MEAT QUALITY AND SENSORY ANALYSIS OF MARINATED BROILER BREAST FILLET PORTIONS AFFECTED WITH WOODY BREAST

by

ALEXANDER MAXWELL

Under the Direction of Koushik Adhikari

ABSTRACT

Recently, the poultry industry has encountered an emerging muscle myopathy known as woody breast (WB), characterized by hardness throughout the *Pectoralis major* muscle. Experiments were performed to assess marination performance of portioned fillets affected with WB and the effect of marination on meat quality factors, and describe sensory characteristics of WB portions using descriptive analysis. Fillets were categorized as normal (NORM), with no WB, or severe (SEV) WB. In Experiment 1, each fillet was portioned into dorsal and ventral halves. Portions from one side of each butterfly breast fillet were used as non-marinated controls, while portions from the other side were vacuum-tumble marinated. Marination performance was measured calculating marinade retention and overall raw product yield. Meat quality factors, including Warner-Bratzler (WB), cook loss, and cooked yield were measured. In Experiment 2, descriptive (n=9 trained panelists) sensory analysis was conducted with NORM and SEV marinated and non-marinated portions.

INDEX WORDS: descriptive sensory, woody breast, broiler, marination, portion, texture

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ALEXANDER MAXWELL

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Major Professor:	Koushik Adhikari
Committee:	Brian Bowker
	Hong Zhuang

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
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DEDICATION

This thesis is dedicated to all the people that found greatness in me and pushed me out of my comfort zone and continuously developed me on my path to help me achieve my impossible. I have succeeded through your efforts.

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CHAPTER 1

INTRODUCTION

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

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

Fillets affected with WB are exhibiting impaired texture and meat quality attributes when compared to normal broiler breast fillets. Texture is a major quality concern with boneless skinless broiler breast fillets (Sams, 1999) and is one of the sensory factors that influences the perception of quality by consumers that affect their purchasing decisions. Currently, the poultry industry is having complaints from consumers, therefore, WB broiler breast meat detected in poultry processing plants are often downgraded and sometimes rejected from human consumption, resulting in significant economic losses for the poultry industry (Petracci et al., 2015; Sihvo et al., 2014).

Based on these considerations, more research is necessary to describe how the texture of WB meat is different than normal (NORM) fillets, and its relation with quality traits, marination and cooking performance, and human sensory perception. Therefore, the objective of this study was to observe the effects of marination in ventral (skin-side) and dorsal (bone-side) butterfly portions, and determine differences in 10 sensory attributes in marinated portions using a trained descriptive sensory panel.

This study investigated the marination and cooking performance and texture properties of marinated NORM and severe (SEV) WB meat in two experiments: 1) Evaluation of the quality and technological traits of marinated SEV portioned fillets and its effect on tenderness using Warner-Bratzler shear force (WBS), and 2) descriptive analysis of marinated portioned fillets using a trained sensory panel (n=9 trained panelists), with WBS measurements performed to correlate with sensory data.

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CHAPTER 2

LITERATURE REVIEW

History and Economic Influences

Broilers are chickens raised for meat that are under 13 weeks of age at harvest and constitute virtually all commercial chicken production (Cochran, 2011; USDA ARS, 2002). Poultry production increased by 5.6 percent per year between 1960 and 1995 due to production efficiencies, genetics, falling retail prices, and an introduction of new chicken-based food products. The post 1970's exponential growth is attributed to the use of vertical integration. Vertical integration relies on contract production between growers and broiler processors. Typical contracts state that the processors supply the birds, feed, veterinary care, and transportation of the birds, while the farmers supply the growout houses and labor to grow the chickens (MacDonald, 2008). In 2011, the broiler industry relied almost exclusively on the integrated contract system, with 97 percent of broilers raised through integrator systems. (MacDonald, 2014)

The U.S. is the largest producer in the world and second largest broiler exporter, only second to Brazil (Davis et al., U.S. broiler exports in 2015 totaled 6.3 billion pounds, shipping to over 120 countries including the European Union, China, Hong Kong, Japan, Mexico, Russia, and Saudi Arabia. In 2015, the U.S. poultry industry produced 53.4 billion pounds of live weight broilers, with a value of $28.7 billion, down 12 percent from 2014 (USDA NASS, 2016). When compared against other animal protein species, broiler meat production has outperformed beef and pork since 1996. Broiler production is projected to increase in the next decade, although the growth rate is expected to be modest for overall live broiler production, however, projections show the highest rate of growth recorded in billions of pounds until at least 2018 (National Chicken Council, 2016d).

Consumption of chicken meat shows increases as well, with a U.S. per capita consumption of 90 pounds (National Chicken Council, 2016c). Increased demand for broiler meat for domestic and export use has driven innovation to improve production efficiencies, increase chicken live weight, and continued use of integration in the industry to closely monitor all aspects of the broiler production cycle (MacDonald, 2008).

Overview of Georgia Poultry Industry

Georgia is the leading broiler producing state, producing 1.3 billion broilers in 2015 with a farmgate value of $4.4 billion on 5,490 farm operations (University of Georgia Cooperative Extension, 2012). Broiler production is the number one commodity grown in the State of Georgia, and makes up 32 percent of the total value of all food and fiber commodities grown in the state. According to the Center for Agribusiness and Economic Development at the University of Georgia, poultry contributed about $25 billion to Georgia's economy through farms, processing and allied industries in 2015, with 109,000 jobs in the state dependent on the poultry industry (The Center for Agribusiness & Economic Development, 2015). The Georgia poultry industry has dramatically increased in size over several decades with 3/4 of the state's 159 counties involved in various segments of production. Major poultry integrators and processors based in Georgia include Cagle's, Claxton Poultry Farms, Fieldale Farms, Harrison Poultry, Keystone

Foods, Mar-Jac Poultry, Perdue Farms, Pilgrim's Pride, Sanderson Farms, Tyson Foods, and Wayne Farms.

Firms in Georgia that produce, process, distribute, and sell poultry products employ over 79,000 people in the state, and generate an additional 154,000 jobs in supplier and allied industries (NAMI, 2016). The processing and sale of poultry products is not only an integral part of the local economies where integrator operations are located, but also contributes to the state's economy with $48.2 billion in total economic activity in the state that is directly attributed to the Georgia poultry industry. This includes sizeable state income, property, and sales tax revenues totaling $1.6 billion in 2016. With continued growth in the global consumption of poultry products, Georgia's poultry industry will remain an integral part of the state and nation's economy.

Factors Influencing Poultry Meat Quality

Meat quality encompasses many different attributes which are important as they can affect many sensory attributes. The first and arguably most important meat quality factor is appearance because consumers use appearance as the basis for retail purchases. When evaluating appearance, several factors are involved including color, firmness/texture, and water holding capacity. These factors can be affected by intrinsic characteristics of meat including meat pH, structure, fiber type, and chemical composition (Aberle et al., 2001a). These intrinsic properties also affect yield, aroma, and palatability. If any of these attributes are below the expected experience of the consumer, repeat purchases may not be made for a chicken meat product, and possibly an entire brand.

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

Color. Meat color is the most influential quality factor that impacts consumer purchasing decisions, because it is used as an indicator of freshness and shelf-life (Mancini, 2009). When evaluating poultry product color, it is important to take into consideration skin color for products sold as whole chickens, and meat color for products sold as skinless pieces. The color of the meat is attributed to several intrinsic factors including: myoglobin content, muscle fiber structure and orientation, and pH. In comparison to red meat products, poultry meat is highly variable in colorimetric values, especially L* and a* values. Poultry has the lightest meat color of all other livestock species with lighter color values (higher L*) and lower red hues (lower a*). The light color associated with chicken meat, especially the *Pectoralis major* muscle, is from a lack of myoglobin (0.01 mg myoglobin/g meat), compared with 6 mg myoglobin/g meat in yearling pork and 8 mg/g in yearling beef (Fletcher, 2002; Savell, 2015). The chemical state of myoglobin (oxymyoglobin, deoxymyoglobin, or metmyoglobin) also affects the color in meat, but has limited effect in chicken breast meat due to the lack of myoglobin (Aberle et al., 2001a).

Extrinsic properties that can affect poultry meat color include animal transportation stress prior to harvest, stunning method, scalding time and temperature, and rate and method of chilling (Fletcher, 2002). During the biochemical reactions required to convert muscle to meat, rate and degree of pH decline has a negative correlation with lightness of meat color (Aberle et al., 2001a; Fletcher, 2002).

Meat color can be measured objectively through the use of pigment extraction, physical methods measuring reflectance and absorbance values with the use of a colorimeter, or subjectively through the use of a human visual panel. Colorimetry is a non-invasive, relatively quick method that can be run on multiple samples. When using a colorimeter, illuminates A, C, D65, and F, can be changed to best fit the objective of the study (AMSA, 2012). The most frequently used illuminate in fresh meat is “A” as it is the most sensitive to changes in red wavelengths. The degree of the observer (2° and 10°) and aperture size can be altered and should be recorded as they affect the recorded color values.

Objective measurement results are displayed using one of several different systems: Hunter L*, a*, b*; Munsell (hue, lightness, and chroma), Commission Internationale de I’Eclairage (CIE) or Minolta values (AMSA, 2012). Colorimeters measure only in trismulus values of CIE which can be recorded on an XYZ or CIE LAB scale, including L* measuring from 0 (black) – 100 (white), a* (green, -a*; red, +a*), and b*, reported in a similar manner to a* except from blue (-) to yellow (+). These measurements are based off how the human eye perceives color through the use of rod and cone receptors (McKee et al., 2012). Color measurements assist in a better understanding of the intrinsic properties of meat and predicting poultry quality, such as pale, soft, and exudative (PSE), without destroying the sample.

***WHC and Yield*.** The poultry industry currently has increased breast size as the main focus of genetic selection as it provides a lean meat source with minimal connective tissue which is ideal for further processed products. Efficient commercial chicken genetic lines present increased feed efficiency, shortening the time from hatchery to harvest (Schmidt et al., 2009). In order to appeal to commercial and consumer markets, efficiency of chicken production is an important characteristic to monitor. Yields can display this information by presenting a ratio between poultry part and the whole carcass weight.

Water holding capacity (WHC) is the ability of meat to retain naturally occurring or added water during application of external forces such as cutting, grinding, pressing, or thermal processing (Aberle et al. 2001a). The water-holding capacity of proteins is influenced by many factors including muscle type, pH, rigor conditions, processing conditions, and ingredients added to the meat. The isoelectric point of a muscle cell is when the positive and negative charges in a cell are equal, allowing the muscle structure to collapse on itself. In meat, this occurs at a pH value of 5.1 (Aberle et al., 2001a). The repulsive charges in muscle fibers increase as the pH moves away from the isoelectric point in either direction, increasing the space in between the fibers available to hold more water. Low pH, associated with PSE qualities, is near the isoelectric point, and limits the water holding capacity of a muscle fiber. The type of muscle fibers in a muscle has been related to the potential quality of meat (Maltin, 2003). A muscle with a greater amount of fast twitch fibers has a greater glycolytic potential as it undergoes anaerobic metabolism, creating more lactic acid, and thus lowers muscle pH. A lower pH affects water holding capacity, instrumental color, sensory properties, and instrumental texture. Lean meat is comprised of about 70 % water, resulting in a water to protein ratio of 3.5:1 in muscle tissue (Honikel, 2004). The large amount of water is held in the meat by hydrogen bonds and the internal structure of the proteins (Barbut, 2002a). Water held within the structure of meat can be divided into three main categories including bound water, immobilized water, and free water (Babrut, 2002a; Keeton and Osburn, 2010).

Meat is composed of 1-2% bound water that is trapped within the muscle proteins, remaining unaffected from extreme mechanical processing or thermal treatment. Immobilized water is a “middle” layer of water molecules attached to the bound water by hydrogen bonds. Up to 80% of the water in meat is immobilized water and is held within the meat by weak associations by hydrogen bonds. This form of water decreases with rigor, but can be manipulated by processors with processing to increase or maintain the amount of immobilized water for greater WHC. Free water, as the name implies, is subject to loss during processing and can easily be removed from the meat system by forces imposed by processing, with the main goal to keep it in the meat product (Keeton and Osburn, 2010). Water-holding capacity is manipulated in two occurrences: the ionic effect and the steric effect. When the postmortem pH of muscle is at the isoelectric point and there is an equal amount of positive and negative charges, it reduces the ability of water to attract to actin and myosin and loses water to drip loss (Apple and Yancey, 2013; Miller, 2002). As meat pH increases or decreases from the isoelectric point, the ratio of positive and negative charges will change increasing the ability of actin and myosin to tightly bind water (Miller, 2002). The steric effect has a larger effect on water-holding capacity depending on the space between the myofibrillar proteins. During contraction the space between the myofibrillar protein structures becomes shorter restricting the space for water to bind to actin and myosin. The state of contraction and muscle pH can alter the amount of interstitial space available to hold water. However, if the sarcomeres are shortened and there is little interstitial space, the water is expelled into the extracellular space of the muscle (Alvarado and Owens, 2006). The ability of actin and myosin to bind water is important to meat quality and is related to many factors of the end product including meat tenderness (Miller, 2002).

Juiciness is an important sensory characteristic which has been found to positively correlate with tenderness, thus it is important for a piece of meat to have a greater amount of bound and immobilized water to increase sensory properties even after cooking (McKee et al., 2012). Cook loss is another beneficial measurement as it relates to the water holding capacity of the muscle, and can be calculated by dividing the difference between raw and cooked weight by raw weight multiplied times 100, describes the structure and water holding capacity of the meat by determining the amount of water and water soluble proteins lost during cooking.

pH. An intrinsic property of meat that affects most other meat quality attributes is pH, the measure of hydrogen ions. When animals are alive, blood and muscle have a pH near neutral (pH of 7), but during the formation of rigor mortis, glycolysis occurs in the muscle which lowers pH from the production of lactic acid. This pH decline is one of the most significant postmortem changes ultimately affecting all other quality attributes (Aberle et al., 2001a; Maltin, 2003). Muscle pH can be correlated to quality attributes including meat color, tenderness, water-holding capacity, cook loss, juiciness, and shelf-life (Fletcher, 1999). Once the resolution of rigor has set in, the pH of the muscle drops due to the buildup of lactic acid and the occurrence of glycolysis. This drop in pH to 5.6-5.8 can be attributed to normal meat color development (Braden, 2013). After 24 hours the normal postmortem pH is 6.0-6.2 in poultry muscle (Keeton and Osburn, 2010). The rate at which the muscle pH declines until rigor is completed is very important in the meat's quality. A rapid pH decline can be attributed to muscle pH values close to the isoelectric point, leading to negative meat quality characteristics. The isoelectric point is a balance between the positive and negative charges on the protein side-groups with a pH level of 5.1 and relates to the ability of the proteins to bind water. Muscle with a rapid decline in pH near the isoelectric point can become watery and pale in color, known as the pale, soft, and exudative (PSE) condition (Miller, 2002; Braden, 2013). This acidic environment can deactivate the enzymes responsible for postmortem tenderization leading to a tougher final product (Maltin, 2003).

The impact that pH has on the color and functionality of the meat is of great importance to processors of fresh and further processed products when it directly affects the profit, shelf-life, and consumer acceptability of the product (Barbut, 2015). Alvarado and Sams (2003) compared marination performance and WHC of broiler breast fillets characterized as "pale" fillets to fillets characterized as "normal." Their findings suggested that the fillet color and pH were highly correlated with WHC and percentage of brine pickup and retention. Fillets characterized as lighter in color had an initial lower pH, lower brine pickup, and higher drip and cook loss compared with fillets that were characterized as dark.

Poultry Meat Quality Defects

Quality measurements differ over the lifetime of the product; from the processing of the carcass to when the consumer purchases the product (Moran Jr., E.T., 1999). The high growth rates needed to sustain the demand of chicken meat have resulting in negative effects, leading to abnormal muscle fibers, reduced water-holding capacity, and higher pH values (Dransfield and Sosnicki, 1999; Duclos et al., 2007; Petracci et al., 2013b). Genetic selection, improved management techniques, and nutrition, have given the poultry industry increased growth rates and breast-yield, but it is at the expense of meat quality traits and abnormalities such as PSE-like meat, and more recently, white striping and woody breast (Anthony, 1998; Lorenzi et al., 2014; Petracci et al., 2015). Poultry production factors, especially feed nutrition and breeding, have an overall impact on the chemical, physical, and structural changes in muscle tissue as it is grown and converted to meat (Northcutt and Buhr, 2010).

Woody Breast Myopathy. Recently, research has observed woody breast (WB) accompanying white striping (WS), and has become one of the more prominent quality issues affecting the pectoralis major in broiler chickens. Woody breast (WB) is a muscle myopathy characterized by muscle that is pale in color, with substantial hard and rigid areas throughout the entire *Pectoralis major* muscle in broilers (Bailey et al., 2015; Sihvo et al., 2014). As with WS, WB is categorized in normal (0), mild (1), moderate (2) and severe (3) categories. Normal, is defined as flexible throughout the fillet with no incidence of WB; mild, is hard mostly in the cranial region and flexible at the caudal region; moderate, hard throughout the fillet with some flexibility in mid to caudal region; and severe, very hard throughout the fillet (Kuttappan et al., 2012a). Fillets with severe WBC possess characteristics including pale color, petechiae, hemorrhaging, and a viscous exudate on the surface (Bailey et al., 2015; Sihvo et al., 2014). Currently, broiler breast fillets affected with woody breast are subjectively detected by palpating the *P. major* muscle (Sihvo et al., 2014; Tijare et al., 2016). Objective methods to assess woody breast are currently being investigated as repeatable and reliable alternative methods by using compression force, shear force, and cook loss as predictors, indicating compression and shear values of raw fillets increased as severity of WBC increased (Bowker et al., 2016; Schrader et al., 2016; Sun and Owens, 2016b).

Increasing hypertrophic muscle growth rates has been suggested as a predisposing factor for WB due to enlarged muscle fiber diameter, muscle fiber degeneration, larger fillet weights, and increased cross sectional area of the *Pectoralis major* muscle (Velleman, 2015; Zotte et al. 2014). Gender of the broiler also affects the occurrence of the woody breast condition, doubling from females to males (Trocino et al., 2015). Histologic analysis of severely affected broiler breast fillets indicate a substantial accumulation of connective tissue replacing degenerated muscle fibers due to muscle fiber necrosis, fibrosis, and muscle fiber regeneration (Bailey et al., 2015; Sihvo et al., 2014; Velleman and Clark, 2015). Soglia et al. (2015) reported that fillets affected with both WB and WS showed higher moisture, fat, and collagen levels with lower amounts of protein accompanied by a higher pH value and lower water-holding capacity. Recent research has suggested that fillets severely affected have a lower activity of glycolysis and gluconeogenesis, which can suggest the higher pH values (Kuttappan et al., 2016).

WB fillets exhibit lower water-holding capacity during both storage and cooking, resulting in increased cook loss, and lower marinade performance. This may be attributed to muscle degeneration and the replacement of salt soluble proteins (actin and myosin) with connective tissue in affected broiler breast fillets (Zotte et al., 2014; Mazzoni et al., 2015; Mudalal et al., 2015). Generally, severe fiber hypertrophy increases the incidence of large and abnormal fibers, therefore, the prevalence of abnormal fibers is considered a strong indicators for the development of meat quality issues (Dransfield and Sosnicki, 1999; Mitchell, 1999; and Rehfeldt et al., 2004). Petracci et al. (2013b) reported that meat from high-breast yield hybrids showed a significant reduction of WHC and increased cook loss values compared to standard hybrids. The abnormal fillets showed higher pH values (>6.0) compared to normal (~5.8); therefore, poor WHC cannot be linked to PSE-like condition because it was not associated with low pH. However, Sihvo et al. (2014) suggested that higher drip losses could be associated with the loss of membrane integrity and the presence of a thin layer of fluid viscous material over the WB (Sihvo et al., 2014). In addition, higher cook loss could be related to the increase of hardness of the WB fillets (Murphy and Marks, 2000).

Recent research also has shown that genetic selection for high breast muscles combined with increased bird weight and growth rate, possibly increases the susceptibility of the broiler chickens to oxidative stress (Petracci and Cavani, 2012a). Petracci et al. (2013b) studied the breast muscle of 2 commercial hybrids with different breast yields and reported that the higher breast yield presented a greater incidence of abnormal fibers compared to standard breast yield hybrid. In addition to this study, Sihvo et al. (2014)

found severe multifocal regenerative myodegeneration and necrosis with different quantities of interstitial connective tissue accumulation or fibrosis in fillets affected by WB.

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

Marination

Marination is the addition of liquids to meat before cooking (Owens et al., 2010). The main objective of marination is to improve sensory properties such as flavor, juiciness, tenderness, and color in addition to extending the shelf life (Young and Buhr, 2000; Barbanti and Pasquini, 2005; and Alvarado and McKee, 2007). Marination has been widely used in the meat industry to increase the water content, using highly alkaline ingredients to raise the pH closer to neutral, therefore improving the WHC of the meat (Barbanti and Pasquini, 2005). Besides improving product functionality, it also has been shown to increase the yield of the raw meat, which can provide benefits to producers and consumers (Xargayo et al., 2001). The functionality of the ingredients plays a major role in marination, especially sodium chloride and phosphates as they improve meat tenderness and flavor (Barbanti and Pasquini, 2005).

Vacuum tumbling is the most popular method of brining chicken meat and other processed poultry muscle products. Massaging and tumbling under vacuum pressure extracts protein exudates including the salt-soluble proteins actin and myosin, which aids cohesion during thermal processing. The extraction of protein exudates improves meat texture during thermal processing by providing two functions. First, the binding properties of the meat are improved when protein coagulates upon heating, and Second, the extracted protein allows for moisture retention by creating a seal on the surface of the meat (Smith, 2001).

Tumbling and Massaging Methods. Tumblers were the first type of equipment specifically designed to produce sectioned and formed meat products (Pearson and Gillett, 1996). Tumbling generally refers to placing meat in a stainless steel drum containing internal baffles (Schmidt, 1981). Tumblers accelerate the extraction of meat proteins through two mechanisms. First, when meat pieces are tumbled with salt and phosphate, the agitation caused by the tumbler allows for increased extraction of proteins, increased water-holding capacity, and tenderization (Rejt, et al., 1977). When meat is tumbled under vacuum conditions, the meat pieces expand allowing for increased protein extraction and improved mixing of adjuncts that improves protein-protein bind. Other advantages of tumbling include producing products with uniform, weight, portion control, decreased cooking losses, use of variety of cuts, and uniformity of color (Schmidt, 1981). Pearson and Gillett (1996) stated that tumbling intermittently for times of 10 to 30 min has demonstrated improved protein functionality. This is due to the meat pieces ability to absorb brine solution more effectively when the tumbler is not moving, and the ability of the tumbler to break open the surfaces of the meat when the tumbler is in motion. Krause et al. (1978) determined that tumbling significantly improved external appearance, taste, aroma, and yield.

Massagers were designed to mimic mixers utilized for emulsion type products. Larger pieces of meat cannot be manipulated with a mixer, so massagers were developed for this purpose. Massaging functions in a similar manner to tumbling, but it is a less severe treatment, which leaves the meat surface more intact. This can be undesirable if the batch is not properly manipulated, resulting in insufficient brine distribution, lower cooking yields, and decreased bind.

Functional Ingredients in Brine Formulation

The industrial marinating of broiler chicken is a well-established process used to deliver ingredients through a brine solution to improve flavor, texture, palatability, and to increase the yield and value of meat (S.M. Yusop et. al, 2011). The functionality of brine solutions is dependent on the adjunct ingredients used to influence the yield and overall quality of the marinated products. According to Toledo (2007), ingredients used in brine solutions can be categorized in two categories based on their functionality. The first category includes technical ingredients that affect water binding based on ionic strength and pH (i.e. salt, phosphates, organic acids, hydrocolloids, enzymes). The second category includes ingredients which affects consumer appear and flavor (i.e. herbs, spices, sweeteners). The two most common ingredients found in brine solutions are phosphates, with sodium tripolyphosphate (STP) most commonly used, and salt (NaCl).

Salt. Salt is one of the oldest, most effective, and inexpensive food preservatives used in preserving meat and various other foods. In poultry, salt serves many functions as a standalone ingredient and in combination with other ingredients including: flavor enhancement, moisture retention, extraction of salt soluble proteins, inhibit bacterial growth, and dehydration when applied in large quantities to the meat's surface (Keeton, 2001). Salt easily dissolves in water, increasing the ionic strength of water from the complete dissociation of the sodium and chloride ions. Poultry meat contains approximately 70 % water, which is ionic due to the ionized mineral salts present in muscle tissue (e.g., cations: Na^+, K^+, and anions: Cl^-, S^-) (Hedrick et al., 1989). The ionic strength of the fluid in the muscle tissue is lower than that of brine, therefore, the brine solution will be absorbed by the meat through osmosis until equilibrium is reached. Under current regulations, there is no regulated concentration of salt in meat products because of its GRAS classification, but it is self-limiting because of the negative effect on the palatability of the final product when used in high concentrations. Brined poultry products typically have a final salt concentration of 2 percent, but can range from 1.5 to 3 percent depending on the product. Due to recent consumer demand for lower sodium products, ingredients such as potassium salts (KCl), phosphates, and other high ionic strength compounds are popular alternatives to NaCl that can also increase water holding capacity (WHC) while maintaining low levels of sodium. However, KCl is not readily used in further-processed products because it can lead to astringent off-flavors in the product (Claus et al., 1994).

Phosphates. Phosphates are utilized in brine solutions to improve water retention through increasing the pH further away from the isoelectric point of the myofibrillar proteins, and exposing additional charged sites available to bind water through the unfolding of proteins (Pearson and Gillett, 1996). Phosphates vary in their solubility and effect on muscle pH, but generally, alkaline phosphates improve water retention by shifting the pH further away from the isoelectric point of the myofibrillar proteins and by unfolding muscle proteins, thereby exposing more charged sites for water binding (Pearson and Gillett, 1996). When phosphates are used for increasing water binding properties of meat products, the USDA requires that phosphate concentrations are no higher than 0.5% of the finished product weight (USDA FSIS, 2017). Although there are many phosphates to choose from, STP remains the most commonly utilized in brine solutions because it is easy to use and inexpensive. Sodium tripolyphosphate accounts for approximately 80% of the phosphates used in further-processed meat products.

The most commonly used phosphates in brine solutions include sodium tripolyphosphate (STP) sodium pyrophosphate (SPP) and sodium hexametaphosphate (SHMP). Alkaline phosphates such as STP serve to increase WHC, increase cook yield, extract muscle proteins, reduce oxidative rancidity, preserve meat color, increase flavor retention, and reduce microbial growth (Keeton, 2000).

Sodium pyrophosphates and diphosphates work best in brine solutions and emulsion products because phosphates are only active in the diphosphate form, and sodium pyrophosphate is most easily hydrolyzed into that form (Pearson and Gillett, 1996). Mixtures of tripolyphosphates and sodium hexametaphosphate are utilized in brine solutions for emulsified and whole muscle products. They are dissolved in water, injected into or tumbled with whole muscle meat, and bacons, and are slowly hydrolyzed to diphosphate. Tetrasodium pyrophosphate allows for the greatest bind in emulsion products, but it is highly caustic at pH 11 and produces soap in the presence of any fat. For this reason, it should never be utilized outside of a blend (Pearson and Gillett, 1996). Sodium acid pyrophosphate should also never be used outside of a blend since its acid nature causes poor water binding. Blends should be alkaline in nature, capable of being hydrolyzed to form diphosphate, and product dependent based on length of the curing process. Desirable properties for blends include proper alkaline pH, good solubility, calcium compatibility, and a high degree of protein modifier effect (Townsend and Olson, 1987).

According to Goodwin and Maness (1984), poultry meat that is injected with a solution of sodium phosphate, shows no difference in fillet tenderness between aged fillets (16 h) and fillets marinated but not aged (deboned 3 h postmortem). In this study, the whole birds were post chilled and aged for 16 h while the marination time without aging was 3 h. Moreover, Zheng et al. (2000) compared the functionality of tetrasodium pyrophosphate, sodium tripolyphosphate, and hexametaphosphate on poultry breast fillet moisture pickup and retention. Their results indicated that tetrasodium pyrophosphate-treated breast fillets had the highest yield, whereas STP had similar effects on purge. They also concluded that SHMP had the highest moisture pickup but the lowest retention.

Alvarado and Sams (2003) investigated using salt and phosphate as a remedy for PSE broiler breast meat. Regardless of the phosphate marinade treatment, moisture binding or retention properties of the PSE meat were not restored to the level of the control group. However, Gorsuch and Alvarado (2002) determined that marination with high-pH phosphates (~pH 11) can reduce the undesirable characteristics of poor quality meat, such as PSE meat, without altering flavor, increasing the development of oxidation, or reducing shelf life. Many phosphates are not easily soluble in most salt brine solutions; therefore, phosphates are typically dissolved in room-temperature water before adding salt and then chilled before use. Some new blends of phosphates on the market have increased solubility regardless of the addition of salt. Some of the new commercial blends of phosphates do not need to be put into solution before salt because of modifications that make them more soluble. Excess phosphate addition can cause “soapy” flavors, rubbery texture, and poor color (Keeton, 2001).

Although phosphates possess very functional properties in poultry meat systems, lately consumers have perceived phosphate use as a negative. Other additives that have been utilized as phosphate replacers include sodium citrate and hydrocolloids to increase water-holding properties. Low-sodium, phosphate-free products tend to be formulated by increasing the amount of protein or by decreasing the amount of water that is added (Miyaguchi et al., 2004). Several additives, for example, sodium citrate, and other ingredients have been used in phosphate-free meat products to enhance their WHC.

Sensory Evaluation of Poultry Meat Attributes

Sensory analysis is used to measure the characteristics of a product through the human senses and sometimes in combination with instrumental methods (Nute, 1999; Guardia et al., 2010). When evaluating food, consumers use all five senses: sight, smell, touch, taste, and hearing, to perceive within a food product. Color and visual appearance is typically used first when consumers purchase meat products from their retail grocery store. Once a product is in the kitchen, the rest of the senses become very important for evaluating raw product safety, aromas while cooking, and the taste, texture, and aroma while eating the meat product. As reported by Maltin et al. (2003), the most common source of customer complaints and failure to repeat purchase a meat product is due to eating qualities.

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

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

Instrumental Texture Profile Analysis of Poultry Meat

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

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

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

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

Purpose of Research

The woody breast muscle myopathy is an emerging issue in the past few years and is causing an increased concern for the poultry industry and consumers alike. Economic losses from downgrading broiler breast meat and unfavorable comments from consumers is a powerful problem. There have been observed complaints relating to texture from foodservice customers have put pressure on processors to sort and grade breast fillets based on their WBC scores.

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

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CHAPTER 3

MARINATION AND COOKING PERFORMANCE OF PORTIONED BROILER BREAST FILLETS AFFECTED WITH WOODY BREAST[1]

[1] Maxwell, A. D., B. Bowker, H. Zhuang, K. Adhikari. To be submitted to *Journal of Poultry Science*

ABSTRACT

The woody breast (WB) condition in broiler breast meat is known to impair technological meat quality. The *Pectoralis major* is an irregular shaped muscle that presents evident histological and tactile changes when affected by the WB myopathy, especially on the ventral surface and cranial end of the breast fillet. Commercially, breast fillets are often portioned horizontally to standardize their size and thickness. The objective of this study was to determine the effects of WB on the marination and cooking performance of the dorsal (bone-side) and ventral (skin-side) portions of broiler breast fillets. One hundred twenty butterfly breast fillets were collected from the deboning line of a commercial plant and sorted into normal (NORM) and severe (SEV) categories. Each fillet was portioned into dorsal and ventral halves. Portions from one side of each butterfly were used as non-marinated controls, while portions from the other side were vacuum-tumble marinated (16 rpm, −60.80 kPa (−0.6 atm), 4°C, 20 min) with 20% (wt/wt) marinade to meat ratio. Marinade was formulated to target a final concentration of 0.75% salt and 0.45% sodium tripolyphosphate in the final product. Fillet portions were cooked to 78°C in a combination oven. Marinade uptake and retention were lower in both the ventral and dorsal portions of the SEV fillets. The dorsal portions had greater marinade uptake and retention than the ventral portions in both NORM and SEV fillets. For non-marinated samples, cook loss was greater in both the ventral and dorsal portions of SEV fillets. In marinated samples, however, cook loss was similar between the dorsal portions of NORM and SEV fillets. Final product yield (%) was calculated based on pre-marination and post-cooking weights. SEV samples exhibited lower final product yields than NORM samples for both the ventral and dorsal portions. For marinated samples, final product yields were greater in the dorsal portions of the fillets than the ventral portions. Overall, data demonstrated that the dorsal portion of the *Pectoralis major* more readily absorbs and retains marinade during vacuum tumbling and storage than the ventral portion. Furthermore, the WB condition negatively influences the marination and cooking performance in both the ventral and dorsal portions of broiler breast fillets.

INDEX WORDS: breast meat quality, woody breast, fillet portion, marination, cook loss

INTRODUCTION

The global consumption of broiler breast meat has steadily increased in the last 50 years. On a per capita basis, poultry meat consumption surpassed beef and pork consumption in 2014, with 90.1 pounds, 55 pounds for beef, and 49.2 pounds, respectively (National Chicken Council, 2016). Factors affecting the steady increased consumption of poultry meat include low prices compared to other meat options, lack of cultural or religious hurdles, and nutritional aspects (Magdelaine et al., 2008). To meet the increasing consumer demand for broiler breast meat, broiler producers adopted methods that led to increased growth rates and higher breast yields. *Pectoralis major* muscle yields increased by 79 and 85% in male and female broilers, respectively, from 1957-2005 as reported by Zuidhof et al. (2014).

Increases in breast yield have resulted in the development muscle myopathies that have negative economic impacts on the broiler industry due to losses from downgrading meat that has decreased functionality when further processed. Woody breast (WB) is a muscle myopathy characterized by *Pectoralis major* muscle that is hard to the touch, outbulging in appearance, pale in color, and often seen accompanied with the white striping myopathy (Sihvo et al., 2014). Histology changes in broiler breast fillets affected with woody breast include myodegeneration and regeneration of muscle fibers, and accumulation of connective tissue (Sihvo et al., 2014; Velleman and Clark, 2015).

Degeneration of muscle fibers result in decreased functionality of the proteins, negatively impacting the quality and technological performance of poultry products. Further processed poultry products developed from woody breast fillets are known to exhibit lower marinade uptakes, higher cooking loss, and lower water-holding capacity (Mudalal et al., 2015; Petracci et al., 2015). Substantial economic losses to the poultry industry are occurring from downgrading broiler breast fillets affected with woody breast (Petracci et al., 2015). The increased connective tissue observed with woody breast develop a complex texture issue that is challenging to overcome using marination alone.

The effects of WB may not be uniform throughout the breast fillet because histologic changes appear to be more prominent on the ventral side of the muscle. Soglia and others (2015) found that histopathological lesions in a WB-affected fillet gradually disappeared when moving from the ventral to dorsal side of the fillet. It was shown that number of muscle fibersis reduced in fillets with severe WB, with separation and/or replacement of the fibers with connective tissue.

Not much research has been done to compare the technological performance on breast fillets that have been separated into dorsal and ventral portions. This method of portioning is currently used in standardizing the size and thickness of fillets because of their irregular shape. To observe the effects of WB between ventral and dorsal portions, this study was performed to determine how WB affects the marination performance of dorsal (bone-side) and ventral (skin-side) portions of broiler breast fillets. Cooking performance was also performed to validate if marination of WB portions affected cook loss and cooked yield. By portioning fillets into dorsal and ventral portions before marination, it is expected that there will be differences in marination and cooking performance between ventral and dorsal portions in both normal (no WB) and severe WB categories.

MATERIALS AND METHODS

Broiler Breast Fillet Sorting, Color, and pH

Breast fillet pairs from 8-week-old broilers (Ross meat line) were collected from the deboning line of a commercial processing plant (approximately 3 h postmortem). The fillets were placed in Ziploc bags (Ziploc Brand Freezer Bags, Johnson & Son Inc., Racine, WI) and transported on ice to the laboratory within 45 min. Fillet pairs were separated, trimmed, and scored into normal (NORM) and severe (SEV) WB categories based on the incidence of diffuse hardened areas throughout the fillets and the severity of palpable hardness. Fillets were also classified into white striping categories based on previously established criteria (Kuttappan et al., 2012) on the prevalence and thickness of white striations on the surface of the muscle. Over 3 different trial days, a total of 60 fillets (10 individual fillets per WB category per treatment per rep) were selected based on their WB scores.

Color and pH measurements (Table B.1) were performed 6 h postmortem on chicken breast fillets after deboning. Surface color measurements (L*, a*, and b* values) were carried out with a Minolta spectrophotometer CM-2600d (Konica Minolta, Ramsey, NJ) with settings of illuminant C, 10° observer, specular component excluded, and an 8-mm aperture. Surface areas were selected that were free from obvious defects (bruises, discolorations, hemorrhages, or any other conditions that might have prevented uniform color readings). Three measurements were taken on the bone side of the fillet. Each measurement was the result of 3 averaged readings by the spectrophotometer. Muscle pH of the fillets was determined with a Hach H280 GB pH meter equipped with a Cole

Parmer spear tip probe (EW-5998-20) (Cole-Parmner, Vernon Hills, IL) at the cranial end. Between measurements, the probe tip was cleaned with a toothbrush and rinsed with deionized water.

Sample Preparation

Breast fillets were stored in unsealed transparent poly nylon vacuum pouches. (Model S-19800, Uline, Pleasant Prairie, WI) after pH and color data were collected. Fillets were stored at 4˚C overnight before portioning. Fillets were split into top (ventral) and bottom (dorsal) portions using a Berkel deli slicer (Model: X13E-PLUS, Illinois Tool Works Inc, Glenview, IL) and weighed. The portion pairs were divided into the two treatment categories, marinated and non-marinated.

Marination and Performance Calculations

Marination protocol was adapted from the method of Zhuang et. al (2014). Portions were tagged and weighed individually before they were vacuum-tumbled (model: DVTS 30 V.S, Daniels Food Equipment, Parkers Prairie, MN) for 20 min at 16 rpm and –60.80 kPa (–0.6 atm) in marinade (20% of initial fillet weight) at 4°C. Marinade contained 5% NaCl and 3% sodium tripolyphosphate (STPP) (Innophos, Inc., Cranbury, NJ) and was formulated with a targeted final concentration of 0.75% NaCl and 0.45% phosphate in the final product. More than the needed marinade (20%) was added in the marination tank to achieve a target pickup of 15% in 20-min vacuum tumbling process. After marination, individual fillets were drained and weighed to determine the percentage of uptake, stored at 4˚C overnight, and then reweighed at 24 h postmarination (48 h postmortem) to determine marination retention and overall product yield. The formulas used for the calculations are as follows:

$$\text{marinade uptake (\%)} = 100 \times \frac{(W_{marinated} - W_{green})}{W_{green}};$$

$$\text{marinade retention (\%)} = 100 \times \frac{(W_{pre\text{-}cook} - W_{green})}{W_{marinated} - W_{green}};$$

$$\text{raw product yield (\%)} = 100 \times \frac{W_{pre\text{-}cook}}{W_{green}};$$

where, W_{green} represents fillet weight immediately before marination at 24 h postmortem, $W_{marinated}$ represents fillet weight immediately following marination, $W_{pre\text{-}cook}$ represents fillet weight following storage for 24 h post-marination. Non-marinated controls were weighed at similar postmortem times to marinated fillets.

Cooking and Yield Calculations

Portioned fillets were vacuum sealed in transparent poly nylon vacuum pouches. (Model S-19800, Uline, Pleasant Prairie, WI) and were cooked in a Henny Penny MCS-6 combination oven (Henny Penny Corporation, Eaton, OH) at 85˚C with the tender steam setting to reach an internal temperature of 78˚C. The internal temperatures were checked in the thickest part of each portioned fillet with a hand-held digital thermometer fitted with a hypodermic needle probe (Doric Digital Thermometer, Model 450-ET; Doric Scientific, San Diego, CA). The cooked samples were drained of liquid, patted dry with paper towels, and weighed. Two 1.9-cm-wide strips were removed from the breast by cutting next to a template aligned parallel to the muscle fibers and adjacent to the cranial end (Figure 3.1). Strip C was used for instrumental shear testing. Cooking loss and overall cooked yield was calculated based on fillet weights pre- and post-cooking. The formulas used for the calculations are as follows:

$$\text{cooking loss (\%)} = 100 \times \frac{W_{pre\text{-}cook} - W_{cook}}{W_{pre\text{-}cookl}}$$

$$\text{overall cooked product yield (\%)} = 100 \times \frac{W_{cook}}{W_{green}}$$

where W_{green} represents fillet weight at 24 h postmortem immediately before marination, $W_{pre\text{-}cook}$ represents fillet weight at 48 h postmortem before cooking and W_{cook} represents fillet weight after cooking, drained of liquid, and patted dry.

Statistical Analysis

Data were subjected to three-way Analysis of Variance (ANOVA) using the GLIMMIX Procedure in SAS (Version 9.4, SAS Institute, Cary, NC) where Condition, Treatment, and Portion were fixed effects, and Rep was treated as a random effect. Least square means were separated statistically with the Tukey's HSD method at 5% level of significance.

RESULTS AND DISCUSSION

The marination performance of NORM and SEV portioned fillets are shown in Table 3.1. Marination is a common method for processors to add value by improving yield and raw meat quality. NORM fillet portions had greater ($P \leq 0.05$) marinade uptake and retention, while both ventral and dorsal SEV portions had lower uptakes in comparison. The dorsal portions had greater marinade uptake and retention than the ventral portions in both NORM and SEV fillets. This greater uptake in dorsal portions can be attributed to the increased exposed myofibrillar proteins on both sides of the portion during tumbling. In these portions, the marinade has greater penetration through the exposed fibers on the cut side from portioning and deboning. Increased marinade pickup could result in enhanced water holding capacity and tenderness in meat. These results support those previously reported by Mudalal et al. (2015), reporting a decrease in marinade uptake in fillets affected with WB when compared to normal fillets. Lower marinade uptake in SEV portions can be attributed to a loss of protein from WB-related fibrosis (Sihvo et al., 2014).

Overall, none of the portions achieved the target marinade pick-up of 15%, with the exception of the NORM bottom portion (Table 3.1). Marinade pick up needs to be closely monitored due to the phosphate regulations set forth by Codex Standard 192-1995 (Joint FAO/WHO Codex Alimentarius Commission, 2016). The lower pickups allowed the fillets to absorb less phosphate than the USDA-allowed level of 0.5%, but more research needs to be done to determine appropriate protocol to achieve a 15% marinade pickup to maximize added value in marination processes for ventral and dorsal portions with varying degrees of WB.

Marination of breast fillets portions with salt and phosphate increases ionic strength and pH, increasing the ability of muscle to retain water during cooking (Farr and May, 1970; Hamm, 1975; Young et al., 1991). This can be seen in the cook loss (%) of the marinated samples (Table 3.2). These samples absorbed and retained marinade that allowed for greater WHC, resulting in a final product with a final cooked yield of 93.14%, 96.71%, 80.22%, and 89.44% in marinated NORM top, NORM bottom, SEV top, and SEV bottom respectively.

The technical ingredients (NaCl and STPP) in the marinade are used synergistic combination to increase the pH and ionic strength of meat protein matrix, enhancing the water binding ability (Miller, 1998). Salt has traditionally been used in brines to improve WHC, with two differing theories on the function of salt on the improvement of the WHC of meat (Ruusunen and Puolanne, 2005; Desmond, 2006), suggested by Hamm (1972) and Offer and Knight (1988). Offer and Knight (1988) proposed that chloride ions interact with muscle proteins to break down the shaft of the myosin filaments, in turn relaxing the myofibrillar scaffold structure. This relaxation combined with the negative osmotic pressure gradient from the sodium ions, draws water into the relaxed scaffold and results in swelling of the myofibrillar framework. Synergistically, the action of phosphates will increase the pH and ionic strength of meat protein matrix enhancing the water binding ability (Miller, 1998). On the other hand, Hamm (1972) suggests that chloride ions in salt interact with the myofibrillar proteins causing repulsion between the myofilaments resulting in swelling and enhanced water holding capacity of the meat on water-binding protein sites. These exposed water-binding protein sites can explain the increased uptake of marinade by the bottom portions. Both sides of the bottom portion have exposed muscle fibers that will more readily absorb marinade, while top portions only have one side with exposed muscle fibers. Based on the marination performance data, it can be determined that bottom portions perform better than top portions due to the exposed area of muscle fibers on both sides of the portion.

The cooking performance of marinated and non-marinated NORM and SEV portioned fillets are shown in Table 3.2. Cook loss (%), or fluid loss resulting from denaturation of chicken breast meat proteins by heat, was recorded to evaluate water holding capacity (WHC) between marinated and non-marinated samples. For non-marinated samples, NORM portions were the least ($P \leq 0.05$) affected with cook loss when compared to SEV portions. Both NORM and SEV top portions showed greater cook loss compared to their bottom portions. Greater ($P \leq 0.05$) cook loss was also observed in all non-marinated portions compared to similar marinated portions.

In marinated portions, NORM portions had the least ($P \leq 0.05$) cook loss when compared to SEV portions. Within the NORM category, the top portion exhibited the lowest ($P \leq 0.05$) cook loss, with improved overall cooking performance when compared to NORM non-marinated portions. SEV top portions did not show significant ($P \geq 0.05$) changes between marinated and non-marinated samples. On the other hand, bottom portions had significantly less ($P \leq 0.05$) cook loss when comparing marinated and non-marinated portions. The results are consistent with those of Mudalal et al. (2015) who found that fillets with WB have lower marinade retention and higher cook loss percentage compared to normal fillets.

Final cooked product yield (%) was calculated based on pre-marination and post-cooking interval weights for both marinated and non-marinated samples. SEV samples exhibited lower final product yields than NORM samples for both the ventral and dorsal portions. For marinated samples, final product yields were greater in the dorsal portions of the fillets than the ventral portions. As expected, all marinated fillets had lower total losses and greater yield compared with non-marinated fillets because of the uptake of marinade.

The differences between the marination and cooking performance and final cooked product yield can also be attributed to the abundance of connective tissue in the ventral portion of the fillets. Soglia and others (2015) found that histopathological lesions in a WB-affected fillet gradually disappeared when moving from the ventral to dorsal side of the fillet, showing a reduction of muscle fibers on the ventral side. When the muscle fiber area is separated, and/or replaced with connective tissue, marinate absorption and retention will be diminished as connective tissues do not readily absorb and retain marinate. As shown in this study, ventral portions had lower marinade pickup and retention with greater cook loss than dorsal portions.

The instrumental texture analysis of marinated and non-marinated NORM and SEV portioned fillets are shown in Table 3.3. No clear differences ($P \geq 0.05$) could be found in top and bottom NORM portions in either treatment group. Portioning did not have an effect on the shear force, despite having the shear measurements taken on an intact surface (top portion) and a cut surface (bottom portion) from the horizontal portioning. There were no significant ($P \geq 0.05$) differences between NORM top fillets, but marinated portions exhibited slightly lower shear force than non-marinated portions. However, a significant ($P \leq 0.05$) reduction in shear force was observed in marinated NORM bottom portions when compared to non-marinated portions. This reduction shows that marination reduced shear force and increased the tenderness of bottom portions of NORM fillets. For SEV fillets, there were no significant ($P \geq 0.05$) differences in shear force for either portion or treatment group. It is good to mention that the marinated SEV top portion had higher shear force compared to the control. This may be attributed to low marinade pickup in SEV top portions which reduces the effectiveness of ingredients at tenderizing meat, consistent with Mudalal et al. (2015). Marinated SEV bottom portions, though not significant ($P \geq 0.05$), showed increased tenderness compared to control portions. From these data, it can be determined that marination does not have a significant impact on increasing the tenderness for SEV fillet portions.

CONCLUSION

It can be concluded that dorsal fillet portions perform better when marinated than ventral portions in terms of marination performance and cook loss. This can be attributed to the increased area of exposed muscle fibers on the cut and deboned surfaces on the bottom portion. Additionally, WB has a negative effect on marination performance in both ventral and dorsal portions. Earlier studies have observed that the selection for high-growth broilers has resulted in a reduction in quality traits as well as technological properties of chicken breast meat. Data from this study demonstrates that WB affects the technological properties of broiler breast fillet dorsal and ventral portions differently, with more detrimental effects observed in SEV top portions. This can be attributed to the increased prevalence of connective tissue on the ventral side of the fillet when compared to the dorsal side. When marinated, the dorsal portion more readily absorbs and retains marinade during vacuum tumbling and storage than the ventral portion, but uptake was lower in both top and bottom SEV portions. It can be determined from this study that the WB condition negatively influences the marination and cooking performance in both the ventral and dorsal portions of broiler breast fillets.

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Table 3.1. Marination performance of broiler breast fillet portions (LS mean ± SE, n = 30)

	Degree of Woody Breast[1]			
	NORM		SEV	
	Top	Bottom	Top	Bottom
Uptake %	8.59c	19.43a	5.18d	10.89b
Marinade Retention %	66.96b	81.55a	42.22c	66.96b
Raw Yield %	105.76c	115.74a	102.34d	107.61b
Cook Loss %	11.97c	16.37b	21.59a	16.89b
Overall Cook Yield %	93.07ab	96.71a	80.22c	89.44b

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

Table 3.2. Cooking performance of broiler breast fillet portions (LS mean ± SE, n = 30)

	Degree of Woody Breast[1]							
	NORM				SEV			
	Control		Marinated		Control		Marinated	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Cook Loss %	18.83cd	21.67bc	11.90e	16.37de	22.75ab	27.43a	21.59bc	16.89cd
Cook Yield %	80.81c	77.82cd	93.14ab	96.71a	74.62de	71.23e	80.22c	89.44b

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

Table 3.3. Warner-Bratzler Force of normal and woody breast broiler fillets (LS mean ± SE, n = 30)

	Degree of Woody Breast[1]			
	NORM		SEV	
	Control	Marinated	Control	Marinated
Top	3267.68[ab]±421.27	2273.19[bc]±424.13	3290.46[ab]±421.20	3436.20[a]±421.20
Bottom	3830.44[a]±424.13	2065.45[c]±421.20	3621.82[a]±421.20	3133.42[abc]±421.20

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

CHAPTER 4

DESCRIPTIVE SENSORY ANALYSIS OF MARINATED WOODY BREAST FILLET PORTIONS[1]

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[1]Maxwell, A. D., D. Chatterjee, H. Zhuang, B. Bowker, K. Adhikari. To be submitted to *Journal of Poultry Science*

ABSTRACT

Broiler breast fillets have recently been impacted by a muscle myopathy known as woody breast (WB). Broilers with this condition have distinct hardness in raw breast fillets, and the condition can vary in severity from normal (NORM) to severe (SEV). The objective of this study was to determine the effects of marination on the perception of visual, texture, and flavor attributes of the ventral (skin-side) and dorsal (bone-side) portions of both NORM and SEV fillets. In each of 3 experimental replications, 20 butterfly breast fillets were collected from the deboning line of a commercial plant and sorted into NORM (no WB) and SEV categories. Each fillet was portioned into ventral and dorsal halves. Portions from one side of each butterfly were used as non-marinated controls, and portions from the other side were vacuum-tumble marinated (16 rpm, –0.6 atm, 4°C, 20 min) with 20% (wt/wt) marinade to meat ratio. Marinade was formulated to target a final concentration of 0.75% (w/v) salt and 0.45% (w/v) sodium tripolyphosphate in the final product. The descriptive panel (n=9 trained panelists) was conducted to analyze visual, texture, and flavor attributes of broiler breast portions. In each experimental replication, both marinated and non-marinated butterfly portions were cooked in a combination oven to an internal temperature of 78°C in vacuum bags. Two 1.9 x 1.9 cm cubes of each treatment were presented to panelists. The descriptive panel used standard meat flavor and texture lexicon and scored on a 0-15-point scale. Results of the descriptive panel indicated marination of fillet portions can influence the perception of negative texture attributes in SEV fillets. Darker color was observed in bottom and SEV top portions.

Greater (P≤0.05) chewiness was perceived in bottom portions. SEV top portions had greater (P≤0.05) springiness and cohesiveness. Increased (P≤0.05) hardness was observed in SEV top portions and control bottom portions. Greater (P≤0.05) fibrousness was found in all SEV portions, excluding the marinated bottom portions. Marinated portions had higher (P≤0.05) saltiness compared to control samples, with bottom portions having the highest saltiness. Greater brothy flavor was also detected in marinated portions. Significant (P≤0.05) effects in the ventral and dorsal portions indicate that the sensory perception of texture attributes in fillets affected with WB differ between ventral and dorsal portions.

INDEX WORDS: woody breast, descriptive sensory, fillet portion, marination, texture

INTRODUCTION

Demand for boneless breast meat in the United States continues to steadily increase and remains a top protein source for consumers (National Chicken Council, 2016b). To meet the increasing consumer demand for breast meat and poultry products, the poultry industry has increased the growth rate of broilers, resulting in improved production efficiency and larger breast fillets. Broilers currently reach a market weight twice the size in half the time compared to production in the 1970s, placing added stress on the bird (Barbut et al., 2008; Zuidhof et al., 2014). The consumption pattern of broiler meat has also changed in that time, as consumers primarily purchase products that are further processed, value-added, and portioned into individual parts (Barbut et al., 2008). The 2015 forecast of marketing broiler meat suggests that 49% of the broiler market is further processed and 40% is cut-up parts (National Chicken Council, 2016a). The change in consumption pattern to further processed products and cut-up parts suggest that meat quality attributes, including water-holding capacity and texture of the product, has become even more essential than ever before.

The rapid growth rate that the poultry industry is currently experiencing is known to affect the meat quality of broiler breast meat, which is most popular among consumers. In recent years, myopathies such as white striping and woody breast have been reported, which negatively affect the appearance and other meat quality attributes of broiler breast meat (Kuttappan et al., 2012a; Petracci et al., 2015; Soglia et al., 2015; Zotte et al., 2014). White striping is characterized by having white striations parallel to the fibers accompanied by infiltration of lipid components and connective tissue

(Kuttappan et al., 2012a; 2013a,b). Woody breast is described as hard, outbulging, and pale fillets that are often seen with white striping along with increased interstitial connective tissue and exhibit low meat quality properties (Sihvo et al., 2014; Mudalal et al., 2015; Tijare et al., 2016). Trocino et al. (2015) reported that fillets affected with woody breast have greater cook losses and shear values.

WB changes the meat quality attributes of the further processed products that consumers typically purchase, resulting in economic losses for the industry. Assessing how these changes in broiler breast meat quality is critical to understand the sensory acceptability of those products. In sensory evaluation of meat, it has been found that connective tissue, fat content, and cook loss directly impact sensory texture attributes such as tenderness and juiciness (Bailey, 1985; Shorthose and Harris, 1991; Purslow, 2005; Hopkins et al., 2006; Hughes et al., 2014). Because the WB condition has been shown to affect similar texture attributes in meat, a descriptive sensory panel was used to define visual, texture, and flavor attributes of broiler breast fillet portions affected with WB. The objective of this study was to investigate the effect of marination of broiler breast fillet ventral and dorsal portions affected with WB on the flavor and texture of chicken breast fillets affected with WB using a sensory descriptive analysis. It is expected that severe WB fillet portions will be harder, chewier, and more fibrous when compared to normal fillet portions. In addition, marinated samples are expected to be more flavorful with increased salty and brothy flavors, increased juiciness, and a reduction in hardness and chewiness when compared to non-marinated fillet portions.

MATERIALS AND METHODS

Broiler Breast Fillet Sorting and Raw Sample Preparation

Breast fillet pairs from 8-week-old broilers (Ross meat line) were collected from the deboning line of a commercial processing plant (approximately 3 h postmortem). The fillets were placed in Ziploc bags (Ziploc Brand Freezer Bags, Johnson & Son Inc., Racine, WI) and transported on ice to the laboratory within 45 min. They were trimmed and scored into normal (NORM) and severe (SEV) WB categories based on the incidence of diffuse hardened areas throughout the fillets and the severity of palpable hardness, as well as into white striping categories based on previously established criteria (Kuttappan et al., 2012) on the prevalence and thickness of white striations on the surface of the muscle. Over 3 different trial days, a total of 60 fillets (30 fillets per rep, per treatment) were selected based on their WB scores. Breast fillets were stored in unsealed transparent poly nylon vacuum pouches (Model S-19800, Uline, Pleasant Prairie, WI) at 4˚C overnight before portioning. Fillets were split into top (ventral) and bottom (dorsal) portions using a Berkel deli slicer (Model: X13E-PLUS, Illinois Tool Works Inc, Glenview, IL) and weighed. The portioned pairs were divided into the two treatment categories (marinated and non-marinated) and stored at 4˚C.

Marination

Portions were tagged and weighed individually before they were vacuum-tumbled (model: DVTS 30 V.S, Daniels Food Equipment, Parkers Prairie, MN) for 20 min at 16 rpm and –0.6 atm in marinade (20% of initial fillet weight) at 4˚C. Marinade contained 5% NaCl and 3% sodium tripolyphosphate (ingredient supplier) and was formulated with a targeted final concentration of 0.75% NaCl and 0.45% phosphate in the final product. After marination, individual fillets were drained and stored at 4˚C overnight.

Cooked Sample Preparation

Portioned fillets were vacuum sealed in transparent poly nylon vacuum pouches (Model S-19800, Uline, Pleasant Prairie, WI) and were cooked in a Henny Penny MCS-6 combination oven (Henny Penny Corporation, Eaton, OH) at 85˚C with the tender steam setting to reach an internal temperature of 78˚C. The internal temperatures were checked in the thickest part of each portioned fillet with a hand-held digital thermometer fitted with a hypodermic needle probe (Doric Digital Thermometer, Model 450-ET, Doric Scientific, San Diego, CA). The cooked samples were drained of liquid and patted dry with paper towels. Prior to serving treatments, two 1.9-cm-wide strips were removed from the breast by cutting next to a template aligned parallel to the muscle fibers and adjacent to the cranial end (Figure 4.1). Strip B was used for sensory evaluation, while strip C was used for instrumental shear testing. Strip B was trimmed into two 1.9 x 1.9 cm cubes and served to panelists in a monadic sequential presentation scheme. Each panelist received two cubes (S1 and S2) from each of the 8 treatments in soufflé cups with water, unsalted soda crackers, and apple slices to rinse and cleanse their palette.

Descriptive Sensory Analysis

Sensory analysis was performed using a descriptive panel of 9 trained panelists with long standing experience of 2-3 y (400+ hr of training) , at the USDA National Poultry Research Center, Athens, GA. The panelists took part in a 3-week orientation training session to familiarize themselves with the two categories of fillets and to evaluate the descriptors from the lexicons used for repeatability and consistency, similar to Lyon and Lyon (1998) and Cavitt et al. (2004). The descriptive panel used standard visual, flavor, and meat texture lexicons to obtain visual, texture, and flavor profiles of the treatments in three replications. The visual attribute of color was measured using color chips associated with varying hues of cooked chicken. The texture attributes (Table 4.1) evaluated include a partial compression attribute of springiness, first bite/chew characteristics (cohesiveness, and hardness), and chewdown characteristics (juiciness, fibrousness). The flavor attributes (Table 4.2) evaluated include the basic tastes of sweet, salt, and sour, and the aromatic attribute (Table 4.2) of brothy. All intensities for each attribute were presented on a 0-15-point scale (with 0.1 point increments) using the Spectrum™ Descriptive Analysis Method, with references assigned for comparison of intensities to the breast fillet sample. Data were collected with Compusense® Cloud (Compusense Inc., Guelph, Canada).

Warner-Bratzler Shear Force Determination

Two 1.9-cm-wide strips were removed from the breast by cutting next to a template aligned parallel to the muscle fibers and adjacent to the cranial end (Figure 4.1). After reaching ambient temperature (20˚C), Strip C was sheared in two locations (WB1 and WB2). Shear force values of were measured using a Texture Analyzer (Model TA-XT-plus, Texture Technologies Corp, Hamilton, MA) with a 50-kg load cell fitted with a slice-shear device according to the methods reported by Lyon and Lyon (1990).

Statistical Analysis

Data were subjected to Analysis of Variance (ANOVA) using the GLIMMIX Procedure in SAS software (Version 9.4, SAS Institute, Cary, NC) where Sample is a fixed effect, and Rep and Panelist were treated as random effects. Least square means were separated statistically with the Tukey's HSD method with an alpha level ($P \leq 0.05$) to determine significance. Principal components analysis (PCA) was carried out on the mean attribute score × samples data matrix using XLSTAT (Addinsoft, New York, NY, USA).

RESULTS AND DISCUSSION

The mean scores of sensory analyses are shown in Table 4.1. Texture attributes during partial compression and the first bite include springiness, cohesiveness and hardness. NORM portions were less ($P \leq 0.05$) springy and cohesive than SEV portions. SEV top portions were the most springy and cohesive of all portions, with no reduction in springiness or cohesiveness when marinated. SEV bottom portions compared similarly in springiness and cohesiveness to NORM portions in both marination treatments. SEV portions were harder ($P \leq 0.05$) than NORM portions. SEV top portions were the hardest of all portions. SEV bottom portions were less hard than SEV top portion, with a significant ($P \leq 0.05$) reduction in hardness when marinated. The marinated SEV and NORM bottom portions were rated at a similar hardness, resulting in no difference between the two WB categories. These results are consistent with the results of Tasoniero et al. (2016) who found that fillets with combined WB and white striping had higher toughness ratings when compared against normal fillets.

Chewdown texture attributes including chewiness, juiciness, and fibrousness, are perceived after multiple chews until the point of swallowing or expectoration. SEV portions were chewier ($P \leq 0.05$) than NORM portions, with top portions rated higher than bottom portions. There was no difference ($P > 0.05$) in juiciness between all portions, however, marinated portions were rated higher than non-marinated portions. SEV portions were more ($P \leq 0.05$) fibrous than NORM portions, with top portions rated as the most fibrous. When marinated, SEV portions were perceived as less fibrous than non-marinated portions. There was a significant reduction in fibrousness in SEV bottom portions when marinated.

Attributes used to describe the visual, flavor, and aromatic attributes include color, salty, sour, and brothy. SEV portions were darker ($P \leq 0.05$) than NORM portions. SEV top portions were darker than bottom portions, with no change ($P > 0.05$) in color when marinated in SEV top and bottom portions. Higher ($P \leq 0.05$) saltiness was detected in marinated samples for both NORM and SEV portions. The marinated bottom portions were saltier than the marinated top portions. This is can be associated with increased uptake of marinade in the bottom portions. There was no difference ($P > 0.05$) between all portions, but SEV portions were rated lower than NORM portions. Brothy aromatics were higher ($P \leq 0.05$) in marinated NORM and SEV portions. Marinated bottom portions had more brothy flavor than top portions. Similarly to saltiness, higher brothy aromatics can be attributed to the uptake of marinate. The results of the descriptive sensory analysis of texture attributes signify the role of connective tissue in texture attributes with the woody breast muscle myopathy as described by recent research (Sihvo et al., 2014; Soglia et al., 2015; Velleman and Clark, 2015).

Principal Component Analysis (PCA) was performed to illustrate the multidimensional relationships among samples and sensory attributes. The first two dimensions of PCA accounted for 87.70% of the total variance (Figure 4.2). PC1 explained 65.45% of the total variance and the second PC (F2) explained 22.25% of the total variance. It can be determined that the F1 axis distinguishes samples based on the degree of WB into either NORM or SEV groups, and the F2 axis distinguished samples based on the marination treatment into marinated and non-marinated groups. The F1 and F2 axes arranged the sensory attributes into two distinct groups, Group 1: WB-related attributes (hardness, cohesiveness, fibrous, chewiness, springiness, color, and WBForce), and Group 2: marination-related attributes (salty, sour, brothy, juiciness).

The PCA biplot (Figure 4.2) shows that SEV portions affected with WB condition are the most positively correlated to Group 1 attributes. These texture attributes are associated with fillets from affected with WB. However, the WB marinated bottom portion (SMB) is the exception by negatively correlated to the texture attribute cluster and more positively correlated to attributes in Group 2. This shows that marination of bottom fillet portions showed a reduction in the intensity of hardness, chewiness, and fibrousness, and compared similarly to the NORM marinated bottom portions. NORM portions are negatively correlated with the Group 1 attributes, as these portions did not possess the textural traits associated with WB.

Marinated portions (NMT, NMB, SMB) are the most positively correlated with Group 2 attributes in. Salty flavor and the brothy aromatic can be attributed to the salt in the marination brine producing flavors and aromas reminiscent of poultry-based soups and stocks. As shown in descriptive analysis, marinated portions were higher in salty and brothy flavors than non-marinated samples. Marination is used to increase the water holding capacity (WHC) of broiler meats, therefore, marinated fillet portions are expected to be more juicy than non-marinated fillet portions. Both SEV (SMB) and NORM (NMB) marinated bottom portions are closely correlated with the juiciness attribute due to the uptake and retention of brine during marination. However, the marinated SEV top portion (SMT) is positively correlated to the texture and visual attributes. This is also seen in the sensory data, with the marinated SEV top portions having similar sensory scores to non-marinated SEV top portions. This shows that the texture attributes associated with WB overpowered the presumed effects of tenderization and increased WHC that marination should have on fillet portions.

Non-marinated portions (NCT, NCB, SCT, SCB) were negatively correlated to the attributes in Group 2, showing a difference between marinated and non-marinated samples. Non-marinated NORM portions (NCT, NCB) also negatively correlated with the texture attributes in Group 1, indicating no relationship between non-marinated NORM portions with attributes associated with WB. On the other hand, non-marinated SEV portions (SCT, SCB) positively correlate with the attributes in Group 1. The SCT portion most closely correlates with chewiness, an indicator of WB in descriptive sensory analysis.

CONCLUSION

Overall, panelists could differentiate samples based on condition and treatment using descriptive sensory lexicon. Attributes of chewiness, hardness, fibrousness, and springiness are associated with texture related to the woody breast muscle myopathy. Marinated samples showed increased intensity in aromatic and flavor attributes, and decreased the intensity of chewiness in severe portions. Marination had a greater impact on bottom portions compared to top portions with increased intensity of aromatic and flavor attributes. Results suggest that significant effects on the two portions indicate that the effects of WB on sensory perception differ in the dorsal and ventral portions of the fillet. In addition, marinating dorsal and ventral breast fillet portions affected with WB can reduce the perception unique texture characteristics associated with the woody breast myopathy.

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Table 4.1. Texture lexicon used for analyzing the texture of broiler breast fillets

Term	Definition	Technique	Reference and Scaling	
Partial Compression				
Springiness	The rate at which the sample returns to its original shape.	Compress the sample partially with molars without breaking the sample.	Cream cheese Pound Cake Soft Pretzel Gummy Bear	2.0 5.0 7.0 15.0
First Bite/Chew				
Cohesiveness	The amount of the sample that deforms rather than splits apart, cracks, or breaks	Place the sample between molars or incisors and fully compress sample.	Corn Bread American Cheese Soft Pretzel Gum	1.0 5.0 8.0 15.0
Hardness	The force required to fully compress the sample	Compress or bite through sample one time with molars	Cream Cheese American Cheese Olive Bordeaux Cookie Life Saver	1.0 4.5 6.0 8.0 14.5
Chewdown Characteristics				
Fibrousness	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 Dried Apricot Pineapple Celery Beef Jerky	2.0 5.0 7.5 10.0 15.0
Juiciness	The amount of moisture coming from the sample	Place sample between molars and chew 3-5 times. Evaluate during chewing	Banana Mushroom Cucumber Watermelon	1.0 4.0 8.0 15.0
Chewiness	The amount of work to chew the sample to the point of swallowing; the cumulative attribute from the first to the last chew.	Chew 1 bite per second	Rye Bread Gum Drop Tootsie Roll	1.8 5.8 12.7

Table 4.2. Flavor lexicon used to analyze aroma and flavor attributes of broiler breast fillets

Term	Definition	Technique	Reference and Scaling
Basic Tastes			
Salt	The basic taste, perceived on the tongue, stimulated by sodium salt, especially sodium chloride	Sodium chloride solutions in filtered water	2.0% solution 2.0 5.0% solution 5.0 10.0% solution 10.0 15.0% solution 15.0
Sour	The basic taste, perceived on the tongue, stimulated by acids, such as citric acid	Citric acid solutions in filtered water	5.0% solution 2.0 8.0% solution 5.0 15.0% solution 10.0 20.0% solution 15.0
Aromatics			
Brothy	Aromatic associated with boiled meat, soup, stock. Weak meaty note.	Chicken stock solutions in filtered water	2.0% solution Low 2.0% solution Med 2.0% solution High

Table 4.3. Mean sensory scores broiler breast fillet portions (mean ± SE, n = 30)

	NORM				SEV			
Sensory	Control		Marinated		Control		Marinated	
Attribute	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Color	3.15^{c}±0.36	3.85^{abc}±0.36	3.72^{abc}±0.36	3.38^{bc}±0.36	4.46^{ab}±0.36	3.91^{abc}±0.36	4.46^{ab}±0.36	3.71^{abc}±0.36
Chewiness	5.08^{bc}±0.38	4.94^{bc}±0.38	4.76^{c}±0.38	4.78^{bc}±0.38	6.13^{a}±0.38	5.51^{abc}±0.38	5.74^{ab}±0.38	5.03^{bc}±0.38
Springiness	5.99^{c}±0.66	5.75^{c}±0.66	5.62^{c}±0.66	5.53^{c}±0.66	7.52^{ab}±0.66	6.45^{abc}±0.66	7.59^{a}±0.66	6.27^{bc}±0.66
Cohesiveness	5.71^{bc}±0.48	5.43^{c}±0.48	5.01^{c}±0.48	4.78^{c}±0.48	7.22^{a}±0.48	5.81^{bc}±0.48	6.87^{ab}±0.48	5.54^{c}±0.48
Hardness	5.30^{bc}±0.41	5.37^{bc}±0.41	5.22^{bc}±0.41	5.01^{c}±0.41	6.15^{a}±0.41	5.93^{ab}±0.41	6.28^{a}±0.41	5.08^{c}±0.41
Juiciness	4.40±0.49	4.21±0.49	4.94±0.49	4.56±0.49	3.83±0.49	3.81±0.49	3.83±0.50	4.72±0.49
Fibrous	3.78^{b}±0.74	4.46^{ab}±0.74	3.90^{b}±0.74	3.44^{b}±0.74	5.55^{a}±0.74	4.82^{ab}±0.74	5.59^{a}±0.75	3.70^{b}±0.74
Salty	2.95^{c}±0.48	2.57^{c}±0.48	4.76^{b}±0.48	7.36^{a}±0.48	2.90^{c}±0.48	2.41^{c}±0.48	4.64^{b}±0.49	6.01^{ab}±0.48
Sour	2.52±0.54	2.42±0.54	2.6±0.54	1.80±0.54	1.70±0.54	1.81±0.54	1.94±0.54	1.66±0.54
Brothy	4.41^{bc}±0.71	4.09^{c}±0.71	5.53^{abc}±0.71	6.58^{a}±0.71	5.17^{abc}±0.71	4.08^{c}±0.71	5.36^{abc}±0.72	5.91^{ab}±0.71

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

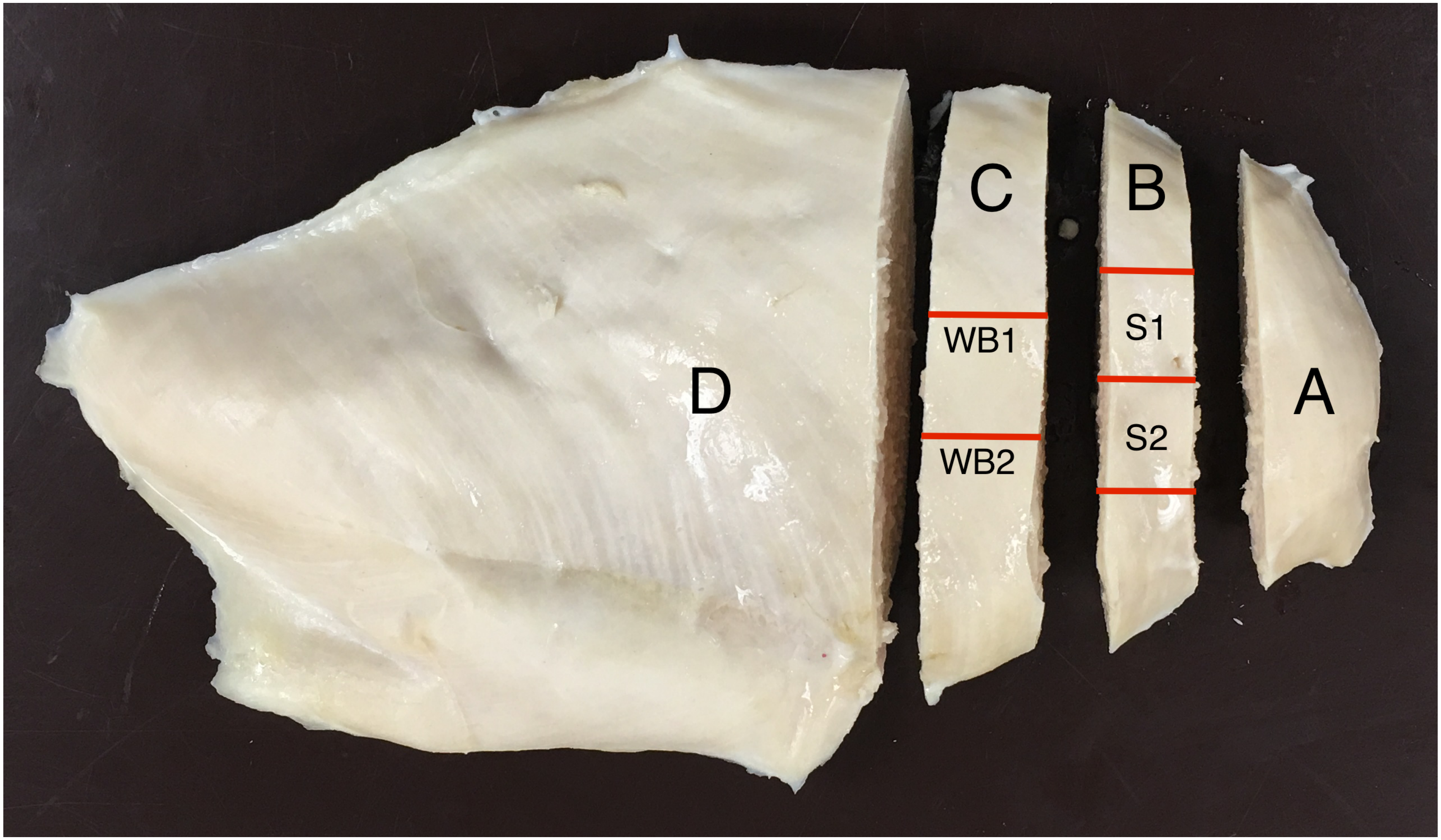

Figure 4.1. Sectioning scheme for cooked broiler breast fillet portion. 1.9-cm strips were obtained using a template for sensory evaluation (Strip B) and Warner-Bratzler (Strip C) shear measurements. Two 1.9 x 1.9 cm cubes (S1 and S2) were portioned out of Strip B of each treatment and presented to panelists for sensory evaluation. Strip C was used for instrumental texture analysis shearing at points WB1 and WB2 to replicate full compression in similar sites used in sensory analysis. Strips A and D were discarded and not utilized for analysis.

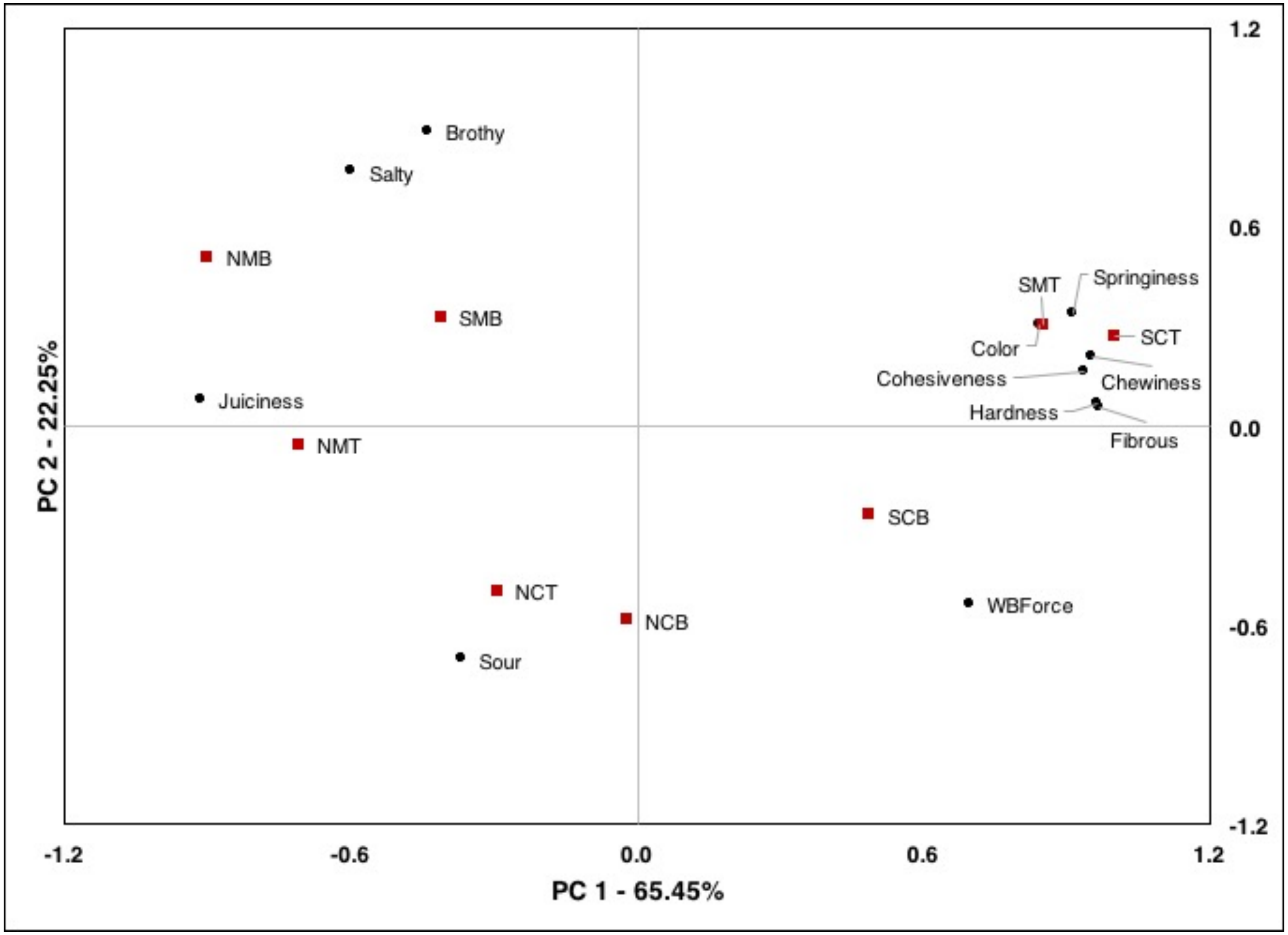

Figure 4.2. Principle Component Analysis of Sensory Attributes, Portioned Fillet Samples, and WB Force. Sensory attributes are labeled with black circle markers. Samples are labeled with red square markers. Sample codes are as follow: NCT (NORM non-marinated top), NCB (NORM non-marinated bottom), NMT (NORM marinated top), NMB (NORM marinated bottom), SCT (SEV non-marinated top), SCB (SEV non-marinated bottom), SMT (SEV marinated top, and SMB (SEV marinated bottom).

CHAPTER 5

CONCLUSION

Differences in marination performance have been detected in broiler breast fillets affected with WB, as well as, textural changes as observed from descriptive sensory analysis and meat quality measurements such as shear force curves. Thus, it appears that WB presents challenges for value-added processing that looks to improve the WHC and tenderness of broiler breast meat. Measuring and describing the differences of the complex texture attributes of WB compared to normal broiler breast fillets deems challenging. Future research should be conducted to determine the consumer acceptability of marinated portioned fillets affected with WB, to determine if consumers can identify textural differences between normal and affected fillets. Additionally, determining reasons for acceptability of severe WB meat associated with consumer groups including price, cooking method, and portioning.

APPENDIX A: SAS CODES USED FOR STATISTICAL ANALYSIS

The GLIMMIX Procedure Code for Cooking Performance Study

```
data cook;
input Condition$    Portion$    Treatment$  Rep$  RawYield    PrecookWt
PstcookWt   CookLoss    CookYld     WBForce     WBEnergy;
datalines;

(Data Deleted)
;
ods rtf;

proc glimmix;
class Condition     Portion     Treatment   Rep;
model RawYield      = Condition|Portion|Treatment/ddfm=sat;
random rep;
lsmeans Condition|Portion|Treatment/pdiff lines adjust=tukey;
run;

proc glimmix;
class Condition     Portion     Treatment   Rep;
model PrecookWt     = Condition|Portion|Treatment/ddfm=sat;
random rep;
lsmeans Condition|Portion|Treatment/pdiff lines adjust=tukey;

run;proc glimmix;
class Condition     Portion     Treatment   Rep;
model PstcookWt    = Condition|Portion|Treatment/ddfm=sat;
random rep;
lsmeans Condition|Portion|Treatment/pdiff lines adjust=tukey;
run;proc glimmix;

class Condition     Portion     Treatment   Rep;
model CookLoss     = Condition|Portion|Treatment/ddfm=sat;
random rep;
lsmeans Condition|Portion|Treatment/pdiff lines adjust=tukey;
run;proc glimmix;

class Condition     Portion     Treatment   Rep;
model CookYld       = Condition|Portion|Treatment/ddfm=sat;
random rep;
lsmeans Condition|Portion|Treatment/pdiff lines adjust=tukey;
```

```
run;proc glimmix;

class Condition       Portion        Treatment     Rep;
model WBForce      = Condition|Portion|Treatment/ddfm=sat;
random rep;
lsmeans Condition|Portion|Treatment/pdiff lines adjust=tukey;
run;proc glimmix;

class Condition       Portion        Treatment     Rep;
model WBEnergy    = Condition|Portion|Treatment/ddfm=sat;
random rep;
lsmeans Condition|Portion|Treatment/pdiff lines adjust=tukey;
run;
ods rtf close;
quit;
```

The GLIMMIX Procedure Code for Marination Performance Study

```
data marinade;
input Condition$	Portion$	Rep$ GreenWt	XXMinWt	Uptake
MarRete	RawYield	PrecookWt	PstcookWt	CookLoss
CookYld	WBForce	WBEnergy;
datalines;

(Data Deleted)
;
ods rtf;

proc glimmix;
class Condition	Portion	Rep;
model GreenWt	= Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;
run;

proc glimmix;
class Condition	Portion	Rep;
model XXMinWt	= Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;
run;

proc glimmix;
class Condition	Portion	Rep;
model Uptake	= Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;
run;

proc glimmix;
class Condition	Portion	Rep;
model MarRete	= Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;
run;

proc glimmix;
class Condition	Portion	Rep;
model RawYield	= Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;
```

```
run;

proc glimmix;
class Condition       Portion         Rep;
model PrecookWt     = Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;

run;proc glimmix;
class Condition       Portion         Rep;
model PstcookWt    = Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;
run;proc glimmix;

class Condition       Portion         Rep;
model CookLoss     = Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;
run;proc glimmix;

class Condition       Portion         Rep;
model CookYld        = Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;
run;proc glimmix;

class Condition       Portion         Rep;
model WBForce       = Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;
run;proc glimmix;

class Condition       Portion         Rep;
model WBEnergy    = Condition|Portion/ddfm=sat;
random rep;
lsmeans Condition|Portion/pdiff lines adjust=tukey;
run;
ods rtf close;
quit;
;
```

The GLIMMIX Procedure Code for Descriptive Sensory Analysis Study

```
data sensory;
input Sample$ Rep$ Panelist$ Color Salty Sour Brothy Chewy Springy Cohesive Hard
Juicy Fiber WBForce
datalines;

(Data Deleted)
;
ods rtf;

proc glimmix;
class Sample Rep Panelist;
model Color = Sample/ddfm=sat;
repeated Rep Panelist;
lsmeans sample/pdiff lines adjust=tukey;

proc glimmix;
class Sample Rep Panelist;
model Salty = Sample/ddfm=sat;
repeated Rep Panelist;
lsmeans sample/pdiff lines adjust=tukey;

proc glimmix;
class Sample Rep Panelist;
model Sour = Sample/ddfm=sat;
repeated Rep Panelist;
lsmeans sample/pdiff lines adjust=tukey;

proc glimmix;
class Sample Rep Panelist;
model Brothy = Sample/ddfm=sat;
repeated Rep Panelist;
lsmeans sample/pdiff lines adjust=tukey;

proc glimmix;
class Sample Rep Panelist;
model Chewy = Sample/ddfm=sat;
repeated Rep Panelist;
lsmeans sample/pdiff lines adjust=tukey;

proc glimmix;
class Sample Rep Panelist;
model Springy = Sample/ddfm=sat;
repeated Rep Panelist;
```

```
lsmeans sample/pdiff lines adjust=tukey;

proc glimmix;
class Sample Rep Panelist;
model Cohesive = Sample/ddfm=sat;
repeated Rep Panelist;
lsmeans sample/pdiff lines adjust=tukey;

proc glimmix;
class Sample Rep Panelist;
model Hard = Sample/ddfm=sat;
repeated Rep Panelist;
lsmeans sample/pdiff lines adjust=tukey;

proc glimmix;
class Sample Rep Panelist;
model Juicy = Sample/ddfm=sat;
repeated Rep Panelist;
lsmeans sample/pdiff lines adjust=tukey;

proc glimmix;
class Sample Rep Panelist;
model Fiber = Sample/ddfm=sat;
repeated Rep Panelist;
lsmeans sample/pdiff lines adjust=tukey;

proc glimmix;
class Sample Rep Panelist;
model WBForce= Sample/ddfm=sat;
repeated Rep Panelist;
lsmeans sample/pdiff lines adjust=tukey;

run;
ods rtf close;
quit;
```

APPENDIX B: RAW FILLET DATA

Table B.1. Characteristics of marinated and non-marinated broiler breast meat with normal (NORM) and severe (SEV) degrees of woody breast (n=60)

		Fillet Wt. (g)	pH	WS Score[1]	Drip Loss %	Color L*	Color a*	Color b*
WB	SEV	523.22	6.01a	2.32a	1.48a	59.40	0.23a	13.20a
	NORM	497.08	5.92b	1.19b	1.10b	60.43	-0.55b	11.48b
	SEM	17.16	0.05	0.1	0.17	1.41	0.16	0.98
Treatment	Non-Marinated	506.86b	5.97b	1.76	1.30a	59.90	-0.15	12.27
	Marinated	513.45a	6.01a	1.75	1.28a	59.93	-0.17	12.40
	SEM	15.98	0.05	0.09	0.16	1.33	0.12	0.95
WB x Treatment	NORM x Non-Marinated	492.45b	5.91c	1.18b	1.10b	60.38	-0.56b	11.53b
	NORM x Marinated	501.72a	5.93c	1.20b	1.10b	60.48	-0.55b	11.43b
	SEV x Non-marinated	521.27ab	6.04b	2.33a	1.49a	59.43	0.25a	13.27a
	SEV x Marinated	525.17a	6.10a	2.30a	1.46a	59.38	0.2a	13.12a
	SEM	17.85	0.05	0.11	0.17	1.43	0.17	0.99

[1]White striping score: normal = 1, moderate = 2, severe = 3.
[a–c]Means within a column with no common superscript differ significantly (P<0.05).

Table B.2. Marination and cooking performance weights for broiler breast fillets with normal (NORM) and severe (SEV) degrees of woody breast (n=30)

	Degree of Woody Breast[1]							
	NORM				SEV			
	Control		Marinated		Control		Marinated	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Green Weight	-	-	242.58b	243.08b	-	-	241.23b	279.44a
20 Minute Weight	-	-	263.23bc	289.52ab	-	-	253.68c	309.43a
Uptake	-	-	8.59c	19.43a	-	-	5.18d	10.89b
Marinade Retention	-	-	66.96b	81.55a	-	-	42.22c	66.96b
Raw Yield	99.53d	99.36d	105.75b	115.74a	97.06d	98.36d	102.34c	107.61b
Pre-Cook Weight	242.18c	239.65c	256.43bc	280.76ab	229.69c	281.78ab	246.77c	300.43a
Post-Cook Weight	197.07cd	187.93d	226.17abc	235.32ab	177.92d	205.59bcd	192.84d	249.90a
Cook Loss	18.83cd	21.67bc	11.90e	16.37de	22.75ab	27.43a	21.59bc	16.89cd
Cook Yield	80.81c	77.82cd	93.14ab	96.71a	74.62de	71.23e	80.22c	89.44b
WBForce	3267.68ab	3830.44a	2273.19bc	2065.45c	3290.46ab	3621.82a	3436.20a	3133.42abc

[a–e]Means within a column with no common superscript differ significantly (*P*<0.05).