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Meat Quality of Broiler Breast Fillets with White Striping and Woody Breast Muscle Myopathies

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Meat Quality of Broiler Breast Fillets with White Striping and Woody Breast Muscle Myopathies

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By

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ABSTRACT

The global poultry industry has been faced with emerging broiler breast meat quality issues known as white striping and woody breast. Two experiments were conducted to evaluate effects of white striping and woody breast hardness on meat quality traits in broiler breast fillets. Birds were processed at 8 wk (Exp.1) and at 6 and 9 wk of age (Exp.2), whereas deboning was carried out at 4 and 2 h postmortem in Exp.1 and 2, respectively. Fillets were categorized as: normal for both white striping and woody breast (NORM); mild for white striping and woody breast (MILD); severe for white striping and mild for woody breast (WS); severe for woody breast and mild for white striping (WB); or severe for both white striping and woody breast (BOTH). Sarcomere length, gravimetric fragmentation index (GFI; Exp.1 only), marination uptake, cook loss, and Meullenet-Owens razor shear energy (MORSE) values on non-marinated and marinated fillets were assessed. Sarcomeres tended to be longer ($P \leq 0.07$) with increasing severity of white striping and woody breast in both experiments, but GFI was not impacted ($P=0.49$). Marinade uptake decreased ($P<0.05$) with increasing severity of white striping and woody breast, with BOTH categorized breast having the least marinade uptake in both experiments. Cook losses of non-marinated and marinated fillets were greatest ($P<0.05$) in the BOTH category. Even though MORSE values did not ($P= 0.28$) differ in non-marinated fillets, in marinated fillets, BOTH breast fillets had greater MORSE values ($P<0.05$) than other categories of fillets in Exp.1. In addition, non-marinated NORM-fillets had greater ($P<0.05$) MORSE values than the other categories among birds processed at 6 wk age; however, MORSE values did not ($P= 0.08$) differ among marinated breasts, regardless of the category, nor were MORSE values affected ($P= 0.05$) by category in marinated fillets processed at 9 wk of age. Results of this study suggest that severe degrees of white striping and woody breast individually or in combination negatively impact meat quality, especially water holding capacity.

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DEDICATION

I would like to dedicate this thesis to my paternal grandfather, Ramchandra Tijare and to my maternal grandmother, Prabha Pattalwar. They would have been proud of me today!

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CHAPTER

INTRODUCTION

Poultry meat remains a popular choice of meat all over the world. In the US, forecasted figures from the National Chicken Council show that consumers will spend $70 billion on chicken (National Chicken Council, 2015a). Healthy image of poultry products and economical cost compared to beef and pork are one of the reasons chicken is widely consumed (Valceschini, 2006). In early 2012, consumers spent merely $ 1.33 for a pound of chicken meat (whole bird) compared to $ 5.25 and $ 3.6 on beef and pork, respectively (National Chicken Council, 2015a). Due to this high demand, the industry has focused on production of birds with increased growth rate, lower Feed Conversion Ratio, higher meat yield and reduction in abdominal fatness (Petracci and Cavani 2012). Currently in the US, over 50% of the birds produced have weights greater than 2.7 kg, such a market is called heavy bird market (National Chicken Council, 2015b). The meat from such market is utilized in the further processing and in cut up retail market after portioning. Production practices like this have helped the industry grow and sustain the growing demand.

Although increased growth rate has been beneficial for the industry as a whole, it has led to growth related myopathies which has resulted in quality issues of meat related to water holding properties and toughness (Dransfield and Sosnicki, 1999). In the past decade, the poultry industry has been facing meat quality problem referred as white striping. White striping is characterized by white striation running parallel to muscle fibers (Kuttappan et al., 2012a). Brest meat with white striping is known to have lower water holding capacity, high drip loss, high cook loss and lower consumer acceptance (Kuttappan et al., 2012b; Petracci et al., 2013). In recent times, another breast muscle abnormality has been observed and referred to as woody breast. Woody breast is identified by palpable hardness partially or throughout the breast fillet. Sihvo et al. (2013) reported regenerative myodegeneration and necrosis with fibrosis. Apart from Sihvo et al. (2013), limited information is available on impact of woody breast on meat quality.

In a forecast, it is estimated that 49% of the chicken produced in the US will be further processed and 40% will be used for cut up market (National Chicken Council, 2015b). With evidence of increase in fat and decrease in protein content of muscle affected by white striping and woody breast (Kuttappan, 2012a; Petracci et al., 2014; Mazzoni et al., 2015), there is a concern over functionality of proteins in further processed products using affected meat. It is therefore imperative to address these abnormalities with respect to meat quality attributes like water holding capacity, marination properties and tenderness of meat. It is also important to identify if postmortem changes in muscle like sarcomere length and fragmentation play a role in hardness of woody breast.

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LITERATURE REVIEW

MUSCLE STRUCTURE

Skeletal muscle is a major component of body which has a complex structure and a primary source of meat from carcass (Forrest et al., 1975). The muscle is surrounded by thick connective tissue sheath called as epimysium and then divided into bundles of fibers. The muscle fibers are surrounded by layer called as perimysium. Endomysium surrounds the individual muscle fibers. The muscular fibers represent 75 to 92% of the total volume of muscle (Judge et al., 1989). The endomysium lies above the muscle cell membrane called sarcolemma and consists of a basement membrane that is associated with an outer layer called reticular layer that is surrounded by a layer of fine collagen fibrils imbedded in a matrix (Bailey and Light, 1989). The individual muscle fiber encompasses individual myofibrils which contain sarcomere, the basic contractile unit of the muscle.

The sarcomere is mainly composed overlapping thin and thick filaments. The thick filament is mostly composed of myosin and C-protein (Morimoto and Harrington, 1973). Myosin is a fibrous protein that constitutes approximately 50 to 55% of the total myofibrillar protein (Smith, 2010). The structure of myosin molecule is elongated rod shape called tail region, neck as middle section, and head region at the end (Hedrick et al., 1994).

The thin filament is composed mainly of actin, which is the second most abundant protein, and comprises about 20 to 25% of the total myofibrillar protein. Actin consists of individual globular proteins (G-actin) which are grouped together to form the fibrous form of actin F-actin (Hedrick et al., 1994). The thin filament also consist of troponin and tropomyosin which help regulate actin and myosin (Warriss, 2000). Two strands of F-actin along with two strands of filamentous tropomyosin and associated troponin are twisted together to form the thin filament. Troponin is made up of three subunits namely, troponin-T which binds to tropomyosin, troponin-I inhibits actomyosin interactions by binding to actin, and troponin C binds to calcium (Alvarado and Owens, 2006). Each myofibril contains a repetitive series of dark and clear bands. The protein dense bands where actin and myosin overlap are called as A bands, an H zone, which presents a dense M line. The less dense area is known as I band which is divided in half by Z line. The distance between two Z lines is considered as sarcomere (Alvarado and Owens, 2006; Sayas-Barbera, 2010).

MUSCLE CONTRACTION

Muscle contracts because sarcomere shortens in length as actin filaments and myosin bonds come together, where the crossed myosin bonds pull the actin filaments into A band (Sayas-Barbera, 2010; Davies, 2004). An electric impulse called an action potential initiates contraction. It arrives at the presynaptic terminal causing voltage gated calcium channel to open which results in Ca^{+2} permeability of the presynaptic terminal. Ca^{+2} enters presynaptic terminal and initiate the release of acetylcholine (neurotransmitter) from synaptic vesicle in the presynaptic terminal. Causing Na^{+} permeability with efflux of K^{+} and depolarization occurs, creating action potential to travel to T-tubule causing opening of calcium channels. There is influx of Ca^{+2} from SR to sarcoplasm, which binds with troponin C on tropomyosin causing a conformational change and tropomyosin moves deeper in groove (Hedrick et al., 1994). Myosin head attaches to the actin-binding site forming actomyosin complex. Adenosine diphosphate (ADP) and inorganic phosphates are released from myosin head causing conformational change. The myosin head attachment angle is changed from 90^0 to 45^0 causing a force that slides actin towards the M-line which is sliding motion of muscle contraction resulting in sarcomere shortening (Huxley and Hanson, 1954; Pearson and Young, 1989; Hedrick et al., 1994; Davies, 2004; Alvarado and Owens, 2006; Sayas-Barbera, 2010).

CONVERSION OF MUSCLE TO MEAT

Slaughter of an animal for meat causes changes in the body like change in pH, temperature of body, and concentration of oxygen and energy supply. The physiological system tries to maintain these physiological conditions. Maintenance of a physiologically balanced internal environment is called as homeostasis. This system helps in adjusting to the external demands that greatly influence the internal environment. When the ability to maintain homeostasis is compromised, major changes occur in the body. The two systems that coordinate adjustments in the function of organs are the nervous system and the endocrine glands (Hedrick et al., 1994). Immobilization of animal is followed by exsanguination in which 50% of blood is removed from body, is the start to series of postmortem changes that occur in muscle (Hedrick et al., 1994; Braden, 2013). As a result of blood loss, the supply of oxygen to the muscle is interrupted. However, myoglobin has a greater affinity for oxygen than hemoglobin so it acts as oxygen supplier until all of it is used by cells for metabolism (Hedrick et al., 1994; Braden, 2013). Such a supply of oxygen for oxidative reactions is limited and does not last long. The metabolism of energy shifts to anaerobic pathway followed by fermentation when oxygen is no longer available through aerobic pathway of tricarboxylic acid cycle (TCA) and electron transport chain cycle and even the stored oxygen from myoglobin is depleted (Hedrick et al., 1994; Sayas-Barbera, 2010; Braden, 2013). With the loss of circulatory system, lactic acid accumulates in muscle as a waste product and increases in concentration until most of the original glycogen stored in muscle is depleted or until the tissue pH becomes so low that the enzymes of glycolysis become inactive (Lyon and Buhr, 1999; Braden, 2013).

Rigor mortis, which is Latin for “stiffness of death”, causes stiffening of muscle after death. It is observed with the formation of permanent cross-bridges between actin and myosin filaments in the muscle as no energy is available for breaking the actomyosin bonds. In poultry breast, rigor mortis takes about an hour to start. (Dransfield and Sosnicki, 1999). The process of rigor can be broken down into four phases, the first phase following exsanguination in which muscle is extensible and elastic is called the delay phase (Hedrick et al., 1994). Phosphorylation of Adenosine diphosphate (ADP) to Adenosine triphosphate (ATP) takes place with the support of creatine phosphate (CP) but with continuous depletion of CP, there is insufficient ADP to maintain tissue in relaxed state. The complete depletion of glycogen marks the start of onset phase of rigor mortis in which the muscle start to lose extensibility and will continue until the completion phase of rigor mortis (Hedrick et al., 1994; Lyon and Buhr, 1999). With the loss of CP, ATP can no longer be formed from ADP which is the completion of rigor mortis where the muscle is inextensible. As the ATP with Mg^{2+} is not available for relaxation of muscle, the actomyosin cross-bridges form and results in shortening of sarcomeres and the cross-bridges cannot be broken. Sarcomere lengths are the shortest at about 1.4 to 2.0 μm when the muscle is in full rigor and the muscle becomes inextensible (Khan, 1974; Dunn et al., 1993; Lyon and Buhr, 1999). This variability in sarcomere length is due to the variable energy reserves available and their utilization (Smith and Fletcher. 1988). Deboning before rigor mortis when ATP is present, initiate nervous signal response in the muscle and contraction takes place (Sams and Owens, 2010). The process of rigor mortis is expedited with early pH decline below 6.3 to 6.2 with peak tension at pH 6.0 as the muscle reaches full rigor (New bold, 1966; Hedrick et al., 1994). The final phase of rigor mortis is disappearance of contraction of muscle filaments post mortem and starts with the decrease in tension in the muscle. The decrease in tension is because of the proteolytic degradation of myofibrillar proteins, resulting in dissolution of Z disks and, loss of ultra-structural integrity (Hedrick et al., 1994; Lyon and Buhr, 1999). The postmortem proteolysis by degradation of Z-disc is carried out by the Ca^{+2} dependent, neutral proteolytic system calpain-calpastatin which include μ calpain and m-calpains (Lyon and Buhr, 1999).

MEAT QUALITY

There are numerous factors which play a part in conversion of live muscle into meat which eventually affects the quality characteristics of meat. Meat quality parameters like color, texture, tenderness and moisture are severely altered by the events occurring during the conversion of muscle to meat (Braden, 2013).

POSTMORTEM pH

The changes in postmortem pH along with temperature during the process of rigor mortis and after its development have major contribution in the development of meat quality attributes like color, water holding capacity and texture (Pearson, 1994; Wulf and Page, 2000; Cavitt and Sams, 2003; Jensen et al., 2004; White et al., 2006; Braden, 2013). Normal pH of muscle just before slaughter is close to neutral (7.0 to 7.3) (Sayas-Barbera, 2010) regardless of species in living muscle but the pH drops because of accumulation of lactic acid with the start of anaerobic glycolysis. The pH later drops between 5.5 and 5.9 in muscles where white fibers predominate and to about 6.1 where red fibers predominate in chickens after the resolution phase of rigor mortis (Sayas-Barbera, 2010; Alvarado and Owens, 2006). Higher temperature can accelerate decline of pH (Marsh, 1954). Meat quality can be negatively affected if there is rapid pH decline after exsanguination (Braden, 2013). This rapid pH can be due to premortem stress in the animal, improper chilling which leads to higher carcass temperature or a genetic condition like PSE defect. Rapid change in pH leads to pH near the isoelectric point of meat which is approximately 5.1 (Alvarado and Owens, 2006). Isoelectric point is where there is zero net charge that is equal, positive and negative charges. Such a pH near to isoelectric point can cause meat to become watery, pale color and soft lean condition called as pale, soft, and exudative (PSE) meat (Braden, 2013). On the other hand, much slower decline in pH and higher pH than 6.1 can led to a condition called as dark, firm and dry (DFD), though this is more likely in red fibered muscles (Hedrick et al., 1994; Offer et al., 1989; Alvarado and Owens, 2006). Both these conditions negatively impact meat quality. Protein denaturation can occur if the muscle pH is lower than normal and muscle temperature is higher (Offer, 1991). Such meat will not perform well in further processing and also can affect water holding capacity and color of fresh meat.

COLOR

From the point of view of a consumer, color is the most critical component of fresh meat appearance and an indicator of meat quality from consumer perception, especially when purchasing meat. Color is dependent upon myoglobin content, pH and the pigmentations. Myoglobin a sarcoplasmic protein which determines color of meat. Myoglobin content is influenced by the function of muscle where muscle subjected to more activity has higher myosin (Padilla, 2010); therefore, thigh and drumstick meat of chicken contains more myoglobin compared to breast meat. More the myoglobin, darker is the color as myoglobin attracts more oxygen which when oxidized forms metmyoglobin to give darker appearance. Hence, thigh and drum meat of chicken has a darker appearance than breast meat. If muscle pH is near to the isoelectric point, due to less water in between fibers and more water on surface, the color of muscle is pale as light scatters from muscle (Adams and Moss, 2000). The incident light on a freshly slaughtered muscle is absorbed by myoglobin and therefore appears dark while, in PSE condition the incident light scatters and cannot penetrate due to denaturation of proteins resulting in a paler color (Offer and Knight, 1988b).

WATER-HOLDING CAPACITY

Water-holding capacity can be defined as the ability of meat to retain its inherent water during storage conditions, thermal processing, force application and/or processing in addition to added water in form of marination (Hamm, 1960; Jeffery, 1983; Hedrick, 1994). Muscle in general consist of 75% water and plays a vital role in muscle food palatability, functionality, and shelf-life (Bechtel, 1986; Hedrick et al., 1994; Honikel and Hamm, 1994).

Water in muscle can be categorized into three types: bound, immobilized, and free water. Bound water is held tightly via myofibrillar protein charges but contributes only 1% of muscle water. Immobilized water is found within the muscle ultra-structure constituting 10 to 15% and the rest is free water which is held within muscle by weak capillary forces (Hamm, 1960; Cooke and Wein, 1971; Eisenberg and Kuda, 1975; Hedrick, 1994; Fennema, 1996; Barbut, 2002). The water-holding capacity in muscle is influenced by two phenomenons, namely ionic effect and steric effect. In ionic effect, as the pH of muscle approaches near to the isoelectric point, the water-holding capacity decreases. As water is a dipolar molecule, there are no charges available to attract to water molecules and therefore water is not able to bind with the myofibrillar protein structure and hence less water is held in the muscle (Bendall, 1973; Hedrick, 1994). Water holding capacity increases and decreases linearly as pH increases or decreases (Apple and Yancey, 2013). In steric effect, less space is available for proteins as the space between muscle protein structure decreases with contraction. The sarcomeres get shortened in the contractile state and less space is available within the muscle to hold water and water is expelled into extracellular space (Hedrick, 1994; Offer and Knight, 1998a). With pH near isoelectric point in muscle, denaturation of myosin occurs and less space for holding water is available as actomyosin bonds are contracted resulting in decrease in water holding capacity (Barbut, 2002). The myosin lattice shrinkage causes expulsion of water into extracellular space (Penny, 1969).

MEAT TENDERNESS

Consumer acceptance is greatly affected by the tenderness of meat. Sarcomere shortening, or contractile state and myofibrillar protein degradation, as well as genetic strain, age and deboning time can influence tenderness of poultry meat (Northcutt et al., 2001; Cavitt et al., 2004). Shorter the sarcomere, more force is required to shear through the muscle (Weaver et al., 2008). Prerigor deboning is major cause of sarcomere shortening because

ATP is still present which provides energy for contraction. Additionally, because meat is removed from carcass, there is no skeletal restraint which limit the shortening of boneless muscle resulting in toughening of cooked meat (Goodwin, 1984; Stewart et al., 1984; Papa and Fletcher, 1988; Papa et al., 1989). Xiong et al. (2006) reported increase in shear parameters from 0.25 to 1.25 h postmortem and overall decrease in shear parameters following 1.25 h until 24 h postmortem when measured by three different instruments. Age is also a major factor by which tenderness of poultry meat is affected. Mehaffey et al. (2006) reported that meat of 7 wk old broilers was tougher than 6 wk old broilers at two different debone times. These differences in age can be due to difference in rates of rigor mortis development and its interaction with debone time. Brewer et al. (2013) reported increased myofiber diameter in older birds, which may contribute to age difference.

Tenderness is also affected by postmortem protein proteolysis. Myofibrillar protein are degraded by endogenous proteolytic enzymes and reduction in muscle tension leads to a tender meat (Devey and Gilbert, 1966; Bandman and Zdanis, 1988; Ouali, 1990; Schreurs, 2000). Proteins like titin, nebulin, desmin, vinculin, dystrophin and troponin-T are degraded by µ and m-calpains (M-calpain and µ-calpain) (Lyon and Buhr, 1999; Geesink et al., 2006; Sayas-Barbera, 2010; Braden, 2013). Temperature and pH play a vital role in postmortem proteolysis. Higher temperatures increase the enzymatic reaction speed and lower pH decline denatures the myofibrillar proteins resulting in higher tenderness of meat (Claeys et al., 2001; Rees et al., 2002). Processing step, like chilling postmortem, also affects tenderness of meat. It is important to have a balance between production and depletion of heat in meat. Higher muscle temperature causes rapid decline in muscle pH which can led to condition such a PSE meat (Lyon and Buhr, 1999). On the other hand, rapidly chilled meat can led to toughness because of shortening of sarcomeres with condition called as cold shortening. Electrical stimulation can help prevent cold shortening as it degrades the ATP prior to release of calcium (Braden, 2013).

Collagen also plays an important role in tenderness of muscle. Perimysium connective tissue which encircle the bundles of muscle are responsible for raw like texture in cooked meat. The number of collagen cross links in the connective tissue increases by age making the meat tougher (Kerth, 2013; Owens and Meullenet, 2010). Generally, the toughness of meat due to connective tissue is not a major factor in poultry as broilers are grown less than 8 weeks of age (Fletcher, 2002; Owens and Meullenet, 2010). Though, in recent times, broilers have been grown longer than 8 wk so this may potentially be more of a problem in future.

GROWTH AND MEAT QUALITY

Chicken is the most popular form of meat because of its low cost, availability and ease of cooking. The per capita consumption of chicken in the United States increased by over 30% from 1995 to projected statistic of 2015 (National Chicken Council, 2015). This increased demand has led to pressure on broiler industry to increase the growth rate and more meat yield with lower feed conversion ratio (Petracci and Cavani, 2012). Such a pattern of growth muscle leads to muscle damage and consequently meat quality issues (Dransfield and Sosnicki, 1999). Studies also show that fast-growing strains are more susceptible to myopathies resulting in impaired meat quality (Anthony, 1998; Duclos et al., 2007). The amount of feed and time required to achieve market weight is reduced significantly over recent years and this progress is mostly due to genetic selection; however, such a selection has led to an increase in physiological breakdowns related to increased growth rate, such as PSE condition (Anthony, 1998). These increased incidences of muscle mayopathies are a result of negative changes in the morphology and biochemistry of muscle along with postmortem events like chilling (Solomon et al., 1998). Petracci et al. (2013c) reported higher breast-yielding birds have greater abnormal fibers than low breast-yielding birds and there is increase in fiber diameter of broilers with lean and high breast yield (Von et al., 2002). Mazzoni et al. (2015) reported that the abnormal muscle fibers had lost its polygonal shape with increased lipid in intrafibrillar spaces with some regeneration of fibers. Intense genetic selection in conjunction with stress often result in syndromes like deep pectoral myopathy in which the *Pectoralis minor* turns green because of necrosis. Muscle activity induced by handling stress, increases the production of lactic acid, which if not carried away by blood results in damage to cells with swelling and edema (Julian, 2005). Eventually, swelling causes pressure to rise within muscle restricting blood flow to the muscle leading to necrosis. Also, PSE muscle conditions in the *Pectoralis major* results in softer texture and reduced water-holding capacity along with pale appearance.

PSE CONDITION

Pale, soft and exudative meat is characterized by pale muscle color, low water-holding capacity, soft texture, and poor protein functionality (Owens et al., 2000; Woelfel et al., 2002; Zhang and Barbut, 2005). The occurrence of myopathy was first observed in swine industry and its effect on pork quality was reported by Briskey (1961), it was reported that this condition results because of postmortem glycolysis rate. Van Hoof (1979) reported the occurrence of similar condition in turkey breast meat. In swine the cause is due to the genetic mutation of ryanodine receptor (RyR) which controls the flux of calcium (Fujii et al., 1991). Due to the flow of Ca^{+2} surrounding the contractile proteins, the metabolism is expedited with increase in body temperature resulting in contraction of muscles rapidly (Strasburg and chiang, 2009). Because poultry has two RyR forms, until now there is no evidence of occurrence of PSE condition in poultry due to genetic mutation (Percival et al., 1994). In poultry, evidence of PSE like condition occurrence is mostly due to premortem factors such as heat, transportation, and handling practices. Water-holding capacity of muscle is greatly affected by this condition due to denaturation of myofibrillar and sarcoplasmic proteins and pH near to isoelectric point resulting in water being expelled in extracellular spaces (Offer, 1991; Pietrzak et al., 1997; Rathgeber et al., 1999; Alvarado and Sams, 2004). In contrast to PSE, dark, firm and dry (DFD) meat is characterized by high water-holding capacity as more space is available to hold water within the muscle due to higher pH away from the isoelectric point. Due to less water in extracellular space, light gets absorbed resulting in darker color.

Incidence of PSE meat is up to 50% in the U.S. (Barbut, 1996; Woelfel et al., 1998; Owens et al., 2000) causing great economic losses to the poultry industry. Marination of meat with this quality issues has proven to be useful in increasing water-holding capacity, which eventually helps in increase of consumer perception of tenderness and juiciness. The most common components of marination are salt and phosphates (Barbut et al., 1989), which help in minimizing loss of moisture during cooking and storage conditions (Forning and Sackett, 1985; Lemos et al., 1999). Sodium chloride (NaCl) is the frequently used salt in marinade solution. Salt increases the ionic strength of water and the meat absorbs marinade by decreasing the sarcolemma integrity by the process of osmosis until equilibrium is achieved (Alvarado and McKee, 2007; Brewer, 2004). Spaces among the protein molecules are opened by unfolding of proteins which allow more water to be held. Salt also lowers the isoelectric point of meat as chloride anions binds strongly to the positive charges of actomyosin but sodium cations bonds weakly with the negative charges. Sodium tripolyphosphates are commonly used in marination of poultry products (Barbut et al., 1989). Phosphates increase the ionic strength of proteins and also increase the pH away from isoelectric point of actomyosin resulting in swelling of myofibrils due to availability of more space to hold water (Pearson and Gillett, 1996). Phosphates also help retain water during cooking (Goodwin and Maness, 1984, Xiong and Kupski, 1999).

WHITE STRIPING

White striping is a condition in which gross white striations appear running parallel to muscle fibers on the breast fillets and chicken thigh. These striations can occur in varying degrees (Kuttappan et al., 2012a). Studies indicate the white striping occurs in modern chicken which is characterized by increased growth rate and breast yield (Kuttappan et al., 2012a; Petracci et al., 2013a). Under experimental conditions, the incidence of white striping can be over 50% (Kuttappan et al., 2012a, b). Under commercial conditions, Petracci et al. (2013a) reported that 12% percent of birds had moderate to severe degrees of white striping. High breast-yielding birds, males, fast-growing birds, high-energy diet, and heavy birds can increase the incidence of white striping (Petracci et al., 2013a; Kuttappan et al., 2012a; Kuttappan 2013a). Kuttappan et al. (2012b) evaluated effect of different levels of dietary vitamin E on the incidence of white striping, and reported that vitamin E had no effect on occurrence of white striping. When severe white-striped fillets were analyzed for histology, elevated serum enzyme levels were associated with degeneration of fibers along with fibrosis and lipidosis, variability in fiber size, lysis of fibers, mild mineralization, occasional regeneration of fibers, mononuclear cell infiltration, and interstitial inflammation (Kuttappan et al., 2013b,c). Proximate analysis of moderate and severe white striped fillets showed increase in fat and decrease in protein content (Kuttappan et al., 2012a; Kuttappan et al., 2013c; Mudalal et al., 2014b; Petracci et al., 2014). The quality of protein is also greatly depreciated with decline in myofibrillar and sarcoplasmic content (Mudalal et al., 2014b). Due to the decline in myofibrillar content, water-holding capacity of muscle is negatively affected with greater cook losses and decrease in marinade uptake (Petracci et al., 2013a, b; Mudalal et al., 2014a, b). Severe white-striped fillets have greater pH, a*, and b* values, suggesting that this condition does not make fillets pale as observed in PSE condition (Kuttappan et al., 2013a; Petracci et al., 2013a; Mudalal et al., 2014a). As this condition is observed in heavy birds, it has been reported that the severe white-striped fillets have greater weight and height (Kuttappan et al., 2013a; Petracci et al., 2013a). Severe white-striped fillets also cause decrease in acceptance by consumers with reason of more fatty appearance of severe fillets (Kuttappan et al., 2012c).

WOODY BREAST

Woody breast is an emerging meat quality problem with limited information available, and is characterized as pale expansive areas of hardness accompanied by white striations (Sihvo et al., 2014). In severe woody breast, muscle tend to be hard and rigid throughout the fillets right from the cranial region to caudal tip. Histological analysis of woody fillets showed myofibers of various diameters and irregular shape (Sihvo et al., 2014). Similar to white striping, degeneration and regeneration of fibers is also seen in woody breast along with thickening of interstitium, variable amount of connective tissue separating the muscle fiber (Sihvo et al., 2014). It is suspected that fibrosis maybe the cause of hardness in woody breast which causes in decline of meat quality parameters (Mudalal et al., 2014a). Woody breast causes significant changes in water holding-capacity with lower marinade uptake and higher cook loss in non-marinated fillets but, in combination with severe white striping, these fillets have even greater cook losses and lower marinade uptake (Mudalal et al., 2014a). Interestingly, the tenderness of fillets is not affected with severity of both white striping and woody breast individually or in combination (Mudalal et al., 2014a).

NEED FOR RESEARCH

White striping has been has been a persistent meat quality issue from the past decade with increasing severity. Researchers all over the world have been addressing this issue and a few reported its effect on meat quality. With the incidence of novel myopathy called as “woody breast” in recent times along with white striping, the poultry industry has been facing great economic losses. Limited information of woody breast is available on its effect on meat quality. Processors around the world have acknowledged these problems and are eager to gain information on effects of these abnormalities on meat quality attributes like water holding capacity, protein functionality and cooking loss.

Woody breast is characterized by palpable hardness of the *pectoralis major* so it is important to identify if this hardness is due to shortening of sarcomeres during contraction. Lower fragmentation of muscle can result in toughness of meat so it is essential to know effect of postmortem proteolysis in the first 24 h. Following slaughter, age and the time of debone can also affect toughness of meat so this study was conducted with different age groups of birds and two different times of debone.

Additionally, traditional method of improving water-holding capacity and tenderness like tumble marination should be evaluated for its effectiveness on such myopathies. The aim of this study was to determine whether these defects negatively impact chicken meat quality and the degree of adversity caused individually and/or in combination.

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MEAT QUALITY OF BROILER BREAST FILLETS WITH WHITE STRIPING AND WOODY BREAST MUSCLE MYOPATHIES

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ABSTRACT

The global poultry industry has been faced with emerging broiler breast meat quality issues including conditions known as white striping (WS) and woody breast (WB). These conditions have been associated with rapid-growing, high-breast yielding broilers. White striping is characterized by white striations parallel to muscle fibers primarily in breast fillets while woody breasts are characterized by palpable hardness of the raw fillets. Two experiments were conducted to evaluate effects of white striping and woody breast hardness on meat quality traits in broiler breast fillets. Birds were processed at 8 wk (Exp. 1) and at 6 and 9 wk of age (Exp. 2), whereas deboning was carried out at 4 and 2 h postmortem in Exp. 1 and 2, respectively. Fillets were categorized as: normal for both white striping and woody breast (NORM); mild for white striping and woody breast (MILD); severe for white striping and mild for woody breast (WS); severe for woody breast and mild for white striping (WB); or severe for both white striping and woody breast (BOTH). Sarcomere length, gravimetric fragmentation index (GFI; Exp. 1 only), marination uptake, cook loss, and Meullenet-Owens razor shear energy (MORSE) values on non-marinated and marinated fillets were assessed. Sarcomeres tend to be longer ($P \leq 0.07$) with increasing severity of white striping and woody breast in both experiments, but GFI was not impacted ($P = 0.49$). Marinade uptake decreased ($P < 0.05$) with increasing severity of white striping and woody breast, with BOTH categorized breast having the least marinade uptake in both experiments. Cook losses of non-marinated and marinated fillets were greatest ($P < 0.05$) in the BOTH category. Even though MORSE values did not ($P = 0.28$) differ in non-marinated fillets, in marinated fillets, BOTH breast fillets had greater MORSE values ($P < 0.05$) than other categories of fillets in Exp. 1. In addition, non-marinated NORM fillets had greater ($P < 0.05$) MORSE values than the other categories among birds processed at 6 wk age; however, MORSE values did not ($P = 0.08$) differ among marinated breasts, regardless of the category, nor were MORSE values affected

(P= 0.05) by category in marinated fillets processed at 9 wk of age. Results of this study suggest that severe degrees of white striping and woody breast individually or in combination negatively impact meat quality, especially water holding capacity.

Key words: Broiler, Meat, Quality, Myopathy

INTRODUCTION

Boneless breast meat is a popular meat choice in the United States and is considered a premium product. To meet the demand of this fast growing industry the processors are adopting high breast-yielding strains of broilers and these heavy debone markets have increased significantly for better supply. Today, chickens and turkeys are marketed in about half the time and at about twice the body weight compared to 50 years ago (Barbut et al., 2008). Challenging birds to attain high body weight within a short period of time can cause various meat quality problems (Kuttappan et al., 2012a). Because these rapid-growing broilers are now grown for longer time to achieve high meat yield, broiler myopathies, like white striping and more recently, woody breasts are severely affecting meat appearance and other meat quality attributes (Kuttappan et al., 2012a; Petracci et al., 2014)

The severity of white striping has increased in recent years and is characterized by white striations parallel to muscle fibers in which muscle fiber degeneration takes place with infiltration of fat and connective tissue (Kuttappan et al., 2012a; 2013b; 2013c). White striping is associated with heavier birds (Kuttappan et al., 2013a) and can be observed in varying degrees of severity. On the other hand, woody breast is a more recent myopathy characterized as pale expansive areas of substantial hardness accompanied with white striation (Sihvo et al., 2014), by hard and rigid fillets in which muscle fiber degeneration 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. According to Sihvo et al. (2014), fast growth rate, along with increased breast meat yield, plays a significant role in development of woody breast in chicken and abnormal fibers were observed in high-yielding breast in study conducted by Petracci et al. (2013b). Researchers have investigated a number of factors affecting white striping, including that males have higher incidences than females (Kuttappan et al., 2013a), high yielding genotypes show higher incidences of white striping than low yielding genotypes (Petracci et al., 2013a), and higher growth rates has are also associated with greater incidence of white striping (Kuttappan et al., 2012a). In a study of histology of abnormal fibers, Mazzoni et al. (2015) reported severe myodegeneration and fibers with divergent diameters and shapes associated with woody breast characteristics, which are very similar to the histological characteristics associated with white striping (Sihvo et al., 2014). Apart from the aforementioned results of Mazzoni et al. (2015), limited information is available concerning the occurrence of woody breasts and associated meat quality defects.

The occurrence of white striping and woody breast is negatively impacting the poultry processing industry, and the industry is facing great economic losses due to customer complaints about as fillets affected by these myopathies. According to a study, consumers are more likely to buy normal fillets without any white striations and, over 50% of consumers indicated that they will probably not or definitely not buy moderate or severely white-striped fillets (Kuttappan et al., 2012c). Consumers also indicated that fillets with severe white striping look fattier and have a marbled appearance (Kuttappan et al., 2012c). Inclusion of such meat in further processed products can impact the final product quality. Kuttappan (2012a) reported that there is increase in fat content and decrease in protein content of white-striped fillets which can be a concern in further processed products due to decrease in functionality of proteins. In Italy, Petracci et al. (2013a) reported increased cook loss and decreased marinade uptake in fillets with white striping whereas, woody breast fillets had lower marinade uptake and greater cooking losses than white-striped fillets for both unprocessed and marinated meat (Mudalal et al., 2014a).

With evidence that white striping and woody breast myopathies can occur simultaneously in a single chicken breast fillet, it is important to study the effects of these myopathies on meat quality. Therefore, 2 experiments were conducted to determine the effects of white striping and woody breast, individually or in combination, on meat quality of broiler breast fillets, and to determine incidence of these myopathies in research flock raised using commercial practices, including variations in age at processing and postmortem debone times.

MATERIALS AND METHODS

Experiment 1

A total of 285 high breast-yielding male broilers with a live weight of approximately 3.97 kg were processed at the age of 61 d using commercial inline system at the University of Arkansas pilot processing plant (Fayettevile). Birds were electrically stunned (11 V, and 11 mA for 11s), manually slaughtered and bled out, soft scalded (53.8°C, 2 min), and picked using inline commercial defeathering equipment (Mehaffey et al., 2006). The carcasses were then manually eviscerated and rinsed. Following evisceration, birds were prechilled at 12°C for 15 min and chilled for 90 min at 1°C in immersion chilling tanks with manual agitation at regular intervals to enhance the efficiency of chilling. After chilling time, the birds were aged at 4°C in a walk-in cooler until the debone time of 4 h postmortem.

The *pectoralis major* muscle was deboned and scored for white striping using normal (0), moderate (1), or severe (2) as described by Kuttappan et al. (2012c) as well as additional category of extreme (3), which was defined as striations greater than 3 mm throughout fillet. Whole breast fillets were evaluated for degree of hardness (woody breast) based on tactile evaluation and categorized as 0= fillets that were flexible throughout (normal); 1= fillets that were hard mainly in the cranial region but flexible otherwise (mild); 2= fillets that were hard throughout but flexible in mid to caudal region (moderate); 3= fillets that were extremely hard and rigid throughout from cranial region to caudal tip (severe). Additionally, fillets were a score of 0.5 and categorized as “Normal” for white striping and woody breast (slight white striations and slight palpable hardness) as it is difficult to find fillets with no striations and hardness. One person carried out the scoring by this subjective method to be consistent with scoring. For the purpose of meat quality analysis, based on incidence, 115 whole breast fillets were categorized into multiple categories described in Table 1.

The whole fillets were packed in zip-sealed bags and stored overnight at 4°C. At 24 h postmortem, fillets were removed from cooler and split into halves. Samples were cut from caudal region of left side and then held at -80°C until analysis of sarcomere length (SL) and gravimetric fragmentation index (GFI). Cranial region of the left side fillet was vacuum packed in plastic bags and stored at -20°C for later determination of cook loss and texture analysis (non-marinated fillets). The right sides of breast fillets were vacuum packed in plastic bags and stored at -20°C for later determination of marinade uptake, cook loss, and texture analysis (marinated fillets). Fillets were removed from the freezer 36 h prior to cooking to ensure adequate thawing. Right side breast fillets which were to be marinated were portioned horizontally with a target height of 40 mm in the cranial region to reduce effect of fillet thickness on marination properties. Fillets were then tagged and tumble marinated in a salt (NaCl) - phosphate (STP) solution for 20 min and a target of 15% marinade pickup with 0.75% NaCl and 0.45% phosphate (Carnal 822; Budenheim USA Inc., Plainview, NY). Marination was carried out in replicates where each category was subjected to two replications. The fillets were allowed to rest 15 minutes after vacuum tumbling and weighed to compute marination uptake percentage. Both left and right side breast fillets were weighed before cooking in aluminum foil covered pans on raised wire racks in an air convection oven to an internal temperature of 76°C (Cavitt et al., 2004). After cooking, the fillets were cooled to room temperature and weighed to calculate cook loss percentage. Individual fillets were wrapped in aluminum foil and stored overnight at 4°C before texture analysis the following day. Texture analysis was carried out using Meullenet-Owens razor shear technique (Cavitt et al., 2004) to assess the tenderness of non-marinated and marinated fillets. This technique uses a texture analyzer (model TAX-T2, Texture Technologies, Scarsdale, NY). Three shear readings were taken perpendicular to the muscle fibers at different locations of each fillet and the razor blade was changed after every 99 shears so the blade does not becomes dull (Cavitt et al., 2004).

Gravimetric fragmentation index was carried out to assess postmortem proteolysis according to the protocol described by Sams et al. (1991). Samples were homogenized in idoacetate solution, vacuum filtered through 250-μm nylon screen and the residue was dried and weighed. Sarcomere length (μm) was measured using laser diffraction method described by Voyle (1971) and Cross et al. (1980).

Experiment 2

High breast-yielding broilers were processed at the age of 6 and 9 wk of age using previously described commercial practices. The average live weight of birds processed 6 and 9 wk of age was approximately 2.66 and 4.62 kg, respectively. Processed broilers were aged on ice in a walk-in cooler at 4°C until time of debone.

Fillets were deboned at 2 h postmortem and scored for severity of white striping by visual evaluation as described by Kuttappan et al. (2012c) and woody breast by tactile evaluation as described previously. For meat quality analyses, 160 fillets and 87 were collected at 6 and 9 wk of age, respectively. In this study, fillets were categorized into 3 classes (normal [NORM], severe for white striping and moderate for woody breast [WS], or severe for white striping and woody breast [BOTH]; Table 4). Based on limited availability, there was no category for severe woody breast with mild white striping as well as mild for both white striping and woody breast.

After storing for 24 h, fillets were split into halves and samples were collected for sarcomere length from the caudal region of left side and then held at -80°C until analysis. Cranial region of the left side fillet was vacuum packed in plastic bags and stored at -20°C for determination of cook loss and texture analysis (non-marinated fillets). The right sides of breast fillets were vacuum packed in plastic bags and stored at -20°C for determination of marinade uptake, cook loss and texture analysis (marinated fillets). Right side breast fillets were portioned horizontally to 40 mm height and marinated as described in Exp. 1. After marination, fillets were allowed to rest 20 minutes after vacuum tumbling and weighed to compute marination uptake percentage. Left and right side breast fillets were weighed and then cooked in aluminum foil covered pans on raised wire racks in an air convection oven to an internal temperature of 76°C (Cavitt et al., 2004). After cooking, the fillets were cooled to room temperature and weighed to calculate cook loss percentage. Texture analysis was carried out using Meullenet-Owens razor shear technique (MORS) (Cavitt et al., 2004) to assess the tenderness of non-marinated and marinated fillets by measuring MORS energy (N.mm). Texture analyzer model TAX-T2 (Texture Technologies, Scarsdale, NY) was used to take four shear readings perpendicular to the muscle fibers at different places of each fillet and the razor blade was changed after every 99 shears so the blade does not become dull (Cavitt et al., 2004).

Statistical Analysis

Data for both the experiments was analysed using the GLM procedure in JMP (SAS, 2014), with the main effect of the category (NORM, MILD, WD, WD, BOTH). Additionally, non-marinated and marinated fillets were analyzed separately for cook loss MORSE values. Due to the difference in age and debone time between experiments, the two experiments were analysed separately. In Exp.2, 6 wk age and 9 week age birds were analysed separately. Means separated by Tukey's HSD and significance level was set at P<0.05.

RESULTS AND DISCUSSION

Experiment 1

The incidence of white striping from the total number of 285 birds was 96.1%, with 63.8% of breast fillets receiving a score of 1 (moderate), which is similar to previous studies (Kuttappan et al. (2012a; 2012b; 2013b), whereas 32.3% of breast fillets received a score of 2 (severe). Furthermore, about 2 % was considered extreme (3), a category of severity not previously observed in this laboratory. The incidence of woody breast was also 96.1%, with 48% scored as mild (1), 28% scored as moderate (2) and 20% of fillets scored as severe (3). Following scoring for white striping and woody breast abnormalities, the fillets were placed into treatment categories of: NORM, MILD, WS, WB and BOTH and the averages scores for white striping and woody breast in each category reported in Table 1.

Woody breast is characterized by hardness of the fillet and is often described as a fillet with outbuldge or a ridge (Mudalal et al., 2014a; Sihvo et al., 2014), having a contracted muscle appearance. Thus, sarcomere lengths of samples in each category were assessed, and, interestingly, the sarcomeres of BOTH and WB-fillets tended to be longer (P=0.07) than NORM-fillets (Table 2).These results would suggest that the hardness in woody breast is not associated with sarcomere shortening.

Table 1. Description of categories analyzed for meat quality based on the average scores of white striping (WS) and woody breast (WB) myopathies (Exp.1)

Categories	Average Score for white striping	Average score for woody breast	Quantity (n)
NORM[1]	0.61	0.47	17
MILD[1]	1	1	28
WS[1]	2.09	1	16
WD[1]	1.11	2.37	28
BOTH[1]	2.26	2.73	26

[1]NORM= normal for WS and WB; MILD= moderate for WS and mild for WB; WS= severe for WS but mild for WB; WB= severe for WB but moderate for WS; BOTH= severe for WS and WB.

As marination is a common method for adding value through improving breast yields, fillets classified as NORM had the greatest (P<0.05) marinade uptake, whereas MILD-fillets had greater (P<0.05) marinade uptake percentages than WB and BOTH-fillets (Table 3). Mudalal et al. (2014a) conducted a similar study on effects of white striping and woody breast on meat quality, which was recently published and these results support the finding of Mudalal et al. (2014a) who reported decrease in marinade uptake in WB and WS+WB categories. A possible reason for lower marinade uptake and higher cook loss (non-marinated) in WS, WB and BOTH can be attributed to greater loss of protein from woody breasts with fibrosis (Sihvo et al., 2013) and white striped breast with lipidosis (Kuttappan et al., 2012a) with the subsequent loss of functionality of myofibrillar proteins (Mudalal et al., 2014b). In marinated fillets, only BOTH has significantly higher cook loss compared to NORM (P<0.05).

Breast fillets categorized as NORM had the lowest (P<0.05) cook loss percentages, whereas those classified as WS and BOTH had greater (P<0.05) cook losses than fillets categorized as MILD (Table 2). There have been varied reports on cook loss in severe white-striped fillets compared to normal. Kuttappan et al. (2013a) reported that cook loss percentage did not differ between normal and severe white-striped fillets; however, Petracci et al. (2013a) reported higher cook losses in severe-white striped fillets compared with normal. Whereas, Mudalal et al. (2014a) reported higher cook loss in marinated fillets with severe woody breast category and severe both abnormalities category compared to normal and severe white striped category fillets. Differences in these studies may be related to genetics of birds, environment, and stress and provided nutrition. Another possible reason for differences of results in this study can be age at processing. Mudalal et al. (2014a) proposed that chicken breast get hard (woody) at later stage of development.

Table 2. Effect of white striping (WS) and woody breast (WB) on quality attributes of non-marinated breast meat (Exp.1)

	Category[1]					
Attribute	NORM	MILD	WS	WB	BOTH	Pooled SEM
n	17	28	16	28	22	
Cook loss (%)	27.75[c]	30.8[bc]	37.09[a]	34.82[ab]	38.11[a]	0.62
MORSE (N.mm)	191.79	205.58	222.22	219.87	210.06	4.10
Sarcomere Length (µm)	1.69	1.73	1.79	1.80	1.80	0.01
GFI[2]	160.57	167.00	143.84	166.52	173.37	4.73

[a-c] means within a row followed by different superscript letters differ significantly (P<0.05).

[1]NORM= normal for white striping and woody breast; MILD= moderate for white striping and mild for woody breast; WS= severe for white striping but mild for woody breast; WB= severe for woody breast but moderate for white striping; and BOTH= severe for white striping and woody breast.

[2]Gravimetric fragmentation index.

Among non-marinated fillets, MORSE values did not (P= 0.28) differ among the 5 categories, indicating that the shearing properties do not change with the both abnormalities (Table 2). In contrast, where right side breast were vacuum marinated, BOTH-fillets had greater ($P<0.05$) MORSE values than those categorized NORM and MILD (Table 3). The increased MORSE values in BOTH-fillets maybe due to the low marinade pickup, which reduced effectiveness of ingredients to tenderize meat, which is consistent with Mudalal et al. (2014a). Interestingly, GFI did not (P=0.49) differ among categories in non-marinated breast fillets suggesting similar status of postmortem proteolysis in the first 24 h.

Table 3. Effect of white striping (WS) and woody breast (WB) on quality attributes of marinated breast meat in (Exp.1)

	Category[1]					
Attribute	NORM	MILD	WS	WB	BOTH	Pooled SEM
n	17	28	16	28	22	
Marinade uptake (%)	10.59^{a}	8.29^{b}	7.15^{bc}	6.26^{c}	5.85^{c}	0.24
Cook loss (%)	16.93^{bc}	15.61^{c}	22.02^{ab}	18.54^{abc}	22.60^{a}	0.52
MORSE (N.mm)	127.03^{b}	129.16^{b}	139.96^{ab}	139.1^{ab}	165.91^{a}	3.14

$^{a-c}$ means within a row followed by different superscript letters differ significantly (P<0.05).

[1]NORM= normal for white striping and woody breast; MILD= moderate for white striping and mild for woody breast; WS= severe for white striping but mild for woody breast; WB= severe for woody breast but moderate for white striping; and BOTH= severe for white striping and woody breast.

Experiment 2

Among fillets from birds processed at 6 wk of age, BOTH-fillets had longer ($P<0.05$) sarcomeres than NORM and WS-fillets, whereas fillets categorized as WS and BOTH had longer ($P<0.05$) sarcomeres than NORM-fillets when birds were processed at 9 wk of age (Table 5). Therefore, it can be concluded that sarcomeres are longer with increasing severity of white striping and woody breast, however, the reason of increase in length is unknown. Much deeper investigation of muscle at cellular level will be needed to understand the reason of differences in sarcomere length with these myopathies. The results further signifies the role of age in these myopathies, as in 6 wk birds, categories NORM and WS had no significant differences ($P>0.05$) in length, however, in birds of 9 wk, category WS had significantly longer ($P<0.05$) sarcomeres compared to NORM.

When processed at 6 wk of age, BOTH-fillets had greater ($P<0.05$) cook loss percentages than NORM and WS-fillets; however, fillets categorized as WS and BOTH had greater ($P<0.05$) cooking losses than NORM-fillets in birds processed at 9 wk (Table 5). While with regard to white striping only, 6 week fillets had similar results to Kuttappan et al. (2013a) who reported no difference ($P>0.05$) between severe white striped fillets and normal fillets. On the other hand, 9 wk non-marinated cook loss % results were similar to Petracci et al. (2013a), Mudalal et al. (2014a), and experiment 1 where severe white striped fillets had higher ($P<0.05$) cook loss than normal category.

Table 4. Description of categories analyzed for meat quality based on the average scores of white striping (WS) and woody breast (WB) myopathies in 6 and 9 week age birds (Exp.2)

Category1	Average score white striping	Average score woody breast	n
6 Weeks			
NORM	0.46	0.13	64
WS	2.00	0.91	46
BOTH	2.05	2.30	50
9 Weeks			
NORM	0.95	0.40	32
WS	2.00	0.75	23
BOTH	3.20	3.07	32

[1]NORM= normal for white striping and woody breast; WS= severe for white striping but mild for woody breast; and BOTH= severe for white striping and woody breast.

Regardless of the age at processing, NORM-fillets had the greatest ($P<0.05$) marinade uptake, and fillets categorized as WS had greater ($P<0.05$) marinade uptake than those categorized as BOTH (Table 6). These findings support the results of Exp.1, where NORM had greater ($P<0.05$) marinade uptake percentages compared to rest of the categories. Mudalal et al. (2014a) and Petracci et al. (2013a) reported similar results where marinade uptake percentage decreased with increasing severity of white striping and woody breast.

Fillets classified as BOTH had greater ($P<0.05$) cook loss percentages than either WS or NORM-fillets, regardless of the bird age at processing (Table 6) These results are consistent with findings of Mudalal et al. (2014a) and Exp.1; however Petracci et al. (2013a) reported that severely white-striped fillets had higher cook loss than normal fillets.

When processed at the age of 6 wk, non-marinated fillets categorized as NORM had greater ($P<0.05$) MORSE values than WS-fillets and BOTH-fillets (Table 5); however, MORSE values were similar ($P= 0.08$) among categories when fillets from 6 wk old birds were marinated (Table 6). Conversely, non-marinated WS-fillets had greater ($P<0.05$) MORSE values than non-marinated NORM-fillets when processed at 9 wk of age, and, when the other side fillets were marinated, those categorized as BOTH had greater ($P<0.05$) MORSE values than WS-fillets (Table 6). Petracci et al. (2013a) reported white striped fillets had greater shear values than normal fillets. The variations in results from past studies and this experiment may be attributed to the difference in strain, age and debone time of broiler birds. Industry reports of consumer complaints regarding texture makes it imperative to study texture assessment by sensory evaluation to note any relation of toughness of woody breast with consumer acceptance.

Table 5. Effect of white striping (WS) and woody breast (WB) on quality attributes of non-marinated breast meat in 6 and 9 week birds (Exp.2)

	Category1			
Attribute	NORM	WS	BOTH	Pooled SEM
6 Weeks				
n	64	46	50	
Cook loss (%)	28.20[b]	28.48[ab]	30.91[a]	0.46
MORS Energy (N.mm)	196.67[a]	180.23[b]	181.06[b]	2.49
Sarcomere Length (µm)	1.58[b]	1.62[b]	1.66[a]	0.007
9 Weeks				
n	32	23	32	
Cook loss (%)	28.26[c]	32.20[b]	35.52[a]	0.58
MORS Energy (N.mm)	193.82[b]	214.86[a]	206.88[ab]	2.68
Sarcomere Length (µm)	1.54[b]	1.63[a]	1.64[a]	0.10

[a-c] means within a row followed by different superscript letters differ significantly ($P<0.05$).

[1]NORM= normal for white striping and woody breast; WS= severe for white striping but mild for woody breast; and BOTH= severe for white striping and woody breast.

Table 6. Effect of white striping (WS) and woody breast (WB) on quality attributes of marinated breast meat in 6 and 9 weeks birds (Exp.2)

		Category[1]		
Attribute	NORM	WS	BOTH	Pooled SEM
6 Weeks				
n	64	46	50	
Marinade uptake (%)	13.98^{a}	10.27^{b}	7.53^{c}	0.30
Cook loss (%)	19.97^{b}	19.83^{b}	24.67^{a}	0.39
MORSE (N.mm)	131.87	124.46	136.74	2.14
9 Weeks				
n	32	23	32	
Marinade uptake (%)	8.61^{a}	7.21^{b}	4.92^{c}	0.26
Cook loss (%)	17.40^{b}	19.20^{b}	30.39^{a}	0.85
MORSE(N.mm)	148.89^{ab}	135.29^{b}	156.79^{a}	2.67

$^{a-c}$ means within a row followed by different superscript letters differ significantly (P<0.05).

[1]NORM= normal for white striping and woody breast; WS= severe for white striping but mild for woody breast; and BOTH= severe for white striping and woody breast.

CONCLUSION

The results of this study suggest that severe degrees of white striping and woody (hardness), together or alone, negatively impact some aspects of meat quality and these impacts on meat quality are driven by the growth rate and age of birds. Older and rapid-growing broilers are more likely to have white striping and woody breast and negatively affect meat quality especially water-holding capacity. Both of these abnormalities have potential to greatly affect the poultry industry, particularly the further-processed industry which will have to reformulate their products to compensate for reduced functionality and/or change in proximate composition (Kuttappan et al., 2012a; Petracci et al., 2014). Future research should include sensory analysis to determine acceptability of meat such abnormalities and to determine the use of white striping and woody breast in further processed products.

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CONCLUSION

White striping and woody breast have proven to be emerging meat quality issues negatively impacting water holding capacity of breast fillets. The sarcomere length was evaluated to identify if postmortem contraction plays a role in hardness of woody breast. However, the sarcomere length increased with the severity of white striping and woody breast, which indicates that postmortem contraction is not responsible for hardness of the fillets. Gravimetric fragmentation index was assessed to determine effect of postmortem proteolysis on hardness of the fillets. There was no difference in GFI indicating that postmortem proteolysis in the first 24h is not affected by both white striping and woody breast. It will be interesting to determine if there is decline in hardness of woody breast with storage time and it will be valuable to analyze GFI several days' postmortem to determine the role of postmortem proteolysis in decline of hardness if the decline occurs. The results of this thesis are important from aspect of meat quality and its use in further processed products. The marinade uptake was negatively affected as the severity of white striping and woody breast increased. The fillets with severity of both white striping and woody breast had the least marinade uptake and higher cook loss so it can be speculated that the severity of white striping and woody breast causes the loss of integrity muscle fibers resulting in inability to hold and retain water in raw state or in cooked form (both, naturally present in muscle and added in form of marination). The results of these studies indicate that the shear energy values (indicator of tenderness) of non-marinated meat are not affected by the severity of both with striping and woody breast. Further research should be conducted to understand consumer's perception on quality of meat affected by these abnormalities and also, the use of such meat in further processed products should be evaluated to understand if any changes take place in the quality of product.