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Effect of Cooking Method on Meat Texture in Normal and Woody Broiler Breast Fillets Using Instrumental Analysis and Descriptive Sensory Analysis

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Effect of Cooking Method on Meat Texture in Normal and Woody Broiler Breast Fillets Using Instrumental Analysis and Descriptive Sensory Analysis

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ABSTRACT

Over the past few decades, broiler breast meat has changed in terms of meat quality. Meat quality has deteriorated with the rise in the occurrence of muscle myopathies. Conditions such as woody breast, which is described as pale and bulging areas of distinct hardness, compromise both the textural and technological traits that have been associated with breast meat. The Meullenet-Owens Razor Shear (MORS) method is a common method for indirectly assessing poultry meat tenderness. A blunt version of the MORS (BMORS) has been shown to be a more sensitive method at higher degrees of toughness. A slightly larger stainless steel incisor blunt blade (IMORS) may offer probe longevity and may also be useful in assessing tough meat with or without WB characteristics. Instrumental analysis was conducted on 56 or 60 d broilers that were processed and scored for woody breast (WB). Individual fillets were separated into right and left fillets and the right fillet and cooked using three different heating methods: bake, grill, or sous vide and were used to measure meat quality attributes such as cook loss, MORS force (MORSF), BMORS force (BMORSF), IMORS force (IMORS), MORS energy (MORSE), BMORS energy (BMORSE), IMORS energy (IMORSE) and peak counts of the shear curves (PC-MORS, PC-BMORS and PC-IMORS). IMORS shear values are higher ($P<0.05$) than both MORS and BMORS. Cook loss was higher ($P<0.001$) in severe woody breast fillets than normal fillets regardless of cook method. In the descriptive sensory analysis, trained panelists (n=9) evaluated normal (NORM) and severe (SEV) left fillets from the 56 d broilers used in instrumental analysis. SEV fillets had a higher score ($P<0.05$) for crunchiness than NORM fillets. SEV fillets cooked sous vide retained more moisture ($P<0.001$) than SEV fillets that were grilled or baked. Results from the instrumental analysis suggest that IMORS may offer a higher sensitivity for tenderness and textural changes related to WB and that peak counts may offer a

visual measure of textural differences related to WB. Descriptive sensory analysis results suggest that certain descriptive attributes are related to WB and that the sous vide cook method may offer improvements of the textual qualities of WB.

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1. INTRODUCTION

In the United States, poultry meat is viewed as a common and versatile protein source by consumers. The United States has seen an almost 10% increase in ready- to-cook basis over the last five years. In 2013, the National Chicken Council reported 37,425 million of pounds on a ready-to-cook basis; in 2017, they reported 41,040 million of pounds on a ready-to-cook basis (National Chicken Council, 2017a). In 2017, Americans consumed, on a per capita basis, 92.2 pounds of chicken, 56.9 pounds of beef and 50.1 pounds of pork making chicken meat the most consumed protein in the United States (National Chicken Council, 2017b). Americans have been increasing their poultry meat consumption since the 1960s and the 2018 estimate and 2019 forecast remain constant with past trends with the estimated 2018 consumption predicted at 93.1 pounds per capita and the 2019 forecasted consumption is 94.5 pounds per capita (National Chicken Council, 2017b). The reason poultry meat is so popular is because poultry meat has been associated with a healthy image to consumers, desirable sensory characteristics such as texture and color, and a naturally mild flavor profile which allows consumers to convey different flavor profiles to the meat thus making the meat more versatile (Petracci et al., 2013). With the increase in demand for poultry meat, producers are responding. In 2017, almost 9 billion broilers were produced weighing approximately 55 billion pounds, live weight (National Chicken Council, 2017c). The poultry industry is not only producing more birds but they are also changing key characteristics of the bird such as growth rate, feed efficiency and muscling (Petracci and Cavani, 2012; Velleman, 2015).

Since meat-type birds have been selected for increased growth rates, there has also been increased breast muscle mass which has led to myopathies affecting breast muscle quality which are often characterized by changes in visual appearance, water-holding capacity, textural

properties and fat content (Velleman, 2015). To date, the wooden breast myopathy has only been reported in the breast muscle of primarily fast-growing broiler lines (Sivho et al., 2014). The Woody Breast myopathy is described as large areas of substantial hardness observed in varying degrees of severity and is often accompanied with white striations (Sivho et al., 2014). Affected fillets are often hard and rigid due to muscle fiber degradation which allows for the infiltration of connective tissue (Sivho et al., 2014 and Mazzoni et al., 2015). White striping is another muscle abnormality that is characterized as visual white striations of varying degrees that run parallel to the muscle fibers and is associated with heavier birds and can ultimately affect final protein functionality due to increased fat content and a decrease in protein content (Kuttappan et al., 2012a). While consumers are more likely to buy poultry meat with no visual discrepancies in the meat, such as white striations, as this is perceived by customers as a fattier appearance which has a negative connotation in terms of poultry meat being seen as a lean protein source (Kuttappan et al., 2012b), another study by Mudalal et al. (2014) reported that breast fillets affected by the woody breast myopathies had decreased marinade up take and increased cooking losses compared to those fillets affected with only white striping. While consumer acceptability of breast fillets with varying degrees of woody breast have been explored, sensory analysis involving alternative heating methods of these affected fillets is not fully understood. Therefore, it is important to explore the sensory analysis of poultry breast fillets with a severe degree of woody breast (scored using the numeric scale described in Tijare et al., 2016) using different heating methods to determine if there is a meaningful and significant difference among the cooking methods. It is also important to instrumentally generate shear values using the Meullenet-Owens Razor Shear (Cavitt et al., 2004) the blunted BMORS (Lee et al., 2008) test as well as a new blade by Texture Technologies Corporation known as the Incisor Blade which

might offer probe longevity and may be useful in assessing tough meat with or without WB characteristics.

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2. LITERATURE REVIEW

MUSCLE STRUCTURE AND FUNCTION

Skeletal muscle of an animal produced for consumption makes of the majority of the carcass weight, about 35 to 65 percent and in terms of muscle mass of an adult bird for consumption, it constitutes about 40-50 percent of the total average body mass (Aberle et al., 2001). Skeletal muscles are organs which are a part of the muscular system that are attached directly or indirectly to bones through means of ligaments, fascia cartilage or skin and their primary function is to support the body and are primarily responsible for movements which result in locomotion (Aberle et al., 2001). These muscles are made up of specialized structural cells known as muscle fibers (Aberle et al., 2001 and Brandebourg, 2013). Muscle fibers makes up approximately 75 to 92 percent of total muscle volume (Hedrick et al., 1994 and Aberle et al., 2001). Avian skeletal muscle fibers are long, multinucleated, unbranched, threadlike cells that taper slightly at both ends (Lawrie and Ledward, 2006 and Aberle et al., 2001). Muscle fibers are surrounded by the sarcolemma which is a cellular membrane composed of protein and lipid material which makes it relatively elastic (Hedrick et al., 1994). The elasticity of the sarcolemma allows for the endurance of distortion that occurs during contraction, relaxation and stretching (Judge et al., 1989). Transverse tubules, also knowns as T-tubules, are a network of invaginations of the sarcolemma and run along the entire length of the fiber and encompasses the fiber itself (Aberle et al., 2001; Swartz, 2009; Brandebourg, 2013). Individual muscle fibers are surrounded by the endomysium, the perimysium surrounds bundles of these muscle fibers and the epimysium encompasses the entire muscle (Warriss, 2010).

The myofibril is an organelle that is unique to the muscle tissue; myofibrils are long, thin rods that are typically 1 to 2 μm in diameter. Myofibrils are bathed in sarcoplasm and run

parallel to the muscle fiber for the entirety of its length (Hedrick et al., 1994). The sarcomere is the repeating structural unit of the myofibril composed of thick and thin filaments made of actin and myosin, thus making sarcomeres the basic units of muscle contraction and relaxation (Hedrick et al., 1994 and Forrest et al., 1975). The thick filaments make up the A band of the sarcomere and are primarily made up of myosin; the thin filaments make up the I band of the sarcomere and constituted predominately of actin (Forrest et al., 1975). Myosin is fibrous, elongated and shaped like a rod and it compromises approximately 45 percent of the total myofibrillar protein. Actin, which is more globular in shape, makes up approximately 20 percent of myofibrillar proteins. One actin molecule is referred to as a G-actin (globular) and when linked together creating a stand, it creates F-actin (filamentous). When two F-actin stands spiral together, they form a helix which is a characteristic of actin (Hedrick et al., 1994 and Judge et al., 1989). Tropomyosin and troponin each constitute about 5 percent of the myofibrillar protein; Tropomyosin lies within each groove of the actin helix while troponin lies closely to the tropomyosin strands (Judge et al., 1989). Skeletal muscles have a striated appearance and this is created by the bands of the myofibril aligning themselves across the length of the muscle fiber (Hedrick et al., 1994). This appearance is due to the banding of the sarcomeres which includes the I band, the lighter band made primarily of actin, the A band which is darker and comprised of myosin and the Z line which bisects the I band (Forrest et al., 1975 and Aberle et al., 2001). The H zone is the central region between the ends of actin the face away from one another and only contains myosin. Within the H zone, lies the m-line which is the mid-point of the sarcomere (Kerth, 2013b). The sarcomere in comprised of an A band which bisects the I band, thus creating two halves, and sits between two adjacent Z lines (Forrest et al., 1975).

MUSCLE CONTRACTION AND RELAXATION

A series of events have to occur in order for muscle contraction and relaxation to take place. There are contractile proteins, actin and myosin, that form the filaments of the myofibril and tropomyosin and troponin, also known as the regulatory proteins, that are responsible for control and moderate the contractile process (Judge et al., 1989). The interaction of actin and myosin in the presence of ATP are the main constituents responsible for contraction (Ebashi, 1991). The discussion regarding muscle contraction dates back over 50 years when Huxley (1954) introduced the sliding filament theory. When contraction occurs, the length of the A band does not change while the length of the I band and the H zone changes in sync with the length of the muscle thus creating the basis for the sliding filament theory (Huxley, 1954). The sliding motion of the actin and myosin filaments allows for the shortening of a single sarcomere and the combined shortening of all the sarcomeres produces an overall shortening of myofibrils (Warriss, 2010).

In order for contraction to take place, a signal from the brain must signal action potential (Swartz et al., 2009). This signal is received by a motor neuron at the motor end plate which creates a neuromuscular junction. At this junction the action potential induces the release of acetylcholine into synaptic clefts which reside on the surface of the muscle fiber which disrupts the resting potential. The sequential depolarization of the sarcolemma allows for Na^+ to move into the cell and K^+ to diffuse out of the cell and across the membrane; normally the concentrations of Na^+ is higher outside of the cell membrane and the concentration of K^+ is high within the cell membrane. When the action potential is transmitted from the transverse tubules through the sarcolemma to the sarcoplasmic reticulum (Lawrie, 1991), Ca^{+2} is released into the sarcoplasm. (Flutcher, 1992). The Ca^{+2} binds with troponin which inhibits tropomyosin as it is

now displaced. This reveals binding sites on the heads of actin and myosin (Warriss, 2010) which allows cross-bridges to form. From here, Adenosine triphosphate, also referred to as ATP, attaches to the myosin head where it is then hydrolyzed into ADP or adenosine diphosphate and phosphate. This allows the myosin molecule to be ready for the binding site on the actin molecule. Once the attachment is complete, ADP and phosphate detach causing it to move in what is referred to as the "power stroke" (Ebashi, 1991). From here, the ATP attaches to the myosin head which in turn releases the myosin from the actin thus allowing the process to repeat as long as Ca^{+2} ions are present (Warriss, 2010).

For relaxation to occur, the membrane must be repolarized, Ca^{+2} must be present in the sarcoplasmic reticulum and ATP must be present (Alvarado and Owens, 2006). The repolarization of the action potential results in the degradation of acetylcholine through the release of cholinesterase. The presence of the Ca^{+2} ions in the sarcoplasmic reticulum allows for the tropomyosin and troponin complex to return to its normal state which in turn inhibits the interaction of the contractile proteins, actin and myosin, thus resulting in the relaxation of the muscle. ATP is the driving force for the sequestration of Ca^{+2} back into the sarcoplasmic reticulum during the process of relaxation and is responsible for moderating the Na^{+}/K^{+} gradients across the sarcolemma (Hedrick et al., 1994).

MUSCLE TO MEAT CONVERSION

During the conversion of muscle to meat there are fundamental biochemical changes that occur at exsanguination (Honikel, 1993 and Braden 2013). After blood flow stops, glycogen stores within the muscle begin to break down and ATP begins to deplete which allows lactic acid accumulation and gradual decrease in the pH of the muscle (Aberle et al., 2001 and Braden,

2013). These key biochemical processes are directed towards the goal of achieving rigor mortis (Honikel, 2004). Rigor mortis, or "stiffness of death," is the known phenomenon that occurs when permanent cross bridges form between the contractile proteins actin and myosin which ultimately leads to the "stiffening" that is associated with this phenomenon (Hedrick et al., 1994). Rigor mortis development occurs in four phases: the delay phase, the onset phase, the completion phase, and the resolution phase. In the delay phase, ATP is still abundant, though slowly degrading, but the muscle is still in a relaxed state (Lawrie, 1998). In the onset phase, the muscle begins to lose extensibility due to the complete depletion of ATP and the formation of the permanent cross-bridges between actin and myosin which form the protein complex known as actomyosin (Aberle et al., 2001). The next phase, the completion phase, the muscles become stiff and unable to extend (Aberle et al., 2001).

Once the ATP within the muscle is entirely depleted, rigor development is rather quick though the point of development depends on the species of the animal. For poultry specifically, the *Pectoralis major* muscle can achieve initial rigor development within an hour after death (Aberle et al., 2001 and Sayas-Barbera et al., 2010). According to Hedrick et al. (1994) this occurs approximately four hours postmortem in commercial broilers. In the final stage of rigor mortis development, the resolution phase, proteolytic degradation of myofribillar proteins allows for the ultimate release of the tension in the muscle (Hedrick et al., 1994). The actomyosin cross-bridges do not break during this phase though in postmortem aging, the Z lines within the muscle are breaking down and are thought to be the primary reason for proteolytic degradation (Sams et al., 1991; Aberle et al., 2001; Warriss, 2010). Postmortem aging can have a significant effect on the decrease of tension in the muscle due to rigor mortis development, however, a disruption to the process such as early deboning can result in decreased tenderness by way of the heightened

accumulation of cross-bridge formation and sarcomere shortening (Lyon et al., 1985). The suggested postmortem age for poultry carcasses to be deboned is between 4-6 hours to allow the rigor mortis process to complete (Alvarado and Owens, 2006 and Schreurs, 2000).

POULTRY MEAT QUALITY ATTRIBUTES

A. WATER-HOLDING CAPACITY

Water-holding capacity (WHC) is described as the ability of meat to retain naturally occurring or added water during the application of external forces such as heating, pressing, cutting, or grinding (Aberle et al., 2001). Genetics, pre-slaughter animal management, animal nutrition, electrical stimulation and carcass chilling can impact the WHC of meat (Apple and Yancey, 2013). Other factors such as muscle type, processing conditions and ingredients added to the meat also can play a critical role in the WHC of meat. Poultry, which is traditionally considered a "lean meat" is comprised of about 75 percent water which results in a water to protein ratio of 3.5:1 (Honkiel, 2004b). Water held within meat can be described as three categories: bound water, immobilized water and free water (Keeton and Osburn, 2010). Bound water is described as the inner layer of water that is directly attached to the thick and thin filament structures and is unable to be changed by processing methodology. Immobilized water is considered a "middle layer" of water molecules which are attached to the bound water by way of hydrogen bonds. Free water is held by surface forces and therefore is weakly bound; free water is extremely important to processed meats as free water can be easily removed during processing and the overall goal is to lose as little free water as possible in further processed meats (Keeton and Osburn, 2010). WHC can be separated into two effects: the ionic effect and the steric effect (Alvardo and Owens, 2005). The ionic effect is when, in postmortem muscle, the

pH of the muscle reaches the isoelectric point the ability for water to attract actin and myosin decreases and water is lost during drip loss (Apple and Yancey, 2013). As the pH strays from the isoelectric point, the ratios of positive and negative charges also change thus having a positive effect on actin and myosin's ability to bind effectively to water (Miller, 2002). The steric effect largely depends on the space between the myofibrillar proteins which can play a larger role in the overall WHC of the meat. The smaller the space between fibers, the less water can be held due to a shortage in space for actin and myosin binding. The state of contraction and muscle pH can change the amount of space available for water to be held. WHC is important to the overall perception of tenderness, appearance and juiciness which makes WHC an important factor for meat quality.

B. APPEARANCE, TEXTURE AND TENDERNESS

Appearance is the first sensory attribute a consumer comes in contact with making it one of the most important quality attributes followed closely by texture for all meat products (Coggins, 2012; Fletcher, 2002). Appearance quality attributes include: meat color, internal cooked meat color, and the presence of defects such as bruises and hemorrhages (Fletcher, 2002).

Texture is the most significant factor affecting final quality assessment in terms of sensory (Fletcher 2002) as it directly affects perception and acceptability (Coggins, 2012). Texture of a muscle can include factors such as the placement of intramuscular fat, intramuscular connective tissue and the size of the muscle fibers (Kemp et al., 2010).

Tenderness is defined as the amount of force needed to bite through a meat sample (Coggins, 2012).Tenderness has generally been associated with live bird quality factors such as

breed, sex, or age, however, plant processing procedures such as the time elapsed post-mortem to debone also are a contributing factor (Fletcher, 2002; Grey et al., 1986). The degree of muscle tenderness to toughness is generally controlled by myofibrillar proteins and connective tissue proteins such as collagen and elastin (Garcia-Segovia et al., 2007; Koohmaraie, 1988; Coggins, 2012). Tenderness and its relationship with myofibrillar proteins within the muscle fiber is changed by the shortening of sarcomeres and the advancement of the stages of myofibrillar protein degradation (Kerth, 2013a). Muscles with longer sarcomeres require less shear force than muscles that exhibit shorter sarcomeres which provides a positive correlation between increased tenderness and increased sarcomere length (Cavitt et al, 2004; Weaver et al., 2008). Post-mortem meat tenderization is the product of the endogenous proteolytic enzymes, calpastatin and μ and m-calpains (Kerth, 2013a). A study conducted in 2006 by Koohmaraie and Geesink, reported that μ-calpastatin is the primary enzyme responsible for post mortem proteolysis and thus tenderization. Factors that can affect postmortem protein proteolysis include rate of pH decline and temperature; this is due to the residual amounts of lactic acid in the muscle from an increased rate of glycolysis before death lowering the pH of the muscle tissues which makes the meat tough (Khan, 1970). Accelerated pH at higher temperatures deactivates the calpains that induce protein degradation resulting in tough meat (Dransfield and Sosnicki, 1999). However, controlling postmortem conditions such as pH, temperature, and enzymatic activity during aging or the storing period can improve overall meat tenderness (Rees et al., 2002).

C. CONNECTIVE TISSUE AND COLLAGEN

Connective tissue is naturally very fibrous and is composed of collagen and elastin fibers embedded in intercellular substances (Baldwin, 2012). Connective tissue holds muscle fibers, bones, and fat in place by surrounding the endomysium, perimysium and the epimysium (Baldwin, 2012). The endomysium is the thin connective layer that separates individual muscle fibers, the perimysium is the connective tissue layer that separates the muscle fibers into muscle fiber bundles and the epimysium is the connective tissue casing that separates individual muscles (Purslow, 2004). In a study by Aaslyng (2002), it was found that muscles with more connective tissues present within the muscle are less tender when compared to muscles that had less connective tissue.

Collagen is available in copious amounts in the body and is recognized as the primary protein of all connective tissue (Owens and Meullenet, 2010; McCormick, 1999). Collagen has a high tensile strength and mechanical stability due to their cross-links that link single collagen molecules and fibrils together (McCormick, 1999). Toughness of meat is directly linked to collagen cross-links, not the total amount of collagen (Weston et al., 2002) as these cross-links in mature animals are insoluble; the collagen in younger animals tends to be more soluble and soluble at lower temperatures (Coggins, 2012; Baldwin, 2012).

Traditionally, in commercial broilers, collagen content has not been an issue within the industry primary due to the young slaughter age for commercial broilers however, with the increased growth rate seen in broiler lines and the increased incidences of muscle myopathies and abnormalities, the content of collagen and connective tissue is changing (Velleman, 2015).

MUSCLE ABNORMALTIES AFFECTING POULTRY MEAT QUALITY

A. WOODY BREAST AND WHITE STRIPING MYOPATHIES

Woody Breast (WB) and White Striping are recent broiler myopathies that have been reported in several countries (Sihvo et al., 2014; De Brot et al., 2016) which expresses the widespread nature of these myopathies. Woody breast causes a decrease in meat quality as the muscle it commonly affects is the superficial pectoral muscle also known as the fillet and causes the fillet to harden or causes "ridges" along the ventral portion of the breast (Bilgili, 2013). It can also exhibit large pale areas that are often hard accompanied by white patterns (Sihvo, et al., 2014). The fillets, when hard and rigid, experience muscle fiber degradation which takes place with infiltration of connective tissue (Sihvo, et al., 2014; Mazzoni et al., 2015). Woody breast is also observed in varying degrees of severity and often observed with white striping (Sihvo et al., 2014). A study by Trocino et al. (2015) suggests that the gender of the broiler affects the occurrence of the woody breast condition reporting that there is a higher incidence of the woody breast myopathy in males than in females. White striping is another broiler myopathy that exhibits characteristics similar to WB such as white striations parallel to muscle fibers in which muscle fiber degeneration takes place with infiltration of fat and connective tissue within the muscle (Kuttappan et al., 2012). Tijare et al. (2016) also states that severe degrees of white striping and woody breast, together or alone, negatively impact cook loss and marinade uptake of whole muscle fillets. Soglia et al. (2015) reported that broiler breast fillets affected with woody breast and white striping myopathies expressed higher moisture, fat and collagen content but also had lower protein levels, increased pH values, and decreased water-holding capacity.

Bilgili (2013) suggests that subtle reductions in perfusion of the muscle tissue, especially at times of higher metabolic demand or an increase in the amount of energy the animal needs to use, is sufficient to induce this degeneration. According to Sihvo et al. (2014), fast growth rate,

along with increased breast meat yield plays a significant role in the development of WB. The increased growth rate compared to that of birds from 50 years ago, produces birds in nearly half the time (Barbut et al., 2008). Additionally, hypoxia appears to be a critical factor in the Wooden Breast myopathy, though it is not apparent whether it is a primary cause for muscle lesions or is occurring secondary to inflammation and myofibril swelling from another cause (Mutyrn et al., 2015).

Histological observations include muscle fiber fragmentation, fibrosis, and necrotic muscle fiber replacement with connective tissue, macrophage infiltration and presence of asymmetrical patches of adipose tissue (Sivho et al., 2014; Velleman and Clark, 2015). Hardened ridges could be from the degeneration of muscle fibers adjacent to the band of muscle fascia (Biligi, 2013).

Even though gross and histologic characteristics of modern myopathies are similar to some of the known conditions, such as hereditary muscular dystrophy, nutritional myopathy, toxic myopathies, and marbling, WS and WB could have a different etiology (Velleman, 2015). As a result, there is a need for future studies to identify markers for WS and WB in live birds and genetic, nutritional, and/or management strategies to alleviate the condition (Kuttappan et al., 2016).

Kong et al., (2017) conducted a study with Barred Plymouth Rock (BPR) and a modern pedigree male broiler. Based on RNA- sequencing and other methods, Kong et al. (2017) suggested that some potential markers for WB were identified assuming that WB is associated with rapid muscle growth and feed efficiency.

Fiber composition may offer an insight to WB. Xiao and Owens (2016) reported that sarcomeres, collected from the cranial region, were longer in severe woody breast than in normal breast fillets. Velleman (2015) noted the importance of skeletal muscle development and the correlation to breast muscle myopathies. “Dark meat” in poultry is known as Type I or slow twitch muscle fibers and its purpose is to store oxygen; this meat has a darker appearance due to high myoglobin concentrations (Mutryn et al., 2015). “White” muscle in chickens is almost completely Type II, or fast twitch muscle fibers and myoglobin is usually not detected or is found in small quantities and glycogen is usually found in large quantities in the breast muscle (Mutryn et al., 2015). Mutryn et al., (2015) suggests that high levels of myoglobin within the meat could be responsible by the phenomenon of “fiber-type switching” which is the change from fast twitch to slow twitch fibers in due to myofibril degeneration and muscle death as found in WB.

COOKING METHODOLOGY

As most meat is cooked before eating, it is important to understand the fundamental concepts of the physical and chemical changes the meat undergoes during heating. Cooking can be described as the heating of meat to a sufficiently high temperature to denature proteins (Davey and Gilbert, 1974). In the process of heating, many meat proteins denature and they cause structural changes in the meat such as destruction of cell membranes, decrease in the length of meat fibers, the aggregation and gel formation of myofibrilar and sarcoplasmic proteins and the shrinkage and the increased ability of connective tissues to become soluble (Tornberg, 2005; Baldwin, 2012). Cooking time and temperature have a significant effects on physical properties of meat and eating quality (Garcia-Segovia et al., 2007). Tenderness is a textural attribute that can be affected by cooking. A study by Lyon and Lyon (1990) reported that there

were significant differences in texture attributes in relation to the cooking method of poultry meat. The heating of the meat generally makes connective tissues more tender by softening the collagen present in the muscle itself (Baldwin, 2012).

Traditional methods of cooking poultry for sensory or instrumental evaluation as described in Sams (1990), Cavitt et al. (2005), Solo et al. (2016), and Yusoup et al. (2010), involves placing fillets on a raised wire rack in an aluminum lined and covered pans in a convection oven to 73C, then cubing immediately and serving to the panelists. Cooking methodology for MORS involves the same parameters as cooking for sensory except the fillets are cooled to room temperature and wrapped in aluminum foil before being stored at 4C for 24 hours as described in Cavitt et al. (2004).

Grill methods have also been used for sensory and instrumental methods. Conventionally practiced grilling procedures operate on the principle of heat transfer by way of conduction from a heated grill surface to the food item (Liebermann, 1996). Any plate that can be heated to and controlled at a temperature deemed operationally safe can be defined as a grill surface plate (Liebermann, 1996). In a study by Aguirre et al. (2018), broiler breast fillets were cooked to an internal temperature of 73C using a flat top grill set at 177C and flipping the fillet when the internal temperature, monitored by copper-constantan thermocouples inserted to the center of the cranial region, reached 37C.

Another method of cooking is sous vide, which is French for “under vacuum”, and is defined as “raw materials or raw materials with intermediate foods that are cooked under controlled conditions of temperature and time inside heat stable vacuumized pouches” (Schellekens, 1996). Sous vide cooking differs from traditional methods in two main ways: the raw materials are vacuum-sealed in heat stable, food-grade plastic pouches and the raw materials

are fully cooked using accurately and specifically controlled heating. Sous vide cooking typically works by cooking submerged in carefully heat controlled water using a long time-low temperature approach (Baldwin, 2012). This temperature control allows for the negative impacts on proteins and lipids to be minimized thus improving texture as well (Karyotis et al., 2017). To prevent undercooking, it is emphasized that the pouches are completely submerged and not closely arranged or overlapping (Ryubka-Rodgers, 1999). Traditional cooking methods make the meat safe to consumer by cooking to an internal temperature of 74C, however, poultry can also be made safe to consume at lower temperatures but it does require a longer period of time (Baldwin, 2012). Cooking poultry breast meat to 60C for 129 minutes is just as safe as cooking to 74C (Baldwin, 2012). This is due to pasteurization times for poultry (USDA, 2017). The loss of liquids and volatile compounds is reduced drastically, almost to the point of prevention, which results in foods that have better taste and smell (Diaz et al., 2008). However, there have been food safety concerns due to the fact that the long time-low temperature process is not able to deactivate or render the populations of *Listeria monocytogenes* and *Salmonella spp*. non-viable and since these pathogens can grow in chilled environments, especially if heat abused, causes concern on the retail and household portions of the industry (Ghazala, 1998 and Juneja et al., 2006). Since it can be difficult to maintain low temperatures, it is important to incorporate extra food safety and quality assurance steps to ensure the safety and wholesomeness of these products (Paik et al., 2006).

INTRUMENTAL TEXTURE PROFILE ANALYSIS OF MEAT

For almost the last century, evaluating meat texture and tenderness mechanically has been a plight for many researchers. Since texture is viewed as the most important attribute of

poultry meat, research has been conducted for many years to evaluate the structure of muscle fibers and intramuscular connective tissue and therefore measure meat tenderness (Lyon et al., 2010). Today, there are many established tests used to complete this task, however, this has not always been the case. Prior to the 1960s, instrumental methodology focused more on ways to cut, compress or manipulate the food samples in some way (DeMan et al., 1979). This was because texture was not well understood at the time and was viewed as a single parameter characteristic, rather than the multi-parametric characteristic it is, and the focus was on creating a single unit of measurement that could be used to measure texture (Cavitt et al., 2004).

Two of the earliest instruments to assess meat texture include the Warner-Bratzler shear device (Bratzler, 1932) and the Allo-Kramer compression-shear device (Kramer et al., 1951). A shear test is where a blade or blades cut perpendicularly to the muscle fibers on a given sample and the force needed to cut through the sample is measured which relays a value that can be associated back to the tenderness or toughness of a meat sample (Lyon et al., 2010). Both methods use a sample of cooked poultry meat that has been cut from its original muscle for use in this analysis but the main difference between the two shear tests is that the Warner Bratzler method uses a single rectangular blade and a spring scale which measures the force (DeMan et al., 1979) while the Allo-Kramer method uses multiple blades to shear the sample(Barbut, 2002; Lyon et al., 2010) and forces the sample through the bottom of stationary shear cell which records the value as kgf/g of the sample weight (Kramer et al., 1951).

However, these methods work on the foundation that texture was not multi-parametric thus leading to innovative methods such as the General Foods Texturometer (Szczesniak, 1965) and the Texture Profile Method and the Texture Profile Analysis (TPA) method (Szczesniak, 1963; Szczesniak et al., 1963) which relates perception of sensory texture attributes (Cavitt et al.,

2004) as it emulates the conditions to which the food is subjected to in the mouth (Bourne, 1978). A need for a multi-point analysis was recognized by Breene (1975), who realized that texture was complex and that a multi-point procedure would give more accurate data than single-point tests. However, Smith et al. (1988) noted that the use of the TPA method on whole could lead to decreased acceptability due to difficulties in application because of the complex and multivariate nature of meat samples. Though there is a chance of decreased acceptability, research has suggested when comparing TPA to Warner-Bratzler shear method to sensory attributes, the TPA method better predicts and correlates human sensory texture (Caine et al., 2003 and Huidobro et al., 2005). Additionally, there have been strides in instrumental methods to assess the tenderness in cooked poultry meat. In addition to the Warner-Bratzler shear force method, the Allo-Kramer compression-shear method and TPA, Cavitt et al. (2004) introduced another shear method for cooked poultry meat assessment known as the Meullenet-Owens Razor shear method (MORS) which streamlined the texture analysis process as there is less sample preparation compared to the Warner-Bratzler and Allo-Kramer methodologies. The MORS method uses a single, replaceable razor blade and cuts the sample in four separate locations along the in-tact breast fillet; this allows for shear force and energy to be derived from the sequential shears (Lyon et al., 2010). In a 2004 study by Cavitt et al, it was suggested that the MORS method better predicted descriptive sensory analysis data for attributes such as initial hardness, chewdown hardness, cohesiveness of mass, cohesiveness, and number of chews to swallow than the Allo-Kramer shear method. In 2008, Lee et al, optimized the MORS method by adding a blunted version of the MORS method known as BMORS. The BMORS method is considered a reliable method and can better differentiate cuts of poultry meat that have been deemed tough, hard and/or rigid (Lee et al., 2008; Lyon et al., 2010).

Multiple past studies have concluded that instrumental methods are good predictors of the correlation of the tenderness of meat and sensory analysis in relation to texture attributes. The purpose of correlating instrumental data to sensory analysis exist as a means to quantify human perception of the textural properties that are present in food (Cavitt et al., 2004). Some methods of texture analysis are better at predicting certain textural characteristics than other methods. A study by Luckett et al. (2014), suggested that the BMORS method was better at predicting hardness and fibrousness while TPA proved to the most ideal instrument in predicting springiness in deli meat derived from poultry meat. In another study, the Warner-Bratzler method expressed high predictability of five sensory texture attributes (cohesiveness, hardness, particle size, bolus size, and chewiness) in broiler breast fillets that were deboned at varying times (Liu et al., 2004). While some methods are better at predicting certain texture attributes, a 2006 study by Xiong et al., used a consumer panel comprised of 74 panelists to evaluate texture and correlate them to the Warner-Bratzler method, the Allo-Kramer method, and MORS and found that all methods had high correlations to the sensory analysis data. While the Warner-Bratzler method and Allo-Kramer method are deemed as good predictors of tenderness, another study by Lyon and Lyon (1990), showed that sensory responses to the tenderness in broiler breast fillets deboned at 0 hours, 2 hours, 6 hours and 24 hours post-mortem and using various cooking methods affected sensory scores and objective shear values. However, the data revealed that the objective Warner-Bratzler values of 6.5 to 3.5kg and the Allo-Kramer values of 8.8 to 6.0 kg per g would correspond to the "slightly tender" to "moderately tender portion of the sensory scale (Lyon and Lyon, 1990). Cavitt et al. (2005) developed scales using hedonic scales for tenderness acceptance and intensity and corresponding them to Warner-Bratzler shear force, Allo-Kramer Shear value, and MORS shear force. Additionally, Cavitt et al. (2005) used

regression models to create a scale using descriptive sensory data to predict sensory attributes from instrumental measurements.

DESCRIPTIVE SENSORY EVALUATION OF POULTRY MEAT ATTRIBUTES

Descriptive sensory tests are one of the most sophisticated tools for sensory scientists (Lawless and Heyman, 1998). Descriptive tests involve detection, also known as discrimination, and description of both quantitative and qualitative sensory elements of a consumer product by trained panelists (Meilgaard, Civille and Carr, 1991 and Murray et al., 2001). The panelists are expected to be capable of identifying and quantifying specific attributes and characteristics and provide information regarding the sensory measurements of food (Lyon et al., 2010). The disadvantage of sensory testing is the range of variability that exists when using people as testing instruments (Bratcher, 2013). Although this disadvantage exists, the information sensory analysis provides is still extremely valuable since instrumental measurements do not fully perceive human perception, but must be controlled by minimizing variability and bias wherever possible (Bratcher, 2013).

Descriptive analysis is a method of sensory evaluation usually comprised of 8-12 trained members to agree on and determine the definitions of both qualitative and quantitative aspects of a product's attributes and their intensities normally in regard to flavor and texture profiles using reference standards (Lawless and Heyman, 2010 and Lyon et al., 2010). A texture profile method was introduced by Lyon and Lyon (1990) was specifically targeted for broiler breast meat which was later expanded to include 20 attributes measured on a numerical line scale from 0-15 which represented the intensity for each attribute. Descriptive analysis data is extremely useful and

valuable for both professional and research application as it provides a unit of measurement to describe all of the sensory characteristics that are detectable in a product (Meilgaard et al., 2007).

NEED FOR RESEARCH

The dramatic increase of the woody breast muscle myopathy has caused increased emerging concern amongst commercial poultry producers and even consumers. Consumers are voicing their concerns with the quality of poultry meat in today's market which is a monumental problem for the poultry industry as a whole. In a consumer driven market, the economic impact lower quality poultry meat can have is a substantial issue. While visual acceptability of breast fillets with the woody breast myopathy is known to have a lower acceptance rate than fillets that are not affected with the woody breast myopathy, the pressure on poultry processors has driven them to downgrade poultry meat, resulting in economic losses, and even create separate processing areas that did not exist before to grade out these affected fillets which also results in economic losses due to increased labor costs.

The incisor blade is a new blade designed by Texture Corp. Technologies and it is currently being used to assess poultry meat texture by foodservice companies but currently there are published research articles to evaluate its effectiveness in assessing poultry meat texture in comparison to current established blades (MORS and BMORS) used for the Meullenet-Owens Razor Shear (MORS) Method.

While Cavitt et al, 2004 found a relationship between instrumental and descriptive and consumer sensory analyses in predicting tenderness in cooked broiler breast fillets, the cooking method used is commonly accepted practice of cooking the breast fillets on a raised wire rack in

a pan lined with aluminum foil and then covering the pan with aluminum foil as well. Different cooking methods such as direct heat (grill) and sous-vide cooking have not been widely observed in poultry meat and is not well understood. Therefore, the objectives of this study were to assess the efficiency of various blunted versions of the MORS Method for predicting tenderness in normal and severely affected woody breast fillets using different heating methods (steam, grill and sous-vide) and their corollaries to descriptive sensory responses for textural and tenderness attributes.

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3. **EFFECT OF COOKING METHOD ON MEAT TEXTURE IN NORMAL AND WOODY BROILER BREAST FILLETS USING INSTRUMENTAL ANALYSIS AND DESCRIPTIVE SENSORY ANALYSIS**

   L. D. Combs

INTRODUCTION

Poultry meat is a sustainable protein source that has been increasing in demand over the last several decades. The estimated United States 2018 poultry meat consumption on a pounds per capita basis is 93.1 pounds with consumption on a pounds per capita basis forecasted for 2019 at 94.5 pounds (National Chicken Council, 2017). Globally, the trend is consistent as poultry meat consumption saw a 125.7% increase from 1990 to 2009 (Henchion et al., 2014). Consumers in all markets desire food products that are of high quality, safe, healthy, and have enjoyable taste and mouthfeel (Trienekens et al., 2012). Poultry meat meets these standards and also has characteristics such as low pricing in comparison to other meat choices on the market and its versatility (Magdelaine et al., 2008). However, with increased demand, poultry producers have aimed to select birds that have increased growth rates, higher feed efficiency and higher breast yield. From 1957 to 2005, broiler growth rates increased by over 400% while reducing the amount of feed to produce chicken meat for consumption by 50% (Zuidhof et al., 2014). This increase in growth rate has resulted in higher yields but have also ensued the development of muscle myopathies.

One of the most recent muscle myopathies to affect the *Pectoralis major* muscle is the woody breast myopathy. This degenerative muscle myopathy is characterized by pale, bulging areas of extensive hardness which can also be seen with another known condition, white striping, which is described as superficial white striations (Sihvo et al., 2014). These conditions negatively affect the appearance of the meat and other meat quality characteristics (Kuttappan et al., 2012). The products developed from fillets affected by woody breast have shown a decrease in marinade uptake, increased cook loss, and decreased water-holding capacity (Petracci et al., 2015). The occurrence of these muscle myopathies are creating economic losses due to customer

complaints (Tijare et al., 2016). Meat consumption trends show that meat saturation has already been met in many markets and the influence of factors such as household income and price are declining over time thus, factors such as quality will rise to become one of the most significant factors that influence consumer preference (Henchion et al., 2014). Texture is considered to be the most significant factor affecting final quality assessment in terms of sensory (Fletcher 2002) as it directly affects perception and acceptability (Coggins, 2012). Perceived quality by consumers have high influence on food satisfaction and food choice (Olsen, 2003) which is why broiler breast meat that is perceived to be less desirable due to meat myopathies is a substantial issue for the poultry industry. Furthermore, the downgrading of meat with woody breast by poultry producers is also contributing to the economic losses the poultry industry is facing (Petracci et al., 2015).

Fillets affected by woody breast show degradation of muscle proteins and an increased amount of connective tissues (Velleman and Clark, 2015) which creates a multifarious texture profile which can be hard to measure. The Meullenet-Owens Razor Shear (MORS) Method is an established and reliable method to assess poultry meat texture (Cavitt et al., 2005). Since woody breast texture is so complex, MORS has not always been associated with these textural changes (Lee et al., 2008). A blunted version of MORS (BMORS) has been shown to be a more sensitive method at higher degrees of toughness (Lee et al., 2008). Some food companies have started to require testing of their finished products with a slightly larger steel incisor blade to assess meat texture in quality control programs (Personal Communication, Randolph Koch). This blade may offer probe longevity and may be useful assessing tough meat with or without these woody breast characteristics. Instrumental shearing methodologies provide an objective measurement of these textural attributes of woody breast. Descriptive sensory analysis allows to give an analysis

of the textural characteristics of broiler breast fillets affected by woody breast. Therefore, to obtain both objective and subjective measurements of broiler breast fillets affected by woody breast, MORS, BMORS and MORS with the newly introduced incisor blade, were conducted to determine any correlations amongst the methods using woody breast meat heated by three methodologies: grill, bake and sous vide. While bake and grill methods are common heating methods that have been researched extensively, sous vide cooking and the instrumental and sensory evaluation of the textural changes that occur as a function of the low temperature-long time cooking method (Baldwin, 2012) is not well understood in poultry broiler breast fillets affected with the woody breast myopathy.

MATERIALS AND METHODS

Processing and Sampling

Samples in Exp. 1 were separated into two trials. In the first trial, a total of 276 broilers at 56 days of age were obtained from a local rearing facility at day of processing and transported to the University of Arkansas Poultry Processing pilot plant. There, the birds were hung on a shackle line and processed; birds were electrically stunned at 11V, 11MA for 11 seconds, the jugular vein and left carotid were manually severed, the birds then bled out for 1.5 minutes before being scaled at 55 C for 2 minutes and feathers were removed in-line using commercial equipment (Meheffey et al., 2006). Carcasses were then manually eviscerated, rinsed and then placed in a pre-chill for 0.25 hour at 12C followed by immersion chilling at 1C for 165 minutes and 345 minutes with manual agitation periodically allowing the carcasses to reach an endpoint temperature of 4C. Carcasses were then manually deboned at 3 h postmortem or 6 h postmortem.

Following the deboning, the whole breast fillets were scored and categorized into 3 classifications of woody breast severity ranging from normal to severe woody breast, based on the methods as classification system described in Tijare et al. (2016). To keep the scoring consistent as this scoring method is subjective, one experienced individual completed the entirety of the scoring process. After the scoring was complete, the breast fillets were kept separate by postmortem debone time (i.e. 3 h and 6 h) as the 3 h postmortem deboned fillets were used in descriptive sensory analysis.

Fillets classified as normal (NORM), moderate, or severe were used in this study, and those classified as moderate or severe were combined into the severe (SEV) category. The breast fillets were split into halves as the right fillet was used to determine cook loss and instrumental meat texture analysis to determine shear force, energy and peak counts of shear curves in. Instrumental analysis used both the 3 h postmortem deboned fillets and the 6 h deboned fillets. Additionally, the left fillet from the 3 h and 6 h postmortem deboned fillets were stored on ice in a 4C cooler until 24 hours postmortem where they were then vacuum sealed in plastic packaging then stored in a 4C cooler until the descriptive sensory analysis, conducted on d 6 postmortem.

For the second trial, broilers at 60 days of age were slaughtered in a commercial processing facility. Fillets were then chilled for 2.5 h and deboned at 2.75 h postmortem. Fillets were scored in-house at the processing facility by the same experienced individual in the first trial for reliability and consistency between both trials. The scored fillets were transported to the University of Arkansas Poultry Processing pilot plant and stored on ice in a cooler until analysis. The fillets were split and the right half was used for cook loss calculation and instrumental analysis. Fillets were then analyzed at 2 d postmortem in two replications.

Instrumental Analysis of Meat Quality

Right fillets were cooked at 6 d postmortem to correspond with the age of the breast fillets at time of the sensory analysis (Trial 1) or 2 d postmortem (Trial 2) . Prior to cooking, the individual breast fillets were weighed in order to calculate cook loss. In each trial, there were three cooking methods: bake, grill and sous vide. For the bake cooking method, pans were lined and covered in aluminum foil and fillets baked on a raised wire rack and cooked to an internal temperature of 76C in a convection oven (Sams, 1990; Cavitt et al., 2004). For the grill method, fillets were cooked on a George Forman plated grill (GE Spectrum Brands, Middleton, WI) until internal temperature reached 76C. For the sous vide method, individual fillets were vacuum sealed in plastic packaging and submersed in a heated, circulating water bath regulated by a Sous Vide Professional (PolyScience, Niles, IL) at 65C. This temperature was chosen because at around 66C, there is a stall period that initiates evaporative cooling which affects moisture retention (Goldwyn and Blonder, 2016). After cooking, the fillets were weighed and cooled to room temperature and then wrapped in aluminum foil and stored for 24 hours at 4C before completing instrumental texture analysis.

To measure texture instrumentally, shear force (N) and shear total energy (N.mm) data was collected using the Meullenet-Owens Razor Shear (MORS) method (Cavitt et al., 2005) which uses a 8.9 mm wide, steel razor straight edge (Texture Technologies, TA-45). Two additional probes were used to represent other blades used in research or quality control programs. A blunted version of the MORS method (BMORS) (Lee et al., 2008) which uses a 8.9 mm wide, 0.5 mm thick steel blunt edge was used along with a blade developed by Texture Technologies Corp. referred to as an incisor blade (Texture Technologies, TA-46) which is a 11 mm wide, 1.5 mm thick stainless steel blunt edge using the TA.XT*Plus* (Texture Technologies

Corp., Hamilton, MA/Stable Micro Systems, Godalming, Surrey, UK). For the purpose of this study, the analysis using the incisor blade will be referred to as IMORS. Fillets were sheared in the cranial region only in three different locations; the readings from the three locations were averaged to perform statistical analysis. For the razor shear method, the blade was changed every 100 shears to ensure the blade was not dull to provide accurate textural analysis (Cavitt et al., 2005). The BMORS was performed on the same fillets parallel to the MORS analysis points of shear using the same technology (Lee et al., 2008) and IMORS was performed the same way. Peak counts of the shear curves for all three blades (PC-MORS, PC-BMORS and PC-IMORS) were calculated using the same texture analyzer and averaged for statistical analysis.

Descriptive Sensory Analysis of Meat Quality

Fillets were subjected to the same storage parameters (vacuum-sealed and stored on ice at 4C for 6 d) and cooked using the same cook methods as described in the instrumental analysis in preparation of the descriptive sensory analysis. After ensuring the fillets had reached a safe internal temperature for each cook method by way of verifying endpoint temperature using a digital thermometer, the cranial region of the fillets were cut into 1-inch cubes. Treatments to evaluate included normal and moderate/severe woody breast fillets as described that were prepared using the three methods of cooking: grilled method, and sous vide. Sensory analysis was conducted by a nine-member trained descriptive panel hosted at the University of Arkansas Sensory Service Center. An initial orientation which was a single three hour session was held with the purpose of familiarizing the panel with the three cook methods and two classifications of fillets. This initial orientation session also allowed to monitor panel performance in terms of repeatability, discriminating ability and uniformity amongst the panelists similarly to Lyon et al. (1998) and Cavitt et al. (2004).

The trained panel used ten descriptive textural attributes (Table 3) to evaluate tenderness and textural properties of partial compression (springiness), First bite and chew characteristics (hardness, moisture release, cohesiveness, and crunchy (Aguirre et al., 2018)) chewdown characteristics (cohesiveness of mass, fibrousness between teeth, and hardness of mass) and residual characteristics (toothpack and loose particles). The lexicon used in this study was similar to those used in Aguirre et al. (2018), Cavitt et al. (2005), and Solo (2016) though panelist added and removed descriptive attributes that better fit the study such as Moisture Release instead of Juiciness. Panelists were presented samples (3 to 4, 1 inch cubes presented on a small white plastic plate) randomly from all treatment groups in duplicates. To achieve this, there were two testing sessions. Between each sample, panelists were instructed to cleanse their palate with room-temperature water and a non-salted cracker. Between the two sessions, there was a 15 minute break period.

Statistical Analysis

Instrumental analysis data was subjected to ANOVA using JMP (SAS, 2015). There was no interaction between debone times thus the fixed effects were replication, cooking method and their interaction. Data was analyzed within meat type (normal and severe) and trials were analyzed separately. Means were separated by Tukey's HSD significance at $P<0.05$.

Sensory Analysis data was subjected to ANOVA using JMP (SAS, 2015). Fixed effects were cook method and replication. Panelists were treated as a random effect. Means were separated by Tukey's HSD significance at $P<0.05$ and student's t test. The effect of meat type was also analyzed and is presented separately within text as only one attribute was affected.

RESULTS AND DISCUSSION

Instrumental Analysis of Meat Quality

Cook loss is a parameter for determining water-holding capacity (Woelfel and Sams, 2001). Water-holding capacity can help affect meat quality characteristics such as tenderness though other attributes of the meat such as texture and degree of firmness is a function of the amount of water held within the muscle (Mir et al., 2017). In Trial 1, cook loss using the bake method was greater ($P<.001$) than grill and sous vide for both NORM and SEV fillets (Table 3). However, results from Aguirre et al. (2018), show that normal, marinated, grilled fillets had a higher cook loss than those baked in an oven and this was not consistent with the results of this study. This could be because of the time spent in higher temperature setting. In this study, the grill method took only 12 minutes at 176C and the bake method took 60 minutes at 176C. Additionally, fillets in this study were not marinated; marination generally improves water-holding capacity of meat (Alvarado and McKee, 2007). However, the findings of Aguirre et al. (2018) show that severe marinated fillets had more cook loss in the oven than grill which is consistent with the results in this study. The differences between the cook loss between the normal and severe woody breast fillets in Aguirre et al. (2018) may be due to marination. It is likely that marination helped normal fillets but not severe woody breast fillets due to a decrease in myofibrillar proteins in severe woody breast fillets which directly impacts protein functionality as well as an increase in collagen which can decrease the ability of the meat retain and bind water (Soglia et al., 2016; Petracci et al., 2013). SEV fillets had an overall higher cook loss in this study which is consistent with findings from Tijare et al. (2016) [in which severe WB non-marinated fillets had a lower cook loss than that of normal fillets].

Meullenet-Owens Razor Shear method of evaluating tenderness is a reliable and established method (Cavitt et al., 2004). MORS instrumental evaluates tenderness by measuring force in Newtons (N), energy (N.mm) and peak counts (Solo, 2016; Cavitt et al., 2004). MORS force (N) and MORS Energy (N.mm) was greater ($P<.001$) in NORM fillets that were baked than those that were either grilled or cooked sous vide (Table 1). The results from this study were inconsistent with the results from Chatterjee et al. (2016). Chatterjee et al. (2016) found that fillets with severe woody breast had higher MORS force and energy readings than normal fillets these differences between studies could be attributed to cook methodology as the fillets in this study were cooked in a vacuum sealed bag in a combi steam oven, age of the bird and/or size of the fillet.

The blunted version of BMORS is also a reliable predictor for poultry meat tenderness (Lee et al., 2008). Lee et al. (2008) reported that tenderness, as perceived by consumers was more correlated to BMORS energy than MORS energy which suggests that BMORS offers better discriminatory ability among especially though meat. While BMORS force (N) was not statistically different in NORM fillets, BMORS Energy (N.mm) was statistically different between grill and sous vide cook methods which may indicate that BMORS is a more sensitive test to find textural differences in cook methods (Table 1). BMORS had higher energy and force values than MORS, with the exception of NORM baked fillets though the difference in those values were not significantly different (Table 1), in both NORM and SEV fillets which is consistent with the findings of Lee et al., 2008.

The incisor blade is another blade used as a replacement of the razor blade in the MORS method for quality assessment in the finished product by some poultry suppliers in the industry. The blunt blade is commonly available from Texture Tech Corp. (Texture Technologies, TA-46)

and is greater in blade width than the razor blade used in MORS or the blunted blade used in BMORS. However, the incisor blade's relationship for assessing poultry meat texture is not well understood. The IMORS Force (N) and IMORS energy (N.mm) was higher overall compared to MORS and BMORS for NORM and SEV fillets; IMORS energy was statistically different among all cook methods for NORM fillets which offers evidence of IMORS being a more sensitive method to assess tough meat with or without woody breast characteristics (Table 1).

Peak counts for IMORS in fillets were lowest for bake ($P < .05$) in trial one (Table 1). Bake and sous vide methods of cooking had lower peak counts compared to grilled. This could be due to the conduction heating of the grill surface vs the convection heating of the oven in the bake method and the water in the sous vide method. The direct heat source may allow for the intense contraction of the muscle fibers which could lead to toughness (Baldwin, 2012). Solo (2016) suggests that peak counts can be used to differentiate between normal and woody breast meat due to the visual difference in the frequency of peaks in the shear curve when analyzing normal fillets compared to fillets affected with the woody breast myopathy. Peak counts may offer a way to measure different characteristics of texture when the textural profile of the meat goes beyond the traditional toughness vs tenderness aspect such as those complex texture profiles found in fillets affected with woody breast (Solo, 2016).

In Trial 2, cook loss was statistically different amongst all cook methods for both NORM and SEV fillets with the bake method having the most cook loss followed by the grill method and finally the sous vide method (Table 2). These results are similar to those in Trial 1. This could be because the stall period that typically occurs at 66C and initiates evaporative cooling did not take place thus allowing for higher moisture retention (Goldwyn and Blonder, 2016). Trends in Trial 2 were similar to those in Trial 1 as IMORS had the highest energy (N. mm) and

force (N) followed by BMORS and MORS, respectively. Peak counts in both trials were highest in MORS and lowest in IMORS regardless of cook method or meat type.

The Meullenet-Owens Razor Shear force (N) was higher in NORM fillets in Trial 2 compared to SEV fillets though the baked method had the highest ($P<.001$) MORS force (N) value for both NORM and SEV fillets (Table 2). In SEV fillets, sous vide values for IMORS force (N) and IMORS energy (N.mm) were lower ($P<0.05$) than those fillets heated with the bake and grill methods. This could be due to the rate of shrinkage of muscle fibers during heating and the increase of solubility of collagen during heating, especially in a moist environment (Baldwin, 2012). Woody breast has a higher content of connective tissues and collagen (Velleman and Clark, 2015), and connective tissues start shrinking around 60C but contract more quickly and intensely at temperatures over 65C (Baldwin, 2012). The slow, precision heating present in sous vide may increase tenderness by dissolving collagen thus increasing tenderness allowing for lower IMORS force and energy since the incisor blade may offer a more sensitive reading than both MORS and BMORS due to the increased blade size. BMORS again had higher energy and force values than MORS which is consistent with the findings of Lee et al. (2008). IMORS had the highest values for both force (N) and energy (N.mm) compared to MORS and BMORS which is consistent with the results from Trial 1. This could be due to the size of the IMORS blade in that it is substantially larger than both the MORS and BMORS blades. IMORS and BMORS also offers a compression aspect that is virtually absent in MORS and the increased size compared to BMORS may offer a higher sensitivity to tough meat.

Descriptive Sensory Analysis of Meat Quality

While instrumental analysis of meat texture predicts tenderness of the meat, descriptive sensory analysis allows to create a profile that encloses all of the perceived sensory characteristics (Murray et al., 2001). For this study, panelists focused on textural attributes of the cranial region of the cooked broiler breast fillets. Panelists found that, overall, SEV fillets had higher scores for crunchy ($P<0.05$) than NORM fillets, regardless of cook method (data not shown. Scores for hardness in NORM fillets were affected by cook method and sous vide had a lower score ($P<0.0549$) than grilled and baked methods though there were no differences due to cooking method in terms of hardness in SEV fillets. Fibrousness between teeth was higher ($P<0.05$) for grilled NORM fillets than the sous vide method but not for bake method; there was no difference in fibrousness between teeth for SEV fillets. These results are similar to those reported by Sanchez-Brambila et al. (2016) where no differences in fibrousness were found between non-marinated NORM and SEV fillets. However, Sanchez-Brambila et al. (2016) did find differences in springiness and hardness in NORM and SEV non-marinated fillets which this study does not corroborate. This could be due to the variation that occurs from fillet to fillet (Cavitt et al., 2004). Additional differences between these studies may include postmortem time at which the fillet was cooked. In Aguirre et al. (2018), the fillets were frozen for 7 days and in this study, fillets were aged on ice for 6 d. Noting the freezing of the fillets is important because meat texture can be affected by freezing and thawing processes (Zhuang and Savage, 2013) and because thawing occurs more slowly than freezing, the thawing process allows for chemical and physical changes as well as tissue damage (Li and Sun, 2002). In this study, grilled breast fillets, regardless of WB category, had a higher score than those reported in Aguirre et al. (2018). The difference between these scores could be attributed to the marination of the fillets used in the

other study. Cohesiveness of mass for NORM fillets was higher ($P<0.05$) for grilled fillets than the other two methods. Scores for cohesiveness of mass were similar in range for both bake and grill methods reported by Aguirre et al. (2018). Moisture release in SEV fillets was affected by cook method in that sous vide had a higher ($P<0.0056$) scores than both grill and bake methods. Sous vide cooking prevents evaporative loss of moisture during heating (Church and Parsons, 2000; Baldwin, 2012) and this, combined with the slow, precision heating which allows for the collagen to dissolve into gelatin (Baldwin, 2012) which could lead to a more moist perception of the SEV fillets. These sensory results, though there were few differences, support instrumental analysis in that panelists identified the crunchy attribute in WB fillets. The crunchiness the panel recognized could be due to the increase in connective tissue, when heated, contracts thus leading to decreased tenderness and a distinguishable texture difference. In instrumental analysis, WB fillets had higher shear values (Table 2) which have been associated with increased toughness associated with the complex characteristics of WB (Tijare et al., 2016; Solo, 2016; Aguirre et al., 2018).

CONCLUSION

In summary, cook loss was higher in SEV fillets than NORM fillets regardless of cook method. Sous vide cooking generally allows for more moisture retention, but did not impact SEV fillets. Sensory analysis of normal and severe fillets showed that out of the 10 attributes, the only attribute in which woody breast had a higher ($P<0.05$) score was crunchiness. This could be due to fillet variation as other studies show contradicting results which further emphasizes the complexity of the textual profile of woody breast. However, sous vide cooked filets showed lower IMORS values and tended to be lower for BMORS compared to other cooking methods;

this indicates that sous vide may offer improvement in textural attributes related to WB. Though instrumental analysis showed that sous vide cooking improved shear values, the sensory panel did not confirm. The effect cook method had on normal and woody meat suggests that sous vide cooking offers improvements for textural properties. Future research is needed to assess the relationship of these instrumental methods and sensory evaluation, especially in fillets from modern broiler exhibiting varying levels of woody breast. IMORS shear values are higher than those of MORS and BMORS but future studies are needed to assess the valuation of these scores in regard to MORS and BMORS. Future studies with the incisor blade need to be investigated to draw a definitive conclusion on the assessment of poultry meat.

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Table 1. Effect of woody breast and cook method on meat quality factors of broiler breast meat (Trial 1).

	Degree of Woody Breast							
	NORM[1]				SEV[2]			
	Cook Method				Cook Method			
	Grill	Bake	Sous vide	SEM	Grill	Bake	Sous vide	SEM
Cook Loss (%)	13.56[b]	28.03[a]	14.12[b]	1.03	18.07[ab]	21.75[a]	15.25[b]	0.82
MORS Force (N)	11.32[b]	14.4[a]	10.33[b]	0.37	10.50	10.61	10.31	0.27
MORSE (N.mm)	156.26[b]	191.91[a]	135.41[b]	4.86	151.67	146.68	142.33	4.22
PC-MORS	11.30[a]	7.87[b]	7.42[b]	0.30	12.53	12.24	10.98	0.46
BMORS Force (N)	13.91	13.04	11.25	0.50	17.18	14.22	14.87	0.64
BMORSE (N.mm)	189.61[a]	174.42[ab]	149.13[b]	6.09	212.75	179.68	193.92	7.22
PC-BMORS	8.30	7.35	7.18	0.25	9.97[a]	8.37[ab]	7.9[b]	0.30
IMORS Force (N)	21.19[a]	23.75[a]	17.2[b]	0.66	19.79	26.32	22.20	1.47
IMORSE	274.19[b]	327.58[a]	223.43[c]	8.51	236.58	239.27	255.24	13.38
PC-IMORS	6.35[a]	4.08[c]	5.13[b]	0.19	7.88[a]	6.39[b]	7.1[ab]	0.21

n=20 per mean

[1]NORM=normal for woody breast

[2]SEV= severe for woody breast

[a-c] Means within meat type within a row followed by different super script letters differ significantly ($P < 0.05$).

Table 2. Effect of woody breast and cook method on meat quality factors of broiler breast meat (Trial 2).

	Degree of Woody Breast							
	NORM[1]				SEV[2]			
	Cook Method				Cook Method			
	Grill	Bake	Sous vide	SEM	Grill	Bake	Sous vide	SEM
Cook Loss (%)	20.83[b]	29.39[a]	12.95[c]	1.00	21.43[b]	27.28[a]	15.57[c]	1.09
MORS Force (N)	11.47[b]	14.24[a]	10.41[b]	0.28	10.08[b]	13.73[a]	11.16[b]	0.34
MORSE (N.mm)	159.63[b]	191.59[a]	138.96[c]	3.64	143.74[b]	190.25[a]	149.43[b]	4.58
PC-MORS	10.07[b]	12.82[a]	8.18[b]	0.42	14.8[a]	14.55[a]	10.08[b]	0.58
BMORS Force (N)	17.57	22.49	12.85	0.68	17.78[ab]	19.98[a]	14.78[b]	0.72
BMORSE (N.mm)	219.12[b]	288.24[a]	167.16[c]	8.39	211.06[ab]	253.3[a]	183.35[b]	8.60
PC-BMORS	5.53	5.58	5.47	0.20	7.77	8.33	7.78	0.23
IMORS Force (N)	28.14	31.68	207.72	0.92	34.93[a]	35.78[a]	23.9[b]	1.51
IMORSE	356.78[a]	388.78[a]	261.77[b]	10.90	356.19[a]	411.92[a]	272.94[b]	15.04
PC-IMORS	3.78	3.48	3.15	0.11	5.88	5.75	5.67	0.19

n=20 per mean

[1]NORM=normal for woody breast

[2]SEV= severe for woody breast

[a-c] Means within meat type within a row followed by different super script letters differ significantly ($P < 0.05$).

T**able 3.** *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 sample partially with molars without breaking the sample.	Cream Cheese 0.0 Pound cake 2.5 Soft Pretzel 5.0 Beef frank 7.5 Weiner 10.5 Gummy bears 15.0
First bite/chew			
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
Moisture Release	The amount of wetness or moistness felt in the mouth after one bite or chew.	Compress sample with molars one time only.	Banana 1.0 Carrot 2.0 Mushroom 4.0 Snap Beans 7.0 Cucumber 8.0 Apple 10.0 Honeydew 12.0 Orange 15.0 (Chew Refs 5 Times)
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

Table 3. Cont. *Texture Lexicon used for analyzing the texture of broiler breast fillets*

Term	Definition	Technique	Reference
Crunchy	The amount and size of the break(s) after biting sample one time. And: The degree of sound and pitch heard when the sample is cracked, broken or compressed 1 time.	Compress sample with molar teeth until sample crumbles, cracks, shatters or breaks.	Peanut 6.5 Carrot 11.0
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 10 x's)*
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

Table 3. Cont. *Texture Lexicon used for analyzing the texture of broiler breast fillets*

Term	Definition	Technique	Reference
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 Carrots 11.0 Almond 11.0 Life Savers 14.5 (Do not chew refs)
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 4. Mean Descriptive sensory texture scores of breast fillets by cook method

	Degree of Woody Breast							
	NORM[1]				SEV[2]			
	Cook Method				Cook Method			
Sensory Attribute	Grill	Bake	Sous vide	SEM	Grill	Bake	Sous vide	SEM
Springiness	6.31	6.58	6.23	0.16	6.06	5.70	6.01	0.23
Hardness	6.79[a]	6.58[ab]	6.22[b]	0.17	6.61	6.23	6.21	0.17
Moisture Release	4.14	4.60	4.63	0.29	4.31[b]	4.07[b]	5.22[a]	0.28
Cohesiveness	7.19[a]	6.81[b]	6.75[b]	0.14	7.03	6.73	6.86	0.18
Crunchy	1.76	1.42	1.45	0.22	2.18	1.63	1.95	0.22
Cohesiveness of mass	6.92	7.06	7.11	0.19	6.69	7.08	7.13	0.21
Hardness of Mass	5.81	5.43	5.55	0.13	5.82	5.62	5.49	0.15
Fibrousness between teeth	5.9[a]	5.67[ab]	5.27[b]	0.19	5.76	5.45	5.86	0.19
Toothpack	1.49	1.36	1.50	0.17	1.24	1.47	1.37	0.18
Loose Particles	4.21	4.23	4.17	0.14	4.47[a]	4.45[a]	4.09[b]	0.15

n=9

[1]NORM=normal for woody breast

[2]SEV= severe for woody breast

[a-c] Means within meat type within a row followed by different super script letters differ significantly ($P < 0.05$).

APPENDIX

UNIVERSITY OF ARKANSAS

To:	Casey Owens Hanning POSC 0-209
From:	, Chair
Date:	09/17/2018
Action:	**Exemption Granted**
Action Date:	09/17/2018
Protocol #:	1808141572
Study Title:	Sensory analysis of poultry meat

The above-referenced protocol has been determined to be exempt.

If you wish to make any modifications in the approved protocol that may affect the level of risk to your participants, you must seek approval prior to implementing those changes. All modifications must provide sufficient detail to assess the impact of the change.

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

cc: Lynda D Combs, Investigator
Han-Seok Seo, Investigator

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