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Use of a Blunt Version of Meullenet-Owens Razor Shear to Analyze Meat Qualities of Broilers with Woody Breast Myopathy and Reared to Various Ages

Famous Lue Yang
University of Arkansas, Fayetteville

Use of a Blunt Version of Meullenet-Owens Razor Shear to Analyze Meat Qualities of Broilers
with Woody Breast Myopathy and Reared to Various Ages

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Famous Lue Yang
University of Arkansas
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University of Arkansas

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Dr. Casey M. Owens
Thesis Director

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Dr. Jason K. Apple   Dr. Han-Seok Seo
Committee Member   Committee Member

Abstract

Broiler breast meat tenderness is an important meat quality attribute. There has been an increase in incidences of woody breast along with white striping as meat quality defects. These defects have been found to negatively impact meat qualities of broiler breast fillets. Woody breast can be classified by the degree of hardness into normal (NORM) and severe (SEV). The Meullenet-Owens Razor Shear (MORS) method was developed to assess broiler meat tenderness and a blunt version (BMORS) has been reported to be more sensitive at higher degrees of toughness. The present study was intended to determine the effect of age, debone time, strain, and woody breast severity on meat quality. Sarcomere length (SL) increased as deboning time increased and high breast yield (HY) strain had greater SL than standard breast yield (SY) strain (P<0.05). HY strain had overall higher cook loss (P<0.05). Older broilers had greater myofibrillar diameter (P<0.05). Older broilers had greater total collagen (P<0.05) and strain had no impact (P>0.05) on collagen content. In NORM fillets there were no significant differences for MORSE and BMORSE, and higher cook yield due to age (P>0.05); on the other hand SEV fillets had greater BMORSE, longer SL and lower cook yield at 9 wks of age (P<0.05). SEV fillets also had greater insoluble, soluble, and total collagen than NORM fillets at 9 wks (P<0.05). The findings suggest that BMORS could be used to differentiate shear values, but more research is needed to determine its relationship to sensory aspects at a wide range of shear values resulting from deboning at multiple debone times and/or varying broiler ages with various severity of woody breast.

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I. Introduction

Broiler meat consumption in the United States has been steadily increasing while beef

consumption has decreased, with pork consumption remaining relatively unchanged over the past

50 years. The per capita consumption of broilers in 2014 was 83.4 lbs as compared to beef, 54.2

lbs, and pork, 46.4 lbs (National Chicken Council, 2015). In the commercial broiler industry,

there have been different markets that have emerged over the past few decades. In these various

markets, broilers have been reared to different ages and sizes, such as small and big bird. For the

small bird market, broilers are typically reared to less than 2.7 kg while big bird markets are

greater than 2.7 kg live weight. The amount of production of broilers in the big bird market has

increased from about 42% in 2010 to about 55% in 2013 (Agri Stats, 2013). With this shift in

market programs, the average live market weight has also increased from 2.6 kg in 2010 to about

2.78 kg in 2014 (National Chicken Council, 2015). It is not uncommon for birds for either

market to be deboned as early as 2 h postmortem (PM) to improve efficiency. Early deboning at

2 h PM prior to the completion of rigor mortis can result in tough breast fillets (Lyon et al., 1973;

Lyon et al., 1985; Dawson et al., 1987; Cavitt et al., 2005a). It is accepted that toughness in

broilers has been primarily associated with early PM debone which causes contraction and

shortening of the sarcomere from energy still in the muscle (Stewart et al., 1984; Cavitt et al.,

2004).

Previous research has indicated that bird size and age can affect meat quality (Poole et

al., 1999; Northcutt et al., 2001). Studies have also suggested that larger birds progress through

rigor at a slower pace (Mehaffey et al., 2006; Brewer et al., 2012). In a comparison of broilers

from 1957 to 2005, broiler growth increased by over 400% with a 50% reduction in feed

conversion ratio (Zuidhof et al., 2005). It is well accepted that the muscle grows through

hypertrophy of the muscle fiber as an animal grows. Increase in fiber diameter has been shown to increase shear force (Acar et al., 1993; Scheuermann et al., 2003). Mature cross-link collagen has also been shown to have an effect on toughening of meat (McCormick, 1999).

Through selection for increased growth rate and breast yield, there has been an increase in breast meat abnormalities such as deep pectoral myopathy and pale, soft, and exudative like meat, and more recently white striping and woody breast (Siller, 1985; Dransfield and Sosnicki, 1999; Kuttappan et al., 2012; Petracci et al., 2015). White striping is characterized by the occurrence of white striations parallel to muscle fibers on the broiler breast and easily identified on the surface of raw breast fillets. White striping can occur in varying degrees and have been associated with heavier birds (Kuttappan et al., 2009; 2012; 2013). The pale, slightly bulging, hardened areas on the breast characterize woody breast and can often be found with a thin layer of clear/slightly turbid material on the surface and varying degrees of white striping (Shivo et al., 2014). It has been reported that the histopathological changes in woody breast and white striping muscles had similar features (Kuttappan et al., 2013; Sihvo et al., 2014; Ferreira et al., 2014) and may have a common cause. In woody breast, the histological changes showed different levels of polyphasic myodegeneration and regeneration with accumulation of interstitial connective tissue (fibrosis) similar to white striping (Sihvo et al., 2014). These conditions have been reported to have a negative effect on functional properties of broiler breast meat. Both conditions results in lower marinade uptake and higher cook loss. (Petracci et al., 2013; Mudalal et al., 2015). The etiology of woody breast and white striping is not currently understood.

With the increase in connective tissue in woody breast in association with higher body weight of broilers, it is important to investigate instrumental texture properties in woody breast (Shivo et al, 2014). The MORS test has been determined as a reliable predictor of tenderness in

broiler breast meat (Cavitt et al., 2004, 2005a, b; Lee et al., 2008) and a blunt version (BMORS) has been reported to have more discriminating ability in tougher broiler breast fillets, such as early-deboned breast fillets (Lee et al., 2008). Brewer (2013) observed higher MORS force and shear energy in broilers rose for big bird programs (60 d) as opposed to small bird programs (40 d). Brewer (2013) also suggested that the higher MORS values are not primarily caused by shortening of sarcomeres but perhaps caused by an increase in fiber diameter and collagen in older broilers. The purpose of this thesis is to determine if the BMORS could be used to differentiate between various ages of broilers and broiler breast meat affected by woody breast.

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II. Review of Literature

Muscle Structure

Animal muscle structure has been extensively reviewed by various researchers (Aberle et al., 2001; Swartz et al., 2009; Brandebourg, 2013; Kerth, 2013b). Skeletal muscle is referred to as striated, voluntary, and constitutes 35 to 65% of carcass weight of meat animals. Skeletal muscle tissue is composed of a highly specialized cell known as a muscle fiber (Aberle et al, 2001; Brandebourg, 2013; Kerth, 2013b). Muscle fibers make up 75 to 92% of total muscle volume with the rest consisting of connective tissues, blood vessels, nerve fibers, and extracellular fluid (Aberle et al., 2001; Kerth, 2013b). Skeletal muscle fibers of mammals and avian are long, multinucleated, un-branched, threadlike cells that taper slightly at both ends (Aberle et al., 2001). Surrounding the muscle fiber is a membrane called the sarcolemma, which is composed of protein and lipid material making it relatively elastic. Along the length of the fiber and around the entire circumference, invaginations of the sarcolemma form a network of tubules called transverse tubules, also referred to as T-tubules (Aberle et al., 2001; Swartz et al., 2009; Brandebourg, 2013; Kerth, 2013b).

Sarcoplasm is the intracellular colloidal substance that contains all organelles and inclusions. It is made up of 75 to 80% water, lipid droplets, glycogen granules, ribosomes, numerous proteins, non-protein nitrogenous compounds, and a number of inorganic constituents (Aberle et al., 2001; Kerth 2013b).

The unique organelle to muscle tissue is the myofibril. They are long, thin rods that usually measure 1 to 2 μm in diameter. Myofibrils are bathed in sarcoplasm and extend the entire length of the muscle fiber (Aberle et al., 2001). There are two types of myofilaments within myofibrils. These are referred to as thick and thin filaments. These filaments are aligned parallel

to each other and arranged in exact alignment across the entire myofibril. There are some overlaps in thick and thin filaments in certain regions along their longitudinal axes gives the appearance of striated or banding of the myofibril. The I-band is the light band and the A-band is the broad dark band. The I-band is bisected by a dark band called the Z disk (Aberle et al., 2001; Swartz et al., 2009; Kerth, 2013b). The H-zone is the lighter colored area in the middle of the A-band. Within the H-zone is the m-line which is the mid-point of a sarcomere (Kerth, 2013b). A sarcomere is the unit spanning from one Z disk to another Z disk. Muscle contraction and relaxation occurs within the sarcomere. The two major myofibrillar contractile proteins are actin and myosin (Aberle et al., 2001; Kerth, 2013b). Actin makes up approximately 20% of the myofibrillar proteins. A single globular actin molecule is referred to as G-actin and when they are linked together in strands, they are referred to as F-actin. The actin filament is formed from two F-actin that are spirally coiled around one another to form a helix. Myosin makes up approximately 45% of myofibrillar protein. Myosin is an elongated rod shape with a thick portion on one end referred to as the head. The long, thin portion is referred to as the rod or tail and the portion between the head and tail is the neck. There are two heads in the head region (Aberle et al, 2001). Two bundles of myosin are joined together at the m-line, tail to tail to form the thick filament in a sarcomere (Kerth, 2013b). The two major regulatory proteins are tropomyosin and troponin and they regulate actin-myosin interactions during contraction. There are also cytoskeletal proteins that serve as the template and/or provide the scaffold for the alignment of myofilaments during myofibril and sarcomere formation (Aberle et al., 2001).

Skeletal Muscle Contraction and Relaxation

The sliding filament theory was discussed by Huxley and Hanson (1954). When a muscle contracts, the thin filaments slide over the thick filaments towards the center of the sarcomere

and the thick filaments move in the opposite direction. This leads to the shortening of a sarcomere and the combined reduction in length of all of the sarcomeres leads to a corresponding shortening of myofibrils and a contraction of the muscle fiber (Warriss, 2010).

The sarcoplasmic reticulum plays a fundamental role in controlling the contractile process. It forms a complex membrane system surrounding each myofibril and functionally continuous with the T-tubule system. Muscles contract as a response to a nervous stimulation. The neuromuscular junction releases acetylcholine, a neurotransmitter that can interact with or bind to a receptor molecule on the surface of the sarcolemma. With acetylcholine a local depolarization of the muscle fiber is produced. This then causes a polarity reverse of the membrane. The inside of the cell is normally maintained at a negative potential by a differential distribution of potassium (K^+) and sodium (Na^+) ions across the membrane. Normally the concentration of K^+ is high inside the cell and Na^+ is high outside. During depolarization, Na^+ moves into the cell and K^+ moves out. Depolarization is spread across the membrane surface and transmitted into the cells and fibrils (Warriss, 2010; Kerth, 2013). Depolarization causes a large release of Ca^+ from the sarcoplasmic reticulum into the sarcoplasm (Flucher, 1992). The Ca^+ ions are then able to bind with troponin and cause the displacement of tropomyosin. This exposes the binding sites on the actin for the myosin heads (Warriss, 2010). Adenosine triphosphate (ATP) attaches to the myosin head and is hydrolyzed into adenosine diphosphate (ADP) and phosphate, causing the myosin molecule to be ready for attachment to the binding site on actin. Once attached, the ADP and phosphate detach from the myosin head causing it to move in what is known as the power stroke. ATP attaches to the myosin head to release the myosin from the actin and the process starts all over again. This process will repeat as long as there are Ca^+ ions (Warriss, 2010).

Conversion of Muscle to Meat

Rigor mortis is Latin for " stiffness of muscle" and is the conversion of muscle to meat. At the death of the animal due to exsanguination the blood circularity system is disrupted and fails and roughly 50% of the animal's blood supply is removed (Braden, 2013). Muscle metabolism switches from aerobic to anaerobic metabolism. ATP can now only be regenerated through the breakdown of glycogen by glycolysis. Essentially the same process breaks down glucose and glycogen. The breakdown of glycogen causes an increase in lactic acid accumulation because of the absence of oxygen (Warriss, 2010; Braden, 2013). The depletion of glycogen in the muscle marks the onset of rigor. Lactic acid, which is normally removed by the blood system, gradually decreases muscle pH causing acidification. The production of lactic acid ceases when the enzyme systems will no longer function at low pH (Warriss, 2010). At this point no ATP is produced and ATP consumption continues. Permanent actomyosin bonds will start to form once ATP levels reach 1 μM/g (Hamm, 1982). Rigor mortis is developed once ATP concentration reaches about 0.1 μM/g and the muscle is not extensible (Sams, 1999). After a period of time, there is a progressive resolution of rigor when the muscles soften. The muscle does not become extensible again as it was pre-rigor. The structure of the myofibrils begins to break down, especially in the z-disks (Warriss, 2010).

Postmortem pH

Muscle pH decline is important and plays a significant role in meat quality. Broiler breast texture can be affected by very slow and fast rates of early postmortem (PM) glycolysis (Brewer, 2013). The live pH of broilers has been found to range from 6.92 to 7.14, averaging 7.04 (Stewart et al., 1984). The water-binding ability of muscle proteins decreases as pH reaches the isoelectric point, 5.4, which cause proteins to become denatured and precipitate out (Lyon and

Buhr, 1999). Rapid PM pH decline while carcass temperatures are still high results in a condition known as pale, soft, and exudative (PSE) meat (Bendall and Swatland, 1988; Barbut, 1993; Kauffman et al., 1993). The combination of rapid pH decline and high temperatures causes protein denaturation, which leads to paler meat color, decreased water-holding capacity (WHC), and poorer texture (Warriss and Brown, 1987; Santos et al., 1994; Lyon and Buhr, 1999; Owens et al., 2000). Animals with PSE meat generally have been stressed moments before slaughter, which leads to an increased rate of pH decline (Owens and Sams, 2000; Qiao et al., 2001). The completion of rigor mortis can be achieved as fast as 10 to 15 minutes after death. The pH can reach values as low as 5.3 (Greaser, 2001). When an animal is stressed much earlier before slaughter, glycogen stores are depleted causing a reduction of PM pH decline. This leads to an earlier onset of rigor at higher muscle temperature and is known as dark, firm and dry (DFD) meat (Lyon and Buhr, 1999; Qiao et al., 2001; Lawrie et al., 2006). The meat has higher ultimate pH, greater water-binding capacity, darker color, sticky texture, and dry appearance (Fletcher, 1999; Lyon and Buhr, 1999; Greaser, 2001).

Color

Color is an important factor for consumer's acceptability of fresh raw meat as it can influence consumer perception of freshness. Factors that can affect meat color include: breeds, age, processing conditions, and pH (Young and West, 2001). In poultry, the main contributing factors to meat color are myoglobin content, chemical state and reactions of the myoglobin, and muscle pH. It has been shown that myoglobin content is primarily related to species, muscle, and age of the animal (Fletcher, 1999). Miller (1994) presented that older animal within the same species had higher myoglobin content.

Myoglobin is a water-soluble protein. In the heme ring there is an iron atom that can form six bonds. Four bonds are with pyrrole nitrogen, fifth with proximal histondine-93, and sixth reversibly with ligands (Mancini, 2013). Since the ligand present and the valence of the iron dictates muscle color, there are four major chemical forms of myoglobin that are primarily responsible for meat color (Mancini and Hunt, 2005). Deoxymyoglobin occurs when there is no ligand present in the 6th coordination site and the heme iron is ferrous, resulting in a purplish-red or purplish-pink color. Oxymyoglobin forms when myoglobin is exposed to oxygen and has a bright cherry-red color. When oxidation of the heme iron in deoxymyoglobin or oxymyoglobin occurs, a brown discoloration is produced as a result of metmyoglobin formation. Carboxymyoglobin is formed when carbon monoxide binds to the 6th coordination site of the heme iron in deoxymyoglobin. This results in a bright cherry-red pigment in muscles with higher myoglobin content (Mancini and Hunt, 2005; Mancini, 2013). Broiler breast muscle is mostly white fibers, which have low myoglobin content in the fiber and has been described to have a tan/pink to beige/tan color depending on the background light, but overall broiler breast meat has a neutral color (Barbut, 2002).

Research has also shown that muscle pH and meat color are highly correlated (Barbut, 1993; Boulianne and King, 1995, 1998; Fletcher 1999). Darker meat has been associated with higher pH and lighter meat with lower pH. Brewer et al. (2001) suggested that L* was a reliable indicator of PSE and/or DFD pork. In turkeys it has been reported that L* had the highest correlation of the L*, a*, and b* color values with PSE-like conditions (Barbut, 1993). Woelfel et al. (2002) determined that a minimum L* threshold of 54 was considered pale in broilers, whereas Qiao et al. (2001) categorized L* > 53 as lighter than normal, 48 < L* <53 as normal, and L* < 46 as darker than normal. Instrumental measures of L* and a* have been easily applied

to muscle color but colors represented by b* (blue and yellow) are not typical or intuitively related to meat. O'Sullivan et al. (2003) suggested that b* value assessment was difficult for sensory panelists and more correlated to brown than to sensory valuation of blue and yellow descriptors. Broilers selected for fast growth and high breast yield have been reported to have lower color intensity (redness and yellowness) and an increase in lightness than broilers not selected for improved growth and breast yield (Berri et al., 2001). Le Bihan-Duval et al. (1991) reported similar findings with a decrease in redness and yellowness in high body weight and breast yield strains, except no difference was reported for L*. In another study, Petracci et al. (2013b) reported that the only color difference between two commercial broiler strains was in b*, with high breast yielding broilers having higher b* value than standard breast yielding broilers. Smith et al. (2002) reported that age did not affect meat color but perhaps meat color was affected by an increase in muscle size in previous studies.

Tenderness

A. Postmortem Aging

Tenderness has been determined as one of the most important factors in overall acceptability of meat (Deatherage, 1963; Bourne, 1982; Schilling et al., 2003). Traditionally in broilers, toughness in the breast fillets has been attributed to increased overlap of the thick and thin filaments resulting from shortened sarcomeres (Papa and Fletcher, 1988). Deboning prior to the completion of rigor mortis will cause the muscle to contract because of the lack of skeletal restraints and energy to dissociate actomyosin bonds, leaving the muscle in a contracted state (Stewart et al., 1984; Cavitt et al., 2005a). Previous research has indicated that broiler carcasses should be aged at least 4 h PM to prevent toughening (Stewart et al., 1984; Lyon et al., 1985;

Dawson et al., 1987; Cavitt et al., 2004, 2005a; Brewer et al., 2012b). Cavitt et al. (2005b) reported that consumers found breast fillets deboned before 2 h PM to be too tough.

B. Sarcomere Length

Sarcomere length is used as a measurement of muscle contraction and has been found to be highly correlated with tenderness (Lyon and Buhr, 1999; Cavitt et al., 2004). The shortest sarcomere lengths are attained when a muscle is in full rigor and the muscle becomes inextensible (Lyon and Buhr, 1999). It has also been found that lower shear values and greater tenderization are associated with longer and shorter sarcomeres (Lyon and Buhr, 1999). Sarcomere length was a good predictor of sensory texture attributes of poultry breast meat (Cavitt et al., 2004).

C. Myofibril Diameter

The growth of tissue can be divided into two categories. The first is hyperplasia, the increase of cells by cell division. Hypertrophy is the increase in cell size. Hyperplasia is determined genetically and fixed at birth. More fibers present at birth leads to a more rapid growth because of the onset of hypertrophy after birth (Warris, 2010).

Muscle fibers vary in diameter from 10 to more than 100 μm within the same species, and even within the same muscle (Aberle et al., 2001). In turkeys it has been reported that greater myofibrillar diameter had higher shear forces (Werner et al., 2008). In beef, muscle fiber size was found to be an important factor affecting tenderness prior to post-mortem storage and proteolysis, but less impact after storage (Crouse et al., 1991). Also in red meat, a positive relationship has been reported between muscle fiber diameter and meat toughness (Tuma et al., 1962; Herring et al, 1965; Crouse et al., 1991). However in pork, it has been suggested that the smaller muscle fiber diameter, the higher their strength (Mutungi et al., 1996). Brewer (2013)

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concluded that there was no difference in myofibril diameter between commercial standard and high yielding strains of both modern-type broilers. However, Brewer (2013) also suggested that myofibrillar diameter increased with age and that much of the toughness of older broilers is associated with this increase in myofibril diameter.

D. Effect of Strain on Breast Tenderness

High breast yielding broilers have been shown to have a different growth curve than standard breast yielding broilers (Brewer, 2012c, d). In another study, Brewer et al. (2012b) reported that high breast yielding broilers had tougher boneless breast fillets than broiler strains that yielded less when deboned 4 h PM at 60 day of age. However, there were no differences between strains at 2 and 6 h PM. Mehaffey et al. (2006) reported similar results with shear value differences in five commercial strains reared to 6 and 7 weeks deboned at 2 and 4 h PM. Mehaffey et al. (2006) also found that there were differences in pH decline, indication of rigor progression, due to strain at 2 and 4 h PM. A positive correlation has been reported between pH and shear values, as pH declines between various debone times (Stewart et al., 1984; Cavitt et al., 2005a). Brewer et al. (2012a) reported a difference in shear values at 2 h PM among 3 commercial strains processed at 40 d, yet no differences in pH or cook loss at 2 h PM. There was also no difference in shear values reported at 4 and 6 h PM among the strains, which could be due to earlier completion of rigor compared to older broilers.

E. Effect of Age on Breast Tenderness

With an increase in age, there has been reported increases in shear values. In a study by Pool et al. (1999), broilers processed at 5 weeks of age had lower shear force values than 6, 7, and 8 weeks of age. In this study, the broilers were considered to be processed roughly 24 h PM so there would be little effect of rigor development on shear values. Mehaffey et al. (2006) also

reported increased shear values in broilers processed at 7 weeks of age compared to 6 weeks of age when deboned at 2 and 4 h PM. Northcutt et al. (2001) recommends using a younger broiler (42-44 d) when deboning early PM (<2 h) instead of older broilers (>49 d). Brewer (2013) similarly reported increased shear force and energy in older broilers (60 d) than younger broilers (40 d) regardless of debone time post-mortem. Brewer (2013) also suggested that the increased in shear force and energy is not perhaps from shortened sarcomeres but an increase in fiber diameter and slower progression of rigor mortis.

As an animal grows, there are many developmental changes taking place. Collagen is the most abundant protein in the animal body in various connective tissues (Swatland, 1994; McCormick, 1999; Warris, 2010). Collagen fibers in meat are converted from strong fibers to gelatin during cooking (Lepetit, 2008; Warriss, 2010). Three polypeptide strands are linked together by stable intra-molecular bonds twisted together into a triple helix to form a tropocollagen molecule. Collagen fibers are made up of long rod-like tropocollagen molecules (Warris, 2010). Collagen fibers are strengthened from the stable intermolecular covalent bonds between adjacent tropocollagen molecules. There are also stable disulfide bonds that can form between the three polypeptides. As an animal grows, the number of covalent cross-links increase and collagen fibers becomes stronger. Therefore, meat from older animals tends to be tougher than younger animals in the same region of carcass. As new collagen is synthesized in younger animals, there are fewer cross-links, even though the existing molecules are developing new cross-links. As the formation of new collagen slows down, the formation of cross-links increase (Swatland, 1994). Some of these new intermolecular cross-links in young animals are susceptible to heat (heat soluble) and are reduced. In older animals, the collagen is less soluble (heat stable).

It has been reported that the highest correlation with toughness was the amount of heat stable collagen (Light et al., 1985; McCormick 1999).

Studies have suggested that slower growth rate can decrease the amount of soluble collagen, thus increasing shear values in steers (Aberle et al., 1981; Fishell et al., 1985). Little research has been done with collagen content within broilers. Most collagen research with chicken has been done on chicken with a higher age than broilers (Sekoguchi et al., 1979; Klandorf et al., 1996; Vaithiyanathan et al., 2008) or in broiler skin (Granot et al., 1991; Cahaner et al. 1993; Pines et al., 1996). However, Nakamura et al., (1975) reported higher shear values associated with increase in collagen content as age increased in chickens from 33-520 d, but various strains were used for different age groups (33-60 d, White Rock x White Cornish; 132-178 d, White Leghorn; 520 d, White Leghorn).

F. Instrumental Prediction of Breast Tenderness

Many instrumental methods have been developed for predicting tenderness. Most research prior to 1960 was focused on how to make instrumental procedures cut, compress, or manipulate food samples in some way (DeMan et al., 1979). The two most commonly used in the poultry industry are the Warner-Bratzler (WB) and Allo-Kramer (AK) shear tests.

The WB was first introduced in 1928 and has gone through a series of modifications to be fitted for motorized multi-test instruments such as the Texture Analyzer and the Instron Universal Testing Machine. The device requires cylindrical meat core samples that are placed over an opening and sheared by a movable vee-shaped shear blade. Multiple studies on poultry have been published on how the geometric dimensions of a sample can greatly affect the cutting force of the WB shear. This results in decreased accuracy of the WB shear as a predictor of

tenderness (DeMan et al., 1979; Lyon and Lyon, 1990; Sams et al., 1990). The WB shear is most often used in the beef industry that uses slice-shears to predict tenderness today.

The AK shear test is more commonly used as a predictor of tenderness in poultry. It was first introduced in the early 1950's by Dr. Kramer and at the time was one of the first general purpose test machines used to measure textural properties of foods by linear deformation. The AK shear consists of a set of multiple blades attached to a system designed to move the blades down and through a sample placed in a stationary shear cell. While shearing, initially the sample exhibits compression forces due to the blunt blades followed by shearing forces that forces the sample through the bottom. The shear value is recorded as kgf/g of sample weight (Kramer et al., 1951).

These two methods can be quite expensive, cumbersome, and time consuming. More recently the Meullenet-Owens Razor Shear (MORS) test was developed specifically for predicting tenderness in broiler breast meat and determined as a reliable predictor of tenderness (Cavitt et al., 2004, 2005a, 2005b; Xiong et al., 2006; Lee et al., 2008). Advantages with the MORS test is no sample cutting or weighing and less destructive to the sample. The MORS test uses a Texture Analyzer with a razor blade width of 8.9 mm and a penetration depth of 20 mm. data points are collected at an acquisition rate of 200 points per second and the blade has to be replaced periodically to ensure that the blade does not dull. Maximum shear force (N) and shear energy (N•mm), calculated as the area under the force deformation curve from beginning to end of test, are recorded (Cavitt et al., 2004, 2005a, 2005b). Lee et al. (2008) suggest using a blunt version of the MORS (BMORS) for tough meat, particularly fillets deboned at 1.5 h or early PM, while the MORS had better discrimination in tender meat such as fillets deboned at 6-24 h PM.

Woody Breast

Recently, a new meat quality defect has been noticed to affect the *Pectoralis major* muscles of broilers. The pale, slightly bulging, hardened areas characterize this new myopathy, woody/wooden breast. A thin layer of clear/slightly turbid material on the surface can also be found with woody breast (Sihvo et al., 2014). Another meat quality defect that can usually be found with woody breast is white striping. White striping is the manifestations of white striations parallel to muscle fibers on the breast and can occur in varying degrees (Kuttappan et al., 2012). It has been reported that the histopathological changes in woody breast and white striping muscles had similar features (Kuttappan et al., 2013; Sihvo et al., 2014; Ferreira et al., 2014) and may have a common cause. Cross-sectional of normal breast fillet show that muscle fibers are polygonal, tightly packed, and relatively similar in size (Figure 1, Sihvo et al., 2014). In woody breast, the histological changes showed different levels of polyphasic myodegeneration and regeneration with accumulation of interstitial connective tissue (fibrosis) similar to white striping (Figure 2, Sihvo et al., 2014). Woody breast have also been reported to have higher amount of total collagen than normal breast fillets, but the collagen was not differentiated between soluble and insoluble collagen (Soglia et al., 2015). These conditions have been reported to have a negative effect on functional properties of broiler breast meat (Petracci et al., 2013a; Mudalal et al., 2015). Both conditions results in lower marinade uptake and higher cook loss. The etiology of woody breast and white striping is not currently understood.

Need for Research

Toughness in boneless broiler breast has been attributed to shortened sarcomere length due to deboning before completion of rigor mortis. Breast fillets from broilers reared to an older age (>54 days of age) have shown higher shear values. Research indicates that there could be

other factors affecting texture and tenderness such as myofibrillar diameter and collagen in older broilers.

With the appearance of woody breast with its characteristic hardness in raw fillets, it is important to assess its effect on broiler breast texture. Research has suggested that there is an increase in collagen in breast fillets with woody breast, thus it is important to determine the amount of insoluble (heat-stable) collagen as this can impact texture and tenderness. A blunt version of the Meullenet-Owens Razor Shear (BMORS) has been suggested to be better suited for texture analysis in tough fillets (deboned ≤ 1.5 h PM). Therefore, the purpose of this research is to determine if the BMORS is a better tool in assessing broiler breast meat texture in young and older broilers raised for various markets and broiler breast fillets with woody breast.

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III. Evaluating breast meat texture and meat qualities of broilers at various ages and gender using the Meullenet-Owens Razor Shear method

F. L. Yang[1], J. K. Apple[2], and C. M. Owens[1]

[1]Department of Poultry Science, University of Arkansas, Fayetteville, AR 72701, United States

[2]Department of Animal Science, University of Arkansas, Fayetteville, AR 72701, United States

Abstract

The Meullenet-Owens Razor Shear (MORS) method has been established as a reliable predictor of broiler breast tenderness. Broiler age and gender have been demonstrated to affect various meat qualities. This experiment use male and female standard breast yield broilers (n=308) processed at 19, 25, 31, 35, 49, and 56 d of age in a batch-processing system. After processing, carcasses were weighed for ready-to-cook (RTC) weight, deboned at 2 h postmortem (PM), and breast yield was calculated. Muscle pH and color were measured immediately after deboning on the right fillet. Cook loss percentage, cooked cranial breast height, MORS energy (MORSE), and MORS force (MORSF), were also determined on the right fillet. Ready-to-cook weight increased (linear, $P<0.0001$) with increasing broiler age and male broilers had greater ($P<0.0001$) RTC weight than females. Breast yield also increased (linear, $P<0.0001$) as broiler age increased, but breast yields were similar ($P=0.85$) between genders. Both L* and b* values increased (quadratic, $P<0.0001$) as broiler age increased, with the lowest L* and b* values at 25, 32, and 35 d of age and highest values at 49 and 56 d of age. In addition, redness (a*) values decreased (linear, $P<0.0001$) as broiler age increased from 19 to 56 d; however, instrumental color measures did not ($P=0.17$) differ between genders. Fillet pH was greatest at 35 d of age and least at 49 d (quadratic, $P<0.0001$) and males had higher ($P<0.001$) pH values than females. Cooked cranial breast height increased (linear, $P<0.0001$) as broiler age increased, and males had greater ($P<0.01$) cooked cranial breast height than females. Both MORSE and MORSF increased (linear, $P<0.0001$) with increasing broiler age, but neither measure of tenderness was affected ($P=0.06$) by gender. Even though gender impacted RTC wt, pH, and cook loss, breast yield, muscle color, and shear values were similar between males and females. As expected, however,

changes in all meat quality attributes measured in this study could be associated with increasing age at slaughter.

Introduction

The forecasted amount of how broilers are marketed as whole broilers, cut-up/parts, and further processed for 2015 was 11, 40, and 49%, respectively (National Chicken Council, 2011). For these different market segments, broilers are raised to difference ages and sizes. Commercial broilers have been selected for improved growth rate and breast yield to meet demand (Petracci and Cavani, 2012). It is not uncommon for broilers to be deboned as early as 2 h postmortem (PM) to improve efficiency. However deboning as early as 2 h PM, prior to the completion of rigor mortis, can result in tough breast fillets (Lyon et al., 1973, 1985; Dawson et al., 1987; Cavitt et al., 2005a). It is accepted that toughness has been primarily associated with early PM debone which causes contraction and shortening of the sarcomere from energy still in the muscle (Stewart et al., 1984; Cavitt et al., 2004).

It has been suggested that bird size and age can affect meat quality (Poole et al., 1999; Northcutt et al., 2001; Brewer et al, 2012a, b). The Meullenet-Owens Razor Shear (MORS) method has been determined to be a reliable predictor of poultry tenderness (Cavitt et al., 2005a, b). This is a preliminary study of the effect of broiler age from 19 to 56 d and gender on various meat qualities.

Materials and Methods

A total of 308 male and female commercial standard breast yield broilers were processed at 19, 25, 31, 35, 49, and 56 d of age (n=70, 60, 60, 60, 36, and 32, respectively) using a batch system. Briefly, 10 broilers were electrically-stunned, carotid arteries manually cut with a 2-min bleed out, scalded (2-min at 54.4°C), defeathered in batch drum defeathering equipment, and eviscerated manually. After evisceration, carcasses were chilled in immersion chill tanks, with a 15-min pre-chill at 12°C, followed by a 90-min chill at 1°C. Carcasses were weighed and

deboned at 2 h PM. Breast yield was calculated based on ready-to-cook (RTC) weight, and right fillets were vacuumed packaged and frozen at -20°C.

At a later date, right fillets were thawed overnight in a 4°C cooler. Muscle pH was measured with a ceramic, spear-tipped, temperature-compensating pH probe/meter (model 205; Testo, Inc., Sparta, NJ) inserted into the cranial portion. In addition, instrumental color (L*, a*, b*) was measured at 3 locations on the dorsal side of the right fillet using a Minolta colorimeter (CR-300; Konica Minolta, Ramsey, NJ), and color readings were averaged for statistical analyses.

Fillets were then weighed and cooked in covered aluminum foiled lined pans on raised wire racks to an endpoint temperature of 76°C in a convection oven pre-heated to 177°C. Fillets were cooled to room temperature, reweighed to determine cook loss (calculated as a percentage of the pre-cooked fillet weight), and subsequently individually wrapped in aluminum foil and stored overnight at 4°C before texture analysis the following day.

The MORS method was conducted to determine shear energy (MORSE) and peak shear force (MORSF) was conducted using a texture analyzer (Model TA-XT*plus*; Texture Technologies, Scarsdale, NY) equipped with an 8.9-mm wide razor blade that sheared fillets at a crosshead speed of 5mm/s. Fillets were sheared in 3 locations on the cranial region and data were averaged for each fillet for statistical analysis. Razor blades were changed after the completion of 100 shears to ensure the blades did not dull (Cavitt et al., 2005a, b). Cooked fillet height was measured on the cranial region where fillets were sheared to ensure that fillets were the correct height to measure MORSE.

All data were analyzed as a completely randomized design, with bird as the experimental unit and treatments in a 2x6 factorial arrangement. The ANOVA was generated using the mixed

models procedure of SAS (SAS Inst, Inc., Cary, NC, 2015), with age, gender, and the 2-way interaction included in the model as fixed effects. Least squares means were computed and separated with the pairwise t-tests (PDIFF option of SAS) when a significant (P<0.05) F-test was noted. In addition, contrasts were used to determine the linear and quadratic effects of broiler age on meat yield and quality characteristics.

Results and Discussion

The RTC weight and breast yield increased (linear, P<0.0001) as broiler age increased (Table 1) and, even though breast yield was similar (P=0.85) between the genders, male broilers had greater (P<0.05) RTC weights than females when processed at 31 d, or older (Figure 1). Increases in breast yield as broiler age increases have been well documented (Acar et al., 1993; Young et al., 2001; Scheuermann et al., 2003). In contrast to findings of this study, there are a number of reports detailing differences in breast yields between males and females (Acar et al, 1993; Young et al., 2001; Scheuermann et al., 2003); however, difference in broiler strains may explain the discrepancy between the present study and results from previous research.

Previous research reported that various factors could affect meat color such as strain, age, gender, moisture content, and rigor development (Froning, 1995; McKee and Sams, 1997a, b; Owens et al., 2000; Woelfel et al., 2002). Lightness (L*) values increased (quadratic, P<0.0001) with increasing broiler age (Table 1), and females had lighter (greater L* values) fillets than males only when processed at 49 d of age (age x gender, P=0.01; Figure 2). Conversely, redness (a*) values decreased (linear, P<0.0001) as broiler age increased, but a* values did not differ (P=0.17) between males and females. It has been reported that as chicken ages, intermediate muscle fibers change to white muscle fibers (Ashmore and Doerr, 1971), which are fast-twitch and have less myoglobin (Barbut, 2002; Mancini, 2013). Therefore, this decrease in redness

could be due to reductions in myoglobin content as intermediate fibers are changed into white fibers as the chicken matures (Ashmore and Doerr, 1971). Similar to L* values, yellowness (b*) values increased (quadradic, P<0.0001) with increasing broiler age, with the greatest b* values at 49 and 56 d, and the lowest b* values observed at 25, 31, and 35 d of age (Table 1). Moreover, males had greater (P<0.05) b* values than females at 19 d of age, whereas fillets of females were more (P<0.05) yellow (greater b* values) than males at 25, 49 and 56 d of age (age x gender, P<0.0001; Figure 3). Female broilers have more fat than males (Moran and Bilgili, 1990; Han and Baker, 1993) and older broilers have more fat than younger broilers (Baéza et al., 2012). Kuttappan et al. (2013) suggested an increase in fat (due to severe white striping) could contribute to higher b* values, but further research is needed to determine the relationship between fat content and b* values in broiler breasts. Smith et al. (2002) reported that age had no effect on color, but the age range in that study was only 42 to 52 d.

Postmortem pH of the breast fillet was measured to determine the state of rigor at time of debone and fillet pH increased (quadratic, P<0.0001), with the greatest pH value at 35 d of age and lowest at 49 d (Table 1). Furthermore, males had greater (P<0.05) pH values than females at 31, 49, and 56 d of age (age x gender, P<0.05; Figure 4). The results indicate that males have higher pH than females, especially as broilers get older. Baéza et al. (2012) also reported an association with increase in pH with age in male broilers due to differences in glycolytic potential and increased muscle fiber size.

One assessment of water-holding capacity is cook loss, and cook loss percentage decreased (quadratic, P<0.0001) with increasing broiler age, with the greatest cook losses at 19 d and lowest cook losses at 31 d; however, cook loss percentages were similar (P=0.55) between males and females.

Cooked height of the cranial region of breast fillets increased (linear, P<0.0001) as broiler age increased (Table 1), and female broilers had thicker cooked cranial breast at 25 d, male broilers had thicker cooked cranial breast at 49 and 56 d of age (age x gender, P<0.0001; Figure 5). Because cooked cranial height at 19 and 25 d was less than the minimum height to accurate measure (20 mm) the MORSE (Cavitt et al., 2004), fillets from the 2 earliest ages were excluded from the MORSE data set. Both MORSE and MORSF increased (linear, P<0.0001) as broiler age increased (Table 1), and, females had greater MORSE and MORSF than males only when slaughtered at 25 d of age (age x gender, P<0.05; Figure 6). Northcutt et al. (2001) reported that males had greater shear force values at 46 d of age than females but failed to note gender differences at 37, 39, 42, 44, 49 and 51 d of age. Cavitt et al. (2005b) established a relationship between MORSE, MORSF, and tenderness intensity. In the present study, fillets from 19-d boilers would be perceived as extremely tender (≤8.83 N), 25-d fillets would be moderately tender (10.15 to 11.45 N), and 31- and 35-d would be perceived as slightly tender (139.51 to 155.99 N•mm). Moreover, fillets from 49-d broilers would be perceived as neither tough nor tender (156.00 to 172.48 N•mm), whereas fillets from broilers slaughtered at 56-d of age would be perceived as slightly tough (172.49 to 188.98 N•mm).

Conclusion

Gender had an impact on RTC weight, fillet pH, and cook losses; otherwise, breast yield, instrumental muscle color, and shear values did not differ between male and female broilers. Age, on the other hand, had more of an impact on meat quality than gender did, with age-associated increases in RTC weight, breast yield, L* and b* values, and shear values as well as decreases in a* values. Further research should be conducted on the effect of age on sarcomere

length, fiber diameter, and collagen of the breast fillet to elucidate explanations for the observed

increased shear values.

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Table 1 Means of meat quality factors of males and females broilers at various ages

	Age						SEM	Gender		SEM	Contrast	
	19	25	31	35	49	56		M	F		Linear	Quadratic
n	70	60	60	60	36	32		156	162			
RTC (g)	521[f]	908[e]	1315[d]	1632[c]	2763[b]	3309[a]	22.6	1881[a]	1602[b]	13.2	<0.0001	<0.0001
Breast yield (%)	19.4[e]	21.7[d]	23.7[c]	24.2[c]	25.9[b]	27.2[a]	0.27	23.7	23.7	0.16	<0.0001	<0.0001
L*[1]	48.2[b]	46.8[c]	47.2[c]	46.3[c]	49.5[a]	49.3[a]	0.79	47.8	48.0	0.20	<0.0001	<0.0001
a*[1]	6.25[a]	5.35[b]	5.48[b]	4.83[c]	3.98[d]	3.15[e]	0.15	4.93	4.75	0.09	<0.0001	0.58
b*[1]	5.19[b]	4.32[c]	4.05[c]	4.13[c]	6.04[a]	6.37[a]	0.20	4.79	5.25	0.11	<0.0001	<0.0001
pH	5.79[c]	5.88[b]	5.83[bc]	6.04[a]	5.62[d]	5.80[c]	0.03	5.87[a]	5.79[b]	0.02	0.0001	<0.0001
Cook loss (%)	30.0[a]	26.7[b]	22.1[d]	25.2[bc]	24.4[cd]	27.6[b]	0.34	25.8	26.2	0.46	0.11	<0.0001
MORSE (N•mm)	-[2]	-[2]	146.3[c]	153.5[bc]	159.3[ab]	173.8[a]	4.58	142.5	149.3	2.52	<0.0001	0.0001
MORSF (N•mm)	8.50[c]	10.46[b]	12.25[a]	12.15[a]	12.13[a]	12.74[a]	0.33	11.17	11.57	0.19	<0.0001	<0.0001
Cooked cranial breast height (mm)	16.2[f]	19.1[e]	24.5[d]	28.6[c]	36.6[b]	43.4[a]	0.36	28.5[a]	27.7[b]	0.21	<0.0001	0.81

[a-f]Within a row, least squares means lacking common superscripted letters differ, P<0.05.
[1]L* is a measurement of darkness to lightness (greater L* values indicate a lighter color); a* is a measurement of redness (greater a* values indicate a redder color); and b* is a measurement of yellowness (greater b* values indicate a more yellow color).
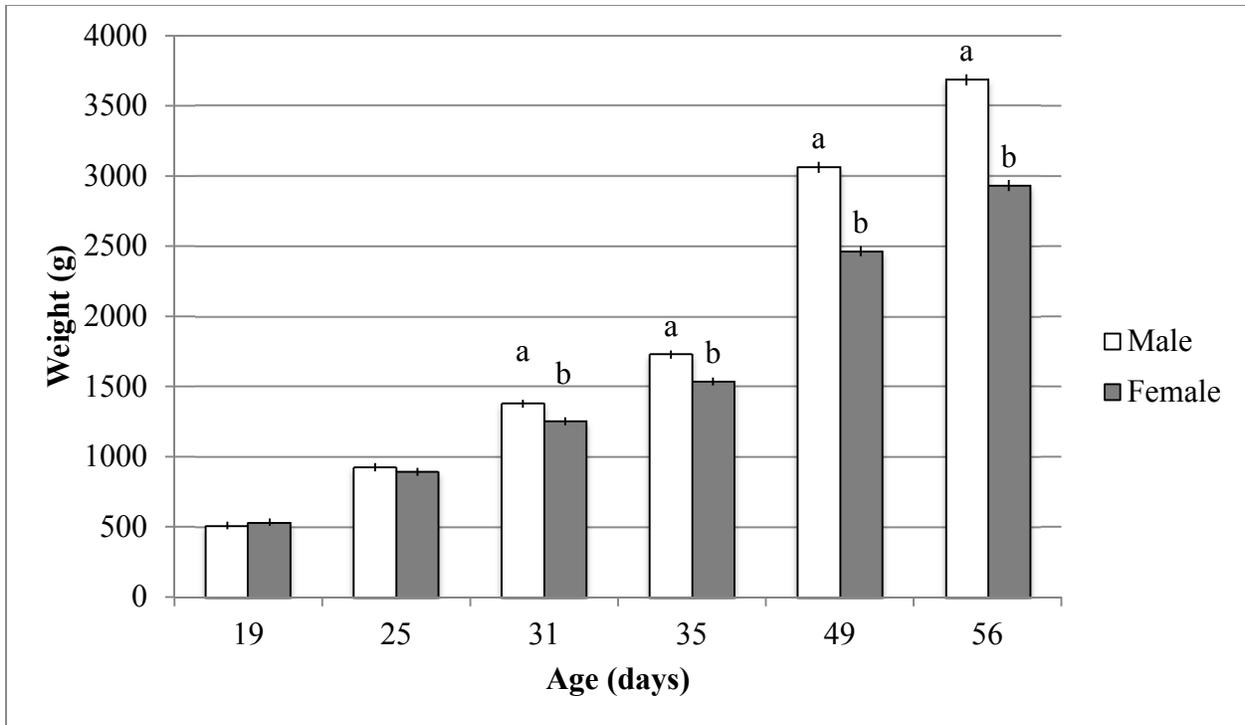[2]Fillets less than 20-mm thick so MORSE not reported.

Figure 1. Ready-to-cook (RTC) weight of male and female from 19 to 56 d of age.
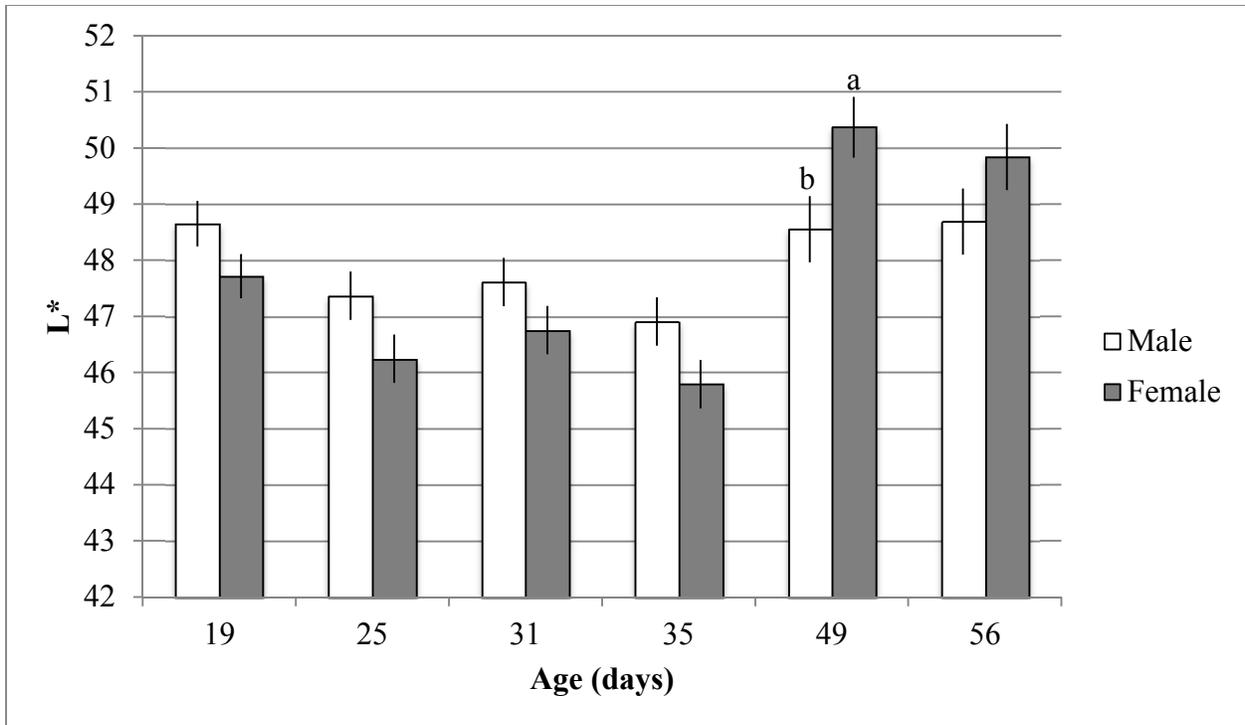[a-b]Means within age with no common superscript differ, P<0.05.

Figure 2. Lightness (L*) of male and female from 19 to 56 d of age.
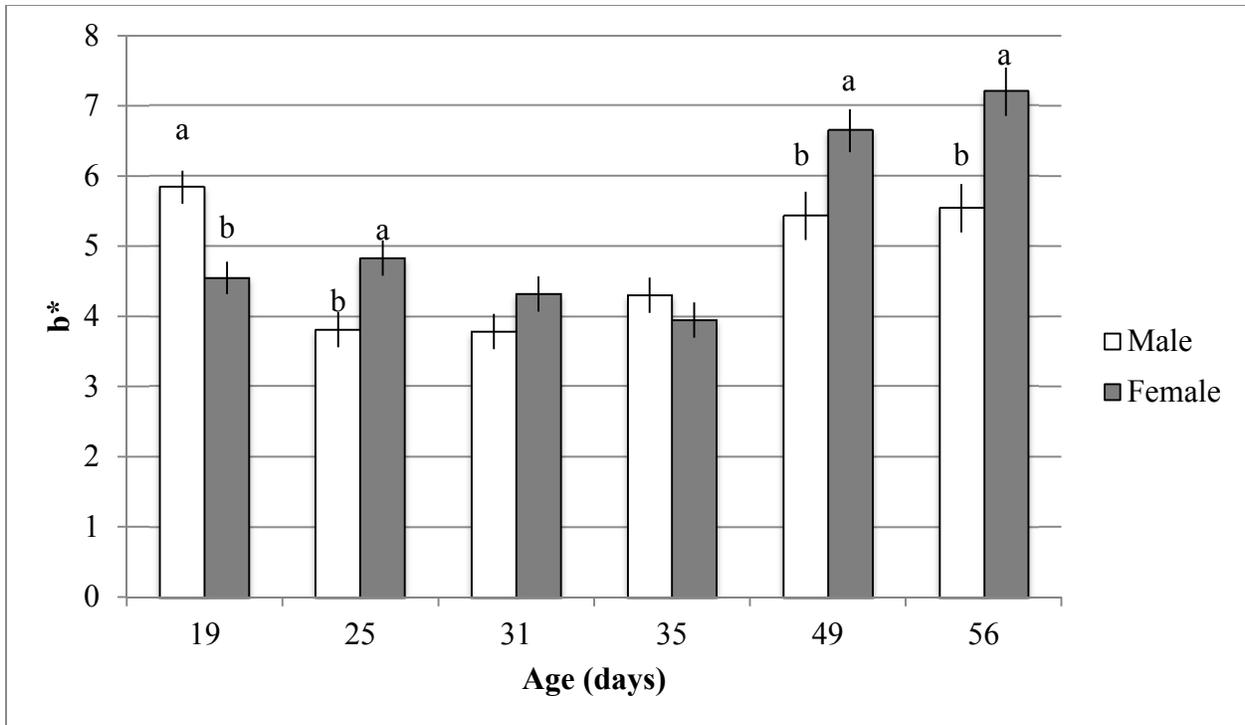[a-b]Means within age with no common superscript differ, P<0.05.

Figure 3. Yellowness (b*) of male and female from 19 to 56 d of age.
[a-b]Means within age with no common superscript differ, P<0.05.
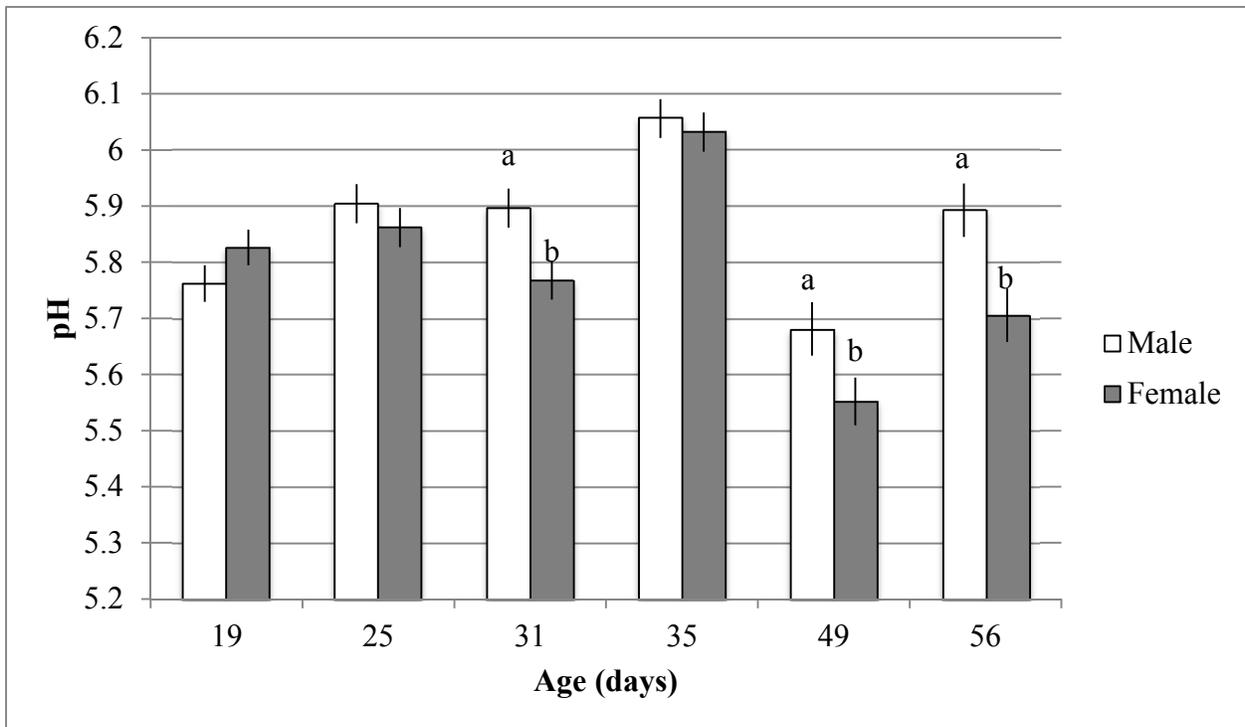
Figure 4. Fillet pH of male and female from 19 to 56 d of age.
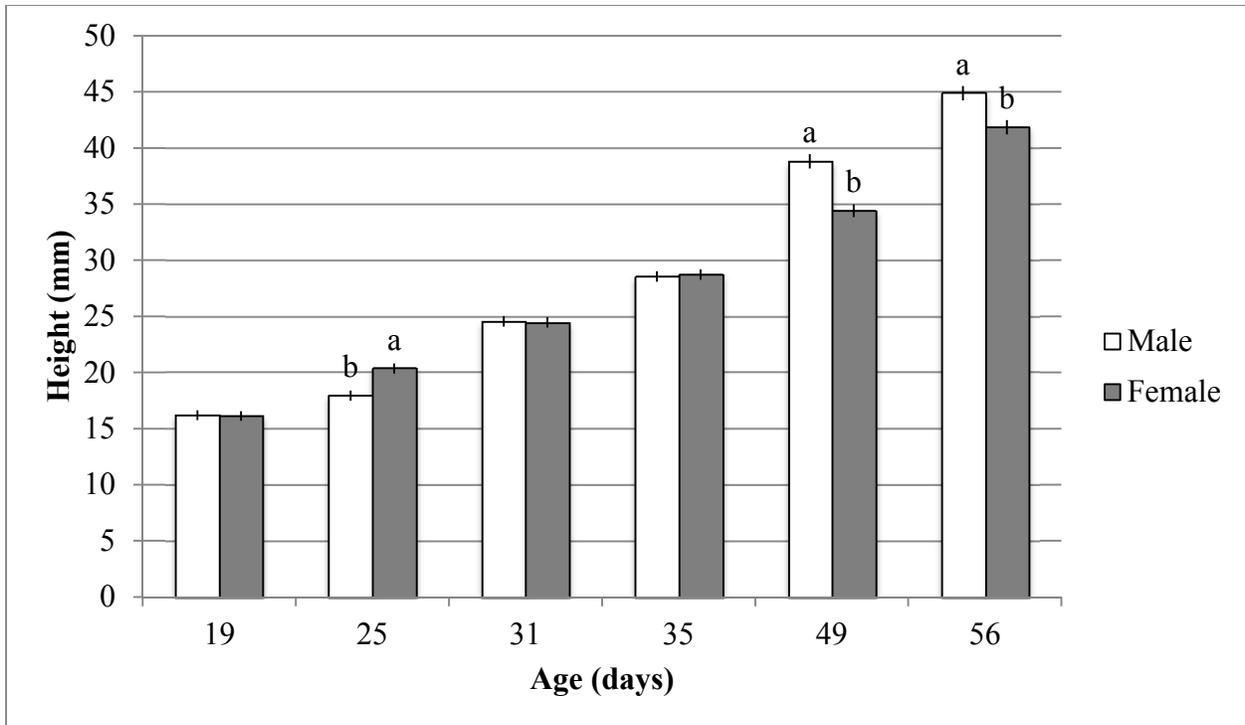[a-b]Means within age with no common superscript differ, P<0.05.

Figure 5. Cooked cranial breast height of male and female from 19 to 56 d of age.
[a-b]Means within age with no common superscript differ, P<0.05.
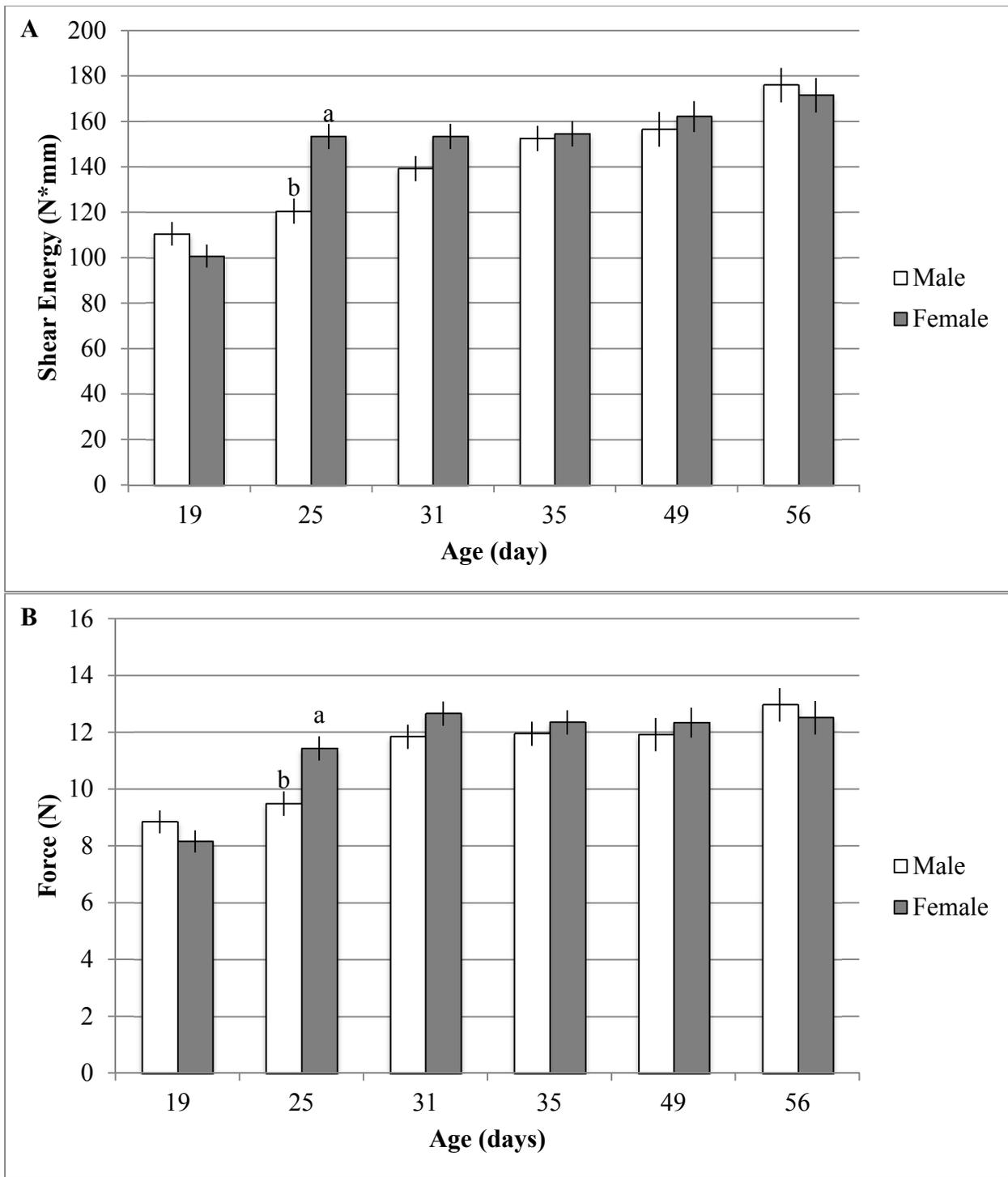
Figure 6. The MORSE (A) and MORSF (B) of male and female broilers from 19 to 56 d of age. [a-b]Means within age with no common superscript differ, P<0.05.

IV. Evaluating breast meat tenderness using a blunt version of the Meullenet-Owens Razor Shear method of broilers raised for small or big bird market programs

F. L. Yang[1], V. V. Tijare[1], A. Giampietro[2], J. K. Apple[3], and C. M. Owens[1]

[1]Department of Poultry Science, University of Arkansas, Fayetteville, AR 72701, United States

[2]FCAVE-UNESP, Jaboticabal, Brazil

[3]Department of Animal Science, University of Arkansas, Fayetteville, AR 72701, United States

Abstract

Broiler breast meat tenderness is an important meat quality attribute and previous research has suggested that older market broilers produce tougher meat at times compared to younger broilers (e.g., 8 vs. 6 weeks). The Meullenet-Owens Razor Shear (MORS) method was developed to assess broiler meat tenderness, and the blunt version of MORS has been reported to be a more sensitive method at higher degrees of toughness. Thus, an experiment was conducted using standard (SY) and high breast yielding (HY) commercial male broilers processed commercially at 40 (n=108/strain) or 54 d age (n=95/strain). Breast fillets were deboned at 2, 4, 6, and 24 h postmortem (PM) for measurement of muscle pH, color (L*, a*, and b*), sarcomere length (SL), myofibrillar diameter (MD), and soluble, insoluble, and total collagen concentrations. Breast fillets were subsequently cooked to 76°C to determine cook loss, and both the standard and blunt version of MORS energy (MORSE and BMORSE, respectively). Obviously, 54-d broilers were heavier (P<0.01) than 40-d broilers, and, within each age, SY birds were heavier (P<0.01) than HY birds. Muscle pH was greater (P<0.01) in 54-d than 40-d broilers, and, muscle pH decreased (P<0.01) at each deboning time. Fillets from 54-d had lighter (greater L* values; P<0.01) fillets than fillets from 40-d. Redness of fillets was greater (P<0.01) in 40-d than 54-d old broilers, with fillets deboned at 6 h PM having greater (P<0.01) a* values than 2 and 4 h PM debone times. Fillets from HY broilers were yellower (greater b* values; P<0.01) than SY broilers; additionally HY at 54-d were yellower (P<0.01) than the rest of the fillets, but debone time did not affect (P0.63) b* values. Fillets from HY broilers had longer (P<0.01) sarcomeres than SY broilers, and SL increased at each deboning time from 2 to 24 h. Fiber diameter was greater (P<0.01) in 54-d than 40-d broilers, but neither strain (P=0.32) or debone time (P=0.64) affected MD. Cooking losses were greater (P<0.01) for 40-d than 54-d birds and HY had greater (P<0.01) cook

losses than SY at both ages. Both MORSE and BMORSE were greater (P<0.05) for fillets from

54-d than 40-d broilers. At 40-d of age, HY had greater (P<0.01) MORSE and BMORSE than

SY; however, only MORSE values were greater (P<0.01) in SY compared to HY at 54-d of age.

In addition, MORSE and BMORSE were greater (P<0.01) in fillets deboned at 2 and 4 h than

those deboned at 6 and 24 h. Concentrations of total and insoluble collagen were greater

(P<0.05) in 54-d than 40-d birds; however, when expressed as a percentage of total collagen, the

proportions of insoluble and soluble collagen were not affected by strain (P=0.79) or age

(P=0.07). Results suggest that increased MD and total collagen content may impact tenderness in

older broilers. Moreover, results of this study indicated that BMORS could be used as effectively

as MORSE to differentiate shear values.

Introduction

In the commercial broiler industry, different markets that have emerged over the past few decades that require broilers to be reared to different ages and sizes; typically, these 2 primary markets programs are referred to as either, small- or big-bird markets. For the small-bird market, broilers are typically reared to less than 2.7 kg, whereas big-bird markets are greater than 2.7 kg. The amount of production of broilers for the big-bird market has increased from about 42 to 55% from 2010 to 2013 (Agri Stats, 2013), resulting in increases in average live market weight from 2.6 kg in 2010 to about 2.8 kg in 2014 (National Chicken Council, 2015). It is not uncommon for birds for either market to be deboned as early as 2 h postmortem (PM) to improve efficiency; however, deboning at 2 h PM prior to the completion of rigor mortis can result in tough breast fillets (Lyon et al., 1973, 1985; Dawson et al., 1987; Cavitt et al., 2005a). It is generally accepted that the toughness associated with early PM deboning is caused by contraction and shortening of the sarcomere from energy still in the muscle (Stewart et al., 1984; Cavitt et al., 2004).

Previous research has indicated that bird size and age can affect meat quality (Poole et al., 1999; Northcutt et al., 2001). Others have also suggested that larger birds progress through rigor at a slower pace (Mehaffey et al., 2006; Brewer et al., 2012b). Muscle grows through hypertrophy of the muscle fiber as an animal grows, and increased fiber diameter has been shown to increase shear force (Crouse et al., 1991; Acar et al., 1993; Scheuermann et al., 2003). Additionally, mature cross-link collagen has been shown to have an effect the on toughening of meat (McCormick, 1999). The Meullenet-Owens Razor Shear (MORS) method has been established as a reliable predictor of poultry tenderness (Cavitt et al., 2005a, b). A blunt version of the MORS method has been shown to be a more sensitive method in tougher breast fillets (Lee et al., 2008). The objective of this study was to: 1) determine the effect of strain, age, and

debone time on broilers of difference ages; and 2) determine if the blunt version of the MORS is an effective tool in analyzing fillets from older broilers.

Materials and Methods

Standard-breast yielding (SY) and high-breast yielding (HY) were processed at 40 (n=108/strain) and 54 d (n=95/strain) of age in 2 replicates. Birds were weighed before being processed on a commercial-style, in-line system according to Mehaffey (2006). Briefly, broilers were electrically stunned (11 V, 11mA, 11 sec), scalded for 2 min at 54.4°C, defeathered using an in-line commercial defeathering equipment, and eviscerated manually. After evisceration, carcasses were pre-chilled for 15-min at 12°C, followed by a 90-min chill at 1°C, in immersion chill tanks to an end-point temperature of 4°C. After chilling, carcasses were packed and aged on ice in a 4°C cooler until deboning at 2, 4, 6, or 24 h postmortem (PM).

Color and muscle pH measurements were taken immediately after debone on right-side fillets. Muscle pH was measured by inserting a ceramic, spear-tipped, temperature-compensating pH probe/meter (Model 205, Testo, Inc., Sparta, NJ) into the cranial portion of the fillet. Instrumental color measurements (L*, a*, b*) were measured at 3 locations on the dorsal side of each fillet using a Minolta colorimeter (CR-300, Konica Minolta, Ramsey, NJ), and color readings were averaged for statistical analyses. Then, samples from the cranial portion were removed and and fixed in 10% neutral buffered formalin for measurement of myofibrillar diameter (MD). In addition, samples for sarcomere length and collagen analysis were collected from the medial region of each right-side fillet and stored at -80°C. The remaining right fillets were then zip-sealed in plastic bags, packed on ice, and held overnight at 4°C, whereas the left fillets were vacuum packaged and frozen at -20°C.

The day following initial processing, right fillets were weighed and cooked in covered, aluminum foil lined pans on raised wire racks to an end-point temperature of 76°C in a convection oven pre-heated to 177°C (Cavitt, 2005a; Mehaffey, 2006). Fillets were allowed to cool to room temperature and reweighed to determine cook loss (calculated as a percentage of the pre-cooked fillet weight) before being individually wrapped in aluminum foil and stored overnight at 4°C for texture analysis the following day (Cavitt, 2005a).

The MORS method was conducted using a texture analyzer (Model TA-XT*plus*; Texture Technologies, Scarsdale, NY), equipped with an 8.9 mm wide razor blade and fillets were sheared in 3 locations of the cranial region at a crosshead speed of 5mm/s (data from the 3 locations were averaged for each fillet for statistical analysis). Razor blades were changed after the completion of 100 shears to ensure the blades did not dull (Cavitt et al., 2005a). In addition, blunt version of the MORS (BMORS) was also conducted on the same fillets to determine shear energy, using the same texture analyzer (Lee et al., 2008).

Sarcomere length was determined using the laser diffraction method of Voyle (1971), as modified by Cross et al. (1981), with a total of 6 sarcomeres measured/sample for each sample.

Fixed fillet (n=5) samples were selected randomly from each strain-age combination deboned at 2 and 24 h PM. Slides were prepared and stained using hematoxylin and eosin, and MD was measured using an Optronix microscope at 20× magnification and image analysis software (4 measurements were taken for each fiber and a total of 8 fibers/sample were measured).

The 24-h debone-time samples from both ages selected for MD were sent to the Department of Animal Sciences and Industry at Kansas State University (Manhattan) for collagen analysis. Soluble, insoluble, and total collagen were extracted and separated following

the methods outlined by Hill (1966). Briefly, samples were freeze-dried and mixed with ¼ strength Ringers solution and heated in a 77°C water bath for 80 min with slight shaking every 10 min. Samples were then centrifuged at 3,000 rpm for 12 min at 20°C, supernatant was decanted, and the pellet fraction was re-centrifuged in ¼ strength Ringers solution at 3,000 rpm for 12 min at 20°C. The supernatant was decanted with the previous supernatant, combined with concentrated sulfuric acid, and marked as the soluble collagen fraction. The residue pellet was combined with 3.5 *M* sulfuric acid and labeled as the insoluble collagen fraction. All samples were then autoclaved at 105°C for 16 to 20 h before being mixed with distilled, deionized water and filtered through Whatman #41 filter paper. Hydroxyproline was determined at 558 nm using an UV/Vis spectrophotometer according to the AOAC (2005) procedures to quantify concentrations (mg collagen/g meat) of total, soluble, and insoluble collagen.

Data were analyzed as a split-plot design, with whole-plot treatments in a 2×2 factorial arrangement, deboning time as the subplot, and individual bird as the experimental unit. The ANOVA was generated with the mixed models procedure of SAS (SAS Inst, Inc., Cary, NC, 2015), with age, strain, debone time, and all 2 and 3-way interactions included in the model as fixed effects. Least square means were compiled and separated statistically using pairwise t-tests (PDIFF option) when a significant ($P<0.05$) F-test was noted. In addition, orthogonal contrasts were used to compare differences between strains (SY vs. HY) and age (40 vs. 54 d).

Results and Discussion

Average live weight was heavier ($P<0.01$) for birds processed at 54 d than 40 d of age, and the SY strain had heavier ($P<0.01$) live weight than the HY strain, regardless of age at slaughter (Table 1). Differences in live weight between strains have been well documented (Acar et al., 1991; Mehaffey et al., 2006).

Postmortem pH decline of the *Pectoralis* muscle was measured in this study to monitor progression of rigor at the variable debone times. Muscle pH decreased (P<0.01) at each deboning time from 2 to 24 h PM (Table 1), and muscle pH of 40-d broilers was lower (P<0.01) than 54-d broilers when deboned at 2h PM and less (P<0.01) than 54-d SY broilers deboned at 4 h PM (age × strain × debone time, P<0.01; Figure 1). Although muscle pH was similar when deboned at 6 h PM, 40-d SY broilers had greater (P<0.01) pH values than 54-d SY broilers when deboned at 24 h PM. Cavitt et al. (2005a) reported that there was no relationship between body weight, in the narrow range of 2.24 to 2.88 kg, and muscle pH progression. In contrast to findings in this study, Mehaffey et al. (2006) suggested that some broiler lines might have a slower rate of rigor development, whereas Brewer et al. (2012a; 2012b) suggested there was no difference in pH among different strains in small- and big-bird programs when deboned at 2, 4 and 6 h PM.

Color is an important measure because it can affect consumer acceptability as well as an indicator of problems in muscle quality, especially PSE (Owens et al., 2000). Various variables can affect the color of meat, such as strain, age, sex, stress, moisture content, and rigor development (Froning, 1995; McKee and Sams, 1997a, b; Owens et al., 2000; Woelfel et al., 2002). Fillets from 54-d HY were lighter (greater L* values, P<0.01) than fillets from 40-d SY and HY broilers, and, among 40-d broilers, fillets from HY were lighter (P<0.01) than those from SY broilers. Debone time had no effect (P=0.62) on L* values.

Fillets from 40-d broilers were redder (greater a* values, P<0.01) than those from 54-d broilers, but a* values were similar (P=0.34) between SY and HY birds (Table 1). This is possibly due to age affecting fiber type. Ashmore and Doerr (1971) found that as chicken ages, intermediate fibers change to white fibers. White muscle fibers are fast-twitch fibers and have

less myoglobin, which is responsible for the red color in meat (Barbut, 2002; Mancini, 2013). Furthermore, fillets deboned at 6 h and greater (P<0.05) than fillets deboned at either 2 or 4 h PM.

Positive b* values are yellow while negative b* values are more green (Konica Minolta Sensing Americas, Inc., 2016). Fillets from 54-d HY broilers were more (P<0.01) yellow (greater b* values) than fillets from 54-d SY and 40-d broilers, regardless of strain (Table 1). In contrast, b* values were not affected (P=0.63) by debone time. Petracci et al. (2013) also reported that high breast yield broilers had higher b* value than standard breast yield broilers at similar age (55 d for HY and 53 d for SY) and live weight (4.2kg).

Broilers selected for high body weight and high breast yield have been reported to have lower color intensity (redness and yellowness) than broilers not selected for high body weight and breast yield (Berri et al., 2001). More specifically, Le Bihan-Duval et al. (1991) reported that, although L* values were not affected by the selection criteria, fillet redness and yellowness decreased in birds selected for high body weight and breast yield strains. Similar, Petracci et al. (2013) reported the only color difference between two commercial broiler strains was in b* values, with high breast yielding broilers having greater b* values than standard breast yielding broilers, but the age range in that study was only 53- to 55-d. Additionally, Smith et al. (2002) reported that processing age did not affect meat color, but perhaps meat color was affected by an increase in muscle size in previous studies.

Cook loss percentage is an indicator of water-holding capacity, and because it can have a significant impact on tenderness and color of fillets (Table 1; Jeffery, 1983). Fillets from 40-d broilers had greater (P<0.01) cooking losses than those from 54-d broilers (Table 1). In addition, fillet cook losses were greater (P<0.01) in HY than SY birds, especially when slaughtered at 40-

d of age. On the other hand, there was no difference (P=0.18) in cook loss among the debone times. Mehaffey et al. (2006) found no consistent relationship between water-holding capacity and strain among five commercial strains, whereas Petracci et al. (2013) reported that HY strains have greater cook losses. Moreover, Brewer et al. (2012a) failed to observe differences in cook loss in fillets from small broilers deboned at 2, 4, and 6 h PM; yet, Mehaffey et al. (2006) reported greater cook loss in fillets deboned at 2 than 4 h PM when broilers were processed at 7 week of age.

Sarcomeres from HY broilers were longer (P<0.01) than those from SY broilers, but sarcomere length did not differ (P=0.69) between slaughter ages (Table 1). As expected, the shortest (P<0.01) and longest (P<0.01) sarcomeres were in fillets deboned at 2 and 24 h PM, respectively, and fillets deboned at 6 h PM had longer (P<0.01) sarcomeres compared to fillets deboned at 4 h PM. In general, SL increased in length as deboning time progressed as a result of a more progressed state of rigor. Cavitt et al. (2004) also reported similar results due to rigor development over debone times ranging from 0.25 to 24 h PM. In contrast to the present study, Brewer (2013a) reported differences in SL between 40- and 60-d broilers deboned at 2 and 4 h PM and suggested that SL increased as broilers increased in age, even though live weights (40d=1.6 kg; 60d=3.3kg) of broilers in that study were much less than the broilers tested in the current study.

Fillets from 54-d SY broilers had the greatest (P<0.05) MORSE values, but fillets of HY broilers had greater (P<0.01) MORSE values compared to SY broilers when processed at 40-d (Table 1). Moreover, BMORSE values were greater (P<0.01) in fillets from 54-d than 40-d broilers, and, similar to MORSE results, HY fillets had greater (P<0.01) BMORSE values than SY fillets at 40-d of age. Previous research has documented that tenderness increases the longer

the carcass is aged prior to deboning (Lyon et al., 1985; Dawson et al., 1987; Thompson et al., 1987; Cavitt et al., 2004). According to relationship between MORSE and consumer perception of tenderness intensity established by Cavitt et al. (2005b), fillets from 40-d SY broilers would be perceived as slightly tender (139.51 to 155.9 N•mm), whereas those from 40- and 54-d HY would be perceived as neither tough nor tender (156.00 to 172.48N•mm), and 54-d SY would be perceived as slightly tough (172.49 to 188.98 N•mm). In addition, fillets deboned at either 2 or 4 h PM had greater (P<0.01) MORSE and BMORSE than fillets deboned at 6 and 24 h PM. So, according to Cavitt et al. (2005b), fillets deboned at 2 h would be perceived as slightly tough, 4 and 6 h PM deboned fillets would be perceived as neither tough nor tender, and 24 h PM deboned fillets would be perceived as slightly tender. Lee et al. (2008) suggested that the MORS was superior to BMORS in predicting tenderness of fillets deboned between 6 and 24 h PM, but BMORS was a more sensitive method of predicting tenderness of fillets deboned at 1.5 h PM or earlier. Results from this study indicate that the BMORS is equivalent to MORS in assessing cooked fillet tenderness.

Fillets from broilers processed at 54-d had greater (P<0.01) myofibrillar diameters (MD) than broilers processed at 40-d of age (Table 1). On the other hand, neither strain (P=0.32) nor debone time (P=0.64) affected MD. These results indicate that muscle fiber hypertrophy was quite rapid during the 14 d between slaughter ages. Previous research indicates that muscle yield and growth is commonly attributed to hypertrophy and elongation of the muscle fiber (Goldspink and Yang, 1999). It was hypothesized that high-yielding strains would have greater MD, but the available literature is not conclusive (Scheuermann et al., 2003; Brewer, 2013b). However, the greater MORSE and BMORSE values observed in older broilers can be attributed, in part, to the

increased MD of these fillets (Crouse et al., 1991; Acar et al., 1993; Scheuermann et al., 2003; Brewer, 2013b).

Collagen content, can affect texture (McCormick, 1999), and fillets from broilers processed at 54-d had more ($P<0.05$) total collagen than those processed at 40-d (Table 1). However, the properties of soluble and insoluble collagen were not affected by age ($P=0.07$) or strain ($P=0.79$). It has been shown that, as animal ages, there is in increase in cross-linking, and increased cross-linking decreases heat solubility of collagen (Foegeding and Lanier, 1996). Shimokonaki et al. (1972) suggested that the total amount of collagen in chicken meat was meaningless; rather, the proportion of insoluble collagen was significantly correlated to tenderness of spent-fowl meat (Nakamura et al., 1975). McCormick (1999) reported that mature cross-links and collagen concentration have an additive effect on the toughening of meat. Thus, even though total collagen content increased with increasing slaughter age, the proportion of the collagen fractions (soluble vs. insoluble) was not affected by processing age.

Conclusion

In this study, age and debone time had more effect on meat quality than strain. Moreover, these results suggest that differences in shear values between ages were impacted more by increases in MD and total collagen content than SL. Lastly, the BMORS method appears to discern tenderness differences between ages in a larger magnitude than the MORS method, and BMORS could be a more appropriate alternative to the MORS when assessing shear values in larger and early-deboned broilers.

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Table 1. Effect of broiler strain and processing age on meat quality attributes of fillets

	Standard yield		High yield			P-value[1]		
	40 d	54 d	40 d	54 d	SEM	STR	AGE	INT
Live weight (kg)	2.80[c]	4.37[a]	2.61[d]	4.28[b]	0.03	<0.01	<0.01	<0.01
Lightness (L*)[2]	49.8[c]	51.0[ab]	50.7[b]	51.5[a]	0.24	<0.01	<0.01	<0.01
Redness (a*)[2]	5.2[a]	4.0[b]	5.3[a]	4.1[b]	0.10	0.34	<0.01	<0.01
Yellowness (b*)[2]	2.4[b]	2.4[b]	2.4[b]	3.5[a]	0.16	<0.01	<0.01	<0.01
Cook loss (%)	25.3[b]	22.5[c]	27.0[a]	23.8[bc]	0.54	<0.01	<0.01	<0.01
Sarcomere Length (μm)	1.72[ab]	1.71[b]	1.75[a]	1.76[a]	0.13	<0.01	0.69	0.03
Fiber diameter (μm)	50.3[b]	71.6[a]	52.2[b]	63.1[a]	3.23	0.32	<0.01	<0.01
MORSE (N•mm)	155.7[c]	172.6[a]	164.2[b]	160.5[bc]	2.83	0.53	0.05	<0.01
BMORSE (N•mm)	187.8[c]	240.0[a]	204.9[b]	227.9[a]	4.89	0.61	<0.01	<0.01
Total Collagen (mg/g)	6.97[b]	9.41[a]	7.40[b]	8.32[ab]	0.53	0.54	<0.01	0.02
Soluble Collagen (%)	40.2	34.5	37.3	36.5	1.68	0.79	0.07	0.13
Insoluble Collagen (%)	59.8	65.5	62.7	63.5	1.68	0.79	0.07	0.13

[a-d]Within a row, least squares means lacking a common superscript letter differ, P<0.05.
[1]F-test probability values of the main effects of strain (STR) and processing age (AGE), as well as the strain × age interaction (INT).
[2]L* values are a measure of darkness to lightness (greater L* values indicate a lighter color); a* values are a measure of redness (greater a* values indicate a redder color); and b* values are a measure of yellowness (greater b* value indicates a more yellow color).
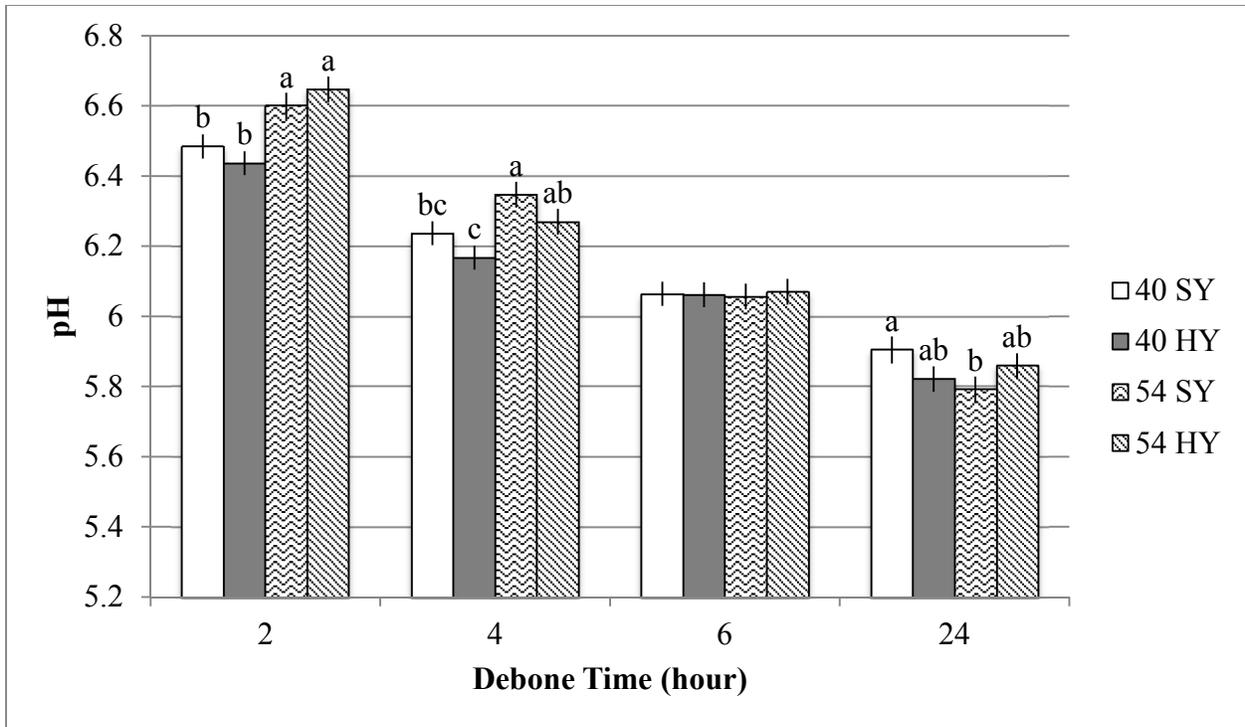
Figure 1. Fillet pH of 40- and 54-d SY and HY broilers at various debone time (h).
[a-c]Means within debone time with no common superscript differ, P<0.05.

Table 2. Effect of deboning time on meat quality attributes of fillets

	Postmortem deboning time (h)				SEM	*P*-value
	2	4	6	24		
Live weight (kg)	3.50	3.57	3.49	3.49	0.031	0.16
Lightness (L*)[1]	50.5	50.7	51.0	50.7	0.24	0.62
Redness (a*)[1]	4.4[b]	4.6[b]	4.9[a]	4.7[ab]	0.10	0.01
Yellowness (b*)[1]	2.6	2.9	2.6	2.7	0.06	0.63
Cook loss (%)	24.9	25.1	25.0	23.6	0.54	0.18
Sarcomere length (μm)	1.62[d]	1.68[c]	1.77[b]	1.86[a]	0.13	<0.01
MORSE (N•mm)	173.8[a]	168.8[a]	157.4[b]	153.1[b]	2.83	<0.01
BMORSE (N•mm)	232.2[a]	226.0[a]	207.1[b]	195.3[b]	4.89	<0.01

[a-d]Within a row, least squares means lacking a common superscript letter differ, P<0.05.
[1]L* values are a measure of darkness to lightness (greater L* values indicate a lighter color); a* values are a measure of redness (greater a* values indicate a redder color); and b* values are a measure of yellowness (greater b* value indicates a more yellow color).

V. Using blunt Meullenet-Owens Razor Shear to assess normal and woody breast from broilers grown to 6 and 9 weeks

F. L. Yang[1], V. V. Tijare[1], J. L. Solo[1], X. Sun[1,2], J. K. Apple[3], and C. M. Owens[1]

[1]Department of Poultry Science, University of Arkansas, Fayetteville, AR 72701, United States

[2]Nanjing Agricultural University, College of Engineering, Nanjing, Jiangsu, 210031, China

[3]Department of Animal Science, University of Arkansas, Fayetteville, AR 72701, United States

Abstract

In recent years, older broilers have been shown to have tougher meat when compared to younger broilers. In addition, woody breast is a condition characterized by a distinct hardness of the raw fillet, and there has been an increase in incidence of woody breasts associated with larger broilers. A blunt version of the Meullenet-Owens Razor Shear (BMORS) has been shown to be a more sensitive tenderness predicting method, especially at higher degrees of toughness. This experiment was conducted using high-breast yielding commercial male broilers (n=600) processed using commercial methods at 6- and 9-wk of age to evaluate the effectiveness of BMORS to differentiate levels of woody conditions (i.e., hardness). Breast fillets were deboned at 2 h postmortem (PM) and aged overnight on ice at 4°C. Fillets were scored for severity of woody breast, and breast fillets (n=234) categorized as normal (NORM) and severe (SEV) were cooked to an endpoint temperature of 76°C to measure cook yield, MORS energy (MORSE), and BMORE energy (BMORSE). Sarcomere length (SL) and collagen samples were collected from the medial region of the right fillets. Broilers grown to 9-wk weighed more (P<0.01) than those grown to 6-wk, and broilers classified as SEV were heavier (P<0.01) at processing than NORM. Cook yields were greater (P<0.05) in NORM fillets, regardless of age at processing, and cook yield was greater (P<0.05) in SEV breast from broilers processed at 6-wk compared to SEV breasts from 9-wk broilers (P<0.01). Fillets from 9-wk broilers categorized as SEV had longer (P<0.05) sarcomeres than NORM fillets, regardless of age at processing (P<0.01). Although MORSE and BMORSE values of NORM fillets were similar (P=0.69) between broiler ages, SEV fillets from broilers processed at 9-wk of age had the greater (P<0.01) BMORSE than SEV fillets from 6-wk broilers. The greater energy values were likely related to the mechanisms related to increased hardness of the fillets. Results indicate a similar trend between the MORSE

and BMORSE, though the magnitude of difference for the SEV samples using BMORSE was greater than using MORSE. Total collagen content of SEV fillets was greater ($P<0.01$) than NORM fillets. Additionally, the percentage of insoluble collagen was greater ($P<0.01$), and the proportion of soluble collagen less ($P<0.01$), in SEV than NORM fillets. The BMORS method could be an effective tool in assessing textural properties of woody breast fillets.

Introduction

The consumption of broilers in the United States has steadily increased over the past 50 years, with per capita consumption of chicken at 37.8 kg compared to 24.6 and 21.0 kg of beef and pork, respectively (National Chicken Council, 2015). This divergence in meat consumption is a global trend, and this is due, in part, to differences in relative prices that have driven the gradual replacement of red meats with white meats (Henchion et al. 2014). With the increase in consumption of broilers, there has been a dramatic change in the modern broiler production with emphasis on rapid growth rates and increased breast yield. In a comparison, broiler growth rate has increased over 400%, with a 50% reduction in feed conversion ratio, since 1957 (Zuidhof et al., 2005).

Through selection for increased growth rate and breast yield, there has been an increase in breast meat abnormalities, such as deep pectoral myopathy and pale, soft, and exudative like meat, and, more recently, white striping and woody breast (Kuttappan et al., 2012; Petracci et al., 2015). White striping is characterized by the occurrence of white striations parallel to muscle fibers on the broiler breast and easily identified on the surface of raw breast fillets. White striping can occur in varying degrees and have been associated with heavier birds (Kuttappan et al., 2009; 2012). The pale, slightly bulging, hardened areas on the breast characterize woody breast, and can often be found with a thin layer of clear/slightly turbid material on the surface and varying degrees of white striping (Shivo et al., 2014). It has been reported that the histopathological changes in woody breast and white striping muscles had similar features (Kuttappan et al., 2013; Sihvo et al., 2014; Ferreira et al., 2014), suggesting a common cause. In woody breast, the histological changes showed different levels of polyphasic myodegeneration and accumulation of interstitial connective tissue (fibrosis) similar to white striping (Sihvo et al.,

2014). These conditions have been reported to have a negative effect on functional properties of broiler breast meat. Both conditions result in lower marinade uptake and higher cook losses. (Petracci et al., 2013; Mudalal et al., 2015); however, the etiology of woody breast and white striping is not fully understood currently.

Due to the accumulation of connective tissue in woody breasts associated with heavier broiler body weights, it is imperative to investigate the instrumental prediction of sensory properties in woody breast. The MORS test is widely accepted as a reliable predictor of tenderness in broiler breast meat (Cavitt et al., 2004, 2005a, b; Lee et al., 2008), whereas the blunt-blade version (BMORS) has been reported to be a more discriminating method, especially among tougher broiler breast fillets, such as early-deboned breast fillets (Lee et al., 2008). Therefore, the objective of this study was to compare the abilities of BMORS and MORS to assess normal and severe woody breast.

Materials and Methods

High-breast yield broilers were processed at 6- (41 d) and 9-wk (61 d) of age in two replicates of 600 broilers for each age. Prior to processing, live birds were weighed, then commercially processed on a commercial-style, in-line system according to Mehaffey (2006), which included electrical stunning (11 V, 11 mA, 11 sec), scalding for 2-min at 54.4°C, de-feathering using an in-line commercial de-feathering equipment, and evisceration. After evisceration, carcasses were subjected to a 90-min chilling process that included a 15-min pre-chill at 12°C followed by a 75-min chill at 1°C in immersion chill tanks. At the completion of chilling, carcasses were packaged and aged on ice until deboning at 2 h postmortem (PM).

Carcasses were deboned and the breast fillets (*Pectoralis major*) were harvested, weighed to assess breast yield (as a percentage of live weight), and whole fillets were classified according

to the scoring system of Tijare et al. (2016) as either: 1) normal, flexible fillets (NORM), or 2) severe woody fillets (SEV), that were extremely hard and rigid throughout from cranial region to caudal tip. A total of 134 fillets were selected at 6-wks and 102 at 9-wks.

Samples were collected from the medial region of right fillets and stored at -80°C for measurement of sarcomere length and collagen analysis at a later date. Then right fillets were zip-sealed in plastic bags, packed on ice, and held overnight at 4°C before being weighed and subsequently cooked on wire racks in aluminum foil-lined, cover pans to an internal end-point temperature of 76°C in a convection oven pre-heated to 177°C (Cavitt et al., 2005a; Mehaffey et al., 2006). Fillets were cooled to room temperature, reweighed to calculate cook yield (as a percentage of the pre-cooked fillet weight), individually wrapped in aluminum foil, and stored overnight at 4°C cooler for shear analysis the following day.

The MORS method was conducted using a texture analyzer (Model TA-XT*plus*; Texture Technologies, Scarsdale, NY), equipped with an 8.9 mm wide razor blade. Fillets were sheared in 4 locations on the cranial region at a crosshead speed of 5mm/s (data from the 4 locations were averaged for each fillet for statistical analysis). After completion of 100 shears, razor blades were changed to ensure the blades did not dull (Cavitt et al., 2005a). In addition, blunt-blade of the MORS (BMORS) was also conducted on the same fillets on the cranial region to determine shear energy, using the same texture analyzer (Lee et al., 2008).

Sarcomere length was determined using the laser diffraction method of Voyle (1971), as modified by Cross et al. (1981), with a total of 6 sarcomeres measured/sample for each sample.

Samples from 9-wk old broilers from both woody breast categories (n=15) were sent to the Department of Animal Sciences and Industry at Kansas State University (Manhattan) for collagen analysis. Soluble, insoluble, and total collagen were extracted and separated following

the methods outlined by Hill (1966). Briefly, samples were freeze-dried and mixed with ¼ strength Ringers solution and heated in a 77°C water bath for 80 min with slight shaking every 10 min. Samples were then centrifuged at 3,000 rpm for 12 min at 20°C, supernatant was decanted, and the pellet fraction was re-centrifuged in ¼ strength Ringers solution at 3,000 rpm for 12 min at 20°C. The supernatant was decanted with the previous supernatant, combined with concentrated sulfuric acid, and marked as the soluble collagen fraction. The residue pellet was combined with 3.5 *M* sulfuric acid and labeled as the insoluble collagen fraction. All samples were then autoclaved at 105°C for 16 to 20 h before being mixed with distilled, deionized water and filtered through Whatman #41 filter paper. Hydroxyproline was determined at 558 nm using an UV/Vis spectrophotometer according to the AOAC (2005) procedures to quantify concentrations (mg collagen/g meat) of total, soluble, and insoluble collagen.

All data were analyzed as a completely randomized design with treatments in a 2×2 factorial arrangement and individual bird was the experimental unit. The ANOVA was generated using the mixed models procedure of SAS (SAS Inst, Inc., Cary, NC, 2015), with age at slaughter (6 vs. 9 wk), woody severity category (NORM vs. SEV), and the age × woody severity category interactions as the fixed effects in the model. Least square means were computed and statistically using pairwise t-tests (PDIFF option of SAS) when a significant (P<0.05) F-test was noted.

Results and Discussion

As expected, broilers processed at 9-wk of age were heavier (P<0.01) than those processed at 6-wk (4.53 vs. 2.73; results not presented); however, broilers producing SEV fillets had greater (P<0.01) live weights than those producing NORM fillets (Table 1). This finding suggests that broilers affected with woody breast may grow more rapidly than high breast yield

birds that produce NORM breast meat. Shivo et al. (2014) reported that woody breast is related to fast growth rate and high breast yield broilers. Breast yield did not differ (P>0.05) among 9-wk birds, regardless of woody breast severity category, and 6-wk birds with SEV breast had greater (P<0.05) breast yields than 6-wk NORM birds (age × severity category, P<0.01; Figure 1). Mudalal et al. (2014) found that the caudal area of woody breast was thicker, and a thicker caudal area of breast fillets is correlated with breast yield (Lubritz, 1997; Scheuermann et al, 2003). Woody breast may result from a similar myopathy as white striping, and white striping has been shown to be growth related (Kuttappan et al., 2012, 2013; Ferreira et al., 2014).

Cook yields were greater (P<0.05) in NORM fillets, regardless of age at processing, whereas cook yield was greater (P<0.05) in SEV breast from broilers processed at 6-wk compared to SEV breasts from 9-wk broilers (age × severity category, P<0.01; Figure 1). Reporting similar results, Mudalal et al. (2014) suggested that the extensive loss of membrane integrity increased cook loss, leading to lower cook yields in woody breast fillets. In addition, high cook loss has been found to be associated with increased toughness of meat (Murphy and Marks, 2000).

Sarcomere length is a measurement of muscle contraction and is highly correlated with cooked breast tenderness (Lyon and Bhur, 1999; Cavitt et al., 2004). Fillets from 9-wk broilers categorized as SEV had longer (P<0.05) sarcomeres than NORM fillets, regardless of age at processing (age × severity category, P<0.01; Figure 2). In theory, it is plausible that sarcomeres from older broilers not affected by woody breast were experiencing greater shortening compared to younger broilers, and the longer sarcomeres in SEV fillets are indicative of the progression of woody breast conditions, which are related to changes in fiber degeneration and fibrosis (Shivo et al., 2014).

Fillets of broilers reared to 9-wk of age had greater (P<0.01; results not presented) MORSE values than fillets of broilers at 6-wk of age, but MORSE values did not differ (P=0.69) between woody categories (Table 1). Mudalal et al. (2014) reported that Warner-Bratzler shear force values were not affected by the woody breast condition in non-marinated fillets, but shear force values were increased in marinated fillets that suffered from both woody breast and white striping.

The greatest (P<0.05) BMORSE values were in SEV fillets from 9-wk broilers, and, within 6-wk broilers, SEV fillets had greater (P<0.05) BMORSE values than NORM fillets (age × severity category, P<0.01; Figure 3). These results indicate that the BMORS may have more discriminating ability in tougher meat (Lee et al., 2008), especially in heavier broilers affected by woody breast.

Collagen is the most abundant connective tissue protein (Swatland, 1994), and Shivo et al. (2014) reported increased collagen-rich connective tissue between muscle fibers in breast fillets with woody breast, with an increase in thickness of the epimysium, covering the *Pectoralis major.* So, it was not surprising that total collagen content of SEV fillets was greater (P<0.01) than NORM fillets (Table 1). Additionally, the percentage of insoluble collagen was greater (P<0.01), and the proportion of soluble collagen less (P<0.01), in SEV than NORM fillets. Insoluble, or heat stable, collagen has been reported to have the highest correlation with toughness (Light et al., 1985; McCormick, 1999). Soglia et al. (2015) also reported that fillets with woody breast had more collagen than normal fillets, but they failed to discern whether the collagen was insoluble or soluble. Thus, the increased BMORSE values of SEV fillets in the present study may be attributed to increases in insoluble collagen concentrations.

Conclusion

Woody breast fillets appear to be growth related and impact meat quality attributes, especially in broilers processed at an older age. There was more total collagen and insoluble collagen in SEV fillets, thereby resulting in increased toughness. The MORS test was unable to detect a difference between NORM and SEV fillets from 9-wk broilers; however, the BMORS test differentiated between the two processing ages in greater magnitude. Therefore, the BMORS could be an effective tool in assessing textural properties of woody breasts; yet further research should be conducted to determine BMORS relationship to sensory threshold values in woody breast fillets.

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Table 1. Comparison of slaughter weight and quality attributes of fillets categorized as either normal (NORM) or severe (SEV) woody breast

| | Woody breast severity category | | | |
	NORM	SEV	SEM	*P*-value
Live weight (kg)	3.53[b]	3.73[a]	0.032	<0.01
MORSE (N•mm)	197.6	196.1	2.74	0.69
Total collagen (mg/g)	7.0[b]	13.6[a]	0.72	<0.01
Soluble collagen (%)	28.9[a]	21.3[b]	1.00	<0.01
Insoluble collagen (%)	71.1[b]	78.7[a]	1.00	<0.01

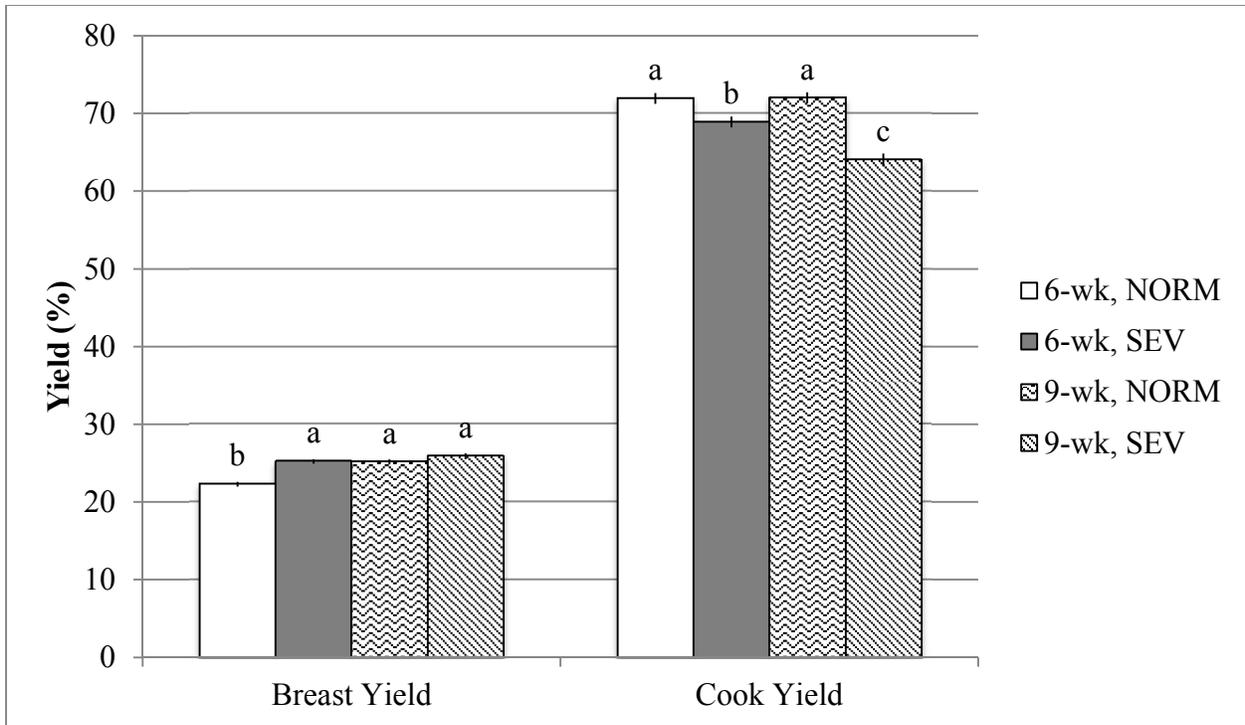[a-b]Within a row, least squares means lacking a common superscript letter differ, P<0.05.

Figure 1. Breast and cook yield of normal (NORM) and severe (SEV) woody fillets from broilers slaughtered at 6- and 9-wk of age, P<0.05.
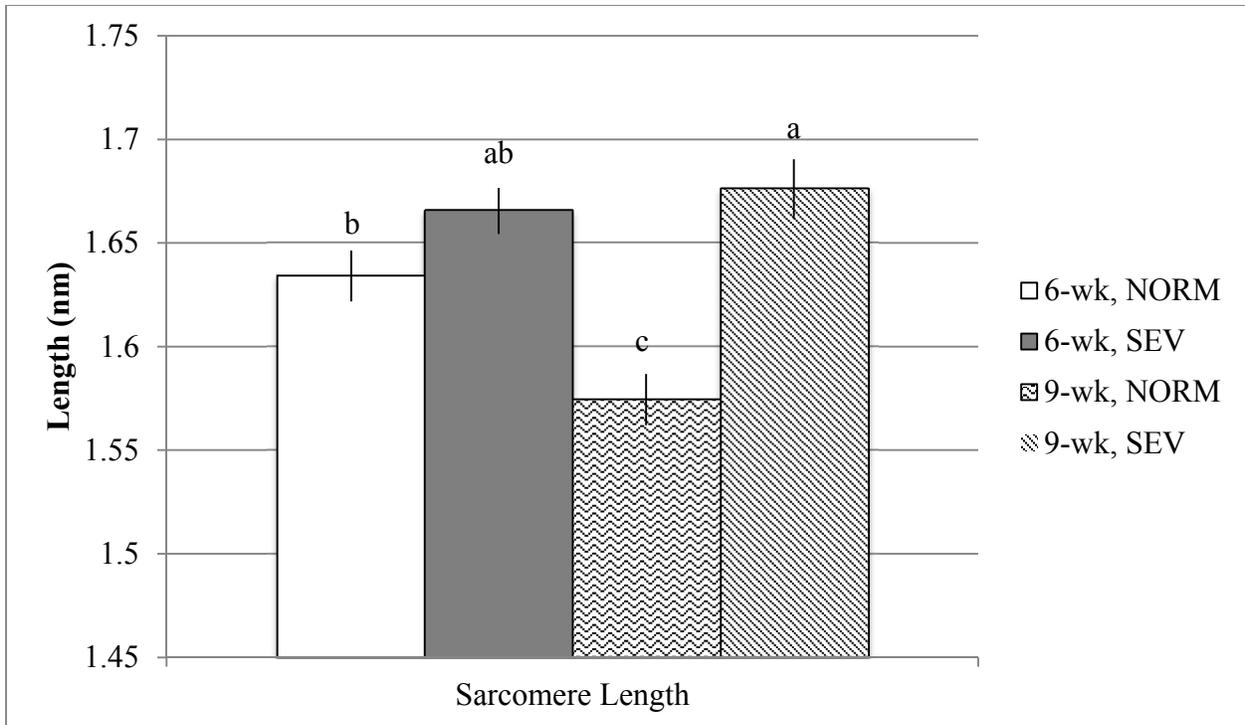
Figure 2. Sarcomere length (SL) of normal (NORM) and severe (SEV) woody fillets from broilers slaughtered at 6- and 9-wk of age, $P<0.05$.
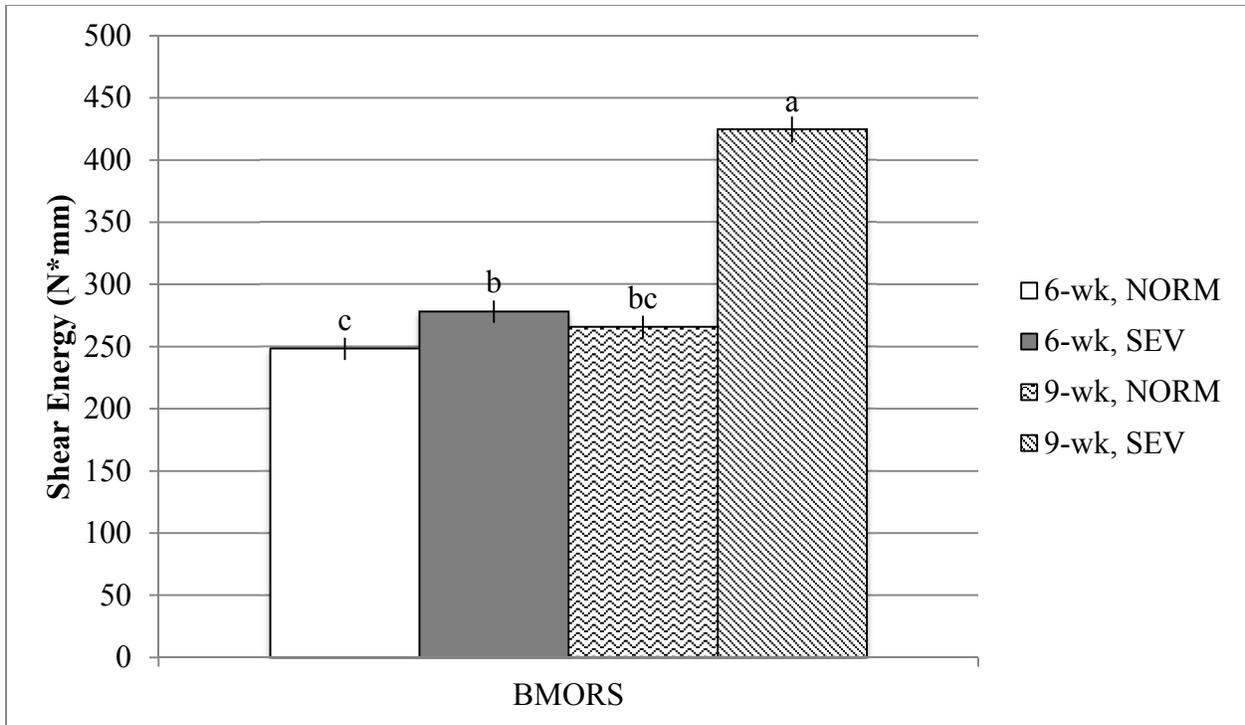
Figure 3. Blunt Meullenet-Owens Razor Shear energy (BMORSE) of normal (NORM) and severe (SEV) woody fillets from broilers slaughtered at 6- and 9-wk of age, P<0.05.

VI. Conclusion

Shear values tend to increase as broiler age increased and this research suggests that increased myofibrillar diameter, total collagen, and proportion of insoluble collagen play a role in the increasing shear values. Furthermore, the BMORS method could be a more appropriate alternative to the MORS when assessing shear values in larger and early-deboned broilers.

The MORS test was unable to differentiate between NORM and SEV fillets at 9 weeks of age, whereas the BMORS test was able differentiate between the two with great magnitude. This is probably due to the added effect of compression when shearing with BMORS. BMORS could be an effective tool in assessing textural properties of woody breasts especially in larger broilers that tend to have higher shear values. There was more total and insoluble collagen in SEV fillets, suggesting that textural properties such as toughness may be affected. Further research should be conducted to determine BMORS relationship to sensory threshold values for tenderness or other textural properties in woody breast cases.