12-2020

Characterization of Growth Patterns and Meat Quality Characteristics of Four Commercial Broiler Strains in Small Bird and Large Bird Programs in The United States

Clay Johnny Maynard
University of Arkansas, Fayetteville

Characterization of Growth Patterns and Meat Quality Characteristics of Four Commercial Broiler Strains in Small Bird and Large Bird Programs in The United States

A thesis submitted in partial fulfilment
of the requirements for the degree of
Master of Science in Poultry Science

by

Clay Johnny Maynard
Oklahoma State University
Bachelor of Science in Food Science, 2018

December 2020
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

_____
Casey M. Owens, Ph.D.
Thesis Director

_____
Michael T. Kidd, Ph.D.
Committee Member

_____
Andy Mauromoustakos, Ph.D.
Committee Member

_____
Sara K. Orlowski, Ph.D.
Committee Member

ABSTRACT

Through current trends in animal protein consumption, the United States poultry industry has seen a drastic rise in production and popularity. Over the last few decades, poultry meat has surpassed both beef and pork production to become the most widely consumed animal protein. This rise may be accredited to an increased transition to more health-conscious consumers. As more consumers purchase poultry as a lean source of protein, the need for a superior quality product is of great interest to poultry integrators.

Relationships between commercial broiler lines have been well documented in previous years, but constant and intensive genetic selection in the poultry industry has morphed modern broiler lines to perform differently from those previously investigated. Therefore, the need to address the impact of genetic selection on broiler meat quality was of paramount importance.

Chapter 2 characterized the growth performance of males and females from four modern broiler lines fed either a low- or high-density diet. Broilers reared for two processing weights were utilized and variation between the two were assessed. High yielding (HY) broilers produced the highest carcass, breast, and tender yields, whereas standard yielding (SY) broilers produced higher body weights, as well as wing and leg yields. Males produced higher final body weights than females, however, females produced higher carcass, breast, and tender yields. High density diets produced larger carcasses, breast, and tender yields while reducing total fat.

Concurrent with Chapter 2, Chapter 3 evaluated these broiler strains for variation in meat quality characteristics. Birds were processed by weight to meet two distinct markets for big bird and small bird debone markets, respectively. High yielding strains produced an increased incidence of all myopathies in comparison to SY strains. Males produced longer and thicker fillets, had increased incidences of white striping, and higher cook loss. Females however,

showed an increase in woody breast and spaghetti meat incidence, higher ultimate pH, lighter fillets, and decreased peak counts. Males of the small bird debone market had decreased tenderness than those from the big bird market. However, females had higher degrees of tenderness in the small bird market. Variation in carcass dimensions were observed as males expressed a decrease in breast width as carcass width increased while female breast width increased as carcass size increased.

For both Chapters, strain and carcass size provided the main variation in samples. Thus, the assessment of specific markets provides opportunistic selection for integrators to assess for maximum return of investment when broilers are placed.

ACKNOWLEDGEMENTS

I would like to begin by saying thank you to all the people that have gotten me to this point. First, I would like to thank my mom and dad for their continued support, and for encouraging me to pursue my dreams. You both consistently showed love through the hard times, as well as the good times, and I will forever be grateful for claiming you both as my parents. Long late-night calls and numerous trips to just check on me helped me stay focused on the task at hand. Without you two, I would not be the man that I am today, so thank you for everything you have already done and continue to do, I love both of you. Secondly, I would like to thank my brother for supporting me and for always having my back. I have always looked up to you as a "perfect" role model and you have always had the ability to make me laugh. Your drive and determination have given me something to compete with and has pushed both of us to be better men. Although we may not get along at times, I know that we will always be close and drop anything at hand to help one another. I am lucky to be able to call you my brother.

Dr. Owens, thank you for taking a gamble on just another country boy and giving me an opportunity to better myself. The past two years have been nothing but beneficial to my success as a professional. Although we have both jumped countless hurdles to get to where we are today, I would not change a single thing. I look forward to the opportunity to continue my education with you and receiving priceless mentoring.

Next, I would like to thank all of my lab mates. Without each of you, I would have devoted countless hours to my project that each of you were willing to save for me. Numerous long nights and early mornings were easier with each of you. Barbara, I would like to thank you for showing me the lab ways and for giving me creative ideas on how to get away from writing all the time. Juan, thank you for showing me how to conduct experiments in the most detailed

manor possibly. You never lacked showing me how to complete a task no matter how many times I asked you to repeat yourself. Ping, you have been an exception lab mom, and I can never repay you for all the warm meals that got me through this process. You guys were truly a life saver.

For my fellow graduate colleagues and friends, you guys are just as influential to my success as I am. Joe, Sara, T-money, Antonio, Lucas, Will, Garrett, and Mike Jr. thank you for answering any questions that I ever asked and for never shying to help when asked. Adventures away from the office were always a highlight with every one of you and those memories will last a lifetime. I appreciate each of you and hope to have the opportunity to work with you one day. Lastly, thank you Cole for always helping and for never denying the opportunity to get hot putting out feed. You saved wear on my body and always found a way to crack a joke to get me to cheer up. I wish you all the best in your professional careers.

To all the plant workers, thank you. Rodney, I would like to say that your knowledge of processing and your constant support have helped me get to where I am today. Conversations about your old days at Campbell's Soup were always a highlight of our time spent together. Ashleigh, Kerrigan, Courtney, Renee, and Katie thank you for making sure the plant was clean, set-up for experiments, and were willing to aid in collecting my data whenever I asked, including all the long nights we spent together.

To all the feed mill boys, thank you for being family away from home. Howard, Justin, Denny, Max, Drew, and Ross thank you for listening to my problems and finding a way to help me through them. Y'all helped take stress off my plate and I appreciate that. Being able to take breaks from school is important and each of you helped me "get away". Howard, thank you for being a great role model, person of character, and always looking to aid in my success. Our time

together was unexpectedly cut short, and I hope you know that I greatly appreciate our friendship while I knew you. You will be missed by all of us, and I will always think of you when I see a feed mill and listen to real country music. I hope you rest easy buddy and I promise to help Cheryl whenever she asks.

To all the farm workers, thank you. David, you and your crew helped me more than I could have ever asked of you. Panicked calls were always answered and you never strayed from sending help even if I did not need it. Weigh days, feed changes, and processing's would not have been possible without each of you.

DEDICATION

I would like to dedicate this thesis to both of my parents, Kyle and Carolyn Maynard.

TABLE OF CONTENTS

INTRODUCTION

INTRODUCTION

In the past decade, poultry production and processing has seen a drastic rise. The National Chicken Council reported that the United States produced 37 billion pounds of ready-to-cook poultry in 2011 (National Chicken Council, 2011). In 2019, the poultry industry achieved an all-time high production of more than 42.1 billion pounds of fresh, ready-to-cook poultry (National Chicken Council, 2019). This 14% increase in production may be the direct result of more health-conscious consumers, as well as an increased demand for more affordable protein options (Valceschini, 2006). The farmer, has also created a niche market opportunity for poultry processors, such as organics, all-natural markets, and no antibiotic ever programs. Integrated companies have adjusted to these niche markets and have tailored products that satisfy consumer demands. For example, breast meat size, shape, and weight currently drive consumer purchasing decisions (Le Bihan-Duval et al., 1999). For this reason, industry geneticists focus on traits that not only increase breast meat yield, but also produce a lean, quality product (Harford et al., 2014).

In conjunction to producing an edible poultry product, Allen and colleagues (1998) suggest that appearance plays the largest role in consumer acceptability. A multitude of factors such as color, tenderness, pH, water holding capacity, and cook-loss can have a direct impact on appearance of poultry products and ultimately consumer acceptability (Barbut, 1997, 1998; Anthony, 1998). Integrators in turn must find ways to mediate each of these parameters to produce an acceptable final product. These factors however, are heavily influenced by bird age, sex, and strain (Lyon et al., 2004; Brewer et al., 2012b). Due to intense genetic selection at the pedigree level, bird strain may have the largest impact on the aforementioned quality factors (Musa et al., 2006; Harford et al., 2014). Although the reasons are yet to be determined, each

genetic strain is selected for specific traits and specific markets which could in turn explain differences in meat quality. Furthermore, meat quality characteristics will continue to be assessed and poultry products adapted as consumer demands change.

With an increase in production and breast meat yield, several breast muscle myopathies have emerged. Many researchers speculate that this increase in myopathies is a result of increased demand for white meat and further processed products. There are several myopathies that the industry faces, however, two conditions are at the forefront. Of primary concern is a condition known as woody or wooden breast (Sihvo et al., 2014), followed by the paired parallel condition commonly referred to as white striping (Kuttappan et al., 2012a). Myopathies are detrimental to the industry as they alter meat quality, with the presence of one potentially causing product to be downgraded or condemned (Kuttappan et al., 2017). Both conditions develop during the growing period, so it is important to understand live production factors that impact broilers in these modern times. Therefore, the following objectives were evaluated. First, to characterize meat quality attributes and product uniformity from four commercial broiler strains selected for varying markets. Second, to evaluate the effect of nutrient density of diets in four commercial broiler stains processed for either a small or large bird debone market.

CHAPTER I

LITERATURE REVIEW

MUSCLE STRUCTURE AND CONTRACTION

Although muscle appears to be simplistic in nature, the fundamental composition is complex. Muscles are an intricate network of components that assimilate to form a structurally sound mass. Muscles, surrounded by the connective tissue epimysium, are first broken down into smaller groups commonly known as muscle fascicles (Bechtel, 1986). Muscle fascicles are coated in a fibrous connective tissue known as the perimysium which allows for support (Lieber, 2002). These tightly bound structures are then broken down into smaller strands known as muscle fibers, or muscle cells, which are encased in yet another fibrous tissue known as the endomysium (Lieber, 2002). Muscle fibers are structural templates comprising of myofibrils interlocking to create the most basic unit of muscle structure, the sarcomere (Lieber, 2002).

The sarcomere is a meticulously developed structure that contains a vast amount of proteins. Predominately, the sarcomere contains two main overlapping thick and thin filaments. The thick filament is comprised of multiple proteins, but its main components include myosin and C-protein (Morimoto and Harrington, 1973). Myosin comprises approximately 50-55% of the total myofibrillar proteins with two main sections. These sections include a globular head that is utilized for binding, and a fibrous tail (Smith, 2010). Globular head binding occurs in conjunction with the thin filament along intermediate binding sights. Moos et al. (1975) suggest that C-protein could possibly be responsible for the underlying assembly of myosin heads and their relation to binding with the thin filament. In addition, the myosin tails are bound together in a web-like pattern to produce a very rigid structure limiting rotation of myosin heads (Lawrie, 1998).

The thin filament also contains a vast number of proteins. Oriented in a double-helix pattern, thin filaments consist of two actin monomers. The thin filament contributes

approximately 20-25% to the total myofibrillar protein complex (Smith, 2010), and contains two regulatory proteins: tropomyosin, and troponin (Marston and Redwood, 2003). Tropomyosin and troponin both act as regulatory proteins that aid muscle contraction. Actin is a double-helix protein, with a small gap between filaments allowing for the protein, tropomyosin, to coil between layers, covering myosin binding sites (Warriss, 2000). Being involved in complicated domains, troponin contains three different subunits that each have a specific role consisting of: troponin C, troponin I, and troponin T. Troponin C is a Ca^{2+} sensitive protein that binds to ions that are released from the synaptic cleft to initiate actomyosin binding. Troponin I is the inhibitory protein that blocks the formation of actomyosin bonds. Troponin T is the linking protein of actin and myosin to create strong actomyosin bonds (Ingraham and Swenson, 1984).

Animal movement is the combination of an action potential, delivered by the nervous system, and a physical change across the muscle gradient (Stephens and Taylor, 1972). Contraction and relaxation of muscle fibers is generally considered to complete in a four-phase cycle. According to Squire (1975), contraction first begins as an action potential is transmitted from the nerve ending. This action potential is sent from the brain to a microscopic endplate known as the axon terminal. As the signal reaches this endplate, Ca^{2+} ions are released into the synaptic cleft, lying between the axon terminal and the dendritic spine. This interstitial space, now filled with Ca^{2+} ions, initiates the release of acetylcholine. Once acetylcholine has been released, depolarization at the dendritic spine between Na^{+} and K^{+} ions allows for the action potential to continue through the axon receptors in the post-synaptic cleft. Upon arrival into the dendritic spine, T-tubules, located laterally throughout muscle cells, receive the signal, and release Ca^{2+} ions within the sarcoplasmic reticulum. This release of Ca^{2+} ions allows troponin C to release from the actin molecule, activating the movement of tropomyosin. As tropomyosin is

un-latched, the protein begins to separate from actin to allow myosin to begin the binding process, completing phase one. Phase two of contraction begins as adenosine diphosphate (ADP) and an inorganic phosphate hydrolyze allowing for a power stroke of myofibrils (Squire, 1975). Completion of the power stroke triggers a cellular adenosine triphosphate (ATP) to attach to the myosin head to begin the relaxation process, also known as phase three (Weber and Murray, 1973). With the attachment of ATP to the myosin head, the compound is hydrolyzed back to ADP and an inorganic phosphate, re-positioning the myosin head at a forty-five-degree angle for muscle contraction to reoccur. The result is the completion of phase four, and a full cycle of muscle contraction known commonly as the sliding filament theory (Hanson and Huxley, 1954; Weber and Murray, 1973; Hill et al., 1975).

RIGOR MORTIS

Rigor mortis is a Latin word that translates to “the stiffness of death”, but is more commonly known as the conversion of muscle (live tissue) to meat (edible product) (Etherington et al., 1987; Dransfield and Sosnicki, 1999). The onset of rigor mortis first begins at the time of death (Lawrie, 1998). Slaughtering of an animal permits a set of biochemical changes within muscle that occur at a lethargic pace. According to Lawrie (1998), exsanguination is the most important step in beginning the conversion of muscle to meat. With proper blood removal, meat quality is improved, and consumer acceptability is increased as blood spots and hemorrhaging are diminished (Lawrie, 1998). Removal of blood from the muscle advertently disrupts the oxygen supply to the skeletal muscle system. As the animal is exsanguinated, muscles act to maintain homeostasis through the oxidation of blood, and maintenance of cellular respiration (Lawrie, 1998). The loss of blood flow eliminates cellular oxygen supply, and glycogen conversion to energy in the muscle via aerobic metabolism ceases (Bate-smith and Bendall,

1947; Lawrie, 1998). Reducing oxygen supply requires that the muscle transition from aerobic metabolism to anaerobic metabolism. With this transition, muscles are forced to utilize creatine phosphate and perform glycolysis on remaining glycogen stores, resulting in an inefficient creation of energy. Creatine phosphate is the most readily available energy source that is stored in minimal amounts within the muscle (Greaser,1986). Creatine phosphate can resynthesize ATP with the adjoining ADP that is released from glycolysis. This requires energy reserves to be created through the breakdown of residual glycogen. Through the process of glycolysis, ATPases are working against myosin creating inorganic phosphates that are utilized for the breakdown of glycogen (Greaser, 1986; Lawrie, 1998). Once these two forms of energy have been utilized, cellular lactic acid build-up occurs (Lawrie, 1998). The latter of these two systems requires the utilization of ATP and accounts for the largest production of lactic acid. This lactic acid causes the pH of the muscle to drop, triggering transition to edible meat. With the accumulation of lactic acid and depletion of ATP to less than 0.5 mg P/g, actomyosin bonds form, and rigor mortis is completed in the postmortem state (Lawrie, 1998).

Rigor mortis occurs in a four-cycle pattern: delay, onset, completion, and resolution (Hedrick et al., 1994; Papinaho and Fletcher, 1996). During the delay stage, and post exsanguination, energy stores remaining in the muscle allow for contraction to continue. The presence of ATP allows the muscle to remain flaccid and extensible (Hedrick et al., 1994). The onset phase is the most critical for rigor development. Adenosine triphosphate (ATP) stores have been completely expended at this point, resulting in a reduction of cleaving actin-myosin bonds. Through the creation of a scaffold network of permanent actomyosin bonds, the elasticity of the muscle slowly decreases (Lawrie, 1998). During the completion phase, all creatine phosphate is utilized to phosphorylate ADP so that no further ATP production can occur. A lack of ATP

allows for complete muscle rigidity and non-breakable bonds between actin and myosin, without the induction of enzymes. The final phase, known as the resolution phase, begins as proteolytic enzymes from live tissue lysosomes are secreted to degrade actomyosin bonds to reduce stiffness (Hedrick et al., 1994; Lawrie, 1998). The resolution phase has varying lengths in differing species, but poultry rigor mortis is complete between two and eight hours postmortem (de Fremery and Pool, 1959; Wiskus et al., 1976; Addis, 1986; Hedrick et al., 1994).

Species differences in relation to size, age, and muscle fiber type directly impact the time required to complete the process of rigor mortis. For example, beef generally require twenty-four hours postmortem to complete the four phases of rigor development (Lawrie, 1998). However, research suggest that poultry meat can complete the four stages of rigor much more rapidly in as little as four hours (Etherington et al., 1987). Muscle from swine and poultry are apt to a condition referred to as pale, soft, and exudative meat (PSE) (Barbut, 1996, 1997, 1998; Owens and Sams, 2000; Owens et al., 2000, 2009; Barbut et al., 2005; Owens, 2014). This condition is impacted by changes in rigor and results in negative meat quality attributes. In PSE-like meat, the pH decline, that normally occurs from lactic acid build-up due to anaerobic metabolism, occurs at an abnormally fast rate (Addis, 1986). Pale, soft, and exudative can be a heritable trait, in swine as the halothane gene, that imparts a drastic reduction in the formation of glycolytic enzymes (Lawrie, 1998). Without glycolytic enzymes, a buildup of inorganic phosphate would then accelerate the completion of postmortem glycolysis (Hedrick et al., 1994).

In addition to species differences, age has been shown to create differences in rigor development. This may be accredited to larger muscle mass at older ages, as muscle mass increases the ability to store sizeable quantities of ATP prior to slaughter (Lawrie, 1998). Age can also directly affect the water content, color, and tenderness of a particular sample (Lawrie,

1998; Smith et al., 2002). These quality attributes can then mitigate changes in rigor development. Additionally, muscle fiber type can directly impact rigor development. Type I and type IIβ red fibers contain higher levels of mitochondria, respiratory enzymes, and myoglobin that aid in ATP production (Bechtel, 1986). Type IIα white muscle fibers, have fewer mitochondria, less myoglobin, and ultimately lower level of ATP creation based on reduced numbers of those specific attributes (Bechtel, 1986). As poultry breast meat contains a higher proportion of white to red fibers when compared to other species, it could explain the decrease in time necessary to complete the rigor phases. Wiskus et al. (1976) suggest that poultry are very dense in αW (alpha white) fiber type, with breast muscle containing between 90 to 100% of this fiber type. This high concentration of fast acting alpha white fibers, then decreases rigor mortis development time through inherent ATPase activity (Wiskus et al., 1976). Such a high concentration of white fibers in poultry benefit processors by reducing rigor completion time and maximizing efficiency by reducing time within the abattoir.

pH

Postmortem pH decline and ultimate pH can have a significant effect on meat quality. According to Bechtel (1986), pH declines postmortem as a result of lactic acid accumulation. In active live muscle, the relative pH ranges from 7.1 to 7.3 range (Dransfield and Sosnicki, 1999). Through the development of rigor, meat declines in pH to reach an ultimate pH of 5.6 to 6.2 for poultry (Dransfield and Sosnicki, 1999; Pearson and Dutson, 1999). The conversion of muscle to meat is significantly affected by ionic charges within the muscle. Continual pH decline pushes meat towards the isoelectric point which is a relative pH of 5.1 (Alvarado and Owens, 2005). Combining positive and negative charges to produce a net charge of zero, forms the term known as the isoelectric point. Having a total charge equal to zero, the lowest level of retained water and

maintained color stability is established in meat science (Lawrie, 1998). Approaching the isoelectric point with a lower than normal pH of 5.1, leads to a condition commonly referred to as PSE (Dransfield and Sosnicki, 1999).

Unlike the well-defined extremes of pH for PSE meat and dark, firm, and dry (DFD) conditions in pork and beef (Hedrick et al., 1959; Barbut et al., 2007), poultry meat still lacks on key meat quality parameters for the origins of these conditions (Qiao et al., 2001). Although currently unknown for poultry, PSE and DFD meat have been accredited to acute and chronic stress prior to slaughter (Lesiow and Kijowski, 2003). Temperature has shown to be highly correlated with rapid pH decline (Lawrie, 1998; Dransfield and Sosnicki, 1999). An increase in environmental temperature increases the rate of glycolysis, producing larger quantities of lactic acid accretion (McKee and Sams, 1997). The increase in lactic acid reduces muscle pH, adversely affecting meat quality attributes as it nears the isoelectric point. Warmer temperatures in the summer months and modified rearing houses, have been used to determine temperature effects on PSE conditions in relation to meat quality (McKee and Sams, 1997). By subjecting birds to pre-slaughter temperature stress the incidence of PSE has been shown to increase (Froning et al., 1978; McKee and Sams, 1997). The PSE condition and resulting rapid pH decline can then cause a decrease in tenderness as a direct result of protein denaturation while carcass temperatures are high (Froning et al., 1978; Barbut, 1996).

Dark, firm, and dry meat has an ultimate pH of 6.4 (Barbut et al., 2005). A decrease in postmortem glycolytic action yields a reduction in lactic acid build up (Pearson and Dutson, 1999). Higher levels of ultimate pH can affect meat quality by increasing water holding capacity and decreasing lightness (L*) values. Contrary to PSE, DFD meat contains a dry surface appearance and a relatively high moisture content (Dransfield and Sosnicki, 1999; Barbut et al.,

2005). Previously, Dadgar (2010) reported that the DFD-like condition may be directly induced through cold stress, as broilers exposed to cold conditions prior to slaughter exhibited higher pH and water holding capacity values. However, Mallia et al. (2000) found that DFD-like poultry meat may be directly correlated to cyanotic carcasses. Cyanosis produces a darker and less acidic meat that is similar in trends to DFD in beef and pork (Mallia et al., 2000). DFD-like meat has an incidence of less than ten percent in commercial poultry production (Lesiow and Kijowski, 2003). Minimal research has been conducted on the presence of DFD-like meat in poultry, but DFD-like meat has exhibited increased tenderness (Barbut et al., 2005). Both of these pH related abnormalities appear in all meat type species. Meat quality can be negatively affected by fluctuating pH leading to a loss in protein functionality in further processed meats.

COLOR

Meat color has shown to be one of the most important purchasing factors in fresh meat products (Allen et al., 1998), as consumers must base their selection solely on package appearance. Common consumers' first impressions of meat are based on exterior color (Nollet, 2012), making exterior surface color critical for meat producers to monitor and maintain. Fletcher (1999) attempted to provide a basic insight on consumer preferences by having plant personnel select breast fillets based on visual lightness or darkness, and found that visual appearance is highly correlated to objective based color values. The objective color measurements commonly used in research are L*, a*, and b* values. L* is defined as the lightness or darkness of a product, a* is defined on a bilateral scale with a positive a* value representing a red color and a negative value correlating to a green color, and b* values follow a bilateral scale with a positive value correlating to a yellow color and a negative value a blue

color (Taub and Singh, 1997; AMSA, 2012). The combination of these values produces hue that can be associated with visual color.

Hue, or the overall "color" that consumers perceive when observing a product is dependent upon many factors. These factors include age, diet, and ion concentration. Wattanachant et al. (2004) suggests that varying collagen deposits can impact the lightness of poultry meat. With collagen being relatively white in color, L* may be affected as collagen deposition increases. As broilers age, the rate of collagen deposition within the muscle increases (Kuttappan et al., 2013a). Additionally, as animals age, the amount of myoglobin present in meat increases (Smith et al., 2002). This increase in myoglobin content may also be a determining factor for color development in raw chicken fillets. In conjunction, Lyon et al. (2004) suggest correlation between muscle color development and age, and determined that increasing age in poultry produces higher levels of myoglobin which affect muscle color development.

Diet has been shown to have a significant impact on color development in the breast meat. Smith et al. (2002), found that dietary feed sources play a vital role in color differences observed in breast fillets. Similar to color variation in beef and pork, carotenoids in the feedstuffs may be the reason for color differences when a corn or milo-based diet is fed to broilers (Smith et al., 2002). Additionally, minute differences in darkness and redness are present when the diet is supplemented with linoleic acid (Lyon et al., 2004). Lyon et al. (2004) also demonstrated that nitrates drastically increase the overall redness of broiler fillets. For the niche markets previously discussed, the ability to alter breast pigmentation via nutrition may be beneficial to the industry if consumer preference changes.

Breast meat color has been shown to be highly correlated to raw meat pH (Allen et al., 1998; Fletcher, 1999; Qiao et al., 2001; Lyon et al., 2004). Based on the visual differences in

color, as described by Qiao et al. (2001) and Karaoglu et al. (2004), fillets with a higher L* had a lower pH when compared to the fillets with a lower L*. PSE-like meat is an undesirable condition that has an impact on multiple meat quality parameters. PSE-like meat has a direct impact on color through an interaction with muscle pH. PSE-like meat has a lower pH (5.4) than meat that is considered normal (5.7) and a lighter muscle color (Fletcher, 1999). A second condition called DFD is found in beef resulting in a higher pH and darker pigmentations (Wills et al., 2017; Mitacek et al., 2018), but has also been observed in poultry (Mallia et al., 2000). Dark, firm, and dry meat is the result of acute stress, prior to slaughter by decreasing glycogen and limiting lactic acid formation in post-rigor muscles (Mitacek et al., 2018). Without lactic acid formation, there is minimal pH decline resulting in a higher ultimate pH, above 6.0, producing a darker fillet (Allen et al., 1998). DFD-like meat has also been attributed to producing an after-flavor and an unwarranted texture (Harford et al., 2014). Surface pigmentation in return has a severe impact on consumer preference, and lightness is the predominate factor in poultry (Qiao et al., 2001). Additionally, genetic selection has assessed the PSE-like and DFD-like conditions to determine heritability (Harford et al., 2014; Orlowski, 2016). Harford et al. (2014) found that heritability for selection of PSE-like and DFD-like conditions were very high (R^2 = 0.47 and 0.51), respectively when selecting for L* alone. The authors also found that with selection for high and low L*, ultimate pH followed similar trends as seen in PSE and DFD meat (Harford et al., 2014). The association between heritability and selection for these traits is important to understand the impact that each condition has on broiler meat quality.

Woelfel et al. (2002) suggest that sorting fillets based on color may be beneficial for functionality. Qiao et al. (2001) claims that sorting color extremes decreases variation in

functionality and increases uniformity. Color has been highly correlated to functional properties of meat. Fletcher (2002) found that fillets that exhibit a lighter appearance, or higher L* value, had decreased water retention in the raw and cooked states. Lighter fillets are also known to produce a softer textured meat, as proteins are denatured through rapid glycolysis and pH decline, producing a poor functional product (Owens et al., 2000; Woelfel and Sams, 2001; Woelfel et al., 2002). Woelfel and Sams (2001) determined that breast fillets with increased lightness resulted in decreased marinade uptake, limiting practical use in further processed products. Further processed products made using PSE-like meat have also shown to develop differences in color profiles. Fresh breast fillets with differing L* values once cooked yielded minute differences in cooked color, which may be detected by consumers (Fletcher et al., 2000). Furthermore, Allen et al. (1998) found that the inclusion of darker fillets in further processing provided higher marinade uptake and moisture, and limited cook-loss and drip-loss. However, cooked color may not be directly impacted by variation in raw fillet color. Fletcher et al. (2000) reported that cooked fillet color was not influenced by initial raw fillet color. Therefore, the need for sorting may not be necessary when considering final cooked fillet color. If sorting was necessary, lighter and darker fillets could be combined in processed formulation to produce an average color profile in an aim to increase functionality. Aside from functionality, Allen et al. (1997) determined that fillets with a lower L* have a decreased shelf-life. Based on bacterial count and odor development, lighter fillets showed better performance and potentially an increase in one day of shelf stability (Allen et al., 1998).

TENDERNESS

Bechtel (1986) determined that postmortem conversion of muscle to meat can have a severe impact on quality attributes, the most important being tenderness. Evaluation of a product

first comes from visual inspection, followed by tenderness evaluation. Since the early 1900's, tenderness has been evaluated through many methods of analysis. Instrumental and subjective based analyses have been conducted to better understand the relationship between quantitative and qualitative tenderness respectively. Although sensory characteristics give a more accurate result in consumer acceptability, instrumental methods utilize a quantitative method to determine values that can be correlated to perceived tenderness (Tornberg, 1996). To establish a comparative result, instrumental methods can utilize different force mediums to more accurately match consumer senses. Force application can be applied through compression, tension, or shear techniques, effectively producing quantitative values (Tornberg, 1996). In addition, force in the form of shear, is generally applied perpendicular to the muscle fibers to create the greatest tensile stress (Tornberg, 1996). The Meullenet Owens Razor Shear, more commonly known as the MORS method, was developed to produce quantitative results in poultry (Cavitt et al., 2004, 2005). This method, along with others such as Allo-Kramer and Warner-Bratzler shear, have been correlated to sensory perception and thus used as indirect measures of tenderness (Lyon and Lyon, 1990; Cavitt et al., 2004). The use of quantitative measures to predict tenderness and ultimately consumer acceptability has proven to be beneficial for researchers and integrators.

Perceived tenderness of a product can be affected by a variety of factors such as bird age and sex. In poultry, a general trend for decreased tenderness is observed with increasing age; increasing age, advertently, increases the toughness of the meat (Musa et al., 2006). In terms of current market ready broilers, an increase in flock age yields a tougher meat (Poole et al., 1999). Additionally, Mehaffey et al. (2006) demonstrated that seven-week-old flocks had increased shear values compared to flocks that were six weeks in age. Collagen deposition increases as bird age increases which may have a direct effect on meat tenderness (Kuttappan et al., 2013a).

Collagen deposits can also be impacted by sex differences (Hoffman et al., 2005). Northcutt et al. (2001) and Brewer et al. (2009) reported that fillets from females possess a higher degree of tenderness than fillets from males. Contrarily, Goodwin et al. (1969) and Poole et al. (1999) found that males generally have lower shear values than females when processed at the same market age. In addition, research has shown that differing breeds, combined with sex, can impact the overall tenderness of male chickens (Musa et al., 2006).

Previous studies have shown that tenderness can be significantly affected by aging time postmortem, regardless of age or sex. Stewart et al. (1984a; b), Dawson et al. (1987), and Cavitt et al. (2004) all report that tenderness is directly affected by debone time, with longer aging times producing more tender meat (i.e. decreased shear values). In an attempt to resolve potential issues with tenderness, aging of whole carcasses has been evaluated for tenderization (Lyon et al., 1985). However, aging whole carcasses and/or front halves can increase processing costs. Carcasses deboned in the early stages of rigor have directly shown a decrease in tenderness when compared to those of samples aged more than four hours postmortem (Cavitt et al., 2004). In addition, Taylor et al. (1995) has shown that longer aging times can be used to greatly improve tenderness. Postmortem proteolysis can generally be attributed to tenderness upon the completion of rigor through prolonged carcass aging (Lyon et al., 1985). Proteases, known as calpains, lead to the degradation of actomyosin bonds which aid in the initial phases of rigor resolution, improving tenderness in broilers (McKee et al., 1997). The proteolytic degradation found in aged meat, however, comes from the exposure of cathepsins on myofibrils within lysosomes inside each muscle cell (Tornberg, 1996). Degradation of protein occurs along the Z-line, separating sarcomeres, which ultimately increase the tenderness of a product (Lawrie,

1998). The importance of rigor resolution and protein degradation play a vital role in increasing the tenderness of a product and can be improved with aging.

Through the initial stages of rigor, a condition known as sarcomere shortening can present itself. Sarcomere shortening occurs as the onset phase of rigor is disrupted, with early deboning of broiler carcasses at two hours postmortem (Papa and Fletcher, 1988). During this pre-rigor stage, Ca^{2+} ions are unable to be re-sequestered by the sarcoplasmic reticulum, stimulating the contractile system to cycle (Lawrie, 1998). This contraction then forces sarcomeres to reduce in length, creating sarcomere shortening, and ultimately a decrease in tenderness. The sarcomeres are then locked into a shortened nature, as actomyosin bonds form and cannot be resolved. Cavitt et al. (2004) reported that sarcomere length and instrumental shear values are highly correlated ($R^2 = 0.86$). Shear values that would simulate a tough fillet expressed sarcomeres that were shorter than those found in fillets that were considered tender (Wiskus et al., 1973; Cavitt et al., 2004). Shear values, simulating perceived tenderness, increased in fillets from larger carcasses when compared to those from smaller carcasses, presumably due to differing times of rigor completion, bird age, and postchill carcass times (Northcutt et al., 2001). This could potentially be attributed to the decreased ability for rigor mortis to complete prior to deboning larger carcasses. Thicker muscles are often harder to shorten, creating a tough "crust" and a soft center as muscles complete rigor mortis (Lawrie, 1998; López et al., 2011). The effects of sarcomere shortening and increased muscle size could then combine to produce a product that is severely tough.

Carcass orientation can be beneficial for preventing sarcomere shortening. First evaluated in beef carcasses, positioning carcass parts to "stretch" target sarcomeres provide a more tender product (Grayson and Lawrence, 2013). Similar techniques have also been evaluated in poultry

carcasses. Orientation of the wing posterior to the breast results in a cross-tension effect that increased the overall tenderness of the *Pectoralis* major (Cason et al., 1997). By creating tension, sarcomeres are required to lengthen reducing the effects of cold shortening. Trimming has also been shown to directly affect the tenderness of poultry carcasses. Breast blisters and damaged wings from over scalding and improper picker placement are removed not only decreasing profit, but decreasing tenderness through pre-rigor excision (Webb and Brunson, 1972). Severe transverse incisions on breast muscles, and the removal of wings, can decrease overall tenderness (Webb and Brunson, 1972). Castaneda et al. (2005a) further assessed the excision of breast blisters, and determined that salvaged parts (such as breasts) produced a tougher product. Reducing the size of excision for breast trimming, and limiting the removal of wings in early postmortem stages, directly increases tenderness and consumer acceptance (Webb and Brunson, 1972; Castaneda et al., 2005a)

A multitude of researchers speculate that electrical stimulation has allowed the poultry industry to make critical advances in deboning carcasses at earlier postmortem periods (Stewart et al., 1984b; Dawson et al., 1987; Sams, 1990). Additionally, the use of electrical stimulation has been assessed on tenderness properties and decreasing the presence of induced cold shortening. It has been documented that Benjamin Franklin first discovered the use of electrical stimulation in 1749, when he used electricity to harvest turkeys making them uncommonly tender (Li et al., 1993). For this reason, the use of electrical stimulation has long since been investigated. Originally, toughness found in broiler chickens was unknown. However, Stewart et al. (1984a; b) found that carcasses that were deboned in early postmortem stages resulted in unreasonably tough meat. Furthermore, Dawson et al. (1987) determined that carcasses deboned within one hour postmortem produced meat that was very tough in nature. In an attempt to

mitigate this toughness, researchers investigated the properties of postmortem glycolysis and developed ways to rapidly reduce the harshness of early deboning (Sams, 1990). Therefore, the use of electrical stimulation was introduced into the modern poultry industry. Birkhold and Sams (1993) reported that electrical stimulation aids in improving meat quality by accelerating ATP depletion, reducing pH, and disrupting muscle fibers for an overall improvement in tenderness (Castaneda et al., 2005b). Muscle fiber tearing has been found to be similar to the effects of prolonged carcass aging as Z-line degradation occurs (Birkhold et al., 1992). The combination of accelerated ATP depletion and muscle fiber disruption reduces prolonged exposure to cold environments to hasten rigor development, and thus mitigates cold shortening (Lawrie, 1998). Improvements from electrical stimulation can then reduce aging times, energy consumption, and possible contamination (Li et al., 1993). Thus the use of electrical stimulation, post exsanguination, reduces chill times to 2.5 hours (Li et al., 1993), improves tenderness (Sams et al., 1991; Pearson and Dutson, 1999; Zocchi and Sams, 1999), and allows for deboning of carcasses to occur earlier than non-stimulated poultry (Clatfelter and Webb, 1987; Li et al., 1993; Pearson and Dutson, 1999).

WATER HOLDING CAPACITY

Juiciness has been related to tenderness, making water holding capacity (WHC) a key factor in customer acceptance (Pearson and Dutson, 1999). Water holding capacity has been shown to affect many meat quality attributes such as texture, juiciness, and color (Brewer et al., 2012a). Water is present throughout meat, constituting seventy-five percent of total muscle weight (Pearson and Dutson, 1999; Alvarado and Owens, 2005), with water present in three forms. Bound water constitutes approximately one percent of the total water. This water is tightly bound to interfilamental spaces and can only be removed by ashing (Alvarado and Owens,

2005). Immobilized water comes as the intermediate state, contributing approximately ten to fifteen percent of the total water, and is held in place by ionic forces (Bechtel, 1986; Alvarado and Owens, 2005). Finally, free water constitutes the remaining eighty-five to eighty-nine percent of water present in meat (Pearson and Dutson, 1999). This water is located extracellularly and can be easily extracted by applying external pressures.

Water holding capacity can be measured from different techniques including moisture content, drip loss, cook loss, and thaw loss (Allen et al., 1998; Woelfel et al., 2002; Lee et al., 2008). Differential methods of measurement are important for determinants that affect WHC, such as the ionic and steric effect. The ionic effect, related to muscle pH, is responsible for approximately one-third of the influence on WHC. This effect is a condition that refers to the isoelectric point. With an ultimate pH of around 5.1, the isoelectric point (pI) of meat produces the minimal WHC that can form in fresh meats (Alvarado and Owens, 2005; Alvarado and McKee, 2007). As the net charge of proteins nears zero, dipolar water molecules are no longer attracted to neutral proteins resulting in reduced WHC (Lawrie, 1998; Alvarado and Owens, 2005). The steric effect, or the spatial arrangement of ions, orients proteins to produce channels for water and nutrient incorporation. Spatial arrangement accounts for the remaining two-thirds influence on WHC, with sarcomere length development also contributing to spatial arrangement (Lawrie, 1998; Pearson and Dutson, 1999; Alvarado and Owens, 2005). As glycolysis completes during rigor development, and muscles begin to form permanent actomyosin bonds, sarcomere shortening forces water out as an exudate as myofibrils shrink laterally (Offer et al., 1989). Lawrie (1998) determined that as actomyosin bonds form, the resulting space between myofibrillar proteins is greatly diminished. Ionic and steric effects can both impact one another.

As the pH value moves further away from the pI, repulsion of similarly charged protein groups increase the distance between the protein network, allowing for a higher WHC (Bechtel, 1986).

COOK LOSS

Bechtel (1986) defines cook loss as the release of fluid after heating with or without the presence of external forces. This definition is beneficial in understanding cook loss' impact on meat quality. Releasing fluid or juice from a fillet will greatly diminish the eating quality of that product. Juiciness and tenderness are the first factors that consumers evaluate after visual confirmation. Pearson and Dutson (1999) describe cook loss to be affected by four main factors: size of sample, temperature profile, final endpoint temperature, and environmental cooking type. Of these factors, Pearson and Dutson (1999) believe that environmental cooking type plays the largest role on meat quality. Differential cooking methods have been used to determine WHC and its' impact on tenderness. Direct steam cooking and convection cooking in covered aluminum pans are the two main techniques (Papa and Lyon, 1989; Cavitt et al., 2004; Mehaffey et al., 2006; Lee et al., 2008). Conditionally, the presence of a moist environment through direct steam cooking has led to increased tenderness when compared to dry heat methods such as convection (Mora et al., 2011). This can be expected as tenderness is highly affected by total juiciness (Pearson and Dutson, 1999). In addition to environmental conditions, other factors also aid in total cook loss. The stage of rigor development and ultimate pH have shown to be highly correlated to cook loss (Offer et al., 1989; Yu et al., 2005). Cold shortened muscle has shown to increase cook loss as more immobilized water is freely released (Bechtel, 1986). Bechtel (1986) also determined that by aging cold shortened beef steaks for seven days postmortem, the relative cook loss is improved and similar to that of normal meat twenty-four hours postmortem. Frozen samples are commonly utilized in the research field as time restraints are crucial for sample

preparation in research settings. Previous studies have shown that freezing samples directly impacts meat quality (Farouk and Swan, 1998; Yu et al., 2005; Lee et al., 2008). Cooking from a frozen state has been shown to increase cook loss as opposed to thawed meat (Zhuang and Savage, 2013). Zhuang and Savage (2009) found that this increased cook loss can be accredited to varying degrees of intramuscular degradation of Z-lines and cytolysis of cellular structure releasing immobilized water. For this reason, samples that are fresh tend to have a lower cook loss than those stored under freezing conditions.

Strain and age have shown varying results in cook loss. Mehaffey et al. (2006) found that minimal differences were present between strain, but age has a significant impact on cook loss. They determined that older aged birds produce higher cook loss values when compared to younger flocks. However, Brewer et al. (2012b) found that strain had no effect on cook loss. Additionally, cook loss showed no significant differences in flock age as reported by Poltowicz and Doktor (2012). Finally, previous studies have shown that sex does not directly influence cook loss (López et al., 2011; Brewer et al., 2012b). The results of these studies indicate that the main factor effecting cook loss is broiler age (i.e. carcass size), with differences likely attributed to higher fat content observed in older birds (Schneider et al., 2012; Soglia et al., 2016a).

WHITE STRIPING

White striping (WS) was first identified as a muscle myopathy in the broiler industry in 2009. Bauermeister et al. (2009) first noted the appearance of white granular striations between broiler *Pectoralis major* muscle fibers that were later considered a muscle myopathy. These white striations are generally noticed running parallel to muscle fibers and are described as being absent, moderate, or severe in deposition. Striations can range from heavy deposits in the cranial region of the breast fillet, with little indentation toward the caudal region, to being expressed

evenly throughout the breast fillet in a more complex pattern. Additionally, the width of each striation is critical in evaluating the degree of WS severity (Kuttappan et al., 2012c). Kuttappan et al. (2013a) determined that increased fillet thickness coincides with increased severity of WS. The emerging myopathy currently present may be an unexpected attribute of the modern high-yielding broilers strains.

The main attribute that sets WS apart from other conditions is visual perception. From a consumer stance, the perceivable portion of a tray pack or individual breast fillet is the deciding factor of acceptance or rejection (Kuttappan et al., 2012c). Since WS shows significant attention in only the optical sector, the presentation of the product is critical. Kuttappan et al. (2012b) found that consumers were less likely to purchase a breast fillet with severe WS by a hedonic scale factor of 2 in comparison to the normal fillet. In addition, consumers showed significant interest in purchasing a tray pack that contained strictly normal fillets in comparison to a variety of WS fillets (Kuttappan et al., 2012c).

Currently, there are no known solutions to eliminate WS in broiler populations. Due to its large role in consumer acceptance from visual characteristics, but minimal taste differences, WS may continue to have a negative impact on the poultry industry.

White striping has been shown to have minor effects on taste profiles, but significant effects on some meat quality aspects have been observed. Kuttappan et al. (2012a) reported that WS fillets had higher fat and collagen content at the cost of reducing protein levels. Ash and lipid content were found to be altered in fillets, with a total reduction in concentration as the degree of WS increased (Soglia et al., 2016b). Additionally, Kuttappan et al. (2013b) reported that under histological analysis, WS fillets possess a high degree of adipocytes and fibrosis in the muscle tissue as a direct cost of reduced myofibrillar proteins. Polyphasic changes within the

fillet may also be a direct result of chronic myopathic lesions that influence the infiltration of adipocytes and lipidosis that occurs in affected fillets (Kuttappan et al., 2013b). Petracci et al. (2013) first noted that fillets affected with WS, in comparison to normal fillets, produced lower water retention, higher cook loss, and elevated shear values. In turn, these chemical composition changes have shown to negatively impact the nutritional qualities of WS fillets for consumers (Petracci et al., 2019; Dalle Zotte et al., 2020).

WOODY BREAST

Modern, high-yielding broilers have seen an increased incidence of muscle myopathies as opposed to flocks from fifty years ago (Owens, 2014). The current increase in myopathies not only results in an economic loss to the industry, but can cause issues for producers and consumers alike. Woody breast (WB) first appeared in the poultry industry in 2014 (Sihvo et al., 2014). This condition is accredited mostly to the stiff-like visual and touch type detection measurements administered on individual breast fillets (Owens, 2014). Woody breast is characterized as having a natural stiffness to the muscle fibers from palpation techniques, as well as having noticeable “ridges” throughout the breast fillet (Sihvo et al., 2014; Tijare et al., 2016). Woody fillets tend to show a greater stiffness or hard texture in the cranial region fading slowly to the middle and caudal regions respectively and have been graded by severity (Tijare et al., 2016). Sihvo et al. (2014) suggested that myodegeneration of fibers occurs in affected woody fillets. An increase in split fibers, fraying from polygonal fiber shape, loss of straited muscle structure, and an increase in inflammatory cells were also noticed in affected fillets (Sihvo et al., 2014). The combination of the aforementioned factors have given rise to the unique appearance of WB (Tijare et al., 2016). Additionally, woody fillets have connective tissue accumulation, also known as fibrosis, that leads to decreased nutritional properties and could explain the hard, rigid-

like abnormality (Owens, 2014; Sihvo et al., 2014; Tijare et al., 2016; Cai et al., 2018). Previous literature suggests that breast muscle utilization in modern broiler strains work in brief bursts of movement (Dransfield and Sosnicki, 1999). This rapid movement may also be an explanation for the formation of WB. Huang and Ahn (2018) reported that muscle tissue outgrows supporting systems in breast muscle, while limiting the blood supply through pinch points that occur during excessive wing flapping. This type of metabolic stress then forces a reduction in capillary oxygen transport and an increase in macrophage production to compensate for decreased muscle growth needed for repair, which could explain the origins of the myopathy (Huang and Ahn, 2018).

A subjective scale is currently used to assess WB in research settings. This scale is subjective as each individual conducting the palpation method may have a difference in opinion. A general scale consists of a score ranging from 0 to 3 in 0.5 increments generated by Tijare et al. (2016). Fillets that were flexible throughout where given a score of 0. As the myopathy progresses, hardness localizes primarily in the cranial region and maintains flexibility throughout creating a mild score with a numeric value of a 1. Fillets with hardness throughout the fillet and flexibility within the middle and caudal regions were categorized as moderate and given a score of 2. Fillets that are hard and rigid throughout from cranial to caudal end are considered a severe myopathy and given a score of 3 (Tijare et al., 2016). Additionally, Livingston et al. (2018) suggests that a scale ranging from 1 to 4 gives a broad spectrum, non-visual bias approach to such a subjective testing system. For this scale, a score of 1 is a normal fillet, a score of 2 has mild hardening in the fillet, a score of 3 resulted from a reduced acceptance of palpation pressure on the fillet, while some breast fillet flexibility was present. Finally, a score of 4 would yield a fillet that showed a severe hardness when palpated (Livingston et al., 2018). Often, for applied

research, these scales are consolidated into subgroups of 0-0.5 (NORM), 1-2 (MILD), and 2-3 (MOD/SEV) categories (Bodle et al., 2018; Maynard et al., 2019).

Woody fillets tend to show a firm presence that does not look visually appealing to consumers (Sihvo et al., 2014; Tijare et al., 2016; Aguirre et al., 2018). For a consumer-based product, visual appearance is one of the main driving factors in consumer acceptability as it is the first indicator of product quality (Allen et al., 1997). However, there is no current literature that indicates consumer acceptability of visually affected WB fillets. The poultry industry utilizes a unique quantifying system to record tenderness evaluation. The MORS evaluation method provides a visual representation of the energy required for relative shear force on poultry products, particularly breast fillets (Cavitt et al., 2004). By evaluating the relative energy required for shear in cooked fillets, trends could be determined between fillets attributed to the woody condition and fillets that are considered normal (Cavitt et al., 2004, 2005). Previous research has shown that approximately 12.9 N and 191.8 N.mm were average shear data for normal fillets, approximately 15.0 N and 205.6 N.mm were recorded for moderate fillets, and 219.9 N.mm for severe woody condition (Chatterjee et al., 2016; Tijare et al., 2016). With changes in tenderness, taste panel evaluation of WB fillets is important. Chatterjee et al. (2016) also found that affected fillets were harder and chewier than normal fillets. Crunchiness is a new texture attribute that has been considered to be prevalent with WB fillets (Aguirre et al., 2018). This factor may have been directly influenced by the amount of compression force required to break the net surface tension of woody fillets and the layers of connective tissue and myofibrillar tissue. The rigid surface of a woody fillet may also be a progressive factor in providing the crunchy nature. With the prevalence of the WB condition in industry increasing, it is important to note that woody fillets tend to coincide with WS (Owens, 2014). Furthermore, the presence of

WS has shown to be moderately correlated to the degree of woody breast severity (Kuttappan et al., 2012a, 2013a; Tijare et al., 2016). Commonly, a breast fillet with severe WB also has severe WS. Bowker and Zhuang (2016) confirmed this by reporting that the presence of WB significantly increases with the degree of WS. White striping has shown no direct effects on taste and touch like those that can be seen in the woody condition.

Previously mentioned, the hard ridge-like abnormality present in the raw fillet, produces a cooked fillet with abnormal characteristics and poor functional properties (Petracci et al., 2019). Woody breast displays poor functionality in protein utilization for further processing, impaired marinade uptake, and decreased water retention in both raw and cooked states (Soglia et al., 2016b; Tijare et al., 2016; Petracci et al., 2019). Similar to WS, woody fillets have decreased protein content (Soglia et al., 2016b), increased fat (Dalle Zotte et al., 2020), and increased insoluble collagen (Petracci et al., 2019). With a marked decrease in protein content, the inherent ability to hold water is reduced (Soglia et al., 2016b). As fillets lose the ability to maintain WHC, fillets often cook faster, dry out quicker, and produce fillets with excessive cook loss (Soglia et al., 2016a; b; Tijare et al., 2016). Therefore, woody breast reduces the functionality of fillets and limits its use for further processing.

NEED FOR RESEARCH

As world population continues to rise, the need for poultry and poultry products will have to improve to meet demand. With increases in production, reduced debone times may continue to be pushed by integrators to maximize processing efficiency. Making this transition may directly affect the eating quality of poultry. Decreasing aging times affects multiple factors that can impact meat quality, such as rigor mortis development, color, pH, WHC, and shear force. Further research needs to be done to evaluate parameters such as electrical stimulation or other muscle

contraction mechanisms to complete rigor faster and the interaction with broilers exhibiting myopathies or modern broilers.

Muscle myopathies have also had a major impact on eating quality. With an increase in WEB, the texture of fillets has been negatively impacted. Relatively high incidences of the myopathy are also problematic for processing facilities. Condemnations are an economic loss to the industry and further processed products are affected by protein functionality (Li et al., 2015). Woody fillets have shown to have decreased protein functionality and as a result, are not ideal for further processing. However, further studies to assess the economic inclusion of afflicted fillets into further processed products need to be evaluated. This may allow processors to produce a value-added product as condemnations could be sold indirectly.

Genetic selection of poultry has shown to be beneficial for selecting traits to result in hybrid vigor. Hybrid vigor is the combination of variable traits to produce the best nirrd. Integrators are continually evaluating broiler strain crosses in order to maximize growth performance including breast meat yield. However, impacts on meat quality are not always considered. Continual research needs to be conducted to understand the nutritional profiles and rearing environment strategies to maximize performance on processing characteristics. During these experiments, it is necessary to characterize the development of myopathies along with changes in meat quality as a result of longer grow out periods.

REFERENCES

Addis, P. B. 1986. Poultry Muscle as Food.Pages 372–405 in Muscle as Food. Schweigert, B.S., ed. First. Academic Press, Inc., Orlando, FL.

Aguirre, M. E., C. M. Owens, R. K. Miller, and C. Z. Alvarado. 2018. Descriptive sensory and instrumental texture profile analysis of woody breast in marinated chicken. Poult. Sci. 97:1456–1461.

Allen, C. D., D. L. Fletcher, J. K. Northcutt, and S. M. Russell. 1998. The Relationship of Broiler Breast Color to Meat Quality and Shelf-Life. Poult. Sci. 76:1042–1046.

Allen, C. D., S. M. Russell, and D. L. Fletcher. 1997. The relationship of broiler breast meat color and pH to shelf-life and odor development. Poult. Sci. 76:1042–1046.

Alvarado, C. Z., and S. R. McKee. 2007. Marination to improve functional properties and safety of poultry meat. J. Appl. Poult. Res. 16:113–120.

Alvarado, C. Z., and C. M. Owens. 2005. Handbook of Food Science, Technology and Engineering. Volume I - Food Science: Properties and Products.Pages 1–14 in Hui, Y.H., ed. 1 ed. CRC Press, Taylor and Francis Group, Boca Raton, FL.

AMSA. 2012. Meat color measurment guidelines. American Meat Science Association. Accessed electronically July 21st, 2020.

Anthony, N. B. 1998. A review of genetic practices in poultry: Efforts to improve meat quality. J. Muscle Foods 9:25–33.

Barbut, S. 1996. Estimates and detection of the PSE problem in young turkey breast meat. Can. J. Anim. Sci. 76:455–457.

Barbut, S. 1997. Problem of pale soft exudative meat in broiler chickens. Br. Poult. Sci. 38:355–358.

Barbut, S. 1998. Estimating the magnitude of the PSE problem in poultry. J. Muscle Foods 9:35–49.

Barbut, S., A. A. Sosnicki, S. M. Lonergan, T. Knapp, D. C. Ciobanu, L. J. Gatcliffe, E. Huff-Lonergan, and E. W. Wilson. 2007. Progress in reducing the pale, soft and exudative (PSE) problem in pork and poultry meat. Meat Sci. 79:46–63.

Barbut, S., L. Zhang, and M. Marcone. 2005. Effects of pale, normal, and dark chicken breast meat on microstructure, extractable proteins, and cooking of marinated fillets. Poult. Sci. 84:797–802.

Bate-smith, E. C., and J. R. Bendall. 1947. Rigor Mortis and Adenosinetriphosphate. J. Physiol. 106:177–185.

Bauermeister, I. J., A. U. Morey, E. T. Moran, M. Singh, C. M. Owens, and S. R. Mckee. 2009. Occurrence of white striping in chicken breast fillets in relation to broiler size. Poult. Sci. 88:104 (Abstr.).

Bechtel, P. J. 1986. Muscle as Food. 1 ed. Academic Press, Inc., Orlando, FL.

Le Bihan-Duval, E., N. Millet, and H. Remignon. 1999. Broiler meat quality: Effect of selection for increased carcass quality and estimates of genetic parameters. Poult. Sci. 78:822–826.

Birkhold, S. G., D. M. Janky, and A. R. Sams. 1992. Tenderization of Early-Harvested Broiler Breast Fillets by High-Voltage Post-Mortem Electrical Stimulation and Muscle Tensioning ,. Poult. Sci. 71:2106–2112.

Birkhold, S. G., and A. R. Sams. 1993. Fragmentation, tenderness, and post-mortem metabolism of early-harvested broiler breast fillets from carcasses treated with electrical stimulation and muscle tensioning. Poult. Sci. 72:577–582.

Bodle, B. C., C. Alvarado, R. B. Shirley, Y. Mercier, and J. T. Lee. 2018. Evaluation of different dietary alterations in their ability to mitigate the incidence and severity of woody breast and white striping in commercial male broilers. Poult. Sci. 97:3298–3310.

Bowker, B., and H. Zhuang. 2016. Impact of white striping on functionality attributes of broiler breast meat1. Poult. Sci. 95:1957–1965.

Brewer, V. B., J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2012a. Small bird programs: Effect of phase-feeding, strain, sex, and debone time on meat quality of broilers. Poult. Sci. 91:499–504.

Brewer, V. B., V. A. Kuttappan, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2009. Big Bird Program: Impact of Strain, Gender, and Debone Time on Meat Quality of Broilers. Poult. Sci. 88:112 (Abstr.).

Brewer, V. B., V. A. Kuttappan, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2012b. Big-bird programs: Effect of strain, sex, and debone time on meat quality of broilers. Poult. Sci. 91:248–254.

Cai, K., W. Shao, X. Chen, Y. L. Campbell, M. N. Nair, S. P. Suman, C. M. Beach, M. C. Guyton, and M. W. Schilling. 2018. Meat quality traits and proteome profile of woody broiler breast (pectoralis major) meat. Poult. Sci. 97:337–346.

Cason, J. A., C. E. Lyon, and C. M. Papa. 1997. Effect of Muscle Opposition during Rigor on Development of Broiler Breast Meat Tenderness. Poult. Sci. 76: 785-787.

Castaneda, M. P., E. M. Hirschler, and A. R. Sams. 2005a. Early Postmortem Carcass Trim Effects on the Tenderness of Broiler Breast Fillets. 84:951–954.

Castaneda, M. P., E. M. Hirschler, and A. R. Sams. 2005b. Functionality of electrically stimulated broiler breast meat. Poult. Sci. 84:479–481.

Cavitt, L. C., R. Xiong, and C. M. Owens. 2005. Changes in Tenderness of Broiler Breast Fillets. J. Muscle Foods 16:223–242.

Cavitt, L. C., G. W. Youm, J. F. Meullenet, C. M. Owens, and R. Xiong. 2004. Prediction of Poultry Meat Tenderness Using Razor Blade Shear, Allo-Kramer Shear, and Sarcomere Length. J. Food Sci. 69:11–15.

Chatterjee, D., H. Zhuang, B. C. Bowker, A. M. Rincon, and G. Sanchez-Brambila. 2016. Instrumental texture characteristics of broiler pectoralis major with the wooden breast

condition. Poult. Sci. 95:2449–2454.

Clatfelter, K. A., and J. E. Webb. 1987. Method of elimitnating aging step in poultry processing. U. S. Patent. 4675947

Dadgar, S. 2010. Effect of cold stress during transportation on post-mortem metabolism and chicken meat quality.

Dalle Zotte, A., R. Ricci, M. Cullere, L. Serva, S. Tenti, and G. Marchesini. 2020. Research Note: Effect of chicken genotype and white striping–wooden breast condition on breast meat proximate composition and amino acid profile. Poult. Sci. 99:1797–1803.

Dawson, P. L., D. M. Janky, M. G. Dukes, L. D. Thompson, and S. A. Woodward. 1987. Effect of Post-Mortem Boning Time During Simulated Commercial Processing on the Tenderness of Broiler Breast Meat. Poult. Sci. 66:1331–1333.

Dransfield, E., and A. A. Sosnicki. 1999. Relationship between muscle growth and poultry meat quality. Poult. Sci. 78:743–746.

Etherington, D. J., A. J. Taylor, and E. Dransfield. 1987. Conditioning of Meat from Different Species, Relationship Between Tenderising and the Levels of Cathepsin B, Cathepsin L, Calpain II and P-glucurinidase. Meat Sci. 20:1–18.

Farouk, M. M., and J. E. Swan. 1998. Effect of Rigor temperature and frozen storage on functional properties of hot-boned manufacturing beef. Meat Sci. 49:233–247.

Fletcher, D. L. 1999. Broiler breast meat color variation, pH, and texture. Poult. Sci. 78:1323–1327.

Fletcher, D. L. 2002. Poultry meat quality. Worlds. Poult. Sci. J. 58:131–145.

Fletcher, D. L., M. Qiao, and D. P. Smith. 2000. The relationship of raw broiler breast meat color and pH to cooked meat color and pH. Poult. Sci. 79:784–788.

de Fremery, D., and M. F. Pool. 1959. Biochemistry of Chicken Muscle as Related to rigor Mortis and Tenderization. J. Food Sci. 38:73–87.

Froning, G. W., A. S. Babji, and F. B. Mather. 1978. The Effect of Preslaughter Temperature, Stress, Struggle and Anesthetization on Color and Textural Characteristics of Turkey Muscle. Poult. Sci. 57:630–633.

Goodwin, T. L., L. D. Andrews, and J. E. Webb. 1969. The influence of age, sex, and energy level on the tenderness of broilers. Poult. Sci. 48:548–552.

Grayson, A. L., and T. E. Lawrence. 2013. Alternative pre-rigor foreshank positioning can improve beef shoulder muscle tenderness. Meat Sci. 96:36–41.

Greaser, M. L. 1986. Muscle as Food.Pages 37–102 in Bechtel, P.J., ed. 1 ed. Academic Press, Inc., Orlando, FL.

Hanson, J., and H. Huxley. 1954. Changes in the Cross-Striations of Muscle during Contraction and Stretch and their Structural Interpretation. Nature 173:973–976.

Harford, I. D., H. O. Pavlidis, and N. B. Anthony. 2014. Divergent selection for muscle color in

broilers. Poult. Sci. 93:1059–1066.

Hedrick, H. B., E. D. Aberle, J. C. Forrest, M. D. Judge, and R. A. Merkel. 1994. Principles of Meat Science. 3rd ed. Kendall/Hunt Publishing, Dubuque, IA.

Hedrick, H. B., J. B. Boillot, D. E. Brady, and H. D. Naumann. 1959. Etiology of Dark-Cutting Beef. Columbia, Missouri.

Hill, T. L., E. Eisenberg, Y. D. Chen, and R. J. Podolsky. 1975. Some self-consistent two-state sliding filament models of muscle contraction. Biophys. J. 15:335–372.

Hoffman, L. C., B. Kritzinger, and A. V. Ferreira. 2005. The effects of region and gender on the fatty acid, amino acid, mineral, myoglobin and collagen contents of impala (Aepyceros melampus) meat. Meat Sci. 69:551–558.

Huang, X., and D. U. Ahn. 2018. The incidence of muscle abnormalities in broiler breast meat - A review. Korean J. Food Sci. Anim. Resour. 38:835–850.

Ingraham, R. H., and C. A. Swenson. 1984. Binary Interactions of Troponin Subunits. J. Biol. Chem. 259:9544–9548.

Karaoglu, M., M. I. Aksu, N. Esenbuga, M. Kaya, M. Macit, and H. Durdag. 2004. Effect of dietary probiotic on the pH and colour characteristics of carcasses, breast fillets and drumsticks of broilers. Anim. Sci. 78:253–259.

Kuttappan, V. A., V. B. Brewer, J. K. Apple, P. W. Waldroup, and C. M. Owens. 2012a. Influence of growth rate on the occurrence of white striping in broiler breast fillets. Poult. Sci. 91:2677–2685.

Kuttappan, V. A., V. B. Brewer, A. Mauromoustakos, S. R. McKee, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2013a. Estimation of factors associated with the occurrence of white striping in broiler breast fillets. Poult. Sci. 92:811–819.

Kuttappan, V. A., Y. S. Lee, G. F. Erf, J. F. Meullenet, S. R. Mckee, and C. M. Owens. 2012b. Consumer acceptance of visual appearance of broiler breast meat with varying degrees of white striping. Poult. Sci. 91:1240–1247.

Kuttappan, V. A., C. M. Owens, C. Coon, B. M. Hargis, and M. Vazquez-A Non. 2017. Research Note Incidence of broiler breast myopathies at 2 different ages and its impact on selected raw meat quality parameters. Poult. Sci. 96:3005–3009.

Kuttappan, V. A., H. l. Shivaprasad, D. P. Shaw, B. A. Valentine, B. M. Hargis, F. D. Clark, S. R. McKee, and C. M. Owens. 2013b. Pathological changes associated with white striping in broiler breast muscles. Poult. Sci. 92:331–338.

Lawrie, R. A. 1998. Lawrie's Meat Science. 6 ed. Woodhead Publishing Ltd, Cambridge, England.

Lee, Y. S., A. Saha, R. Xiong, C. M. Owens, and J. F. Meullenet. 2008. Changes in broiler breast fillet tenderness, water-holding capacity, and color attributes during long-term frozen storage. J. Food Sci. 73:162-168.

Lesiow, T., and J. Kijowski. 2003. Impact of PSE and DFD meat on poultry processing: A

review. Polish J. food Nutr. Sci. 12:3–8.

Li, Y., T. J. Siebenmorgen, and C. . Griffis. 1993. Electrical Stimulation in Poultry: A Review and Evaluation. Poult. Sci. 72:7–22.

Li, K., Y. Y. Zhao, Z. L. Kang, P. Wang, M. Y. Han, X. L. Xu, and G. H. Zhou. 2015. Reduced functionality of PSE-like chicken breast meat batter resulting from alterations in protein conformation. Poult. Sci. 94:111–122.

Lieber, R. L. 2002. Skeletal Muscle Structure, Function, and Plasticity - Richard L. Lieber - (T Julet, Ed.). Second Edi. Lippincott Williams & Wilkins, Baltimore, MD.

Livingston, M. L., C. Landon, H. J. Barnes, and J. Brake. 2018. White striping and wooden breast myopathies of broiler breast muscle is affected by time-limited feeding, genetic background, and egg storage. Poult. Sci. 98:217–226.

López, K. P., M. W. Schilling, and A. Corzo. 2011. Broiler genetic strain and sex effects on meat characteristics. Poult. Sci. 90:1105–1111.

Lyon, C. E., D. Hamm, and J. E. Thomson. 1985. pH and Tenderness of Broiler Breast Meat Deboned Various Times After Chilling. Poult. Sci. 64:307–310.

Lyon, C. E., and B. G. Lyon. 1990. The Relationship of Objective Shear Values and Sensory Tests to Changes in Tenderness of Broiler Breast Meat. Poult. Sci. 69:1420–1427.

Lyon, B. G., D. P. Smith, C. E. Lyon, and E. M. Savage. 2004. Effects of diet and feed withdrawal on the sensory descriptive and instrumental profiles of broiler breast fillets. Poult. Sci. 83:275–281.

Mallia, J. G., S. Barbut, J. P. Vaillancourt, S. W. Martin, and S. A. McEwen. 2000. A Dark, Firm Dry-Like Condition in Turkeys Condemned for Cyanosis. Poult. Sci. 79:281–285.

Marston, S. B., and C. S. Redwood. 2003. Modulation of Thin Filament Activation by Breakdown or Isoform Switching of Thin Filament Proteins: Physiological and Pathological Implications. Circ. Res. 93:1170–1178.

Maynard, C. W., R. E. Latham, R. Brister, C. M. Owens, and S. J. Rochell. 2019. Effects of Dietary Energy and Amino Acid Density during Finisher and Withdrawal Phases on Live Performance and Carcass Characteristics of Cobb MV × 700 Broilers. J. Appl. Poult. Res. 28:729–742.

McKee, S. R., E. M. Hirschler, and A. R. Sams. 1997. Physical and Biochemical Effects of Broiler Breast Tenderization by Aging after Pre-rigor Deboning. J. Food Sci. 62:959–962.

McKee, S. R., and A. R. Sams. 1997. The Effect of Seasonal Heat Stress on Rigor Development and the Incidence of Pale, Exudative Turkey Meat. Poult. Sci. 76:1616–1620.

Mehaffey, J. M., S. P. Pradhan, J. F. Meullenet, J. L. Emmert, S. R. McKee, and C. M. Owens. 2006. Meat quality evaluation of minimally aged broiler breast fillets from five commercial genetic strains. Poult. Sci. 85:902–908.

Mitacek, R. M., A. R. English, G. G. Mafi, D. L. VanOverbeke, and R. Ramanathan. 2018. Modified Atmosphere Packaging Improves Surface Color of Dark-Cutting Beef. Meat

Muscle Biol. 2:57–63.

Moos, C., G. Offer, R. Starr, and P. Bennett. 1975. Interaction of C-protein with myosin, myosin rod and light meromyosin. J. Mol. Biol. 97:1–9.

Mora, B., E. Curti, E. Vittadini, and D. Barbanti. 2011. Effect of different air/steam convection cooking methods on turkey breast meat:Physical characterization, water status and sensory properties. Meat Sci. 88:489–497.

Morimoto, K., and W. F. Harrington. 1973. Isolation and composition of thick filaments from rabbit skeletal muscle. J. Mol. Biol. 77:165–175.

Musa, H. H., G. H. Chen, J. H. Cheng, E. S. Shuiep, and W. B. Bao. 2006. Breed and sex effect on meat quality of chicken. Int. J. Poult. Sci. 5:566–568.

National Chicken Council. 2011. Accessed electronically July 21st, 2020.

National Chicken Council. 2019. Accessed electronically July 21st, 2020.

Nollet, L. M. L. 2012. Handbook of Meat, Poultry and Seafood Quality (LML Nollet, T Boylston, F Chen, PC Coggins, G Hyldig, L McKee, and CR Kerth, Eds.). 2 ed. John Wiley & Sons Inc., Ames, IA.

Northcutt, J. K., R. J. Buhr, L. L. Young, C. E. Lyon, and G. O. Ware. 2001. Influence of age and postchill carcass aging duration on chicken breast fillet quality. Poult. Sci. 80:808–812.

Offer, G., P. Knight, R. Jeacocke, R. Almond, T. Cousins, J. Elsey, N. Parsons, A. Sharp, R. Starr, and P. Purslow. 1989. The structural basis of the water-holding, appearance and toughness of meat and meat products. Food Microstruct. 8:151–170.

Orlowski, S. K. 2016. Characterization of Broiler Lines Divergently Selected for Breast Muscle Color.

Owens, C. M. 2014. Identifying quality defects in poultry processing. Watt Poult. USA:42–50.

Owens, C. M., C. Z. Alvarado, and A. R. Sams. 2009. Research developments in pale, soft, and exudative turkey meat in North America. Poult. Sci. 88:1513–1517.

Owens, C. M., E. M. Hirschler, S. R. McKee, R. Martinez-Dawson, and A. R. Sams. 2000. The characterization and incidence of pale, soft, exudative Turkey meat in a commercial plant. Poult. Sci. 79:553–558.

Owens, C. M., and A. R. Sams. 2000. The influence of transportation on turkey meat quality. Poult. Sci. 79:1204–1207.

Papa, C. M., and D. L. Fletcher. 1988. Pectoralis muscle shortening and rigor development at different locations within the broiler breast. Poult. Sci. 67:635–640.

Papa, C. M., and C. E. Lyon. 1989. Shortening of the Pectoralis Muscle and Meat Tenderness of Broiler Chickens. Poult. Sci. 68:663–669.

Papinaho, P. A., and D. L. Fletcher. 1996. The influence of temperature on broiler breast muscle shortening and extensibility. Poult. Sci. 75:797–802.

Pearson, A. M., and T. R. Dutson. 1999. Qulaity Attributes and Their Measurement in Meat, Poultry and Fish Products. 1 ed. Aspen Publishers, Inc., Gaithersburg, MD.

Petracci, M., S. Mudalal, A. Bonfiglio, and C. Cavani. 2013. Occurrence of white striping under commercial conditions and its impact on breast meat quality in broiler chickens. Poult. Sci. 92:1670–1675.

Petracci, M., F. Soglia, M. Madruga, L. Carvalho, E. Ida, and M. Estévez. 2019. Wooden-Breast, White Striping, and Spaghetti Meat: Causes, Consequences and Consumer Perception of Emerging Broiler Meat Abnormalities. Compr. Rev. Food Sci. Food Saf. 18:565–583.

Poltowicz, K., and J. Doktor. 2012. Effect of slaughter age on performance and meat Quality of slow-growing broiler chickens. Ann. Anim. Sci. 12:621–631.

Poole, G. H., C. E. Lyon, R. J. Buhr, L. L. Young, A. Alley, J. B. Hess, S. F. Bilgili, and J. K. Northcutt. 1999. Evaluation of age, gender, strain, and diet on the cooked yield and shear values of broiler breast fillets. J. Appl. Poult. Res. 8:170–176.

Qiao, M., D. L. Fletcher, D. P. Smith, and J. K. Northcutt. 2001. The effect of broiler breast meat color on pH, moisture, water-holding capacity, and emulsification capacity. Poult. Sci. 80:676–680.

Sams, A. R. 1990. Electrical Stimulation and High Temperature Conditioning of Broiler Carcasses. Poult. Sci. 69:1781–1786.

Sams, A. R., S. G. Birkhold, and K. A. Mills. 1991. Fragmentation and Tenderness in Breast Muscle from Broiler Carcasses Treated with Electrical Stimulation and High-Temperature Conditioning. Poult. Sci. 70:1430–1433.

Schneider, B. L., R. A. Renema, M. Betti, V. L. Carney, and M. J. Zuidhof. 2012. Effect of holding temperature, shackling, sex, and age on broiler breast meat quality. Poult. Sci. 91:468–477.

Sihvo, H. K., K. Immonen, and E. Puolanne. 2014. Myodegeneration With Fibrosis and Regeneration in the Pectoralis Major Muscle of Broilers. Vet. Pathol. 51:619–623.

Smith, D. M. 2010. Functional Properties of Muscle Proteins in Processed Poultry Products (DM Smith, Ed.). 2 ed. CRC Press LLC, Boca Raton, FL.

Smith, D. P., C. E. Lyon, and B. G. Lyon. 2002. The effect of age, dietary carbohydrate source, and feed withdrawal on broiler breast fillet color. Poult. Sci. 81:1584–1588.

Soglia, F., L. Laghi, L. Canonico, C. Cavani, and M. Petracci. 2016a. Functional property issues in broiler breast meat related to emerging muscle abnormalities. Food Res. Int. 89:1071–1076.

Soglia, F., S. Mudalal, E. Babini, M. Di Nunzio, M. Mazzoni, F. Sirri, C. Cavani, and M. Petracci. 2016b. Histology, composition, and quality traits of chicken Pectoralis major muscle affected by wooden breast abnormality. Poult. Sci. 95:651–659.

Squire, J. M. 1975. Muscle filament structure and muscle contraction. Annu. Rev. Biophys. Bioeng. 4:137–163.

Stephens, J. A., and A. Taylor. 1972. Fatigue of Maintained Vountary Muscle Contraction in Man. J. Physiol. 220:1–18.

Stewart, M. K., D. L. Fletcher, D. Hamm, and J. E. Thomson. 1984a. The Influence of Hot Boning Broiler Breast Muscle on pH Decline and Toughening. Poult. Sci. 63:1935–1939.

Stewart, M. K., D. L. Fletcher, D. Hamm, and J. E. Thomson. 1984b. The Effect of Hot Boning Broiler Breast Meat Muscle on Postmortem pH Decline. Poult. Sci. 63:2181–2186.

Taub, I. A., and R. P. Singh. 1997. Food Storage Stability (IA Taub and RP Singh, Eds.). 1 ed. CRC Press LLC, Boca Raton, FL.

Taylor, R. G., G. H. Geesink, V. F. Thompson, M. Koohmaraie, and D. E. Goll. 1995. Is Z-disk degradation resonsible for postmortem tenderization? J. Anim. Sci. 73:1351–1367.

Tijare, V. V., F. L. Yang, V. A. Kuttappan, C. Z. Alvarado, C. N. Coon, and C. M. Owens. 2016. Meat quality of broiler breast fillets with white striping and woody breast muscle myopathies. Poult. Sci. 95:2167–2173.

Tornberg, E. 1996. Biophysical aspects of meat tenderness. Meat Sci. 43:175–191.

Valceschini, E. 2006. Poultry meat trends and consumer attitudes.Pages 1–10 in Proc. XII Eur. Poult. Conf. Verona, Italy.

Warriss, P. D. 2000. Meat Science: An Introductory Text (PD Warris, Ed.). 1 ed. CABI Publishing, Oxon, UK.

Wattanachant, S., S. Benjakul, and D. A. Ledward. 2004. Composition, color, and texture of thai indigenous and broiler chicken muscles. Poult. Sci. 83:123–128.

Webb, J. E., and C. C. Brunson. 1972. Effects of Eviscerating Line Trimming on Tenderness of Broiler Breast Meat. Poult. Sci. 51:200–203.

Weber, A., and J. M. Murray. 1973. Molecular control mechanisms in muscle contraction. Physiol. Rev. 53:612–672.

Wills, K. M., R. M. Mitacek, G. G. Mafi, D. L. Vanoverbeke, D. Jaroni, R. Jadeja, and R. Ramanathan. 2017. Improving the lean muscle color of dark-cutting beef by aging, antioxidant-enhancement, and modified atmospheric packaging. J. Anim. Sci. 95:5378–5387.

Wiskus, K. J., P. B. Addis, and R. T.-I. Ma. 1973. Postmortem Changes in Dark Turkey Muscle. J. Food Sci. 38:313–315.

Wiskus, K. J., P. B. Addis, and R. T.-I. Ma. 1976. Distribution of βR, αR and αW Fibers in Turkey Muscles. Poult. Sci. 55:562–572.

Woelfel, R. L., C. M. Owens, E. M. Hirschler, R. Martinez-Dawson, and A. R. Sams. 2002. The characterization and incidence of pale, soft, and exudative broiler meat in a commercial processing plant. Poult. Sci. 81:579–584.

Woelfel, R. L., and A. R. Sams. 2001. Marination Performance of Pale Broiler Breast Meat. Poult. Sci. 80:1519–1522.

Yu, L. H., E. S. Lee, J. Y. Jeong, H. D. Paik, J. H. Choi, and C. J. Kim. 2005. Effects of thawing temperature on the physicochemical properties of pre-rigor frozen chicken breast and leg muscles. Meat Sci. 71:375–382.

Zhuang, H., and E. M. Savage. 2009. Variation and Pearson correlation coefficients of Warner-Bratzler shear force measurements within broiler breast fillets. Poult. Sci. 88:214–220.

Zhuang, H., and E. M. Savage. 2013. Comparison of cook loss, shear force, and sensory descriptive profiles of boneless skinless white meat cooked from a frozen or thawed state. Poult. Sci. 92:3003–3009.

Zocchi, C., and A. R. Sams. 1999. Tenderness of broiler breast fillets from carcasses treated with electrical stimulation and extended chilling times. Poult. Sci. 78:495–498.

CHAPTER II

CHARACTERIZATION OF GROWTH PATTERNS AND CARCASS CHARACTERISTICS OF MALE AND FEMALE BROILERS FROM FOUR COMMERICAL STRAINS FED ONE OF TWO DIETS

ABSTRACT

Over the last few decades, the poultry industry has seen the emergence of various market segments that are beneficial for rearing various flock sizes. Two concurrent experiments consisting of 1,200 broilers were conducted to evaluate the effects of sex and diet on the performance of four commercially available broiler strains, including standard yielding (SY) and high yielding (HY) strains. Within each experiment, a small bird and big bird debone market were targeted to give variable carcass size. Two common polyphasic diets were assessed using varying levels of digestible Lys. The low-density diet (LD) consisted of 1.20, 1.10, 1.00, and 0.96% digestible Lys and the high-density diet (HD) consisted of 1.32, 1.21, 1.10, and 1.06%. Weekly BW, BW gain, feed intake (FI), FCR, and processing yields were assessed during both experiments. Broilers fed the HD diets responded better than those fed the LD diets, regardless of sex, with increased BW and decreased FCR ($P<0.05$). Additionally, males converted a higher BW with a lower FCR ($P<0.05$) than their female cohorts. Male HY strains provided the highest carcass yields ($P<0.05$) compared to SY strains, with no differences observed in females ($P>0.05$). High density diets also produced increases in carcass, breast, and tender yield ($P<0.05$) for males, but was not present for females ($P<0.05$). Overall, the impact of strain had the highest effect on performance traits and carcass yields. Therefore, the use of specific strains for various market segments is beneficial for integrators to maximize return.

Key Words: broiler, amino acid density, sex, strain, yields

INTRODUCTION

The world poultry market is continually morphing to meet consumer demands for variety in lean protein sources. To meet this demand, continual genetic selection by primary breeder companies is conducted to lower feed conversion (FCR) and increase breast meat yield in broilers (Kerr et al., 1999). As an unintended consequence, meat quality attributes of high-yielding broilers has been declining due to numerous unknown genetic and non-genetic factors (Owens, 2014; Bailey et al., 2015). Previous researchers have found that high-yielding broilers have an increased incidence of breast meat myopathies linked to growth rate, resulting in increased condemnations in processing plants and profit loss (Kuttappan et al., 2013b; Owens, 2014; Tijare et al., 2016). Despite an unknown etiology for these myopathies, extra-genetic factors such as strain, sex, and dietary nutrient density have also been linked with meat quality (Abdullah et al., 2010).

Broiler performance, as indicated by body weight, feed intake (FI), and FCR, have been shown to vary among broiler strain (Smith and Pesti, 1998; Smith et al., 1998). Standard and high yielding broiler strains are the two main categories of broilers found in the commercial market. Previous data has reported that standard yielding broilers can have twice the body weight gain of their high yielding counterpart (Han and Baker, 1993). High yielding strains are selected to have increased high value breast meat yield while standard yielding strains have better FCR (Mehaffey et al., 2006). However, López et al. (2011) found that strain had no impact on live growth performance for BW when grown to 42 days. Differences among strains can be beneficial for selecting flocks for economic advancement. With significant differences reported in feed intake and feed conversion ratio between strain, integrators are looking to optimize

production costs by reducing feed cost, which represents the largest input cost in live production (Jackson et al., 1982; Abdullah et al., 2010; Maynard et al., 2019).

Sex has also been shown to influence broiler performance. Growth patterns for female broilers tend to crest at earlier ages than male broilers, corresponding with increased fat deposition for female birds (Waldroup et al., 1990). These differences in growth patterns result in higher body weights and lower FCR for male broilers (Coon et al., 1981). Differences attributed to sex also extend to carcass traits with female broilers producing higher white meat yield, whereas male broilers produce higher dark meat yields (Corzo et al., 2005). Some researchers have indicated that because of the difference in growth patterns between males and females, nutritional requirements are also dependent on broiler sex (Han and Baker, 1993). While minor differences in amino acid requirements have been reported between male and female broilers, the largest differences have been observed for the digestible lysine requirement (Hunchar and Thomas, 1976; Han and Baker, 1993; Rosa et al., 2001a; b; Dozier et al., 2009; Maynard et al., 2020). These responses have led researchers to theorize that essential amino acid requirements, expressed relative to digestible lysine, are similar between the sexes limiting responses when individual amino acids are titrated (Wu, 2014). However, the nutritional amino acid plane, or density, is increased for male broilers compared to females (Wu, 2014).

Dietary nutritional differences can directly impact the performance of broiler chickens. The current corn-soy based diets utilized today are supplemented with various feed-grade amino acids in an attempt to decrease diet cost and improve performance (Kidd et al., 2013). A previous study conducted by Waldroup et al. (1990) found that dietary amino acid content directly influences growth performance. Corzo et al. (2005) found that broilers fed a high density amino acid diet, when compared to broilers fed a low density diet, produced lower levels of fat but an

increased percent of breast meat and tender yield. Dozier et al. (2008) reported that dietary amino acid interactions vary for broilers raised for different markets (i.e. fast food vs. tray pack). Body weight gain, for example, positively responds to increased amino acid density from hatch to 5 wk of age, whereas it is not as responsive post 5 wks (Dozier et al., 2008). Vieira and Angel (2012) established that standard yielding broilers respond favorably to higher density diets for performance when compared to high yielding strains. A multitude of projects have assessed the effects of amino acid density in the diet and have concluded that feeding diets with increased amino acid density result in better FCR, body weight gain, and higher breast meat yield (Corzo et al., 2005; Dozier et al., 2008, 2009; López et al., 2011; Vieira and Angel, 2012). Therefore, the aim of the present work was to assess dietary and sex effect, as well as their interactions, on growth performance, carcass size and traits, and meat quality characteristics of four commercial strains.

MATERIALS AND METHODS

All animal rearing was approved by the Institutional Animal Care and Use Committee at the University of Arkansas (protocol # 20016).

Animal Husbandry

Two concurrent experiments were conducted using a total of 2,400 sex separate broiler chicks from four commercial strains (two standard yielding (SYA and SYB) and two high yielding (HYA and HYB)) that were sourced from a local commercial hatchery. Experiment 1 utilized 1,200 male broiler chicks, whereas Experiment 2 utilized 1,200 female broiler chicks. Upon arrival to the University of Arkansas poultry research farm, 25 broiler chicks were group weighed and placed in 1.2 x 1.82-meter floor pens (48 pens per experiment; 0.09 m^2 per bird). Each pen was outfitted with fresh pine shavings, a hanging feeder, and a nipple drinker water line. Birds were allowed unrestricted access to feed and water throughout the trial.

Environmental conditions were maintained in a closed-sided house with a set point temperature of 32^{o}C when placed. The set point was reduced by 2^{o}C each week resulting in an endpoint temperature of 15^{o}C. A lighting schedule was set at 24L:0D from day 0 to 1, 23L:1D from days 1 to 7, and 16L:8D from days 7 to 54 for the remainder of the trial (Maynard et al., 2019). Crumbled starter diets were fed from day 0 to day 14, whereas the grower, finisher, and withdrawal diets were fed as pellets from 15 to 28, 29 to 42, and 43 to 54 days of age, respectively. Weekly body weights (**BW**) and feed consumption (**FI**) were recorded by pen and used to calculate individual body weight gain (**BWG**) and feed conversion ratio (**FCR**). Mortality and culled birds were collected and weighed twice daily to allow for calculation of mortality corrected feed conversion ratio.

Dietary treatments

Diets were fed across four feeding phases including: a starter (d 0 to 14), grower (d 15 to 28), finisher (d 29 to 42), and withdrawal (d 43 to 54). High and low amino acid density diets were formulated for each dietary phase (Table 1). Digestible lysine levels were 1.20, 1.10, 1.00, and 0.96% for the low amino acid diets and 1.32, 1.21, 1.10, and 1.06% for the high amino acid density diets for the starter, grower, finisher, and withdrawal phases, respectively. Dietary treatments were intended to be held constant throughout both experiments, but starter diets were inadvertently switched resulting in dietary treatments of low, high, high, high (Diet 1) and high, low, low, low (Diet 2).

Processing

Broilers from both experiments were processed on two days targeting a carcass size of 2.5 kg and 3.8 kg corresponding with small bird (i.e. small bird) and large bird (i.e. big bird debone) market weights. Birds were processed on day 38 and 47 in Experiment 1 and days 40 and 54 for Experiment 2. Following a 10-hour feed withdrawal period, 12 randomly selected

broilers from each pen were transported to the University of Arkansas pilot processing plant, and individually weighed upon arrival to the plant. Birds were then hung on inline shackles, electrically stunned (11 V, and 11 mA for 11 s), exsanguinated, scalded in hot water (53.8°C, 2 min), and then defeathered (Mehaffey et al., 2006). Prior to mechanical evisceration, necks and hocks were manually removed from each bird. Following evisceration, abdominal fat was collected according to Waldroup et al. (1990), weighed, and hot carcass weights were recorded. Carcasses were then subjected to a 0.25-hour prechill, at 12°C, before being placed in 0°C immersion chilling tanks for 2.5-hours with manual agitation. At 3-hours postmortem, chilling tanks were then drained of water, and carcasses re-weighed and deboned to determine *Pectoralis major* and *P. minor*, wing, and leg weights. Part weights were then divided by individual back dock live weight to determine percent yields.

Statistics

Pen served as the experimental unit and treatments were assigned in a randomized complete block design, with pen location serving as the blocking factor. Due to differences in growth period, data from male and female trials were analyzed separately creating more uniform comparisons. Both experiments were comprised of a 2 x 4 factorial arrangement (diet × strain), with each treatment represented by six replicate pens of 24 birds. Mortality data were arcsine square root transformed prior to statistical analysis.

Results for each processing within each experiment were combined and analyzed as a 2 x 2 x 4 factorial (diet x carcass size x strain). Mortality data were arcsine square root transformed prior to analysis to normalize data. All data were subjected to a two-way ANOVA using JMP Pro 14 software to detect effects of strain or diet and their subsequent interactions. Statistical significance was set at $P \leq 0.05$. Where appropriate, means were then separated using a Student's *t* test.

RESULTS

Analyzed values for dietary crude protein were higher than formulated values for all feeding phases. Overall, analyzed crude protein trends agreed with formulated values, displaying separation in the formulated low and high diets. Overall final broiler performance exceeded breeder specifications (Figures 1 through 3). Final mortality in Experiment 1 and Experiment 2 was 1.75% and 2.00%, respectively.

Experiment 1 Live performance of males

Live performance data from Experiment 1 can be found in Tables 2 through 5. Body weight gain was influenced ($P<0.05$) by broiler strain throughout the experimental period, while diet had no effect on BW gain ($P>0.05$). Weekly assessment results of cumulative BW gain indicated that SYA had the highest ($P<0.05$) BW gain, HYB had the lowest, and HYA and SYB were intermediate through four weeks of age. At d 35, BW gain was highest ($P<0.05$) for SYA broilers, followed by SYB, HYA, and HYB broilers with separation between all broiler strains ($P<0.05$). At 42 d of age, SYA and SYB broilers had the highest ($P<0.05$) BW gain, HYB the lowest, and HYA intermediate. A strain × diet interaction ($P<0.05$) was observed for 0 to 47 d BW gain where SYA broilers fed Diet 2 had the highest BW gain and HYB broilers fed Diet 2 had the lowest.

Similar to BW gain, feed intake was influenced ($P<0.05$) by strain throughout the experimental period but diet did not influence ($P>0.05$) feed intake. For the 0 to 7 d period, SYA broilers had higher ($P<0.05$) feed intake than all other broiler strains. At d 14, SYA broilers had higher ($P<0.05$) feed intake than HYB, while HYA and SYB broilers were intermediate. At d 21, SYA broilers had the highest ($P<0.05$) feed intake followed by HYA, SYB, and HYB broilers with separation ($P<0.05$) between all strains. On d 28, trends in feed intake returned to those

observed at d 14 where SYA broilers had higher ($P<0.05$) feed intake than HYB, while HYA and SYB broilers were intermediate. A strain × diet interaction ($P<0.05$) was observed for feed intake on d 35 where FI was highest for SYA broilers fed Diet 2, lowest for HYB broilers fed Diets 1 and 2, and intermediate for all other broilers fed either Diet 1 or Diet 2. This interaction continued ($P<0.05$) throughout the experiment.

An interaction ($P<0.05$) was observed for 0 to 7 d FCR where SYA and HYB broilers fed Diet 1 had the highest FCR, HYA broilers fed Diet 1 had the lowest, and SYA broilers fed Diet 2 and SYB fed Diet 1 were intermediate. High yielding strain A broilers fed Diet 2 were intermediate ($P>0.05$) of SYA and HYB broilers fed Diet 1 and SYA broilers fed Diet 2 and SYB fed Diet 1, while SYB broilers fed Diet 2 were intermediate ($P>0.05$) of SYA broilers fed Diet 2 and SYB fed Diet 1 and HYA broilers fed Diet 1. An interaction was again observed at d 21 where SYA broilers fed Diet 1, HYA broilers fed Diet 2, and HYB broilers fed Diet 2 had the highest FCR, HYA and SYB broilers fed Diet 1 had the lowest, and all others being intermediate. No differences ($P>0.05$) were observed on 0 to 28 d FCR as a result of strain, diet, or their interaction. For main effect of strain 0 to 35 d FCR, HYA broilers had higher ($P<0.05$) FCR than SYB, while HYA and HYB were intermediate. The main effect of diet on 0 to 35 d FCR indicated that broilers fed Diet 2 had a higher FCR ($P<0.05$). High yielding strain A had higher ($P<0.05$) FCR for the 0 to 42 d period than all other broilers. As with 0 to 35 d FCR, the main effect of diet indicated at broilers fed Diet 2 had higher FCR. At the conclusion of the experiment (0 to 47 d), FCR was highest ($P<0.05$) for HYA and HYB broilers, lowest for SYB broilers, and intermediate for SYA broilers.

Experiment 1 Processing of males

No strain × diet × carcass interactions were observed for any processing measurement in Experiment 1 (males, Table 6). Chilled carcass yields were higher ($P<0.05$) for HYA and HYB broilers than SYA and SYB broilers. Breast yields were highest ($P<0.05$) for HYB broilers followed by HYA, SYA, and SYB broilers. Leg yields were highest ($P<0.05$) for SYB broilers, lowest for HYA and HYB broilers, and intermediate for SYA broilers. Broilers processed at 3.8 kg displayed larger ($P<0.05$) hot carcass, fat, chilled carcass, breast, and tender yields than broilers processed at 2.5 kg who had larger ($P<0.05$) wing and leg yields. Feeding Diet 1 resulted in higher ($P<0.05$) hot carcass, chilled carcass, breast, and tender yields while lowering ($P<0.05$) fat yields than when broilers were fed Diet 2.

Experiment 2 Live performance of females

No strain × diet interactions ($P>0.05$) were observed for any live performance measurement in Experiment 2 (females, Tables 7 through 10). Body weight gain for the 0 to 7 d period was highest ($P<0.05$) for SYA followed by HYA, SYB, and HYB with separation between all strains. Weekly cumulative BW gain for the 0 to 14 and 0 to 21 d periods was highest ($P<0.05$) for SYA broilers, lowest for HYB broilers, and intermediate for HYA and SYB broilers. For the 0 to 28 d period, BW gain was highest ($P<0.05$) for SYA broilers followed by SYB, HYA, and HYB broilers will separation between all broiler strains. Weekly cumulative BW gain for the 0 to 35 through 0 to 49 d periods was highest ($P<0.05$) for SYA broilers, lowest for HYB broilers, and intermediate for SYB and HYA broilers. Body weight gain at the conclusion of the experiment (0 to 54 d) was higher ($P<0.05$) for SYA and SYB broilers than for HYA and HYB broilers.

Feed intake was highest (P<0.05) for SYA and HYA broilers and lowest for SYB and HYB broilers during the 0 to 7 d period. For the 0 to 14 and 0 to 21 d periods, feed intake was highest (P<0.05) for SYA broilers followed by HYA, SYB, and HYB broilers with separation between all broiler strains. For the 0 to 28 to 0 to 42 d periods, feed intake was highest (P<0.05) for SYA broilers, lowest for HYB broilers, and intermediate for HYA and SYB broilers. On d 49 feed intake was highest (P<0.05) for SYA and SYB broilers and lowest for HYA and HYB broilers. At the conclusion of the experiment (0 to 54 d) SYA broilers had the highest (P<0.05) feed intake, HYB the lowest, and HYA intermediate. Standard yielding strain B had a feed intake similar (P>0.05) to SYA and HYA broilers.

Feed conversion ratio was not influenced by strain (P>0.05) for the 0 to 7 or 0 to 14 d periods. For the 0 to 14 d period, FCR was highest (P<0.05) for broilers fed Diet 1 and lowest for broilers fed Diet 2. The main effect of strain on FCR for the 0 to 21 d period displayed the highest (P<0.05) FCR for SYA and HYA broilers and lowest for SYB and HYB broilers. For the 0 to 28 d period, FCR was highest (P<0.05) for HYA broilers followed by SYA, HYB, and SYB broilers with separation between all strains. For the 0 to 35 and 0 to 42 d periods, FCR was highest (P<0.05) for SYA and HYA broilers and lowest for SYB and HYB broilers. At d 49, FCR was highest (P<0.05) for HYA broilers, lowest for HYB broilers, and intermediate for SYB broilers. Feed conversion ratio for SYA broilers was intermediate (P>0.05) of that of SYB and HYB broilers. At the conclusion of the experiment (0 to 54 d), FCR was highest for HYB broilers, lowest for HYA broilers, and intermediate for SYA and SYB broilers. For the 0 to 21 to 0 to 49 d periods, broilers fed Diet 2 had a higher (P<0.05) FCR than broilers fed Diet 1.

Experiment 2 Processing of females

No strain × diet × carcass interactions were observed for any processing measurement in Experiment 2 (Table 11). Breast meat yield was highest ($P<0.05$) for HYB broilers, lowest for SYA broilers, and intermediate for HYA and SYB broilers. Tender yields were higher ($P<0.05$) for HYA and HYB broilers than for SYA and SYB broilers. Female broilers processed at 2.5 kg yielded lower ($P<0.05$) for all processing yields, with the exception of leg, than broilers processed at 3.8 kg. Female broilers fed Diet 1 had higher ($P<0.05$) breast and tender yields and lower ($P<0.05$) fat and wing yields than broilers fed Diet 2.

DISCUSSION

In both experiments, d 0 BW varied among strains due to the age of the breeder flocks the chicks were sourced from (SYA, 40 wk; SYB 35 wk; HYA, 37 wk; HYB, 36 wk). Reports in the literature show that initial chick weight (i.e. hatching egg weight) can influence BW, BW gain, and carcass parts weights but does not necessarily affect FCR or carcass yields (Proudfoot and Hulan, 1981; Vieira and Moran, 1998). Therefore, discussion of live performance for both experiments will focus on FCR.

Interestingly, the occurrence of a strain × diet interaction for male FCR was not consistent, only appearing for the 0 to 7 and 0 to 21 d periods. These interactions occurred 7 days into when a novel feed was placed due to the misplacement of starter feed at the beginning of the experiment. Studies evaluating research in the literature have theorized that a 7 to 10 d adaption period is necessary for broilers to normalize feed intake (Cherry et al., 1983; Leeson et al., 1996). The presence of these interactions may indicate that the efficiency in which the modern broiler may be able to adapt to feed changes involving differences in nutrient density may be dependent upon the strain of broiler being fed. Corzo et al. (2010) conducted an amino acid

density study evaluating the use of amino acid regimens in male Cobb × Cobb 500 broilers. Due to the style of study, Corzo et al. (2010) included treatments that emulate those fed during the current male study. At 14 d, Corzo et al. (2010) observed a reduced FCR for broilers fed a higher density starter diet in agreement with the current findings. At 28 d, Corzo et al. (2010) observed a 5 point separation in FCR with broilers fed a high amino acid starter and medium amino acid grower having a FCR of 1.46 and broilers fed a medium amino acid starter and high amino acid grower having a FCR of 1.41. This separation in FCR was not observed in the present study at 28 d. Corzo et al. (2010) carried out their experiment to 42 d where the feeding regimen containing a high amino acid starter, medium amino acid grower, and medium amino acid finisher had an approximate 6.5 points of FCR higher than broilers fed a feeding regimen containing a medium amino acid starter, high amino acid grower, and high amino acid finisher. Similarly, a difference of approximately 6.5 points of FCR was observed between male broilers fed Diet 1 and Diet 2 in the current experiment. The aforementioned interactions were not observed in female broilers in Experiment 2. After the diets were switched at 14 d, the differences that were observed in female FCR due to the effect of diet were maintained throughout the rest of the study. The lack of observation of interactions in females similar to those observed in male broilers in Experiment 1 is potentially due to female broilers reduced responsiveness to dietary amino acid level and may indicate that females have a shorter adaptation diet when the nutrient density changes across feeding phases (Kidd et al., 2004).

Differences in FCR according to strain varied in the two studies presented here. Male broiler FCR trends show a difference between the cumulative FCR of both standard yielding strains and both of the high yielding strains, whereas in females a distinction appears to be drawn between SYA and HYA and SYB and HYB. Corzo et al. (2005) conducted a three-level factorial

evaluating diet density, sex, and strain and reported significant effects of strain on FCR where multipurpose strains (standard yielding strains) had lower FCR values than high-yielding strains. They also observed interactive effects of strain × sex on FCR, in which females all performed similarly, regardless of strain, while male multipurpose strains (standard strains) had improved FCR compared to male high-yielding strains (Corzo et al., 2005).

Differences in male carcass and parts yields as a result of strain primarily aligned with differences associated with the strains used. High yielding broilers had higher yields for carcass, breast, and tenders whereas the standard yielding broilers had higher yields for wings and legs. High yielding strains are genetically selected for increased white meat yield while standard yielding strains are selected for more uniform growth and genetic selection focused on live performance traits (Dozier et al., 2009). Corzo et al. (2005) similarly found that high-yielding strains produced higher breast meat yield than multipurpose strains (standard yielding strains). Differences in their experiments showed that carcass part yields were limited to breast and tender yields and fell in line with the male data from Experiment 1 without outlying effects on carcass, wing, and leg yields. The targeted change in yields associated with strains in females as opposed to that in males can likely be tied to females having a larger breast meat yield than males leaving less room to adjust the yields of other carcass parts, leading to numerical trends which generally agreed with those observed in males.

For both male and female broilers, increasing carcass size at slaughter influenced carcass and parts yields the same with the exception of wing yield which decreased in males and increased in females. In a series of papers published by Brewer et al. (2012a; b; c; d) similar trends can be observed when increasing carcass size at slaughter as reported herein. These changes in carcass traits are likely attributed to the effects of allometric growth and genetic

selection, where modern broilers prioritize lean muscle accretion (Zuidhof et al., 2014). Lean muscle accretion appears as convex in allometric breast meat growth curves, versus internal organ growth, which can be seen as concave growth within allometric liver growth curves (Zuidhof et al., 2014). Dietary treatments affected male and female broilers differently. Female carcass parts were less responsive than males, where only fat, wing, breast, and tender yields were impacted. These parts encompass both an indicator of the efficiency of amino acid usage (i.e. fat) and the key area (i.e. white meat) in which amino acid density has the most effect (Kidd et al., 2005; Corzo et al., 2010).

CONCLUSION

In conclusion, male broilers reached target carcass weights quicker than females with better FCR. Strain and diet have a larger effect on male broiler growth and carcass traits than on females, affecting all carcass parts instead of those that are reported to be directly influenced by amino acid density. Therefore, varying rates of amino acid inclusion may be beneficial for integrators to assess in regards to performance and yield.

ACKNOWLEDGMENTS

The authors are appreciative for the support of Cobb-Vantress, Inc. (Siloam Springs, AR) and the University of Arkansas Division of Agriculture (Fayetteville, AR) throughout this project.

REFERENCES

Abdullah, A. Y., N. A. Al-Beitawi, M. M. S. Rjoup, R. I. Qudsieh, and M. A. A. Ishmais. 2010. Growth performance, carcass and meat quality characteristics of different commercial crosses of broiler strains of chicken. J. Poult. Sci. 47:13–21.

Bailey, R. A., K. A. Watson, S. F. Bilgili, and S. Avendano. 2015. The genetic basis of pectoralis major myopathies in modern broiler chicken lines. Poult. Sci. 94:2870–2879.

Barbut, S. 2020. Understanding the woody breast syndrome and other myopathies in modern broiler chickens.Pages 99–102 in Australian Poultry Science Symposium. Sydney, Australia.

Brewer, V. B., J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2012a. Small bird programs: Effect of phase-feeding, strain, sex, and debone time on meat quality of broilers. Poult. Sci. 91:499–504.

Brewer, V. B., V. A. Kuttappan, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2012b. Big-bird programs: Effect of strain, sex, and debone time on meat quality of broilers. Poult. Sci. 91:248–254.

Brewer, V. B., C. M. Owens, and J. L. Emmert. 2012c. Phase feeding in a big-bird production scenario: Effect on growth performance, yield, and fillet dimension. Poult. Sci. 91:1256–1261.

Brewer, V. B., C. M. Owens, and J. L. Emmert. 2012d. Phase feeding in a small-bird production scenario : Effect on growth performance , yield , and fillet dimension Phase feeding in a small-bird production scenario : Effect on growth performance , yield , and fillet dimension. Poult. Sci. 91:1262–1268.

Cherry, J. A., D. E. Jones, D. F. Calabotta, and D. J. Zelenka. 1983. Feed Intake Responses of Mature White Leghorn Chickens to Changes in Feed Density. Poult. Sci. 62:1846–1849.

Coon, C. N., W. A. Becker, and J. V. Spencer. 1981. The Effect of Feeding High Energy Diets Containing Supplemental Fat on Broiler Weight Gain, Feed Efficiency, and Carcass Composition. Poult. Sci. 60:1264–1271.

Corzo, A., M. T. Kidd, D. J. Burnham, E. R. Miller, S. L. Branton, and R. Gonzalez-Esquerra. 2005. Dietary amino acid density effects on growth and carcass of broilers differing in strain cross and sex. J. Appl. Poult. Res. 14:1–9.

Corzo, A., M. W. Schilling, R. E. Loar II, L. Mejia, L. C. G. S. Barbosa, and M. T. Kidd. 2010. Responses of Cobb × Cobb 500 broilers to dietary amino acid density regimens. J. Appl. Poult. Res. 19:227–236.

Dozier, W. A., A. Corzo, M. T. Kidd, P. B. Tillman, and S. L. Branton. 2009. Digestible lysine requirements of male and female broilers from fourteen to twenty-eight days of age. Poult. Sci. 88:1676–1682.

Dozier, W. A., M. T. Kidd, and A. Corzo. 2008. Dietary amino acid responses of broiler chickens. J. Appl. Poult. Res. 17:157–167.

Han, Y., and D. H. Baker. 1993. Effects of sex, heat stress, body weight, and genetic strain on the dietary lysine requirement of broiler chicks. Poult. Sci. 72:701–708.

Hunchar, J. G., and O. P. Thomas. 1976. The tryptophan requirement of male and female broilers during the 4-7 week period. Poult. Sci. 55:379–383.

Jackson, S., J. D. Summers, and S. Leeson. 1982. Effect of dietary protein and energy on broiler performance and production costs. Poult. Sci. 61:2232–2240.

Kerr, B. J., M. T. Kidd, K. M. Halpin, G. W. Mcward, and C. L. Quarles. 1999. Lysine level increases live performance and breast yield in male broilers. J. Appl. Poult. Res. 8:381–390.

Kidd, M. T., A. Corzo, D. Hoehler, E. R. Miller, and W. A. Dozier. 2005. Broiler Responsiveness (Ross × 708) to Diets Varying in Amino Acid Density. Poult. Sci. 84:1389–1396.

Kidd, M. T., C. D. McDaniel, S. L. Branton, E. R. Miller, B. B. Boren, and B. I. Fancher. 2004. Increasing amino acid density improves live performance and carcass yields of commercial broilers. J. Appl. Poult. Res. 13:593–604.

Kidd, M. T., P. B. Tillman, P. W. Waldroup, and W. Holder. 2013. Feed-grade amino acid use in the United States: The synergetic inclusion history with linear programming. J. Appl. Poult. Res. 22:583–590.

Kuttappan, V. A., V. B. Brewer, A. Mauromoustakos, S. R. McKee, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2013a. Estimation of factors associated with the occurrence of white striping in broiler breast fillets. Poult. Sci. 92:811–819.

Kuttappan, V. A., Y. S. Lee, G. F. Erf, J. F. Meullenet, S. R. Mckee, and C. M. Owens. 2012. Consumer acceptance of visual appearance of broiler breast meat with varying degrees of white striping. Poult. Sci. 91:1240–1247.

Kuttappan, V. A., C. M. Owens, C. Coon, B. M. Hargis, and M. Vazquez-A Non. 2017. Research Note Incidence of broiler breast myopathies at 2 different ages and its impact on selected raw meat quality parameters. Poult. Sci. 96:3005–3009.

Kuttappan, V. A., H. l. Shivaprasad, D. P. Shaw, B. A. Valentine, B. M. Hargis, F. D. Clark, S. R. McKee, and C. M. Owens. 2013b. Pathological changes associated with white striping in broiler breast muscles. Poult. Sci. 92:331–338.

Leeson, S., L. Caston, and J. D. Summers. 1996. Broiler Response to Energy or Energy and Protein Dilution in the Finisher Diet. Poult. Sci. 75:522–528.

López, K. P., M. W. Schilling, and A. Corzo. 2011. Broiler genetic strain and sex effects on meat characteristics. Poult. Sci. 90:1105–1111.

Maynard, C. W., R. E. Latham, R. Brister, C. M. Owens, and S. J. Rochell. 2019. Effects of Dietary Energy and Amino Acid Density during Finisher and Withdrawal Phases on Live Performance and Carcass Characteristics of Cobb MV × 700 Broilers. J. Appl. Poult. Res. 28:729–742.

Maynard, C. W., S. Y. Liu, J. T. Lee, J. V. Caldas, J. J. Diehl, S. J. Rochell, and M. T. Kidd.

2020. Determination of dietary digestible valine:lysine ratio for Cobb MV × 500 male and female broilers from 15 to 35 d of age. Poult. Sci. 99:Abstr.

Mehaffey, J. M., S. P. Pradhan, J. F. Meullenet, J. L. Emmert, S. R. McKee, and C. M. Owens. 2006. Meat quality evaluation of minimally aged broiler breast fillets from five commercial genetic strains. Poult. Sci. 85:902–908.

Owens, C. M. 2014. Identifying quality defects in poultry processing. Watt Poult. USA:42–50.

Proudfoot, F. G., and H. W. Hulan. 1981. The Influence of Hatching Egg Size on the Subsequent Performance of Broiler Chickens. Poult. Sci. 60:2167–2170.

Rosa, A. P., G. M. Pesti, H. M. Edwards, and R. I. Bakalli. 2001a. Threonine requirements of different broiler genotypes. Poult. Sci. 80:1710–1717.

Rosa, A. P., G. M. Pesti, H. M. Edwards, and R. Bakalli. 2001b. Tryptophan requirements of different broiler genotypes. Poult. Sci. 80:1718–1722.

Smith, E. R., and G. M. Pesti. 1998. Influence of Broiler Strain Cross and Dietary Protein on the Performance of Broilers. Poult. Sci. 77:276–281.

Smith, E. R., G. M. Pesti, R. I. Bakalli, G. O. Ware, and J. F. M. Menten. 1998. Further Studies on the Influence of Genotype and Dietary Protein on the Performance of Broilers. Poult. Sci. 77:1678–1687.

Soglia, F., A. K. Silva, S. Tappi, L. M. Lião, P. Rocculi, L. Laghi, and M. Petracci. 2019. Gaping of pectoralis minor muscles: Magnitude and characterization of an emerging quality issue in broilers. Poult. Sci. 98:6194–6204.

Tijare, V. V., F. L. Yang, V. A. Kuttappan, C. Z. Alvarado, C. N. Coon, and C. M. Owens. 2016. Meat quality of broiler breast fillets with white striping and woody breast muscle myopathies. Poult. Sci. 95:2167–2173.

Trocino, A., A. Piccirillo, M. Birolo, G. Radaelli, D. Bertotto, E. Filiou, and M. Petracci. 2015. Effect of genotype , gender and feed restriction on growth , meat quality and the occurrence of white striping and wooden breast in broiler chickens. Poult. Sci. 94:2996–3004.

Vieira, S. L., and C. R. Angel. 2012. Optimizing broiler performance using different amino acid density diets: What are the limits? J. Appl. Poult. Res. 21:149–155.

Vieira, S. L., and E. T. Moran. 1998. Broiler Yields Using Chicks from Egg Weight Extremes and Diverse Strains. J. Appl. Poult. Res. 7:339–346.

Waldroup, P. W., N. M. Tidwell, and A. L. Izat. 1990. The effects of energy and amino acid levels on performance and carcass quality of male and female broilers grown separately. Poult. Sci. 69:1513–1521.

Wu, G. 2014. Dietary requirements of synthesizable amino acids by animals: a paradigm shift in protein nutrition. J. Anim. Sci. Biotechnol. 5:1–12.

Zuidhof, M. J., B. L. Schneider, V. L. Carney, D. R. Korver, and F. E. Robinson. 2014. Growth, efficiency, and yield of commercial broilers from 1957, 1978, and 2005. Poult. Sci. 93:1–13.

Table 1. Experimental[1] starter (0 to 14 d), grower (15 to 28 d), finisher (29 to 42 d), and withdrawal diets (43 to 54 d) fed to male and female broilers from 0 to 54 d of age.

	Starter		Grower		Finisher		Withdrawal	
Item, % as-fed	L	H	L	H	L	H	L	H
Corn	60.610	55.201	63.010	58.513	65.559	62.644	65.396	64.468
Soybean meal	34.288	38.824	30.943	34.694	27.513	29.886	27.738	28.355
Poultry fat	1.608	2.445	2.834	3.522	3.999	4.419	4.063	4.136
DL-Methionine	0.319	0.376	0.274	0.329	0.260	0.321	0.226	0.301
L-Lysine-HCL	0.206	0.225	0.183	0.212	0.162	0.219	0.104	0.213
L-Threonine	0.133	0.157	0.099	0.126	0.079	0.117	0.048	0.109
Limestone	1.090	1.063	1.052	1.029	1.014	0.999	1.013	1.009
Dicalcium phosphate	0.974	0.958	0.835	0.821	0.695	0.687	0.693	0.692
Salt	0.405	0.399	0.411	0.406	0.418	0.415	0.418	0.417
Vitamin and mineral premix[2]	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
Choline chloride (60%)	0.055	0.041	0.047	0.036	0.040	0.032	0.039	0.037
Phytase	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Coccidiastat[3]	0.050	0.050	0.050	0.050	0.000	0.000	0.000	0.000
Calculated composition, % unless noted otherwise[4]								
AME, kcal/kg	3,000	3,000	3,100	3,100	3,200	3,200	3,200	3,200
CP	21.50	23.34	20.00	21.54	18.50	19.54	18.50	18.92
Ca	0.90	0.90	0.84	0.84	0.78	0.78	0.78	0.78
Available P	0.45	0.45	0.42	0.42	0.39	0.39	0.39	0.39
Na	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
dLys	1.20	1.32	1.10	1.21	1.00	1.10	0.96	1.06
dTSAA	0.90	0.99	0.83	0.91	0.78	0.86	0.75	0.83
dThr	0.82	0.90	0.74	0.81	0.67	0.74	0.64	0.71
dVal	0.92	0.99	0.86	0.92	0.80	0.84	0.81	0.81
dIle	0.83	0.91	0.78	0.84	0.72	0.76	0.72	0.73
dArg	1.31	1.44	1.21	1.32	1.11	1.18	1.12	1.13
dTrp	0.24	0.27	0.22	0.24	0.20	0.22	0.21	0.21
Total Gly+Ser	1.99	2.15	1.86	1.99	1.72	1.81	1.73	1.75
Analyzed composition, %								
CP	24.45	24.9	22.7	23.85	20.55	21.05	20.25	21.05

[1]L = low amino acid density; H = high amino acid density

[2]The vitamin and mineral premix contained (per kg of complete feed): manganese, 100.0 mg; zinc, 100.0 mg; iron. 50.0 mg;
copper, 11.3 mg; iodine, 1.5 mg; selenium, 0.2 mg; vitamin A, 7716 IU; vitamin D_3, 2756 ICU; vitamin E, 17 IU; vitamin B_{12},
0.01 mg; menadione, 0.83 mg; riboflavin, 6.61 mg; d-panthothenie acid, 6.61 mg; thiamine, 1.10 mg; niacin, 27.56 mg;
pyridoxine, 1.38 mg; folic acid, 0.69 mg; biotin, 0.03 mg; choline, 385.81 mg.

[3]Supplied 60g of salinomycin Na per 907.2 kg of complete feed to prevent coccidiosis

[4]d = digestible

Table 2. Live performance[1] of male broilers from various strains fed Diet 1 or Diet 2 from 0 to 14 d post-hatch.

	0 to 7 d					0 to 14 d			
Treatment	BW d0	BW d7	BWG	FI	FCR	BW d14	BWG	FI	FCR
Interactions (n = 6)									
SYA, 1	0.041	0.182	0.141	0.164	1.171^{a}	0.465	0.424	0.522	1.234
SYA, 2	0.041	0.185	0.144	0.150	1.035^{b}	0.474	0.433	0.507	1.171
HYA, 1	0.039	0.171	0.132	0.138	0.882^{c}	0.452	0.413	0.490	1.191
HYA, 2	0.039	0.167	0.129	0.135	1.049^{ab}	0.430	0.392	0.463	1.182
SYB, 1	0.038	0.167	0.129	0.138	1.033^{b}	0.439	0.401	0.476	1.190
SYB, 2	0.038	0.168	0.130	0.132	1.011^{bc}	0.442	0.404	0.457	1.134
HYB, 1	0.038	0.161	0.123	0.143	1.178^{a}	0.403	0.365	0.449	1.234
HYB, 2	0.038	0.161	0.123	0.131	1.063^{ab}	0.406	0.369	0.432	1.172
SEM	0.0003	0.0021	0.0021	0.0057	0.0465	0.0069	0.0068	0.0083	0.0134
Main effect of strain[2] (n = 24)									
SYA	0.041^{a}	0.184^{a}	0.140^{a}	0.157^{a}	1.103	0.470^{a}	0.429^{a}	0.514^{a}	1.203^{a}
HYA	0.039^{b}	0.169^{b}	0.131^{b}	0.136^{b}	0.966	0.441^{b}	0.402^{b}	0.476^{b}	1.186^{ab}
SYB	0.038^{c}	0.167^{b}	0.127^{b}	0.135^{b}	1.022	0.440^{b}	0.403^{b}	0.467^{b}	1.162^{b}
HYB	0.038^{c}	0.161^{c}	0.121^{c}	0.137^{b}	1.120	0.405^{c}	0.367^{c}	0.441^{c}	1.203^{a}
SEM	0.0002	0.0015	0.0015	0.0040	0.0328	0.0049	0.0048	0.0059	0.0095
Main effect of diet[3] (n = 48)									
1	0.038	0.167	0.129	0.138	1.033	0.439	0.401	0.476	1.190^{a}
2	0.038	0.168	0.130	0.132	1.011	0.442	0.404	0.457	1.134^{b}
SEM	0.0003	0.0021	0.0021	0.0057	0.0465	0.0069	0.0068	0.0083	0.0134
P-values									
Strain	**<0.001**	**<0.001**	**<0.001**	**0.001**	**0.006**	**<0.001**	**<0.001**	**<0.001**	**0.012**
Diet	1.000	0.741	0.649	0.414	0.740	0.759	0.770	0.112	**0.006**
Strain × Diet	0.981	0.465	0.449	0.744	**0.009**	0.133	0.123	0.894	0.160

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]BW = body weight, BWG = body weight gain, FI = feed intake, FCR = feed conversion ratio

[2]SYA = Standard yielding A, HYA = high yielding A, SYB = standard yielding B, HYB = high yielding B

[3]Diet 1 = LHHH; Diet 2 = HLLL

Table 3. Live performance[1] of male broilers from various strains fed Diet 1 or Diet 2 from 0 to 28 d post-hatch.

	0 to 21 d				0 to 28 d			
Treatment	BW d21	BWG	FI	FCR	BW d28	BWG	FI	FCR
Interactions (n = 6)								
SYA, 1	0.989	0.948	1.220	1.288[a]	1.644	1.604	2.214	1.382
SYA, 2	1.000	0.959	1.237	1.283[ab]	1.689	1.648	2.310	1.407
HYA, 1	0.959	0.920	1.183	1.243[c]	1.593	1.554	2.176	1.406
HYA, 2	0.929	0.891	1.163	1.304[a]	1.549	1.511	2.142	1.419
SYB, 1	0.960	0.922	1.148	1.237[c]	1.613	1.575	2.124	1.350
SYB, 2	0.936	0.898	1.128	1.252[bc]	1.587	1.549	1.113	1.366
HYB, 1	0.870	0.833	1.062	1.274[ab]	1.457	1.419	1.957	1.384
HYB, 2	0.851	0.813	1.053	1.291[a]	1.408	1.370	1.963	1.448
SEM	0.0124	0.0124	0.0157	0.0107	0.0259	0.0258	0.0263	0.0227
Main effect of strain[2] (n = 24)								
SYA	0.995[a]	0.954[a]	1.228[a]	1.286	1.667[a]	1.626[a]	2.262[a]	1.394
HYA	0.944[b]	0.906[b]	1.173[b]	1.273	1.571[b]	1.532[b]	2.159[b]	1.412
SYB	0.948[b]	0.910[b]	1.138[c]	1.245	1.600[b]	1.562[b]	2.119[b]	1.358
HYB	0.860[c]	0.823[c]	1.057[d]	1.282	1.432[c]	1.394[c]	1.960[c]	1.416
SEM	0.0088	0.0088	0.0111	0.0076	0.0183	0.0182	0.0186	0.0160
Main effect of diet[3] (n = 48)								
1	0.960	0.922	1.148	1.237	1.613	1.575	2.124	1.350
2	0.936	0.898	1.128	1.252	1.587	1.549	2.113	1.366
SEM	0.0124	0.0124	0.0157	0.0107	0.0259	0.0258	0.0263	0.0227
P-values								
Strain	**<0.001**	**<0.001**	**<0.001**	**0.002**	**<0.001**	**<0.001**	**<0.001**	0.056
Diet	0.180	0.176	0.388	0.327	0.484	0.483	0.772	0.613
Strain × Diet	0.360	0.358	0.615	**0.023**	0.253	0.258	0.087	0.662

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]BW = body weight, BWG = body weight gain, FI = feed intake, FCR = feed conversion ratio

[2]SYA = Standard yielding A, HYA = high yielding A, SYB = standard yielding B, HYB = high yielding B

[3]Diet 1 = LHHH; Diet 2 = HLLL

Table 4. Live performance[1] of male broilers from various strains fed Diet 1 or Diet 2 from 0 to 42 d post-hatch.

	0 to 35 d				0 to 42 d			
Treatment	BW d35	BWG	FI	FCR	BW d42	BWG	FI	FCR
Interactions (n = 6)								
SYA, 1	2.378	2.338	3.209^{b}	1.379	3.136	3.095	4.424^{b}	1.482
SYA, 2	2.408	2.367	3.387^{a}	1.432	3.260	3.220	4.676^{a}	1.534
HYA, 1	2.291	2.252	3.171^{b}	1.391	3.083	3.044	4.401^{b}	1.516
HYA, 2	2.208	2.169	3.131^{b}	1.452	2.931	2.892	4.341^{b}	1.557
SYB, 1	2.349	2.311	3.101^{b}	1.338	3.218	3.180	4.378^{b}	1.450
SYB, 2	2.278	2.241	3.103^{b}	1.388	3.081	3.043	4.381^{b}	1.514
HYB, 1	2.138	2.100	2.854^{c}	1.360	2.923	2.886	4.023^{c}	1.475
HYB, 2	2.092	2.054	2.875^{c}	1.401	2.850	2.812	4.032^{c}	1.521
SEM	0.0306	0.0305	0.0394	0.0129	0.0541	0.0540	0.0510	0.0137
Main effect of strain[2] (n = 24)								
SYA	2.393^{a}	2.352^{a}	3.298	1.405^{ab}	3.198^{a}	3.157^{a}	4.550	1.508^{b}
HYA	2.249^{c}	2.211^{c}	3.151	1.421^{a}	3.007^{b}	2.968^{b}	4.371	1.536^{a}
SYB	2.314^{b}	2.276^{b}	3.102	1.363^{c}	3.149^{a}	3.112^{a}	4.379	1.482^{b}
HYB	2.115^{d}	2.077^{d}	2.864	1.381^{bc}	2.886^{c}	2.849^{c}	4.028	1.498^{b}
SEM	0.0216	0.0216	0.0278	0.0091	0.0383	0.0382	0.0361	0.0097
Main effect of diet[3] (n = 48)								
1	2.349	2.311	3.101	1.338^{b}	3.218	3.180	4.378	1.450^{b}
2	2.278	2.241	3.103	1.388^{a}	3.081	3.043	4.381	1.514^{a}
SEM	0.0306	0.0305	0.0394	0.0129	0.0541	0.0540	0.0510	0.0137
P-values								
Strain	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.003**
Diet	0.112	0.110	0.974	**0.010**	0.081	0.081	0.967	**0.002**
Strain × Diet	0.270	0.271	**0.046**	0.883	0.054	0.053	**0.020**	0.836

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]BW = body weight, BWG = body weight gain, FI = feed intake, FCR = feed conversion ratio

[2]SYA = Standard yielding A, HYA = high yielding A, SYB = standard yielding B, HYB = high yielding B

[3]Diet 1 = LHHH; Diet 2 = HLLL

Table 5. Live performance[1] of male broilers from various strains fed Diet 1 or Diet 2 from 0 to 47 d post-hatch.

	0 to 47 d			
Treatment	BW d47	BWG	FI	FCR
Interactions (n = 6)				
SYA, 1	3.813^{ab}	3.572^{ab}	4.986^{b}	1.446
SYA, 2	3.787^{a}	3.746^{a}	5.197^{a}	1.466
HYA, 1	3.569^{bc}	3.530^{bc}	4.970^{b}	1.476
HYA, 2	3.404^{cd}	3.365^{cd}	4.885^{b}	1.509
SYB, 1	3.892^{ab}	3.854^{ab}	4.895^{b}	1.404
SYB, 2	3.590^{b}	3.552^{b}	4.907^{b}	1.455
HYB, 1	3.409^{cd}	3.371^{cd}	4.590^{c}	1.445
HYB, 2	3.335^{d}	3.297^{d}	4.619^{c}	1.490
SEM	0.0611	0.0611	0.0508	0.0186
Main effect of strain[2] (n = 24)				
SYA	3.700	3.859	5.091	1.456^{ab}
HYA	3.487	3.448	4.928	1.493^{a}
SYB	3.841	3.803	4.901	1.429^{b}
HYB	3.372	3.334	4.604	1.468^{a}
SEM	0.0432	0.0432	0.0359	0.0131
Main effect of diet[3] (n = 48)				
1	3.892	3.854	4.895	1.404
2	3.590	3.552	4.907	1.455
SEM	0.0611	0.0611	0.0508	0.0186
P-values				
Strain	**<0.001**	**<0.001**	**<0.001**	**0.014**
Diet	0.245	0.246	0.867	0.057
Strain × Diet	**0.044**	**0.0442**	**0.044**	0.829

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]BW = body weight, BWG = body weight gain, FI = feed intake, FCR = feed conversion ratio

[2]SYA = Standard yielding A, HYA = high yielding A, SYB = standard yielding B, HYB = high yielding B

[3]Diet 1 = LHHH; Diet 2 = HLLL

Table 6. Carcass and parts yields (%) of male broilers of various strains fed Diet 1 or Diet 2 and processed at a live weight of approximately 2.5 or 3.8 kg

Treatment	Hot carcass	Fat	Cold carcass	Wing	Breast	Tender	Leg quarter
Interactions[1] (n = 6)							
SYA, 1, 2.5	73.84	1.01	76.55	7.59	20.08	4.28	22.34
SYA, 2, 2.5	73.31	1.15	76.03	7.58	19.19	4.10	22.77
HYA, 1, 2.5	74.38	0.98	76.77	7.53	21.51	4.48	21.94
HYA, 2, 2.5	74.03	1.06	76.64	7.54	20.77	4.45	21.98
SYB, 1, 2.5	73.81	0.79	76.31	7.58	20.07	4.22	22.92
SYB, 2, 2.5	73.57	0.99	76.32	7.74	19.00	4.06	23.17
HYB, 1, 2.5	74.85	0.77	77.25	7.53	22.30	4.67	22.08
HYB, 2, 2.5	74.38	0.95	77.00	7.63	21.49	4.46	22.26
SYA, 1, 3.8	75.21	1.13	77.42	7.48	22.68	4.51	22.12
SYA, 2, 3.8	74.70	1.21	76.73	7.42	21.75	4.44	22.35
HYA, 1, 3.8	76.14	1.03	78.25	7.35	24.05	4.78	22.02
HYA, 2, 3.8	75.08	1.22	77.32	7.40	22.96	4.69	21.80
SYB, 1, 3.8	75.23	0.91	77.38	7.44	21.99	4.44	23.00
SYB, 2, 3.8	74.60	1.08	76.77	7.54	20.79	4.29	23.21
HYB, 1, 3.8	76.07	0.87	78.07	7.32	24.90	4.70	21.64
HYB, 2, 3.8	75.45	1.03	77.57	7.38	23.39	4.71	21.71
SEM	0.174	0.043	0.272	0.058	0.214	0.050	0.152

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]Values reported are on a percent basis in relation to live weight

Table 6. (Cont.)

Treatment	Hot carcass	Fat	Cold carcass	Wing	Breast	Tender	Leg quarter
Main effect of strain[2] (n = 24)							
SYA	74.26[c]	1.12[a]	76.68[b]	7.52[ab]	20.92[c]	4.33[b]	22.39[b]
HYA	74.90[b]	1.07[a]	77.25[a]	7.45[b]	22.32[b]	4.60[a]	21.93[c]
SYB	74.30[c]	0.94[b]	76.69[b]	7.57[a]	20.46[d]	4.25[c]	23.08[a]
HYB	75.19[a]	0.90[b]	77.47[a]	7.46[b]	23.02[a]	4.63[a]	21.92[c]
SEM	0.087	0.021	0.136	0.029	0.107	0.025	0.076
Main effect of carcass size[3] (n = 48)							
2.5	74.02[b]	0.96[b]	76.61[b]	7.59[a]	20.55[b]	4.34[b]	22.43[a]
3.8	75.31[a]	1.06[a]	77.44[a]	7.41[b]	22.81[a]	4.57[a]	22.23[b]
SEM	0.062	0.015	0.096	0.021	0.076	0.018	0.054
Main effect of diet[4] (n = 48)							
1	74.94[a]	0.94[b]	77.25[a]	7.48[b]	22.20[a]	4.51[a]	22.26
2	74.39[b]	1.08[a]	76.80[b]	7.53[a]	21.17[b]	4.40[b]	22.41
SEM	0.062	0.015	0.096	0.021	0.076	0.018	0.054
P-values							
Strain	**<0.001**	**<0.001**	**<0.001**	**0.016**	**<0.001**	**<0.001**	**<0.001**
Carcass Size	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.009**
Diet	**<0.001**	**<0.001**	0.001	0.097	**<0.001**	**<0.001**	0.052
S × CS	0.682	0.983	0.757	0.678	0.114	0.143	**0.046**
S × D	0.733	0.611	0.845	0.217	0.745	0.602	0.256
CS × D	0.080	0.963	0.092	0.635	0.161	0.164	0.312
S × CS × D	0.483	0.605	0.826	0.926	0.712	0.237	0.963

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]Values reported are on a percent basis in relation to live weight

[2]SYA = Standard yielding A, HYA = high yielding A, SYB = standard yielding B, HYB = high yielding B

[3]2.5 kg = small bird market, 3.8 kg = big bird debone market

[4]Diet 1 = LHHH, Diet 2 = HLLL

Table 7. Live performance[1] of female broilers from various strains fed Diet 1 or Diet 2 from 0 to 14 d post-hatch.

	0 to 7 d					0 to 14 d			
Treatment	BW d0	BW d7	BWG	FI	FCR	BW d14	BWG	FI	FCR
Interactions (n = 6)									
SYA, 1	0.040	0.176	0.136	0.144	1.018	0.433	0.393	0.479	1.222
SYA, 2	0.040	0.178	0.138	0.145	1.009	0.446	0.405	0.483	1.192
HYA, 1	0.039	0.169	0.130	0.142	1.004	0.419	0.381	0.467	1.227
HYA, 2	0.038	0.171	0.132	0.142	1.034	0.426	0.388	0.469	1.210
SYB, 1	0.037	0.161	0.124	0.136	1.004	0.413	0.376	0.455	1.220
SYB, 2	0.037	0.161	0.124	0.130	1.048	0.418	0.381	0.445	1.168
HYB, 1	0.037	0.156	0.119	0.132	0.979	0.381	0.344	0.425	1.237
HYB, 2	0.037	0.155	0.118	0.126	0.843	0.382	0.344	0.411	1.200
SEM	0.0003	0.0019	0.0019	0.0032	0.0510	0.0048	0.0047	0.0053	0.0114
Main effect of strain[2] (n = 24)									
SYA	0.040[a]	0.177[a]	0.137[a]	0.144[a]	1.013	0.439[a]	0.399[a]	0.481[a]	1.207
HYA	0.038[b]	0.170[b]	0.131[b]	0.142[a]	1.019	0.423[b]	0.384[b]	0.468[b]	1.219
SYB	0.037[c]	0.161[b]	0.124[c]	0.133[b]	1.026	0.416[b]	0.379[b]	0.450[c]	1.194
HYB	0.037[c]	0.156[c]	0.119[d]	0.129[b]	0.911	0.381[c]	0.344[c]	0.418[d]	1.218
SEM	0.0002	0.0014	0.0013	0.0023	0.0360	0.0034	0.0033	0.0038	0.0081
Main effect of diet[3] (n = 48)									
1	0.037	0.161	0.124	0.136	1.004	0.413	0.376	0.455	1.220[a]
2	0.037	0.161	0.124	0.130	1.048	0.418	0.381	0.445	1.168[b]
SEM	0.0003	0.0019	0.0019	0.0032	0.0510	0.0048	0.0047	0.0053	0.0114
P-values									
Strain	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.095	**<0.001**	**<0.001**	**<0.001**	0.118
Diet	1.000	0.807	0.755	0.183	0.544	0.464	0.472	0.201	0.002
Strain × Diet	0.986	0.820	0.813	0.569	0.289	0.646	0.661	0.304	0.475

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]BW = body weight, BWG = body weight gain, FI = feed intake, FCR = feed conversion ratio

[2]SYA = Standard yielding A, HYA = high yielding A, SYB = standard yielding B, HYB = high yielding B

[3]Diet 1 = LHHH; Diet 2 = HLLL

Table 8. Live performance[1] of female broilers from various strains fed Diet 1 or Diet 2 from 0 to 28 d post-hatch.

	0 to 21 d				0 to 28 d			
Treatment	BW d21	BWG	FI	FCR	BW d28	BWG	FI	FCR
Interactions (n = 6)								
SYA, 1	0.914	0.874	1.121	1.273	1.496	1.456	2.020	1.394
SYA, 2	0.906	0.866	1.143	1.311	1.476	1.436	2.064	1.438
HYA, 1	0.859	0.821	1.076	1.288	1.387	1.349	1.911	1.421
HYA, 2	0.869	0.831	1.106	1.322	1.402	1.364	1.976	1.450
SYB, 1	0.875	0.838	1.056	1.231	1.440	1.402	1.906	1.366
SYB, 2	0.861	0.824	1.060	1.288	1.423	1.386	1.932	1.395
HYB, 1	0.800	0.763	0.985	1.262	1.311	1.274	1.767	1.389
HYB, 2	0.780	0.743	0.977	1.262	1.302	1.265	1.785	1.415
SEM	0.0094	0.0093	0.0121	0.0144	0.0172	0.0172	0.0214	0.0054
Main effect of strain[2] (n = 24)								
SYA	0.910[a]	0.870[a]	1.132[a]	1.292[a]	1.486[a]	1.446[a]	2.042[a]	1.416[b]
HYA	0.864[b]	0.826[b]	1.091[b]	1.305[a]	1.395[c]	1.356[c]	1.943[b]	1.435[a]
SYB	0.868[b]	0.831[b]	1.058[c]	1.259[b]	1.431[b]	1.394[b]	1.919[b]	1.381[d]
HYB	0.790[c]	0.753[c]	0.981[d]	1.262[b]	1.306[d]	1.269[d]	1.776[c]	1.402[c]
SEM	0.0066	0.0066	0.0085	0.0102	0.0122	0.0121	0.0151	0.0038
Main effect of diet[3] (n = 48)								
1	0.875	0.838	1.056	1.231[b]	1.440	1.402	1.906	1.366[b]
2	0.861	0.824	1.060	1.288[a]	1.423	1.386	1.932	1.395[a]
SEM	0.0094	0.0093	0.0121	0.0144	0.0172	0.0172	0.0214	0.0054
P-values								
Strain	**<0.001**	**<0.001**	**<0.001**	**0.005**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Diet	0.292	0.288	0.816	**0.008**	0.489	0.501	0.398	**0.001**
Strain × Diet	0.418	0.413	0.401	0.274	0.733	0.723	0.698	0.332

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]BW = body weight, BWG = body weight gain, FI = feed intake, FCR = feed conversion ratio

[2]SYA = Standard yielding A, HYA = high yielding A, SYB = standard yielding B, HYB = high yielding B

[3]Diet 1 = LHHH; Diet 2 = HLLL

Table 9. Live performance[1] of female broilers from various strains fed Diet 1 or Diet 2 from 0 to 42 d post-hatch.

	0 to 35 d				0 to 42 d			
Treatment	BW d35	BWG	FI	FCR	BW d42	BWG	FI	FCR
Interactions (n = 6)								
SYA, 1	2.113	2.072	2.924	1.410	2.727	2.687	4.078	1.532
SYA, 2	2.067	2.027	2.989	1.474	2.705	2.665	4.122	1.599
HYA, 1	1.967	1.928	2.747	1.415	2.587	2.549	3.864	1.550
HYA, 2	1.952	1.914	2.847	1.484	2.564	2.526	3.963	1.612
SYB, 1	2.059	2.022	2.757	1.352	2.722	2.685	3.942	1.505
SYB, 2	2.020	1.983	2.805	1.414	2.703	2.666	4.009	1.550
HYB, 1	1.878	1.841	2.551	1.373	2.525	2.488	3.833	1.507
HYB, 2	1.862	1.825	2.594	1.403	2.408	2.371	3.860	1.560
SEM	0.0245	0.0244	0.0325	0.0115	0.0278	0.0278	0.0443	0.0088
Main effect of strain[2] (n = 24)								
SYA	2.090[a]	2.050[a]	2.956[a]	1.442[a]	2.716[a]	2.676[a]	4.100[a]	1.565[a]
HYA	1.959[c]	1.921[b]	2.797[b]	1.449[a]	2.576[b]	2.537[b]	3.913[b]	1.581[a]
SYB	2.040[b]	2.003[a]	2.781[b]	1.383[b]	2.712[a]	2.675[a]	3.976[b]	1.527[b]
HYB	1.870[d]	1.833[c]	2.572[c]	1.388[b]	2.466[c]	2.429[c]	3.846[c]	1.533[b]
SEM	0.0173	0.0172	0.0230	0.0082	0.0197	0.0197	0.0313	0.0062
Main effect of diet[3] (n = 48)								
1	2.059	2.022	2.757	1.352[b]	2.722	2.685	3.942	1.505[b]
2	2.020	1.983	2.805	1.414[a]	2.703	2.666	4.009	1.550[a]
SEM	0.0245	0.0244	0.0325	0.0115	0.0278	0.0278	0.0443	0.0088
P-values								
Strain	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Diet	0.270	0.265	0.311	**<0.001**	0.638	0.638	0.294	**0.001**
Strain × Diet	0.898	0.893	0.809	0.337	0.231	0.234	0.865	0.613

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]BW = body weight, BWG = body weight gain, FI = feed intake, FCR = feed conversion ratio

[2]SYA = Standard yielding A, HYA = high yielding A, SYB = standard yielding B, HYB = high yielding B

[3]Diet 1 = LHHH; Diet 2 = HLLL

Table 10. Live performance[1] of female broilers from various strains fed Diet 1 or Diet 2 from 0 to 54 d post-hatch.

	0 to 49 d				0 to 54 d			
Treatment	BW d49	BWG	FI	FCR	BW d54	BWG	FI	FCR
Interactions (n = 6)								
SYA, 1	3.414	3.374	5.405	1.667	3.775	3.735	6.013	1.674
SYA, 2	3.376	3.336	5.478	1.740	3.739	3.898	6.101	1.746
HYA, 1	3.239	3.201	5.178	1.702	3.596	3.558	5.772	1.707
HYA, 2	3.215	3.177	5.298	1.763	3.589	3.550	5.911	1.763
SYB, 1	3.398	3.361	5.291	1.658	3.729	3.892	5.902	1.677
SYB, 2	3.410	3.373	5.407	1.700	3.797	3.760	6.063	1.712
HYB, 1	3.197	3.160	4.892	1.650	3.583	3.546	5.460	1.647
HYB, 2	3.060	3.023	4.939	1.714	3.448	3.411	5.506	1.705
SEM	0.0355	0.0355	0.0514	0.0120	0.0444	0.0444	0.0601	0.0126
Main effect of strain[2] (n = 24)								
SYA	3.395^{a}	3.355^{a}	5.441^{a}	1.703^{ab}	3.757^{a}	3.717^{a}	6.057^{a}	1.710^{ab}
HYA	3.227^{b}	3.189^{b}	5.238^{b}	1.732^{a}	3.592^{b}	3.554^{b}	5.841^{b}	1.735^{a}
SYB	3.404^{a}	3.367^{a}	5.349^{a}	1.679^{b}	3.763^{a}	3.726^{a}	5.983^{ab}	1.694^{bc}
HYB	3.128^{c}	3.091^{c}	4.915^{c}	1.682^{c}	3.515^{b}	3.479^{b}	5.483^{c}	1.676^{c}
SEM	0.0251	0.0251	0.0363	0.0085	0.0314	0.0314	0.0425	0.0089
Main effect of diet[3] (n = 48)								
1	3.398	3.361	5.291	1.658^{b}	3.729	3.892	5.902	1.677
2	3.410	3.373	5.407	1.700^{a}	3.797	3.760	6.063	1.712
SEM	0.0355	0.0355	0.0514	0.0120	0.0444	0.0444	0.0601	0.0126
P-values								
Strain	**<0.001**	**<0.001**	**<0.001**	**0.002**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Diet	0.805	0.805	0.119	**0.019**	0.287	0.287	0.066	0.057
Strain × Diet	0.199	0.201	0.874	0.597	0.165	0.167	0.776	0.523

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]BW = body weight, BWG = body weight gain, FI = feed intake, FCR = feed conversion ratio

[2]SYA = Standard yielding A, HYA = high yielding A, SYB = standard yielding B, HYB = high yielding B

[3]Diet 1 = LHHH; Diet 2 = HLLL

Table 11. Carcass and parts yields (%) of female broilers of various strains fed Diet 1 or Diet 2 and processed at a live weight of approximately 2.5 or 3.8 kg

Treatment	Hot carcass	Fat	Chilled carcass	Wing	Breast	Tender	Leg quarter
Interactions[1] (n = 6)							
SYA, 1, 2.5	73.27	1.37	76.26	7.55	20.24	4.64	22.06
SYA, 2, 2.5	73.22	1.44	76.20	7.61	19.92	4.64	22.97
HYA, 1, 2.5	74.32	1.24	77.06	7.51	21.67	4.84	21.62
HYA, 2, 2.5	73.80	1.48	76.43	7.64	21.06	4.83	21.44
SYB, 1, 2.5	73.99	1.10	77.05	7.69	20.63	4.55	22.64
SYB, 2, 2.5	73.37	1.26	76.42	7.88	19.70	4.45	22.57
HYB, 1, 2.5	74.53	0.97	77.26	7.53	22.85	4.97	21.59
HYB, 2, 2.5	74.19	1.12	76.78	7.73	21.74	4.85	21.83
SYA, 1, 3.8	76.65	1.57	78.54	7.35	23.14	4.97	21.61
SYA, 2, 3.8	77.14	1.41	79.08	7.20	24.03	4.98	21.07
HYA, 1, 3.8	76.95	1.51	79.01	7.26	24.04	5.21	21.20
HYA, 2, 3.8	76.61	1.75	78.39	7.36	22.97	5.00	21.84
SYB, 1, 3.8	76.97	1.40	78.98	7.25	24.16	5.12	21.37
SYB, 2, 3.8	76.89	1.57	78.43	7.34	23.23	5.01	21.57
HYB, 1, 3.8	77.17	1.55	78.84	7.28	23.54	5.21	21.40
HYB, 2, 3.8	76.97	1.41	78.75	7.31	23.94	5.09	21.39
SEM	0.346	0.077	0.362	0.068	0.453	0.073	0.355

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]Values reported are on a percent basis in relation to live weight

Table 11. (Cont.)

Treatment	Hot carcass	Fat	Chilled carcass	Wing	Breast	Tender	Leg quarter
Main effect of strain[2] (n = 24)							
SYA	75.07	1.45[a]	77.52	7.43	21.83[c]	4.81[b]	21.93
HYA	75.37	1.49[a]	77.72	7.44	22.44[ab]	4.97[a]	21.52
SYB	75.30	1.33[b]	77.72	7.54	21.93[bc]	4.78[b]	22.04
HYB	75.71	1.26[b]	77.91	7.46	23.02[a]	5.03[a]	21.55
SEM	0.162	0.036	0.169	0.032	0.212	0.034	0.166
Main effect of carcass size[3] (n = 48)							
2.5	73.81[b]	1.25[b]	76.68[b]	7.64[b]	20.98[b]	4.72[b]	22.09[a]
3.8	76.92[a]	1.52[a]	78.75[a]	7.29[a]	23.83[a]	5.07[a]	21.43[b]
SEM	0.114	0.025	0.120	0.022	0.150	0.024	0.117
Main effect of diet[4] (n = 48)							
1	75.48	1.34[b]	77.88	7.43[b]	22.53[a]	4.94[a]	21.69
2	75.25	1.43[a]	77.56	7.51[a]	22.07[b]	4.86[b]	21.84
SEM	0.113	0.025	0.118	0.022	0.148	0.024	0.116
P-values							
Strain	0.051	**<0.001**	0.455	0.063	**0.001**	**<0.001**	0.060
Carcass Size	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Diet	0.146	**0.012**	0.064	**0.012**	**0.031**	**0.016**	0.363
S × CS	0.156	**0.009**	0.367	0.064	**0.001**	**0.005**	**0.028**
S × D	0.391	**0.023**	0.236	0.136	0.160	0.547	0.987
CS × D	0.214	0.076	0.420	**0.045**	0.184	0.488	0.640
S × CS × D	0.966	0.328	0.916	0.726	0.292	0.638	0.099

[a-d] Means without a common superscript were determined to be significantly different ($P < 0.05$) by a Student's *t* test

[1]Values reported are on a percent basis in relation to live weight

[2]SYA = Standard yielding A, HYA = high yielding A, SYB = standard yielding B, HYB = high yielding B

[3]2.5 kg = small bird market, 3.8 kg = big bird debone market

[4]Diet 1 = LHHH; Diet 2 = HLLL

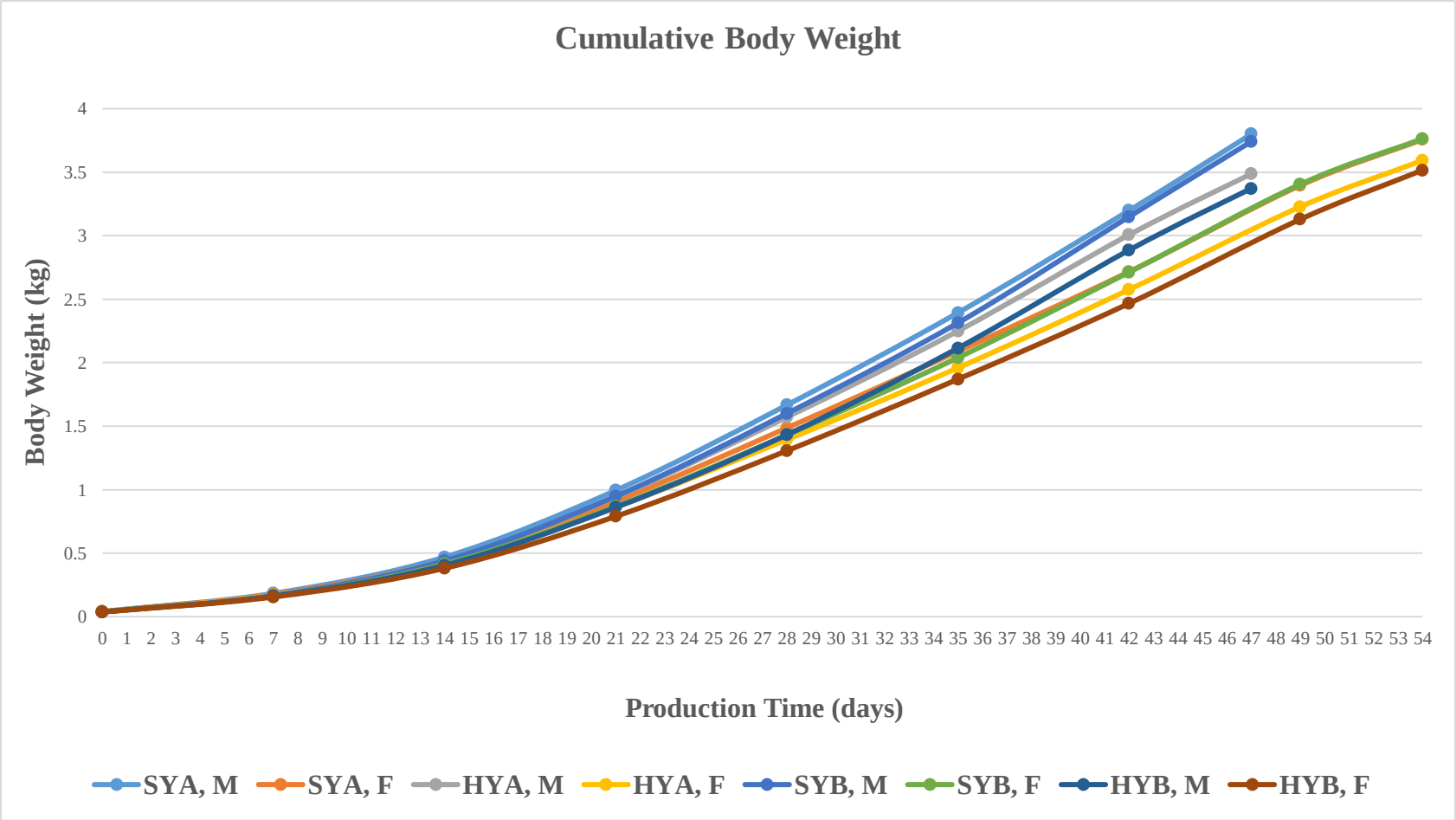

Figure 1. Cumulative body weight of male and female broilers from four broiler strains. Male 49 and 54 d weights not recorded. SYA, M = Standard Yielding A Male, SYA, F = Standard Yielding A Female, SYB, M = Standard Yielding B Male, SYB, F = Standard Yielding B Female, HYA, M = High Yielding A Male, HYA, F = High Yielding A Female, HYB, M = High Yielding B Male, HYB, F = High Yielding B Female

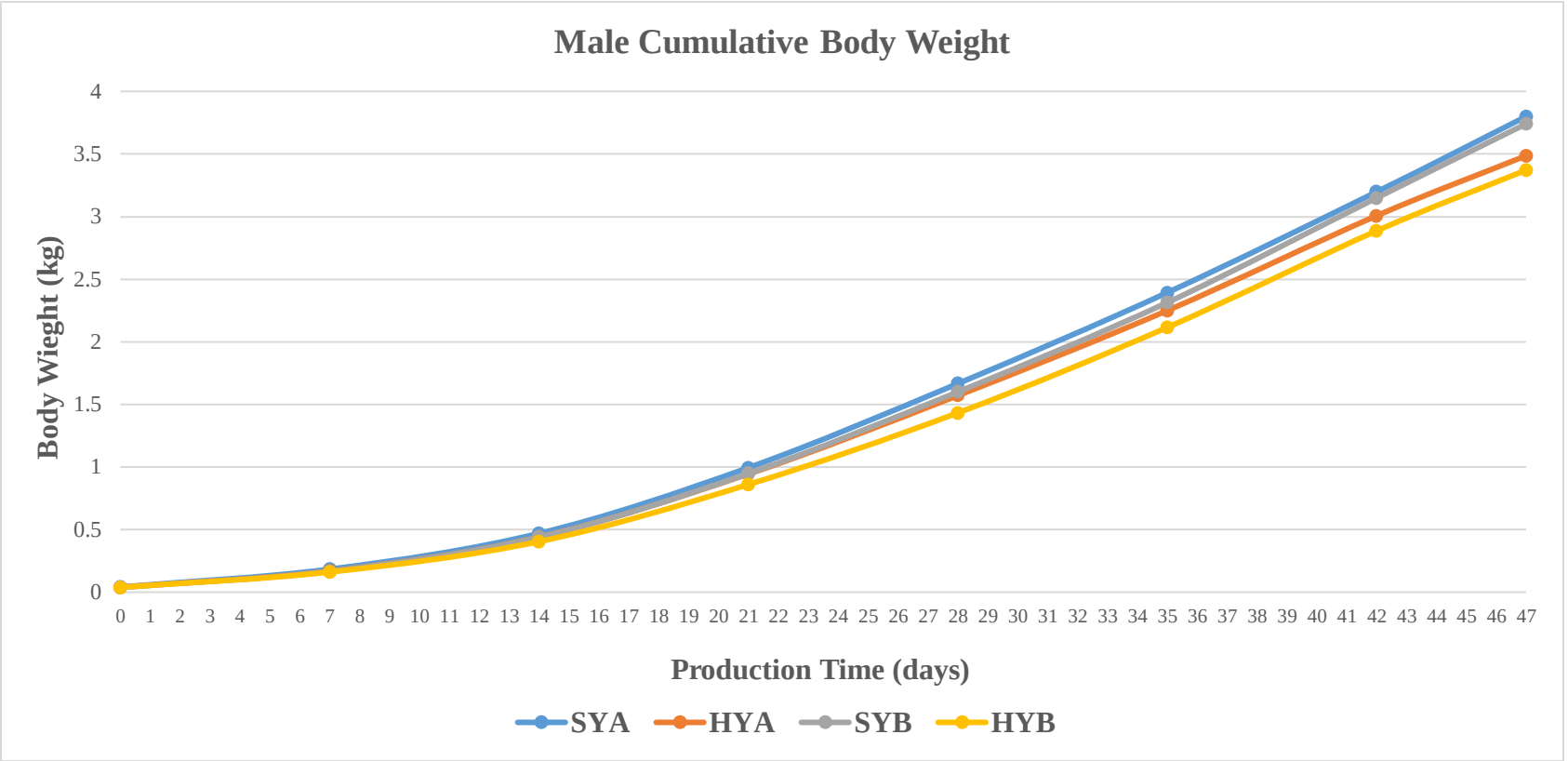

Figure 2. Cumulative body weight of male broilers from four broiler strains grown to 47 days.
SYA = Standard Yielding A, HYA = High Yielding A, SYB = Standard Yielding B, HYB = High Yielding B

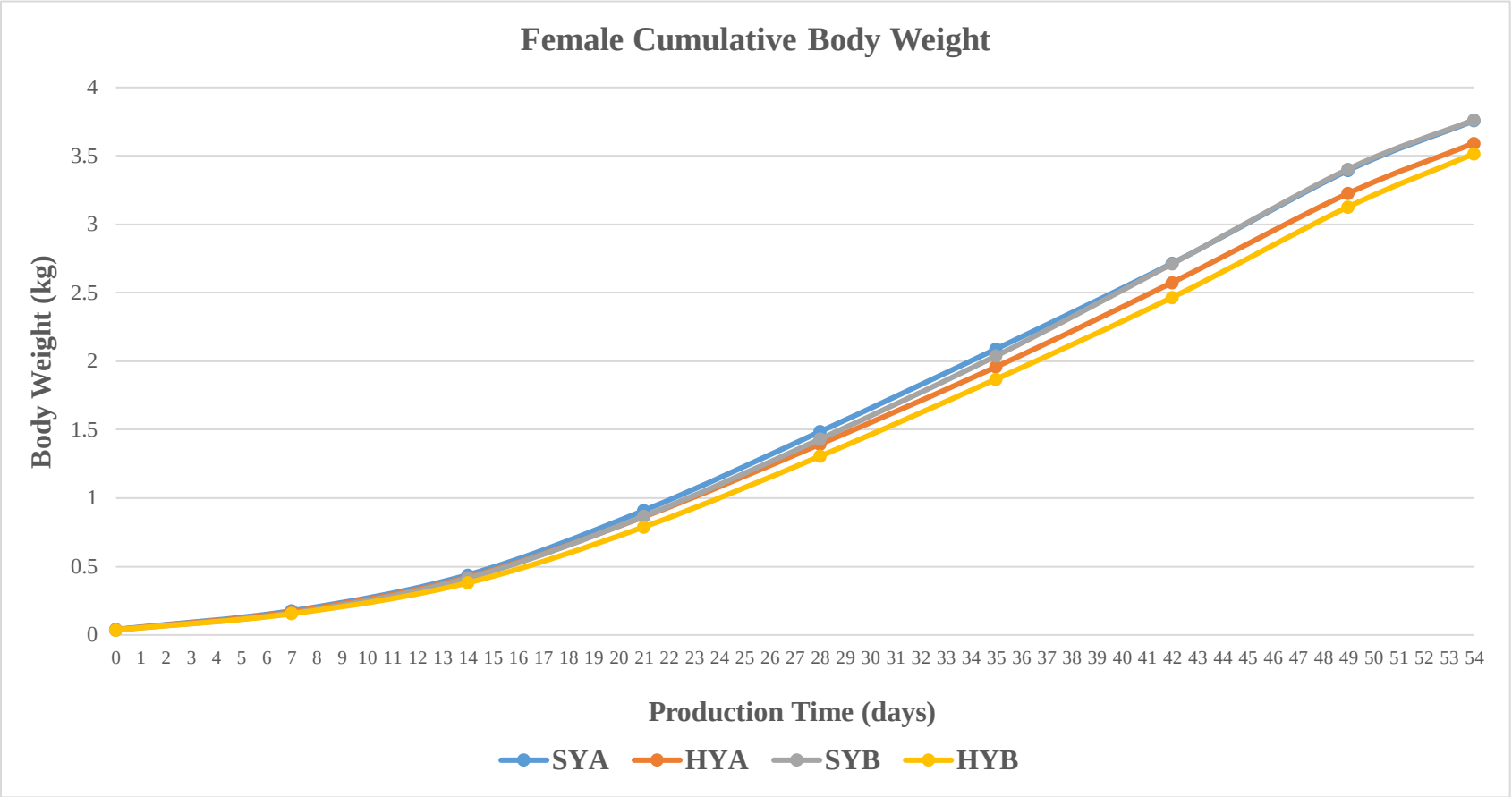

Figure 3. Cumulative body weight of female broilers from four broiler strains grown to 54 days.
SYA = Standard Yielding A, HYA = High Yielding A, SYB = Standard Yielding B, HYB = High Yielding B

CHAPTER III

EFFECT OF SEX AND CARCASS SIZE ON THE QUALITY ATTRIBUTES OF FOUR COMMERCIAL STRAINS IN THE UNITED STATES

ABSTRACT

In recent times, meat quality has become a key aspect of poultry production. In a study to evaluate meat quality, 2,400 sex separate broilers from four commercial strains were placed to evaluate performance when grown to two market weights. Broilers were also fed one of two diets with varying degrees of amino acid inclusion. Upon analysis, diet had little effect ($P>0.05$) on parameters and was therefore excluded. Birds were processed in accordance to a targeted weight of 2.5 kg and 3.8 kg found within the United States small bird and big bird debone markets, respectively. At day of processing, high yielding (HY) strains produced higher breast and tender yields ($P<0.05$) when compared to standard yielding (SY) strains. In addition, and as expected, females exhibited higher breast and tender yields ($P<0.05$) than males. However, males had significantly thicker ($P<0.05$) and longer ($P<0.05$) fillets, higher incidences ($P<0.05$) of white striping, and higher ($P<0.05$) cook loss. Differences were also observed in tenderness as SY strain A produced the lowest shear values, whereas SY strain B produced the highest shear values across parameters ($P<0.05$). Concomitantly, SY strains in the small bird (SB) market performed better than SY strains in the big bird (BB) market as smaller carcasses had lower incidences of white striping, woody breast, spaghetti meat, woody tender, and tender feathering and improved quality attributes ($P<0.05$). Similar trends were observed ($P<0.05$) in HY strains as SB carcasses produced a better overall product. Differences in carcass size directly impacted quality ($P<0.05$) as SB markets showed improvements in most parameters assessed, but broilers representing BB markets had greater breast yield. Although strain had some impact on quality measures, carcass size and sex had greater impacts in terms of muscle myopathies, water holding capacity, and shear properties.

Keywords: meat quality, myopathies, tender myopathies, tenderness, color

INTRODUCTION

Since the mid-twentieth century, poultry production has seen a consistent rise in the United States and around the world. For 2019, the poultry industry hit an all-time high production of more than 42.1 billion pounds of fresh, ready-to-cook poultry within the United States (National Chicken Council, 2019). This increase may be the direct result of more health-conscious consumers as well as an increased demand for more affordable protein options (Valceschini, 2006). As the demand for poultry continues to rise, pressures on geneticists, nutritionists, and managers have increased. With an aim to decrease feed conversion, growth rate, and breast meat yield, integrators are producing broilers that, on average, are twice the size of birds from those 50 years ago in half the time (Petracci and Cavani, 2012; Owens, 2014).

Integrators have recently started investigating the financial return on rearing sex separate broiler flocks (Dozier et al., 2008). This rearing style produces a more uniform flock that can target specific consumer markets. Targeting uniformity then fixates feeding and processing costs, as well as reduces variation to better fit different retail markets. Studies have shown that sex separate rearing can improve feed conversion as well as growth and carcass uniformity (Corzo et al., 2005; Dozier et al., 2009; Maynard et al., 2020). However, the effectiveness of improving these characteristics have not been assessed further in meat quality analysis. Northcutt et al. (2001) and Brewer et al. (2009) reported that female fillets possess a higher degree of tenderness than males regardless of aging time at 46 and 49 days, respectively. Conversely, Goodwin et al. (1969) and Poole et al. (1999) reported that males generally possess a higher degree of tenderness than females when processed at the same market age of eight weeks and aged for 24 hours and 1 hour, respectively. Conflicting reports such as these result in the need to further understand the impact of sex on meat quality, especially with the modern broiler of today.

The influence of diet on meat quality traits has not been well documented in poultry. Nutrition has been known to play the largest role in live production expenses and continues to be the largest input (Skinner et al., 1992a; b; Maynard et al., 2019), and with such a high emphasis on feed cost, assessment for the best fit diet returning the highest yield and quality should be paramount. Li et al. (2010) suggested that manipulation of nutrient density can improve growth performance and carcass quality. Increased carcass qualities could then potentially impact final meat quality characteristics. Previously, Kuttappan et al. (2012a) found that high energy diets had a negative impact on the quality of breast fillets with increased white striping myopathy. However, Fanatico et al. (2007), Li et al. (2010), and Lilly et al. (2011) found that diet density has no direct impact on meat quality traits. Minimal publications exist past these, so further investigation would be beneficial to better understand the effect of diet on meat quality of modern broiler strains.

Aside from environmental factors, genetic selection has been shown to play a significant role in meat quality for various species (Le Bihan-Duval et al., 2003). Influential precursors of meat quality attributes, related to selection techniques, have not been well defined in the poultry literature. However, selection for high yielding birds for further processing, has shown to negatively impact the sensory and functional properties of poultry meat (Dransfield and Sosnicki, 1999; Le Bihan-Duval et al., 1999, 2003). Recently, sensorial qualities of the current broiler market have become a concern for consumers. Fletcher (2002) suggests that tenderness is one of the most crucial attributes for determining acceptability of a product. Mouthfeel is generally referred to as the accepting factor for consumers, but visual appearance of raw fillets has been known to influence consumer preferences (Allen et al., 1998; Kuttappan et al., 2012c). Although the potential heritability of tenderness is unknown, visual color is known to be a highly

heritable trait (Harford et al., 2014). Muscle color has also shown a strong correlation to other quality factors such as muscle pH (Owens et al., 2000; Woelfel et al., 2002; Harford et al., 2014; Orlowski, 2016) and water holding capacity (Barbut, 1996, 1997). These three factors are beneficial in understanding the importance of heritability and their relationship with meat quality; specifically, the pale, soft, and exudative-like condition as it is well defined (Anthony, 1998; Le Bihan-Duval et al., 2001, 2003; Woelfel et al., 2002; Orlowski, 2016). Although the presence of PSE-like poultry has reduced in recent years, shifting markets to heavier birds have come with some drawbacks. Harford et al. (2014) found that emerging myopathies, such as wooden or plank breast and white striping, may be the explanation for color variation in fillets and further investigation of heritability should be considered.

Muscle myopathies have become a major issue with broiler meat quality in the past decade (Owens, 2014; Sihvo et al., 2014; Kuttappan et al., 2016). This coincides with some of the changes observed in the industry with the new high yielding strains and longer grow out periods (Lubritz, 1997; Bodle et al., 2018; Wilhelmsson et al., 2019). The two main myopathies that are a concern to the poultry industry today are white striping and woody breast (Kuttappan et al., 2012a; Tijare et al., 2016). The severity of these conditions can vary, however it has been associated with heavier-late maturing broilers, especially from strains selected for high breast meat yield (Kuttappan et al., 2012a). Furthermore, the results of Macrae et al. (2007) suggest that the influence of rapid growth has outpaced the ability of healthy muscle growth, creating the formation of distinct myopathies. These myopathies are issues in the global poultry industry which can range from 10 to 40% incidence of moderate/severe cases in single flocks (Petracci et al., 2019). High incidences of these myopathies have led to poor meat quality and decreased

yield due to condemnations, providing severe economic implications to the industry (Kuttappan et al., 2016; Soglia et al., 2016b).

Since the poultry industry relies heavily on strict consumer specifications, integrators aim to provide the highest quality product available. Hence, the need for meat quality assessment is substantial. Although numerous studies have evaluated various single meat quality parameters, few exist evaluating strain differences on multiple factors including muscle myopathies. Therefore, the objective of this study was to assess the interactive effects between sex, diet composition, strain, and carcass size on meat quality. Specifically, standard and high yielding strains from two readily available primary breeder companies were utilized. In combination, high or low nutrient dense diet were fed, giving a varying degree of nutritional planes. Furthermore, a small bird and big bird market were targeted to look for comparisons in quality attributes such as myopathies, fillet dimensions, color, pH, water holding capacity, and tenderness.

MATERIALS AND METHODS

All animal rearing was approved by the Institutional Animal Care and Use Committee at the University of Arkansas (protocol # 20016).

Animal Husbandry

A total of 2400 sex separate broiler chicks from four commercial strains (two standard yielding (**SYA** and **SYB**) and two high-yielding (**HYA** and **HYB**), were reared at the University of Arkansas poultry research farm. Upon arrival to the University of Arkansas poultry research farm, 25 broiler chicks were group weighed and placed in 1.2 x 1.82-meter floor pens (96 pens per experiment; 0.09 m^2 per bird). Each pen was outfitted with fresh pine shavings, a hanging feeder, and a nipple drinker water line. Birds were allowed unrestricted access to feed and water throughout the trial. Environmental conditions were maintained in a closed-sided house with a

set point temperature of 32°C when placed. A stepwise reduction in temperature was set to decrease temperatures by 2°C each week resulting in an endpoint temperature of 15°C. A lighting schedule was set at 24L:0D from day 0 to 1, 23L:1D from days 1 to 7, and 16L:8D from days 7 to 54 for the remainder of the trial (Maynard et al., 2019).

Dietary treatments

Diets were fed across four feeding phases including: a starter, grower, finisher, and withdrawal. Crumbled starter diets were fed from d 0 to d 14, whereas the grower, finisher, and withdrawal diets were fed as pellets from 15 to 28, 29 to 42, and 43 to 54 d of age, respectively. High and low amino acid density diets were formulated for each dietary phase. Digestible lysine levels were 1.20, 1.10, 1.00, and 0.96% for the low amino acid diets and 1.32, 1.21, 1.10, and 1.06% for the high amino acid density diets for the starter, grower, finisher, and withdrawal phases, respectively. Dietary treatments were intended to be held constant throughout both experiments, but starter diets were inadvertently switched resulting in dietary treatments of low, high, high, high (Diet 1) and high, low, low, low (Diet 2).

Processing

Broilers were raised to two target weights (2.5 and 3.8 kg) to represent two market segments. Processing days were selected to achieve those target weights based on previous data collected in our lab. At day of processing (38 and 47 for males, 40 and 54 for females), 12 birds per pen were transported from the research farm on the back of a flatbed trailer to the University of Arkansas pilot processing plant. Following a 10-hour feed withdrawal period, birds were weighed on the back dock, hung on an inline shackle system, and processed according to Mehaffey et al. (2006). Briefly, broilers were electrically stunned (11 V, and 11 mA for 11 s), exsanguinated, scalded in hot water (53.8°C, 2 min), and then defeathered. Prior to mechanical

evisceration, necks and hocks were manually removed from each bird. Carcasses were then subjected to a two-stage chilling system consisting of a 0.25 h prechill, at 12°C, before being placed in immersion chilling tanks held at 0°C for 2.5 h with manual agitation. At 3 h postmortem, chilling tanks were then drained of water, and carcasses deboned to determine *Pectoralis major* (breast) and *P. minor* (tender), wing, and leg weights. *Pectoralis major* and *P. minor* were then utilized for further analysis of the following parameters: woody breast, white striping, spaghetti meat, woody tender, tender feathering, fillet dimensions, WHC, color, pH, and tenderness evaluation.

Fillet Dimensions

Breast fillets were then placed dorsal side down and measured for thickness, length, and width at 1/3 of the length from the caudal end (Figure 1). Measurements were recorded by one single trained personnel continuously throughout the trial to maintain consistency. Additionally, measurements were recorded using a calibrated caliper (Model 500-764-10* IP67, Mitutoyo U.S.A., Aurora, Illinois, U.S.A.).

Muscle Myopathies

After being weighed, boneless breast butterflies were visually scored for white striping (**WS**) and scored for woody breast (**WB**) through palpation method by a single individual. Measurements ranged from 0 to 3 in increments of 0.5, with 0 being an absence of the myopathy and a 3 being the most severe following the scales presented in Kuttappan et al. (2012c) and Tijare et al. (2016), respectively. Tenders were also evaluated for the presence of hardness (**WT**) through tactile evaluation based on a similar 0 to 2 scale with 0.5 increments (Figure 2). Tenders that expressed no palpable hardness were given a score of 0, hardness localized in the cranial region with flexibility in the caudal region a score of 1, and finally, tenders that exhibited stiff

hardness continually throughout the tender were given a score of 2. In addition, tenders were evaluated for feathering (**TF**; Figure 3) and categorized as: 0 = tenders with no visible fiber fraying (normal); 1 = moderate fiber fraying throughout (moderate); 2 = sever fiber fraying throughout (severe) similar to the scale presented in Soglia et al. (2019) referring to tender gaping. These measurements were also subjected to a 0.5 increment scale for feathering. To reduce variability in scoring, one trained personnel scored all tenders.

Color

At 24-hr postmortem, intact left fillets had color recorded with a handheld Minolta colorimeter and data was configured using SpectraMagic NX software (Minolta CM-400, Konica Minolta Sensing Americas Inc., Ramsey, N.J., U.S.A), set with a 2-degree observer, decreasing surface reflectance, and illuminant parameters of D65. Before measuring, the colorimeter was calibrated to CIE specifications using a white calibration tile in agreeance with the procedure provided by AMSA (2012). Intact fillets were positioned dorsal side up on white storage trays where measurements could be recorded on the left fillet. Three separate L^*, a^*, and b^* values were recorded for each fillet in the cranial, medial, and caudal locations which were then subsequently averaged.

pH

Immediately after color was recorded, pH of each left fillet was measured. Left halves were also evaluated at 24-hr postmortem for pH using a spear tip pH probe with automatic temperature compensation (Model 205, Testo instruments, West Chester, Pennsylvania, U.S.A.). Samples were collected by inserting the pH probe near the wing joint area of each fillet and allowed to equilibrate until a reading was maintained for three seconds.

Water Holding Capacity (WHC)/Drip Loss

After being scored for myopathies and measured, fillets were placed on white plastic storage trays, wrapped in plastic overlay liners, and placed in a walk-in cooler held at 4°C until 24-h postmortem. At 24-h postmortem, breast fillets were removed from the cooler and reweighed for determination of drip loss. Drip loss percentage was calculated as a percent by weight in relation to deboned weight.

Cook Loss

Due to time constraints, cooking for texture analysis could not be conducted within 48 hours postmortem, so individual tagged butterflies were bagged in groups of eight, vacuum sealed, and frozen in an air blast freezer (–28°C) and subsequently placed in a larger freezer (–18°C) for long-term storage. Prior to cooking, butterflies were thawed at 4°C for 64 h and reweighed prior to cooking. Deboned butterflies were trimmed of excess fat and any residual skin was removed. Butterflies were excised down the keel line and identification was kept on an individual basis for each right fillet. Eight fillets of similar weight were cooked in aluminum foil covered pans (65×395× 290 mm) on elevated baking racks in a commercial convection oven (Model E101-E, Duke Manufacturing Company, St. Louis, Missouri, U.S.A.) set to 176°C. A final end point temperature of 76°C (Model HT1000 thermometer, Cooper Instruments, Concord, Canada) was reached before the fillets were removed and allowed to cool at room temperature on white plastic storage trays. After cooling for approximately 1 h at room temperature, fillets were reweighed to determine cook loss percentage. Cook loss was calculated as a percent, by weight, in relation to precook weight. Fillets were then wrapped individually in aluminum foil sheets and were stored in refrigerated conditions (4°C) for approximately 24 h until instrumental texture analysis could be completed.

Texture Analysis

Using a texture analyzer (Model TA-XT2 Plus, Texture Technologies, Scarsdale, N.Y., U.S.A.), tenderness was indirectly determined using the Meullenet–Owens Razor Shear (MORS), as described by Cavitt et al. (2004), during which MORS force (MORSF, N), MORS energy (MORSE, N.mm), and total peak counts (sums) were recorded. Briefly, a 5-kg load cell using a razor blade with a height of 24 mm and a width of 8.9 mm was set to a penetration depth of 20 mm. Crosshead speed was set at 5 mm/s and was triggered by a 5 g contact force. Data points were collected with an acquisition rate of 200 points per second. Breasts were punctured perpendicular to muscle fibers in four locations and shear energy was calculated as the area under the force deformation curve from the beginning to the end of the test (Figure 4). Breast fillets were considered tough (>172 N.mm), neither tough nor tender (155 to 172 N.mm), or tender (<155 N.mm) by consumers as described by Cavitt et al. (2004).

Image Collection and Analysis

Images of broiler carcasses were captured prior to evisceration in accordance to (Caldas-Cueva et al., 2018). Additionally, images were analyzed according to Caldas-Cueva et al. (2020), with minor modifications. Instead of calculating M0-M11, modifications permitted the use of M1-M6, and an additional M7 measurement that evaluated the angle of the breast keel as pictured in Figure 6 and described in Table 5.

Statistics

All data were subjected to a three-way ANOVA using JMP Pro 14 software to detect effects of sex, strain, carcass size, or diet and their associated interactions. This gave appropriate consideration for a completely randomized block design so that a factorial arrangement of treatments could be used. Statistical significance was set at $P \leq 0.05$. Where appropriate, means

were then separated using Student's *t* test. In an attempt to simplify data, myopathy scores were pooled together on a whole number basis. Whole number pools then allowed each myopathy to be sorted into one of three categories. An absence of myopathies was set at 0 to 0.5, mild or moderate occurrence was considered at 1 and 1.5, and lastly, 2 to 3 was considered severe in occurrence. Myopathies were then analyzed based on percent incidence for the three aforementioned levels on a pen basis. After initial analysis, diet was found to have a main effect on L*, b*, pH, and drip values, but lacked any interactions for quality parameters. Therefore, data was pooled and diet was intentionally removed from the model and will not be discussed.

RESULTS AND DISCUSSION

Live weight and Yields

Live production data for this experiment was reported in Chapter II. Both final live weight and total white meat yields (breast and tender) were influenced ($P<0.05$) by strain in both market segments (Table 1). As expected, SY strains produced higher live weights, but had decreased breast and tender yield compared to HY strains ($P<0.05$). Previous researchers have determined that live weight can be directly impacted by strain as SY birds produce higher body weights than HY broilers when processed at the same age (Young et al., 2001; Mehaffey et al., 2006; Brewer et al., 2012a; b; c). According to Bilgili et al. (1992) strain can directly impact yield, with high-yielding birds outperforming their standard yielding cohorts (Corzo et al., 2005). There was an impact of sex on live weight, but this was expected since processing dates were planned to reach similar body weights for each segment. Sex also had a significant influence ($P<0.05$) on both breast and tender yields. In the current study, females produced higher yields ($P<0.05$) than males for both breast and tender yields which supports the findings of Young et al. (2001). Carcass size for different market segments also influenced ($P<0.05$) final live weight,

breast, and tender yields. Since two markets were targeted, carcass size influenced all weight and yield parameters as expected. The BB market had higher ($P<0.05$) breast and tender yields than the SB market. A sex x carcass size interaction was observed as females yielded higher breast and tender yields ($P<0.05$) with increasing carcass size, while males yielded higher carcass size than females ($P<0.05$), but lower breast and tender yields. Similar to the impact of sex, this interaction was expected as two market weights were targeted, allowing females to surpass males in final weight. No strain x sex, strain x carcass size, or strain x sex x carcass size interactions were observed in final live weight or breast and tender meat yield.

Fillet Dimensions

Changes in market trends have forced integrators to evolve into specialty markets for targeted products (Northcutt et al., 2001). Small bird debone markets require specific breast fillet dimensions to meet consumer specifications. Whole-muscle products are very popular among consumers in the fast food market, specifically sandwiches, which prove to be the most important when trying to meet a specific fillet dimension. Breast fillet dimensions presented in this experiment show that strain significantly impacts fillet thickness and length ($P<0.05$), which are in agreement with Brewer et al. (2012c; d). A main effect of strain was observed ($P<0.05$) in all listed dimensions, with the exception of breast fillet width, as HY strains expressed increased thickness and length (Table 2). Additionally, HY strains exhibited a greater incidence ($P<0.05$) in myopathy scores compared to SY strains. Important for the SB market specifically, breast thickness and length can negatively impact the eating quality of a product by being too thick or too long in nature as they will not properly cover a sandwich bun. With an aim to decrease variation in both length and thickness, fillets utilized for sandwiches are more uniform in nature to meet customer specifications. Dozier and Moran (2002) hypothesized that fillet length varies

with frame size, and genetic potential, which could explain the strain effect on length presented in this experiment. Furthermore, Lubritz (1997) found that heavy genetic line selection and sex can directly impact the length, width, and thickness of breast fillets. A sex x carcass size interaction was observed as females possessed longer breast length with increasing carcass size ($P<0.05$) while males decreased in breast length with increasing carcass size. However, no interactions were observed in strain x sex ($P>0.05$). As seen in this experiment, heavy selection for breast meat yield could explain the strain effect for breast fillet thickness as HY strains had increased thickness, which was supported by Lubritz (1997) who reported that increased breast thickness was related to increases in yield. In the present experiment, the SB market males expressed longer and generally thicker fillets than females, however, that finding cannot be concluded for the BB segment due to variation in ages to meet market size. Lubritz (1997) also found that males tended to possess longer, wider, thicker, and heavier fillets when compared to female fillets when processed at the same age. However, his findings concluded that fillets from males, at any given age, were approximately 7.75 grams heavier which could explain the increased thickness in males compared to females (Lubritz, 1997). All listed dimensions, with the exception of breast thickness, were affected ($P<0.05$) by sex, as males generally had more uniform dimensions than females for the SB market and vice versa for the BB market.

Breast Meat Myopathies

The increasing prevalence of myopathies across the globe have forced integrators to try and elucidate their origins. Woody breast has been well defined as the occurrence of a hard touch type consistency and the visual appearance of a solid ridge running through the fillet (Sihvo et al., 2014; Trocino et al., 2015; Tijare et al., 2016). High-yielding strains exhibited a higher incidence of all myopathies, when compared to the SY strains in the current experiment (Table

2) ($P<0.05$). These findings are similar to those presented in Livingston et al. (2018), in which HY strains showed strong correlation to increased incidences of WB when compared to SY strains. Previous research also suggests that males exhibit higher incidences of woody breast (Trocino et al., 2015; Livingston et al., 2018). However, in the current study, sex had an effect on the incidence of WB, regardless of strain, with females possessing a higher incidence compared to males, which was supported by Barbut (2020). Mallmann (2019) reported that males had higher WB than females between 3.2 and 3.6 kg, but had similar WB at higher weights (e.g., 3.6 to 4 kg). A potential reason for this effect is that with targeted carcass size, body weight as a direct result of increasing age, may directly influence the incidence of myopathies. Age has inherently been known to increase the collagen content and decrease the acceptability of a product (Lawrie, 1998). Increasing age has also been related to increasing the incidence of muscle myopathies (Kuttappan et al., 2017). The incidence rate of WB in the current study followed that pattern as BB exhibited almost twice that observed in the SB ($P<0.05$). Similar to strain, carcass size influenced ($P<0.05$) all myopathy parameters, with the exception of SM. A strain x sex x carcass size interaction was observed in WB scores with BB, HY females producing the highest degrees of severity while SB, SY males produced the lowest degrees of WB severity ($P<0.05$). The interaction between strain x sex x carcass size suggests that genetic background, sex, and processing age of the bird all contribute to increased myopathy incidences with HY birds expressing higher incidence rates of WB, WS, and SM as age increases. Mallmann (2019) reported similar findings with HY birds exhibiting three times the incidence of WB than SY birds, regardless of market age, past 5 week. Additionally, woody breast has been observed in conjunction with white striping (Tijare et al., 2016; Bowker et al., 2019). The

severity of each myopathy has also been shown to be moderately correlated (Tijare et al., 2016; Kuttappan et al., 2017).

White striping is characterized by the concentration of white striations parallel to muscle fibers in the cranial end of breast fillets from infiltration of fat and connective tissue (Kuttappan et al., 2012a; b, 2013b). The results from the present study found that HY strains had increased incidence of WS when compared to SY strains, which is in agreement with Kuttappan et al. (2013a). However, Kuttappan et al. (2013a) assessed HY strains and moderate yielding strains providing similar results with the SY strains used in the current experiment. Kuttappan et al. (2013a) also found that fillet thickness is important in WS, but when paired with genetic strain, the significance was lost. An interaction between breast thickness and genetic strain could have potentially explained variation in myopathy incidence within yield types, but the loss of this interaction eliminates that theory. In the same study by Kuttappan et al. (2013a), sex was not shown to be significant in producing various degrees of WS. However, the authors determined that males showed increasing severity of WS over that of females, mainly due to increased carcass size. Males had a higher incidence ($P<0.05$) of WS over that observed in females, which is in agreeance with Kuttappan et al. (2013a). This could be explained by the dimorphic growth patterns seen between males and females, with males producing heavier fillet and carcass weights, ultimately leading to an increase in severity (Anthony et al., 1991; Kuttappan et al., 2012a). However, the current study is in disagreement with Livingston et al. (2018), as they found males produced lower incidence rates of WS compared to females of the same strain. Mallmann (2019) also reported that females had higher WS than males at moderate weights, but differences were not noted at higher weights. The differences between this study and previous studies is that broilers were processed at similar weights, rather than identical ages. Similar to

WB, the incidence of WS also increases with carcass size ($P<0.05$). The current study reports that birds targeted for the BB market expressed an increased incidence of WS when compared to the SB market, which is in agreeance with Kuttappan et al. (2012a). A strain x carcass size interaction was observed for WS with HY possessing the highest degree of severity compared to the SY strains possessing the lowest degree of severity for both carcass sizes. This interaction could be explained by a study from Kuttappan et al. (2012a) who reported that the incidence of WS was reported to increase with age, inferring an increase in carcass size, as older ages exhibited a higher degree of severity. Moreover, Kuttappan et al. (2015) found that increasing age through different market ages produces a higher incidence of WS with each additional week of growth. Similarly, the carcass size x strain interaction within this study was predominately influenced by growth rate and type.

Spaghetti meat, or the visual fraying of muscle fibers within the breast fillet, has recently emerged as another myopathy. Moreover, SM splits and tears easily while obtaining a mushy texture (Bilgili, 2015; Petracci et al., 2019). First reported in an article by Bilgili (2015), this myopathy has not been well reported in the literature and little is known about its etiology or emergence. However, Baldi et al. (2017) reported that previous literature had a similar occurrence of the abnormality in turkeys some decades ago. They found that turkeys exhibited loose muscle structure in which fiber bundles would “pull away” like fingers (Swatland, 1990). Reports suggest that the incidence of SM in poultry is widely inconsistent, but some flocks may contain up to 20% incidence (Petracci et al., 2019). Additionally, Bilgili (2015) found that the myopathy tends to be sex dependent with almost direct association to female fillets. In the current study, the incidence of SM follows this pattern as females in both market segments possessed higher severities of SM ($P<0.05$) than their male cohorts. Interestingly, males of the

SB strains had more SM while males of the BB strains exhibited none, and this decreased with age. This phenomenon is not generally common with myopathies, as increasing age increases incidence (Mallmann, 2019). However, as males continue to age, the separation of uniformity in growth performance begins to occur between sexes, and this could explain the differences noticed in SM severity. Furthermore, female BB market broilers expressed an increased incidence of SM ($P<0.05$) than the females of the SB market, much like the observations of Mallmann (2019). Mallmann (2019) reported that SM increased with age and a max peak incidence was observed when broilers reached 7 week of age. For the current experiment, BB were processed post 7 week, which could explain the lower incidence rate than expected. Another interesting find in the current study is that SM is influenced by strain ($P<0.05$). Much like the patterns observed in WB and WS, HY broilers selected for breast meat yield produced higher incidences of SM, which are in agreeance with Petracci et al. (2019). The relatively slower growth rate, paired with exceptional breast meat growth, may cause an imbalance in physiological soundness, producing the high rate of all myopathies in these strains. Distributions of all three myopathies are presented in Figures 7 through 9.

Tender Myopathies

Two conditions that affect the *Pectoralis minor* have been receiving attention from integrators around the world. Recently, quick serve restaurants that rely on whole muscle tenders have reported toughness and feathering of the *Pectoralis minor* (Owens, 2020). Much like the woody condition seen in the *Pectoralis major*, a similar condition is emerging in tenders. To date, there are currently no other studies that evaluate the effects of woody tenders (**WT**); however, similar trends for firmness are present in *Pectoralis minors* as observed in the *Pectoralis major*. Therefore, in the present study, the presence of WT was quantified using the

similar scoring technique in breast fillets as described in Tijare et al. (2016). Evaluation of woody tenders in males revealed that HY broilers had higher ($P<0.05$) average scores with a decreased incidence of normal tenders and increased incidence of moderate tenders. Similar to the findings of WB in this experiment, strain and carcass size influenced ($P<0.05$) the presence of WT. The woody tender myopathy also expressed a sex x carcass size interaction as males increased in incidence of WT ($P<0.05$) with larger carcass size and females decreased WT severity with increasing carcass size. This interaction, however, does not follow the interaction seen in WB, as males exhibit the lowest incidence of WB for both markets. Strain, sex, and carcass size all influenced ($P<0.05$) the occurrence of tender feathering (**TF**) in the current experiment. In accordance with the strain impact of WT discussed, generally males of HY broilers exhibited higher incidences of TF than their SY cohorts ($P<0.05$). Additionally, tender feathering is directly impacted by size, as increased carcass size increased the incidence of the myopathy ($P<0.05$) in which the effect was greater in males. In regards to feathering, even less is known about the condition and its' effects on tender quality. A recent study by Soglia et al. (2019) coined the term "gaping", similar to conditions observed in fish production (Jacobsen et al., 2017), as reference to the previously described feathering. Through the assessment of commercial abattoir sample collection, Soglia et al. (2019) reported that the incidence in commercial flocks can range up to 17% in Italy, much like the incidence rate seen in spaghetti meat. Although the exact etiology of this tender myopathy is currently unknown, the myopathy is very similar to the fraying observed in SM. It should be noted that in the current study, broilers were raised in a controlled research environment, in opposition to commercially grown broilers in Soglia et al. (2019), allowing for more proper uniformity, which may directly affect the presence of this myopathy. With little knowledge of this myopathy, an interesting effect of sex

was observed in this data. Females had a higher average score for TF than males in the SB market, but there was no effect of sex in the BB market (carcass size x sex $P<0.05$). Distributions of both myopathies are presented in Figures 10 and 11.

Breast Meat pH

Postmortem pH decline and ultimate pH, can have a severe impact on meat quality (Bechtel, 1986). The effects of pH on meat quality have been well documented on functionality (Castaneda et al., 2005b; Li et al., 2015), color (Allen et al., 1997, 1998; Owens and Sams, 2000; Owens et al., 2000), water holding capacity (**WHC)** (Owens et al., 2000; Qiao et al., 2001; Mehaffey et al., 2006; Bowker and Zhuang, 2016), and shelf life (Fanatico et al., 2007). For the present study, all pH values were within a normal range of 5.6 to 6.0 (Table 3; Qiao et al., 2001). Generally, a lower pH (5.1) has been known to occur in PSE-like meat (Owens et al., 2000) and a higher than normal pH (6.1) has been noticed in DFD-like meat (Mallia et al., 2000). The current experiment did not express any pH values in relation to these defects and were therefore considered normal. A significant main effect of strain, sex, and carcass size were observed in the current study. High-yielding strain B had the highest ultimate pH, HYA the lowest, and both SYA and SYB strains were intermediate ($P<0.05$). Previously, Berri et al. (2001) stated that fast growing, high-yielding strains result in limiting the reduction rate and extension of pH decline. The current experiment contradicts this finding, as inconsistencies in ultimate pH cycle between HY and SY strains. Additionally, as processing weights were targeted, variation in processing day may impacted changes in ultimate pH. The effect of sex was significant ($P<0.05$) on pH development. In contrast to Brewer et al. (2012a; b), males progressed through rigor mortis faster than females, as indicated by pH ($P<0.05$). A main effect of sex on ultimate pH suggests that females had a higher pH than males ($P<0.05$) for both market ages. Moreover, carcass size had

an influence (P<0.05) on pH development. Previous research suggest that postmortem pH decline is directly affected by carcass size and environment (Mehaffey et al., 2006; Orlowski, 2016). Similar findings are present in this experiment as BB fillets reached an ultimate pH that was higher (P<0.05) than those found in the SB fillets. Aside from previous research, an interaction of sex x carcass size was observed (P<0.05). Males in the big bird market exhibited the highest pH values while males in the small bird market exhibited the lowest pH values (P<0.05). Le Bihan-Duval et al. (2001) determined that heritability of pH can be highly controlled through selection principles and developmental markets which may explain this interaction. Although the exact reason is not known, males in the SB market were heavier than females and vice versa in the BB market, which may explain the differences in pH decline.

Breast Meat Color

Meat color has shown to be one of the most important purchasing factors in fresh meat and poultry (Allen et al., 1998), as consumers must base their selection solely on package appearance. For poultry, a predominately light pink color should be seen in raw fillets (Mehaffey et al., 2006). Alongside consumer acceptance, other meat quality factors can be predicted, as muscle pH is highly correlated (-0.70 and -0.64) to color reflectance 1.5 h and 24 h postmortem (Owens et al., 2000). Light or color reflectance measures for L*, a*, and b* allowed for determination of surface appearance. L* values indicating the lightness or darkness of product showed high heritability through main effects within genotype, sex, and carcass size (P<0.05)(Table 3). Le Bihan-Duval et al. (2001) determined that breast fillet color was the most heritable trait of meat quality attributes in the modern broilers explaining the current main effect of strain. Similar to findings in Brewer et al. (2012b), fillets from females were lighter in color than fillets of males (P<0.05). In the current experiment, fillets in the BB market were lighter in

color ($P<0.05$) than those in the SB market, which is in agreeance with Abdullah and Matarneh (2010). A three-way interaction was also observed ($P<0.05$) with the female SYB strain in the big bird market expressing the lightest meat, the male SYA and HYA strains in the small bird market expressing the darkest meat, and all other combinations being intermediate. All L* values in the present study were considered to be in the $L^* \geq 49$ range which suggests the PSE-like condition (Barbut, 1997; Owens et al., 2000; Dozier and Moran, 2002). However, the presence of PSE-like conditions was not visually observed presently, when paired with pH readings, which are considered in the normal range. The SY strains had lower a* values and higher b* values than the HY strains ($P<0.05$). Sex did not impact b* values, but a* values were influenced (M>F; $P<0.05$) by sex. Males tended to show increased redness, regardless of strain or carcass size, in correspondence to females. Carcass size influenced the apparent redness and yellowness of the meat; ($P<0.05$) regardless of strain. Big bird market broilers expressed an increased ($P<0.05$) a* and an increased ($P<0.05$) b* compared to those in the SB market. An additional sex x carcass size interaction was observed ($P<0.05$) in b* values as females and males both increased in b* values as carcass size increased. This interaction contradicts the findings of Abdullah and Matarneh (2010) who found sex and carcass size had no influence on total redness. However, they did suggest that an interaction could occur between redness and carcass size, as animal size increases the overall myoglobin content increases explaining a shift to darker and redder color.

Water Holding Capacity (WHC)/Drip Loss/Cook Loss

Water retention, through water-holding capacity and drip loss, in meat products is important for maintaining juiciness and tenderness of a product (Jeffery, 1983). Offer et al. (1989) states that meat is inherently known to release water as soon as it is deboned and can release water from surface evaporation or exudation through a cut surface. Drip loss was

influenced by strain as HY strains had more water loss ($P<0.05$) than SY strains. Similar trends were noted in genotype effects on drip loss in Mehaffey et al. (2006). An analogous effect was observed with cacrcass size, with larger carcasses exhibiting more drip loss ($P<0.05$). Although the study conducted by Mehaffey et al. (2006) did not asses two market types, two flock ages were processed and resulted in numerical differences in drip loss where older birds tended to have greater drip than younger birds. Data suggets that varying flock ages for processing could then lead to increased drip as flock age increases. Conversely, a study conducted by Le Bihan-Duval et al. (1999) reported that HY strains had improved WHC ability over that observed in SY broilers. Offer et al. (1989) also suggests that drip losses increase as meat weight increases exposing more surface area. A strain x carcass interaction was observed ($P<0.05$) with drip loss as HY strains expressed the most drip while SY expressed lower amounts of drip. An explanation for this interaction would then be that HY strains paired with larger carcass size would then yield the most drip loss through individual characteristic assessment. No effect of strain ($P>0.05$), nor carcass size, was present for cook loss in the current experiment which is in agreement with previous research (Northcutt et al., 2001; Mehaffey et al., 2006; Fanatico et al., 2007; Brewer et al., 2012a; b). However, sex had an effect ($P<0.05$) on total cook loss, as males exhibited higher cook loss than females similar to the results of Brewer et al. (2012b). Poole et al. (1999) reported that regardless of age, and carcass size, males produced higher cook losses compared to females. Furthermore, as noticed in the two-way interaction of sex x carcass size ($P<0.05$), males exhibited higher cook loss than females, but females expressed an increase in cook loss as carcass size increased. This interaction is interesting as Brewer et al. (2012a; b) reported that females had higher cook loss than males in SB markets and vice versa in BB markets.

Tenderness/Shear Values

Previous research suggests that increasing aging time of carcasses increases tenderness and overall acceptability through extended postmortem proteolysis, retained moisture during cooking, and decreased shear force values (Stewart et al., 1984a; Northcutt et al., 2001; Mehaffey et al., 2006). Consumer satisfaction of poultry meat has shown to be driven predominately through texture (Fletcher, 2002). Consumer taste panels would be the most accurate way of determining the acceptability of a product, but are generally impossible to conduct on such a wide scale. As a compromise, the Meullenet Owens Razor Shear, more commonly known as the MORS method, was developed to produce quantitative results predicting poultry meat tenderness (Cavitt et al., 2004, 2005). This method, along with others such as Allo-Kramer and Warner-Bratzler shear, have been correlated to sensory perception and thus used as indirect measures of tenderness (Lyon and Lyon, 1990; Cavitt et al., 2004). Additionally, values of these methods have been compared to sensorial characteristics to give a more modified range of acceptability. Strain showed to significantly ($P<0.05$) impact overall MORSF, MORSE, and MORSE-PC. Interestingly, no differences were observed in shear values for HY broiler strains, but a difference in tenderness was observed from SY strains A and B. For all shear values expressed, SYB had higher values than those observed in SYA ($P<0.05$). Furthermore, shear values in the current experiment are similar to those observed in Mehaffey et al. (2006) and Brewer et al. (2012a; b). Poole et al. (1999) stated that meat-type White Rock birds had increased tenderness compare to egg-type Brown Leghorns. For that reason, Poole et al. (1999) speculated that continual selection in meat-type chickens may be beneficial in producing more tender meat. A main effect of sex was observed ($P<0.05$) for MORSE and

MORSE-PC. However, their associated effects were not similar. In the current experiment, females exhibited higher MORSE values ($P<0.05$) than males. This main effect of MORSE was in disagreement with Brewer et al. (2012a; b) who found that male energy values were higher than females, regardless of debone time and processed at the same age, but were in agreeance with Lyon and Wilson (1986). In opposition to the main effect of energy, males exhibited higher MORSE-PC ($P<0.05$) than did females. Furthermore, shear energy was shown to be influenced ($P<0.05$) by carcass size. Independent of strain or sex, BB carcasses produced higher energy values in relation to SB carcasses, which is in agreeance with Mehaffey et al. (2006). A sex x carcass size interaction was observed ($P<0.05$) for energy. Female values increased with carcass size ($P<0.05$) whereas male values decreased with increasing carcass size. A similar interaction was observed for MORSF, but this finding was expected as MORSF and MORSE measurements are highly correlated (Cavitt et al., 2004). Considering the combined observations from the series of papers by Brewer et al. (2012a; b; c; d), general trends can be inferred regarding shear energy. The authors found that in both the BB and SB scenario, that MORSE values tended to be higher for males and lower for females in both scenarios. It may be noted that within that series of papers, market age was targeted as a final processing date, whereas in the current study, target weight was the factor considered for processing. Therefore, the age of the females in the BB market of the current study were older which may explain the reasoning for females possessing a higher degree of shear force and energy. Lastly, total peak counts (**PC**) were influenced ($P<0.05$) by a sex x carcass size interaction, as females decreased in total counts with increasing carcass size and the inverse for males. Dransfield and Sosnicki (1999) reported that fast-growing chicken strains have larger diameter fibers than slow-growing strains reducing the total number of fibers present. This could potentially explain differences in strain association and their significance to

PC. Additionally, these authors state that with increasing age, hyperplasia is limited in the adult stages, so hypertrophy may explain decreases in tenderness (Dransfield and Sosnicki, 1999). Little research has been published evaluating the effects of peak counts on muscle structure, but we generally attribute PC with sheared muscle fibers that are present within fillets. Lyon and Wilson (1986) found that when shearing was in motion, the resistance that the blade found was through perimysial connective tissue requiring more shear than that of muscle fibers. Therefore, reported PC could then be considered a combination method of muscle fiber and connective tissue puncture. The first known publication of PC measurements were reported by Sun et al. (2016), who concluded that blunted-MORS (BMORS) methods could be used to potentially detect WB severity in breast fillets. In a recent publication by Bowker and Zhuang (2019), the authors reported on the incidence of WB and its impact on PC. They found that with increasing severity of WB, PC simultaneously increased. Furthermore, potential explanations for this increase were not clearly known, the authors suggested that excessive connective tissue resists shearing in fillets (Bowker and Zhuang, 2019). Since minimal research is known evaluating PC, the interaction of sex x carcass size in the current experiment may be beneficial to investigate in further research models.

Image Analysis

The use of image analysis is a rudimentary technique currently being evaluated in the poultry industry. Caldas-Cueva et al. (2020) demonstrated that image analysis may be beneficial in detecting WB in broiler carcass. Generally, sex had a significant ($P<0.05$) effect on all parameters expressing variation between carcass shapes, regardless of strain or carcass size (Table 5). As previously mentioned, the dimorphic growth patterns between sexes may explain this difference in carcass size (Anthony, 1998). There was a strain x sex interaction observed for

the M4 measurement as HY strains had larger angle values ($P<0.05$) as opposed to SY strains, which was in agreeance with Caldas-Cueva et al. (2020). This interaction may be explained by variation in yields, as HY strains produce large breast yields, the angle formed by M4 may shift to a larger degree accommodating this transformation. Furthermore, a strain x carcass size interaction was observed for M1 measurements. Big bird broilers expressed wider breast in the cranial region ($P<0.05$) than those from the SB market (Table 5). A potential explanation for this interaction may be that as two market segments were targeted, the conformation for body growth results in physiological soundness to produce a wider breast region. Since the use of image analysis is such a novel technique utilized in the poultry industry, further investigation may be beneficial for plant implementation.

CONCLUSION

Overall, the assessment of strain, sex, and various carcass size have direct implications on the performance of broiler carcasses and meat quality. Although strain had some impact on quality measures, carcass size and sex had greater impacts in terms of myopathies, water holding capacity, and shear properties. Differences in carcass size directly impacted quality as smaller markets showed improvements in most parameters assessed. However, broilers in big bird markets had greater yield. Quality also varied between males and females at a given weight. These results suggest that variation in quality at processing in industry may be partly due to processing varying live weights, as well as straight run broilers. Integrators should also strive for a balance between yield and quality.

ACKNOWLEDGEMENTS

The authors are appreciative for the support of Cobb-Vantress, Inc. (Siloam Springs, AR) and the University of Arkansas Division of Agriculture (Fayetteville, AR) throughout this project.

REFERENCES

Abdullah, A. Y., and S. K. Matarneh. 2010. Broiler performance and the effects of carcass weight , broiler sex , and postchill carcass aging duration on breast fillet quality characteristics. J. Appl. Poult. Res. 19:45–58.

Allen, C. D., D. L. Fletcher, J. K. Northcutt, and S. M. Russell. 1998. The Relationship of Broiler Breast Color to Meat Quality and Shelf-Life. Poult. Sci. 76:1042–1046.

Allen, C. D., S. M. Russell, and D. L. Fletcher. 1997. The relationship of broiler breast meat color and pH to shelf-life and odor development. Poult. Sci. 76:1042–1046.

AMSA. 2012. Meat color measurment guidelines. Accessed electronically July 21st, 2020.

Anthony, N. B. 1998. A review of genetic practices in poultry: Efforts to improve meat quality. J. Muscle Foods 9:25–33.

Anthony, N. B., D. A. Emmerson, K. E. Nestor, W. L. Bacon, P. B. Siegel, and E. A. Dunnington. 1991. Comparison of growth curves of weight selected populations of turkeys, quail, and chickens. Poult. Sci. 70:13–19.

Baldi, G., F. Soglia, M. Mazzoni, F. Sirri, L. Canonico, E. Babini, L. Laghi, and C. Cavani. 2017. Implications of white striping and spaghetti meat abnormalities on meat quality and histological features in broilers.Pages 1–10 in The Animal Consortium.

Barbut, S. 1996. Estimates and detection of the PSE problem in young turkey breast meat. Can. J. Anim. Sci. 76:455–457.

Barbut, S. 1997. Problem of pale soft exudative meat in broiler chickens. Br. Poult. Sci. 38:355–358.

Barbut, S. 2020. Understanding the woody breast syndrome and other myopathies in modern broiler chickens.Pages 99–102 in Australian Poultry Science Symposium. Sydney, Australia.

Bechtel, P. J. 1986. Muscle as Food. 1 ed. Academic Press, Inc., Orlando, FL.

Berri, C., N. Wacrenier, N. Millet, and E. Le Bihan-Duval. 2001. Effect of selection for improved body composition on muscle and meat characteristics of broilers from experimental and commercial lines. Poult. Sci. 80:833–838.

Le Bihan-Duval, E., C. Berri, E. Baeza, N. Millet, and C. Beaumont. 2001. Estimation of the genetic parameters of meat characteristics and of their genetic correlations with growth and body composition in an experimental broiler line. Poult. Sci. 80:839–843.

Le Bihan-Duval, E., C. Berri, E. Baeza, V. Sante, T. Astruc, H. Remignon, G. Le Pottier, J. Bentley, C. Beaumont, and X. Fernandez. 2003. Genetic parameters of meat technological quality traits in a grand-parental commercial line of turkey. Genet. Sel. Evol. 35:623–635.

Le Bihan-Duval, E., N. Millet, and H. Remignon. 1999. Broiler meat quality: Effect of selection for increased carcass quality and estimates of genetic parameters. Poult. Sci. 78:822–826.

Bilgili, S. F. 2015. Worthwhile Operational Guidelines & Suggestions (WOGS). Auburn,

Alabama.

Bilgili, S. F., E. T. Moran, and N. Acar. 1992. Strain-cross response of heavy male broilers to dietary lysine in the finisher feed: live performance and further-processing yields. Poult. Sci. 71:850–858.

Bodle, B. C., C. Alvarado, R. B. Shirley, Y. Mercier, and J. T. Lee. 2018. Evaluation of different dietary alterations in their ability to mitigate the incidence and severity of woody breast and white striping in commercial male broilers. Poult. Sci. 97:3298–3310.

Bowker, B., and H. Zhuang. 2016. Impact of white striping on functionality attributes of broiler breast meat1. Poult. Sci. 95:1957–1965.

Bowker, B., and H. Zhuang. 2019. Detection of razor shear force differences in broiler breast meat due to the woody breast condition depends on measurement technique and meat state. Poult. Sci. 98:6170–6176.

Bowker, B., H. Zhuang, S. C. Yoon, G. Tasoniero, and K. Lawrence. 2019. Relationships Between Attributes of Woody Breast and White Striping Myopathies in Commercially Processed Broiler Breast Meat. J. Appl. Poult. Res. 28:490–496.

Brewer, V. B., J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2012a. Small bird programs: Effect of phase-feeding, strain, sex, and debone time on meat quality of broilers. Poult. Sci. 91:499–504.

Brewer, V. B., V. A. Kuttappan, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2009. Big Bird Program: Impact of Strain, Gender, and Debone Time on Meat Quality of Broilers. Poult. Sci. 88:112 (Abstr.).

Brewer, V. B., V. A. Kuttappan, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2012b. Big-bird programs: Effect of strain, sex, and debone time on meat quality of broilers. Poult. Sci. 91:248–254.

Brewer, V. B., C. M. Owens, and J. L. Emmert. 2012c. Phase feeding in a big-bird production scenario: Effect on growth performance, yield, and fillet dimension. Poult. Sci. 91:1256–1261.

Brewer, V. B., C. M. Owens, and J. L. Emmert. 2012d. Phase feeding in a small-bird production scenario : Effect on growth performance , yield , and fillet dimension Phase feeding in a small-bird production scenario : Effect on growth performance , yield , and fillet dimension. Poult. Sci. 91:1262–1268.

Caldas-Cueva, J. P., A. Mauromoustakos, X. Sun, and C. M. Owens. 2020. Use of image analysis to identify woody breast characteristics in 8-week-old broiler carcasses. Poult. Sci. Submitted.

Castaneda, M. P., E. M. Hirschler, and A. R. Sams. 2005. Functionality of electrically stimulated broiler breast meat. Poult. Sci.:479–481.

Cavitt, L. C., R. Xiong, and C. M. Owens. 2005. Changes in Tenderness of Broiler Breast Fillets. J. Muscle Foods 16:223–242.

Cavitt, L. C., G. W. Youm, J. F. Meullenet, C. M. Owens, and R. Xiong. 2004. Prediction of Poultry Meat Tenderness Using Razor Blade Shear, Allo-Kramer Shear, and Sarcomere Length. J. Food Sci. 69:11–15.

Corzo, A., M. T. Kidd, D. J. Burnham, E. R. Miller, S. L. Branton, and R. Gonzalez-Esquerra. 2005. Dietary amino acid density effects on growth and carcass of broilers differing in strain cross and sex. J. Appl. Poult. Res. 14:1–9.

Dozier, W. A., A. Corzo, M. T. Kidd, P. B. Tillman, and S. L. Branton. 2009. Digestible lysine requirements of male and female broilers from fourteen to twenty-eight days of age. Poult. Sci. 88:1676–1682.

Dozier, W. A., M. T. Kidd, and A. Corzo. 2008. Dietary amino acid responses of broiler chickens. J. Appl. Poult. Res. 17:157–167.

Dozier, W. A., and E. T. Moran. 2002. Dimensions and light reflectance of broiler breast fillets: Influence of strain, sex, and feeding regimen. J. Appl. Poult. Res. 11:202–208.

Dransfield, E., and A. A. Sosnicki. 1999. Relationship between muscle growth and poultry meat quality. Poult. Sci. 78:743–746.

Fanatico, A. C., P. B. Pillai, J. L. Emmert, and C. M. Owens. 2007. Meat quality of slow- and fast-growing chicken genotypes fed low-nutrient or standard diets and raised indoors or with outdoor access. Poult. Sci. 86:2245–2255.

Fletcher, D. L. 2002. Poultry meat quality. Worlds. Poult. Sci. J. 58:131–145.

Goodwin, T. L., L. D. Andrews, and J. E. Webb. 1969. The influence of age, sex, and energy level on the tenderness of broilers. Poult. Sci. 48:548–552.

Harford, I. D., H. O. Pavlidis, and N. B. Anthony. 2014. Divergent selection for muscle color in broilers. Poult. Sci. 93:1059–1066.

Jacobsen, A., H. Joensen, and J. Eysturskarð. 2017. Gaping and loss of fillet firmness in farmed salmon (Salmo salar L.) closely correlated with post-slaughter cleaning of the abdominal cavity. Aquac. Res. 48:321–331.

Jeffery, A. B. 1983. Principles of water-holding applied to meat technology. J. Sci. Food, Agric. 34:1020–1021.

Kuttappan, V. A., V. B. Brewer, J. K. Apple, P. W. Waldroup, and C. M. Owens. 2012a. Influence of growth rate on the occurrence of white striping in broiler breast fillets. Poult. Sci. 91:2677–2685.

Kuttappan, V. A., V. B. Brewer, A. Mauromoustakos, S. R. McKee, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2013a. Estimation of factors associated with the occurrence of white striping in broiler breast fillets. Poult. Sci. 92:811–819.

Kuttappan, V. A., J. P. Caldas, F. L. Yang, V. V. Tijare, B. M. Hargis, C. N. Coon, J. Escobar, M. Vasquez-Anon, and C. M. Owens. 2015. White striping and woody breast: Effect on raw broiler breast fillet quality. Page 521P in Poultry Science.

Kuttappan, V. A., S. D. Goodgame, C. D. Bradley, A. Mauromoustakos, B. M. Hargis, P. W.

Waldroup, and C. M. Owens. 2012b. Effect of different levels of dietary vitamin E (DL-α-tocopherol acetate) on the occurrence of various degrees of white striping on broiler breast fillets. Poult. Sci. 91:3230–3235.

Kuttappan, V. A., B. M. Hargis, and C. M. Owens. 2016. Review White striping and woody breast myopathies in the modern poultry industry : a review. Poult. Sci. 95:2724–2733.

Kuttappan, V. A., Y. S. Lee, G. F. Erf, J. F. Meullenet, S. R. Mckee, and C. M. Owens. 2012c. Consumer acceptance of visual appearance of broiler breast meat with varying degrees of white striping. Poult. Sci. 91:1240–1247.

Kuttappan, V. A., C. M. Owens, C. Coon, B. M. Hargis, and M. Vazquez-A Non. 2017. Research Note Incidence of broiler breast myopathies at 2 different ages and its impact on selected raw meat quality parameters. Poult. Sci. 96:3005–3009.

Kuttappan, V. A., H. l. Shivaprasad, D. P. Shaw, B. A. Valentine, B. M. Hargis, F. D. Clark, S. R. McKee, and C. M. Owens. 2013b. Pathological changes associated with white striping in broiler breast muscles. Poult. Sci.:331–338.

Lawrie, R. A. 1998. Lawrie's Meat Science (RA Lawrie, Ed.). 6 ed. Woodhead Publishing Ltd, Cambridge, England.

Li, W. B., Y. L. Guo, J. L. Chen, R. Wang, Y. He, and D. G. Su. 2010. Influence of lighting schedule and nutrient density in broiler chickens: Effect on growth performance, carcass traits and meat quality. Asian-Australasian J. Anim. Sci. 23:1510–1518.

Li, K., Y. Y. Zhao, Z. L. Kang, P. Wang, M. Y. Han, X. L. Xu, and G. H. Zhou. 2015. Reduced functionality of PSE-like chicken breast meat batter resulting from alterations in protein conformation. Poult. Sci. 94:111–122.

Lilly, R. A., M. W. Schilling, J. L. Silva, J. M. Martin, and A. Corzo. 2011. The effects of dietary amino acid density in broiler feed on carcass characteristics and meat quality. J. Appl. Poult. Res. 20:56–67.

Livingston, M. L., C. Landon, H. J. Barnes, and J. Brake. 2018. White striping and wooden breast myopathies of broiler breast muscle is affected by time-limited feeding, genetic background, and egg storage. Poult. Sci. 98:217–226.

Lubritz, D. L. 1997. A statistical model for white meat yield in broilers. J. Appl. Poult. Res. 6:253–259.

Lyon, C. E., and B. G. Lyon. 1990. The Relationship of Objective Shear Values and Sensory Tests to Changes in Tenderness of Broiler Breast Meat. Poult. Sci. 69:1420–1427.

Lyon, C. E., and R. L. Wilson. 1986. Effects of Sex , Rigor Condition , and Heating Method on Yield and Objective Texture of Broiler Breast Meat 1. Poult. Sci. 65:907–914.

Macrae, V. E., M. Mahon, S. Gilpin, D. A. Sandercock, and M. A. Mitchell. 2007. Skeletal muscle fibre growth and growth associated myopathy in the domestic chicken (Gallus domesticus). Brit. Poult. Sci. 47:264–272.

Mallia, J. G., S. Barbut, J. P. Vaillancourt, S. W. Martin, and S. A. McEwen. 2000. A Dark, Firm

Dry-Like Condition in Turkeys Condemned for Cyanosis. Poult. Sci. 79:281–285.

Mallmann, B. A. 2019. Prediction and Evaluation of Breast Myopathy.

Maynard, C. W., R. E. Latham, R. Brister, C. M. Owens, and S. J. Rochell. 2019. Effects of Dietary Energy and Amino Acid Density during Finisher and Withdrawal Phases on Live Performance and Carcass Characteristics of Cobb MV × 700 Broilers. J. Appl. Poult. Res. 28:729–742.

Maynard, C. W., S. Y. Liu, J. T. Lee, J. V. Caldas, J. J. Diehl, S. J. Rochell, and M. T. Kidd. 2020. Determination of dietary digestible valine:lysine ratio for Cobb MV × 500 male and female broilers from 15 to 35 d of age. Poult. Sci. 99:Abstr.

Mehaffey, J. M., S. P. Pradhan, J. F. Meullenet, J. L. Emmert, S. R. McKee, and C. M. Owens. 2006. Meat quality evaluation of minimally aged broiler breast fillets from five commercial genetic strains. Poult. Sci. 85:902–908.

National Chicken Council. 2019. Accessed electronically July 21st, 2020.

Northcutt, J. K., R. J. Buhr, L. L. Young, C. E. Lyon, and G. O. Ware. 2001. Influence of age and postchill carcass aging duration on chicken breast fillet quality. Poult. Sci. 80:808–812.

Offer, G., P. Knight, R. Jeacocke, R. Almond, T. Cousins, J. Elsey, N. Parsons, A. Sharp, R. Starr, and P. Purslow. 1989. The structural basis of the water-holding, appearance and toughness of meat and meat products. Food Microstruct. 8,:151–170.

Orlowski, S. K. 2016. Characterization of Broiler Lines Divergently Selected for Breast Muscle Color.

Owens, C. M. 2014. Identifying quality defects in poultry processing. Watt Poult. USA:42–50.

Owens, C. M. 2020. Personal Communication.

Owens, C. M., E. M. Hirschler, S. R. McKee, R. Martinez-Dawson, and A. R. Sams. 2000. The characterization and incidence of pale, soft, exudative Turkey meat in a commercial plant. Poult. Sci. 79:553–558.

Owens, C. M., and A. R. Sams. 2000. The influence of transportation on turkey meat quality. Poult. Sci. 79:1204–1207.

Petracci, M., and C. Cavani. 2012. Muscle growth and poultry meat quality issues. Nutrients 4:1–12.

Petracci, M., F. Soglia, M. Madruga, L. Carvalho, E. Ida, and M. Estévez. 2019. Wooden-Breast, White Striping, and Spaghetti Meat: Causes, Consequences and Consumer Perception of Emerging Broiler Meat Abnormalities. Compr. Rev. Food Sci. Food Saf. 18:565–583.

Poole, G. H., C. E. Lyon, R. J. Buhr, L. L. Young, A. Alley, J. B. Hess, S. F. Bilgili, and J. K. Northcutt. 1999. Evaluation of age, gender, strain, and diet on the cooked yield and shear values of broiler breast fillets. J. Appl. Poult. Res. 8:170–176.

Qiao, M., D. L. Fletcher, D. P. Smith, and J. K. Northcutt. 2001. The effect of broiler breast meat color on pH, moisture, water-holding capacity, and emulsification capacity. Poult. Sci.

80:676–680.

Sihvo, H. K., K. Immonen, and E. Puolanne. 2014. Myodegeneration With Fibrosis and Regeneration in the Pectoralis Major Muscle of Broilers. Vet. Pathol. 51:619–623.

Skinner, J. T., A. L. Waldroup, and P. W. Waldroup. 1992a. Effects of dietary amino acid level and duration of finisher period on performance and carcass content of broilers forty-nine days of age. Poult. Sci. 71:1207–1214.

Skinner, J. T., A. L. Waldroup, and P. W. Waldroup. 1992b. Effects of dietary nutrient density on performance and carcass quality of broilers 42 to 49 days of age. J. Appl. Poult. Res. 1:367–372.

Soglia, F., S. Mudalal, E. Babini, M. Di Nunzio, M. Mazzoni, F. Sirri, C. Cavani, and M. Petracci. 2016. Histology, composition, and quality traits of chicken Pectoralis major muscle affected by wooden breast abnormality. Poult. Sci.:651–659.

Soglia, F., A. K. Silva, S. Tappi, L. M. Lião, P. Rocculi, L. Laghi, and M. Petracci. 2019. Gaping of pectoralis minor muscles: Magnitude and characterization of an emerging quality issue in broilers. Poult. Sci. 98:6194–6204.

Stewart, M. K., D. L. Fletcher, D. Hamm, and J. E. Thomson. 1984. The Influence of Hot Boning Broiler Breast Muscle on pH Decline and Toughening. Poult. Sci. 63:1935–1939.

Sun, X., F. L. Yang, J. L. Solo, B. A. Mallmann, C. N. Coon, and C. M. Owens. 2016. Using peak counts in shear data to detect woody breast in cooked broiler fillets. Poult. Sci. 95:52 (Abst.).

Swatland, H. J. 1990. A Note on the Growth of Connective Tissues Binding Turkey Muscle Fibers Together.Pages 239–241 in Canadian Institue of Food Science and Technology. Elsevier.

Tijare, V. V., F. L. Yang, V. A. Kuttappan, C. Z. Alvarado, C. N. Coon, and C. M. Owens. 2016. Meat quality of broiler breast fillets with white striping and woody breast muscle myopathies. Poult. Sci. 95:2167–2173.

Trocino, A., A. Piccirillo, M. Birolo, G. Radaelli, D. Bertotto, E. Filiou, and M. Petracci. 2015. Effect of genotype , gender and feed restriction on growth , meat quality and the occurrence of white striping and wooden breast in broiler chickens. Poult. Sci. 94:2996–3004.

Valceschini, E. 2006. Poultry meat trends and consumer attitudes.Pages 1–10 in Proc. XII Eur. Poult. Conf. Verona, Italy.

Wilhelmsson, S., J. Yngvesson, L. Jönsson, S. Gunnarsson, and A. Wallenbeck. 2019. Welfare quality assessment of a fast-growing and a slower-growing broiler hybrid, reared until 10 weeks and fed a low-protein, high-protein or mussel-meal diet. Livest. Sci. 219:71–79.

Woelfel, R. L., C. M. Owens, E. M. Hirschler, R. Martinez-Dawson, and A. R. Sams. 2002. The characterization and incidence of pale, soft, and exudative broiler meat in a commercial processing plant. Poult. Sci. 81:579–584.

Young, L. L., J. K. Northcutt, R. J. Buhr, C. E. Lyon, and G. O. Ware. 2001. Effects of age, sex,

and duration of postmortem aging on percentage yield of parts from broiler chicken carcasses. Poult. Sci. 80:376–379.

Table 1. Live weights and white meat yields of male and female broilers processed in different market segments[1] from four commercial strains[2]

		SYA		SYB		HYA		HYB		*P*-Value							
Parameter	Sex	SB	BB	SB	BB	SB	BB	SB	BB	SEM	Strain (St)	Sex (S)	CS	StxS	StxCS	SxCS	StxSxCS
Live Weight (kg)[3]	M	2.57	3.74	2.50	3.67	2.44	3.49	2.27	3.40	0.080	**<0.001**	0.226	**<0.001**	0.437	0.422	**<0.001**	0.706
	F	2.43	3.75	2.39	3.75	2.28	3.60	2.20	3.50								
Pectoralis Major Yield (%)[4]	M	19.63	22.22	19.53	21.38	21.14	23.51	21.9	24.14	0.198	**<0.001**	**<0.001**	**<0.001**	0.439	0.105	**0.042**	0.785
	F	20.14	22.88	20.16	22.39	21.37	24.09	22.31	25.28								
Pectoralis Minor Yield (%)[4]	M	4.19	4.48	4.14	4.37	4.47	4.73	4.57	4.70	0.042	**<0.001**	**<0.001**	**<0.001**	0.382	0.096	**0.001**	0.996
	F	4.61	5.03	4.50	4.87	4.83	5.23	4.86	5.16								

[a-b] Means without a common superscript were determined to be significantly different between carcass size ($P < 0.05$) by a Student's *t* test

[x-y] Means without a common superscript were determined to be significantly different between sexes ($P<0.05$) by a Student's *t* test

[1]SB = small bird, BB = big bird

[2]SYA = standard yielding A, SYB = standard yielding B, HYA = high yielding A, HYB = high yielding B

[3]Live weight is expressed in kilos to meet demand for specific bird markets

[4]Yields were calculated in relation to live weight on a percent basis

Table 2. Fillet dimensions and myopathy scores of male and female broilers processed in different market segments[1] from four commercial strains[2]

		SYA		SYB		HYA		HYB			*P*-Value						
Parameter	Sex	SB	BB	SB	BB	SB	BB	SB	BB	SEM	Strain (St)	Sex (S)	CS	StxS	StxCS	SxCS	StxSxCS
Thickness (mm)[3]	M	30.92	40.13	30.75	39.26	31.64	40.48	32.28	41.66	0.477	**<0.001**	0.102	**<0.001**	0.745	0.293	0.058	0.867
	F	30.81	38.75	30.97	38.12	31.9	40.22	32.15	41.05								
Length (mm)[4]	M	152.97	176.09	151.56	173.58	150.57	171.4	147.38	168.79	1.068	**<0.001**	**0.048**	**<0.001**	0.694	0.794	**<0.001**	0.818
	F	151.71	177.47	149.95	177.14	149.48	175.45	147.04	172.63								
Width (mm)[5]	M	132.4	158.4	133.93	159.66	134.06	157.29	133.96	158.39	2.294	0.489	**<0.001**	**<0.001**	0.815	0.921	0.052	0.994
	F	140.61	170.23	142.34	172.12	139.17	167.59	139.89	169.39								
WB[6]	M	0.56^{by}	1.16^{ay}	0.55^{by}	1.14^{ax}	0.73^{by}	1.13^{ay}	0.71^{by}	1.25^{ay}	0.042	**0.001**	**<0.001**	**<0.001**	0.082	**0.007**	**0.004**	0.794
	F	0.85^{bx}	1.27^{ax}	0.82^{bx}	1.08^{ay}	0.86^{bx}	1.31^{ax}	0.88^{bx}	1.39^{ax}								
WS[7]	M	0.78	1.53	0.81	0.98	0.78	1.57	0.89	1.56	0.073	**<0.001**	**<0.001**	**<0.001**	0.085	**0.006**	0.786	**0.003**
	F	0.55	1.28	0.52	1.13	0.62	1.08	0.65	1.31								
SM[8]	M	0.17	0.00	0.07	0.00	0.17	0.00	0.24	0.00	0.041	**0.001**	**<0.001**	0.357	0.083	0.074	**<0.001**	0.123
	F	0.26	0.45	0.27	0.54	0.37	0.4	0.4	0.67								
Woody Tender[9]	M	0.21	0.67	0.31	0.70	0.28	0.76	0.35	0.77	0.035	**0.002**	0.087	**<0.001**	0.470	0.654	**<0.001**	0.197
	F	0.51	0.37	0.53	0.38	0.66	0.38	0.60	0.39								
Tender Feathering[10]	M	0.33	0.69	0.34	0.76	0.36	0.68	0.44	0.74	0.043	**0.024**	**0.003**	**<0.001**	0.828	0.573	**<0.001**	0.694
	F	0.55	0.66	0.56	0.66	0.54	0.57	0.61	0.73								

n=12 pens per mean

[a-b] Means without a common superscript were determined to be significantly different between carcass size ($P < 0.05$) by a Student's *t* test

[x-y] Means without a common superscript were determined to be significantly different between sexes (P<0.05) by a Student's *t* test

[1]SB = small bird, BB = big bird

[2]SYA = standard yielding A, SYB = standard yielding B, HYA = high yielding A, HYB = high yielding B

[3]Measured in mm at the thickest part of the cranial region

[4]Measured in mm from the uppermost portion of the cranial region to the tip of the caudal tail

[5]Measured in mm at 1/3 the distance from the caudal end of the *Pectoralis major*

[6]Woody Breast. Scored on a numeric scale from 0-3 with 0.5 increments as described in Tijare et. al 2016. Values presented are the averages for each respective treatment

[7]White Striping. Scored on a numeric scale from 0-3 with 0.5 increments as described in Kuttappan et. al 2012. Values presented are the averages for each respective treatment

[8]Spaghetti Meat. Value based on the presence or absence of the emerging myopathy. Visual fiber fraying in any location through the *Pectoralis* major are considered to obtain the myopathy. Values
presented are the averages for each respective treatment

[9]Scored on a numeric scale from 0-2 with 0.5 increments. Similar to the procedure described in Tijare et. al 2016, however, a minor modification of evaluating the *Pectoralis minor* instead of the
Pectoralis major was utilized. Values presented are the averages for each respective treatment

[10]Scored on a numeric scale from 0-2 with 0.5 increments. Tenders were considered for tender feathering if the tender displayed no visible fiber fraying, moderate fiber fraying throughout, or severe fiber
fraying throughout the length of the tender. Values presented are the averages for each respective treatment

Table 3. Various meat quality parameters of male and female broilers processed in different market segments[1] from four commercial strains[2]

		SYA		SYB		HYA		HYB			*P*-Value						
Parameter	Sex	SB	BB	SB	BB	SB	BB	SB	BB	SEM	Strain (St)	Sex (S)	CS	StxS	StxCS	SxCS	StxSxCS
pH[3]	M	5.83	5.98	5.85	5.97	5.82	5.94	5.86	5.99	0.018	**0.008**	**<0.001**	**<0.001**	0.677	0.161	**<0.001**	0.124
	F	5.94	5.93	5.95	5.94	5.91	5.96	5.94	6.02								
L*[4]	M	56.36^{b}	57.21^{a}	57.17^{y}	57.51^{bx}	56.61^{b}	57.36^{a}	56.27^{by}	57.56^{a}	0.228	**<0.001**	**<0.001**	**<0.001**	0.177	0.372	0.709	**0.046**
	F	56.42^{b}	57.67^{a}	57.88^{bx}	58.52^{ay}	56.82^{b}	57.74^{a}	57.15^{x}	57.24								
a*[4]	M	3.06	3.28	2.87	3.24	3.11	3.39	3.42	3.35	0.145	**0.010**	**<0.001**	**0.039**	0.265	0.867	0.524	0.151
	F	3.02	3.05	2.61	2.74	3.17	3.03	2.73	3.12								
b*[4]	M	9.51	9.91	9.51	9.80	9.35	9.68	9.11	9.44	0.186	**0.004**	0.746	**<0.001**	0.300	0.796	**0.011**	0.916
	F	9.07	10.01	9.39	9.95	9.35	10.31	8.84	9.64								
Drip Loss (%)	M	0.95	1.50	0.85	0.98	1.02	1.29	1.06	1.31	0.100	**0.003**	0.758	**<0.001**	0.234	**0.002**	0.2478	0.072
	F	0.96	1.20	1.18	0.88	1.00	1.30	1.03	1.53								
Cook Loss (%)	M	25.5	25.9	26.83	24.59	25.17	25.36	25.9	26.1	0.662	0.830	**<0.001**	0.070	0.806	0.094	**0.004**	0.555
	F	23.51	24.49	23.84	24.57	23.59	25.26	23.02	25.9								
MORSF (N)[5]	M	13.37	12.07	14.19	12.74	13.79	13.14	13.32	12.95	0.238	**<0.001**	0.874	0.596	0.683	0.163	**<0.001**	0.074
	F	12.45	13.03	12.53	14.16	12.83	13.74	12.76	13.92								
MORSE (N.mm)[5]	M	181.35	170.99	191.07	182.09	184.31	184.91	179.96	182.64	3.307	**<0.001**	**0.008**	**<0.001**	0.721	0.193	**<0.001**	0.068
	F	174.4	187.17^{ax}	175.04	203.37	179.04	196.13	180.12	197.41								
MORS-PC[5]	M	8.17	9.25^{x}	8.74	9.11	8.05	8.76	7.92	8.85	0.174	**0.002**	**0.003**	0.054	0.520	0.094	**<0.001**	0.912
	F	8.56	8.30^{y}	8.86	8.10	8.48	8.16	8.36	7.96								

[a-b] Means without a common superscript were determined to be significantly different between carcass size ($P < 0.05$) by a Student's *t* test

[x-y] Means without a common superscript were determined to be significantly different between sexes (P<0.05) by a Student's *t* test

[1]SB = small bird, BB = big bird

[2]SYA = standard yielding A, SYB = standard yielding B, HYA = high yielding A, HYB = high yielding B

[3]pH was collected 24 h postmortem

[4]All color measurements were recorded on the dorsal side of breast fillets 24 h postmortem

[5]Meullenet-Owens Razor Shear F = force; E = Energy; PC = peak counts

Table 4. Various carcass dimensions of male and female broilers processed in different market segments[1] for four commercial strains[2]

		SYA		SYB		HYA		HYB		*P*-Value							
Parameter	Sex	SB	BB	SB	BB	SB	BB	SB	BB	SEM	Strain	Sex	TW	StxS	StxTW	SxTW	StxSxTW
M1 (cm)	M	16.27	16.04	15.80	16.25	16.54	16.18	16.33	16.47	0.219	0.119	**0.036**	0.588	0.985	**0.044**	0.610	0.057
	F	16.03	16.83	16.07	16.52	16.69	16.46	16.84	16.29								
M2 (cm)	M	5.03	5.10	4.86	5.06	4.92	4.92	4.73	4.80	0.062	<**0.001**	0.317	<**0.001**	0.738	0.241	0.188	0.884
	F	4.92	5.15	4.90	5.12	4.94	5.01	4.73	4.89								
M3 (cm)	M	10.08	10.37	9.78	10.03	10.55	10.65	10.75	11.01	0.193	<**0.001**	<**0.001**	<**0.001**	0.197	0.642	0.215	0.933
	F	10.50	10.97	10.23	10.87	10.95	11.11	10.67	11.25								
M4 (°)	M	90.51	89.68	89.08	89.59	94.00	93.40	96.49	96.73	0.500	<**0.001**	<**0.001**	0.356	**0.002**	0.249	0.810	0.774
	F	93.18	92.39	92.50	92.03	95.60	94.98	96.73	97.45								
M5 (cm)	M	25.50	26.60	23.87	25.51	26.09	26.33	25.59	26.59	0.786	0.116	**0.002**	<**0.001**	0.625	0.451	0.175	0.979
	F	26.00	28.43	25.19	27.99	27.29	28.02	25.40	27.70								
M6 (cm)	M	35.69	36.00	33.64	34.78	36.17	36.26	36.27	37.55	0.971	0.061	**0.006**	**0.003**	0.561	0.518	0.130	0.944
	F	36.14	38.12	34.87	38.27	37.30	37.99	35.97	38.64								
M7 (°)	M	122.62	122.22	121.68	125.49	125.73	129.84	131.91	135.23	1.609	<**0.001**	<**0.001**	**0.014**	0.338	0.544	0.384	0.647
	F	134.76	135.52	135.20	137.84	138.19	137.68	142.03	144.37								

n=10 processing pens per mean

[a-b] Means without a common superscript were determined to be significantly different between carcass size ($P < 0.05$) by a Student's *t* test

[x-y] Means without a common superscript were determined to be significantly different between sexes (P<0.05) by a Student's *t* test

[1]SB = small bird, BB = big bird

[2]SYA = standard yielding A, SYB = standard yielding B, HYA = high yielding A, HYB = high yielding B

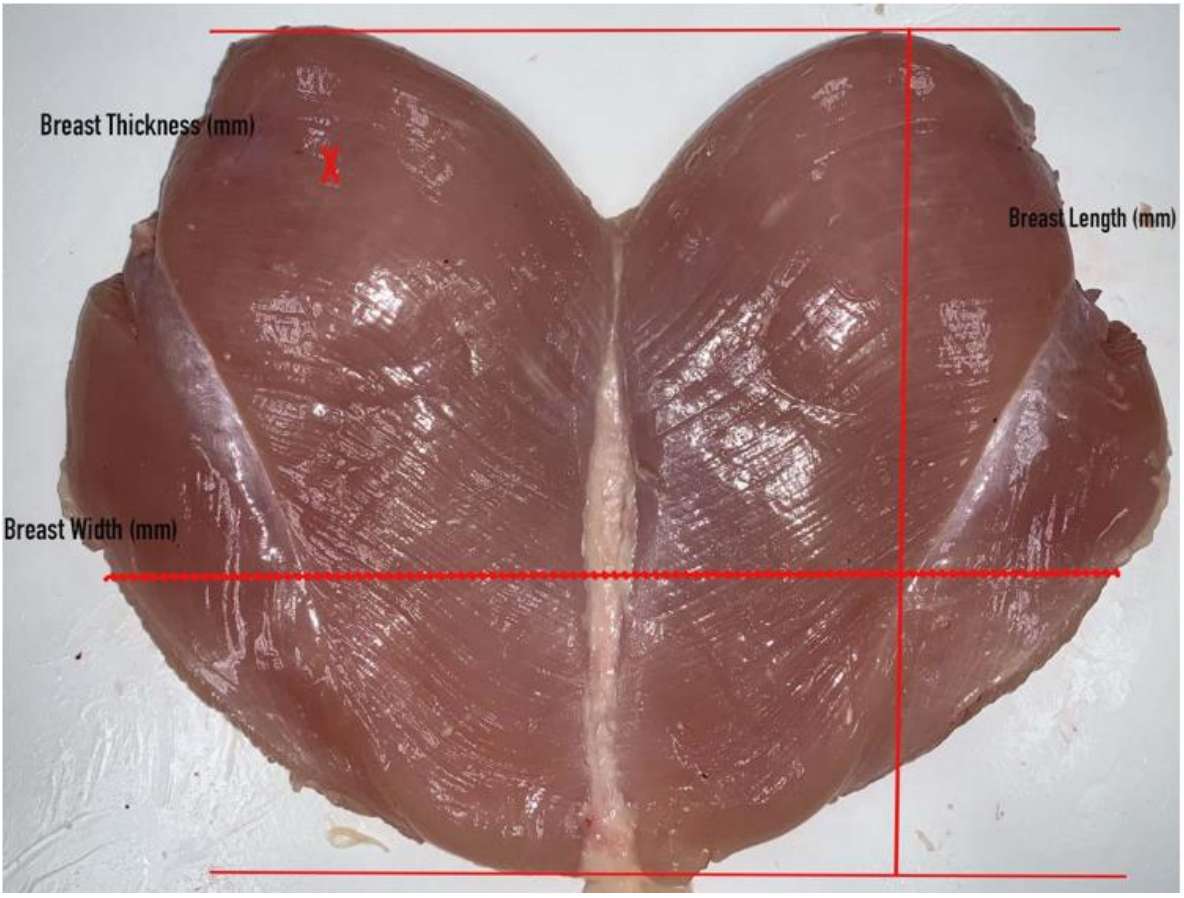

Figure 1: Fillet dimension measurements for breast length, width, and thickness

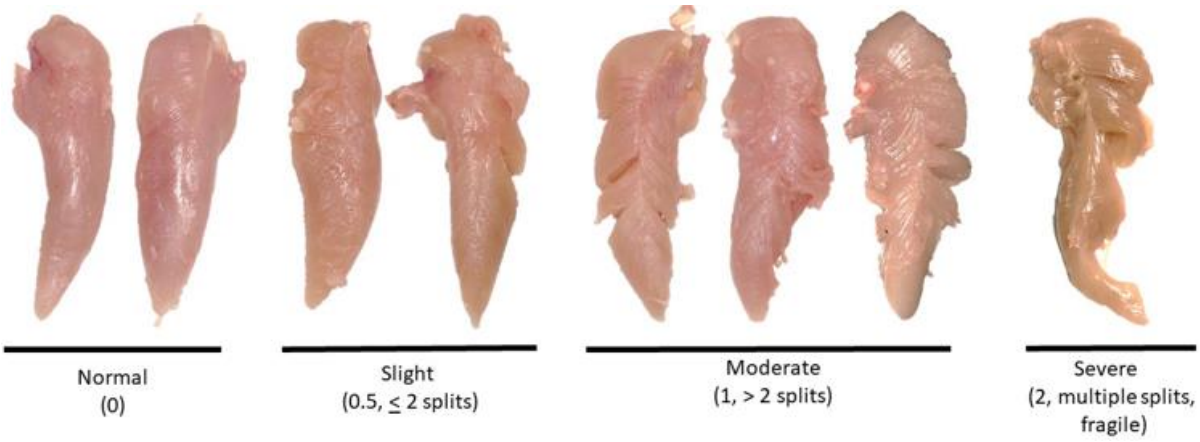

Figure 2: Tender feathering (TF) score methodology used to classify fraying throughout the tender

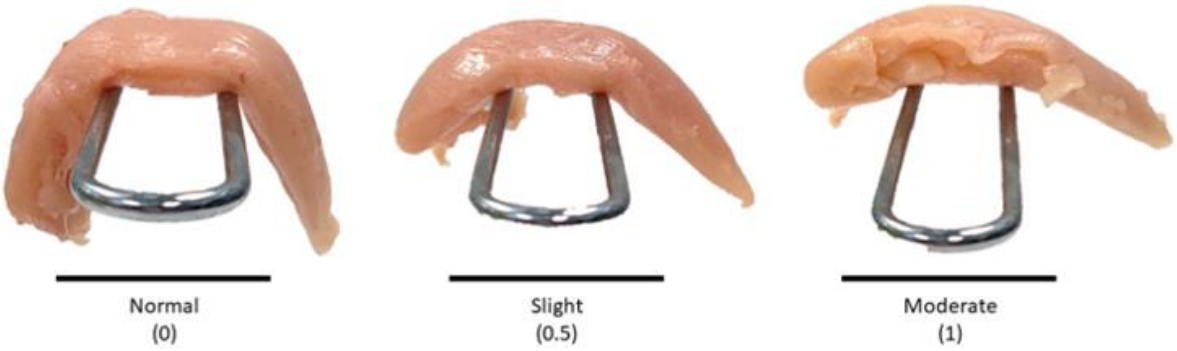

Figure 3: Woody tender (WT) score methodology used to classify hardness throughout the tender

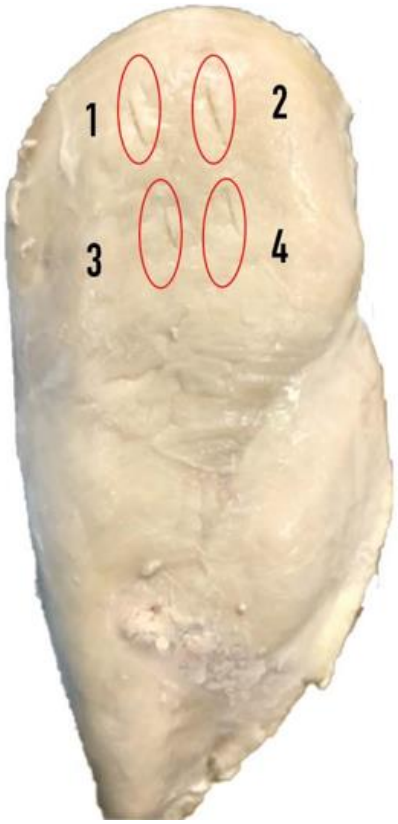

Figure 4: Shear analysis location for cooked breast fillet

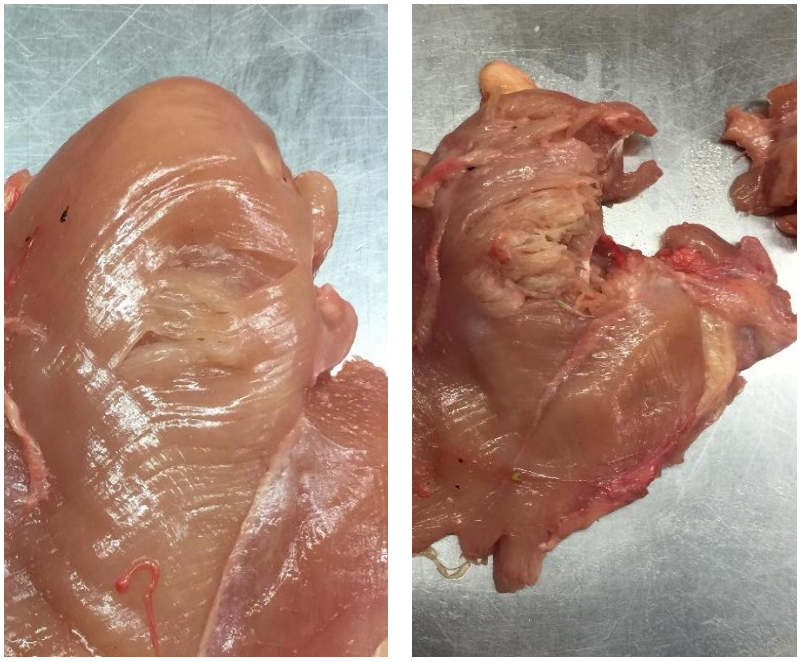

Figure 5: Spaghetti meat (SM) incidences of mild (left) and severe (right)

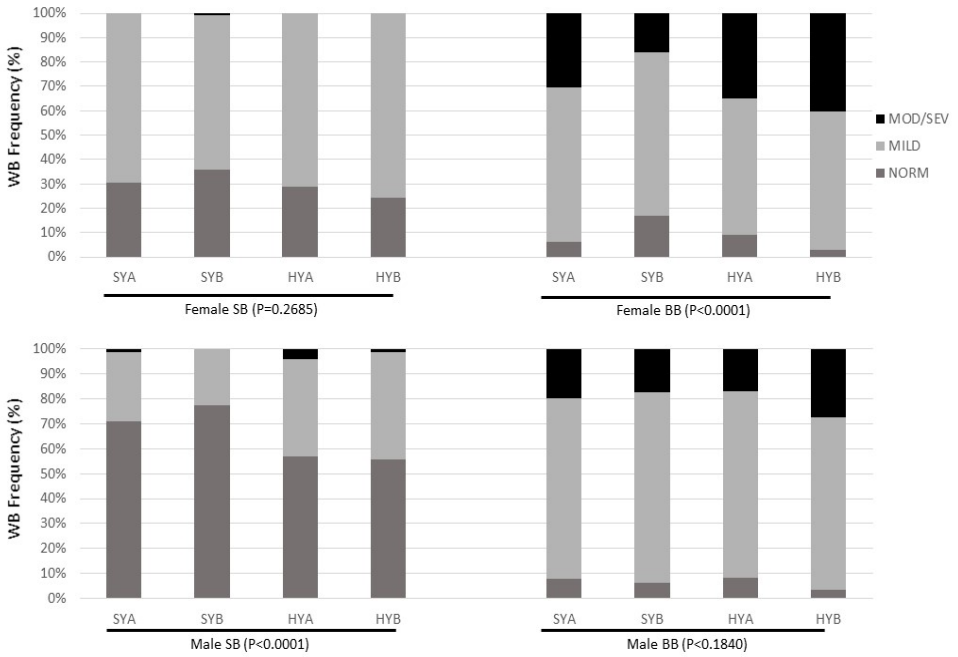

Figure 7: Woody breast (WB) incidence of male and female broilers from four commercial strains grown for two debone markets. SYA = Standard Yielding A, HYA = High Yielding A, SYB = Standard Yielding B, HYB = High Yielding B. SB = Small Bird, BB = Big Bird.

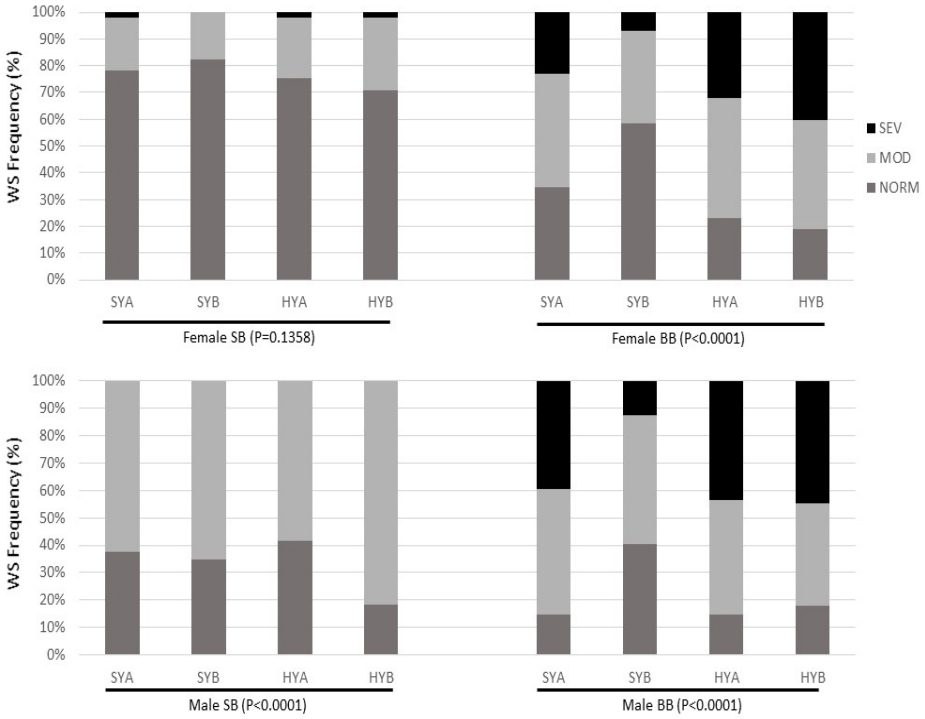

Figure 8: White striping (WS) incidence of male and female broilers from four commercial strains grown for two debone markets. SYA = Standard Yielding A, HYA = High Yielding A, SYB = Standard Yielding B, HYB = High Yielding B. SB = Small Bird, BB = Big Bird.

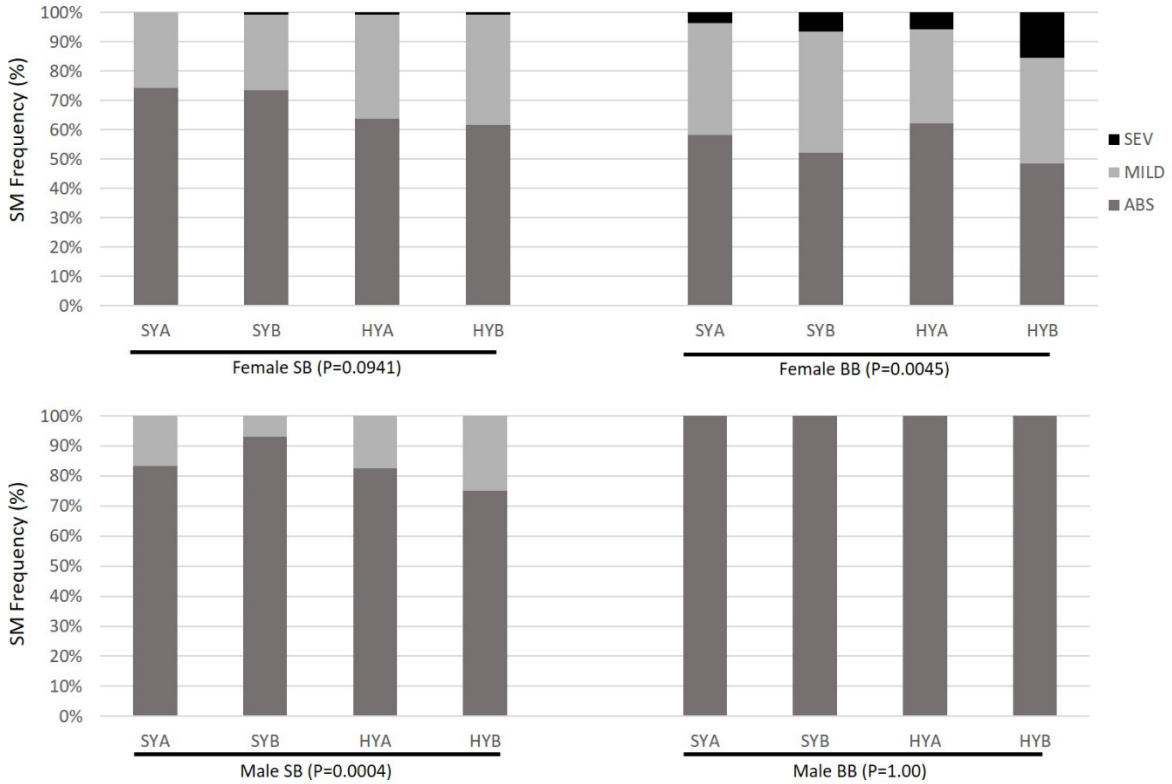

Figure 9: Spaghetti meat (SM) incidence of male and female broilers from four commercial strains grown for two debone markets. SYA = Standard Yielding A, HYA = High Yielding A, SYB = Standard Yielding B, HYB = High Yielding B. SB = Small Bird, BB = Big Bird.

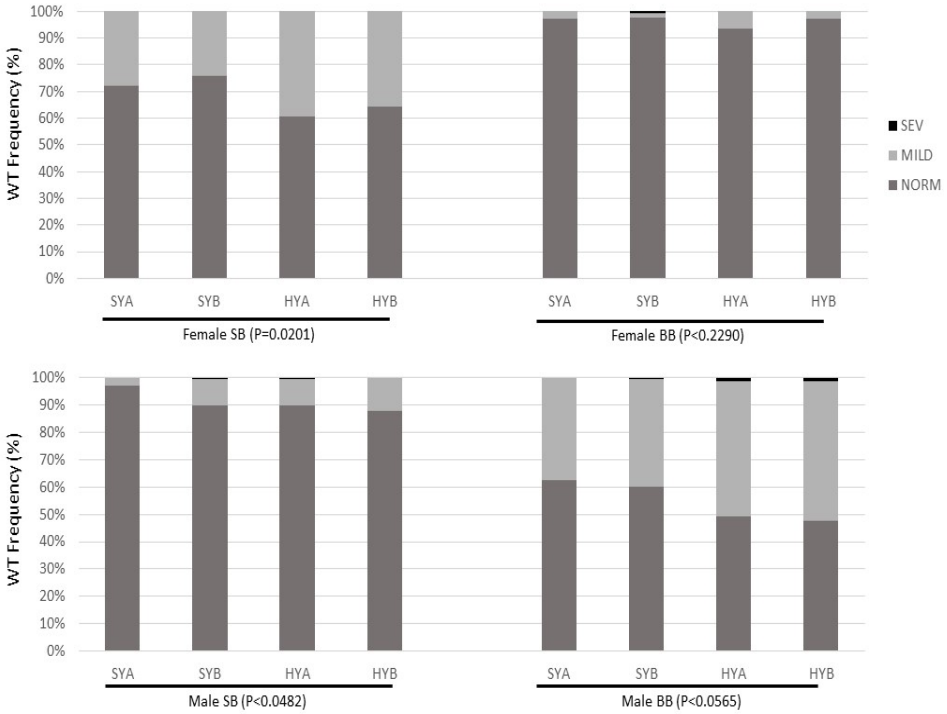

Figure 10: Woody tender (WT) incidence of male and female broilers from four commercial strains grown for two debone markets. SYA = Standard Yielding A, HYA = High Yielding A, SYB = Standard Yielding B, HYB = High Yielding B. SB = Small Bird, BB = Big Bird.

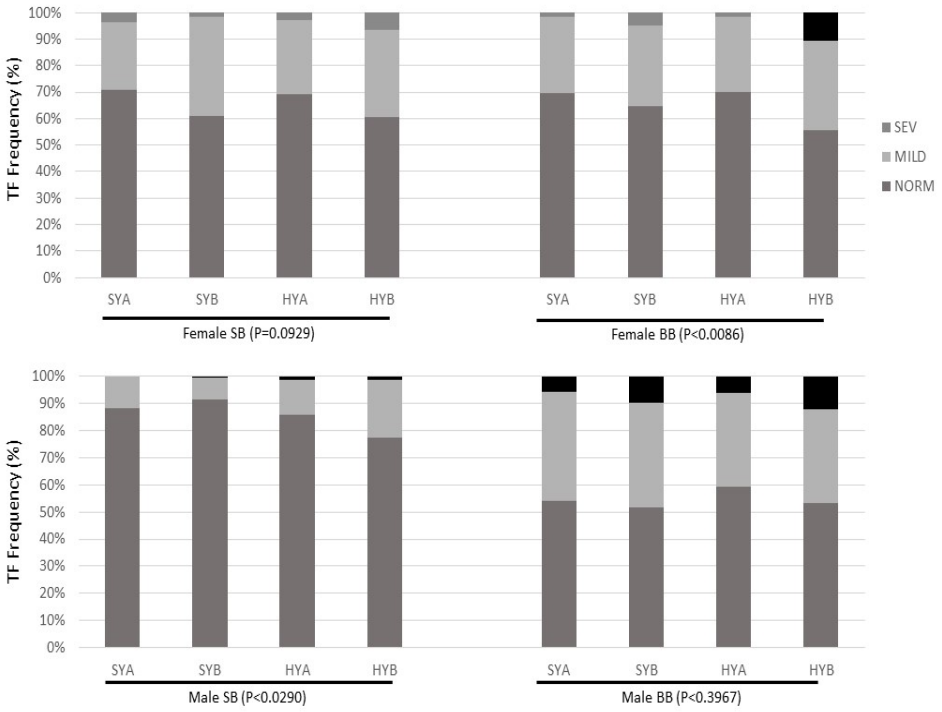

Figure 11: Tender feathering (TF) incidence of male and female broilers from four commercial strains grown for two debone markets. SYA = Standard Yielding A, HYA = High Yielding A, SYB = Standard Yielding B, HYB = High Yielding B. SB = Small Bird, BB = Big Bird.

CONCLUSION

CONCLUSION

Advancements in genetic improvement have led to producing heavier, leaner broiler carcasses in the modern industry. Standard yielding strains have shown to improve feed conversion but produce lower yields, as opposed to their high yielding cohorts. Decreases in feed conversion have shown to reduce input cost, which inherently reduce final cost to the consumer. Additionally, standard yielding birds express rapid weight gain to provide final heavier live weights in a shorter time than high yielding strains. Rearing sex separate flocks may also be beneficial in meeting market demands as growth performance for males and females is different. Finally, higher inclusion rates of feed grade amino acids in poultry diets can provide an increase in lean meat accretion and a reduction in total fat to meet high consumer demands.

Conformational changes in growth performance have been beneficial for growth and yields, but relative meat quality has seen some impactful changes. High yielding strains produce higher incidences of myopathies leading to a decrease in functional use. Additionally, SY strains have shown improvements for WHC and drip loss which prove to be beneficial for fresh, retail markets. However, if total yield for increases in weight are targeted, HY strains should be used to maximize return. Sex also proved to be significant in determining differences in meat quality. Females produced wider fillets than males, regardless of strain, which may be beneficial for processors when whole muscle portioning with DSI cutting is utilized. Finally, females processed for SB markets could potentially lead to a more tender final product, whereas males for BB markets provide a higher level of tenderness.

Therefore, the characterization of the modern broiler strains aided in determining the effects of strain, sex, diet, and carcass size and their direct implications on growth and meat quality.

APPENDIX

APPENDIX A

UNIVERSITY OF ARKANSAS

Office of Research Compliance

To:	Casey Owens
Fr:	Billy Hargis
Date:	September 9th, 2019
Subject:	IACUC Approval
Expiration Date:	August 29th, 2022

The Institutional Animal Care and Use Committee (IACUC) has APPROVED your protocol # **20016:** *Assessment of Meat Quality of Broilers Used in the Poultry Meat Industry: Effect of Genetic Strains and Diet*.

In granting its approval, the IACUC has approved only the information provided. Should there be any further changes to the protocol during the research, please notify the IACUC in writing (via the Modification form) prior to initiating the changes. If the study period is expected to extend beyond August 29th, 2022 you must submit a newly drafted protocol prior to that date to avoid any interruption. By policy the IACUC cannot approve a study for more than 3 years at a time.

The following individuals are approved to work on this study: Casey Owens, Sam Rochell, Mike Kidd, Clay Maynard, Juan Cuervas Caldas, Namping Wang, Wayne Kuenzel, Byung Whi Kong, Hakeem Kadhim, Seong Kang, and Stephanie Shouse. Please submit personnel additions to this protocol via the modification form prior to their start of work.

The IACUC appreciates your cooperation in complying with University and Federal guidelines involving animal subjects.

BMH/tmp

20016

APPENDIX B

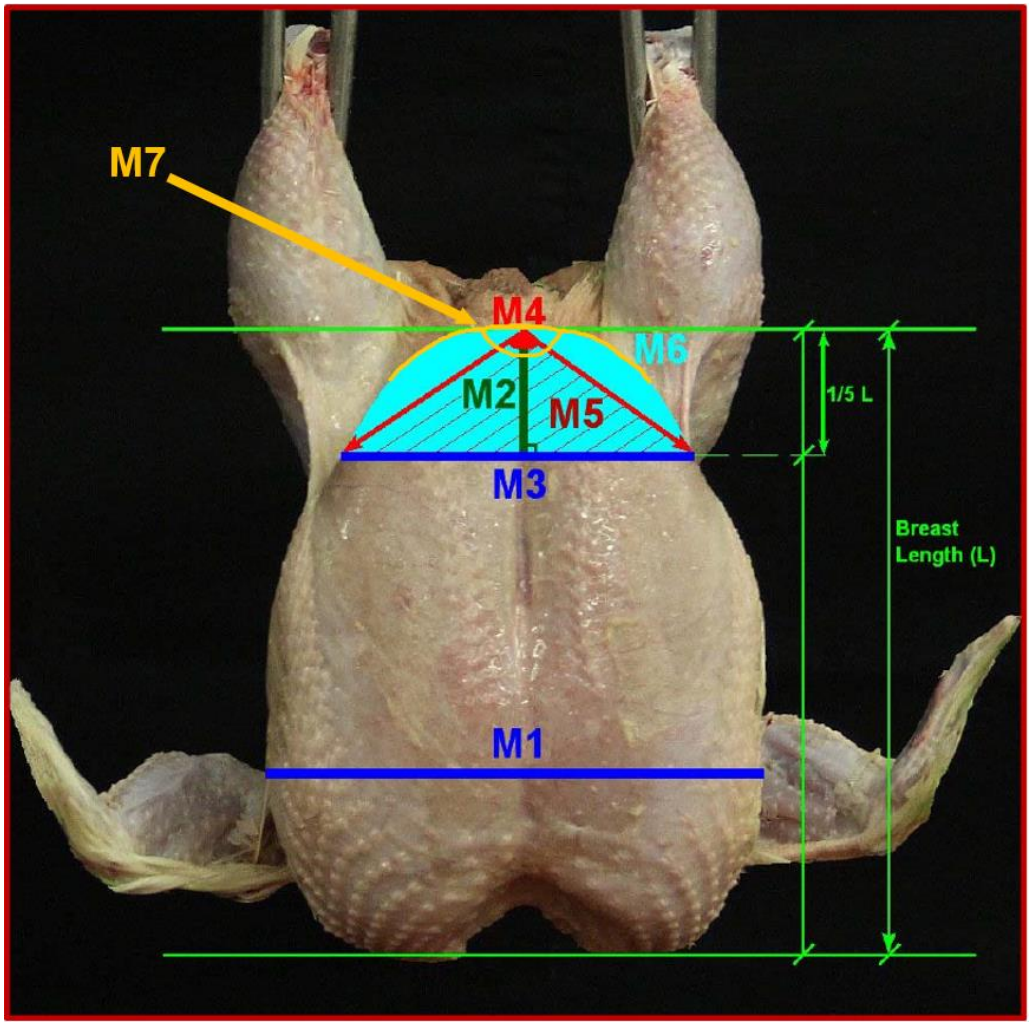

Figure 5: Structural measurements from broiler carcass images

Table 1. Structural information from broiler carcass images

Measurement	Description
M1	Breast width in the cranial region
M2	A vertical line from the tip of keel to 1/5th or 20% of breast length (right side)
M3	Breast width at the end of M2
M4	Angle formed at the tip of keel and extending to outer points of M3
M5	Area of the triangle formed by M3 and lines generated by M4
M6	Area of breast section formed above M3
M7	The angle touching the edge of the curved side from the tip of the breast fillet