where Iberian pigs consume products of the meadowland (Benito et al., 2006). Carrapiso et al. (2003), studied the relationship between rearing systems and sensory characteristics of

Iberian hams. Differences were shown between rearing systems (indoor vs. outdoor) and sensory characteristics (texture, aroma, and taste). Results showed a consumer preference of products from pigs exposed to the "*montanera"* system (Carrapiso et al., 2003). An inverse relationship is observed between dry cured meat products and price (Resano et al., 2012). As prices of dry cured products increase, consumers tend to direct attention to alternative products with lower prices (Resano et al., 2011b Resano et al., 2012;). However, these products tend to lack the desired flavor and overall eating experience provided by more costly dry cured products (Resano et al., 2011b Resano et al., 2012;). European dry cured markets and rearing systems are continuing to evolve working toward improving the flavor profile and overall palatability of dry cured products to better meet consumer demand while maintaining a reasonable product price.

Consumer Demand

Pork is the most widely consumed protein in the world followed by poultry, beef, sheep and goats (Davis and Lin, 2005; Font-i-Furnols and Guerrero, 2014). However, due to the increased demand for production of lean pork, detrimental effects on quality and overall palatability of fresh pork products have been noted (Cannon et al., 1995). Conflicting demands by consumers in terms of the quality of pork they prefer differ upon location of consumers such as Mexican consumers prefer a high lean product while Japanese consumers desire a darker, more marbled product (Lowell et al., 2019). Demands of different products require producers to re-direct breeding objectives towards pork quality and carcass characteristics to meet export market demands (Miar et al., 2014). Consumer perception of pork quality is determined by intrinsic and extrinsic quality cues (Troy and Kerry, 2010). Intrinsic quality cues relate to the product itself i.e. color, marbling, and texture while

extrinsic quality cues do not relate to the product such as price or origin (Troy and Kerry, 2010). Many of these quality cues influence the decision of consumers when making purchasing decisions. Consumers expectations of fresh pork products include a bright pink color as well as a higher degree of intramuscular fat (Papanagiotou et al., 2013). These attributes directly contribute to overall quality and palatability thus relating to the overall eating experience i.e. tenderness, juiciness and taste (Papanagiotou et al., 2013).

Processed pork. In the United States, 22% of pork consumption is in the form of further processed meat products (Daniel et al., 2011). Specifically, 18.2 % is in the form of bacon consumed in households (Soladoye et al., 2015). Moreover, Resano et al. (2011a), stated the highest yearly consumption of dry-cured ham in Spain, Italy, France, Belgium and Germany with Spain reporting the highest consumption at 4.4 kg and Belgium with the lowest at 0.4 kg.

An increased consumption of dry-cured ham has led consumers to focus on taste, healthiness, convenience and price of the products (Resano et al., 2011a). As consumers become more health conscious of their diet with a focus on saturated fatty acids, cholesterol and salt in foods they consume, an alternative product such as further processed meats is needed. Further processed meats are capable of meeting demands by providing specific health benefits to the consumer while maintaining the convivence of the product (Grasso et al., 2014; Shan et al., 2017a). Processed meats provide consumers with B-vitamins, trace-minerals, specifically iron and zinc, as well as dietary proteins (Shan et al., 2017a). Addition of health benefits to further processed meats can be obtained through feeding management of the animal by incorporating less saturated fatty acids and utilizing plant feed sources i.e. tree nuts to avoid adding additives such as fat replacers to the end product (Grasso et al., 2014).

Consumer intention of purchase relies on the quality and expected fulfilment of the product, however, cost can negatively affect these purchasing decisions (Papanagiotou et al., 2013).

Consumer acceptance and preference of dry-cured products. Many factors affect consumer acceptance and preference of dry-cured products such as specific sensory attributes i.e. flavor, aroma, intramuscular fat, texture, color, and saltiness (Morales et al., 2013). Bacon quality is constantly driven by consumers preference for leaner bellies with less saturated fatty acids while still adhering to the crispiness attribute which is preferred (Soladoye et al., 2015). Craving this higher lean-to fat ratio has reduced the chemical fat content of pork belly from about 74% to 45-55% thus decreasing the amount of saturated fatty acids by 29% (Smith et al., 1975; Scramlin et al., 2008; Soladoye et al., 2015). However, large bacon slabs with firmer fat, which are not desired by consumers, are needed to produce a crispy, less distorted bacon product (Soladoye et al., 2015). Finding the common balance between consumer preference, acceptability of bacon, technological qualities and profitability for the processor is needed as the demand alters (Soladoye et al., 2015).

Dry cured ham products, commonly referred to as Iberian ham, have been well maintained in Mediterranean diets and are considered a traditional, high quality product (Ventanas et al., 2006; Resanon et al., 2011a; Morales et al., 2013). Typically, a dry-cured ham product is evaluated based on crumbliness, softness, flavor and sweetness by consumers (Resano et al, 2010; Morales et al., 2013). Negative factors influencing acceptability and preference of dry-cured hams includes mold odors and saltiness (Resano et al., 2010; Morales et al., 2013). Morales et al. (2013), conducted a conjoint analysis to determine consumer preference of dry-cured products and its relation to price, processing time, and texture. Consumers tended to prefer a product with a long processing time due to advanced

product flavor and aroma profile as well as an intermediate level of intramuscular fat due to health benefits (Morales et al., 2013). Willingness of consumers to purchase intermediate dry-cured hams is higher due to the quality of the product (Morales et al., 2013). Another study conducted by Lorido et al. (2019), evaluated the emotional responses of dry-cured hams and found consumers perceive this product as being "festive", "traditional" and "family" as well as being a "natural" product. Other panelist described the sensory attributes of the product as "cured flavor", "juicy", "intense", "authentic" and "pleasant" (Lorido et al., 2019). Overall, sensory characteristics as well as consumer acceptance of dry-cured ham is favored by health-conscious consumers.

Genetic Predisposition for Meat Quality

Genetic selection of pig breeds is one of the most influential effects on pork quality and carcass composition (Lo et al., 1992; Cannon et al., 1995; Fuentes et al., 2014; Alonso et al., 2015). While many other factors are observed to affect meat quality, i.e. nutrition, handling and transport, specific genes within breeds may alter the overall quality and composition of the carcass thus decreasing processing capabilities as well as consumer appeal (Gariepy, et al., 1999; Andersen et al., 2005; Ventanas et al., 2006). There are two common genes which are related to poor pork quality: halothane gene and rendement napole (RN-). Leaner producing pigs tend to express the halothane gene which is associated with pale, soft and exudative pork commonly referred to as PSE (Cannon et al., 1995; Gariepy et al., 1999; Lonergan et al., 2001). Moreover, RN- gene is affiliated with a low overall pH, higher drip loss and decreased protein content thus negatively impacting carcass composition and meat quality (Cannon et al., 1995; Gariepy et al., 1999; Lonergan et al., 2001). Through genetic selection and reduced handling during pre-slaughter, the number of occurrences of

these expressed genes will be reduced (Cannon et al., 1995). Additionally, incorporating different breeds into production systems may positively impact the overall product which is desired.

Duroc. Duroc hogs were introduced in the United States and Europe due to their ability to increase intramuscular fat, improve production efficiencies and overall durability (Lonergan et al., 2001; Ventanas et al., 2006; Ramirez and Cava, 2007; Pugliese and Sirtori, 2012; Fuentes et al., 2014; Alonso et al., 2015). Efforts have been made by producers to include Duroc sired pigs in their production systems to improve fresh and dry-cured products (Pugliese and Sirtori, 2012; Alonso et al., 2015). In conjunction with improvements of fresh and dry-cured products, Newcom et al. (2004) studied the differences among multiple breeds i.e. Yorkshire, Duroc, Hampshire, Chester White, Berkshire, Poland China and Landrace, and its correlation to color concentrations. Newcome et al. (2004), determined Duroc pigs possessed higher levels of intramuscular fat similar to Hampshire and Yorkshire, higher a* values (redness) similar to Hampshire pigs as well as higher myoglobin concentration thus improving the overall color of the fresh or cured pork product. Similarly, Lowell et al. (2019) reported a darker, more marbled pork loin supporting the findings of the previous study. Inclusion of Duroc genetics in production systems can increase growth performance while altering pork quality.

Iberian x Duroc crossbreeding. Crossbreeding, a phenomenon utilized in production systems among different species, is commonly used to improve growth performance of an animal and meat quality (Ventanas et al., 2006). Due to the increased consumption of dry-cured meat products, Duroc sired pigs have been crossbred with Iberian pigs to improve weight gain during all phases and carcass yield (Ventanas et al., 2006; Fuentes et al., 2014;

Alonso et al., 2015). However, crossing Duroc and Iberian pigs has led to negative meat quality attributes such as pale color, less intramuscular fat, increased concentrations of saturated fatty acids and decreased oxidative stability (Ventanas et al., 2006; Fuentes et al. 2014). Ramirez and Cava (2007) studied crossing two different genotypes (growth performance versus manufacturing of dry-cured meat products) of sired Duroc pigs with a maternal Iberian pig to determine influences on production and meat quality. Genotypes of Duroc pigs selected for manufacturing of dry-cured products, revealed a higher percentage of intramuscular fat combined with an increase in quality of fresh and cured meat products (Ramirez and Cava, 2007). However, genotype of Duroc sired pigs for improved growth performance revealed an increase in muscle production but negatively impacted quality and sensory attributes of fresh and cured meat products (Ramirez and Cava, 2007). Additional focus of Duroc genetics and crossbreeding with Iberian pigs, must be emphasized for manufacturing of dry-cured products in hopes of alleviating poor meat quality attributes of fresh and cured products (Fuentes et al., 2014).

Pork Quality

Pork quality is dependent on multiple factors such as genetics, breed, production system, nutrition, slaughter, processing and storage conditions (Cannon et al., 1995; Cannon et al., 1996; Rosenvold and Andersen, 2003a). Pork quality audits have been conducted to depict quality and palatability attributes of pork products (Cannon et al., 1995). Kauffman et al (1992) evaluated 14 different pork plants to determine a percent of pork which was undesirable. Through their research, 16% of pork was considered PSE and 10% was DFD (Kauffman et al., 1992). By determining specific factors affecting pork quality, producers

and processing facilities can develop strategies to minimize these negative defects (Cannon et al., 1995).

Temperature and pH. There are many factors associated with the conversion of muscle to meat in the postmortem model. Temperature and pH are two of the most influential mechanisms affecting the chemical reaction within meat quality (Aberle et al., 2012; Yuan et al., 2014). During the conversion of muscle to meat, temperature will increase due to harvesting processes i.e. heat (stress or anxiety prior to slaughter), scalding, and singeing of hair (Aberle et al., 2012). Denaturing of muscle due to high temperature can ultimately impact the chemical reaction needed for the conversion of muscle to meat (Aberle et al., 2012; Yuan et al., 2014). Denaturing of muscle proteins is also dependent on the rate of pH decline (Maribo et al., 1998). Decline of pH is referred to as the accumulation of Hydrogen ions from glycolysis and hydrolysis of ATP to ADP (Aberle et al., 2012). An animal's pH is relatively neutral (~7 – 7.4) and will steadily begin to decrease to 5.3 to 5.7 postmortem (Aberle et al., 2012). An increase rate of pH decline may cause the proteins to denature faster thus leading to pale, soft and exudative (PSE) pork (Fernandez et al., 1994; Maribo et al., 1998; Aberle et al., 2012). Carcass exhibiting a rapid pH decline experience decreased carcass yields and juiciness combined with an increased cook loss (Aberle et al., 2012). Moreover, a loss of color intensity and protein solubility as well as the capability to bind water is affected within the muscle (Topel et al., 2019). Many factors influence this phenomenon such as genetic predisposition, acute stress and slow chilling during harvesting (Topel et al., 2019). However, a high ultimate pH will reveal a darker color, firmer texture and dry (DFD) due to myoglobin and muscle proteins denaturing at a slower rate combined with a dry consistency due to the myofibrils and proteins ability to bind water and swell

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(Aberle et al., 2012; Yuan et al., 2014; Topel et al., 2019). Studies have been conducted to determine other factors affecting the ultimate pH of meat such as the glycolytic potential. Glycolytic potential is commonly explained as the amount of glycogen present during slaughter (Huff-Lonergan et al., 2002). Increased amount of glycogen in the muscle prior to slaughter will cause glycolysis to occur under anaerobic conditions thus increasing the amount of lactic acid produced, reducing the ultimate pH level (Monin and Sellier, 1984; Huff-Lonergan et al., 2002; Bee et al., 2007). Reducing the ultimate pH level, causes degradation of intermediate filament (desmin and talin) and shrinkage of muscle fibers causing a shift in water from intracellular to extracellular (Bee et al., 2007).

Water Holding Capacity. Water makes up a vast majority of the muscle structure, 70 to 80%, respectively (Apple, 2007; Toldra, 2003). Typically, water molecules are found within myofibrils consisting of the intracellular space as well as the extracellular space, between muscle cells and muscle bundles (Huff-Lonergan and Lonergan, 2005; Pearce et al., 2011; Toldra, 2003). Distribution of the water molecule, dipole in nature, is attracted to proteins and classified as bound, immobilized, or free (Huff-Lonergan and Lonergan, 2005). Bound water, small in fraction, is highly attracted to proteins thus reducing mobility and its capability of moving to other compartments (Huff-Lonergan and Lonergan, 2005; Pearce et al., 2011). The force which is established between bound water and proteins, is unlikely to be broken from thermal reactions such as freezing or heating (Huff-Lonergan and Lonergan, 2005; Pearce et al., 2011). The second form of water is immobilized which is held by the attraction to bound water or space. Unlike bound, immobilized is the most affected during the conversion of muscle to meat due to the pH decline's effect on muscle cell structure thus allowing the water to escape/purge (Huff-Lonergan and Lonergan, 2005). Additionally, this

form is less resistant to ice crystal formation and/or drying processes. Finally, the weakest force between proteins is classified as free water. Free water is located in the capillaries and held by intermolecular forces to the surrounding matrix (Pearce et al., 2011). As the water molecules shift closer to the matrix of the cell membrane, the amount of force needed to extract these molecules is decreased thus allowing more mobility in the cell membrane space (Pearce et al., 2011). Many factors during the conversion of muscle to meat influence the amount of water within a myofibril such as net charge of the myofibrillar proteins, decrease in sarcomere length and components, and extracellular space (Huff-Lonergan and Lonergan, 2005). In the postmortem model, as the glycolytic potential occurs and formation of lactic acid increases, the ultimate pH steadily decreases closer to isoelectric point thus decreasing water molecules ability to bind since proteins are becoming more neutral (Toldra, 2003). Additionally, as the sarcomere begins to shrink due to rigor, the amount of space available decreases thus decreasing the space for water to bind in the myofibrillar (Huff-Lonergan and Lonergan, 2005). In dark, firm and dry (DFD) products, less drip loss is observed due to minimal myofibrils transverse shrinkage causing a net negative charge and proteins to repel one another (Warner, 2014). Furthermore, pale, soft and exudative (PSE) products ability to bind water is reduced due to lateral shrinkage caused by the denaturing of myosin heads when temperature is increased (Pearce et al., 2011). Water holding capacity (WHC) is the ability of muscle to bind to water and retain water during cooking, pressing, cutting and transport (Hughes et al., 2014). Influences of water holding capacity are due to denaturing of myosin prior to pre-rigor, sarcomere shortening, decline in muscle pH, and proteolysis of cytoskeletal proteins thus increasing the amount of purge or drip loss of the product (Warner, 2014). Water holding capacity influences many sensory attributes (i.e. color, texture and

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firmness) consumers use while making purchasing decisions. One of the most influential attributes is the correlation between color and water holding capacity. The color of the product can be perceived as the light which is reflected form the surface of the meat (Hughes et al., 2014). Lightness or light scattering, is a mechanism where light is deflected by particle collision, differ based on the connective tissue, muscle fiber and structures as well as the amount of fluid in the structure (Hughes et al., 2014).

Pork Color. Color is one of the most important quality attributes which impacts consumers intent to purchase based on quality and freshness of the product (Lindahl et al., 2001; Rosenvold and Andersen, 2003b). Influences of color in the muscle may be altered due to rapid pH decline, light reflectance and the chemical state of myoglobin. Myoglobin can be displayed in three different forms: deoxymyoglobin (Mb), reduce myoglobin and purple pigment of muscle under vacuum; oxymyoglobin (MbO$_2$) oxygenated myoglobin and associated with bright reddish-pink color; and metmyoglobin (MetMb), oxidized myoglobin and associated with grey-brown pigment (Tikk et al., 2008; Karamucki et al., 2013). Myoglobin forms consisting of a more greyish or brownish pink color (Mb and MetMb) are associated with non-fresh products and perceived as undesirable (Lindahl et al., 2001; Rosenvold and Andersen, 2003). The opacity and translucency of meat products is influenced by the state of muscle proteins (Feldhusen, 1994). There are subjective and objective methods for evaluating the color of fresh or processed product such as the *Lab*-system, which determine the *L* (light to dark), *a* (red to green) and *b (*yellow to blue)*, as well as Japanese color standards (Nakai et al., 1973) or color standards developed by National Pork Board (Rosenvold and Andersen, 2003).

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Instrumental measurements of color, during an industry environment, are well affected by the amount of time the tissue is exposed to oxygen. This initial point in time of 30 – 60 minutes is considered the "bloom" time of a tissue thus allowing a reduction of deoxymoglobin to a desirable reddish – pink form of oxymyoglobin (Brewer et al., 2001). Bloom time, of instrumental color, showed no effect on L^*; however, a^* was impacted as early as 10 minutes after cutting (Brewer et al., 2001). The amount of time allowed for meat to bloom is also dependent on the availability of oxygen and reducing equivalents as well as ultimate pH (Bendall and Swatland, 1988; Brewer et al., 2001).

Color stability is reliant on certain intrinsic and extrinsic factors. Many intrinsic factors include animal, age, breed, sex, muscle type, diet, or pH while extrinsic factors include pre-slaughter treatment, electrical stimulation, chilling, or light exposure (Rosenvold and Andersen, 2003). Rosenvold and Andersen (2003), revealed pre-slaughter stress affected the color stability of the longissimus dorsi because it can be more efficiently chilled than other muscles. Furthermore, color of pork is dependent on the pigment content, chemical form and muscle structure (Lindahl et al., 2001). Different muscles display myoglobin content at different levels, for instance, *rectus femoris* and *bicep femoris* are considered red oxidative muscles while the *longissimus dorsi* and *gluteus medius* are white glycolytic muscles (Lindahl et al., 2001).

Fat Percentage. Over the past several decades, consumer demand for leaner pork has risen thus negatively impacting the amount of intramuscular and subcutaneous fat within a product (Kouba and Sellier, 2011). Total amount of fat on a carcass has decreased from 35 – 45% to less than 20%, respectively, due to breeding practices for leaner pork (Nguyen et al., 2004). Selecting for leaner pork has resulted in decreased hardness of fat, separation of

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tissues, increased toughness combined with reduced flavor and juiciness (Sather et al., 1995). Increased amount of intramuscular fat in the muscle reduces the force for chewing and promotes saliva secretion while increasing juiciness and tenderness (Wood et al., 2003). Increased intramuscular fat is extremely important for preparation and sensory quality of dry-cured meat products (Ramirez et al., 2007).

There are different adipose tissues found in a carcass: subcutaneous, intermuscular and intramuscular fat. The rate at which these tissues develop in the growing animal vary such as intermuscular fat is slower than subcutaneous fat (Kouba and Sellier, 2011). The development of fat as the animal developments is due to an increase in adipocyte size. As weight gain of animal increases, the cellular development of the adipose tissue changes from hyperplasia (growing number of adipose cells) to hypertrophy (filling of adipose cells) (Kouba and Sellier, 2011).

Pork Fat Quality

Altering fatty acid composition plays a major role in providing healthier meat products for consumers while positively influencing pork quality (Wood et al., 2003). A major source of saturated fatty acids in the diet are in the form of meat products (Wood et al., 2003). Wiegand et al. (2011), stated leaner pigs experience a change in saturation concentration due to a decrease in *de novo* synthesis of fatty acids. Fatty acid composition predicts multiple attributes associated with the end product such as the firmness/oiliness, oxidative stability, flavor and muscle color (Wood et al., 2008). A fatty acid consists of a hydrocarbon chain capped by a carboxyl group. Fatty acids can be divided into three different forms, differing based on their carbon double bonds: saturated fatty acids, monounsaturated fatty acids and polyunsaturated fatty acids. Saturated fatty acids have no

double bonds on their carbon chain which allows them to align and form triglycerides which are not easily broken. Unsaturated fatty acids include one or more double bond thus creating transformations (cis and trans) and allowing them to be easily broken.

Fatty acids possess the capability of altering the firmness/oiliness of an end product due to the melting points of saturated and unsaturated fatty acids. Saturated fatty acids, such as stearic acid, reveal a higher melting point of 69.6°C while oleic has a melting point of 13.4°C (Wood et al., 2003). An increase in double bonds leads to a decrease in the melting point. Structure of the unsaturated fatty acids in the form of cis and trans, reveal different melting points as well. Trans fatty acids melt at a higher temperature than cis-isomers (Enser, 1984; Wood et al., 2003). Fat color is an important aspect of fatty acids due to the differences in melting point thus whiter solidified fat cells possess a higher melting point than liquid fat cells with a lower melting point (Wood et al., 2003). Decreasing the melting point, allows for the fresh or cured product to be soft therefore affecting processors and producers (Wood et al., 2003; Johnston and Li, 2011). Iodine value serves as a representation of the firmness of fat due to its ability to measure the degree of unsaturation of fatty acids in fat depots (Johnston and Li, 2011). Increased iodine values correlate with softer fat with iodine values ranging from 55 to 95, respectively (Johnston and Li, 2011). Shelf life stability may also be affected by manipulation of fatty acids due to unsaturated fatty acids ability to oxidize and become rancid as display time increases (Wood et al., 2003). In conjunction with rancidity, color alterations of the product are due to oxidation of oxymyoglobin to metmyoglobin (Wood et al., 2003). Inclusion of antioxidants in the diets of animals, have shown to extend the shelf life by decreasing lipid and color oxidation (Wood et al., 2003).

In general, pigs display higher proportions of polyunsaturated fatty acids specifically linoleic acid in adipose and muscle tissues (Wood et al., 2008). This is due to the ability of linoleic acid to pass through the pig's stomach undetected and absorb in the bloodstream of the small intestine and deposit in the tissues (Wood et al., 2008). Due to this increase in proportion of linoleic acid, the ratio of n – 6: n – 3 is higher. Inclusion of cereal based diets consumed by animals produces a higher content of 18:2 in the meat thus revealing an undesirable n-6: n-3 ratio (Wood et al., 2003). Recommended ratio of n-6: n-3 is to be less than 4.0 thus pigs are unbalanced when compared to ruminants (Scollan et al., 2006; Wood et al., 2008). However, the recommended ratio of polyunsaturated fatty acids (PUFA) to saturated fatty acids (SFA) should be increased to above 0.4 (Wood et al., 2003; Wood et al., 2008). Increasing concentrations of PUFA results in an increased risk of lipid oxidation thus products leading to off-odors, flavor and color changes (Wood et al., 2003).

Wiegand et al. (2011) explained differences between fat depots and the mechanism impacting the weak reaction. Pigs tend to fatten from the distal end towards the visceral cavity (Hammond, 1932). Due to this finding, pigs deposit fat at the jowl first before depositing fat in the shoulder and belly (Wiegand et al., 2011). Differences of physiological maturity at market weight can relate to differences in the total fat content (Wiegand et al., 2011). Pigs who are light weight may be accumulating muscle at a rapid rate instead of fat tissue (Wiegand et al., 2011). Synthesis of triglycerides takes place in adipose tissue from existing triglycerides due to adipose lipoprotein lipase activity (Ramirez et al., 2007). Stearoyl-CoA-desaturase converts SFA to MUFA (Kouba et al., 2003). Acetly-CoA-carboxylase is the first step in the fatty acid biosynthetic process and major role is to regulate fatty acid biosynthesis in animal tissues (Kouba et al., 2003). Two key enzymes are utilized

in supplying NADPH for the reductive biosynthesis of fatty acids: malic enzyme and glucose-6-phosphate-dehydrogenase (Wise and Ball, 1964; Young et al., 1964). The pentose phosphate pathway utilizes glucose-6-phosphate-dehydrogenase while malic enzyme converts malic acid to pyruvic acid (Ramirez et al., 2007). Acetyl CoA and malonyl CoA produce palmitic acid which is synthesized into stearic acid by elongation (Ramirez et al., 2007). Lipogenic enzyme activity is dependent on animal genotype and the diet which was fed to the animal (Morales et al., 2002).

Tannins in Animal Diets

Tannins are phenolic compound designed to precipitate proteins, reduce digestibility of protein and amino acids as well as alter vitamin and mineral uptake (Huang et al., 2018; Rezar et al., 2017; Jansman, 1993). The binding process of tannins to proteins occur when the hydroxyl group on a tannin interacts with the carbonyl group structure of proteins (Jansman, 1993). In the plant model, tannins serve as a secondary defense mechanism against pathogens and insects thus encompassing multiple antinutritional properties which are beneficial to certain animal species (Huang et al., 2018). Tannins act in microbial, viral and parasitic defense as well as lipid oxidative stability. Multiple studies have been conducted on the impact of feeding tannins to ruminants, as well as the role tannins play in ruminal flow and nitrogen excretion (Kumar and Singh, 1984; McSweeney et al., 2001; Silanikove et al., 2001; Makkar, 2003; Frutos et al., 2004; Gisele de Oliveira et al., 2007; Bueno et al., 2015; Jayanegara et al., 2015; Mendez-Ortiz et al., 2018). Hydrolysable and condensed tannins are subgroups which differ based on their structure and function. Hydrolysable tannins possess a polyol central molecule with surrounding gallic acids attached by depside bonds (Huang et al., 2018; Mueller-Harvey, 2001; Shirmohammadli et al., 2018). Due to their simple phenol

form, they are easily hydrolyzed by weak acids or bases thus producing phenolic acid and carbohydrates (Shirmohammadli et al., 2018). Hydrolysable tannins, such as chestnuts, are used due to their antimicrobial and antiviral effects (Shrimohammadli et al., 2018) Condensed tannins are commonly found and tend to be more complexed in their structure due to their polyhydroxy-flavan-3-ol oligomer group (Huang et al., 2018; Schofield et al., 2001; Shirmohammadli et al., 2018). Since they lack the ability to be degraded by anaerobic enzymes, condensed tannins are depolymerized by oxidative and acidic hydrolysis (Mueller-Harvey, 2001).

Effects on growth performance of animals. Tannins have been shown to negatively impact feed intake, feed efficiency, milk yield, wool growth and digestibility when readily available in the diet (Mueller-Harvey, 2001 & 2006; Huang et al., 2018). Additionally, gut health environment has improved while feed palatability and digestion decreased with the addition of tannins (Huang et al., 2018). Maintaining this balance will positively impact the overall growth performance of monogastric animals (Huang et al., 2018).

Chestnuts as Feedstuffs

Throughout Europe, there is an abundance of chestnuts which are produced and utilized in different industries due to their nutritional properties. Additionally, chestnuts are underutilized and are incorporated into diets to reduce the price of commercial concentrated feed (Jesus et al., 2016a). During the autumn months, pigs are fattened in chestnut groves for approximately two to three months to mimic the Corsican rearing system thus allowing the pigs to double their weight and acquire the desired chemical composition for dry-cured meats (Coutron – Gambotti et al., 1998). Chestnuts used within animal diets can serve as an antioxidant for meat and further meat products to reduce the likelihood of oxidation

(Echegaray et al., 2018). Several by-products are generated i.e. chestnut wood, flowers, leaves and shells during processing and are used in the food, pharmaceutical and cosmetic industry (Echegaray et al., 2108).

When compared to corn, chestnuts consist of a high moisture (~ 50%) and starch content while having a low protein and fat content (Kellems and Church, 2010; Jesus et al., 2016a). Minerals, vitamins and fiber are readily available in large quantities (Echegaray et al., 2018). The fruit contains greater amounts of polyphenols, including gallic acid and ellagic acid (Goncalves et al., 2010). Polyphenols are utilized to prevent oxidative damage, predators and microorganism in the plant model (Echegaray et al., 2018). Organic acids such as glutamic, ascorbic and citric are commonly found in the fruit and act against several diseases i.e. psoriasis, and inflammation (Echegaray et al., 2018). Fatty acid composition of chestnuts is primarily comprised of linoleic (18:2n6c), oleic (18:1n9), palmitic (16:0), and linolenic (18:3) (Astorga Espana et al., 2011).

Chestnuts have been used in other monogastric species such as rabbits. Liu et al. (2009) conducted a study to determine the effect of chestnuts on meat quality, lipid oxidation and fatty acid composition of rabbit meat. Inclusion of chestnuts in the diet did not affect ADFi, ADG, feed consumed, or final body weight (Liu et al., 2009). No effect was seen due to the antinutritional properties tannins possess by protecting the intestinal mucosa against oxidative damage and pathogens (Goel et al., 2005; Liu et al., 2009; Kermauner and Laurencic, 2008). Inclusion of chestnuts did not affect the fatty acid profile; however, a positive effect was seen with an inclusion of 0.5% but a pro-oxidative effect was seen at 1% inclusion (Liu et al., 2009). In general, inclusion of chestnuts in the diet have not negatively impacted growth performance of pigs (Liu et al., 2009; Prevolnik et al., 2012).

Many studies have evaluated feeding chestnuts to pigs and its effect on meat quality (Bermudez et al., 2012; Diaz et al., 2009; Jesus et al., 2016a). Pugliese et al., (2007) and Temperan et al. (2014) did not observe any differences in color parameters between pigs fed diets including chestnuts or the control. However, Pugliese et al. (2013), revealed high muscle iron content when tannins of chestnuts increased thus resulting in increasing *L**, *a**, and *b** values in the *longissimus lumborum* muscle of pigs. Moreover, Sirtori et al. (2012) found similar results of increased *L**, *a**, and *b** values when chestnuts were fed for one or three months as well as a higher percentage of MUFA and PUFA. A negative effect on meat quality was observed when pigs were fed chestnuts for three months thus displaying high drip and cook loss values (Sirtori et al., 2012).

Jesus et al. (2016b) evaluated the effect of feeding 15% and 25% of dried chestnuts on the fatty acid profile of dry-cured lacon, a dry cured meat product from the foreleg. Lacon from pigs fed the dried chestnut treatments (15% and 25%) showed a lower concentration of SFA and MUFA in addition to a higher concentration of PUFA than the control (Jesus et al., 2016b). Inclusion of chestnuts in the concentrated diet revealed a decrease in SFA and MUFA in the intramuscular fat while PUFA increased (Jesus et al., 2016a). An increased concentration of PUFA was observed because the variation of *de novo* synthesis of fatty acids from carbohydrates occurred during the desaturation and elongation process of specific fatty acids (Coutron-Gambotti et al., 1998). Bermudez et al. (2012), determined the fatty acid profile of dry-cured hams from pigs fed chestnuts during the finishing stage. A decrease proportion of SFA and an increase percentage of MUFA was reported along with a higher concentration of n – 3 fatty acids thus providing a more desirable n – 6: n – 3 ratio (Bermudez et al., 2012).

By-products of chestnuts have been utilized to replace the use of artificial antioxidants i.e. butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) (Echegaray et al., 2018). Incorporating natural antioxidants into meat products has shown to improve the nutritional properties and provide health benefits to the consumer while positively influencing shelf life (Echegaray et al., 2018). Conflicting results have been documented in regard to the shelf life and oxidation of products. Lorenzo et al. (2013), observed an increase in lightness and redness values when dry-fermented sausages were exposed to chestnut leaves. Additionally, a decrease in thiobarbituric acid reactive substances (TBARS) value were seen after the addition of the extract combined with a decrease in mold and yeast counts. However, Lorenzo et al. (2014) revealed chestnut leaves extract decreased the redness value and increase TBAR values of pork patties stored under modified atmosphere packaging (MAP). Pateiro et al. (2014), observed similar findings of adding chestnut leaves extract to pig liver pâté but during weeks 4 and 8, the extract protected the pâté from oxidative damage.

Inclusion of chestnuts in the diet has not been shown to negatively impact growth performance; however, fresh meat parameters and fatty acid composition has been altered due to the concentration of chestnuts included as well as the duration the diets were fed. More research must be conducted on chestnut by-products to determine a true antioxidant effect of including natural by-products on fresh and processed meats.

Acorns as Feedstuffs

The demand for dry-cured hams from free-range pigs fed an acorn diet, is increasing in popularity among United States consumers. Consumers interest in extensive production has begun to expand thus allowing producers to utilize native pig breeds and local feed

resources (Nieto et al., 2002). Commonly, acorns are consumed by wildlife as an energy source, however, including acorns in diets of livestock has become popular in Mediterranean countries (Cappai et al., 2013). Acorns can be incorporated into the diet by free range systems (*montanera* and *dehesa)* or mixed diets which are commonly fed during the late finishing stage (Cappai et al., 2013; Tejerina et al., 2011). According to Rey et al. (2006), higher prices are reached with products exposed to these preferred management systems.

The nutrient content of acorns consists of a high concentration of monounsaturated fatty acids, fat and starch while displaying low concentrations of protein (Nieto et al., 2002). Animals fed diets containing acorns reveal high proportions of oleic acid in conjunction with low proportions of palmitic and stearic acid (Tejerina et al., 2011). Moreover, nutrient content, availability and fatty acid composition of acorns can be altered due to multiple factors such as weather conditions, germination, as well as parasitic load (Tejerina et al., 2011). Tejerina et al. (2011) reported fatty acid profiles of acorns is dependent on the year (November – January) and between years (2006 – 2007 and 2007 – 2008) thus explaining variation between the tissues of pigs raised under extensive conditions.

Inclusion of acorns in the diet tend to negatively impact growth performance and feed intake as well as toxic effects such as hepatotoxicity, toxic nephrosis, and esophageal cancer (Cappai et al., 2013). Some animal species altered tannins toxic effects by developing tanning binding proteins (TBPs) in saliva as a defense mechanism (Cappai et al., 2013). Cappai et al., (2013) found a higher feed conversion rate when acorns where included in the diet. Rey et al. (2006), evaluated differences between production systems and the inclusion of acorns in the diet. Pigs fed acorns with a high fat content revealed higher backfat thickness when compared to formulated diets (Rey et al., 2006). A difference was detected between the

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inner and outer backfat layers thus outdoor production systems showed higher inner backfat measurements (Rey et al., 2006). Wood et al. (1975) explained this difference between the two layers because as live weight increases, the rate of cell diameter in the inner layer increased in size compared to the control. Pigs fed acorns in a confinement operation revealed highest concentrations of SFA (37.55%), and low concentrations of MUFA (57.60%) and PUFA (4.85%), respectively (Rey et al., 2006). However, Pugliese et al. (2009) and Rey et al. (1997), found lowest concentrations of SFA and highest percentage of MUFA, specifically oleic acid.

Acorns incorporated into the monogastric model serve as a lipid oxidative stability for meat quality and further processed meat products (Tejerina et al., 2011). Due to acorn tannin content and its antioxidant properties, acorns have the capability to prolong the shelf life stability of products where oxidation occurs more rapidly such as poultry (Ozunlu et al., 2018). Implementing acorns in animal diets provides a natural antioxidant rather than synthetic antioxidant to improve consumer perception of antioxidants used in meat products. Tocopherols, a vitamer, is the compound affiliated with antioxidant properties of acorns to prevent lipid oxidation specifically, α and γ. According to Tejerina et al. (2011), acorns are specifically rich in both tocopherols, however, concentrations of these compounds reveal to vary over seasons.

Antioxidant for meat products. In the meats industry, lipid oxidation is a major issues in fresh and further processed meat products (Ladikos and Lougovois, 1990). Lipid oxidation is the mechanism in which unsaturated fatty acids react with oxygen via a free radical to form fatty acyl hydroperoxides or peroxides which are the primary product of oxidation (Gray, 1978). A secondary reaction causes degradation of lipids and development

of oxidative rancidity resulting in an increase amount of volatile compound and loss of nutritional value (Ladikos and Lougovois, 1990). Intake of dietary antioxidants of animal species possess health benefits to consumers while maintaining quality characteristics of meat products undergoing rancidity and color deterioration (Andersen and Ramussen, 1992). Tocopherols are found in four forms (alpha, beta, gamma and delta) and differ based on the number and position of methyl groups on the chromanol ring. Rey and Lopez-Bote (2014), reported high concentrations of gamma-tocopherol in fat from pigs fed acorns. However, Cava et al. (2000), observed a high content of alpha-tocopherol in the muscle thus displaying a high lipid oxidative stability. Rearing system and feeding regime are two common factors effecting the content of tocopherol in meat products and its lipid oxidative stability (Cava et al., 2000).

Dry – Cured Pork Products

Dry cured products are heavily consumed and readily available in Mediterranean areas (Jimenez-Colmenero et al., 2010). Typically, dry cured products are consumed due to their palatability attributes instead of their health benefits. Therefore, improving feeding practices, production system and further processing techniques will alter the product to meet consumers demand for a healthier product. In countries such as Europe, pig production and processing of high added value products are relied upon by consumers (Virgili, and Schivazappa, 2002). Production of dry cured meats is dependent on specific muscle traits such as pH, proteolytic enzymes, and fat content.

Dry – Cured Ham. Dry-cured hams, also referred to as Iberian or Corsican ham, contain high-fat content and undergo the curing process consisting of a dry salting stage at low temperatures and a long ripening stage (7 – 14 months) at high temperatures (Narvaez-

Rivas et al., 2008). There are two different dry-cured hams which are produced based on their rearing systems: rustic/free-ranged or intensively reared white pigs. Commonly, both types of hams produced undergo extensive fattening stages to develop intramuscular fat and adipose tissue (Jimenez-Colmenero et al., 2010). These compositions play a major role in sensory attributes consumer desire for a dry-cured ham. In achieving these desired sensory attributes, proteolysis must occur within the muscle. Proteolysis, degradation of myofibrillar proteins, is the most influential reaction occurring during the manufacturing of dry cured hams (Harkouss et al., 2015). This phenomenon is referred to as endogenous enzyme activity which includes calpains, cathepsins, peptidases and cytosolic enzymes (Luccia et al., 2005). Many factors influence these enzymes: temperature, relative air humidity and salt content (Harkouss et al., 2015; Arnau et al., 2003). Increased temperature has been shown to increase the amount of non-protein nitrogen compounds found in the product thus interrupting the course of proteolysis (Morales et al., 2007). Additionally, increase water content in the muscle has been shown to increase proteolysis due to an increase in water activity (Serra et al., 2005). Salt and water transfer may be different between muscles of the ham thus affecting the time allotted for proteolysis to occur (Harkouss et al., 2015). Controlling the duration and rate at which proteolysis occurs is advantageous in the flavor and texture of the end product. Comparable to other products, lipid oxidation may occur during the processing and storing of the product; however, lipid oxidation is utilized in developing the aroma profile of dry-cured products.

During production of dry – cured products, the pH of the product may range from 5.3 to 5.9 (Virgili and Schivazappa, 2002). Inclusion of PSE hams in the manufacturing of dry-cured hams should be avoided as greater weight loss, increased absorbance of salt, and

intense proteolysis during curing are observed and expressed as undesirable (Banon et al., 1998). Manufacturing of dry-cured hams using DFD hams revealed a higher moisture content, lower non-protein nitrogen which displayed a softer, pastier and crumbly product (Guerrero et al., 1999).

Fatty acid composition of dry-cured ham products consists of approximately 30-35% saturated fatty acids (SFA), 54-58% monounsaturated fatty acids (MUFA) and 8-12% polyunsaturated fatty acids (PUFA) because high proportions of oleic acid is perceived when acorns are fed during the fattening stage (Jimenez-Colmenero et al., 2010). Saturated fatty acids of dry-cured hams are due to abundant concentrations of palmitic acid, stearic acid and myristic acid thus contributing to the increase risk of cardiovascular disease (Fernandez et al., 2007). Ratios of PUFA: SFA and n-6/n-3 are important for human health and must be considered when evaluating if a product is considered healthy. Dry-cured hams reveal a PUFA: SFA of 0.14 to 0.35, where the recommended ratio must be above 0.4 (Jiminez-Colmenero et al., 2010). Additionally, n-6: n-3 ratio must not exceed 4 because risk of cancer, autoimmune disease and inflammatory response may occur (Simopoulos, 2002). Dry-cured hams possess values exceeding the desired n-6/n-3 ratio thus genetic and feeding management practices are needed to improve this value to meet the recommended ratio (Jiminez-Colmenero et al., 2010).

Bacon

Pork bellies are extremely important to the industry due to the increasing demand in bellies and bacon (Person et al., 2005). As consumer preference has altered to reduce the fat content and increase the lean in hogs, the general composition of the belly has changed to heavier hams and loins (Stites et al., 1991; Stetzer and McKeith, 2003). During this

transformation, belly weights have stayed relatively consist, but the total loss of the carcass has increased (Scramlin et al., 2008). Adipose tissue is the majority makeup of pork bellies (~55 – 60%) but has decreased over the years (Person et al., 2005). Bacon production includes curing and smoking of the bellies to characterize flavor, quality and final yield (Soladoye et al., 2015). Liquid brine, consisting of water, salt, sugar, nitrite and/or nitrate, sodium erythorbate and phosphate, is infused at 113% of the bellies initial green weight (Soladoye et al., 2015). Many of the ingredients used in bacon production have specific restrictions associated with them such as phosphates cannot exceed 0.3 – 0.4%, sodium erythorbate cannot exceed 550 ppm, nitrite is limit to 120 ppm, salt may not exceed 1.5 – 2% and sugar should be included between 0.1 – 2%. Increased levels of phosphates and sugars may result in a soapy flavor or unwanted caramelization of the final product (Soladoye et al., 2015). Smoking of the bellies is commercially done through a heating process in conventional thermal processing units (Soladoye et al., 2015). Bacon core temperature should range between 46°C – 53°C. These processes aid in the flavor development as well as quality of the bacon slabs.

Bacon Quality

Consumer demand for a leaner pork carcass has resulted in thinner bellies, decreased processing yield and potential quality problems. Thick bellies are preferred by processors because of their high processing yield and an increase in profitability potential (Person et al., 2005). Currently there is no standard grading system for bacon; however, manufactures classify slices as grade 1 or grade 2 based on uniformity, leanness and consumer appeal (Soladoye et al., 2015). Bacon quality parameters vary between processors and include: belly dimensional parameters (i.e. size, thickness, shape or weight), firmness and absence of hair

follicles, bones and mammary gland (Soladoye et al., 2015). Measurements to predict bacon quality prior to processing are processing yield, i.e. pump, cook, curing, and smoke yield, and slice yield (Robles, 2004). Following processing a multitude of analysis are conducted to determine bacon quality including cook yield ([cooked weight-initial weight)/initial weight]x100), sliced bacon characteristics to calculate commercial slicing yield, moisture and fat content, belly flop and slice lean: fat image analysis (Soladoye et al., 2015).

Firmness of bacon slabs can be measured utilizing multiple different techniques such as belly flop, finger test, belly flex, iodine value (IV), fatty acid composition and Durometer (Soladoye et al., 2015). Finger testing methodology includes manipulating fat with your hand while belly flop or belly flex uses a rod and measures the bend angle and flex measurement (Apple, 2010). Bellies with minimal flex is suggestive of firmer fat while softer bellies will present a larger flex (Johnston and Li, 2011). Iodine value have been used to measure the amount of unsaturated fatty acids to predict the softness of the fat depots or bacon slabs (Soladoye et al., 2015). Durometer is an objective measure of fat firmness with a higher value equating to firmer belly fat (Seman et al., 2013). Visual appraisal of belly consists of photographic standards, magnetic resonance imaging and computer-assisted tomography (Fredeen et al., 1975; Soladoye et al., 2015). All visual appraisals of bacon slabs are used to predict the muscle to fat content of pigs with some degree of accuracy. A gold standard has not been developed to predict bacon quality.

CHAPTER II

EVALUATING PIG PERFORMANCE, CARCASS MERIT AND PROCESSED PORK QUALITY WHEN CHESTNUTS AND ACORNS ARE FED TO DUROC-INFLUENCED PIG GENETICS DURING LATE FINISHING

ABSTRACT

The objective of this study was to determine effects of feeding chestnuts and acorns on growth performance, carcass quality and further processed products of Duroc/Duroc crossbred finishing barrows. Barrows ($n = 30$) were individually housed in pens, blocked by body weight and randomly assigned to one of three treatments: control ($n = 10$), inclusion of acorns at 15% of the diet ($n = 7$), inclusion of chestnuts at 15% of the diet ($n = 13$). Pigs were fed ad libitum for 28 d prior to harvest. Feed refusal and individual pig weights were collected every 7 d and used to calculate average daily gain (ADG), gain-to-feed (G:F), and average daily feed intake (ADFi). Following harvest, carcass quality was determined by objective color (L^*, a^* and b^*), fat composition and marbling scores. Fat samples were removed from four fat depots (backfat, seam, jowl, kidney and pelvic) and analyzed for fatty acid composition. Sample chops were removed between the 10th and 11th rib of the left side of each carcass and analyzed for fatty acid composition, moisture and fat content. Bellies were removed from the left side of each carcass, further processed into bacon slabs and

analyzed for slice quality, fatty acid composition, moisture and fat content. Carcass characteristics, particle size and bacon quality were analyzed using GLM procedure of SAS. Growth performance and fatty acid composition were analyzed using MIXED procedure of SAS. Significance was determined at P-value < 0.05. No differences were detected for ADG, ADFi and G:F across treatments ($P > 0.05$). Dietary treatments did not impact ($P > 0.05$) carcass characteristics or carcass quality. Inclusion of chestnuts or acorns within the diet did not impact ($P > 0.05$) moisture and fat content of chops and bacon slices ($P > 0.05$). Moreover, feeding acorns tended to similar concentrations ($P = 0.079$) of oleic acid (18:1n9c) and linoleic acid (18:2n6c) when compared to the control diet. However, feeding diets containing chestnuts tended to greater proportions ($P = 0.079$) of oleic acid and lower proportions ($P = 0.079$) of linoleic acid when compared to the control and acorn treatments. Acorns tended to increase ($P < 0.0001$) the total concentration of omega-6 fatty acids (n-6) when compared to chestnut diets, but no differences ($P > 0.05$) were observed between acorn and control diets. Inclusion of acorns and chestnuts did not negatively impact carcass characteristics, carcass quality or bacon quality, nevertheless, including acorns and chestnuts tended to alter oleic acid (18:1n9c), linoleic acid (18:2n6c) and total n-6 fatty acids.

Introduction

Consumer preference for a healthier product has risen in demand for leaner, more efficient hogs. As consistency of pork and pork quality have evolved, consumer preference for a novel, healthy and added value product is increasing in popularity (Ward, 1997). A large majority of pork products sold in the United States are in the form of further processed meat products specifically cured ham, and bacon (Wright et al., 2005; Davis and Lin, 2005).

Management practices and selective breeding of pig genetics has led to an expansion in utilizing natural feedstuffs to reduce the cost of feed while altering the profile of dry-cured products. Through the utilization of chestnuts and acorns in the finishing stage of pigs, producers are able to alter the fatty acid profile to reflect a healthier niche market for dry-cured products.

Material and Methods

Animals

The University of Missouri Animal Care and Use Committee approved animal care and experimental protocols prior to initiation of this experiment (#EX-9346). Duroc/Duroc crossbred barrows (n = 30), were individually housed at the University of Missouri Swine Teaching Facility in Columbia, MO. Upon arrival, barrows were blocked by body weight and randomly allocated to one of the three treatments: control, inclusion of acorns at 15% of the diet, inclusion of chestnuts at 15% of the diet. Animals were weighed and stratified across treatments by initial weight. Single spaced feeder and nipple waterer were provided *ad libitum* throughout the study. Pigs were fed treatment diets for 28 d prior to harvest.

Management of Animals

Shortly after arrival, two pigs were observed to have abnormal respiration rate (tachyonic) and treated with Draxxin (Zoetis Services LLC., Parsippany – Troy Hills, NJ) and Noromectin (Norbrook Laboratories, Newry, United Kingdom) on d 7. On d 8 through d 12, all pigs (n = 30) received Denegard (Elanco Animal Health, Greenfield, IN) through their waterers. Additionally, twenty-nine pigs received a dose of Noromectin (Norbrook Laboratories, Newry, United Kingdom) for internal parasites. On d 67 prior to the start of

trial, two pigs were treated for wheezing with Baytril (Bayer, Leverjusen, Germany) and Flunixin Meglumine (Merck and Co., Kenilworth, NJ). On d 83 prior to the start of trial, one pig received a dose of Noromectin (Norbrook Laboratories, Newry, United Kingdom) for internal parasites. During the study, one control pig was treated for lameness with Flunixin Meglumine (Merck and Co., Kenilworth, NJ) and Draxxin (Zoetis Services LLC., Parsippany – Troy Hills, NJ) on d 1 and d 4 of the trial.

Diets

Prior to the finishing stage, all barrows (n = 30) received a typical grower phase diet. Ten barrows were randomly assigned to receive a control corn-soybean diet, seven barrows were fed an inclusion of acorns at 15% of the diet and thirteen barrows were fed an inclusion of chestnuts at 15% of the diet. Chestnuts and acorns were harvested at the University of Missouri Horticulture and Agroforestry Research Center (HARC) and transported to the Animal Research Center. Following delivery, acorn caps, rocks, mold and stems were removed from the acorn. Burs, mold and sticks were removed from the chestnuts. Due to the high moisture content, chestnuts were placed in a drying oven at 54°C for four days. On day two, all chestnuts were cracked, and moldy chestnuts were removed and placed back in the drying oven. After sorting and drying of the chestnuts, acorns and chestnuts were hammer milled through a 43.18 cm by 81.28 cm screen and included at a 15% inclusion rate. Diets were formulated to meet or exceed NRC (2017) requirements. Residual feed was measured on individual pig weigh days in order to calculate growth performance. Feed samples were collected, and a proximate feed analysis was conducted by the University of Missouri Experimental Station Chemical Laboratories.

Feed Particle Size Determination

Approximately 104 – 105 g of each dietary treatment was placed into a Ro-Tap Sieve Shaker (WS Tyler Co., Cleveland, OH) consisting of thirteen different sieve sizes; 3350, 2360, 2000, 1180, 850, 595, 425, 300, 250, 177, 150, 125, and 63 micrometers. For each treatment diet, sieves were tapped and shaken for seven minutes. Duplicate values were averaged to compute distribution of particles represented as a percentage as well as mean particle size. Mean particle size was computed according to Wilcox, Deyoe and Pfost (1970) and shown in Equation 1. The standard deviation of particle size was calculated and shown in Equation 2:

Equation 1: $d_{gw} = \log^{-1}\left[\dfrac{(\Sigma W_i \log d_i)}{(\Sigma W_i)}\right]$

W represents the weight of the feedstuff from the ith sieve, and

d_i is the geometric mean of the diameter openings of the ith sieve and the sieve immediately   preceding the ith sieve.

Equation 2: $S_{gw} = \log^{-1}\left[\dfrac{[\Sigma W_i (\log d_i - \log d_{gw})^2]}{(\Sigma W_i)}\right]$

Growth Performance

Body weight (BW), feed consumed (FC), average daily gain (ADG), average daily feed intake (ADFi) and gain to feed ration (G:F) were calculated for each individual barrow at days 0, 14. 28, 42, 56, 70, 84 and 90 during the grower phase and days 0, 7, 14, and 28 days during the experiment.

Harvest

Barrows access to feed was restricted 8 hours prior to slaughter and transported 5 km to the University of Missouri Abattoir where pigs were allowed to rest in lairage with access to water. Hogs were humanely slaughtered under USDA-FSIS inspection criteria. Following evisceration and splitting, carcasses were weighed and Hot Carcass Weight (HCW) was determined.

Carcass Fabrication

Approximately 24 hours postmortem, the left side of each carcass was transported to the University of Missouri Meat Science Laboratory. Jowl, seam, subcutaneous, intramuscular, kidney and pelvic fat were collected 24 h post mortem from chilled carcasses and placed into Whirl-pak® bags. Jowl samples were removed from the anterior region of the jowl at the point of head removal. Seam samples of the shoulder were removed dorsal to the neck bones and ribs. Subcutaneous and intramuscular samples were removed between the 10th and 11th rib specifically the 10th rib. Two boneless chops were removed from the full pork loin, vacuum sealed and labeled for fatty acid analysis and fat/moisture content. Kidney and pelvic samples were removed from a region on the midline posterior to the sternum and anterior to mammary tissue. Bellies were removed lateral to the loin, spare ribs were removed, anterior and posterior end were squared to remove lymph, and mammary tissue was removed. Following fabrication, bellies were frozen at -20°C and transported to Paradise Meat Locker in Trimble, MO for curing (sugar cure). Hams were removed approximately 3 inches anterior to the aitch bone and the foot was removed below the hock joint. Hams were

frozen at -20°C prior to transporting to Volpi Foods Inc., Union, MO to be further processed into prosciutto.

Meat Quality Measurements

After 24 h post mortem, objective meat quality measurements were measured and recorded in the University of Missouri Meat Science Laboratory. The left side of each carcass was ribbed between the 10th and 11th rib and allowed to bloom for 30 minutes. Loin muscle area, 10th rib back fat and last rib fat were measured utilizing a grid (Iowa State University, Ames, IA) and probe (Nasco, Wisconsin). A portable pH meter (Meat Probes, Inc., Topeka, KS, USA) was utilized to determine the pH of the loin muscle between the 10th and 11th rib. Subjective marbling scores were recorded using the Pork Board color standards based on numerical values by the same person. According to the marbling standards (NPB, 1999), a score of 1.0 is considered devoid whereas 10.0 is considered abundant. Objective color was measured by the CIE system L* (lightness), a* (redness), and b* (yellowness) using a HunterLab MiniScan Spectrocolorimeter (MiniScan XE; Hunter and Assoc., Reston, VA) with a 2.5 cm port and glass cover calibrated against a white tile. Instrumental color readings were utilized to calculate a/b ration, saturation index (SI), and hue angle (HA) values.

Myoglobin Concentration

Myoglobin concentrations, deoxymyoglobin (Dmb), oxymyoglobin (Omb) and metmyoglobin (MMb) were determined on the surface of the longissimus dorsi (AMSA, 2012). Reflectance was measured at wavelengths of 470, 530, 570, and 700 nm which were

determine by a HunterLab MiniScan Spectrocolorimeter (MiniScan XE; Hunter and Assoc., Reston, VA). Objective color readings were obtained in triplicate. The reflectance (R) was converted to reflex attenuance (A) using Equation 1. The A-values were then inserted into Equation 2 to calculate MMb and into Equation 3 to calculate Deoxymyoglobin (DMb). Oxymyoglobin was then calculated using Equation 4:

Equation 1: $A = \log(1/R)$

Equation 2: $\%MMb = \{1.395-[(A570-A700)/(A530-A700)]\} \times 100$

Equation 3: $\%DMb = \{2.375x-[1-(A470-A700)/(A525-A700)]\} \times 100$

Equation 4: $\%OMb = 100-(\%MMb+\%DMb)$

Fat and Moisture Percentage

Determination of fat percentage was done in triplicate utilizing microwave drying and nuclear magnetic resonance as described in Dow et al. (2011) with a CEM SMART Trac rapid fat analysis system 5 (Matthews, NC, USA). Briefly, two CEM sample pads were heated and dried before 3.75 - 4.5 g of minced sample was smeared across one pad and topped with the remaining pad. Samples were dried using the CEM Moisture/Solids Analyzer, and moisture was determined on a dry weight basis. Following determination of moisture, sample pads were wrapped in TRAC paper, inserted into a CEM TRAC tube and was placed into the CEM Rapid Fat Analyzer. Fat percentage of samples was then determined on a dry basis using NMR and was ultimately converted to a wet basis. Triplicate values were averaged to determine overall fat percentages for each sample.

Bacon Quality

Commercial bacon slabs are evaluated for uniformity, leanness and consumer appeal. Following evaluation, slices are classified into one of two classes: grade 1 or grade 2 (Soladoye et al., 2015). All slab bacons were further processed at Paradise Meat Locker, Trimble, MO and cooled at 2°C for seven days before evaluation. Ten slices were removed from each end and discarded. Slices were individually removed from packaging and arranged in order. Number 1 slices were established based on uniformity and desirable lean-to fat ratio of 50:50 (50 percent lean:50 percent fat). Furthermore, number 2 slices were determined by the irregular shape and a higher lean-to fat ration of 60:40 (60 percent lean: 40 percent fat). Lastly, defective slices were categorized as irregular slices, evidence of cartilage and a higher lean-to fat ratio of 80:20 (80 percent lean:20 percent fat). Percent of number 1, number 2 and defective slices were calculated and recorded.

% of Number 1 Slices = # Number 1/ Total Slices

% of Number 2 Slices = # Number 2/Total Slices

% of Defective Slices = # Defective/Total Slices

Fatty acid determination

Fatty acid composition was determined according to an adaption of methods described by M et al. (1957) and Morrison and Smith (1964). Approximately 2 g of feed sample, 1 g of ground longissimus dorsi, 0.5 g of ground bacon slice, and 100 mg of adipose tissue (seam, jowl, and kidney/pelvic) were homogenized in 5 mL of chloroform:methonal (CHCL3:CH3OH, 2:1, v/v) in a glass tube to extract lipids. Samples were homogenized for 30 seconds using an Omni International 2000 homogenizer (Waterbury, CT, U.S.A).

Following homogenization, feed samples were filtered through Whatman P4 filter paper and a plastic funnel into a 34 mL tube. All other samples were filtered through a sintered glass funnel fitted with a Whatman 2.4 cm GF/C filter. Following filtration, 8 mL of 0.74% KCl solution was added to each sample. Samples were allocated two hours to separate into two distinct phases. The upper phase was removed and discarded while the lower phase was transferred to 34 mL tube and evaporated to dryness with nitrogen gas in a heated water bath at 70°C using a Meyer N-Evap Analytical Evaporator (Organomation Associates Inc., Berlin, MA, U.S.A). After complete dryness, 1 mL of 0.5 N KOH in MeOH was added to each tube and heated in a water bath at 70°C for 10 minutes. Moreover, 1 mL of 14% boron trifluouride (BF_3) in MeOH was added to the tube, flushed with nitrogen, loosely capped and heated in 70°C water bath for an additional 30 minutes in order to form fatty acid methyl esters (FAME). Following cooling, 2 mL of saturated NaCl and 2 mL of HPLC grade hexane was added to the tube. Once again, two distinct phases were formed, the upper layer was removed and added in a 20 mL glass tube with approximately 800 mg of Na_2SO_4. An additional 2 mL of hexane was added to the tube containing saturated NaCl and once more, the upper layer was removed and added to the tube containing Na_2SO_4. The liquid portion was removed from the salt and transferred to a scintillation vial. Scintillation vials were placed in a water bath at 70°C and evaporated to dryness under nitrogen flow. Following evaporation, samples were rehydrated with 1 mL HPLC grade hexane and transferred to gas chromatograph vials.

The fatty acid methyl esters (FAMEs) were analyzed by a Varian 420 gas chromatograph (Varian, Palo Alto, CA, U.S.A.) to determine fatty acid composition. Samples were injected onto a fused silica capillary column (SP™ – 2,560; 100 m x 0.25 mm x 0.2 μm film thickness; Supelco, Bellefonte, PA, U.S.A.). Temperature of the flame-ionization

detector was held constant at 260°C while the injector was held constant at 240°C, respectively. The carrier gas used was Helium and maintained at a constant pressure of 37 psi. The oven operated at 140°C for 5 minutes then temperature programmed 2.5°C/min to 240°C and held for 16 minutes. Fatty acids were normalized and the area under each peak represents a percentage of the total area. Iodine Value (IV) from fatty acid profiles were determined according to the equation described by AOCS (1998): IV = (0.95 x C16:1) + [0.86 X (C18:1n9t + C18:1n9c)] + [1.732 x (C18:2n6t + C18:2n6c)] + (2.616 x C18:3n3) + (0.785 x C20:1).

Statistical Analysis

The experiment was defined as a randomized complete block design with 3 dietary treatments. Carcass characteristics, particle size and bacon quality were analyzed using the PROC GLM procedure of SAS 9.3 (SAS Inst., Cary, NC) with individual pig serving as the experimental unit. Growth performance and fatty acid composition were analyzed using PROC MIXED procedure of SAS 9.3. PROC UNIVARIATE procedure of SAS 9.3 (SAS Inst., Cary, NC) was utilized to evaluate normality of the data points. The statistical model included the fixed effects of location (jowl, seam, subcutaneous, intramuscular, kidney/pelvic, and bacon) and dietary treatments (Control, Chestnuts or Acorns). Initial weight and initial weight by treatment interaction were used as a covariate in the model. Data for Palmitic acid (16:0) was not normal; therefore, it was transformed using the log transformation. Least square means and standard errors were estimated utilizing the PDIFF option. Level of significance was predetermined at P-value < 0.05 and tendencies at P-value < 0.10.

Results

Particle Size of Diets

No differences ($P > 0.05$) were observed for sieve sizes of 3350, 2360, 2000, 1180, 850, 595, 425, 250, 177, 150 and 125. A difference ($P = 0.014$) was observed between the four different diets in relation to the 300 μm sieve opening. The grower diet revealed a decreased weight of particles compared to the treatment diets. Moreover, the control and acorn diets contained similar particle weight; however, chestnut diet revealed increased weight compared to the treatment diets and the grower diet. A difference ($P = 0.015$) was observed between the four diets fed in relation to the 63 μm sieve opening. The grower diet revealed an increased weigh of particles compared to all treatment diets. Mean particle size of the control diet was different ($P = 0.046$) when compared to the other diets.

Growth Performance

Inclusion of chestnuts or acorns at 15% of the diet did not negatively or positively impact growth performance, shown in Table 2.6. No differences were detected for initial BW, final BW, ADG, ADFi and G:F across treatments ($P > 0.05$).

Carcass Composition

Dietary treatments did not impact ($P > 0.05$) carcass characteristics or carcass quality (Table 2.7). DP, last rib fat, and 10th rib fat was not affected by the inclusion of chestnuts or acorns in the diet ($P > 0.05$).

Muscle and Fat Quality

Inclusion of chestnuts and acorns did not have an effect on muscle or fat quality. No differences ($P > 0.05$) in marbling score, loin pH, color, moisture or fat percentage of chops between the dietary treatments.

Bacon Quality

No differences ($P > 0.05$) were detected in belly weight, number 1 slices, number 2 slices, defective slices or moisture and fat content. Iodine value (IV) did not differ between dietary treatments.

Fatty Acid Composition

Inclusion of chestnuts and acorns did not affect total SFA, MUFA, PUFA, PUFA: SFA, n-3 FA, n-6: n-3, and IV in all fat depots (subcutaneous, seam, intramuscular, jowl, bacon and kidney and pelvic). There was no treatment x depot interaction ($P > 0.05$) on total SFA, MUFA, PUFA, PUFA: SFA, n-3 FA, n-6 FA, n-6: n-3, and IV. A significant difference ($P < 0.0001$) was observed between all fat depots that were analyzed.

Moreover, feeding acorns tended to similar concentrations ($P = 0.079$) of oleic acid (18:1n9c) and linoleic acid (18:2n6c) when compared to the control diet. However, feeding diets containing chestnuts tended to greater proportions ($P = 0.079$) of oleic acid and lower proportions ($P = 0.079$) of linoleic acid when compared to the control and acorn treatments. Acorns tended to increase ($P = 0.052$) the total concentration of omega-6 fatty acids (n-6) when compared to chestnut diets, but no differences ($P > 0.05$) were observed between acorn and control diets.

Discussion

The control treatment diet displayed a higher mean particle size when compared to chestnut and acorn diets and grower diets ($P = 0.046$). Particle size is extremely important in the efficiency of a growing-finishing animal (Wondra et al., 1995). Reduction of mean particle size has been shown to increase in nutrient digestibility (Owsley et al., 1981; Wondra et al., 1995). Finely ground diets (< 600 μm) can become problematic for flowability and palatability of pigs because of the development of gastric ulcers (Wondra et al., 1995). Wondra et al. (1995) developed an optimal particle size of 600 microns or less for meal or pelleted diets thus all diets were in the optimal range.

In agreement with other studies, our results show inclusion of 15% chestnuts or acorns in the diet did not negatively impact final BW, ADG, ADFi, and G: F (Liu et al., 2009; Prevolnik et al., 2012; Ranucci et al., 2015). Temperan et al. (2014) showed similar results to the present study as inclusion of chestnuts did not alter the growth performance of pigs fed chestnuts. Coutron-Gambotti et al. (1998) and Pugliese et al. (2013) concluded inclusion of chestnuts in the finishing diet did not positively impact growth performance. Additionally, Rey et al. (2006) revealed no differences between acorn diets, formulated diets and free-range systems on live weight parameters. However, Prevolnik et al. (2012) detected an increase in feed consumption and conversion of chestnuts during the first fattening stage. Jesus (2016) observed higher live weights and carcass weights from pigs fed an inclusion of 15% chestnuts versus 25% chestnuts. Moreover, Daza et al. (2008) studied the effect of acorn size consumed on growth performance, carcass characteristics and fat quality. The size of acorn revealed a lower average daily intake as well as a lower feed conversion ratio compared to larger acorns (Daza et al., 2008). Cappai et al. (2013) described a negative effect

on growth performance due to the increased amount of tannins in acorns. A negative effect on growth performance was not observed in our study since the tannin content of the acorns used were low in tannins.

Carcass characteristics and fresh meat parameters were not affected ($P > 0.05$) with the inclusion of chestnuts and acorns. In agreement with this data, Jesus et al. (2016) found no difference in dorsal fat thickness between the inclusion rates of chestnuts at 15% and 25%. Additionally, Temperan et al. (2014) did not find significant differences in backfat thickness when pigs were fed only chestnuts three months prior to slaughter. Rey et al. (2006) conducted a study to determine the difference between free-range of acorns and confinement (formulated diet to mimic free-range) on carcass yield and characteristic. This study (Rey et al., 2006) found acorns revealed higher thickness of backfat compared to formulated diet due to the high fat content of acorns.

In this study, pH was not significant between dietary treatments. This does not agree with the work done by Jesus et al. (2016a), Temperan et al. (2014) and Pugliese et al. (2013). Conflicting results between these studies show a decrease in ultimate pH values when chestnuts are fed to pigs (Jesus et al., 2016a) which was also confirmed by Temperan et al. (2014). However, Pugliese et al. (2013) noted a slight decrease in pH after chestnuts were included in the diet but there was no difference between the control and chestnut when the diet was fed for three months. Rearing system and time on feed may be an important factor influencing the pH value.

Color parameters were not different between treatment diets which agrees with Jesus et al. (2009), Pugliese et al. (2007) and Temperan et al. (2014). However, Pugliese et al. (2013) and Sirtori et al. (2012), found an increase in L^*, a^*, and b^* values of the *longissimus*

lumborum of pigs fattened with chestnuts due to the muscle iron level increasing as tannin levels increase.

Fatty acid profile was not altered when chestnuts and acorns were fed at 15% inclusion. However, some tendencies did occur in chestnut diets due to greater proportions of oleic acid and lower proportions of linoleic acid. Additionally, acorns included in the diet tended to alter the total omega-6 proportion when compared to the control and chestnut diet. Temperan et al. (2014) and Jesus et al. (2016) found similar results to this study. Dominguez et al. (2015) revealed highest concentration of oleic acid in the intramuscular fat of pigs fed chestnuts due to the increase amount of oleic acid in the diet. Differences of fatty acid profiles were observed in these studies (Temperan et al., 2014; Dominguez et al., 2015; Jesus et al., 2016) because pigs on dietary treatments were fed for one to three months prior to slaughter. Tejerina et al. (2011) reported pigs fed acorns revealed a proportion of oleic acid and a low proportion of palmitic and stearic acid. In conjunction with Tejerina et al., (2011), Rey et al. (2006) reported a decrease in proportion of saturated fatty acids as well as an increase proportion of oleic acid in the intramuscular lipids on pigs fed acorns on a free-range system. A difference ($P < 0.0001$) was observed between all fat depots that were analyzed. Wiegand et al. (2011) indicated fat deposits from the distal end to the visceral cavity thus fat in the jowl or shoulder will be deposited first and fat in the belly or loin region will follow. Differences in maturity and age of the animal can influence *de novo* synthesis and fat deposition thus explaining the variation between animals within treatments (Wiegand et al., 2011).

Bacon quality of barrows fed chestnuts and acorns did not differ among dietary treatments. Iodine value (IV) were not different ($P > 0.05$) among treatments diets. Increased

iodine values correlate with softer fat with iodine values ranging from 55 to 95, respectively (Johnston and Li, 2011). The iodine values presented in this study are well within the range and are considered firm bellies.

Conclusion

Inclusion of chestnuts and acorns in the diet did not negatively affect growth performance, carcass characteristics and fresh meat parameters. However, a tendency was observed between the treatment diets in relation to oleic acid, linoleic acid and omega-6. Further research needs to be conducted to prolong days on feed and evaluate the impact on fatty acid profile. Additionally, pigs utilized in the study need to similar in their growth curve and maturity to truly evaluate the effect chestnuts and acorns have on fatty acid profile of fat depots and bacon quality.

Table 2.1 Distribution and mean particle size of barrows fed treatment diets including 15% of chestnuts or acorns

Sieve[1] opening, μm	Control Wt[2], g	%	Chestnut Wt[2], g	%	Acorn Wt[2], g	%	SEM	P – Value
	Control		**Chestnut**		**Acorn**			
3350	0.88	0.83	1.40	1.32	0.95	0.91	0.33	0.287
2360	4.15	3.93	4.60	4.35	4.25	4.05	0.49	0.382
2000	9.72	9.22	9.14	8.65	9.98	9.51	0.52	0.383
1180	20.22	19.18	16.61	15.72	18.81	17.93	2.21	0.476
850	14.23	13.50	12.88	12.20	12.71	12.11	1.23	0.325
595	15.25	14.46	14.59	13.81	13.20	12.58	1.27	0.199
425	11.01	10.44	11.58	10.96	10.52	10.02	1.08	0.281
300	15.32[a,b]	14.54	18.00[a]	17.04	13.46[b]	12.83	1.15	0.014
250	2.94	2.79	4.06	3.84	3.87	3.68	0.46	0.304
177	2.34	2.22	2.41	2.28	3.88	2.69	0.62	0.299
150	3.33	3.16	3.20	3.03	4.44	4.23	0.69	0.453
125	5.41	5.13	6.57	6.22	8.28	7.89	0.91	0.306
63	0.62	0.59	0.61	0.58	0.61	0.58	0.05	0.015
Pan	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.107
Mean Particle Size[3]	617.73 ± 1.35[b]		578.89 ± 1.37[a]		571.84 ± 1.41[a]		7.78	0.046

[a,b,c] Indicates differences within row between treatments ($P < 0.05$)

[1]Sieves mounted on Ro-Tap Test Sieve Shaker

[2]Wt = Weight

[3]$(\Sigma W_i \log d_i) \backslash (\Sigma W_i)$ = Mean Particle Size; $[\Sigma W_i (\log d_i - \log d_{gw})^2] \backslash (\Sigma W_i)$ = Standard deviation

Table 2.2 Proximate composition of chestnuts and acorns (shell on)

Item	Tree Nuts	
	Chestnuts	Acorns
Crude Protein, %	5.91	5.45
Crude Fat, %	1.35	2.80
Crude Fiber, %	8.85	10.10
Moisture, %	20.64	29.25
Ash, %	1.71	2.94
Calcium, %	0.08	0.19
Phosphorus, %	0.14	0.12
Sodium, ppm	42.00	110.00
Chlorine, %	<0.10	<0.10

Table 2.3 Amino acid composition of chestnuts and acorns (as fed basis)

	Treatments	
Item	Chestnuts	Acorns
Taurine	0.19	0.16
Hydroxyproline	0.11	0.07
Aspartic Acid	0.54	0.56
Threonine	0.19	0.21
Serine	0.20	0.22
Glutamic Acid	0.69	0.71
Proline	0.23	0.24
Glycine	0.24	0.25
Alanine	0.32	0.28
Cysteine	0.09	0.08
Valine	0.29	0.32
Methionine	0.07	0.06
Isoleucine	0.22	0.24
Leucine	0.36	0.40
Tyrosine	0.10	0.10
Phenylalanine	0.21	0.24
Hydroxylysine	0.18	0.04
Ornithine	0.01	0.02
Lysine	0.33	0.29
Histidine	0.15	0.15
Arginine	0.29	0.35
Tryptophan	0.04	0.04

Table 2.4 Fatty acid analysis of treatment diets with 15% inclusion of chestnuts or acorns

Fatty acid, %	Control Finisher	Chestnut Finisher	Acorn Finisher
Lauric Acid (12:0)	0.14	0.15	0.34
Palmitic Acid (16:0)	14.09	15.23	15.23
Palmitoleic Acid (16:1)	0.53	0.54	0.68
Stearic Acid (18:0)	4.09	3.37	5.25
Oleic Acid (18:1n9c)	28.66	29.07	32.49
Linoleic Acid (18:2n6c)	49.89	49.13	43.14

Table 2.5 Proximate analysis of finisher diets with 15% inclusion of chestnuts or acorns

Item	Control Finisher	Chestnut Finisher	Acorn Finisher
Corn	83.47	68.55	68.50
SBM, 48%	13.50	13.50	13.50
Chestnuts	-	15.00	-
Acorns	-	-	15.00
Dical 18.5% P	0.93	0.96	0.96
Limestone - Ground	0.77	0.69	0.64
Choice White Grease	0.50	0.50	0.50
Salt	0.38	0.39	0.38
MU VTM	0.25	0.25	0.25
L-Lysine ADM MHC 98%	0.15	0.14	0.14
L-Threonine ADM 98%	0.043	0.006	0.052
L-Tryptophan 98%	0.014	0.017	0.017
Crude Protein, %	13.47	12.80	12.41
Crude Fat, %	2.79	2.14	2.85
Crude Fiber, %	1.92	2.77	3.07
Ash, %	3.63	3.54	4.66
Moisture, %	12.78	12.46	13.09

Table 2.6 Growth performance of barrows fed diets with 15% inclusion of chestnuts or acorns

	Treatments				
Item	Control	Chestnuts	Acorns	SEM	*P*-value
Initial BW[1], kg	107.95	103.12	108.07	3.78	0.43
Final BW[1], kg	131.57	135.58	131.38	2.08	0.33
Gain, kg	25.68	29.70	25.50	2.08	0.33
ADG[2], kg	0.92	1.06	0.91	0.07	0.33
ADFi[3], kg	3.68	3.60	3.59	0.20	0.11
G:F[4], kg	0.25	0.29	0.25	0.01	0.15

[1]Body Weight
[2]Average Daily Gain
[3]Average Daily Feed Intake
[4]Gain:Feed

Table 2.7 Carcass characteristics of barrows fed diets with 15% inclusion of chestnuts or acorns

Item	Control	Chestnuts	Acorns	SEM	P-value
		Treatments			
Live Weight, kg	131.57	135.58	131.38	2.08	0.33
HCW[1], kg	104.83	107.79	103.92	1.53	0.50
DP[2], %	79.68	79.51	79.06	0.49	0.37
Last Rib Fat, cm	3.88	3.89	4.05	0.31	0.95
10th Rib Fat, cm	3.02	3.24	3.02	0.30	0.64
LM area, cm^2	65.03	65.71	59.38	2.26	0.23

[1]Hot Carcass Weight
[2]Dressing Percentage determined by (HCW/Live Weight)*100

Table 2.8 Fresh meat parameters of pork loins from barrows fed diets with 15% inclusion of chestnuts or acorns

| | Treatments | | | | |
Item	Control	Chestnuts	Acorns	SEM	P-value
Marbling score	2.20	2.62	2.43	0.41	0.67
Loin pH	5.55	5.58	5.52	0.03	0.54
L*[1]	58.62	59.63	61.55	1.67	0.89
a*[1]	10.92	10.69	10.22	0.48	0.22
b*[1]	18.08	18.28	18.43	0.40	0.14
a*:b*	0.61	0.59	0.55	0.03	0.70
SI[2]	21.14	21.22	21.10	0.45	0.06
HA[3]	58.88	59.73	61.15	1.19	0.68
Mmb[4]	32.12	32.26	32.09	0.31	0.64
Dmb[5]	22.43	21.14	21.07	1.88	0.21
Omb[6]	45.45	46.60	46.84	1.74	0.22

[1]HunterLab MiniScan Objective Color Values
[2]Saturation Index = $a*+b*^{1/2}$
[3]Hue Angle = Degrees(aTAN(b*/a*))
[4]Metmyoglobin = {1.395-[(A570-A700)/(A530-A700)]}X100
[5]Deoxymyoglobin = {2.375x-[1-(A470-A700)/(A525-A700)]}X100
[6]Oxymoglobin = 100(%MMb+%DMb)

Table 2.9 Fatty acid composition of backfat, jowl, seam and kidney/pelvic fat from barrows fed diets with 15% inclusion of chestnuts or acorns[1]

	Treatments													*P*-Value
	Control				Chestnuts				Acorns					
Item	BF[2]	J[3]	S[4]	KP[5]	BF[2]	J[3]	S[4]	KP[5]	BF[2]	J[3]	S[4]	KP[5]	SEM	Trmt[6]
Palmitic Acid (16:0)	24.02	24.19	26.79	26.89	24.36	24.05	26.55	27.17	24.13	23.78	27.02	26.15	0.17	0.101
Palmitoleic acid (16:1)	1.57	2.14	2.41	1.55	1.62	2.02	2.22	1.53	1.69	2.16	2.63	1.65	0.06	0.322
Stearic Acid (18:0)	14.95	11.43	13.56	18.16	14.57	11.52	13.67	18.19	14.14	11.10	12.55	16.68	0.24	0.790
Oleic Acid (18:1n9c)	42.16	44.96	41.18	38.90	42.72	46.10	41.33	39.35	42.42	44.46	41.52	40.03	0.25	0.079
Linoleic Acid (18:2n6c)	10.72	10.90	9.55	8.98	10.15	9.53	9.57	8.02	10.83	11.19	9.54	9.39	0.17	0.071
Arachidonic Acid (20:4n6)	1.07	0.80	0.77	0.81	1.07	0.98	0.71	0.87	1.08	0.77	0.81	0.89	0.03	0.848
Total SFA[7]	40.93	37.95	42.92	47.18	40.87	37.63	42.59	47.34	40.42	37.24	42.22	45.02	0.36	0.292
Total MUFA[8]	45.92	49.59	45.99	42.31	46.63	50.70	46.00	42.80	46.37	49.29	46.40	43.63	0.31	0.170
Total PUFA[9]	12.76	12.83	11.03	10.40	12.33	11.86	11.43	9.76	12.93	13.16	11.22	11.08	0.20	0.488
PUFA:SFA	0.32	0.34	0.26	0.22	0.30	0.31	0.27	0.21	0.32	0.36	0.27	0.25	0.006	0.168
Total n-3 FA[10]	0.59	1.00	1.00	0.38	0.57	0.95	1.17	0.37	0.63	0.84	1.09	0.44	0.05	0.444
Total n-6 FA[11]	12.05	11.73	9.84	9.91	11.43	10.60	9.86	9.03	12.14	12.21	10.03	10.45	0.18	0.052
n-6:n-3	19.84	14.17	12.39	24.99	20.17	14.14	10.50	25.11	19.22	15.74	11.97	23.76	4.63	0.174
IV[12]	56.32	59.58	54.24	50.47	55.85	58.06	54.23	49.19	56.85	59.68	54.74	52.26	0.38	0.461

[1]Values are a percentage of fatty acids detected   [2]Backfat   [3]Jowl fat   [4]Seam fat   [5]Kidney, pelvic fat   [6]Treatment
[7]Saturated Fatty Acid   [8]Monosaturated Fatty Acid   [9]Polyunsaturated Fatty Acid   [10]Omega – 3
[11]Omega – 6   [12]Iodine Value = (0.95 x C16:1) + (0.86 X C18:1n-9) + (1.732 x C18:2n-6); AOCS (1998)

Table 2.10 Fatty acid composition of fat[1] from barrows fed diets with 15% inclusion of chestnuts or acorns[2]

Item	Control	Chestnuts	Acorns	SEM	P-Value
		Treatments			
Palmitic Acid (16:0)	25.49	25.67	25.29	0.17	0.101
Palmitoleic acid (16:1)	2.20	2.11	2.31	0.06	0.322
Stearic Acid (18:0)	13.99	14.01	13.12	0.24	0.790
Oleic Acid (18:1n9c)	42.66	43.07	42.96	0.25	0.079
Linoleic Acid (18:2n6c)	9.24	8.62	9.44	0.17	0.071
Arachidonic Acid (20:4n6)	0.72	0.76	0.74	0.03	0.848
Total SFA[3]	41.71	41.78	40.68	0.36	0.292
Total MUFA[4]	47.43	47.80	48.00	0.31	0.170
Total PUFA[5]	10.73	10.41	11.07	0.20	0.488
PUFA:SFA	0.26	0.25	0.28	0.006	0.168
Total n-3 FA[6]	0.53	0.56	0.56	0.05	0.444
Total n-6 FA[7]	10.15	9.59	10.44	0.18	0.052
n-6:n-3	50.18	44.48	42.38	4.63	0.174
IV[8]	54.76	53.97	55.50	0.38	0.461

[1]Composite average of backfat, seam, jowl, intramuscular far, KP, and bacon slices
[2]Values are a percentage of fatty acids detected
[3]Saturated Fatty Acids
[4]Monounsaturated Fatty Acids
[5]Polyunsaturated Fatty Acids
[6]Omega – 3
[7]Omega – 6
[8]Iodine Value = (0.95 x C16:1) + (0.86 X C18:1n-9) + (1.732 x C18:2n-6); AOCS (1998)

Table 2.11 Fatty acid composition of intramuscular fat and bacon slices of barrows fed diets with 15% inclusion of chestnuts or acorns[1]

| Item | Treatments | | | | | | | P-Value |
| | Control | | Chestnuts | | Acorns | | | |
	B[2]	IMF[3]	B[2]	IMF[3]	B[2]	IMF[3]	SEM	Trmt[4]
Palmitic Acid (16:0)	25.67	25.37	25.88	25.98	25.74	24.97	0.17	0.101
Palmitoleic acid (16:1)	2.26	3.21	2.27	2.99	2.45	3.29	0.06	0.322
Stearic Acid (18:0)	13.29	12.55	13.29	12.83	12.39	11.82	0.24	0.790
Oleic Acid (18:1n9c)	43.79	44.95	43.97	44.92	44.08	45.23	0.25	0.079
Linoleic Acid (18:2n6c)	8.79	6.48	8.29	6.19	8.91	6.79	0.17	0.071
Arachidonic Acid (20:4n6)	0.05	0.81	0.07	0.83	0.06	0.82	0.03	0.848
Total SFA[5]	41.32	39.98	41.50	40.74	40.56	38.69	0.36	0.292
Total MUFA[6]	48.40	52.40	48.69	51.99	48.97	53.36	0.31	0.170
Total PUFA[7]	10.10	7.28	9.86	7.23	10.37	7.67	0.20	0.488
PUFA:SFA	0.25	0.19	0.24	0.18	0.26	0.20	0.006	0.168
Total n-3FA[8]	0.05	0.17	0.06	0.22	0.07	0.26	0.05	0.444
Total n-6 FA[9]	10.02	7.33	9.54	7.06	10.17	7.66	0.18	0.052
n-6:n-3	186.32	38.14	172.24	34.80	136.65	30.87	4.63	0.174
IV[10]	55.03	52.93	54.32	52.19	55.66	53.79	0.38	0.461

[1]Values are a percentage of fatty acids detected
[2]Bacon Slices
[3]Intramuscular Fat of Chops
[4]Treatment
[5]Saturated Fatty Acid
[6]Monosaturated Fatty Acid
[7]Polyunsaturated Fatty Acid
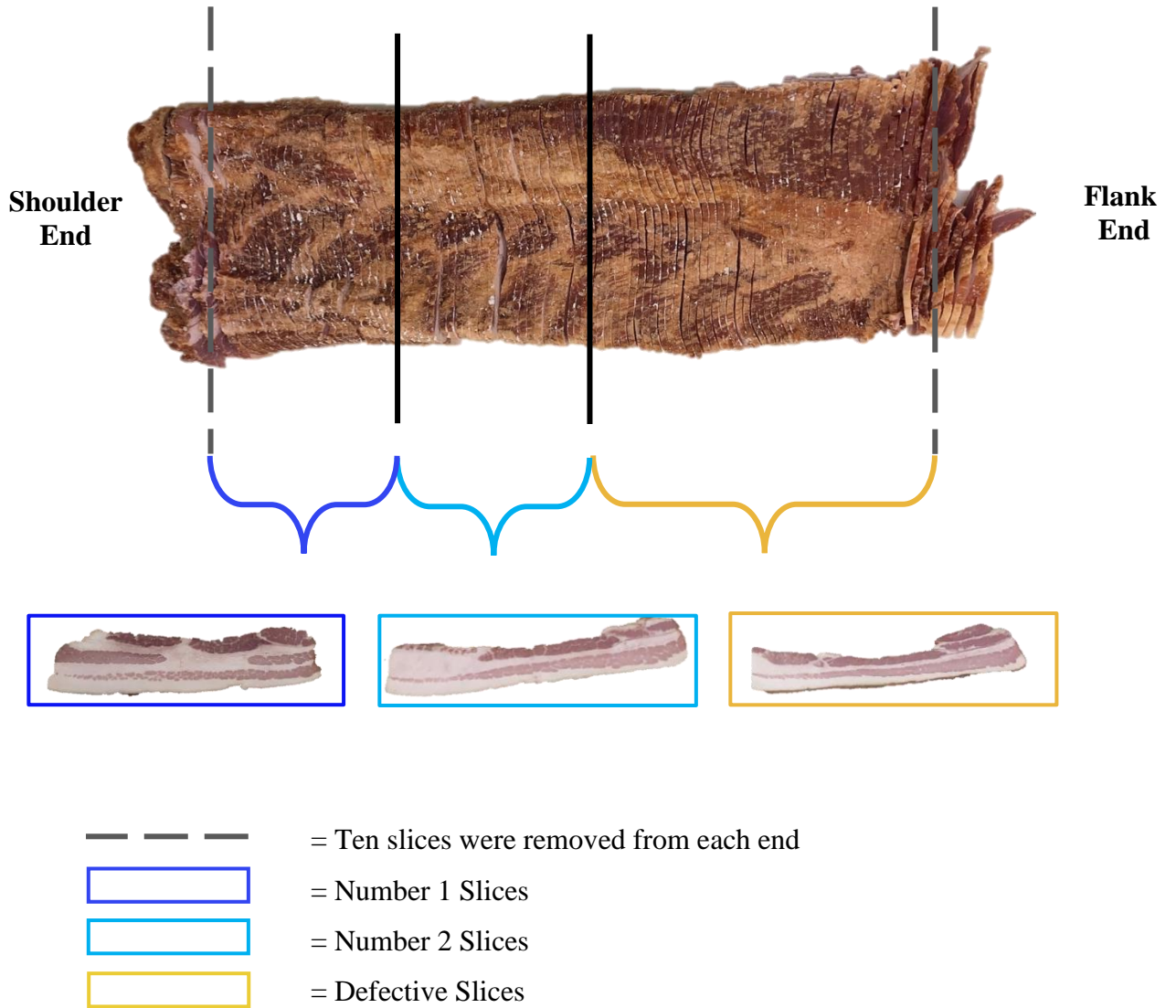[8]Omega – 3
[9]Omega – 6
[10]Iodine Value = (0.95 x C16:1) + (0.86 X C18:1n-9) + (1.732 x C18:2n-6); AOCS (1998)

Table 2.12 Pork loin chop and bacon slice quality from barrows fed diets with 15% inclusion of chestnuts or acorns

Item	Treatments			SEM	*P*-Value
	Control	Chestnuts	Acorns		
Loin Chop					
Moisture, %	71.49	71.75	71.55	0.40	0.89
Fat, %	2.88	2.96	2.90	0.36	0.83
Bacon					
Moisture, %	38.04	38.65	38.85	1.66	0.71
Fat, %	46.94	46.42	45.62	2.44	0.77
Belly Weight, kg	4.17	4.43	4.00	0.23	0.84
Number 1 Slices, %	26.02	30.33	21.64	3.88	0.96
Number 2 Slices, %	25.46	22.51	27.52	3.19	0.13
Defective Slices[1], %	48.53	47.16	48.19	4.61	0.70

[1]High lean to fat ratio, evidence of cartilage, and irregular slices

Figure 1. Evaluation of sliced bacon, quality and yield

Shoulder End

Flank End

- - - - - = Ten slices were removed from each end

[ ] = Number 1 Slices

[ ] = Number 2 Slices

[ ] = Defective Slices

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