PROCESSED MEAT CHARACTERISTICS BETWEEN COMMERCIAL DUROC SIRED AND HERITAGE BREED LARGE BLACK PIGS

by

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Dedicated to my families close and afar that have supported me through this eventful journey

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LIST OF ABBREVIATIONS

a*	Redness
b*	Yellowness
BHA	Butylated hydroxyanisole
BW	Body Weight
CON	Control Diet
d	Day
DDGS	Distiller's dried grains with solubles
DFD	Dark, Firm, and Dry
DS	Duroc Sired Pigs
FDA	Food and Drug Administration
FIB	Fiber Diet
FSIS	Food Safety Inspection Service
g	Gram
IMPS	Institutional Meat Purchase Specifications
L*	Lightness
LA	Lean Area
LB	Large Black Pigs
LC	Livestock Conservancy
^{O}C	Celsius
pH	Potential Hydrogen
PSE	Pale, Soft, and Exudative
SA	Slice Area
SL	Slice Length
TCA	Trichloroacetic acid
USDA	United States Department of Agriculture
WBSF	Warner Bratzler Shear Force
Wt	Weight

ABSTRACT

The United States is ranked third for global pork production as well as first in pork exports according to the USDA Economic Research Service in 2019. The majority of the commercial pork production in the United States applies some form of confinement system with environmentally adapted facilities. However, with information and easy media access to the US consumers, news and reports on different farming practices and potential issues in the animal industry have come under the spotlight. Consumers are becoming more interested in knowing what goes on behind the scenes of the commercial animal industry and where and how their food is produced. Whether it is due to personal beliefs, ethical concerns, novelty-seeking, eating experience, or choice of lifestyle, consumers are demanding diversity in their meat purchasing options. Although the commercial pork industry has shifted to fewer and larger farms in the last 40 years, small specialty farms such as heritage breed pork are on the rise to form a niche market. Large Black pig is a pasture-raised heritage breed originating in England, and it remains one of the rarest British pig breeds. Due to differences in husbandry, pasture-raised Large Black pigs consume a relatively high forage diet compared to corn-based diet used in commercial swine production. Although heritage pork has been lauded to have unique and superior quality, enhanced eating experience, and is often sold at a premium price, there are very little data on pork quality of Large Black pig compared to Duroc-sired breeds which are commonly used in commercial pork production. The purpose of this study is to fill the dearth and investigate differences in pork processing characteristics between commercial Duroc-sired and Large Black genetic lines fed high forage or commercial diets.

The study contained a total of 50 pigs: 25 Duroc-sired (DS) and 25 Large Black sired (LB) pigs. After all the pigs were weighed, the pigs were randomly assigned with heavy and light weights as blocks to two dietary treatments: Fiber (FIB) and Control (CON); and the feeding trial lasted a total of 126 days. There were 14 Large Black pigs fed fiber diet (LB FIB); 11 Large Black pigs fed control diet (LB CON); 14 Duroc-sired pigs fed fiber diet (DS FIB) and 11 Duroc-sired pigs fed control diet (DS CON). Pigs were fed either a control Corn-Soybean Meal-DDGS based diet or a high fiber diet with wheat middlings and dehydrated alfalfa meal replacing corn and soybean meal in the control diet. Diets were fed over six 21 days phases with fibrous ingredient levels increasing from 8.5 to 30 percent of the diet with sequential dietary phase from 1 to 6. Pigs were harvested at a common age with some variations in body weight between genetics (DS 125

± 2.23 kg, LB 99 ± 2.28 kg; *P* < 0.001). Individual batches of 80% lean : 20% fat sausage patties with seasoning (136g per patty) were made from the shoulder of each pork carcass. PVC packaging was applied to each batch of sausage patties. Fat smear was noted on day 0 with a fat smear scale of 1 (excessive far smearing) to 8 (clear fat particle definition). Color parameters that include lightness (L*), redness (a*), yellowness (b*), and lipid oxidation (2-Thiobarbituric acid reactive substances, TBARS) due to retail display effect were measured at days 0, 3, and 7 by placing packaged sausage patties under the retail display lighting. Boneless bellies were removed and weighed (fresh weight) from each pig and measurements for belly thickness, length, and firmness were recorded. Fresh bellies were injected to 110% fresh weight, thermally processed (62°C), and cooled (1°C internal temperature). Cooked weight was obtained before slicing. Belly processing yield was calculated as a percentage using (cooked weight / fresh weight) x 100. Adobe Photoshop was used to perform visual image analysis for bacon slice length (SL; cm), slice area (SA; cm^2), and slice lean area (LA; %), one 0.64 cm bacon slice was obtained from 25, 50, and 75% distance respectively from the blade end of each cooked bellies for the analysis. RStudio (1.2.1335) was used to analyze data with breed and diet as fixed effects and least square means separated at (*P* < 0.05).

Results showed that only diet was significant for patty fat smear (*P* = 0.0104), CON patties had better particle definition than FIB patties. Difference for patty color L* (*P* = 0.0051), a* (*P* < 0.0001) and b* (*P* < 0.0001) were found for days of retail display. Breed was significant in L* (*P* < 0.0001) and a* (*P* < 0.0001) with DS patties being lighter and less red than LB patties. Days under retail display (*P* < 0.0001) and breed x diet interaction (*P* = 0.0014) were found in lipid oxidation. DS CON had the least amount of lipid oxidation throughout retail display time. Breed and diet were significant for both belly thickness and length. LB (*P* = 0.0263) and CON (*P* < 0.0001) bellies were thicker than DS and FIB bellies respectively. DS (*P* < 0.0001) and CON (*P* = 0.0045) bellies were longer than LB and FIB bellies respectively. A breed x diet interaction (*P* = 0.0527) was observed in belly firmness and LB CON had the firmest bellies. Processing yield was found to be greater in DS bellies (*P* = 0.0014) than LB bellies. Breed effect had a tendency (*P* = 0.065) on SL, DS slices were longer. CON had greater SA (*P* < 0.0048) than FIB slices. DS slices had significantly higher LA (*P* < 0.0001) than LB slices.

The study provided novel insights into the differences in processing characteristics between the DS and LB genetic lines as well as the effect of diet on each breed. Results such as thicker and firmer belly, lower LA in LB were expected since LB is a minor swine breed that has not undergone intense genetic selection for percent lean meat. Overall, each breed had a better product when fed their accustomed diet (FIB for LB, CON for DS) such as less lipid oxidation in sausage patties for DS CON compared to LB CON. Although LB fits into the niche market of heritage breed pork, future studies in management systems, processing methods, and genetic improvement should be considered to improve product quality to better meet modern consumer demands.

CHAPTER 1. LITERATURE REVIEW

1.1 Introduction

In an age where technology is developing rapidly, ways to obtain information and new trends have become easier than ever. With social media casting sundry impressions on the animal agriculture industry, through advertisements of new products, news on innovative concepts and ideas, consumers – especially those that were unfamiliar with the field of agriculture –are being exposed to a much more diverse market and have subsequently started to shift their purchasing decisions based on the information that was presented to them. Many consumers have begun seeking options like organic, grass-fed, pasture-raised, local, or heritage breed meats instead of purchasing from commercial production lines. In addition to consumers seeking diversity, the commercial pork industry has simultaneously been presented with consumers' criticisms about decreased meat quality. Unfavorable consumer perception has been found regarding fresh pork eating quality (Moeller et al., 2010). Many have complained that pork from modern commercial production lines tastes bland and claimed that the pork back in the days was more flavorful and had a better eating experience (Ngapo & Gariépy, 2008). Whether the claims had scientific support or not, consumer perception has pushed the industry to explore ways to improve fresh pork eating quality or bring back the "old taste". Existing work to resolve this challenge includes the examination of animal effects, including species, breeds, ultimate pH, etc (Ngapo & Gariépy, 2008). Although the commercial system is still responsible for the majority of pork production, a niche market has formed that allows consumers to get something more diverse and presents buyers with a chance to find some nostalgic taste.

Large Black Pigs, one of the minor swine breeds in the United States, is well fitted into the niche market of heritage breed and pasture-raised pork. The breed originated from southwestern England and has established a relatively small breeding population in the United States. Pork quality plays an important role in the niche market (Lammers et al., 2007), and the Large Black pigs are often being advertised as premium pork. Although there has been a study published examining pork quality of crossbred Large Black Pigs (Whitley et al., 2012), there have been very few studies examining the pork quality and processing characteristics of purebred Large Black Pigs (LB) in comparison to commercial Duroc sired pigs (DS).

High energy diets are usually used in commercial swine production, however, because of the outdoor-foraging nature of the Large Black Pigs, their diet consists of more fibrous material and is lower in energy. Due to variability in diet, genetics, and methods of husbandry, there has not been a meaningful comparison made between Duroc sired pigs and Large Black Pigs concerning their meat quality and processing characteristics. This study will attempt to fill this dearth in the literature by examining the differences between Duroc genetics and Large Black genetic lines fed high forage or commercial diets regarding their pork processing characteristics.

1.2 Genetics

1.2.1 Brief Description of the Large Blacks Genetics

The LB was known as the Lop Eared Black initially, likely due to its signature “floppy” ears. The breed thrived in the late 1800s. Livestock Conservancy states that: “the mature boars weigh 318-363 kg and mature sows weigh 272-318 kg”. According to The Livestock Conservancy: “The breed was selected for large size and efficiency of production on pasture and other forages… it was one of the most numerous of the English pig breeds in 1900.” LB was crossed with large white breeds like Yorkshires and resulted in ideal hybrid vigor and therefore the cross was desired commercially (Livestock Conservancy). The breed peaked in popularity in the 1920s and was exported to other countries including the United States. With the shifting in husbandry needs and focus after World War II, the LB population declined due to its outdoor nature and was nearly extinct in the mid-1900s and still exists as one of the rarest British pig breeds (Livestock Conservancy). Unlike many modern commercial swine breeds that have been through intense genetic selections, LB as a minor swine breed in the United States underwent very little genetic modification since its first importation in the early 1900s. With consumers seeking diversified products, LB as a minor swine breed and its ability to forage and live outdoors make it a good candidate for producers who were wanting to meet certain consumer demands in a niche market.

Figure 1.1 Photo of American Large Black sow in 2019. Photo taken by Yufei Guo, Purdue University, West Lafayette, IN.

1.2.2 Brief Description of the Duroc Genetics

Durocs, commonly associated with their signature red coat, is heavily used as a terminal sire in crossbreeding systems and is known to produce market pigs with excelled growth and carcass attributes (National Swine Registry, n.d.). In the early 1810s, “Red Hogs” were bred in New York and New Jersey and eventually these strains crossed paths and created the foundation for today’s Duroc (National Swine Registry, n.d.). Duroc pigs are known for their desired carcass traits and therefore are a very popular choice as terminal sire breed in the pork industry in the United States. Numbers of studies examined the differences in carcass traits of crossbred pigs sired by Duroc as well as other terminal sire breeds. Crossbred pigs sired by Duroc, Landrace, and Large White boars were compared for their growth performance and carcass quality: Duroc cross had the highest feed efficiency and growth rate, increased intramuscular fat in the *longissimus dorsi*, and 8% less subcutaneous fat (McGloughlin et al., 1988). Similar results were discovered in Lo et al., (1992) that Duroc sired pigs had shorter carcasses, more intramuscular fat, less subcutaneous fat, larger loin eye area, and better growth performance. Based on the Nation Swine Registry: “Durocs were identified as a superior genetic source for improving eating qualities of pork in the recent National Pork Producers Council Terminal Sire Line Evaluation.”

1.3 Attributes of Fresh Pork Quality

The profitability of the meat industry largely depends on consumer perceptions and behaviors. The industry continues to modify its operation methods in an effort to better meet consumer preference and therefore continue to make a profit. Safety, price, and taste have been identified as the top three values that consumers view when making food purchasing decisions (Lusk & Briggeman, 2009). However, when it comes to animal-related products, production methods and product attributes also impact consumer decisions (Cummins et al., 2016). According to the Niche Pork Production Handbook from Iowa State University: “The quality of pork is the result of a combination of genetic and environmental factors. There are four major criteria used in measuring pork quality: color, marbling, water-holding capacity, and ultimate pH.”

1.3.1 Color

Color is the most important factor when it comes to consumer perception of meat quality during purchase. With color being the first and easiest observation, consumers often associate the color with the freshness of the meat product (Faustman & Cassens, 1990, Liu et al., 1995, Troy & Kerry, 2010). Meat color is the first quality attribute consumers would see when they make purchasing decisions. The bright cherry red for beef, brick red for lamb, and pink for chicken and pork are attractive to consumers; therefore, many attempts regarding packaging, processing, etc. to preserve the desired color longer in retail settings have been made by the industry. Although meat color is important to consumers, the bright color does not necessarily guarantee a good eating experience. Consumers would have negative perceptions about discolored meat products, which resulted in heavy discounting or further processing on significantly discolored meat (Sherbeck et al., 1995).

Meat color is dependent predominately on myoglobin and small amounts of hemoglobin. The amount of myoglobin in meat varies among species and is affected by factors like age, location of the muscle, gender, diet, genetics, etc (Troy & Kerry, 2010). For instance, locomotive muscles have increased myoglobin concentration. Myoglobin, as the main source of iron in meat, is responsible for storing oxygen within tissues and it is composed of two parts: globin and heme ring. The sixth ligand, which is a binding site on the heme ring, determines the color of the meat. The three states of myoglobin concerning fresh meat include deoxymyoglobin, oxymyoglobin, and metmyoglobin. Iron is at the ferrous state during deoxymyoglobin, oxygen is absent at the sixth ligand and the meat is purple or dark red in color. This is often the color observed when immediately cutting into a deep muscle or meat under vacuum packaging (Renerre, 2007). Meat appears to be in the desired bright red color during the oxymyoglobin stage. It happens shortly after deoxymyoglobin is exposed to oxygen. Oxygen binds to the sixth ligand and forms oxymyoglobin and iron are still at the ferrous state. This is the most desirable stage for coloration but at the same time, it's the least stable. After extended exposure to oxygen, water binds to the sixth ligand, iron is oxidized to a ferric state, and metmyoglobin forms. Meat in this stage appears to be brown and consumers often associate the color with an undesirable product that lacks freshness (Hood & Riordan, 1973). Despite the meat being safe for consumption in all three states of the myoglobin reaction, from a quality standpoint, the brown color that accompanies metmyoglobin is not appealing to consumers. Intrinsic factors like muscle fiber type, pH, other physiological aspects of the animal, and extrinsic factors like pre-harvest handling, post-harvest processing, retail lighting, packaging, etc. can all affect the rate of oxidation that contributes to discoloration of the meat product (Troy & Kerry, 2010).

1.3.2 Intramuscular Fat

Intramuscular fat—also referred to as marbling—exists between muscle bundles and is a valuable aspect in terms of quality. Like meat color, marbling is also a visual factor and the amount of intramuscular fat present could impact consumer perception of the quality of the meat along with color (Troy & Kerry, 2010). Intramuscular fat melts during cooking and can serve as a barrier to moisture loss. Increased marbling has been associated with increased palatability; however, the presence of excessive marbling could promote health concerns for some consumers and hence negatively affect the perception of the product (Miller, 2002). Preference for fat content could be market-specific (Troy & Kerry, 2010), for instance, Iowa State University's Niche Pork Production Handbook mentions that 2-4% is the target amount of fat for nutrition, flavor, and health benefits, but it was found that meat which contains 3-7.3% of fat is still accepted but fat content over 7.3% raises worries for health-conscious consumers (Miller, 2002).

As a visual characteristic, the appearance in terms of color and amount of fat can attract or deter some consumers. Fat is generally perceived to be white by consensus, however, the appearance of fat could be affected by animal diet and other biological factors. Carcasses of animals fed primarily forage diet, grass-fed beef for instance, often show yellow-colored fat. The yellow color does not affect palatability, but consumers tend to negatively associate products that have the non-, white-colored fat with an old or unhealthy animal (Troy & Kerry, 2010). Aside from color, the amount of marbling varies among breed, slaughter weight, feeding system, etc. Marbling scores are often used to describe the marbling characteristic in meat—a higher score indicates more intramuscular fat. Studies done on beef steaks showed that trained sensory panels found meat with higher marbling scores to be juicier, tenderer, and more intense in flavor. Warner-Bratzler shear force values were inversely related to the marbling score which is consistent with the finding of the trained sensory panels (Miller, 2002). Similar studies with pork have been conducted internationally. Two studies, one conducted in the United States and the other one conducted in Japan, utilized pork loin chops that differ in pH, fat content, and tenderness (measured by the Warner-Bratzler shear force values) were distributed to consumers. The fat content of the chops did not affect the ratings for consumers in the United States(Miller, 2002). Conversely, Japanese consumers reported increased juiciness, flavor, and likeness of visual appearance includes color and amount of fat to chops with higher National Pork Producer Council (NPPC) marbling score (Miller, 2002). According to Miller (2002): "NPPC marbling scores are a visual assessment of intramuscular fat and they are related to a chemical lipid value." However, chops with an excessive amount of visible fat were not favored by Japanese consumers. The marbling and meat palatability relationship exists but its strength varies among species and consumer populations. Flavors like bloody, metallic, etc. are mostly associated with cooked lean meat. The overall flavor profile of a cut can be balanced by the cooked fat aromatic from increased marbling hence intramuscular fat can aid in the improvement of meat qualities (Miller, 2002).

1.3.3 Water Holding Capacity

Water holding capacity is the muscles' ability to retain water and is an attribute in juiciness. In Warner (2017), meat juiciness is defined as: "the impression of moisture and lubrication when meat is chewed in the mouth." Water and fat content make up the two components that affect meat juiciness. The water content in the meat is thought to be responsible for the first feel of wetness during the initial chewing that is caused by fluid being rapidly released from the meat. And the impression of wetness during persistent chewing is due to the fat content of the meat (Winger & Hagyard, 1994). Forms of water within the muscle and isoelectric point all contribute to water holding capacity. The isoelectric point as defined in Warner (2017) "the point of minimum charge of the myofibrillar proteins" is around 5.0-5.2. As the muscle pH approaches the isoelectric point, meat proteins react and bind with each other instead of water molecules hence water holding capacity decreases. In pork, low pH meat tends to appear lighter/paler and high pH meat displays darker/redder color. Bound water, immobilized water, and free water are three types of water within the muscle. Bound water accounts for about 1% of water in meat, which refers to water physically attached to the muscle proteins and retains in the muscle after cooking (Huff-Lonergan & Lonergan, 2005). Immobilized water accounts for up to 85% of water in meat; it is not physically attached to the proteins, but it is trapped between the thin and thick filaments by steric effects and capillary forces. Immobilized water can leave the meat when the pressure applied is greater than the capillary forces; the conversion of muscle to meat, process of rigor mortis and the ultimate pH greatly affects the retention of this water (Huff-Lonergan & Lonergan, 2005, López-Bote, 2017). Free water is held in meat by weak surface forces and it can easily flow through tissue and exit the meat (Huff-Lonergan & Lonergan, 2005). This escaped water is responsible for drip loss, purge and exudate that can be observed in packaging. Meat with poor water holding capacity would have greater drip/purge loss and facilitates decreased yield and quality (Aaslyng, 2002). Excessive exudate in packaging may act as a negative visual deterrent to consumers when making purchasing decisions. This would also indicate increased water loss, resulting in a product that lacks juiciness when consumed (Warner, 2017).

Many factors can contribute to meat water holding capacity. Despite gender, age, species, etc., postmortem glycolytic mechanisms, rate of pH decline and ultimate pH are the main deciding factors of water holding capacity of the meat product. During slaughter, exsanguination completely disrupts the circulatory system and lactic acid builds up in the muscle. With no oxygen, oxidative metabolism fails and the shift from aerobic to anaerobic metabolism begins. Since there is no functioning circulatory system to remove the waste, the accumulation of lactic acid causes the decrease in pH from about 7.0 to 5.6. As pH approaches the isoelectric point, charges on myofibrils proteins begin to alter, and results in filaments attracting each other and therefore cause the myofilament lattice shrinkage which expels some water from the carcass (Warner, 2017). Both insufficient and excessive pH decline would cause issues in water holding capacities, safety, and quality. Proper rate of pH fall along with ultimate pH are crucial for product quality and safety.

1.3.4 pH

The ultimate pH, which is measured 24 hours post-slaughter, has been found to have linkages with attributes like meat color, tenderness and water holding capacity, hence it can be used as an indicator to predict pork quality (Boler et al., 2010). Moeller et al., (2010) found that consumer desire for juiciness and tenderness was directly proportional to pH. Consumer satisfaction of eating quality decreased for pork with near 5.4 ultimate pH. As the ultimate pH gradually increased to 6.4, consumer likeness of juiciness, tenderness and flavor increased as well (Moeller et al., 2010). Ultimate pH and water holding capacity is tightly intertwined, in addition, the pH effects on water holding capacity can be extended to color and juiciness as well. Higher pH tends to mean increased water holding capacity. When pH is close to the isoelectric point, the net charges of the meat proteins reach zero which means the proteins have equal amount of negative and positive charges. This would then result in the proteins to be attracted to one another instead of holding onto water, hence negatively affecting the water holding capacity. This attraction among proteins that make up the myofibrils also causes reduction in space within the myofibrils due to no repulsion of the same charges to maintain the structural integrity. The reduction of space within the myofibrils indicates less room for water storage hence further decreasing water holding capacity (Huff-Lonergan & Lonergan, 2005). Decreased water holding capacity results in more drip loss and causes water accumulation on the meat surface. The moist surface facilitates more light reflections, making the product appear paler (Boler et al., 2010). On the other hand, if the ultimate pH is too high due to insufficient pH decline, the meat would appear much darker due to water retention and decreased light reflection. Along with increased pH, Boler et al., (2010) found increased subjective meat quality scores (color, firmness, and marbling), decreased purge loss, L* value and cooking loss; methods to improve the ultimate pH can positively contribute to the overall consumer perception of the product (Moeller et al., 2010).

Two common quality defects related to pH in pork are PSE (Pale, Soft and Exudative) and RSE (Red, Soft and Exudative). Factors that induce PSE include genetics (halothane gene), acute stress and rapid pH decline while the muscle is still warm. Accelerated pH decline accompanied by high temperature causes many functional proteins to denature (Huff-Lonergan & Lonergan, 2005). Denaturation of myosin prior to rigor plays a part in the high drip loss and softness in PSE meat (Offer, 1991). The halothane gene is a mutation that affects the calcium release channel in the animal and an animal with this mutation can produce too much lactic acid under stress. The mutation causes calcium leakage which contributes to unregulated muscle contraction, increased rate of postmortem glycolysis and rapid pH decline. Fortunately, a commercial test is available to detect the halothane gene in the parent stock and can effectively eliminate the mutation by avoid breeding of carrier pairs. While the halothane gene mutation has been successfully eliminated in most commercial herds in the United States, acute stress prior to slaughter in normal animals can still cause PSE. The stress could be enough to not only affect their metabolism while they are alive but also increase postmortem muscle metabolism. This would cause a faster pH decline compared to normal- non-stressed animals. The condition may not appear as severe as PSE caused by the halothane gene mutation, but protein denaturation still occurs which leads to increased drip loss than un-stressed normal animals that had a normal rate of pH decline (Huff-Lonergan & Lonergan, 2005).

RSE is believed to be caused by the Rendement Napole (RN-) gene in pork. Similar to PSE, RSE pork lacks firmness and has increased drip loss, however, it has the red color which is desired by consumers (Miller, 2002, Warner et al., 1997). The adenosine monophosphate (AMP) kinase has been mutated in RN- animals. AMP regulates glycogen synthase and mutated AMP kinases lack the proper ability to inhibit glycogen production (Miller, 2002). Animals with RN- gene produce 70% more glycogen and have reduced technological yield than normal- non-carrier animals. And the high glycogen content in muscle causes increased lactic acid build-up. Although the condition does not affect early postmortem pH, it results in a lower ultimate pH and it is often referred to as “acid pork” (Huff-Lonergan & Lonergan, 2005, Rosenvold & Andersen, 2003). Increased myosin tails and sarcoplasmic protein denaturation are found in RN-carrier animals compared to non-carriers. Advanced protein denaturation negatively contributes to the water holding capacity of RSE meat (Deng et al., 2002). Aside from quality attributes like poor water holding capacity and lowered ultimate pH, inferior protein extractability has also been found in RN- animals. RN- animals have 10% less total protein content compared to normal animals. This may cause issues during processing, since decreased protein content could indicate loss of salt soluble proteins which can negatively impact processes like ham production (Estrade et al., 1993, Miller, 2002). The reduced processing yield raises problems for the industry regarding further processing since only a portion of the production is sold as fresh meat (Rosenvold & Andersen, 2003).

1.4 Attributes of Processed Pork Quality

Meat consumption in the United States has been rising: red meat accounts for 58% of the meat consumption and 22% of the meat consumed were processed meats (Daniel et al., 2010). In 2009, bacon and sausage both were ranked in the top three processed pork items consumed by US households (Soladoye et al., 2015). While plenty of studies have examined the processing characteristics for commercial pigs, very limited data were available on the heritage Large Black Pigs.

1.4.1 Bacon

The belly which makes up bacon is a primal cut of the pig carcass that is high in value. Subcutaneous and intermuscular fat are the two main fat layers contained in pork belly. *Cutaneous trunci* and *latissimus dorsi* are responsible for the major parts of the lean muscle in the belly. Depending on cutting specifications, muscles like *serratus ventralis, diaphragm, teres major, triceps brachii-long head, intercostal externi,* and *obliquus abdominis interni* could be included in the belly as well (Soladoye et al., 2015). The lean-to-fat ratio of the pork belly is determined by the total amount of lean muscle and fat present in the belly. The lean-to-fat ratio as a visual factor of the pork belly could influence bacon quality and consumer perceptions of the product (Stiffler et al., 1975). Methods to measure belly quality include 4-, 5- or 6 - point scale visual assessment, finger testing, and belly flop test (suspended round bar or v-shaped smokehouse stick) for firmness, and non-invasive methods like electromagnetic scanning for belly composition (Soladoye et al., 2015). The amount and composition of the fat layers in pork belly could determine the thickness and softness of the belly. Bacon that retains shape is more appealing to consumers and these kinds of bacon would most likely be from thicker and firmer bellies (Shackelford et al., 1990). Genetic pursuit in lean meat has led to a thin belly and soft belly which both negatively contribute to profitability. Thin bellies cause decreased processing yield like high cooking shrink while soft bellies have inferior sliceability, reduced shelf life, and unattractive product packaging (Person et al., 2005, Shackelford et al., 1990). Pork belly and subsequently bacon quality can be majorly influenced by animal genetics, environmental and dietary factors. Altering swine diet can effectively change the fat composition and result in more ideal bellies in terms of thickness and firmness.

1.4.2 Sausage

Sausage, composed of lean meat and fat, is one of the most consumed processed pork products. Fat composition and amount would influence the quality of sausage in aspects like texture, juiciness, color, and rate of oxidation (Wenjiao et al., 2014). Sausage with higher fat content has been associated with increased flavor and succulence (Vural, 2003) but the high-fat content also exposed these products to an increased degree of lipid oxidation. Rancidity, which is negatively perceived by consumers, is a major contributor to quality defection in sausage. It occurs along with lipid oxidation and/or microbial growth (Bradley et al., 2011). The development of rancidity is generally due to the reaction between unsaturated fatty acids with oxygen, and the process is influenced by heat, light, property of functional ingredients, like antioxidants, in sausage (Cheng et al., 2007). 2-Thiobarbituric acid reactive substances (TBARS) assay is widely used to examine the degree of oxidation and subsequently serve as an indicator for product quality (Wenjiao et al., 2014). Thiobarbituric acid reactive substances like malondialdehyde are produced as a byproduct of lipid peroxidation and can be measured by reagent thiobarbituric acid (TBA). The retail display involves heat, time, temperature, and lighting which is an ideal condition that facilitates lipid oxidation. Wenjiao et al., (2014) found TBARS content to be proportionally related to storage time. Product discoloration often accompanies an increased TBARS value due to the oxidation of myoglobin in the lean meat that makes up the sausage. Discolored products appear to be undesirable to consumers and this could reduce the products' shelf-life. The ratio of fat and lean in the sausage mixture, functional ingredients, animal genetics, and diet could all possess a role in lipid oxidation which could decrease processed product quality.

1.5 Nutrition

Corn and soybean-based high-energy diets are standardly used in commercial pork production. Due to Large Black Pigs' outdoor nature, their diets contain a higher level of forage and fibrous materials which also indicate lower energy. Pigs fed low energy diet were found to have decreased fat deposition (Ngapo & Gariépy, 2008). Diverse lysine content has been shown to affect the amount of marbling, carcass leanness; and fatty acid composition in the diet can impact the fatty acid profile of fat in finished pigs. The pigs' fatty acid composition can alter meat flavor and palatability (Miller, 2002). For instance, growing pigs fed fish oil were found to have a fishy taint when their meat was consumed (Hertzman et al., 1988, Ngapo & Gariépy, 2008). Feed that contained more unsaturated fatty acids translated to higher unsaturated fatty acids concentration in meat and resulted in a product more susceptible to oxidation (Hertzman et al., 1988). A softer and greasier appearance was found in meat that had increased unsaturated fatty acids levels (Miller, 2002). Despite genetic factors, differences in fat composition, meat flavor, oxidation rate, and other quality attributes could be developed just due to pigs fed a standard corn-soybean-based diet or a more fibrous diet. Since Large Black Pigs and commercial Duroc sired pigs are rarely fed the same diet, there is very little comparable data evaluating Large Black pork quality or processing characteristics to commercial breeds. This gap of knowledge presents a unique opportunity to examine the differences in pork quality and processing characteristics between commercial Duroc-sired genetics and Large Black genetic lines fed high forage or commercial diets.

1.6 Summary

Duroc is a major swine breed known for ideal carcass traits. The breed is commonly used as terminal sire genetics in the commercial swine industry in the United States. On the contrary, LB is a much less prominent pasture-raised heritage breed swine breed in the United States, due to minimum genetic selection, the LB breed still maintains very similar physical characteristics as when it was first imported in the early 1900s. With consumer complaints regarding decreased meat quality in commercially produced pork, the industry continues to modify and change in order to meet consumers' needs and generate a profit. In doing so, a niche market that offers products like pasture-raised pork, organic, heritage breed meat, etc. is increasing in popularity.

Color, marbling, water-holding capacity, and ultimate pH are four major pillars of fresh pork quality. Aside from fresh meat, sausage and bacon were two of the top three processed pork products consumed in the United States when reported in 2009. While LB fits into the niche market very nicely and can provide some novelty and diversity for consumers, there's very little data evaluating their fresh or processed meat quality and characteristics. Since LB and Duroc pigs consume different diets and vary in methods of management, it is critical to raise them in a similar manner in order to compare their meat quality and processing characteristics. There have not been any studies evaluating purebred LB fresh as well as processed meat qualities in comparison to commercial genetics (DS) when fed the same diets.

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CHAPTER 2. DIFFERENCES IN PROCESSED MEAT CHARACTERISTICS BETWEEN DUROC SIRED AND LARGE BLACK PIGS

2.1 Abstract

Heritage bred pork is praised as premium pork for its unique fresh meat quality characteristics, however, there is very little data evaluating Large Black pork quality or processing characteristics in comparison to commercial breeds. Therefore, the objectives of this study were to examine differences in pork processing characteristics between commercial Duroc-sired genetics and Large Black genetic lines fed high forage or commercial diets.

Fifty pigs were utilized in the study with a 2 x 2 factorial design of breed and diet. Duroc sired (DS, n=25 pigs) and Large Black sired (LB, n=25 pigs). All the pigs were weighed and allocated to two dietary treatments: Fiber (FIB) or Control (CON), (LB FIB, n=14; LB CON, n=11; DS FIB, n=14; DS CON, n=11). Dietary treatments were fed throughout the grow-finish period (101 or 140 d) in six phases. CON diet was corn-soybean meal-DDGS based and FIB diet used increasing amounts of wheat middlings (1-10%) and dehydrated alfalfa meal (7.5-20%) replacing corn and soybean meal in the CON diet, from phase 1-6. Pigs were harvested at a common age but BW varied between genetics (DS 125 ± 2.23 kg, LB 99 ± 2.28 kg; $P < 0.001$). Bellies (IMPS 408) were measured for thickness, length, firmness, and weight (fresh weight). Bellies were injected to 110% of fresh weight with a manual compressed air stitch pump, were thermally processed to 62°C, cooled to 1°C internal temperature, and weighed (cooked weight). Pump uptake and belly processing yield (%) were measured. A 0.64 cm bacon slice was removed at 25, 50 and 75% distance from the blade end of the cooked bellies for visual image analysis. Images of the slices were analyzed with Adobe Photoshop for bacon total slice length (SL; cm), total slice area (SA; cm^2) and lean area (LA; %). Lean and fat trim was obtained from the shoulder of each carcass, formulated to 80% lean:20% fat, ground, seasoned and mixed to create individual sausage batches. Sausage patties (136g each) from each batch were placed in PVC packaging under retail display lighting for 0, 3, and 7d. Fat smear was determined on d0 by a trained evaluator using a scale of 1 (excessive fat smearing) to 8 (little/no fat smearing). Retail display effect on color (Minolta colorimeter) and lipid oxidation (Thiobarbituric acid reactive substances; TBARS) were examined

each display day. Data were analyzed with breed and diet as fixed effects using RStudio (1.2.1335) with least square means separated at ($P < 0.05$).

Results showed DS bellies were longer ($P < 0.001$) but thinner ($P = 0.0263$) than LB. FIB bellies were shorter ($P = 0.0045$) and thinner ($P < 0.001$;) than CON. No breed x diet interactions were found in belly length ($P = 0.7245$) or thickness ($P = 0.5300$). Differences in firmness due to a breed x diet interaction ($P = 0.0527$) were found; LB CON were the firmest bellies ($P < 0.01$), with LB FIB intermediate in firmness ($P = 0.0325$), and DS CON and DS FIB were not different ($P = 0.5577$). DS bellies had greater ($P < 0.01$) processing yield than LB bellies. A tendency for a breed effect was observed in SL with DS slices longer than LB slices ($P = 0.0650$). Diet was significant for SA as slices from CON bellies were larger than FIB slices ($P = 0.048$). Breed was significant for LA, as DS slices had greater LA than LB slices ($P < 0.01$). No breed x diet interaction was found in slice images. For sausage patty fat smear, CON had better particle definition than FIB ($P = 0.0104$), but no differences were observed in breed ($P = 0.3979$), or breed x diet ($P = 0.3024$). Differences in L* ($P = 0.0051$), a* ($P < 0.001$) and b* ($P < 0.001$) were found among display days, consistent with color deterioration over time. DS patties were lighter (L*, P < 0.0001) and less red (a*, P < 0.0001) than LB patties with no breed differences in patty b* (P=0.7107). No diet differences were found for patty L* ($P = 0.4708$), a* ($P = 0.1337$) or b* ($P = 0.7698$). Breed x diet showed no differences for patty L* ($P = 0.5282$), a* ($P = 0.4955$) or b* ($P = 0.7443$). TBARS analysis showed days under retail display ($P < 0.001$) and breed x diet interaction ($P = 0.0014$) to be significant. DS FIB had the most lipid oxidation and DS CON had the least amount of lipid oxidation, particularly at d3 and d7.

This experiment found variations in processing characteristics between DS and LB genetic lines and their diets. DS bellies were longer but thinner when compared to LB bellies. CON bellies were longer and thicker than FIB bellies. LB bellies had decreased LA as well as decreased processing yield. LB had improved firmness due to a greater amount of backfat. FIB patties had more fat smearing than CON patties. This provides novel insight into the comparison between these breeds and diets. While LB pork may have niche market value, the integration of this breed into commercial bacon processing has limitations in composition that need to be further evaluated to improve the product desirability.

2.2 Introduction

Based on reports from the USDA Economic Research Service in 2019, the United States ranked in the top three for pork producers and was the leading pork exporter globally (U.S. Department of Agriculture, 2019). Various types of confinement systems with high energy corn-based diets are used in most commercial swine production in the United States. Commercially produced pork has been readily available for public purchase, however, based on customer experiences, some pork quality shortcomings have been detected. Moeller et al., (2010) reported unfavorable consumer perceptions regarding fresh pork eating quality including flavor and tenderness. Purebred Duroc pigs sired by "current time" and "old time (mid 1980s)" period boar genetics were evaluated for pork quality; trained sensory panel reported less pork flavor and more off-flavor in pigs sired by the "current time" boar genetics (Schwab et al., 2006). Similar findings regarding favorable impression of the "old time flavor" and bland taste in commercially produced pigs were reported in Ngapo & Gariépy, (2008). Schwab et al. (2006) suggested that selection for carcass composition over time had come at the expense of palatability traits. Thus, studies exploring various breeds and nutritional management strategies could be helpful in resolving the challenge faced by commercial swine production.

Some consumers have started to broaden their searches for the "nostalgic taste" once offered by the swine industry. Heritage breed pork started to form a niche market to offer these consumers an alternative to commercially produced pork. One of the criteria of heritage breed is that the breed has a long history in the United States (The Livestock Conservancy, n.d.). Large Black pigs, as one of the pasture-raised minor swine breeds in the United States, has not been through intense genetic selection for increased carcass lean. Though there has yet to be any published studies evaluating Large Black pork quality attributes, the breed has often been marketed for their superior meat quality. The breed has maintained the "old time" characteristics when fatty pigs were desirable due to lard demand. Large Black pigs have historically been raised under outdoor management systems. Due to their grazing nature, the Large Black pigs consume a diet that contains greater amount of fibrous material and lower energy, unlike commercial swine feed. Although the Large Black pigs appear to be well fitted for the niche market, relatively limited data are available regarding the breeds' carcass and processing characteristics.

Whitley et al., (2012) examined pork quality and sensory characteristics in Large Black x Yorkshire (LBY) crosses in comparison to other Yorkshire crosses; thicker backfat and smaller loin muscle area were observed in LBY pigs. Aside from findings by Whitley et al., (2012), there has been very limited number of studies evaluating purebred Large Black pork qualities. Furthermore, the commercial Yorkshire breed has not focused on pork quality in selection criteria similar to the Duroc breed. Due to diet, genetics, and methods of husbandry variabilities, a meaningful comparison must include both breed and diet variables. To this aim, both breeds of pigs should be managed under the same husbandry system, and both types of diets should be represented in both the Duroc sired and Large Black pigs. This study was designed to fill the gap in knowledge by comparing Duroc and Large Black genetic lines fed high forage or commercial diets to determine differences regarding pork processing characteristics. Therefore, the objective of this study was to examine differences in processing characteristics between Duroc sired and Large Black genetics lines with high forage and commercial diets.

2.3 Materials and Methods

2.3.1 Animals and Harvest

Fifty pigs were utilized in the study with a 2 x 2 factorial design of breed and diet. Duroc sired (DS, n=25 pigs) and Large Black sired (LB, n=25 pigs). All the pigs were weighed and allocated to two dietary treatments: Fiber (FIB) or Control (CON), (LB FIB, n=14; LB CON, n=11; DS FIB, n=14; DS CON, n=11). Dietary treatments were fed throughout the grow-finish period (101 or 140 d) in six phases. The CON diet was concentrate based, and included corn, soybean meal and distiller's dried grains with solubles (DDGS). The FIB diet contained wheat middlings (1-10%) and dehydrated alfalfa mean (7.5-20%) in replacement of corn and soybean meal to mimic a more natural diet of the LB considering their pasture raised and foraging nature. Dietary treatments were fed throughout the grow-finish period (101 to 140 d) in six phases. Pigs were slaughtered at a common age with variations in BW among genetics (DS 125 ± 2.23 kg, LB 99 ± 2.28 kg) at Purdue University after the completion of diet phase 6.

Electrical stunning was applied to each pig before exsanguination during slaughter. Dehairing was achieved using a scalder therefore no skin or backfat was removed during the process. Hot carcass weight was recorded (Rice Lake Weighing Systems, Rice Lake, WI), and carcasses were chilled for 24 h in blast cooler (4 ^{o}C) prior to further processing. At one day postmortem, the right side of each carcass was fabricated into wholesale cuts with the picnic shoulders, Boston butts and bellies (IMPS 408) utilized for this study.

2.3.2 Boneless Belly

All bones and cartilages were removed from the pork bellies according to the guidelines stated in Institutional Meat Purchase Specifications for item No. 408 – Pork Belly (IMPS 408), and fresh belly weigh was recorded. For belly thickness and length, each belly was laid skin side down. The length of the belly was measured from the anterior (blade) end to posterior (flank) end (Figure 2.1). Belly thickness was measured using data collected from 4 locations at points 25% and 75% the distance from the blade end (Figure 2.2). A sharp knife was used to make small perpendicular cuts on the belly to mark the locations and a ruler was used to measure the thickness at each location. The final thickness of the belly was calculated by averaging measurements collected at all 4 locations. Belly firmness was measured similar to methods outlined by Rentfrow et al., (2003) by suspending the belly (skin side down) horizontally over a PVC pipe (diameter = 8.89 cm). The PVC pipe was attached to a board with an X-axis and Y-axis (Figure 2.3). The coordinates were used to measure the distance between Point A (Blade end) and Point B (Flank end) of the belly. Smaller distance between Point A and Point B suggested decreased firmness and greater distance between the points indicated that it was a firmer belly.

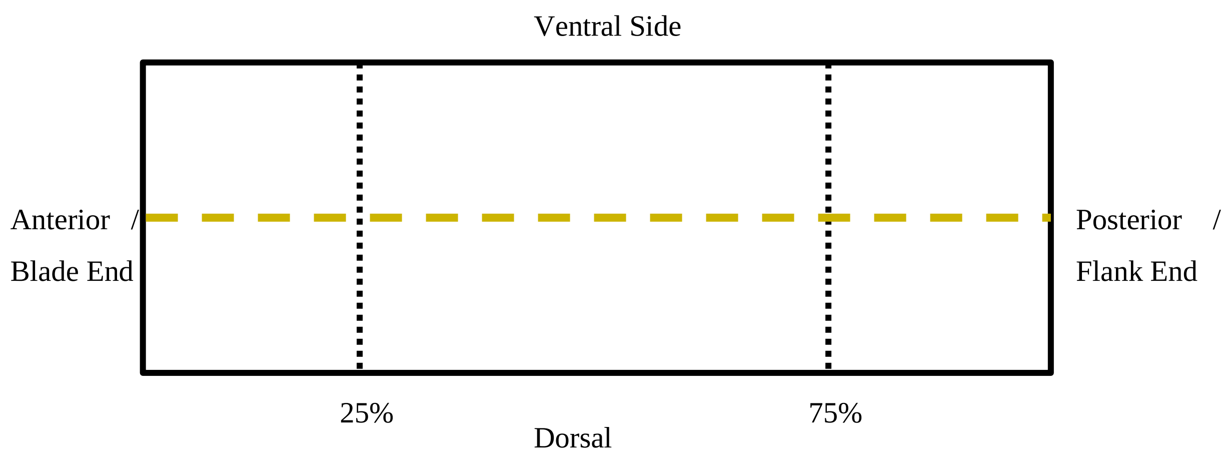

Figure 2.1 Belly length measured from anterior (blade) end posterior (flank) end along the belly midline.

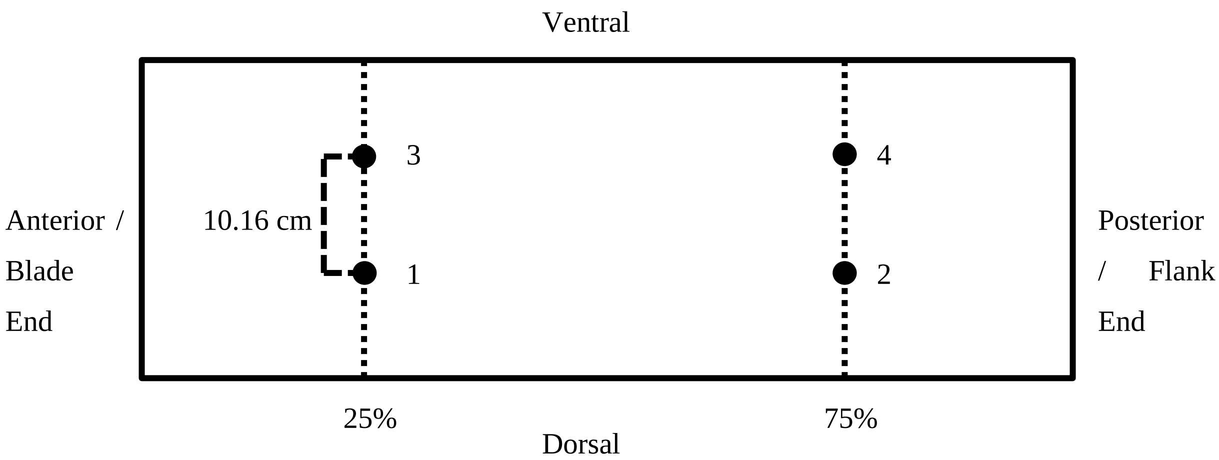

Figure 2.2 Belly thickness measured at four locations at points 25 and 75% the length from the anterior (blade) end, spaced 10.16 cm apart.

Figure 2.3 Belly firmness measured placing the boneless belly skin side down on a PVC pipe (diameter = 8.89 cm), with an X- and Y-axis grid. The distance between grid lines is 2.54 cm.

2.3.3 Sausage

An individual batch of sausage was made for each carcass using trim from the picnic shoulder and Boston butt. Lean and fat trim were collected to generate an 80:20 lean-to-fat ratio. Each batch weighed 1.14 kg and contained 0.23 kg of fat and 0.91 kg of lean trim. Each batch was ground twice using a tabletop grinder with a #22 2.4 mm plate. A Kitchen Aid mixer was then used to mix the ground pork and the seasoning (0.023 kg of Pork Sausage Seasoning Blend 10 from A.C. Legg, INC, AL) for a standardized time of mixing. Five 0.14 kg sausage patties from each batch were made using patty molds and were randomly assigned to 0 d (1 patty), 3 d (2 patties), or 7 d (2 patties). Each observation day's patties were packaged on a foam tray, PVC overwrapped, and placed under retail display lighting to evaluate color changes and lipid oxidation over time.

2.3.4 Color

Color measurements of the patties were taken using a Minolta CR-400 Chroma Meter (Konica Minolta, Tokyo, Japan). Minolta CR-400 (8mm aperture, 2^o observer) was calibrated with PVC wrap on the eye and the measurements were taken using illuminant D_{65} through the PVC packaging. On each measurement day, the surface of each patty within a package was measured 3 times. After color measurements were taken on their respective days, all patties were vacuum packaged individually and placed in a -40^oC freezer for lipid oxidation analysis.

2.3.5 Fat Smear

A fat smear scale (Figure 2.4) was made to assess the fat smearing condition of each sausage patty. The scale ranges from 1 (excessive fat smearing) to 8 (very little fat smearing). The score of 8 showed fat particles that held their shape and the edges of the particles were easily identified. A score of 1 suggests that the fat particles were smeared and mixed with the lean part of the patty, and the edges of the fat particles were unclear to identify. Both patties for each displayed day were scored, and an average was taken to calculate the final fat smear score for each batch.

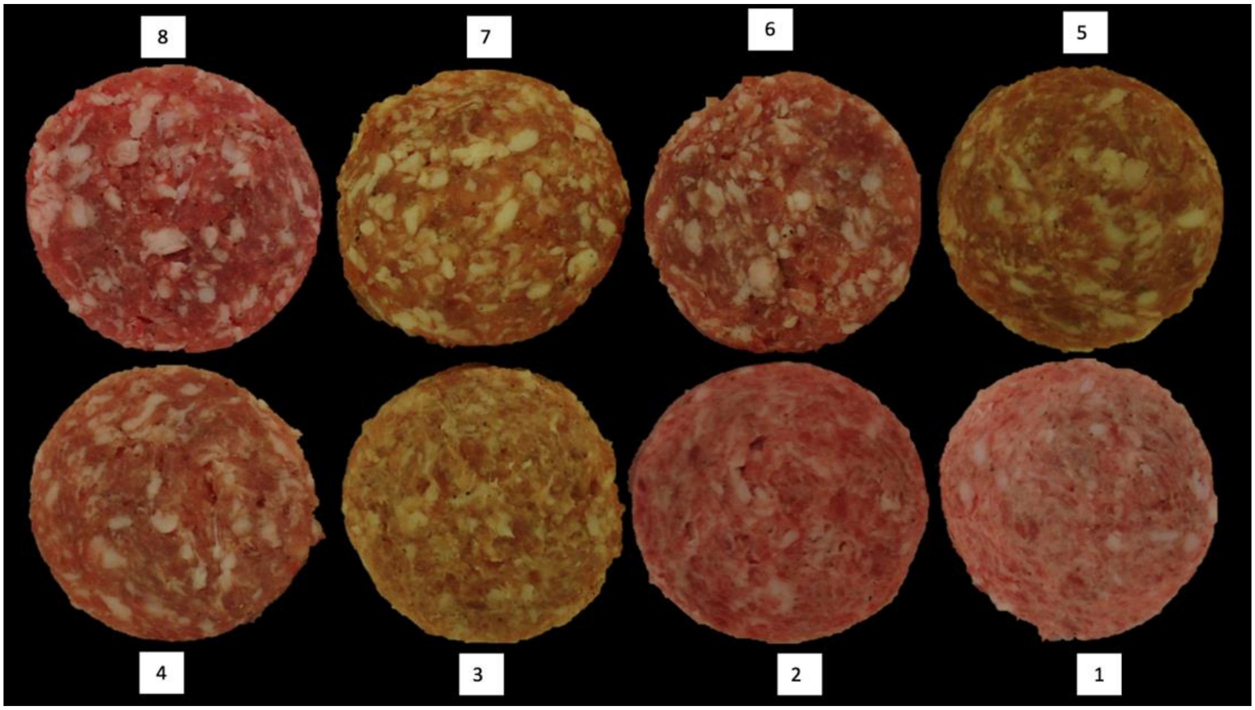

Figure 2.4 Sausage fat smearing score used to score each sausage patty with 1 displaying excessive fat smearing, and 8 displaying very little fat smearing.

2.3.6 Lipid Oxidation

Lipid oxidation for the sausage patties was examined with the 2-Thiobarbituric acid reactive substances assay (TBARS). The TBARS protocol was modified from Buege and Aust, (1978) Methods in Enzymol. 52:302. One patty from each displayed day was taken to perform TBARS, with two samples from each patty used during the TBARS analysis. All solutions (Butylated hydroxyanisole (BHA) and Trichloroacetic acid (TCA)) were made prior to the start of TBARS to ensure consistency throughout the analysis. 531nm was used to read the absorbance of the supernatant using a 96-well plate. Data was exported into Excel and pooled for analysis after all samples were examined.

2.3.7 Bacon

Fresh bellies were weighed to obtain fresh weight. Bacon Brine Additive with Salt from A.C. Legg. INC. (Blend JM-95-145-000, Blended of Salt, Sodium Phosphates (10.47%), Sodium Erythorbate) mixed with water was used to make the brine solution. Brine was injected with a manual compressed air stitch pump until the belly reached 110% of its fresh weight. Pump uptake

(%) was calculated with the equation: (pumped weight – fresh weight) / fresh weight x 100. The pumped bellies were rested for 3.5 hours before placing into the smokehouse. Bellies were thermally processed for 4 hours until the internal temperature reached 62°C. Thermally processed bellies were cooled to 1°C internal temperature and weighed to obtain cooked weight. Belly processing yield (%) was calculated with the equation: (cooked weight / fresh weight) x 100. Bellies were then cut at 25%, 50%, and 75% of the distance from the blade end, and a 0.64 cm thick slice was taken from each cut surface for visual image analysis.

2.3.8 Visual Image Analysis

Each 0.64 cm bacon slice removed at 25%, 50%, and 75% distance from the blade end of the thermally processed bellies was labeled and photographed with a standardized ruler for scale reference. Each bacon slice was photographed at the same distance from the camera. Images of each slice were analyzed for slice length (SL; cm), slice area (SA; cm^2), and slice lean area (LA; %) with Adobe Photoshop (22.2.0 Release). The ruler tool was used to measure the number of pixels in 1 cm per image as well as the slice length in pixels. The magnetic lasso tool was used to trace the outline of each slice and the area selected was automatically provided by the software for SA. The same technique was used to measure lean muscle area and lean % was calculated with the equation: (lean area / slice area) x 100. All measurements were recorded in pixels then converted to cm (SL) or cm^2 (SA). All bacon measurements, data obtained from 25%, 50% and 75% of the thermally processed belly, were averaged together to calculate SL, SA and LA for each carcass.

2.3.9 Statistical Analysis

The data were analyzed as a 2 x 2 factorial design with breed and diet as fixed effects. All the data was analyzed with RStudio (1.2.1335) with least square means determined significant $P < 0.05$. Functions used in the analysis included linear model and ANOVA. Tukey's test was performed if any interactions such as breed x diet or measurements x days were found to be significant.

2.4 Results

2.4.1 Physical Belly Characteristics

The main effects of breed and animal diet for belly length, average thickness, firmness, brine pump uptake and belly processing yield are reported in Table 2.1 and Table 2.2. Both breed ($P < 0.001$) and diet ($P = 0.0045$) were significant for fresh belly weight and no breed x diet interaction ($P = 0.5571$) was found. Fresh bellies from DS pigs were 0.86 kg heavier than bellies from LB pigs. Pigs fed CON diet had heavier bellies than pigs fed FIB diet by 0.76 kg. Data showed significance in breed ($P < 0.0001$) and diet ($P = 0.0005$) for belly length, but no breed x diet interaction ($P = 0.724$) was observed. LB bellies were 4.7cm shorter than DS bellies, and CON bellies 3.3 cm longer than FIB bellies. Breed ($P = 0.0263$) and diet ($P = 0.0002$) were found to be significant for average belly thickness, and no breed x diet interaction ($P = 0.5230$) was discovered. Bellies from DS pigs were 0.36 cm thinner than the LB bellies, and CON bellies were thicker than FIB bellies by 0.66 cm. Belly firmness was measured by the distance between the blade and flank end of each belly when suspended over a PVC pipe. Although both breed ($P < 0.0001$) and diet ($P < 0.0001$) were shown to be significant for belly firmness, but a breed x diet interaction ($P = 0.0527$) was observed. LB CON pigs had the firmest bellies DS FIB had the softest bellies (Figure 2.6). While intermediate, LB FIB had firmer bellies than DS CON. No breed ($P = 0.1392$) or breed x diet interaction were ($P = 0.19723$) observed for belly pump uptake. However, a diet effect ($P = 0.0534$) was observed in brine pump uptake. FIB had a slightly greater pump uptake than CON bellies by 0.41%. Breed ($P = 0.0014$) was found to be significant for belly processing yield while no diet ($P = 0.43856$) effect and breed x diet interaction ($P = 0.27309$) were observed. DS sired pigs had 0.95% more belly processing yield than Large Black pigs.

2.4.2 Bacon Quality and Characteristics

Bacon quality results were reported in Table 2.3 and Table 2.4. Breed did not have any significant effect on bacon total slice area and total slice length. However, DS pigs had 20.32% more lean area ($P < 0.0001$) than bacon slices obtained from LB pigs. Contrary to breed, diet had a significant effect on bacon total slice area ($P = 0.0484$). Bacon slices from CON bellies had a greater total slice area than FIB bellies. Diet did not have any effects on total slice length ($P = 0.6448$) nor lean area ($P = 0.2028$).

2.4.3 Sausage Patties Fat Smear Score, Color and Lipid Oxidation

Sausage patties made from the picnic shoulder from each pig were examined for fat smearing. No breed effect ($P = 0.3979$) or breed x diet interaction ($P = 0.3024$) were observed on fat smearing; however, diet ($P = 0.0104$) was significant. Patties made from CON pigs had the greater fat smearing scores compared to FIB pigs, which indicated that CON patties had the best particle definition and least amount of fat smearing (Figure 2.5).

Time under retail display lights negatively impacted color and lipid oxidation of the sausage patties (Figure 2.7). Days were found to be significant for L* ($P = 0.0051$), a* ($P < 0.0001$), and b* ($P < 0.0001$) which was expected given meat product color typically changes over time. TBARS value increased during retail display period indicated that more lipid oxidation occurred as time went on which was expected as well. No breed x diet x days interactions were found in L*, a*, b* or TBARS measurements. Breed was significant for L* ($P < 0.0001$) and a* ($P < 0.0001$) but did not impact b* over the entire display period. DS patties had a greater L* value but lesser a* value when compared to LB pigs (Figure 2.10 and Figure 2.11) therefore patties LB pigs were darker and redder than DS pigs. There was no diet effect or breed x diet interaction found for any of the three color measurements. Regardless of time, a breed x diet interaction ($P = 0.0014$) was observed for patty lipid oxidation (Figure 2.8). DS CON patties had the least amount of lipid oxidation regardless of retail display time whereas LB CON patties had the most lipid oxidation.

2.5 Discussion

The objective of this study was to determine differences in pork processing characteristics between commercial Duroc-sired genetics and Large Black genetic lines fed diets similar to the commercial management of their respective breeds. There were relatively few studies examining the processing traits of Large Black pigs. Results from multiple studies suggested that the Duroc genetic resulted in superior carcass qualities compared to other breeds such as increased intramuscular fat and loineye area, decreased subcutaneous fat (Lo et al., 1992; McGloughlin et al., 1988). In the present study, the DS pigs were used to represent pigs from modern-day swine production since the Duroc genetics were commonly used in commercial settings due to their ability to produce high-quality offspring. Contrary to the commercial production pigs, the LB pigs represented products from the growing heritage breed niche market where the breed had undergone very minimal genetic selection for percent lean. Two types of diets respective to breeds (CON for DS, FIB for LB) were used in the study since DS and LB pigs are typically produced under different management systems. The CON diet which contained corn, soybean meal was composed to represent the common feed utilized in commercial swine settings. The FIB diet was high in alfalfa to mimic the natural foraging diet of LB pigs since the breed tends to be pasture-raised.

The differences in fresh belly characteristics found between breeds could be attributed to LB pigs' smaller sizes compared to DS pigs at the time of slaughter. This could be indicative of lower production efficiency of LB pigs compared to DS pigs. Due to DS pigs' larger sizes and higher percent lean from genetic selection over time, it was expected that the DS pigs would have heavier and longer bellies than LB pigs. Regardless of breed, pigs fed CON diet had heavier and longer bellies than pigs fed FIB diet, this is probably due to higher energy concentration in the corn and soybean meal based diet. LB pigs had visibly greater amount of backfat which was consistent with previous findings by Whitley et al., (2012). The greater amount of subcutaneous fat contributed to increased belly thickness as well as belly firmness in LB pigs. The breed x diet interaction observed in belly firmness suggested that LB CON had the firmest belly whereas DS FIB had the softest belly among all treatments. It was interesting to note that feeding the naturally opposite diet (LB fed CON and DS fed FIB) resulted in the firmest belly (LB CON) and the softest belly (DS FIB). This could be due to differences in metabolisms between the breeds and how their bodies interacted with the diets. Future fatty acid analysis could be helpful to examine the adipose composition and determine if the diets had an impact on fat saturation. Although all the bellies had a 10% target brine uptake, FIB bellies had better brine absorption based on the tendency observed in diet effect on pump uptake. Previous literature has shown that bacon slices with larger lean area had greater processing yield (Scramlin et al., 2008), this could be attributed to that larger lean area means there would be more protein present to absorb brine. This was replicated in the current study where bacon slices from DS pigs showed 20.3% more lean area and 0.95% more processing yield than LB pigs.

The impact of diet on sausage patty fat smearing could be attributed to fat saturation, as FIB patties had the most fat smearing. Saturated fatty acids have a higher melting point, which tends to lead to firmer fats with improved ability to maintain structural integrity. Increased fat smearing could be indicative of increased unsaturated fatty acid in pigs fed FIB diet. Although breed was not significant for patty fat smearing, but differences in fatty acid composition due to genetics is still anticipated. The lack of significance in breed effect on fat smearing result could be due to diet having greater influence on fat composition than genetic.

Lipid oxidation negatively impacts food quality (Fan et al., 2019) since it can cause rancidity which is detrimental for product flavor. The patties of the study were packaged with PVC wrapping which was an aerobic packaging method and placed under retail lighting. With light and oxygen being pro-oxidants, it was expected to observe increased lipid oxidation with increased retail display time. Regardless of time, a breed x diet interaction was observed in TBARS value. DS CON patties had the least amount of lipid oxidation which was the most desirable. However, LB CON patties resulted in the most lipid oxidation. The result was not surprising since the Duroc genetic line has been genetically selected to suit modern commercial swine production and adapted to the high energy diet. On the other hand, it was likely that LB pigs were not able to effectively metabolize the corn, soybean meal based diet since historically the breed has always been raised outdoors with a high fiber diet due to its grazing nature. This could suggest that it was best to feed each genetic line their respective diet: DS CON and LB FIB.

The impact of retail display time on color measurements (L*, a* and b*) was expected since color deteriorates over time. The present study found that LB patties were darker and redder than DS patties even though they were raised in the same confined environment during the project. It's speculated that there could be variations in muscle fiber types due to genetics among the breeds which resulted in the color differences. Muscle fiber typing could potentially be performed for future studies to further examine the physiological differences between DS and LB genetic lines.

2.6 Conclusion

The study provided various novel insights into the processing characteristics of LB and DS pigs fed CON and FIB diets. In terms of breed, the DS pigs had greater belly processing yield, and contained much higher percent lean compared to the LB pigs. Although firmer bellies could be ideal during slicing, however, the excessive amount of backfat on the LB bellies may have outweighed the benefit of increased firmness. Overall, both breeds performed best when fed diets similar to their commercial management practices (i.e. high energy for DS and high fiber for LB). The LB genetics sustained the historic imprint of a time when society favored fat pigs for lard production. Even though the niche market of heritage breed pork continues to grow due to consumers seeking diversity and preferring a historic flavor in commercial pork, there still are limitations for market incorporation for the LB breed. For the future, trained sensory panels as well as consumer panels should be conducted to examine any differences in palatability for the breeds and diets of various fresh and processed products. Further studies examining the fatty acid composition of the various fat depots may be insightful in examine differences in animal metabolism. Finally, methods to improve percent lean, processing yields while preserving potential desirable flavor traits in the LB pigs would be beneficial to improve product quality and probable commercial integration.

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Table 2.1 Mean value of physical belly characteristics by breed

	Breed*		
	DS	LB	P-Value
Fresh belly wt (kg)	6.64[a]	5.78[b]	<0.0003
Length (cm)	64.07[a]	59.34[b]	<0.0001
Belly thickness (cm)	3.72[a]	4.08[b]	0.0263
Belly firmness (cm)	22.08[a]	40.49[b]	<0.0001
Pump uptake (%)[c]	10.10	9.80	0.1392
Belly yield (%)[d]	90.62[a]	89.67[b]	0.0014

*DS = Duroc sired and LB = Large Black pigs
[ab]Means within row with different superscripts differ (*P*<0.05)
[c]Pump uptake: (pumped belly weight - fresh belly weight)/fresh belly weight x 100
[d]Belly yield: (cooked belly weight / fresh belly weight) x 100

Table 2.2 Mean value of physical belly characteristics by animal diet.

	Diet*		
	CON	FIB	P-Value
Fresh belly wt (kg)	6.64[a]	5.88[b]	0.0011
Length (cm)	63.54[a]	60.26[b]	0.0045
Belly thickness (cm)	4.27[a]	3.61[b]	0.0002
Belly firmness (cm)	36.48[a]	27.20[b]	<0.0001
Pump uptake (%)[c]	9.72	10.13	0.0534
Belly yield (%)[d]	90.27	90.05	0.4386

*CON = diet of corn-soybean meal-DDGS based and FIB = diet used increasing amounts of wheat middlings (1-10%) and dehydrated alfalfa meal (7.5-20%) replacing corn and soybean meal in the CON diet
[ab]Means within row with different superscripts differ (*P*<0.05)
[c]Pump uptake: (pumped weight-fresh weight)/fresh weight x 100
[d]Belly yield: (cooked weight/fresh weight) x 100

Table 2.3 Mean value of bacon slice characteristics by breed

	Breed*		
	DS	LB	P-Value
Total slice area (cm^2)	98.36	96.54	0.6755
Total slice length (cm)	24.37	23.12	0.0653
Lean area (%)	39.67[a]	19.35[b]	<0.0001

*DS = Duroc sired and LB = Large Black pigs
[ab]Means within row with different superscripts differ ($P<0.05$)

Table 2.4 Mean value of bacon characteristics by animal diet

	Diet*		
	CON	FIB	P-Value
Total slice area (cm^2)	102.39[a]	93.56[b]	0.0484
Total slice length (cm)	23.58	23.89	0.6448
Lean area (%)	28.63	30.20	0.2028

*CON = diet of corn-soybean meal-DDGS based and FIB = diet used increasing amounts of wheat middlings (1-10%) and dehydrated alfalfa meal (7.5-20%) replacing corn and soybean meal in the CON diet
[ab]Means within row with different superscripts differ ($P<0.05$)

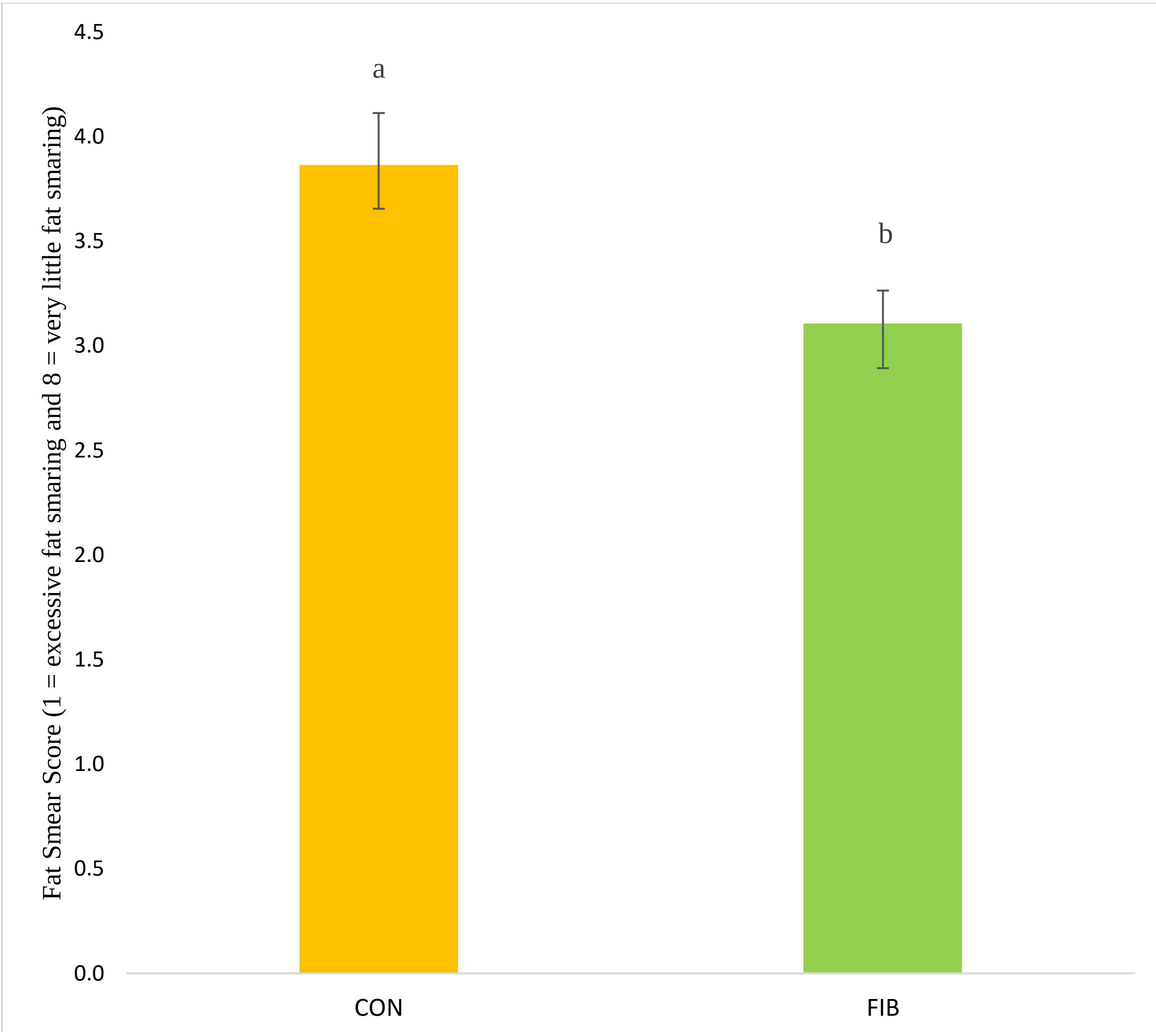

Figure 2.5 Effect of animal diet on sausage patty average fat smear score*

*CON = diet of corn-soybean meal-DDGS based and FIB = diet used increasing amounts of wheat middlings (1-10%) and dehydrated alfalfa meal (7.5-20%) replacing corn and soybean meal in the CON diet

[ab]Means with different superscripts differ (P<0.05)

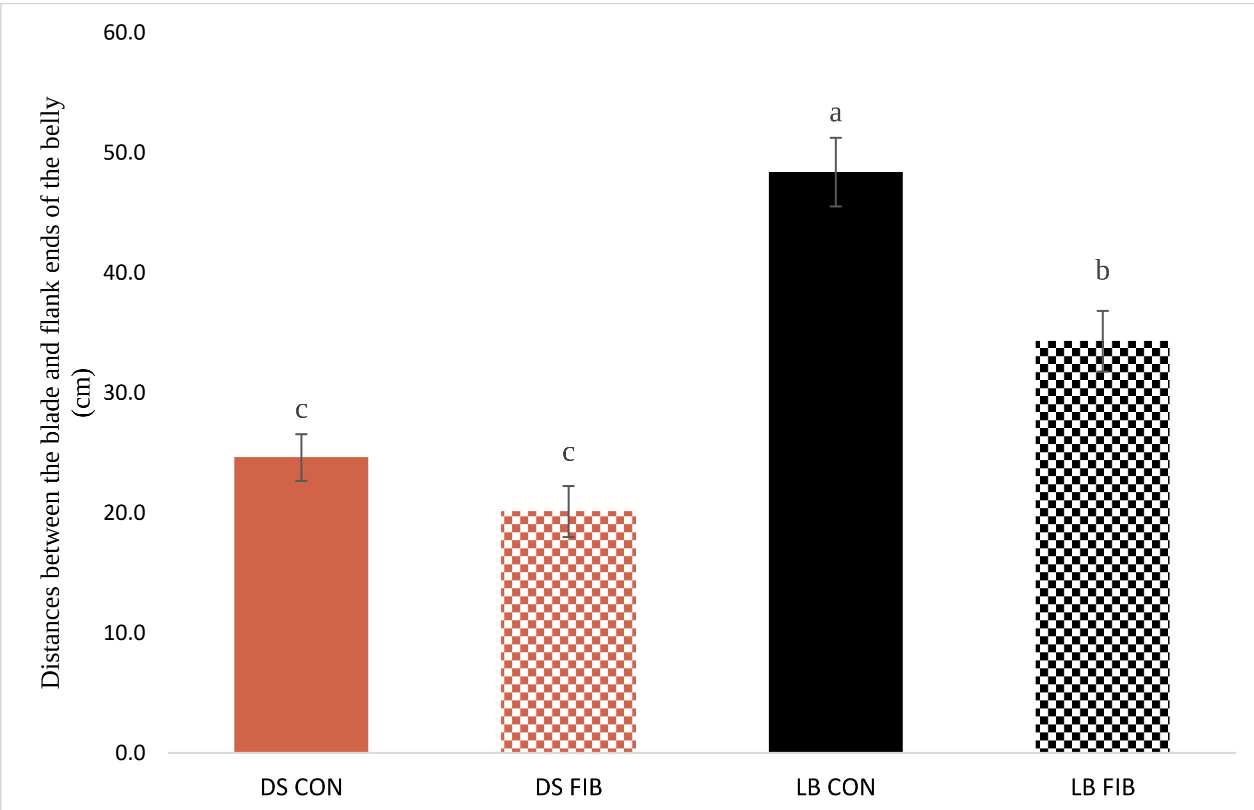

Figure 2.6 Effect of breed x diet interaction on belly firmness by the distance between the blade and flank ends of the belly of a belly placed skin-side down on a stationary PVC pipe (diameter = 8.89 cm)*

*CON = diet of corn-soybean meal-DDGS based and FIB = diet used increasing amounts of wheat middlings (1-10%) and dehydrated alfalfa meal (7.5-20%) replacing corn and soybean meal in the CON diet. DS = Duroc sired and LB = Large Black pigs
[ab]Means with different superscripts differ (*P*<0.05)

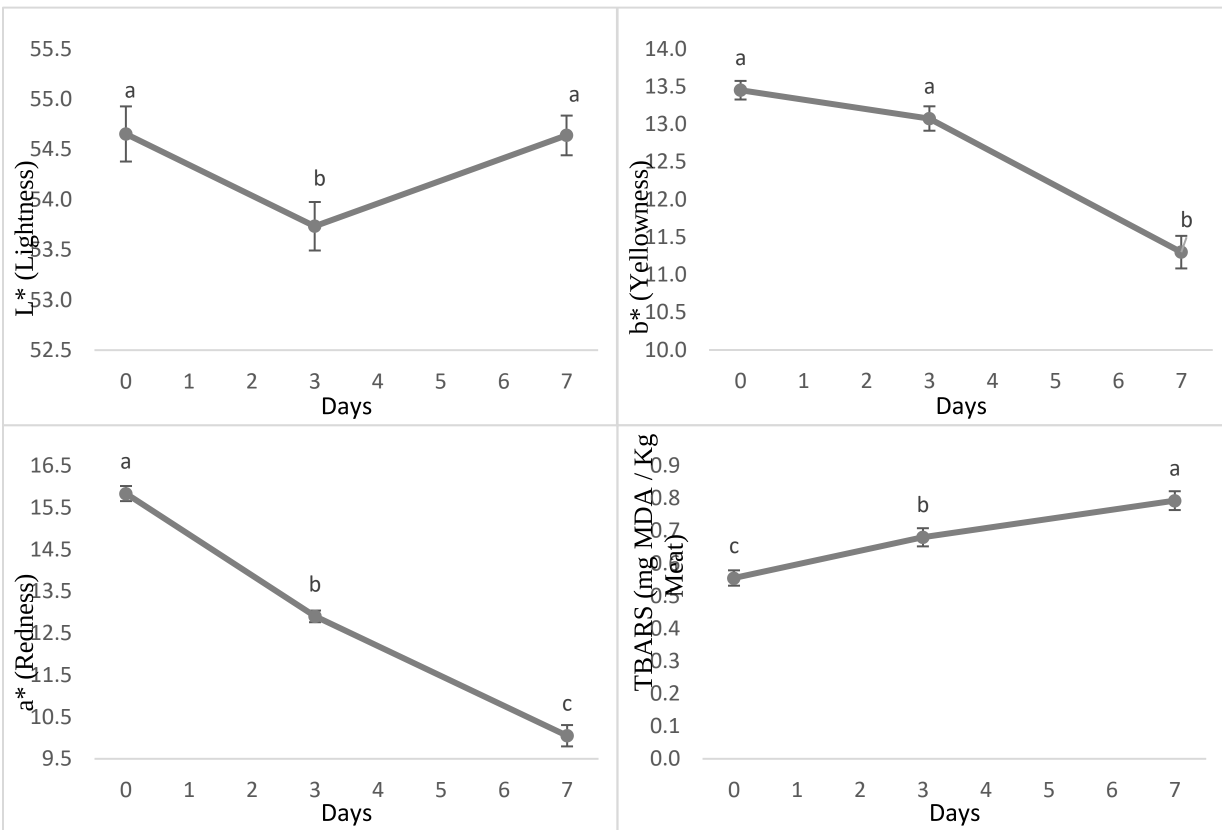

Figure 2.7 Retail display effect on sausage patty lightness (L*), redness (a*), yellowness (b*) and lipid oxidation (TBARS value) over time (d)

[ab]Means with different superscripts differ (*P*<0.05)

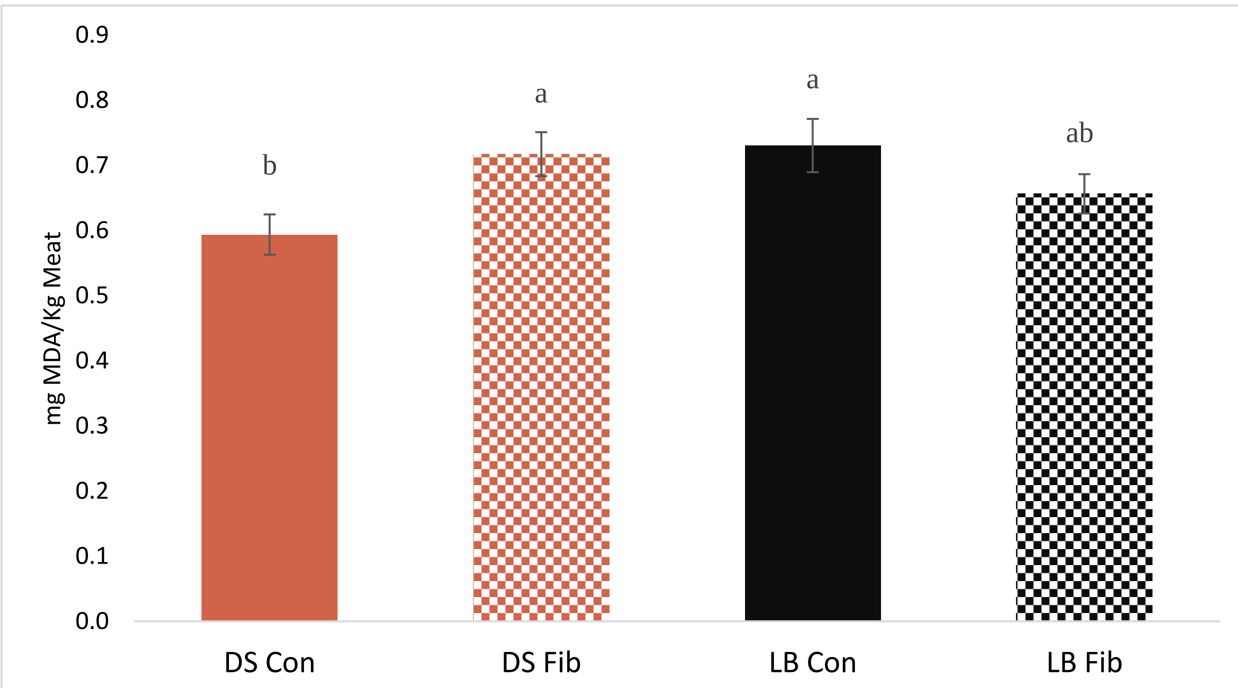

Figure 2.8 Effect of breed x diet interaction on sausage patty lipid oxidation.

*CON = diet of corn-soybean meal-DDGS based and FIB = diet used increasing amounts of wheat middlings (1-10%) and dehydrated alfalfa meal (7.5-20%) replacing corn and soybean meal in the CON diet. DS = Duroc sired and LB = Large Black pigs

[ab]Means with different superscripts differ (*P*<0.05)

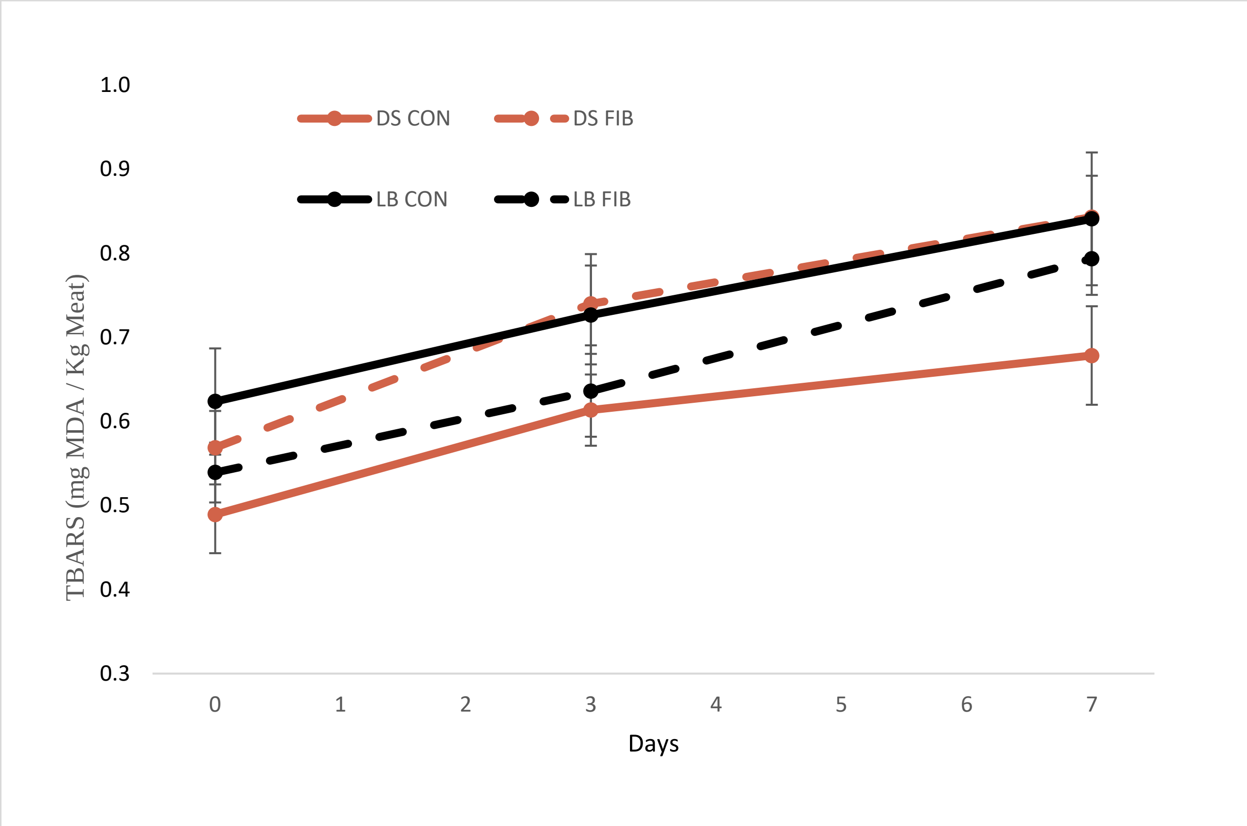

Figure 2.9 Lipid oxidation (TBARS value) of sausage patties under retail display settings over time for DS CON, DS FIB, LB CON and LB FIB*

*CON = diet of corn-soybean meal-DDGS based and FIB = diet used increasing amounts of wheat middlings (1-10%) and dehydrated alfalfa meal (7.5-20%) replacing corn and soybean meal in the CON diet. DS = Duroc sired and LB = Large Black pigs

[ab]Means with different superscripts differ (P<0.05)

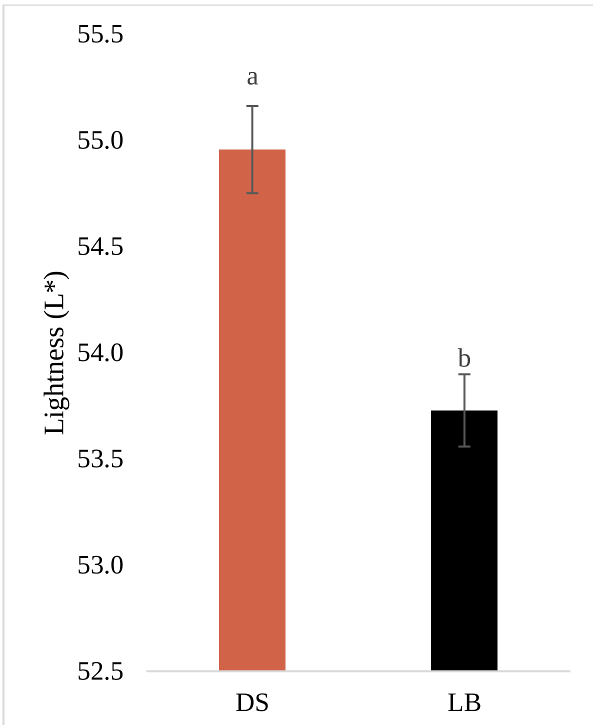

Figure 2.10 Effect of breed on sausage patty lightness (L*)[1]

[1]DS = Duroc sired and LB = Large Black pigs

[ab]Means with different superscripts differ (*P*<0.05)

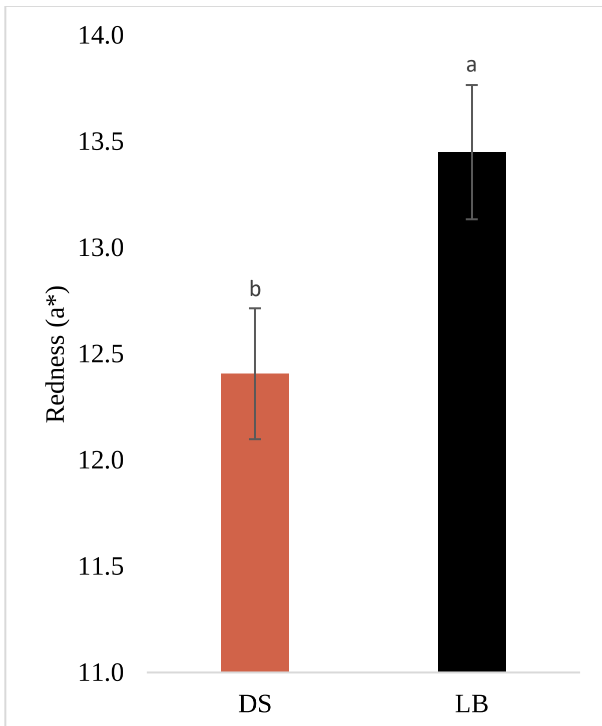

Figure 2.11 Effect of breed on sausage patty redness (a*)[1]

[1]DS = Duroc sired and LB = Large Black pigs
[ab]Means with different superscripts differ (*P*<0.05)

APPENDIX A. TBARS ASSAY PROTOCOL

PROTOCOL:

TBARS (Lipid oxidation)

Date: **May 26, 2011 (updated October 30th 2014)**
From: Brad Kim

Reference:
Modified from JA Buege and SD Aust, 1978
Methods in Enzymol. 52:302

Reagents and materials:

1. Chemicals

(1) 2-thiobarbituric acid (TBA)
  1) Purity: >=98%, MW: 144.15
  2) Cat. No. Sigmaaldrich, T5500-100g

(2) Trichloroacetic acid (TCA)
  1) Cat No. Fisher, A322-500

(3) Butylated hydroxytoluene (BHT)
  1) Purity: 99%, MW: 220.35
  2) Cat No. Sigma, B1378-100g

(4) Butylated hydroxyanisole (BHA)
  1) Purity: 98.5%, MW: 180.24
  2) Cat No. Fisher, AC43969-1000

➔Either BHT or BHA can be used.****But different volume – be cautious!!

(5) 1,1,3,3-tetra-ethoxypropane (TEP)
  1) MW: 220.31, 97% purity, d=0.918 g/mL

2. Reagents

(1) 20mM TBA/15% TCA solution (500mL)
  1) Weigh 1.47g of TBA in a 500 mL beaker.
  2) Add around 300mL DW to the beaker.
  3) Dissolve TBA on the hot plate (do not boil).
    a. TBA is not dissolved in cold water.
  4) When TBA is dissolved completely, cool it down.
  5) Add 75g of TCA into the TBA solution.
  6) Mix it well.
  7) Transfer the solution into a 500mL mass flask and make it to 500mL with DDW.

(2) 6% BHT solution in 100% ethanol
  1) Weigh 6.1g BHT into a 100mL mass flask.
  2) Add 80mL 100% ethanol and mix well.
  3) Make it to 100 mL with 100% ethanol

(3) 10% BHA solution in 90% ethanol
1) Weigh 10.2g BHA into a 100mL mass flask.
2) Add 80mL 90% ethanol and mix well.
3) Make it to 100 mL with 90% ethanol

Procedures:

1. **5g (± 0.03) sample + 15mL DW and 100uL BHT (or 50uL BHA)** :homogenize for 10-15 sec using a Ultraturrex at speed 7-8 (green/red)
2. Take 1 mL of the homogenates into 16x100mm test tubes, combine with 2 mL of TCA/TBA reagent, mix thoroughly (vortex)
3. Heat the solution for 15 minutes in a boiling water bath (80°C).
4. Cool for 10 minutes in cold/ice water
5. Vortex thoroughly
6. Centrifuge at 2000xg for 10 minutes at 25°C.
7. Filter supernatant through Whatman filter paper #4
8. Read absorbance of the supernatant at 531nm using a 96-well plate or a UV-SPEC
9. Read absorbance of the supernatant at 531nm against a blank that contains all the reagents minus the sample. (Zero with Blank= 2mL DW & 4mL TBA/TCA)

10. Calculate the amount TBARS expressed as mg malondialdehyde per kg meat
    i. Using equation from TEP standards
       TBARS (mg MDA/kg meat) =5.3102*Abs + 0.0356
    ii. Using molecular extinction coefficient
       1.56 x 105 M-1cm-1
       TBARS (mg MDA/kg meat) = Abs * 12 * 72 / 156 mg MDA/kg meat
       = **Abs * 5.54**