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Meat Quality and Sensory Analysis of Broiler Breast Fillets with Woody Breast Muscle Myopathy

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Meat Quality and Sensory Analysis of Broiler Breast Fillets with Woody Breast Muscle Myopathy

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By

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ABSTRACT

Recently, the poultry industry has encountered an emerging muscle myopathy known as woody breast (WB), which is characterized by hardness throughout the *Pectoralis major* muscle. Two experiments were performed to assess sensory characteristics and acceptability of WB meat and to determine the effect of broiler age on meat quality factors in varying severities of WB. Fillets were categorized as normal (NORM), moderate (MOD), or severe (SEV) WB. In Experiment 1 (Exp. 1), descriptive (n=9 trained panelists) and consumer (n=74 panelists) sensory analysis was conducted with NORM and SEV fillets at hot and cold serving temperatures (HOTNORM, COLDNORM, HOTSEV, COLDSEV). In Experiment 2 (Exp. 2), a consumer sensory panel (n=70 panelists) evaluated acceptability of normal and WB meat from broilers processed at 45 or 63-d of age. Meat quality factors, including compression force, sarcomere length, MORS energy (MORSE), BMORS energy (BMORSE), cook loss, and peak counts of the shear curves (PC-MORS and PC-BMORS), were measured on broilers processed at 45, 63, and 70-d of age. In Exp. 1, descriptive sensory results showed that COLDSEV fillets had greater ($P<0.05$) hardness than HOTSEV fillets. Consumer sensory results indicated higher ($P<0.05$) overall impression and chicken texture scores for NORM fillets than SEV fillets. HOTNORM fillets had higher ($P<0.05$) chicken texture JAR scores than HOTSEV, while COLDNORM fillets had higher ($P<0.05$) chicken juiciness JAR scores than COLDSEV. Consumer sensory analysis in Exp. 2 resulted in 3 segmented groups (Group A, B, C) among the panelists based on overall liking of the samples. Panelist responses indicated that Group C had higher ($P<0.05$) overall liking scores for SEV fillets than NORM fillets. Meat quality analysis from Exp. 2 demonstrated greater ($P<0.05$) compression force, sarcomere length, and cook loss in SEV fillets than NORM fillets. Both MORSE and BMORSE values increased ($P<0.05$) with age, and SEV fillets had greater ($P<0.05$) PC-BMORS than MOD and NORM fillets. Results suggest descriptive attributes and consumer acceptability responses are related to WB. Meat quality is also affected by both WB and age, and compression force and peak counts may serve as an appropriate measurement to distinguish WB from normal fillets.

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1. INTRODUCTION

Consumption of poultry meat is consistently a common protein source for consumers in the United States. In 2015, the United States produced close to nine billion broilers resulting in Americans consuming 90 pounds per capita, making chicken meat to be the most popular protein consumed in the United States (National Chicken Council, 2016a). The popularity of poultry meat among consumers is due to the healthy image of poultry meat, sensory properties such as desirable texture and color, and the mild flavor profile allowing consumers to impart desired flavors to the meat (Petracci et al., 2013). It is estimated that in 2016 the per capita consumption of broiler meat will be 90.1 pounds, 55 pounds for beef, and 49.2 pounds for pork (National Chicken Council, 2016c). Respectively, the per capita consumption of broilers in 1966 was 32.1 pounds, beef totaled 78.1 pounds, and pork was reported at 50.3 pounds (National Chicken Council, 2016c). The demand for poultry meat has steadily increased and projections predict that the demand will continue to rise. This increase in demand has led the poultry industry to increase the growth rate, feed efficiency, and the size of the breast muscle (Petracci and Cavani, 2012).

U.S. broiler performance has increased from a market live weight of 2.5 pounds in 1925 requiring 4.7 pounds of feed to gain one pound of meat to a live weight of 6.12 pounds and feed to meat gain of 1.89 pounds in 2014 (National Chicken Council, 2016d). The increased growth rate has reached the goals for higher yields and improved feed efficiency, but it is at the expense of meat quality attributes resulting from growth related muscle myopathies (Dransfield and Sosnicki, 1999). The muscle abnormalities that have been observed as a result of the fast-growing broiler is a pale, soft, and exudative (PSE)-like condition, white striping, and woody breast in the *Pectoralis major* muscle of broilers (Petracci et al., 2015). The PSE-like condition is characterized by a pale color and its inability to hold and bind water during storage and further processing (Petracci et al., 2015). White striping is known for the appearance of white striations of varying degrees running parallel to the muscle fibers of broiler breast fillets in heavier broilers (Kuttappan et al., 2012a). The woody breast myopathy is described by palpable hardness, out-bulging, and pale attributes in the *Pectoralis major* often accompanied by white striping and interstitial connective tissue accumulation (Sihvo et al., 2014). Previous research by Zotte et al. (2014) indicate that broiler breast fillets affected with woody breast are associated with negative meat quality attributes such as decreased water-holding capacity during storage and cooking as well as increased fillet weights and cross-sectional areas, which is an indicator of the increased growth rate problem. Studies have reported fillets affected with woody breast alone, or accompanied with white striping, showed higher fat and collagen contents, lower amounts of protein, higher pH values, lower water-holding capacity, lower marinade uptakes, and increased drip and cook losses (Mazzoni et al., 2015; Soglia et al., 2015).

It is apparent that fillets affected with wooden breast are exhibiting a lower nutritional value, harder texture, and impaired meat quality attributes than normal broiler breast fillets. The broiler breast meat detected in poultry processing plants are often downgraded and sometimes rejected from human consumption, which equates to significant economic losses for the poultry industry (Petracci et al., 2015; Sihvo et al., 2014). Kuttappan et al. (2012b) studied consumer acceptability in the visual appearance of broiler breast fillets affected with varying degrees of white striping and found that white striping does affect consumer acceptance based on the appearance. Consumer acceptability of fillets affected with woody breast is still unknown. In 2010, the retail market accounted for 56 percent of the amount of chicken produced in the U.S., while foodservice made up the other 44 percent with fast food taking up 57 percent of the foodservice market (National Chicken Council, 2016b). The amount of broiler breast meat that reaches the hands of consumers is exponential and providing a quality product in the retail and foodservice settings is essential. Therefore, it is important to identify consumer acceptability of texture attributes in broiler breast fillets with varying degrees of woody breast. It is also critical to determine if sarcomere length of the muscle and shear values using the MORS test and the blunted BMORS test correlate with sensory analysis data and play a role in the consumer acceptability of breast fillets affected with woody breast.

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2. LITERATURE REVIEW

MUSCLE STRUCTURE AND FUNCTION

Skeletal muscle of a meat animal constitutes the majority, 35 to 65 percent, of the animal's carcass weight and more specifically 40-50% of the average body mass of an adult bird (Aberle et al., 2001; Barbut, 2015). Skeletal muscles are organs of the muscular system that are attached directly or indirectly to bones by ligaments, fascia, cartilage, or skin and are primarily responsible for movement and support of the body (Aberle et al., 2001; Kerth, 2013b). The structural unit of skeletal muscle tissue is a highly specialized cell known as the muscle fiber, which compromises 75 to 92 percent of total muscle volume (Aberle et al., 2001). Mammalian and avian skeletal muscle fibers are long, multinucleated, unbranched, threadlike cells that taper slightly at both ends (Lawrie and Ledward, 2006; Aberle et al., 2001). Surrounding the muscle fiber is a protein and lipid material called the sarcolemma. The sarcolemma is fairly elastic to endure distortion that occurs during contraction, relaxation, and stretching of the muscle (Judge et al. 1989). Individual muscle fibers are surrounded by the endomysium, while bundles of fibers are surrounded by the perimysium, and the whole muscle is contained by the epimysium (Warriss, 2010).

The myofibril is an organelle unique to muscle tissue and are long, thin, cylindrical rods running parallel to the fiber for the entire length of the fiber. The sarcomere is the repeating structural unit of the myofibril and the basic unit of muscle contraction and relaxation (Forrest et al. 1975). The sarcomere consists of overlapping regions called thick and thin filaments. The thick filaments make up the A band of the sarcomere and predominantly consist of myosin. The thin filaments constitute the I band of the sarcomere and consist primarily of actin (Forrest et al. 1975). Myosin is a fibrous, elongated rod shape protein that compromises 45 percent of the total myofibrillar protein. The myosin molecule has a head region and a tail region lying in the center of the A band. Actin is a globular shaped molecule that constitutes about 20 percent of the myofibrillar proteins. The globular shaped molecules, referred to as G-actin, are linked together in strands to form a single fibrous molecule called F-actin. Two strands of F-actin spirally coil around each other to form a helix that is characteristic of actin (Judge et al. 1989). Tropomyosin makes up 5 percent of the myofibrillar protein and each strand lies in close contact to each groove of the actin helix. Troponin is also 5 percent of the total myofibrillar and is also present within the actin filament along the tropomyosin strands (Judge et al. 1989). The bands of each myofibril align themselves across the length of the muscle fiber giving the characteristic striated appearance of the muscle. The light band of the striated appearance includes the I band, which only contains actin, the broad dark band is designated as the A band, which is much denser than the I band, and the Z line is known as the dark thin band that bisects the I band (Aberle et al. 2001). The H zone is known as the central region between the ends of the opposing actin filaments and contains only myosin. The M line is the narrow dense band that bisects the center of the A band. The sarcomere includes both an A band and the two half I bands located on either side of the A band and sits between two adjacent Z lines (Forrest et al. 1975).

MUSCLE CONTRACTION AND RELAXATION

The proteins actin, myosin, tropomyosin, and troponin work together for contraction and relaxation of the muscle. Actin and myosin serve as the contractile proteins and form the filaments of the myofibril, whereas tropomyosin and troponin are known as regulatory proteins that regulate the contractile process (Judge et al. 1989). Early discussion of muscle contraction by Huxley (1958) introduced the sliding filament theory, which has yet to be disproven. Huxley (1958) reported that the length of the A band remains constant while the length of the I band and the H zone changes with the length of the muscle as it contracts making the conclusion of the sliding filament theory. This theory is still described as the myosin and actin filaments sliding over one another so that the length of the sarcomere shortens (Warriss, 2010). Cross-bridges are formed to link the myosin and actin filaments together. The cross-bridges are formed by the myosin head molecules and the "ratchet" movement that the cross-bridges perform to along the actin chains (Warriss, 2010). Activation of contraction of a muscle fiber originates by an impulse from the brain signaling an action potential (Swartz et al., 2009). The action potential is received from a motor neuron at the motor end plate. At the motor end plate, the action potential causes the release of acetylcholine into the synaptic clefts on the surface of the muscle fiber causing the resting potential to change. Next, the depolarization of the sarcolemma occurs for an influx of Na^+ and efflux of K^+ for polarization reversal of the membrane. When the action potential reaches the sarcoplasmic reticulum from the transverse tubules opening the voltage gated calcium channel, action potential spreads inside the muscle fiber allowing the sarcoplasmic reticulum to release Ca^{+2}. The release of Ca^{+2} allows the ions to bind to troponin, which releases the inhibition of tropomyosin, allowing myosin and actin to bind and form crossbridges. The myosin ATPase hydrolyzes ATP into ADP and phosphate, giving the energy for the myosin head to "ratchet" along the actin filament for contraction. The actin filament is pulled toward the center of the sarcomere, closing the gap between the Z lines, thus shortening the sarcomere, which has been reviewed by several authors (Swatland, 1994; Aberle et al., 2001; Alvarado and Owens, 2006; Sayas-Barbera, 2010). When relaxation occurs, the membrane has to be repolarized, Ca^{+2} has to be resequestered into the sarcoplasmic reticulum, and ATP must be regenerated. Repolarization of the sarcolemma is established by the Na^+/K^+ pump transporting

Na^+ out of the cell and K^+ into the cell and resequestration of Ca^{+2} is pumped back into the sarcoplasmic reticulum via ATPase (Alvarado and Owens, 2006).

MUSCLE TO MEAT CONVERSION

When an animal is slaughtered, many biochemical changes occur at the cellular level in the muscles of the body (Braden, 2013). In a living animal, muscle and other organs of the body, must maintain an efficient environment in which they all function in a well ordered physiological state known as homeostasis. Homeostasis allows an animal to survive under adverse environmental conditions such as temperature variation, oxygen deficiency, and antemortem stress. Many of the biochemical changes that occur in the conversion from muscle to meat are a direct result of an animal's body attempting to maintain homeostasis (Aberle et al. 2001). Chemical changes in muscle metabolism begin when immobilization occurs. Exsanguination happens next in which 50% of the blood volume is lost and homeostasis and oxygen supply to the muscle is compromised (Braden, 2013). When blood flow ceases, metabolism of ATP for energy must occur anaerobically by the breakdown of glycogen stored in the muscle through glycolysis. As the glycogen stores in the muscle are broken down and ATP is depleted, lactic acid accumulates and gradually lowers the pH of the muscle (Aberle et al. 2001; Braden, 2013; Warriss, 2010).

Latin for "stiffness of death", rigor mortis is known as the phenomenon that forms permanent cross-bridges between actin and myosin filaments losing extensibility of the muscle. Each muscle fiber goes into rigor relatively quickly once ATP is completely depleted, but that time point varies depending on species. For example, breast muscles of poultry meat can reach rigor as soon as an hour after death (Aberle et al. 2001; Sayas-Barbera et al. 2010, Warriss, 2010). The period after exsanguination when the muscle is still extensible is referred to as the delay phase of rigor mortis. When the muscles begin to lose extensibility because the ATP supply is exhausted and permanent cross-bridges are formed is called the onset phase of rigor. The completion stage of rigor mortis is when the muscles become inextensible (Aberle et al., 2001). As time increases after postmortem, a decrease in tension of the muscle occurs, which is known as the resolution stage of rigor mortis. The permanent cross-bridges are not being broken, but protein degradation of the Z lines in the muscle is taking place during postmortem aging (Aberle et al., 2001; Warriss, 2010). Enzymes known to be responsible for the protein degradation of the muscle are calpains present in the sarcoplasm (Aberle et al. 2001). While postmortem aging can decrease the tension in muscles from rigor, a disruption such as early deboning, to the muscle before rigor mortis is completed can result in decreased tenderness by increasing cross-bridge formation and sarcomere shortening. Therefore, it has been recommended for poultry carcasses to age 4-6 hours postmortem before other processing steps so that rigor mortis can be completed (Alvarado and Owens, 2006; Dawson et al. 1987; Schreurs, 2000). Using shortened aging periods can have negative impacts on meat quality (Sams and Owens, 2010).

MEAT QUALITY

Quality characteristics of muscle foods are influenced by muscle appearance, color, texture, juiciness, mouthfeel characteristics, etc. These quality parameters are dependent on many predetermining factors that affected the live animal before being converted from muscle to meat (Coggins, 2012).

A. COLOR AND pH

Meat color influences retail purchasing decisions more than any other quality factor because consumers use color as an indicator of spoilage and shelf-life solely by visual appearance (Mancini, 2009; Guidi and Castigliego, 2010). The color of meat primarily comes from the red myoglobin molecules found in muscle tissue, while hemoglobin plays a minor role due to the small amounts present (Guidi and Castigliego, 2010; Barbut, 2015). However, there are many factors such as breed, nutrition, muscle type, postmortem changes, processing methods, and packaging can affect meat color (Barbut, 2015). The main factors affecting color inside the muscle include myoglobin content, muscle fiber orientation, space between the muscle fibers, and pH (Barbut, 2015). Different muscles have varying contents of myoglobin, which can directly affect the color and color stability. The breast meat of chicken is primarily made of white muscle fibers, which is low in myoglobin while the thigh meat is composed of red fibers, which is higher in myoglobin making them appear darker (Barbut, 2015). Whether the iron molecule of myoglobin is oxidized or reduced and what compounds are attached to the heme ring of myoglobin affects meat color. When oxygen is attached and the iron molecule is reduced, the color of the meat is bright red. When the iron molecule is oxidized, the meat has a brown color from the lack of oxygen inside the muscle (Barbut, 2002b). The color of meat is also impacted by the structure and spacing of the sarcomeres in muscle tissue. The sarcomere structure influences the way that light is absorbed and reflected off of the meat's structure. An example is with pale, soft, and exudative (PSE) meat, which has a more open sarcomere structure allowing more reflection of light resulting in a paler appearance (Barbut, 2015; Swatland, 2008).

Muscle pH and meat color are highly correlated. Muscle pH has been associated with a multitude of other quality attributes such as tenderness, water-holding capacity, cook loss, juiciness, and shelf-life (Fletcher, 1999). Once the resolution of rigor has set in, the pH of the muscle drops due to the build-up of lactic acid and the occurrence of glycolysis. This drop in pH to 5.6-5.8 can be attributed to normal meat color development (Braden, 2013). After 24 hours the normal postmortem pH is 6.0-6.2 in poultry muscle (Keeton and Osburn, 2010). The rate at which the muscle pH declines when it reaches the completion of rigor is very important. A rapid pH decline can be attributed to muscle pH values close to the isoelectric point, thus leading to negative meat quality characteristics. The isoelectric point is a balance between the positive and negative charges on the protein side-groups with a pH level of 5.1 and relates to the ability of the proteins to bind water and thus subsequent meat quality characteristics such as juiciness and tenderness of the meat (Miller, 2002). Muscle with a rapid pH decline and a pH value near the isoelectric point can be characterized as watery and pale in color known as the pale, soft, and exudative (PSE) condition (Miller, 2002; Braden, 2013). However, if the pH decline is limited in rate and/or extent, the pH levels will be much higher than the isoelectric point leading to dry meat that is dark in color. This condition is known as the dark, firm, and dry (DFD) condition (Miller, 2002; Braden, 2013). The impact that pH has on the color and functionality of the meat is of great importance to processors of fresh and further processed products when it directly affects the profit and shelf-life of the product (Barbut, 2015).

B. WATER-HOLDING CAPACITY

Water-holding capacity is known as the ability of meat to retain naturally occurring or added water during application of external forces such as cutting, heating, grinding, or pressing (Aberle et al. 2001). Water-holding capacity of proteins is influenced by many factors including muscle type, rigor conditions, processing conditions, and ingredients added to the meat. Lean meat is comprised of about 75% water, resulting in a water to protein ratio of 3.5:1 in muscle tissue (Honikel, 2004). The large amount of water is held in the meat by hydrogen bonds and the internal structure of the proteins (Barbut, 2002a). Water held within the structure of meat can be divided into three main categories including bound water, immobilized water, and free water

(Babrut, 2002; Keeton and Osburn, 2010). Bound water is the water directly attached as an inner layer on the thick and thin filament structures and can't be changed by processing methods. Immobilized water is a "middle" layer of water molecules attached to the bound water by hydrogen bonds. The free water is mostly held by surface forces in the protein resulting in weakly held bonds. This category is very important in further processed meats due to the fact that free water can be easily removed from the meat system by forces imposed by processing and the goal is to keep it in the meat product (Keeton and Osburn, 2010). Water-holding capacity is manipulated in two occurrences: the ionic effect and the steric effect. When the postmortem pH of muscle is at the isoelectric point and there is an equal amount of positive and negative charges, it reduces the ability of water to attract to actin and myosin and loses water to drip loss (Apple and Yancey, 2013; Miller, 2002). As meat pH increases or decreases from the isoelectric point, the ratio of positive and negative charges will change increasing the ability of actin and myosin to tightly bind water (Miller, 2002). The steric effect has a larger effect on water-holding capacity depending on the space between the myofibrillar proteins. During contraction the space between the myofibrillar protein structures becomes shorter restricting the space for water to bind to actin and myosin. The state of contraction and muscle pH can alter the amount of interstitial space available to hold water. However, if the sarcomeres are shortened and there is little interstitial space, the water is expelled into the the extracellular space of the muscle (Alvarado and Owens, 2006). The ability of actin and myosin to bind water is important to meat quality and is related to many factors of the end product including meat tenderness (Miller, 2002).

C. MEAT TEXTURE AND TENDERNESS

Texture and tenderness are characteristics rated as most important by the average consumer when all attributes of eating quality are considered (Lawrie and Ledward, 2006). Texture of a muscle includes the fineness and definition of muscle fibers and the degree and placement of intramuscular fat within the meat. Tenderness can be referred to as the amount of force that is needed to bite through a meat sample (Coggins, 2012). These attributes can be determined by factors such as age, muscle fiber type, sex, and processing conditions such as deboning time (Grey et al., 1986; Cavitt et al., 2004; Coggins, 2012). Meat toughness to tenderness can generally be contributed to two factors in the muscle: the muscle fibers and connective tissue (Kerth, 2013a; Koohmaraie, 1988; Coggins, 2012). Tenderness in relation to the myofibrillar proteins in the muscle fiber is altered by the shortening of sarcomeres and how much myofibrillar protein degradation has occurred (Kerth, 2013a). Muscles with longer sarcomeres require less shear force than muscles with shorter sarcomeres, resulting in a positive relationship between improved tenderness and sarcomere length of the muscle (Herring et al., 1967; Marsh et al., 1974; Cavitt et al., 2004; Weaver et al., 2008). More shear force is required because the shorter sarcomeres have increased overlap of the actin and myosin and thus more actomyosin cross-bridges (Weaver et al., 2009). A previous study suggested longer sarcomeres associated with an increased tenderness in bovine *longissimus* muscle with 11 of 12 steaks measuring more tender by both a 12-member sensory panel and a Warner-Bratzler apparatus (Smulders et al., 1990). Thaw rigor and cold shortening are two phenomena that result in shortened sarcomeres before the completion of rigor. Thaw rigor occurs when the meat is frozen before rigor is complete and leads to shortening when the meat is thawed while cold shortening is rapid cooling to a temperature below 10^{o}C before the onset of rigor (Aaslyng, 2002; Swatland, 1994). These prerigor deboning conditions occur due to ATP and Ca^{2+} being present in the muscle fiber together causing the excess Ca^{2+} to trigger muscle contraction (Kerth, 2013a). Since the muscle is taken from the skeletal system, the muscle will continue to contract even further when rigor is complete (Cavitt et al., 2004). An aging period before the skeletal muscle is removed from the carcass is needed to acquire acceptable tenderness levels in broiler breast meat. Because meat quality parameters are most affected by debone time, aging for 4-6 h postmortem is suggested (Sams and Owens, 2010). Shear values used to measure tenderness indicated that early debone times had higher shear values when compared to lower shear values in broiler breast fillets that were allowed an aging period (Lyon et al., 1985; Dawson et al., 1987). Higher shear values are also associated with broilers reared to older ages and differences in rigor development could be attributed to the increased toughness (Brewer-Gunsaulis and Owens, 2013). Mehaffey et al. (2006) reported that regardless of age, deboning at 2 h postmortem resulted in higher shear values, pH values, and L* values compared to breast meat deboned at 4 h postmortem.

Tenderness of meat is increased by postmortem protein proteolysis and subsequently the degradation of myofibrillar proteins. The meat tenderization is the result of endogenous proteolytic enzymes calpastatin and μ and m-calpains (Kerth, 2013; Lon and Buhr, 1999). Koohmaraie (2006) suggested that μ-calpain is primarily responsible for postmortem proteolysis and tenderization of muscle tissue. These enzymes degrade myofibrillar and cytoskeletal proteins troponin T, tropomyosin, desmin, nebulin, titin, and connectin (Bower et al., 2010; Lawrie and Ledward, 2006). Muscle structure changes such as destruction of Z-line structure, loss of integrity at the Z-line and I band junction, and the attachment of the Z-line and M-line to the sarcolemma is disrupted (Bowker et al., 2010; Sayas-Barbera et al., 2010; Schreurs, 2000). The rate of pH decline and the temperature at which it occurs influences the postmortem protein proteolysis. The amount of lactic acid remaining in the muscle from accelerated glycolysis prior to and following death of the animal decreases the pH of the muscle tissue and renders the meat tough (Khan, 1970). A faster decline in pH at a high temperature will render the calpains responsible for protein degradation inactive resulting in tougher meat (Dransfield and Sosnicki, 1999; Dransfield, 1994). Thus, an aging or storage period with manipulated conditions such as pH, temperature, and enzyme activity can improve tenderness (Koohmaraie, 1996; Rees et al., 2002).

The amount of connective tissue and the solubility of it impacts meat tenderness and texture (Koohmaraie and Geesink, 2006). Connective tissue is fibrous in nature and primarily composed of collagen fibers. There are three levels of organization of connective tissue in muscle tissue including the epimysium, perimysium, and endomysium. The epimysium is a thick layer of connective tissue around the whole muscle while the perimysium is a thinner layer surrounding muscle bundles and the endomysium surrounds individual myofibers (Coggins, 2012; Swatland, 1994). In beef, most of the collagen content resides in the perimysium ranging from 54 to 98 percent. Collagen content of the endomysium is 24 to 42 percent, while the epimysium contains around 13 to 24 percent collagen in beef muscles (Aberle et al., 2001). Extensive research has been conducted proving that muscles with more connective tissue are less tender when compared to muscles with less connective tissue (Aaslyng, 2002). Connective tissue in poultry is primarily seen in spent hens due to increased cross-linking of connective tissue at older ages (Vaithiyanathan et al., 2008). It has been reported in poultry that collagen is soft from young birds and rigid from old birds (Nakamura et al., 1975). Traditionally, collagen content has not been an issue with young poultry due to early slaughter ages for meat broilers, but with increasing growth rates and recent muscle myopathies collagen content in young poultry is changing (Velleman, 2015).

Tenderness of meat can also be altered with various cooking methods. Lyon and Lyon (1990a) reported that cooking method resulted in significant differences in texture attributes of poultry meat. Generally, cooking makes connective tissue more tender by softening the collagen in the muscle tissue. The softening is due to breaking in the perimysium at 20 to 50^{o}C and the loss of the strength in the collagen fibers in the perimysium (McCormick, 2009). Longer cook time at a lower temperature decreases the toughness of the meat and is recommended for muscles with higher amounts of connective tissue (Lawrie and Ledward, 2006). Powell et al (2000) noted that during cooking, connective tissue in the muscle is influenced by the heating rate and end-point temperature. Another study conducted by Combes (2003) reported that mechanical tenderness measurements were drastically affected by cooking temperature resulting in increased meat toughness with increased cooking temperature. It is important to note a balance in cooking time and temperature due to collagen gelatinizing at high temperatures followed by a toughening of the myofibrillar proteins for acceptable meat tenderness.

D. COLLAGEN AND MEAT QUALITY

Collagen is the most abundant protein in the body and is the primary protein of all connective tissue proteins (Owens and Meullenet, 2010). Collagen molecules are bound together by molecular cross-links that provide structure and strength (Weston et al., 2002). Each collagen molecule, known as tropocollagen, is made up of three polypeptide chains that are coiled around each other to create a triple helix (Kerth, 2013b; Owens and Meullenet, 2010). The cross-links in collagen form between and within the tropocollagen triple helices and give the strength of the collagen in meat (Kerth, 2013b). When the age of an animal increases there is a greater amount of collagen cross-links than in younger animals and those cross-links become insoluble in mature animals leading to an increase in meat toughness (Coggins, 2012; Nakamura et al., 1975). The mature cross-links, rather than the total amount of collagen, are key to collagen-related toughness (Weston et al., 2002). However, the amount of collagen cross-links is irrelevant in young broilers because the cross-links have not formed yet and the collagen present is soluble and will melt when cooked (Owens and Meullenet, 2010). It is important to note that some current production practices require broilers to be grown longer and collagen content could be altered.

A major change in the collagen structure during heating is the alteration from an organized quarter-stagger parallel pattern into a random pattern. This change causes shortening of the collagen and a rubber-like texture (Lepetit, 2008). The shrinkage of collagen above 60°C gives connective tissue the elastic characteristic and influences meat tenderness (Lepetit, 2007). A positive effect is a decrease in elasticity, while a negative effect is an increase in muscle fiber resistance due to forced contraction. A balance between these two occurrences is crucial for meat tenderness (Lepetit, 2007).

QUALITY DEFECTS AFFECTING POULTRY MEAT QUALITY

Quality measurements differ from the beginning of the live bird to progression to processing of the carcass and at the end when the consumer receives the product (Moran Jr., E.T., 1999). Negative effects of higher growth rates can include muscle abnormalities leading to abnormal muscle fibers, paler breast meat, reduced water-holding capacity, and higher pH values (Dransfield and Sosnicki, 1999; Duclos et al., 2007; Petracci et al., 2013b). Genetic selection along with improved management techniques and nutrition, has given the poultry industry increased growth rates and breast-yield, but it is at the expense of meat quality traits and abnormalities such as PSE-like meat, and in recent times white striping, and woody breast (Anthony, 1998; Lorenzi et al., 2014; Petracci et al., 2015). Poultry production factors from "farm-to-fork" have an impact on the chemical, physical, and structural changes in muscle tissue as it is converted to meat (Northcutt and Buhr, 2010).

A. PSE-LIKE CONDITION

Pale, soft, and exudative (PSE) meat is known for its pale color, exudative appearance, low pH values, poor water-holding capacity and soft texture (Sams and McKee, 2010; Shen et al., 2009). The myopathy was first recognized in the swine industry and later acknowledged that the cause of PSE comes from a genetic mutation of the ryanodine receptor (RyR) that regulates the fluctuation of calcium in the muscle tissues in pigs selected for heavy muscle characteristics (Fuji et al., 1991). In the mutation, there is no regulation of calcium and it floods the sarcoplasmic reticulum with calcium increasing the rate of muscle metabolism (Strasburg and Chiang, 2009). Skeletal muscle of poultry has two RyR isoforms that play a significant role in regulating calcium from the sarcoplasmic reticulum, which could result in implications such as PSE-like meat similar to those in PSE pork (Strasburg and Chiang, 2009). Previous research suggests that there is a difference in gene expression between normal and PSE-like turkey including the calcium signal pathway supporting abnormal calcium regulation and lower expression of genes altering oxidative metabolism resulting in rapid postmortem metabolism (Malila et al., 2013; Sporer et al., 2012). Fast postmortem glycolysis causes a build-up of lactic acid in the muscle earlier than usual, and thus resulting in a rapid decrease in pH (Shen et al., 2009). The rapid rate of glycolysis in postmortem muscle generates significant heat in the animal and increases internal temperature of the animal. The low pH from lactic acid accumulation and the heat that is unable to dissipate causes protein denaturation of not only myosin, but also actin denaturation attributing to poor meat quality traits (Li et al., 2015; Shen et al., 2009; Sosnicki et al., 1998). The reduced protein functionality causes poor water-holding capacity resulting in excess purge and poor product binding in further processed products (Sams and McKee, 2010). The color of the meat is pale due to more light being reflected from the open muscle structure of PSE meat (Barbut, 2002b; Swatland, 2008). Studies have confirmed that the rate of postmortem glycolysis in PSE turkey was twice as fast as normal turkey muscle and poultry muscle affected with PSE shows an increase in fiber size and calcium flooding and permanent myosin insolubility due to low pH values and high temperatures results in PSE turkey breast muscle (Pietrzak et al., 1997; Sayas-Barbera et al., 2010). Research has shown a disturbance of calcium functions in muscle leading to growth-related muscle myopathies could be connected to genetic selection in poultry for traits such as increased growth rate, altered body frame, and improved feed conversion, which is a similar scenario to genetic traits found in PSE pork (Anthony, 1998; Mitchell, 1999).

PSE meat texture and integrity is severely compromised when cooked such as forming soft gels and losing up to 66 percent more moisture than normal chicken breast fillets (Zhang and Barbut, 2005; Padilla, 2010). A previous study reported that PSE broiler breast meat resulted in lower protein extraction with less heavy myosin chains, larger intracellular spaces among the endomysium and perimysium, lower yield, and higher shear force values when compared to normal and dark, firm, and dry (DFD) meat (Barbut et al., 2005; Alarcon-Rojo, 2010). Short-term procedures implemented to prevent PSE-like conditions in poultry include reducing antemortem stress and better chilling methods and identifying gene markers in when selecting traits of poultry in the long-term (Barbut et al., 2008). Sams and Alvarado (2004) investigated chilling rates and concluded that slower chilling rates resulted in lower pH values, meat pale in color, increased cook loss, and lower gel strength in turkey breast muscle. Molette et al. (2003) observed higher drip loss and cook loss and lower protein extraction in turkey breast muscles held at 40°C when compared to 4°C and 20°C resulting in PSE-like characteristics. PSE-like meat in the poultry industry represents 5-40 percent of the meat that is produced and with further-processed products, a loss of $200 million to the turkey industry per year is due to PSE-like meat (Owens et al., 2009). Previous reports indicated 40% of turkey breast fillets and 47% of broiler breast fillets selected for being pale in color exhibited poor water-holding capacity suggesting PSE-like meat makes up a large portion of commercial turkey and broiler production (Owens et al., 2000; Woelfel et al., 2002).

B. WHITE STRIPING MYOPATHY

White striping is a muscle myopathy referring to white striations of varying degrees that run parallel to the muscle fibers of breast fillets and thighs of heavier broilers (Kuttappan et al., 2012a; Kuttappan et al., 2012c). Based on the varying degrees of the white striations, fillets can be grouped as normal (NORM), moderate (MOD), or severe (SEV) in white striping (Kuttappan et al., 2012c; Kuttappan et al., 2013c). Research has suggested that increasing the growth rate of broilers resulting in larger body weights, heavier breast fillet weights, larger cranial fillet thickness, and higher average daily gain (ADG) confirms higher occurrences of white striping in broiler breast fillets (Lorenzi et al., 2014; Kuttappan et al., 2012a,b; Kuttappan et al., 2013a; Russo et al., 2015). Kuttappan et al. (2013b) reported that broiler breast fillets severely affected with white striping showed a rise in levels of serum enzymes indicating muscle damage is a factor in this degenerative muscle myopathy. Broiler breast meat affected by white striping negatively influences visual acceptance by consumers, nutritional components of the meat, and processing characteristics (Lorenzi et al., 2014). As the degree of white striping increases, the consumer acceptance rate based on visual evaluations of the fillet decreases significantly because of the dislike of the fatty appearance associated with white striping (Kuttappan et al., 2012c). Proximate analysis results stated an increase in fat content, decrease in protein content, and an increase in collagen content as the severity of white striping increased resulting in a higher calorie content and lower nutritional value in broiler breast fillets (Kuttappan et al., 2012a; Kuttappan et al., 2013c; Petracci et al., 2014). The implications of white striping on meat quality traits during processing have been investigated and confirmed as the degree of white striping increases there is an increase in cook loss, a decrease in marinade uptake, an increase in pH value, and an increase in b* value (Kuttappan et al., 2013a; Petracci et al., 2013a). Protein functionality is also decreased due to a reduced amount of myofibrillar and sarcoplasmic proteins and a high amount of stromal proteins in fillets with the white striping myopathy (Mudalal et al., 2014). Even though a decrease in protein functionality is observed in PSE meat, the increased b* value and pH values indicate that fillets affected by the white striping muscle myopathy are not pale in color and are different from the PSE condition (Mudalal et al., 2014; Petracci et al., 2013a). The negative quality attributes are likely related to the absence of myofibrillar proteins rather than a denaturation of proteins observed in PSE meat.

C. WOODY BREAST MYOPATHY

Woody or wooden breast is a recent muscle myopathy characterized by muscle pale in color with substantial hard and rigid areas generally seen with the white striping muscle myopathy throughout the entire *Pectoralis major* muscle in broilers (Bailey et al., 2015; Sihvo et al., 2014). In severe cases of woody breast, characteristics observed in the fillets include a pale color, hemorrhaging, and a viscous exudate on the surface (Bailey et al., 2015). Currently, broiler breast fillets affected with woody breast are subjectively detected by palpating the *Pectoralis* *major* muscle (Sihvo et al., 2014; Tijare et al., 2016). Objective methods to assess wood breast are recently being investigated as a repeatable and reliable measurement by using compression force, shear force, and cook loss as predictors, which indicate compression and shear values of raw fillets increased as severity of woody breast increased (Bowker et al., 2016; Schrader et al., 2016; Sun and Owens, 2016b). An increase in growth rate based on hypertrophy muscle growth has been suggested as a predisposing factor for woody breast due to increased muscle fiber diameter, abundant muscle fiber degeneration, larger fillet weights and an increased cross-sectional area of the *Pectoralis major* muscle (Petracci and Cavani, 2012; Velleman, 2015; Zotte et al. 2014). Gender of the broiler also affects the occurrence of the woody breast condition, doubling from females to males (Trocino et al., 2015). Histology samples of severely affected broiler breast fillets indicated a considerable degree of connective tissue accumulation replacing degenerated muscle fibers separated and round in shape due to muscle fiber necrosis, fibrosis, and muscle fiber regeneration (Bailey et al., 2015; Sihvo et al., 2014; Velleman and Clark, 2015). Muscle structure for woody breast fillets show an increase in sarcomere length and gravimetric fragmentation index measurement indicating degradation of the muscle fiber (Sun and Owens, 2016b). Soglia et al. (2015) reported that fillets affected with both woody breast and white striping showed higher moisture, fat, and collagen levels with lower amounts of protein accompanied by a higher pH value and lower water-holding capacity. Recent research has suggested that fillets severely affected have a lower activity of glycolysis and gluconeogenesis, which may be the reason for higher pH values (Kuttappan et al., 2016). Woody breast fillets exhibit lower water-holding capacity during storage and cooking, increased cook loss, and lower marinade uptake, which may be attributed to muscle degeneration and the replacement of myofibrillar proteins actin and myosin with connective tissue in affected broiler breast fillets

(Zotte et al., 2014; Mazzoni et al., 2015; Mudalal et al., 2015). Higher compression and shear force values are also exhibited in broilers with increasing severity of woody breast when compared to normal fillets (Brambila et al., 2016; Sun and Owens, 2016b; Trocino et al., 2015). Sensory studies have shown that fillets affected by woody breast show differences in characteristics such as springiness (Brambila et al., 2016). It has been concluded that the emergence of white striping and woody breast is associated with higher percentages of downgrading poultry meat into further processed items (Petracci et al., 2015). However, the effects on storage of fillets affected with woody breast could be favorable to processors with recent studies showing that compression and shear force values decrease for all degrees of woody breast during short-term storage (Brambila et al., 2016; Sun and Owens, 2016a, b). However, the increased collagen content in woody breast (Velleman, 2015), would not change due to aging, suggesting that quality attributes may remain unchanged.

SENSORY EVALUATION OF POULTRY MEAT ATTRIBUTES

Sensory analysis is used to measure the characteristics of a product through the human senses and sometimes in combination with instrumental methods (Nute, 1999; Guardia et al., 2010). People measure appearance, aroma/color, taste, texture, and sound while instruments measure physical or chemical characteristics of a product that can relate to the sensory experience (Lyon et al., 2010). The challenging aspect of using sensory testing is the downfall of variability from using people as testing instruments (Bratcher, 2013). Therefore, it is important to minimize variability in all other areas of sensory testing when conducting descriptive analysis or consumer panels. Instrumental measurements used to assess the sensory experience do not fully capture human perception, which make data analysis from descriptive and consumer sensory panels very valuable (Bratcher, 2013).

Descriptive analysis is a type of sensory evaluation usually using 8-12 trained panelists to agree on and determine the meaning of the qualitative and quantitative aspects of product attributes and the intensity of the attributes, generally being related to flavor and texture profiles using reference standards (Lawless and Heymann, 2010; Lyon et al., 2010; Meilgaard et al., 2007b). The Arthur D. Little Company developed the first flavor profile method in 1949 to describe and quantify the attributes (Lyon et al., 2010; Meilgaard et al., 2007b). In the 1960s General Foods Research introduced a way to assess texture characteristics from the first bite to after swallowing (Lyon et al., 2010). A texture profile method specifically for broiler breast meat was developed by Lyon and Lyon (1990a), which was later expanded to include 20 attributes measured on 0-15 numerical line scales for intensity of each attribute. Trained panelists with a meat science background concentrate more on texture and flavor because appearance and aroma characteristics are controlled (Bratcher, 2013). Meat descriptive analysis has been described and standardized by the American Meat Science Association (AMSA) providing for whole-muscle meat samples the primary descriptive attributes include juiciness, muscle fiber tenderness, connective tissue amount, overall tenderness, and flavor intensity (Miller, 1994). Descriptive analysis data results are applicable to research and professional settings to provide parameters to describe all of the sensory characteristics that can be detected in a product (Meilgaard et al., 2007b).

Consumer panels use untrained panelists to assess consumers’ preferences and acceptability of a product utilizing qualitative tests such as focus groups and quantitative tests such as preference and acceptance tests (Lyon et al., 2010). Humans provide information on texture characteristics that instruments cannot such as mouthfeel, juiciness, toothpack, moisture, and changes in texture while chewing (McKee et al., 2012). Consumer panels are growing in the meat industry as researchers and companies alike try to identify and put a value to changing consumer trends (Cox, 2013). The panelists chosen should represent the population of people who consume the product as current or potential customers (Meilgaard et al., 2007a). When measuring consumer responses for acceptability and preference, using intensity, hedonic, or "just about right" scales to obtain consumer results with the option to relate to descriptive analysis data (Meilgaard et al., 2007a). The hedonic scale is a reliable measurement for the degree of liking for a product, which is most commonly used as a 9-point scale ranging from like extremely to dislike extremely (Curtis, 2013). There are nine points of equal distance with descriptors at each point showing the panelist that the middle is a neutral evaluation with the extremes at each end of the 9-point hedonic scale (Cox, 2013). Since each point on the scale is equally spaced it is straightforward to quantify with a variety of statistical analyses (Cox, 2013). The just-about-right scales allow an assessment of the intensity and level of appropriateness of the product attributes perceived by the panelists (Meilgaard et al., 2007a). A study conducted by Cavitt et al. (2005) found a relationship between instrumental tests and descriptive and consumer sensory analysis to predict tenderness in cooked broiler breast meat on an intensity of tenderness scale. The instrumental measurements were calculated for the tenderness category consumers perceived ranging from "extremely tough" to "extremely tender" (Cavitt et al., 2005; Lee et al., 2008c). A combination of instrument analysis, descriptive sensory analysis, and consumer panel evaluations are important in assessing tenderness of meat (Cavitt et al., 2005).

INSTRUMENTAL TEXTURE PROFILE ANALYSIS IN POULTRY MEAT

Texture is described as being the most important attribute of poultry meat and for this reason extensive research has been conducted on instrumental methods to evaluate the structure of muscle fibers and in turn measure meat tenderness (Lyon et al., 2010). Instrumental methods to evaluate tenderness in cooked poultry meat include the Warner-Bratzler shear force method, Allo-Kramer shear method, Meullenet-Owens Razor Shear (MORS) test, and instrumental Texture Profile Analysis (TPA) data (Lyon et al., 2010).

Shear tests cut perpendicularly through the fibers of a muscle sample with a single blade or multiple blades to measure the total force needed to cut through the sample, which will relate a value back to the tenderness or toughness of the meat sample (Lyon et al., 2010). The Warner-Bratzler method and Allo-Kramer test both use cut samples of cooked poultry meat, however the primary difference is that the Warner-Bratzler method uses a single, rectangular blade while the Allo-Kramer test uses multiple blades to shear the meat sample (Barbut, 2002a; Lyon et al., 2010). The MORS method is more efficient for measuring poultry meat tenderness than the previously mentioned methods because it may be performed on intact muscle rather than small cut samples (Lyon et al., 2010). The MORS method uses a single razor blade to cut the sample in four different locations and shear force and energy are calculated on a texture analyzer (Lyon et al., 2010). Another method, called BMORS, is a blunt version of MORS to better differentiate tough cuts of poultry meat and has been determined as a reliable method when testing tough meat (Lee et al., 2008b; Lyon et al., 2010). In a study by Cavitt et al. (2004), it was suggested that the razor blade shear test, which is a general term for the MORS method, was a better predictor of descriptive sensory analysis data for attributes such as initial hardness, chewdown hardness, cohesiveness, cohesiveness of mass, and number of chews to swallow than the Allo-Kramer shear test.

The instrumental TPA method is a sensitive and versatile compression test known for providing multiple texture attributes due to the complexity of texture in food (Lyon et al., 2010). The sample used for TPA is a circular core obtained from the cooked meat sample which is contacted twice by a metal plate with a calculated compression force to analyze attributes such as hardness, springiness, cohesiveness, and chewiness (Barbut, 2002a; Lyon et al., 2010). Previous studies reported that TPA data were highly correlated with sensory scores for attributes such as hardness and springiness that relate to texture showing a relationship between the two methods of evaluating texture (Lyon and Lyon, 1990a; Meullenet et al., 1998). Research has also suggested that when comparing TPA to the Warner-Bratzler shear method to sensory characteristics, the TPA data better explains and predicts sensory texture than the Warner-Bratzler shear method (Caine et al., 2003; Huidobro et al., 2005). Lee et al. (2008a) investigated a laser air puff system to evaluate poultry meat tenderness by using pressurized air to deform the surface of the fillet, which resulted in the potential of tenderness classifications. More recent research has shown a noninvasive deformation test may be useful to assess the tenderness of cooked broiler breast meat by tenderness levels by using cylindrical probes on a texture analyzer to measure deformation of the fillet (Lee et al., 2015).

Many studies have revealed that instrumental methods can predict tenderness of meat that correlate to sensory analysis data for texture attributes. Xiong et al. (2006) used a consumer panel with 74 panelists to evaluate texture attributes as well as the Allo-Kramer shear test, Warner-Bratzler shear test, and razor blade method resulting in a high correlation between the sensory and all instrumental method results. Yancey et al. (2010) reported that the relationship of instrumental tenderness measurements were higher when asking panelists to evaluate tenderness than when evaluating overall impression of the samples. It is important to note that certain instrumental methods are better at predicting specific texture attributes than others and should be taken into consideration. Research conducted by Luckett et al. (2014) suggested that the BMORS test performed well in predicting hardness and fibrous, while TPA proved to be the best instrument to predict springiness in poultry deli meat. It is essential to have objective instrumental methods to put a value to the sensory results provided by humans to understand quantitatively what is considered “tough” or “tender” when evaluating poultry meat. Lyon and Lyon (1990b) conducted a similar study correlating Warner-Bratzler and Allo-Kramer shear values that would be rated in the tender range to the acceptable texture category presenting a relationship between objective measurements of shear tests to sensory responses to tenderness.

NEED FOR RESEARCH

The woody breast muscle myopathy is an emerging issue in the past few years and is causing an increased concern for the poultry industry and consumers alike. Economic losses from downgrading broiler breast meat and unfavorable comments from consumers is a powerful problem. C.M. Owens has observed complaints relating to texture from foodservice customers have put pressure on processors to sort/grade breast fillets (University of Arkansas, Fayetteville, Arkansas, personal communication). However, there is no published data on the consumer acceptability of woody breast.

It is known that the visual acceptance of woody breast by consumers is low, but the consumer acceptability of the texture of broiler breast fillets when cooked is not well understood. Descriptive and consumer sensory panels can give researchers an understanding of advanced characteristics of a product and the perception and acceptability of a product by average consumers. It is important to learn how to describe the unique texture of fillets affected with the woody breast condition and how well, if at all, consumers accept the characteristics of cooked fillets affected with woody breast. The objective of this study was conducted with descriptive and consumer panels to determine texture attributes of the woody breast condition to describe its unique texture and examine if this muscle myopathy negatively impacts the acceptability of chicken breast fillets of consumers.

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3. DESCRIPTIVE AND CONSUMER SENSORY ANALYSIS OF WOODY BROILER BREAST MEAT

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ABSTRACT

Recently, broiler breast fillets have been impacted by a condition known as woody breast resulting in a distinct hardness of raw fillets. Woody breast can vary in severity from normal (NORM) to severe (SEV). In 2 experiments, NORM and SEV woody breast fillets were used for descriptive and consumer sensory analysis. The descriptive panel (n=9 trained panelists) was conducted to obtain a flavor and texture profile of 60-d broiler breast fillets, whereas the consumer panel (n=74 consumers) was designed to assess consumer acceptance of 63-d broiler breast fillets. In both panels, non-marinated breast fillets were cooked to an internal temperature of 74ºC in aluminum foil covered pans. Samples were held at either 60ºC or 3ºC prior to serving and 2 HOT (60ºC) and 2 COLD (3ºC) 2.54 x 2.54 cm cubes of each treatment were presented to panelists, resulting in 4 treatment combinations: HOTNORM, COLDNORM, HOTSEV, and COLDSEV. The descriptive panel used standard flavor and meat texture lexicons. Consumers expressed their overall liking for impression, flavor, and texture on a 9-point hedonic scale (9 = like extremely to 1 = dislike extremely). For the consumer panel, the ballot included an open-ended comment section to assess individual panelist likes and dislikes. Results of the descriptive panel indicated that COLDSEV fillets had greater ($P<0.05$) hardness than HOTSEV, whereas COLDNORM samples showed less ($P<0.05$) blood serum/metallic aromatics than all other samples. Both NORM and SEV samples had greater ($P<0.05$) initial moistness at a hot temperature. Results of the consumer panel analysis indicated higher ($P<0.05$) hedonic scores for overall impression and chicken texture for NORM fillets than SEV fillets at both holding temperatures. Chicken texture Just-About-Right (JAR) results indicated higher ($P<0.05$) scores for HOTNORM than HOTSEV and chicken juiciness JAR results showed higher ($P<0.05$) scores for COLDNORM compared to COLDSEV fillets. Open ended comments indicated more dislike

comments related to texture in the SEV than NORM breast meat. Results suggest that severe woody breast negatively affects consumer acceptability in terms of overall impression and texture.

INTRODUCTION

The demand of boneless breast meat in the United States is increasing at a steady rate and continues to be a top protein source for consumers (National Chicken Council, 2016b). The pressure to meet the high consumer demand has propelled the poultry industry to increase growth rate, resulting in improved feed efficiency and larger breast fillets. Compared to 50 years ago, broilers are currently reared to a market weight twice the size in half the time, which puts more stress on the bird (Barbut et al., 2008; Zuidhof et al., 2014). The consumption pattern of broiler meat has also changed in that time, as consumers are now primarily buying products that are further processed and cut-up parts (Barbut et al., 2008). The 2015 forecast of marketing broiler meat suggests that 49% of the broiler market is further processed and 40% is cut-up parts (National Chicken Council, 2016a). The change in consumption pattern to further processed products and cut-up parts suggest that meat quality attributes, including water-holding capacity and texture of the product, has become even more essential than ever before.

The rapid growth rate that the poultry industry is currently experiencing is known to affect the meat quality of broiler breast meat, which is most popular among consumers. In recent years, myopathies such as white striping and woody breast have been reported, which negatively affect the appearance and other meat quality attributes of broiler breast meat (Kuttappan et al., 2012a; Petracci et al., 2015; Soglia et al., 2015; Zotte et al., 2014). White striping is characterized by having white striations parallel to the fibers accompanied by infiltration of lipid components and connective tissue (Kuttappan et al., 2012a; 2013a,b). Woody breast is described as hard, outbulging, and pale fillets that are often seen with white striping along with increased interstitial connective tissue and exhibit low meat quality properties (Sihvo et al., 2014; Mudalal et al., 2015; Tijare et al., 2016). Trocino et al. (2015) reported that males exhibited higher incidences of woody breast fillets, and fillets affected with woody breast have greater cook losses and Allo-Kramer shear values.

White striping and woody breast change the meat quality attributes of the further processed products that consumers typically purchase, which in turn causes huge economic losses for the industry. It is critical to assess how consumers perceive broiler breast meat that is affected with woody breast and the acceptability of those products. Therefore, descriptive and consumer sensory panels were used to define texture and flavor attributes of broiler breast fillets affected with woody breast, as well as consumer acceptability of normal breast fillets compared to breast fillets severely affected with woody breast served hot and cold to mimic various food service settings.

MATERIALS AND METHODS

A. DESCRIPTIVE SENSORY PANEL

Fillets from a common strain of broilers typically found in industry were processed at 60 days of age using an inline system at a commercial processing plant. Birds were aged 2 h postmortem before deboning, and categorized as either normal (NORM) or severe (SEV) woody breast condition as described by Tijare et al. (2016). It is important to note that fillets were heavily affected by white striping as well. At 24 h postmortem, deboned breast fillets were stored frozen at 1ºC. Fillets were allowed to thaw at 4ºC for 12 h before cooked to 76ºC to ensure a safe internal temperature of non-marinated fillets. Fillets were cooked at 176ºC in a convection oven in aluminum lined and covered pans with raised wire racks. The internal end point temperature was verified using a digital thermometer before the fillets were taken out of the convection oven. After cooking, fillets were cut into 2.54 x 2.54-cm cubes. Treatments to evaluate included samples held at either 60ºC (HOT) or 4ºC (COLD) prior to serving to represent an array of products served in the marketplace. Fillets used for 4ºC treatments were cooked first to allow time for cooling. After cooking 4ºC treatments, the fillets were cut and cooled for 30 minutes prior to serving. Fillets for 60ºC treatments were cooked and cut last. Prior to serving 60ºC treatments, the cut samples were held for a rest period of 10 minutes. Each panelist received two cubes from each of the 4 treatments in soufflé cups with water and soda crackers to rinse their palette. Treatments included NORM fillet served HOT (HOTNORM), NORM fillet served COLD (COLDNORM), SEV fillet served HOT (HOTSEV), and SEV fillet served COLD (COLDSEV).

Sensory analysis was performed using a meat-texture descriptive panel of 9 trained panelists with long standing experience of about 20 yr, at the University of Arkansas Sensory Service Center. The panelists took part in a 3-h orientation training session to familiarize themselves with the 2 categories of fillets and to evaluate the descriptors from the lexicons used for repeatability and consistency similar to Lyon and Lyon (1998) and Cavitt et al. (2004). The descriptive panel used standard flavor and meat texture lexicons to obtain texture and flavor profiles of the treatments in two replications. The texture attributes (Table 1) evaluated include a partial compression attribute of springiness, first bite/chew characteristics (initial moistness, cohesiveness, and hardness), chewdown characteristics (cohesiveness of mass, hardness of mass, and fibrous between teeth), and residual characteristics of toothpack and loose particles. The flavor attributes (Table 2) evaluated include the basic tastes of sweet, salt, sour, and bitter, whereas aromatic attributes (Table 2) included cooked chicken, brothy, warmed-over/freezer burnt, blood serum/metallic, oxidized/cardboard, and barnyard/dirty/feedy, as well as the feeling factors of astringent and metallic. All intensities for each attribute were presented on a 15-point scale, with references assigned for comparison of intensities to the breast fillet sample.

B. CONSUMER SENSORY PANEL

A strain of high breast-yielding broilers with an average live weight of 4.62 kg were processed at 63-d of age using a commercial in-line system with electrical stunning (11 V, 11mA for 11 sec), scalding (2 min at 53.8°C), a commercial defeathering system, and manually eviscerated (Mehaffey et al., 2006). To chill the carcasses to an endpoint temperature of 4°C, a carcasses were placed in a pre-chill at 12°C for 15 min, followed by chilling at 1°C for 90 minutes in an immersion chiller, with frequent manual agitation. Following chilling, carcasses were aged for 2 h on ice in a walk-in cooler at 4°C until deboning.

After deboning, the *Pectoralis major* muscle was scored for white striping using categories of normal (0), moderate (1), and severe (2) in accordance to Kuttappan et al. (2012b) along with an extreme (3) category (described as having striations greater than 3 mm throughout the whole fillet). Whole breast fillets were also scored and classified into two groups of severity of woody breast including normal (NORM) and severe (SEV) degrees of woody breast based on criteria described by (Tijare et al., 2016). One person performed the subjective scoring to keep consistency in scoring values. Following the scoring classification, whole fillets selected for sensory analysis were vacuum packaged in plastic bags and stored at 4°C until 24 hours postmortem, when fillets were split into halves and taken to the University of Arkansas Sensory Service Center.

A total of 74 consumers from the Fayetteville, AR area were recruited based on consumption of broiler breast meat at least 2 to 3 times per month. Non-marinated fillets were cooked in aluminum covered and lined pans in an air convection oven preheated to 176°C to an internal endpoint temperature of 76°C (Cavitt et al., 2004). The internal endpoint temperature was verified using a digital thermometer before the fillets were taken out of the convection oven.

After cooking, fillets were cut into 2.54 x 2.54-cm cubes. Treatments to evaluate included samples held to either 60ºC (HOT) or 4ºC (COLD) prior to serving. Fillets used for 4ºC treatments were cooked first to allow time for cooling. After cooking 4ºC treatments, the fillets were cut and cooled for 30 minutes prior to serving. Fillets for 60ºC treatments were cooked and cut last. Prior to serving 60ºC treatments, the cut samples were held for a rest period of 10 minutes. Each consumer received two samples of each treatment combination (HOTNORM, COLDNORM, HOTSEV and COLDSEV) in soufflé cups with water and soda crackers to rinse their palette. Each consumer reported their overall liking on a 9-point hedonic scale (9 = like extremely; 1 = dislike extremely) for overall impression, flavor, and texture. Questions regarding the appropriateness of each treatment were also posed to consumers based on a 5-point Just-About-Right (JAR) scale for tenderness, juiciness, and overall flavor. The ballot also included an open-ended comments section to determine any other likes and dislikes of the treatments.

Sensory data was subjected to analysis of variance using the mixed models procedure of SAS (2014) with panelist treated as a random effect. Least square means were separated statistically with the PDIFF option of SAS. Penalty analysis was conducted to evaluate the mean drop (difference) in the overall texture, juiciness, and flavor acceptability between consumer groups who found texture, juiciness, or flavor to be Just-About-Right and the group who found a treatment to be too tough, too dry, or too weak of a flavor. Penalty analysis is used to determine the impact of sensory attributes at a less than optimal level (scores above and below the JAR score) (AMSA, 2015). Consumers are divided into three groups (JAR, too weak, too strong). The average liking scores were calculated for all three groups as well as the percentage of consumers represented in each group. To conclude an attribute is at a less than optimal level, a minimum of 20% of consumers are needed in the "too weak" or "too strong" categories (AMSA, 2015). The total penalty scores are calculated by subtracting the average score for the JAR group from the mean scores of the “too weak” or “too strong” groups.

RESULTS AND DISCUSSION

Texture attributes described in the descriptive sensory analysis demonstrated greater ($P<0.05$) initial moistness for both NORM and SEV woody breast served HOT than NORM and SEV fillets served COLD (Table 3). An increase ($P<0.05$) in hardness was reported for COLDSEV fillets when compared to the HOTSEV fillets (Table 3). There were no impacts on flavor attributes during the descriptive sensory analysis (Table 4), however there was higher ($P<0.05$) blood serum/metallic aromatics associated with all samples when compared to COLDNORM fillets as shown in Table 5. The results of the descriptive sensory analysis signify the role of connective tissue in texture and aroma attributes with the woody breast muscle myopathy as described by recent research (Sihvo et al., 2014; Soglia et al., 2015; Velleman and Clark, 2015).

Consumer panelists rated HOT fillet samples greater ($P<0.05$) for overall impression, flavor, and chicken texture than COLD fillets, regardless of woody breast category (Table 6). Overall impression and chicken texture results indicated higher ($P<0.05$) scores for NORM fillets when compared to SEV fillets at both hot and cold temperatures and higher ($P<0.05$) for hot samples than cold samples (Table 6). A higher ($P<0.05$) overall flavor was reported for HOTSEV fillets than COLDSEV fillets (Table 6). Results for the chicken texture Just-About-Right (JAR) sensory attribute indicated higher ($P<0.05$) scores for HOTNORM fillets when compared to HOTSEV fillets. WB category and serving temperature had an impact on chicken juiciness JAR with higher ($P<0.05$) scores for COLDNORM fillets than COLDSEV and higher ($P<0.05$) scores for HOTSEV fillets when compared to COLDSEV fillets (Table 6).

Figure 1 represents the distribution of consumer group who found texture, juiciness, and flavor of the samples to be Just-About-Right and the consumer groups who found the texture, juiciness, and flavor of the samples to be too strong or too weak. As shown in Figure 1, the consumer group who found the texture, juiciness, and flavor to be too weak represented more than 20% of the responses for those attributes, which is the minimum requirement to run penalty analysis (AMSA, 2015). Figure 2 presents the penalty analysis results that were conducted to gain an understanding of the level of appropriateness for certain attributes among consumers. As previously stated, the texture, juiciness, and flavor exhibited a large amount of consumers who found those attributes to be too tough, too dry, and too weak. The calculated total penalties for texture, juiciness, and flavor all ranged from 0.63 to 0.71units indicating a high tier penalty. Total penalties units can be categorized into different tiers to improve overall liking if the specific attribute is brought to JAR. A low tier penalty indicates no changes are needed, a mid-tier penalty suggests consider changing, and high tier penalty indicates a must change (AMSA, 2015). This suggests that WB may impact the texture, juiciness, and flavor of the fillets.

The percentage of overall impression in the dislike categories for the SEV fillets were greater than that for NORM fillets (Figure 3), and more specifically, COLDSEV fillets had a greater proportion of responses in the dislike categories when compared to all other treatments (Figure 5). Consumers had an even higher percent of responses in the dislike categories of the hedonic scale for chicken texture compared to overall impression according to Figure 6. Moreover, COLDSEV fillets had a critical amount of responses in the dislike categories for chicken texture than overall impression (Figure 4). These results suggest that SEV fillets, regardless of serving temperatures, have a greater percentage of responses in the dislike categories. Open-ended comments were counted based on frequency of occurrence for both

NORM and SEV fillets, and SEV fillets tended to receive more negative consumer comments, especially in relation to texture, than NORM fillets, which received more positive comments related to texture. (Table 7).

CONCLUSION

Some descriptive attributes associated with texture and flavor are related to the woody breast muscle myopathy. Some of these attributes may be attributed to serving temperature and unique texture characteristics of severely affected fillets. Consumer sensory results indicate consumers have a lower acceptability of severe woody breast than normal breast in terms of overall impression and texture. . Analysis of open-ended comments section of the consumer sensory responses suggest that the panelists had more dislike comments related to texture than like comments.

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Table 1. Texture lexicon used for analyzing the texture of broiler breast fillets.

Term	Definition	Technique	Reference
Partial compression			
Springiness	The rate at which the sample returns to its original shape.	Compress the sample partially with molars without breaking the sample.	Cream cheese 0.0 Pound cake 2.5 Soft pretzel 5.0 Beef frank 7.5 Wiener 10.5 Gummy bears 15.0
First bite/chew			
Initial moistness	The amount of wetness or moistness felt in the sample after 1-2 bites.	Compress sample with molars 1-2 times only.	Saltine 4.5 Pound cake (12x's) 10.5 Jell-O 14.0 Water 15.0
Cohesiveness	The amount the sample deforms rather than splits apart, cracks, or breaks.	Place sample between the molar teeth and compress fully. May also be done with incisors.	Corn muffin 1.0 Am cheese 5.0 Soft pretzel 8.0 Raisins 10.0 Starburst 12.0 Caramel 13.0 Gum 15.0
Hardness	The force required to compress the sample.	Compress or bite through sample one time with molars or incisors.	Cream cheese 1.0 Egg white 2.5 Am cheese 4.5 Beef frank 5.5 Olive 7.0 Peanut 9.5 Almond 11.0 Life Savers 14.5
Chewdown characteristics			
Cohesiveness of mass	The amount that the chewed sample holds together.	Chew sample with molar teeth up to 15 times and evaluate.	Shoestring licorice 0.0 Carrots 2.0 Mushrooms 4.0 Beef frank 7.5 Am cheese 9.0 Brownie (5x's) 13.0 Dough 15.0 (chew refs 10x's)

Table 1. Texture lexicon used for analyzing the texture of broiler breast fillets.

Term	Definition	Technique	Reference
Chewdown characteristics			
Hardness of mass	The force required to bite through the chewed sample.	Chew the sample up to 15 chews. Form a bolus with the chewed sample and evaluate the force required to bite through the chewed sample.	Cream cheese 1.0 Egg white 2.5 Am cheese 4.5 Beef frank 5.5 Olive 7.0 Peanut 9.5 Almond 11.0 Carrots 11.0 Life Savers 14.5 (Do not chew refs)
Fibrousness between teeth	The amount of grinding of fibers required to chew through the sample.	Place sample between molars and chew 10-12 times. Evaluate during chewing.	Apple 2.0 Apricot 5.0 Salami 7.0 Celery 9.0 Toasted oats (4-5) 10.0 Bacon 12.0 Beef jerky 20.0
Residual characteristics			
Toothpack	The amount of product packed into the crowns of your teeth after mastication.	Chew sample 15-20 times, expectorate and feel the surface of the crowns of the teeth to evaluate.	Capt. Crunch (3) 5.0 Heath bar 10.0 None-------------Much)
Loose particles	The amount of particles remaining in and on the surface of the mouth after swallowing.	Chew sample with molars, swallow and evaluate.	Carrot 10.0 None-------------Much)

Table 2. Flavor lexicon used to analyze aroma and flavor attributes of broiler breast fillets.

Term	Definition	Technique	Reference
Basic taste			
Sweet	The basic taste, perceived on the tongue, stimulated by sugars and high potency sweeteners.	Sucrose solutions in spring water.	2% 2.0 5% 5.0 10% 10.0 16% 15.0
Salt	The basic taste, perceived on the tongue, stimulated by sodium salt, especially sodium chloride.	Sodium chloride solutions in spring water.	0.2% 2.0 0.35% 5.0 0.5% 8.5 0.55% 10.0 0.7% 15.0
Sour	The basic taste, perceived on the tongue, stimulated by acids, such as citric acid.	Solutions of citric acid in spring water.	0.05% 2.0 0.08% 5.0 0.15% 10.0 0.20% 15.0
Bitter	The basic taste, perceived on the tongue, stimulated by substances such as quinine, caffeine, and certain other alkaloids.	Caffeine solutions in spring water.	0.05% 2.0 0.08% 5.0 0.15% 10.0 0.20% 15.0
Aromatics			
Cooked chicken	The aromatic associated with cooked white meats like chicken.	Baked/broiled chicken breast.	Intensities based on Universal scale: Saltine 3.0 Applesauce 7.0 Orange juice 10.0 Grape juice 14.0 Big Red gum 16.0
Brothy	Aromatic associated with boiled meat, soup, stock. Weak meaty note.	Chicken stock or soup, beef drippings, stock soup.	Intensities based on Universal scale:
Warmed-over/freezer burnt	Aromatic associated with re-warmed cooked meat after it has been refrigerated for 4-48 hours.	Roasted refrigerated beef, turkey, or pork.	Intensities based on Universal scale:

Table 2. Flavor lexicon used to analyze aroma and flavor attributes of broiler breast fillets.

Term	Definition	Technique	Reference
Aromatics			
Blood serum/metallic	Aromatic taste sensation associated with raw lean meat, cooked blood, serum.	Drippings from raw beef, cooked blood.	Intensities based on Universal scale:
Oxidized/cardboard	The aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging.	Wet cardboard.	Intensities based on Universal scale:

Table 3. Mean descriptive sensory texture scores of normal and woody broiler breast fillets.

	Degree of Woody Breast[1]				
	NORM		SEV		
Sensory Attribute	Hot	Cold	Hot	Cold	SEM
Springiness	3.86	3.77	4.01	4.15	0.33
Initial moistness	5.16[ab]	4.68[c]	5.38[a]	4.87[bc]	0.20
Cohesiveness	5.76	5.90	6.13	6.30	0.33
Hardness	6.20[ab]	6.30[a]	5.76[b]	6.64[a]	0.23
Cohesiveness of mass	4.80	5.06	5.36	5.00	0.18
Hardness of mass	5.23	5.43	5.05	5.47	0.22
Fibrous between teeth	5.70	5.27	5.13	5.62	0.27
Toothpack	2.06	2.23	2.01	2.16	0.24
Loose particles	5.74	5.76	5.25	5.38	0.27

[a-c]Means within a row containing different letters are significantly different (P<0.05).
[1]NORM=normal for woody breast and SEV= severe for woody breast.

Table 4. Mean descriptive sensory flavor scores of normal and woody broiler breast fillets.

	Degree of Woody Breast[1]				
	NORM		SEV		
Sensory Attribute	Hot	Cold	Hot	Cold	SEM
Basic Taste					
Sweet	0.36	0.29	0.42	0.41	0.10
Salt	1.83	1.58	1.82	1.54	0.15
Sour	0.85	0.75	0.75	0.72	0.12
Bitter	0.01	0.002	0.05	0.07	0.07
Flavor					
Cooked chicken	5.90	5.40	6.10	5.29	0.36
Oxidized/cardboard	0.52	0.93	0.70	1.27	0.40
Brothy	1.77	1.90	1.95	1.84	0.36
Blood serum	3.39	2.30	2.86	2.89	0.33
Barnyard/dirty/feedy	0.13	0.38	0.13	0.63	0.24
Freezer burnt/warmed over	1.15	1.02	0.98	1.58	0.33
Astringent	5.61	5.74	5.57	5.65	0.16
Metallic	2.48	2.40	2.47	2.40	0.37

[a-b]Means within a row with different letters are significantly different (P<0.05).
[1]NORM=normal for woody breast and SEV= severe for woody breast.

Table 5. Mean descriptive sensory aroma scores of normal and woody broiler breast fillets.

	Degree of Woody Breast[1]				
	NORM		SEV		
Sensory Attribute	Hot	Cold	Hot	Cold	SEM
Aromatics					
Cooked chicken	4.95	5.27	4.93	5.11	0.22
Brothy	1.81	2.34	2.08	2.24	0.32
Barnyard/dirty	0.86	0.28	0.87	0.60	0.35
Blood serum/metallic	3.24[a]	1.64[b]	2.78[a]	2.48[a]	0.39
Oxidized/cardboard	0.69	0.27	1.00	0.50	0.29
Chicken feathers	0.79	0.20	0.62	0.86	0.30

[a-b]Means within a row with different letters are significantly different ($P<0.05$).

[1]NORM=normal for woody breast and SEV= severe for woody breast.

Table 6. Mean consumer sensory texture scores of broiler breast fillets at different temperatures and woody breast category.

	Degree of Woody Breast[1]				
	NORM		SEV		
Sensory Attribute	Hot	Cold	Hot	Cold	SEM
Overall Impression Hedonic	6.00^{a}	5.16^{c}	5.73^{b}	4.86^{d}	0.23
Overall Flavor Hedonic	5.78^{ab}	5.31^{bc}	5.88^{a}	5.11^{c}	0.23
Chicken Texture Hedonic	5.62^{a}	5.01^{b}	5.15^{b}	4.77^{c}	0.26
Chicken Texture JAR	2.51^{a}	2.28^{ab}	2.27^{b}	2.18^{b}	0.09
Chicken Juiciness JAR	2.59^{a}	2.39^{a}	2.41^{a}	2.16^{b}	0.08
Overall Flavor JAR	2.54	2.42	2.42	2.43	0.10

$^{a\text{-}c}$Means within a row with different letters are significantly different ($P<0.05$).
[1]NORM=normal for woody breast and SEV= severe for woody breast.

Table 7. Categories of terms, examples of comments, and the frequencies of occurrence for each degree of woody breast.

		Degree of woody breast	
Category	Open-ended Comment	NORM	SEV
Texture			
Good texture (+)	Easy to bite, good consistency/mouthfeel	66	37
Bad texture (-)	Tough, chewy, hard, stringy, rubbery, gristle, flaky, crunchy	69	97
Tenderness/Toughness			
Tender (+)	Very tender	15	5
Tough (-)	Very tough, too tender	32	35
Moisture			
Good moisture (+)	Juicy and moist	41	29
Bad moisture (-)	Too dry, too wet	33	40
Aftertaste			
Good taste (+)	No aftertaste present	1	0
Bad taste (-)	Slight aftertaste	3	2
Flavor			
Good flavor (+)	Good/strong chicken flavor	48	48
Bad flavor (-)	Strange flavor, off putting, raw flavor	18	11
Appearance			
Good look (+)	Good color, not fatty, visually pleasing	9	12
Bad look (-)	Wasn't attractive, pale, fat lines/pieces	12	8

[1]Positive (+) and negative (-) are terms based on the consumers' like or dislike.
[2]NORM=normal for woody breast and SEV= severe for woody breast.

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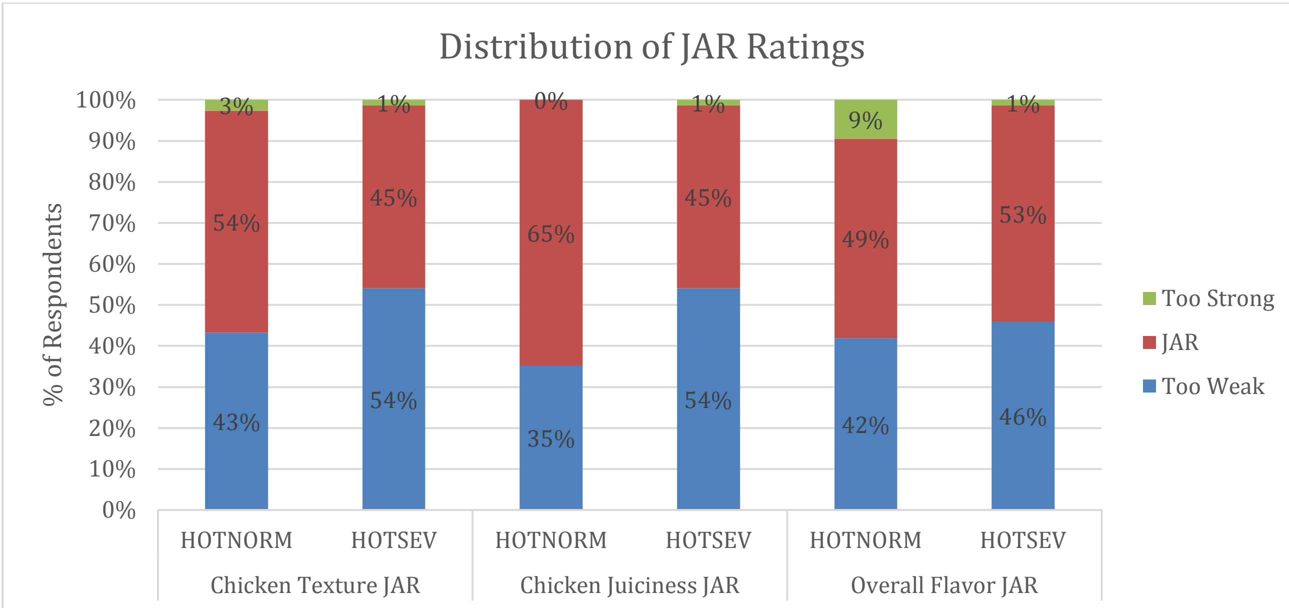

Figure 1. Frequency distribution of Just-About-Right sensory scores for HOT fillets combined in "Chicken Texture", "Chicken Juiciness", and "Overall Flavor" in broiler breast fillets.

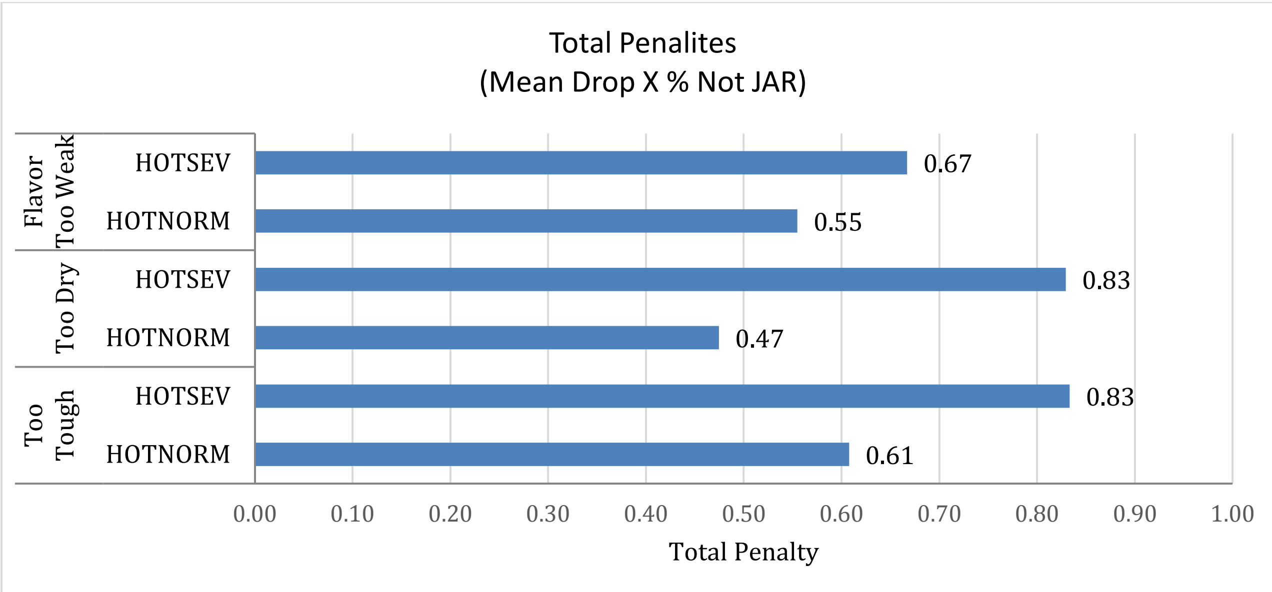

Figure 2. Total penalty analysis of JAR ratings for HOT fillets combined from consumer groups that rated samples less than optimal in "Overall Flavor", "Chicken Juiciness", and "Chicken Texture" in broiler breast fillets.

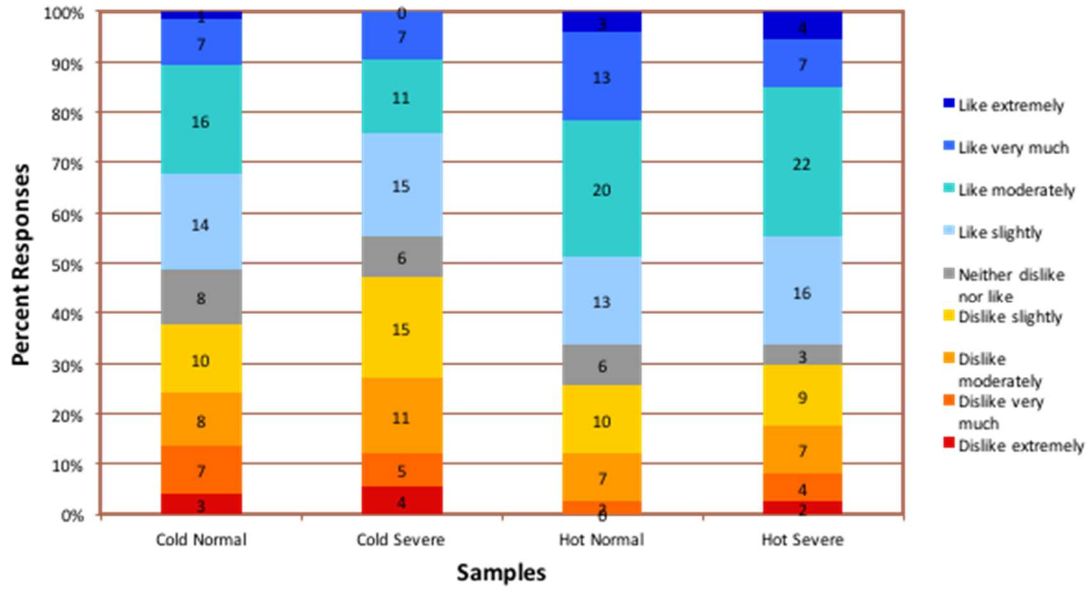

Figure 3. Frequency distribution in percent of panelists' responses for "Hedonic overall impression" of cooked broiler breast meat with normal (NORM) and severe (SEV) woody breast served at hot and cold temperatures.

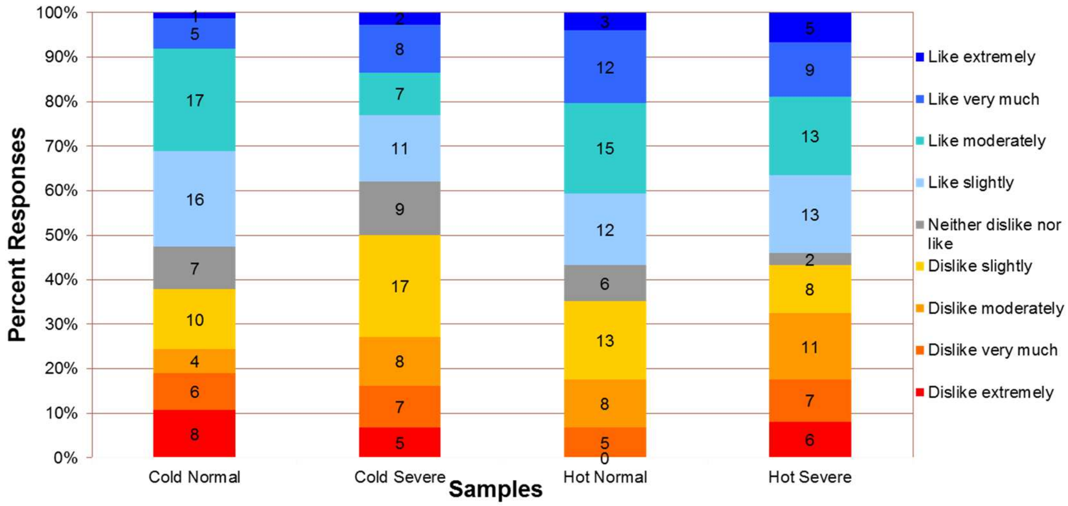

Figure 4. Frequency distribution in percent of panelists' responses for "Hedonic chicken texture" of cooked broiler breast meat with normal (NORM) and severe (SEV) woody breast served at hot and cold temperatures.

Appendix

A. IRB Approval Letter

UNIVERSITY OF ARKANSAS

Office of Research Compliance
Institutional Review Board

July 14, 2015

MEMORANDUM

TO:	Jessica Solo Tonya Tokar Casey Owens
FROM:	Ro Windwalker IRB Coordinator
RE:	PROJECT CONTINUATION
IRB Protocol #:	13-02-520
Protocol Title:	*Consumer Sensory Evaluation of Marinated and Non-Marinated Broiler Breast Filets*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Previous Approval Period:	Start Date: 03/07/2013 Expiration Date: 03/06/2015
New Expiration Date:	03/06/2016

Your request to extend the referenced protocol has been approved by the IRB. If at the end of this period you wish to continue the project, you must submit a request using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. Failure to obtain approval for a continuation on or prior to this new expiration date will result in termination of the protocol and you will be required to submit a new protocol to the IRB before continuing the project. Data collected past the protocol expiration date may need to be eliminated from the dataset should you wish to publish. Only data collected under a currently approved protocol can be certified by the IRB for any purpose.

This protocol has been approved for 245 total participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 109 MLKG Building, 5-2208, or irb@uark.edu.

4. THE RELATIONSHIP OF MEAT QUALITY AND CONSUMER SENSORY ANALYSIS IN WOODY BROILER BREAST FILLETS

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ABSTRACT

Woody breast (WB) has become a major issue in the poultry industry worldwide, and is characterized by palpable hardness, and WB typically increases in severity as slaughter age of broilers increases. Experiments were conducted to determine effect of age on meat quality factors of WB fillets, and to assess consumer acceptability of varying degrees of WB meat. In Exp. 1, birds were processed at 45 (n=80), 63 (n=50), and 70-d of age (n=41) and categorized as either normal (NORM) or severe (SEV) woody condition. In Exp. 2, samples were collected from the 45 and 63-d broilers and sorted into severity categories of NORM, moderately woody (MOD), and SEV. Compression force (CF), sarcomere length (SL), cook loss (CL), MORS energy (MORSE), and BMORS energy (BMORSE) were measured, along with peak counts of the shear curves (PC-MORS and PC-BMORS), in Exp. 1. Consumer sensory analysis (n=70 panelists) was conducted using a 9-point hedonic scale for overall impression, texture liking, and flavor liking, as well as 5-point Just-About-Right (JAR) scales for tenderness and juiciness in Exp 2. In Exp. 1, CF, SL, and CL were greater ($P<0.05$) in SEV fillets than NORM fillets. Both MORSE and BMORSE were greater ($P<0.05$) in fillets from broilers slaughtered at 70 and 63-d than 45-d and SEV fillets had greater ($P<0.05$) PC-MORS and PC-BMORS than NORM at all slaughter ages. Peak counts were greater ($P<0.05$) at 63 and 70-d than 45-d. Using agglomerative hierarchical analysis, consumers were segmented into 3 groups (groups A, B, and C) based on overall liking of the samples tested in Exp 2. Sensory data was analyzed using "segmentation" (group), "woody" and "age" as the main effects including their interaction. Consumers in group C rated SEV fillets greater ($P<0.05$) for overall impression and texture liking than NORM fillets (segmentation x woody, $P<0.05$), and group C consumers gave greater flavor liking scores ($P<0.05$) to fillets from broilers slaughtered at 63 than 45-d (segmentation x woody, $P<0.05$).

Results of this study suggest that WB category and age both affect meat quality, and compression force, and peak counts can differentiate between WB categories more accurately than shear energy. Sensory evaluation results suggest that severe WB may have positive texture acceptability with some consumers.

INTRODUCTION

The global consumption of broiler breast meat has been consistently on the rise for half a century. On a per capita basis, poultry meat consumption surpassed beef and pork consumption in 2014, with 45.6 kg compared to 24.6 kg and 21.0 kg, respectively (National Chicken Council, 2016). Factors affecting the steady increased consumption of poultry meat include low prices compared to other meat options, lack of cultural or religious hurdles, and nutritional aspects (Magdelaine et al., 2008). Between 1990 and 2009, beef, pork, and poultry meat consumption increased by 8, 20, and 75%, respectively, clearly depicting the dominance that the poultry industry has on meat consumption (Henchion et al., 2014). The trend of increasing consumption has transformed broiler production to adopt increased growth rates and higher breast yields at lower market weights. Zuidhof et al. (2014) reported that the yield of the *Pectoralis major* muscle increased by 79 and 85% in male and female broilers, respectively; increases in breast yield have resulted in the development of economically relevant muscle myopathies.

The most recent muscle myopathy, known as woody breast, is characterized by *Pectoralis major* muscle that is hard to the touch, has an outbulging appearance, pale in color, and often seen accompanied with white striping (Sihvo et al., 2014). Histology changes in broiler breast fillets affected with woody breast include myodegeneration of the muscle proteins, regeneration of the muscle proteins, and accumulation of connective tissue (Sihvo et al., 2014; Velleman and Clark, 2015). Degeneration of muscle proteins result in decreased functionality of the proteins. Thus, negatively impacting the quality of poultry products and, in turn, consumer acceptance. Further processed poultry products developed from woody breast fillets are known to exhibit lower marinade uptakes, higher cooking loss, and lower water-holding capacity (Mudalal et al., 2015; Petracci et al., 2015).

Substantial economic losses to the poultry industry are occurring from downgrading broiler breast fillets affected with woody breast (Petracci et al., 2015). The combination of increased connective tissue and degradation of the muscle proteins observed with woody breast develop a complex texture issue that is challenging to measure. The Meullenet-Owens Razor Shear (MORS) method and the blunted version (BMORS) have been reported as reliable measurements in assessing tough and tender broiler breast meat (Cavitt et al., 2005a, b; Lee et al., 2008). It is essential to use instrumental shearing methods to determine differences in texture of woody broiler breast fillets accompanied with consumer sensory analysis to determine if there is a relationship between the two methods. Therefore, consumer sensory analysis, in conjunction with MORS and BMORS shear methods, their peak counts, and sarcomere length measurements were conducted to determine if a relationship exists among subjective and objective evaluations of woody breast.

MATERIALS AND METHODS

In Exp. 1, male commercial broilers were processed at 45 (n=142), 63 (n=128), and 70 days of age (n=115) in at least four replicates per day. Birds were processed using a commercial in-line system with electrical stunning (11 V, 11mA for 11 sec), scalding (2 min at 53.8^{o}C), a commercial defeathering system, and manually eviscerated (Mehaffey et al., 2006). Carcasses were placed in a pre-chill for 15 min at 12^{o}C, followed by being at 1^{o}C for 90 minutes in an immersion chiller, which included frequent manual agitation to reach an endpoint temperature of 4^{o}C. Following chilling, carcasses were aged for 2.5 h on ice in a walk-in cooler at 4^{o}C until deboning.

After deboning, white striping of the *Pectoralis major* muscle was categorized as normal (0), moderate (1), or severe (2) according to the standards of Kuttappan et al. (2012c), along with an extreme (3) category (having striations greater than 3 mm throughout the whole fillet). Whole breast fillets were also scored and classified into 3 groups of severity of woody breast including normal (NORM), moderate (MOD), and severe (SEV) degrees of woody breast based on criteria described by Tijare et al. (2016). A single person performed the subjective scoring for consistent scoring. Following the scoring classification, fillets were split into halves. The left fillet was used for meat quality analysis in Exp. 1, including sarcomere length, compression, cook loss, shear force energy, and peak counts of the shear curves. Sarcomere length and collagen samples were taken from the medial region and stored at -80^{o}C freezer, whereas shearing and compression tests were performed on the cranial to medial region. Furthermore, right fillets from broilers processed at 45 and 63-d of age were vacuum packaged in plastic bags, and stored at 4^{o}C until 24 hours postmortem before being frozen at -20^{o}C until the sensory panel sessions in Exp. 2.

In Exp. 1, the day after processing, the left fillets were weighed and cooked to an internal temperature of 76^{o}C in aluminum lined and covered pans in a convection oven (Cavitt et al., 2004). Following cooking, fillets were cooled to room temperature and weighed to calculate cook loss, and each fillet was subsequently wrapped in aluminum foil and stored overnight at 4^{o}C for texture analysis the next day. Texture analysis to evaluate the shear force energy (N.mm) was performed using the Meullenet-Owens Razor Shear (MORS) method and the blunted version of MORS (BMORS) with the TA.XT*Plus* Texture Analyzer (Texture Technologies Corp., Hamilton, MA/Stable Micro Systems, Godalming, Surrey, UK). Fillets were sheared on the cranial to medial region in four different locations. The three readings from the different locations were averaged for statistical analysis. The razor blade was changed after 100 shears to confirm the blade was not dull (Cavitt et al., 2005a). Additionally, BMORS shear force energy was performed on the same fillets parallel to the MORS readings for texture analysis using the same technology (Lee et al., 2008). Peak counts of the shear curves were calculated (PC-MORS and PC-BMORS) and averaged for each fillet using the same texture analyzer technology. Sarcomere length was evaluated using the laser diffraction method measuring six sarcomeres from each sample (Voyle, 1971; Cross et al., 1981).

In Exp. 2, right fillets were thawed in a 4^{o}C cooler for 16 h before transportation to the University of Arkansas Sensory Service Center. A total of 70 consumers from the Fayetteville, AR area were recruited for two consecutive days of sensory sessions based on consumption of broiler breast meat at least 2 to 3 times per month. Non-marinated fillets were cooked in aluminum covered and lined pans in an air convection oven until the internal temperature of each fillet reached 76^{o}C (Cavitt et al., 2004), verified using a digital thermometer. Fillets were then cut into 2.54 x 2.54-cm cubes and served immediately to consumers in soufflé cups. Each panelist received two samples of each treatment combination: 45NORM, 63NORM, 45MOD, 63MOD, 45SEV, and 63SEV. Consumers rated each sample for overall liking on a 9-point hedonic scale (9 = like extremely to 1 = dislike extremely) for overall impression, flavor, and texture, as well as a 5-point Just-About-Right (JAR) scale for tenderness, juiciness, and overall flavor. The ballot also included an open-ended comments section to determine any other likes and dislikes of the treatments.

Meat quality data for Exp. 1 were subjected to analysis of variance using the mixed models procedure of SAS (2014), with the main effect being category (NORM and SEV) and fixed and random effect being. Least square means were separated statistically with the PDIFF option of SAS. The experimental unit for Exp. 1 was the bird due to the woody breast category being identified at the time of deboning. Linear and quadratic contrasts were used to determine the effects of WB level and age. PROC IML was used to generate proper contrast statements.

Sensory data in Exp. 2 was subjected to analysis of variance using the mixed models procedure of SAS (2014) with panelist treated as a random effect to discern means of each sensory attribute. The main effects for this experiment were. Least square means were separated statistically using the PDIFF option of SAS. Pearson Chi square analysis was performed on the open-ended comments to observe differences in comments among the treatements. Agglomerative hierarchical clustering (AHC) analysis using the Ward's method was performed with Euclidean distances to measure dissimilarities in panelist responses and to segment panelists into groups based on overall liking of broiler breast meat. Cluster analysis was performed in XLSTAT (2016) using the main effects of "segmentation" (group), "woody," and "age," as all 2 and 3-way interactions, among the means of overall impression, texture liking, flavor liking, JAR tenderness, and JAR juiciness.

Penalty analysis was conducted to evaluate the mean drop (difference) in the overall texture, juiciness, and flavor acceptability between consumer groups who found texture, juiciness, or flavor to be Just-About-Right and the group who found a treatment to be too tough, too dry, or too weak of a flavor. Penalty analysis is used to determine the impact of sensory attributes at a less than optimal level (scores above and below the JAR score). Consumers are divided into three groups (JAR, too weak, too strong) (AMSA, 2015). The average liking scores were calculated for all three groups as well as the percentage of consumers represented in each group. To conclude an attribute is at a less than optimal level, a minimum of 20% of consumers are needed in the "too weak" or "too strong" categories (AMSA, 2015). The total penalty scores are calculated by subtracting the average score for the JAR group from the mean scores of the "too weak" or "too strong" groups.

RESULTS AND DISCUSSION

In Exp. 1, compression force, sarcomere length, and cook loss were all greater (P<0.05) in SEV fillets than MOD and NORM fillets (Table 4). Compression force increased (P<0.05) with age when comparing broilers processed at 63 and 70 days to those processed at 45 days (Table 5). Sun et al. (2015) reported compression force was higher in SEV woody broiler breast fillets when compared to NORM breast fillets during short-term storage. These findings suggest that woody breast can be detected with compression force. Yet, results from this experiment suggest that compression force can only distinguish between NORM and SEV fillets and may be more sensitive in detecting woody breast. Cook loss was greater (P<0.05) at 63 and 70 days when compared to 45 days of age (Table 5). These results are supported by Soglia et al. (2015) and Tijare et al. (2016), who reported increased cook loss in breast fillets affected with both woody breast and white striping over that of normal broiler breast fillets. Zotte et al (2014) also reported greater cooking losses in woody breast fillets when compared to normal fillets. Sarcomere length increased (P<0.05) with WB severity due to SEV fillets with longer (P<0.05) sarcomere lengths than MOD fillets, which were longer (P<0.05) than NORM fillets (Table 5). Tijare et al. (2016) reported that sarcomeres affected with woody breast and both woody breast and white striping tended to be longer than normal breast fillets. Similar research showed that sarcomeres from the cranial region were longer in breast fillets severely affected with woody breast when compared to normal breast fillets (Xiao and Owens, 2016). Results of longer sarcomeres in woody broiler breast meat suggest that the hardness observed in woody fillets is occurring due to occurences other than sarcomere shortening.

Shear energy (MORSE and BMORSE), respectively were greater (P<0.05) at 70 and 63 days of age than broilers processed at 45 days (Table 5). Trocino et al. (2015) reported greater

Allo-Kramer shear forces for fillets affected with woody breast when compared to normal fillets or fillets with white striping. Previous research has suggested that the BMORS method may be more sensitive in measuring tougher meat in heavier broilers (Lee et al., 2008). In woody breast fillets, this can be due to the compression force of the blunted blade against the layers of connective tissue observed in woody breast. The SEV fillets had greater (P<0.05) PC-BMORS compared to NORM fillets, and PC-BMORS if MOD fillets were greater (P<0.05) at 70 and 63 days of age compared to those processed at 45 days of age (Table 4). PC-BMORS increased (P<0.05) as WB severity increased for all categories of WB. Interactive effects of both MORSE and BMORSE shown in Figure 1 indicate MORSE is greater (P<0.05) in fillets from broilers slaughtered at 63-d and 7-d than 45-d. In SEV fillets, BMORSE increased (P<0.05) with age (Figure 1). Figure 2 shows the interactive effects of compression force indicating compression force increased (P<0.05) with age in MOD and SEV fillets. Compression force increased (P<0.05) with severity of WB for all ages (Figure 2). In Figure 3, interactive effects of PC-BMORS indicate peak counts increase (P<0.05) with WB severity in birds slaughtered at 70-d of age. PC-BMORS are greater (P<0.05) in fillets from birds slaughtered at 63-d and 70-d than 45-d of age (Figure 3). These results indicate that peak counts can be used to distinguish between normal and woody broiler breast meat and may be a better technique to assess woody breast due to the visual difference in frequency of peaks when measuring woody broiler breast meat compared to normal breast meat. Compression force and peak counts may be able to evaluate different characteristics of texture than the traditional tenderness vs. toughness aspect.

Consumer sensory analysis results in Exp. 2 suggested no impact of age on the sensory attributes that were evaluated as shown in Table 2. However, overall impression and texture liking attributes scored higher (P<0.05) in SEV fillets when compared to MOD fillets. SEV fillets scored higher (P<0.05) among consumers when evaluating chicken texture and chicken juiciness on the Just-About-Right scale (Table 2). Figure 4 represents the distribution of consumer group who found texture and juiciness of the samples to be Just-About-Right and the consumer groups who found the texture and juiciness of the samples to be too strong or too weak. As shown in Figure 4, the consumer group who found the texture, juiciness, and flavor to be too weak represented more than 20% of the responses for those attributes, which is the minimum requirement to run penalty analysis (AMSA, 2015). Figure 5 presents the penalty analysis results that were conducted to gain an understanding of the level of appropriateness for certain attributes among consumers. As previously stated, the texture and juiciness exhibited a large amount of consumers who found those attributes to be too tough and too dry. The calculated total penalties for texture and juiciness ranged from 0.50 to 0.56 units indicating high tier penalties. Total penalties units can be categorized into different tiers to improve overall liking if the specific attribute is brought to JAR. A low tier penalty indicates no changes are needed, a mid-tier penalty suggests consider changing, and high tier penalty indicates a must change (AMSA, 2015). This suggests that WB and age may be texture and juiciness factors regarding broiler breast fillets.

In Exp. 2, using the agglomerative hierarchical cluster analysis, consumer panelists were segmented into three groups based on overall liking of the broiler breast meat samples tested. Table 1 demonstrates the mean age of the panelists for Group A was 51.2 (n=23), which was higher (P<0.05) than Group B at 40.6 (n=24) and Group C at 41.2 (n=23). Group B and Group C were not different (P<0.05). Income levels were higher (P<0.05) for Group C than the other two groups (Table 1). When analyzing “segmentation” (group), “woody” and “age”, for overall impression and texture liking, there were segmentation x woody interactions, which showed that

Group C had a higher ($P<0.05$) score for SEV fillets compared to NORM fillets while there were differences in the other two groups as shown in Table 3. This result suggests that severe woody breast meat may have positive texture acceptability with some consumers. For flavor liking, there was no impact of woody breast, but there was a segmentation x flavor interaction where Group C had higher ($P<0.05$) flavor liking scores for fillets from broilers processed at 63 days than fillets processed at 45 days. In SEV fillets, broilers processed at 45 days had higher JAR tenderness and JAR juiciness than those processed at 63 days, but there was no age difference observed in NORM fillets ($P<0.05$). For MOD fillets, broilers processed at 63 days had higher JAR juiciness than those fillets from broilers processed at 45 days (Table 3). Open-ended comments were analyzed using the Pearson Chi square method based on the frequency of occurrence for specific comments among NORM, MOD, and SEV fillets as shown in Table 4. Consumer comment results suggest that SEV fillets had more positive comments related to texture, tenderness, and moisture. SEV fillets also showed more negative comments related to the aftertaste, while MOD fillets resulted in more negative comments related to the tenderness and moisture of the sample (Table 4). These results suggest that the SEV fillets have positive attributes among consumers, while MOD fillets have negative attributes that consumers can detect.

CONCLUSION

The results of this study indicate that severe cases of woody breast and increasing age in broiler breast fillets negatively affect meat quality factors including compression force, shear force energy, and peak counts of the shear force curves. Compression force and peak counts have proven to distinguish between normal breast fillets and fillets with severe woody breast and may be a better technique in evaluating woody breast than traditional shear energy. However, even though meat quality measurements indicated severe woody breast fillets were negatively impacted, consumer sensory groups showed that certain consumer groups had higher acceptability for overall liking and texture for fillets with severe woody breast. Future research is needed to determine the reason for increased acceptability of broiler breast fillets severely affected with woody breast associated with particular groups of consumers.

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Table 1. Demographic comparisons of the three cluster segmentations based on the agglomerative hierarchical cluster analysis.

	Cluster Segmentation[1]		
Demographics	Group A	Group B	Group C
n	23	24	23
Gender Ratio (Female:Male)	5:18	8:16	5:18
Mean age	51.2[a]	40.6[b]	41.2[b]
Annual household income level	0.147	0.2832	0.214
$0-$29,999	5	5	1
$30,000-$79,999	11	11	6
$80,000 and up	7	8	16
Frequency of chicken meat consumption			
Once a month or less	0	3	1
2-3 times per month	5	6	6
Weekly	18	15	16

[a-b]Means within a row followed by different letters are significantly different at (P<0.05).
[1]Groups A-C= consumer panelists segmented into groups by overall liking of samples.

Table 2. Mean consumer sensory scores of normal and woody broiler breast fillets.

	WB Severity[1]				Slaughter Age, d		
	NORM	MOD	SEV	SEM	45	63	SEM
Overall Impression	5.92[ab]	5.64[b]	6.05[a]	0.13	5.86	5.89	0.12
Texture Liking	5.87[ab]	5.62[b]	6.04[a]	0.13	5.82	5.86	0.11
Overall Flavor	5.95	5.76	6.01	0.12	5.84	5.98	0.11
Chicken Texture JAR	2.49[b]	2.45[b]	2.79[a]	0.05	2.61	2.54	0.04
Chicken Juiciness JAR	2.38[b]	2.29[b]	2.79[a]	0.05	2.45	2.52	0.04

[a-c]means within a row followed by different letters are significantly different

[1]NORM=normal for woody breast; MOD= mild for woody breast; and SEV= severe for woody breast.

Table 3. Means and standard deviation of three clusters for each sensory attribute and treatment analyzed.

	Treatment[1]						
	NORM		MOD		SEV		
	45	63	45	63	45	63	P<0.05[2]
Overall Liking	5.94±1.8	5.90±1.9	5.49±2.0	5.81±1.9	6.17±2.0	5.94±2.0	S, W, SxW
Cluster 1	7.09±1.2	6.64±1.6	7.23±1.2	7.11±1.1	7.20±1.5	7.09±1.6	
Cluster 2	5.00±1.8	4.94±1.9	4.23±1.8	4.63±1.8	4.73±2.0	4.29±1.8	
Cluster 3	5.81±1.7	6.19±1.7	5.15±1.7	5.79±1.8	6.67±1.6	6.52±1.4	
Texture Liking	5.91±1.8	5.81±1.9	5.46±2.0	5.78±1.8	6.12±2.1	5.98±2.0	S,W, SxW
Cluster 1	7.00±1.4	6.73±1.5	6.98±1.5	6.93±1.3	7.16±1.8	7.14±1.4	
Cluster 2	5.00±1.8	5.00±2.0	4.50±2.1	4.85±1.7	4.92±2.1	4.38±1.8	
Cluster 3	5.81±1.8	5.77±1.9	5.02±1.6	5.65±1.8	6.38±1.8	6.46±1.6	
Flavor Liking	5.97±1.7	5.94±1.8	5.56±1.9	5.96±1.6	6.01±1.9	6.01±1.8	S, SxA
Cluster 1	7.25±1.0	6.82±1.6	7.18±1.1	6.77±1.2	6.89±1.5	7.07±1.4	
Cluster 2	4.96±1.6	5.00±1.8	4.42±1.7	5.10±1.6	5.04±1.9	4.71±1.8	
Cluster 3	5.81±1.6	6.13±1.4	5.23±1.7	6.08±1.4	6.19±1.7	6.35±1.2	
JAR Tenderness	2.46±0.7	2.51±0.7	2.43±0.8	2.46±0.7	2.94±0.8	2.64±0.8	S, W, WxA
Cluster 1	2.59±0.6	2.55±0.7	2.68±0.6	2.57±0.7	2.98±0.7	2.89±0.6	
Cluster 2	2.40±0.8	2.44±0.7	2.29±0.9	2.31±0.7	2.81±1.0	2.31±0.9	
Cluster 3	2.40±0.8	2.56±0.8	2.33±0.7	2.50±0.7	3.04±0.7	2.75±0.7	
JAR Juiciness	2.30±0.7	2.46±0.7	2.16±0.7	2.41±0.7	2.89±0.8	2.69±0.7	S,W, WxA
Cluster 1	2.45±0.5	2.66±0.6	2.43±0.5	2.55±0.6	2.95±0.8	2.77±0.5	
Cluster 2	2.23±0.7	2.31±0.8	2.06±0.8	2.25±0.7	2.85±0.9	2.56±0.8	
Cluster 3	2.23±0.8	2.42±0.7	2.02±0.7	2.46±0.7	2.85±0.6	2.75±0.6	

[1]NORM45= normal for woody breast processed at 45 d of age; NORM63= normal for woody breast and processed at 63 d of age; MOD45= moderate for woody breast processed at 45 d of age; MOD63= moderate for woody breast and processed at 63 d of age; SEV45= severe for woody breast processed at 45 d of age; SEV63= severe for woody breast and processed at 63 d of age**.**

[2]S= segmentation significance at P<0.05; W= woody breast category significance at P<0.05; SxW= segmentation by woody breast category interaction at P<0.05; WxA= woody breast category by chicken age interaction at P<0.05.

Table 4. Categories of terms, examples of comments, and the frequencies of occurrence for each degree of woody breast.

Category[1]	Open-ended Comment	Degree of woody breast[2] NORM	MOD	SEV	P-Value
Texture					
Like texture (+)	Easy to bite, good consistency/mouthfeel	134	122	149	0.07
Dislike texture (-)	Chewy, hard, stringy, rubbery, gristle, flaky, crunchy	153	163	157	0.69
Tenderness					
Like Tenderness (+)	Very tender	70	51	80	0.01
Dislike Tenderness (-)	Very tough, too tender	70	73	48	0.02
Moisture					
Like moisture (+)	Juicy, moist	80	46	105	0.0001
Dislike moisture (-)	Dry, too wet	121	143	77	0.0001
Aftertaste					
Like taste (+)	No aftertaste present	1	0	1	N.S.
Dislike taste (-)	Slight aftertaste	3	4	11	0.04
Flavor					
Like flavor (+)	Good/strong chicken flavor	133	120	106	0.07
Dislike flavor (-)	Strange/weird flavor, off putting, raw flavor	18	18	28	0.18
Appearance					
Like look (+)	Good color, not fatty, visually pleasing	36	33	34	0.93
Dislike look (-)	Wasn't attractive, pale, fat lines/pieces, veiny, bad color	4	7	11	0.18

[1]Positive (+) and negative (-) are terms based on the consumers' like or dislike.
[2]NORM=normal for woody breast; MOD= mild for woody breast; and SEV= severe for woody breast.

Table 5. Effect of woody breast (WB) and age on meat quality factors of broiler breast meat.

	WB Severity[1]				Slaughter Age, d					
	NORM	MOD	SEV	SEM	45	63	70	SEM	LIN[2]	QUAD[2]
Compression force (N)	8.06^{c}	13.55^{b}	19.21^{a}	0.63	10.94^{b}	14.60^{a}	15.28^{a}	0.64	<.0001	0.5157
Cook loss (%)	24.6^{c}	28.3^{b}	31.6^{a}	0.01	26.0^{c}	30.4^{a}	28.1^{b}	0.01	0.0002	<.0001
MORSE (N.mm)	201.21	195.01	193.47	7.78	169.80^{b}	207.61^{a}	212.28^{a}	7.78	<.0001	0.1581
PC-MORS	9.06^{b}	8.80^{b}	10.21^{a}	0.35	8.23^{b}	10.10^{a}	9.74^{a}	0.35	<.0001	0.0200
BMORSE (N.mm)	273.37^{a}	248.04^{b}	254.10^{ab}	10.04	213.54^{b}	278.45^{a}	283.52^{a}	10.07	<.0001	0.1062
PC-BMORS	5.73^{c}	6.82^{b}	8.79^{a}	0.18	6.08^{b}	7.78^{a}	7.47^{a}	0.18	<.0001	0.0018
Sarcomere length (μm)	1.64^{c}	1.71^{b}	1.75^{a}	0.01	1.72	1.69	1.69	0.01	0.0849	0.5452

[a-c]means within a row followed by different letters are significantly different
[1]NORM=normal for woody breast; MOD= mild for woody breast; and SEV= severe for woody breast.
[2]Probability values for linear (LIN) and quadratic (QUAD) polynomials.

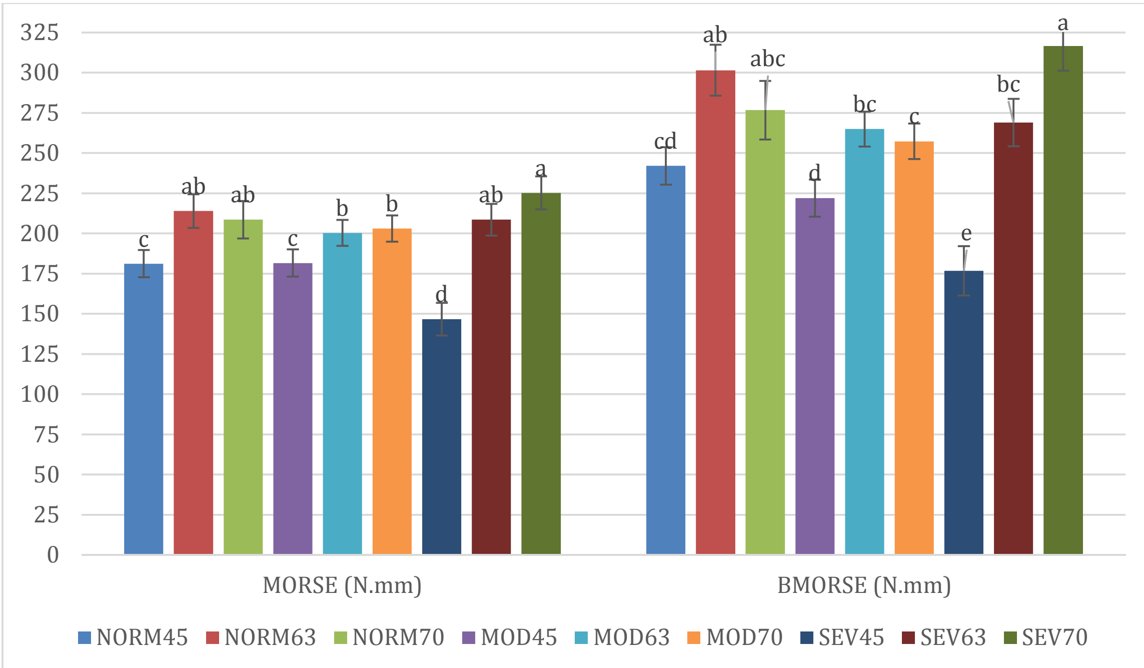

Figure 1. Interactive effects of woody breast categories and age on MORSE and BMORSE.

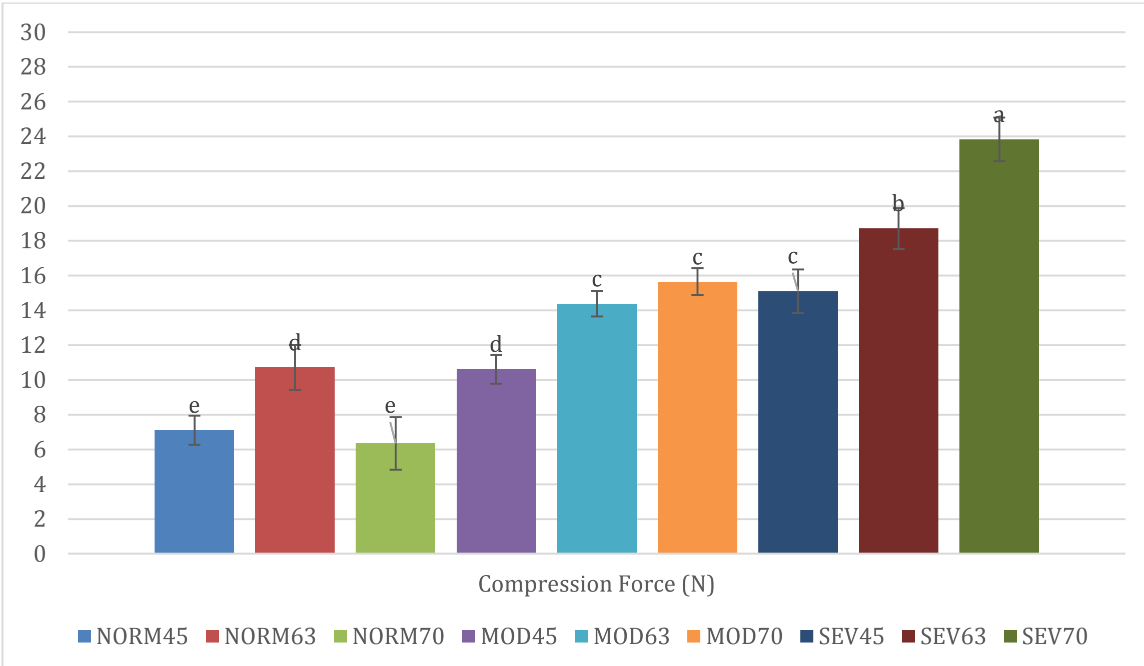

Figure 2. Interactive effects of woody breast categories and age on compression force.

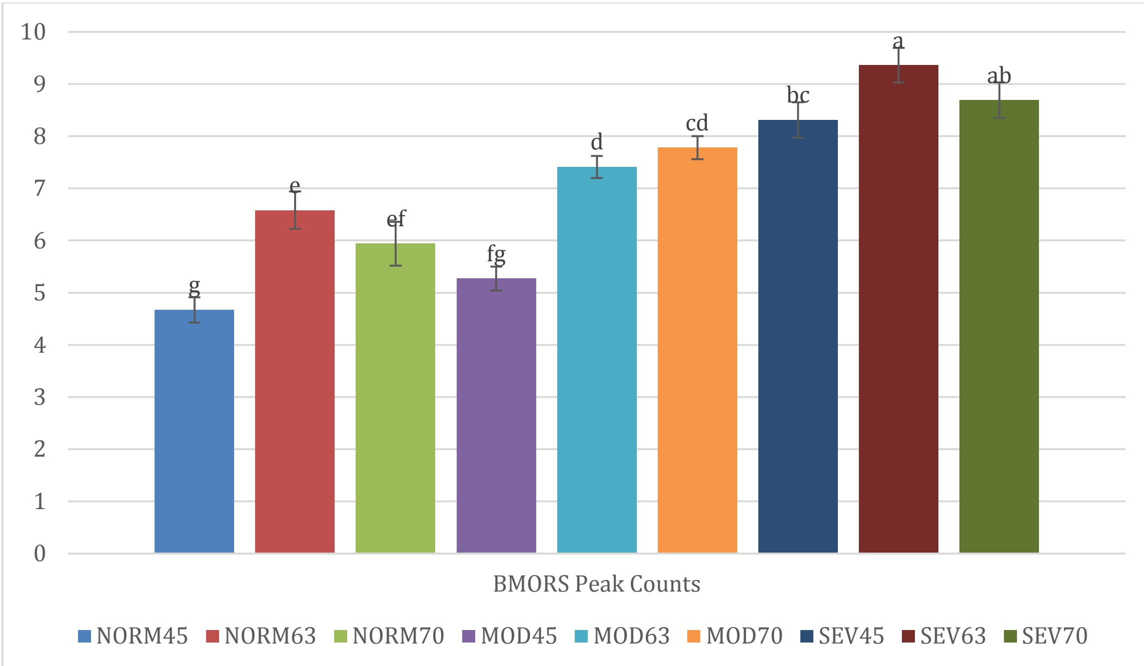

Figure 3. Interactive effects of woody breast categories and age on BMORS peak counts.

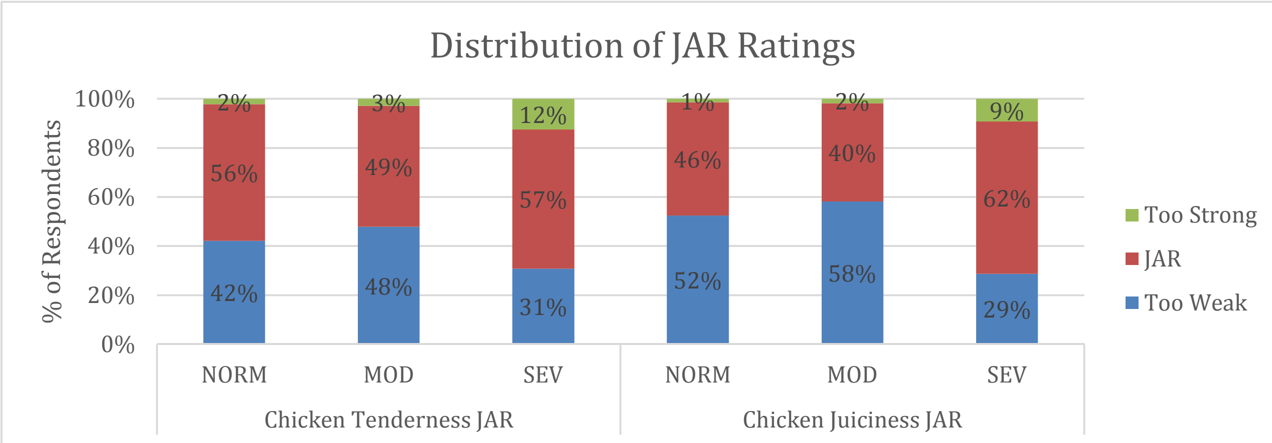

Figure 4. Frequency distribution of Just-About-Right sensory scores for broilers 45 and 63-d of age combined for “Chicken Tenderness” and “Chicken Juiciness” in broiler breast meat.

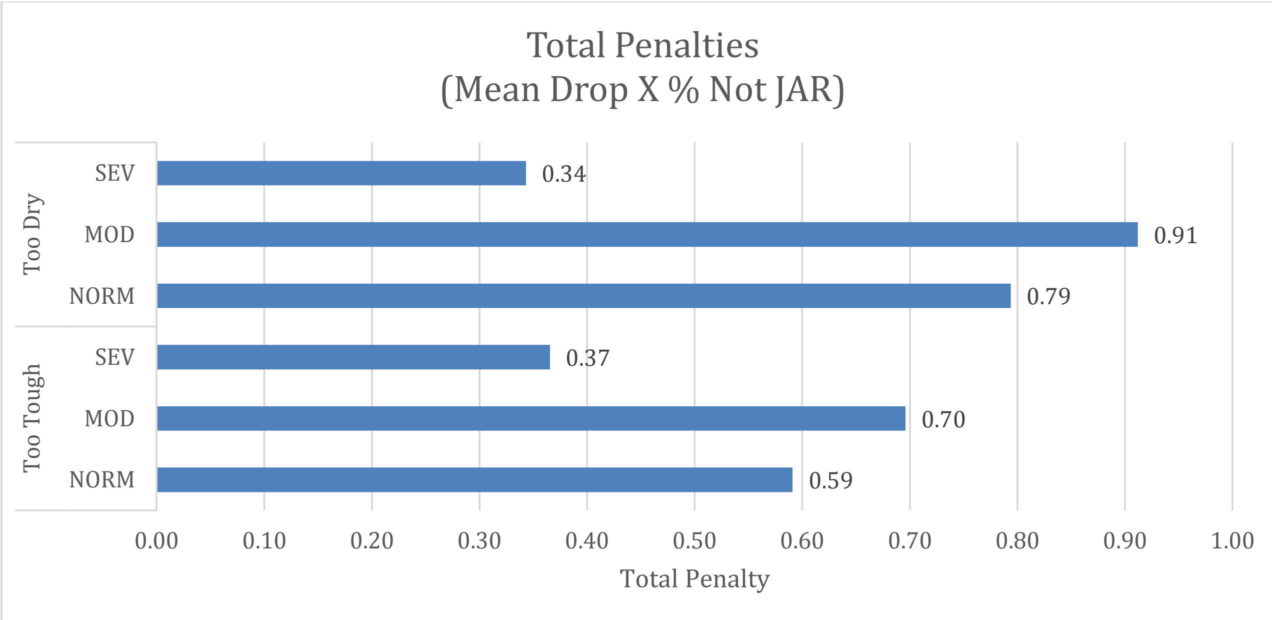

Figure 5. Total penalty analysis of JAR ratings for broilers 45 and 63-d of age combined from consumer groups that rated samples less than optimal in “Chicken Juiciness” and “Chicken Tenderness” in broiler breast fillets.

Appendix

A. IRB Approval Letter

UNIVERSITY OF ARKANSAS

Office of Research Compliance
Institutional Review Board

July 14, 2015

MEMORANDUM

TO:	Jessica Solo Tonya Tokar Casey Owens
FROM:	Ro Windwalker IRB Coordinator
RE:	PROJECT CONTINUATION
IRB Protocol #:	13-02-520
Protocol Title:	*Consumer Sensory Evaluation of Marinated and Non-Marinated Broiler Breast Filets*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Previous Approval Period:	Start Date: 03/07/2013 Expiration Date: 03/06/2015
New Expiration Date:	03/06/2016

Your request to extend the referenced protocol has been approved by the IRB. If at the end of this period you wish to continue the project, you must submit a request using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. Failure to obtain approval for a continuation on or prior to this new expiration date will result in termination of the protocol and you will be required to submit a new protocol to the IRB before continuing the project. Data collected past the protocol expiration date may need to be eliminated from the dataset should you wish to publish. Only data collected under a currently approved protocol can be certified by the IRB for any purpose.

This protocol has been approved for 245 total participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 109 MLKG Building, 5-2208, or irb@uark.edu.

5. CONCLUSION

Textural differences have been detected in broiler breast fillets affected with the woody breast myopathy as observed from descriptive sensory analysis and meat quality measurements such as compression force and peak counts of shear force curves. Certain consumer groups have indicated positive texture acceptability of woody breast meat, while additional consumer comments have shown more dislike comments related to texture than like comments. Thus, it appears that consumers may not consistently be able to identify these textural differences. The open-ended comments suggest that consumers do indeed notice differences, but measuring and describing the differences of the complex texture attributes of woody breast compared to normal broiler breast fillets deems challenging.

Future research should be conducted to determine the effects of debone time on the results of consumer sensory analysis of woody breast fillets and evaluate if texture attribute responses change. Additionally, additional research should include instrumental measurements and sensory analysis on the region of the woody breast fillet that sensory samples are taken from to determine if there is a relationship between the region of the fillet and consumer acceptance scores for texture. Finally, further research is needed to determine possible reasons for increased acceptability of severe woody breast meat associated with specific consumer groups.