DESCRIPTIVE SENSORY AND TEXTURE PROFILE ANALYSIS OF WOODY BREAST IN MARINATED CHICKEN

A Thesis

by

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ABSTRACT

The broiler industry has a variable meat texture issue known as woody breast. This research compares quality attributes of normal (NOR) and severe woody breast (SWB) in 3 experiments. The objective of Experiment I was to evaluate the quality traits of marinated NOR and SWB fillets and their effect on tenderness. A total of 333 fillets were categorized into NOR (n = 180, flexible through the fillet) and SWB (n = 153, rigid through the fillet). Quality traits (drip loss and cook loss %) and tenderness measurements (Warner Bratzler shear force and sarcomere length) were evaluated. SWB fillets had higher drip loss % and higher cook loss % compared to normal fillets ($P < 0.05$). No statistical differences were found in Warner Bratzler shear force and sarcomere length. Experiment II objectives were to develop and validate a sensory texture profile of marinated SWB meat using 6 trained panelists and two different cooking methods, and to evaluate the texture profile analysis (TPA) using the texture analyzer. In two replicates, normal (n = 32) and severe woody breast (n = 32) were assessed and pH, color, cook loss and marination properties were measured. Fillets were cooked (73° C) either on a flat top grill or in an air convection oven. The texture cranial portion of the fillet was used to evaluate texture using trained panelists and TPA. SWB had higher weights compared to NOR fillets (333.8 and 405.7 g, respectively; $P < 0.05$). SWB lower technological properties compared to NOR fillets ($P < 0.05$). No differences were found within the cooking methods ($P > 0.05$). Sensory texture attributes were higher for SWB than NOR fillets (*P* <0.05) and crunchiness and fibrousness were the main texture attributes to describe SWB fillets. In Experiment III, both oven and grill cooking methods were used to evaluate TPA to determine differences between NOR and SWB either stored fresh (4° C) or frozen (-29° C). No differences were found in cooking methods. TPA of SWB was higher than NOR in fresh and frozen storage (*P* <0.05). In conclusion, storage temperature and cooking method do not influence the texture of SWB. Crunchy and fibrous are better descriptors for SWB meat instead of tough. TPA is a fast and reliable method to measure texture in chicken breast and is comparable to descriptive sensory results.

DEDICATION

To my lovely mother, Yolanda Cando

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NOMENCLATURE

WB	Woody breast
PSE	Pale, soft and exudative
DFD	Dark, firm and dry
WHC	Water holding capacity
pH	Potential of hydrogen
USDA	United Stated Department of Agriculture
STPP	Sodium tripolyphosphate
TPA	Texture profile analysis
WBSF	Warner Bratzler shear force
NOR	Normal breast fillet
SWB	Severe woody breast fillet
h	Hour
d	Day
g	Grams

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CHAPTER I

INTRODUCTION

Meat consumption patterns have been changing over the past 50 years. Currently, the consumption of broiler chicken meat is almost double compared to other meats, and it is estimated that chicken consumption will increase even more within the next decade (NCC, 2016). Kennedy et al. (2004) reported that consumers perceived chicken meat as having “added value” in terms of health because of its low fat content, reduced waste, and convenience. This increase in consumer demand for chicken meat has led to progressive changes in selection criteria of broiler chickens (Fletcher, 2004). In 1965, chickens were marketed mainly as whole carcasses, while today the cut-up/pieces and the further processed products represent up to 90% of the chicken market (NCC, 2015b). In this regard, producers have improved the growth rate and feed conversion of live birds (Petracci et al., 2014). However, in the last few decades, this selection for muscle growth has led to an increase in meat quality problems such as texture changes, pale color, and reduced water holding capacity, especially in the *pectoralis major* muscle (Dransfield, 1999).

Recently, research has observed a new type of muscle abnormality accompanying white striping meat called woody breast (WB). Woody breast is an unknown emerging quality problem characterized by the abnormal hardness, pale color, and exudate on the surface of the fillet caused by histological changes and necrosis

(Sihvo et al., 2014). Within the last three years, this novel meat quality issue has been increasing in several countries around the world. Although there are no human health effects related to the consumption of woody breast meat, the quality of the meat is severely affected.

Petracci et al. (2013b) found that higher breast yield hybrids presented a greater incidence of abnormal fibers compared to standard hybrids. In addition, Sihvo et al. (2014) and Mazzoni et al. (2015) showed that these fibers have severe multifocal regeneration myodegeneration with different quantities of collagen-rich connective tissue or fibrosis. These fiber changes are affecting quality traits such as pH, color, water holding capacity and texture of non-marinated and marinated woody breast fillets (Kuttappan et al., 2012a; Petracci et al., 2013a; 2013b; Mazzoni et al., 2015; and Tijare et al., 2016). On the other hand, Mudalal et al., (2014) and Tijare et al. (2016) found no difference in shear test and sarcomere length between normal and woody breast meat meaning that there is no difference in tenderness. However, several publications reported that the poultry industry is facing a highly variable meat texture problem.

Texture is a major quality concern with boneless skinless broiler breast fillets (Sams, 1999). It is one of the sensory factors that influences the perception of quality by consumers and can affect their purchasing decisions. Currently, the poultry industry is having complaints from consumers. Therefore, the producers are forced to downgrade this type of meat and transform it into processed meat products leading to economic losses (Petracci et al., 2015).

Based on these considerations, more research is necessary to describe how the texture of SWB meat is different than NOR fillets, and its relation with quality traits, cooking methods and storage temperatures. Since there are no information available on the texture analysis on marinated meat affected by SWB, this study investigated the quality and texture properties of marinated NOR and SWB meat in three experiments: 1) Evaluation of the quality traits of marinated SWB and its effect on tenderness using Warner Bratzler shear force and sarcomere length measurements; 2) development and validation of a Descriptive Texture Profile of marinated SWB meat using 6 trained panelists and two different cooking methods and evaluation of mechanical and geometrical texture attributes using the Texture Analyzer; and 3) evaluation of the effect of storage temperatures on the Texture Profile Analysis of NOR and SWB meat using two cooking methods.

CHAPTER II

LITERATURE REVIEW

Status of the industry

The evolution of the consumer demand for chicken meat has led to progressive changes in selection criteria of broiler chickens. In 1940, chickens were marketed, as live birds and the selection criteria was base on the live performance. In the 1960s, the broiler chickens were offered in the form of prepared carcasses in markets and grocery stores in towns and cities, based on carcass yield. In the 1970s, the cut-up market demand increased, leading to an economic interest in selecting birds according to cut-up yields (i.e. breast, legs). During the last 20 years, the consumers demand for versatile and convenient products caused an increased market for further-processed products. This last change and the preference of breast meat in Western countries has changed the selection to broilers-chickens with high breast development (Fletcher, 2004).

Over the years, chicken breast meat has benefited from consumers interest in health and concern regarding dietary fat. Currently, competitive prices, nutritional facts, sensory properties and the lack of cultural or religious obstacles make chicken highly consumed when compared to other meats (Larry, 2002; Valceschini, 2006). Additionally, breast meat is very suitable for quick and easy home-cooking style, which is very important for modern societies (Petracci et al., 2013a).

The persistent growing consumer demand of chicken breast and the increased consumer concern about animal welfare raises the pressure on producers to improve the production performance of live birds (i.e. growth rate and feed conversion) versus growing more birds (Petracci et al., 2014). According to the National Chicken Council (2015) the average number of days it takes to raise a chicken was reduced from 112 in 1925 to 47 in 2015 while the broilers live weight increased from 2.5 lbs to 5.8 lbs. In 1935, the per capita consumption was only 0.7 pounds (Larry, 2002). Currently, per capita chicken consumption has increased to 91.4 pounds per person and rivaled beef for the highest per capita consumption of any meat (NCC, 2016). Additionally, current projection studies have predicted an increase of in chicken consumption in the future.

Today, the poultry industry is highly integrated which provide products of constant quality (Petracci et al., 2014). As a result, chickens are marketed in about half the time and at about twice the body weight compared to 50 years ago (Barbut et al., 2008). The majority of these improvements in growth rate are mainly due to the genetic selection to increase feed conversion by the bird as well as muscle growth (meat yield), management of the live operation, and improved nutrition practiced by commercial organizations (Bailey et al., 2015 and Havenstein et al., 2003). However, it is also believed that this selection for muscle growth has resulted in an increase in meat quality problems related with toughness, poor cohesiveness, pale color, and reduced water holding capacity (Dransfield and Sosnicki, 1999).

Meat quality

In today's economy, meat quality is of great importance to all the poultry industry segments. Meat quality of broiler chickens can be associated with several ante mortem and post mortem factors. Lately, post mortem factors affecting quality have been highly researched. Depending on the post-mortem glycolysis in the muscle tissue, attributes such as color (appearance), water holding capacity (juiciness), PSE (pale, soft and exudative), and texture (tenderness) can be affected and can further affect consumers perception of chicken meat.

Color

Color is the consequence of the light reflected from the meat surface. It is considered as one of the most important visual attributes influencing consumers perception when buying skinless poultry meats. Meat color is defined by fiber type and myoglobin content. The differences in color between muscles can be associated with the relative amounts of white and red fibers. Chicken breast is mainly composed of white fibers and low myoglobin content and therefore has a lighter color compared to other muscles (Barbut, 2002).

Color variation in fresh meat can be associated with a different flavor or product spoilage and therefore can affect purchasing decisions (Kerth, 2013). This can represent economic losses in the poultry industry. Smith et al. (2000) reported a $1 billion annual revenue loss in the beef industry due to color variation.

In the poultry industry, color measurements are used as an important quality control (Barbut, 2002). Froning (1995) reported this condition mainly in turkey breast meat, in addition, he found the occurrence of pink to red discolorations in fully cooked poultry meat products. However, the difference in color has been increasing rapidly in the broiler chickens as well. Fletcher (1999) conducted a grocery store survey of broiler breast fillet packages and reported that about 7% of the multiple-fillet packages have significant differences in color either lighter or darker.

For many years, color defects of raw and cooked poultry meat have been a problem for the poultry industry. Several authors have shown a significant relationship between raw breast meat color and raw meat pH and the further effect in WHC (Barbut, 1993; Boulianne and King, 1995, 1998; Allen et al., 1997; and Fletcher, 1999). There are two conditions known as pale, soft and exudative (PSE) and dark, firm and dry (DFD) meat that can be developed in poultry meat as a result of short and long term stress.

One of the major well-known color defects associated with low pH in poultry meat is PSE-like (pale, soft, exudative), which is defined as the rapid pH decline condition were the final pH is lower than normal (<5.8) and closer to the isoelectric point of proteins. When the pH is close to the isoelectric point, the ability of the protein to hold water is reduced; therefore, the increase of water on the surface causes a light reflection which results in paler color and decrease in water holding capacity. Dark firm and dry DFD meat is characterized by high ultimate pH >6.3, which is very susceptible to more rapid microbial growth even when initially being relatively low microbially-contaminated (Allen et al., 1997). However, the incidence of DFD in poultry meat is very low.

Although consumers evaluate meat color visually, the disadvantage to conduct visual panels is that the measure can be subjected to consumer perception. Therefore, researchers are using instrumental surface color evaluation as an objective tool. The instrument (colorimeter) absorbs and reflects light wavelengths that are detected by an instrument or an observer (Owens et al., 2010). This method is very rapid and nondestructive and uses reflectance to measure surface color (Kerth, 2013). The most commonly used reflectance variables are *L, a*, b*: where **L*, is the lightness component, which ranges from 0 (black) to 100 (white); *a** is the redness component which ranges from green to red where positive values are red; *b** is the yellowness component, which ranges from blue to yellow where increasing b* indicate more yellow (Yam and Papadakis, 2004). Of these variables, the poultry industry is more interested in *L because the lighter the color the lower the quality of the meat.

Water holding capacity (WHC)

Although color is important because it is easier to detect by consumers, the most important quality characteristic of raw products is the ability to retain moisture (Huff-Lonergan and Lonergan, 2005). Water holding capacity is defined as the amount of water that a meat product can retain within the muscle fibers through a capillary and ionic force (Alvarado and McKee, 2007). By definition, water is a dipolar molecule, which is attracted by proteins. In fact, some of the water in muscles cells is very closely bound to protein (Offer and Knight, 1988).

In meat, water is present in three forms: bound, immobilized, and free water. Bound water represents a very small (less than a tenth) fraction of the total water in muscle cells (Offer and Knight, 1988), and is the water bound chemically in the meat structure and cannot be freed. *Immobilized water*, is held either by steric effects or by attraction to the bound water represents <40%. And *free water*, is easily lost during processing procedures such as cutting, cooking, and storage as it is held between the fibers mainly by capillary forces (Hedrick et al., 1989 and Honikel and Hamm, 1994).

The ability of the meat to hold water can be affected by the final pH (Alvarado and McKee, 2007 and Petracci et al., 2012b). Studies indicate that as pH increases and get closer to neutral, a number of ionic charges increase between the muscle fibers, therefore increasing the amount of water moved from the free to the immobilized state; as a result, the amount of water retained can be increased. Thus, the higher the pH, the higher the WHC of meat and better: texture, juiciness and flavor perception of the cooked meat by consumers (Heath and Owens, 1987 and Owens et al., 2010).

In contrast, as pH reaches the isoelectric point (~5.1) of actin and myosin (Heath and Owens, 1987 and Owens et al., 2010), the electrical charge of the protein fibers is a net zero charge and the water holding ability of free water is lost, therefore causing a PSE-like condition. Thus, the reduction of water content and the change in color and texture can affect sensory perception by consumers (Heath and Owens, 1987; Alvarado and McKee, 2007; and Gorsuch and Alvarado, 2010) not only in cooked meat but also in fresh meat appearance.

Pale, soft and exudative (PSE)

Pale, soft and exudative condition began in poultry meat approximately 40 years ago (Vanderstoep and Richards, 1974). However, the occurrence of PSE in broiler chickens started to increase in 1995 in combination with the increased demand for further-processed products (Fletcher, 2004). Reports on the incidence of PSE meat in broiler-chicken are 28% (Barbut, 1997) and 47% (Woelfel et al., 2002). Under normal conditions, the pH of the chicken breast is about 7.2 (before slaughter) and after 6 hours post mortem decreases to 5.7-6.0 (Owens et al., 2010 and Sams, 1990a). In contrast, PSE is characterized by the accelerated post mortem metabolism, which causes a rapid pH decline in hot carcasses (Pietrzak et al., 1997).

There are two types of PSE conditions: 1) fast-acidifying meat, where the pH declines below 6 in <1 hour post mortem (similar to PSE in pork meat) and 2) the high glycolytic potential content causes a lower ultimate pH that is close to the isoelectric point of protein (<5.8). However, both conditions have a paler breast meat color and poor WHC (Barbut, 2002; Berri et al., 2005 and Petracci et al., 2015). According to Warriss and Brown (1987) and Santos et al. (1994), the low pH combined with high carcass temperatures during processing and prior to chilling can cause protein denaturation, which influences the development of PSE and causes soft texture and decreased WHC.

Sandercook et al. (2006) and Strasburg and Chiang (2009) reported that the incidence of PSE condition is higher in heavier birds. Therefore, one of the hypotheses is that heavier birds are more susceptible to stress due to reduced thermoregulatory capacity. Furthermore, broilers diet was demonstrated to affect the glycolic potential of breast muscles and the pH of meat. Guardia et al. (2014), found lower pH values in broilers fed lysine-deficient diets. Another study showed that lysine promoted protein synthesis and increase yields in chicken breast muscles (Berri et al., 2008).

The PSE condition in pork has been widely studied during the last few decades, and it is identified as a mutation in the ryanodine receptor. Because this condition is genetic in pigs, it can be successfully removed by culling the stress-susceptible pigs from the herd. This statement led several researchers in the poultry industry to associate this problem with genetically inherited stress susceptibility shown in some birds. However, that gene mutation has not yet been identified in poultry. Owens et al. (2000b) tested the sensitivity of some live turkeys to halothane gas, which is used to identify susceptible pigs, and did not find significant higher incidence of PSE at slaughter compared to control.

The difference between poultry and pigs is the number of isoforms. Pigs have one isoform of the ryanodine receptor (control calcium metabolism in the muscle) in their skeletal muscle system while poultry has two isoforms. So one hypothesis is that if one of the two receptors is normal, it can compensate for the defective receptor. The pork industry is using halothane and DNA tests to identify and remove homozygous-recessive animals (both copies of the ryanodine receptor are defective). Heterozygotes with one normal receptor seem to have sufficient stress tolerance to pass the test. However, the two-ryanodine isoforms in poultry can make the situation difficult, because each copy can be either normal or defective, and the number of potential combinations can be higher (Barbut, 1998; Owens et al., 2000a).

Overall, It is known that PSE meat has important functional defects, such as low water holding capacity and ultimate pH, which may cause a lost of more moisture making the product drier and affecting different textural characteristics

Texture

Texture is the sensory and functional manifestation of the structural, mechanical and surface properties of foods (Szczesniak, 2002). It can be perceived by several senses such as visual, tactile and auditory. Moreover, is a major factor that impacts the perceived food safety and quality of meat by consumers (Owens et al., 2010 and Saha et al., 2009). Research showed that visual texture evaluation could generate consumer expectations related to the mouth feel characteristics of the product. In chicken meat products, the perceived texture is one of the most important sensory attributes. Some examples of undesirable characteristics in chicken products are mushy texture in deli-loaves and hot dogs.

Lately, there is an increasing number of further processing products, such as nuggets, deli-loaves, frankfurters and other ready-to-cook and ready-to-eat products. However, the quality of these products is directly related to the quality of the meat used to prepare them (Garcia et al., 2010).

In meat, texture is influenced by other quality factors such as color, pH, WHC and PSE. According to Zhang et al. (2005) the higher cook loss and moisture of PSE meat affect the juiciness of the chicken breast meat and therefore other textural characteristics. However, the meat industry in general use marinades solutions in order to improve the texture of meat. The marination is used to improve the juiciness of the meat product and reduce the water loss during cooking (Alvarado and McKee, 2007).

The increase in demand of chicken meat has increased the output of chicken processing facilities and reduced the times of deboning before the onset of rigor (conversion muscle to meat) has been completed (Alvarado and Sams, 2004 and Alvarado and McKee, 2007). As a result, the meat is tougher. Therefore, marination has been used on early, deboned chicken to increase the water content thus improving the poultry meat quality.

Breast muscle abnormalities

Several studies found a correlation between high growth rate and high breast yield and the occurrence of quality defects affecting the *Pectoralis major* and other muscles (Kuttappan et al., 2012a, 2013a; Lorenzi et al., 2014; Sihvo et al., 2014; and Petracci and Cavani, 2012a). During the last few years, two new abnormalities known as white striping and woody breast started to emerge and raise concern over the quality of the meat (Mudalal et al., 2014 and Petracci et al., 2015). Both abnormalities have shown macroscopic changes and similar histological impact in the *pectoralis major* (Sihvo et al., 2014). Currently, the poultry industry is facing complaints from consumers and food service establishments; therefore, the industry is possibly downgrading white striping and woody breast meat because of low acceptability (Mudalal et al., 2014).

White striping

White striping (WS) has been defined by the presence of white striations parallel to muscle fibers on the surface of the *Pectoralis major* muscle (Bauermeister et al., 2009 and Kuttappan et al., 2009). White striping is visually evaluated and categorized into normal (no distinct white lines), moderate (white lines <1 mm thick) and severe (very visible white lines >1 mm thick) (Kuttappan et al., 2012b). The causes of WS development are still not very well identified. However, according to recent research several factors (i.e., genotype, sex, growth rate and diet) during the live broiler production can be involved (Petracci et al., 2013a; Kuttappan et al., 2012a; 2013a; and Lorenzi et al., 2014).

In Italy, moderate and severe WS affects approximately 12% of medium size birds from high breast meat yield genotypes raised under commercial conditions (Petracci et al., 2013b). Likewise, under experimental conditions the incidence of WS can be over 50% (Kuttappan et al., 2012b). This result agrees with several authors who found evidence 15 years ago about the dramatic quality changes in meat as a consequence of the selection for high breast meat yield genotypes (Dransfield and Sosnicki, 1999; Duclos et al., 2007; Petracci and Cavani, 2012a).

One of the main quality changes in the *pectoralis muscle* is the weight and thickness of the fillet. Kuttappan et al. (2013a) found that moderate and severe WS could be mainly associated with heavier and thicker fillets. Brewer et al. (2012) observed a higher correlation (r = 0.84) between fillet weights and the cranial thickness of the fillets. Additionally, male birds showed higher percentages of severe WS compared to females. As a result, the difference in WS percentage can be related to higher weight and thicker fillets in males compared to females (Kuttappan et al., 2013).

Another important factor is diet, which has been widely studied over the years due to the influence in broiler yield performance. Kuttappan et al. (2012c) assessed the effect of growth rate on the incidence of WS and suggested that high fat diet showed higher percentages of WS compared to birds fed a low fat diet. Likewise, it was once thought the occurrence of WS could be associated with dietary deficiency of vitamin E. However, Brewer et al. (2012) used diet formulations that contained vitamin E levels equal to or above of NRC (1994) recommendations and found that occurrence of WS was observed regardless of the diet treatments. This statement confirms the findings from the study conducted by Kuttappan et al. (2012c).

As a result, improved growth, resulting in higher breast yield and thicker cranial fillets could increase the stress on the broilers, resulting in muscle damage. However, besides the visual appearance, changes such as chemical composition of the muscle and quality properties are also involved in WS meat (Kuttappan et al., 2012a and Petracci et al., 2013).

Histological observations of WS meat indicated the occurrence of a degradation process in the muscle fibers. Kuttappan et al. (2013b), Petracci et al. (2013b) and Sihvo et al. (2014) suggested that there are an increased eosinophilia, floccular/vacuolar degeneration and lysis of fibers, occasional regeneration (multinuclear cells), mononuclear cell infiltration, lipidosis and interstitial inflammation and fibrosis in severe WS meat. According to Mudalal et al. (2014) and Petracci et al. (2014), these changes in muscle fibers may explain the increase of pH, lipids and collagen content and decrease in protein content in severe WS fillets.

Previous research showed that WS meat had a significantly higher pH compared to normal (>5.8), which is common in dark, firm and dry meat (Fletcher, 2002). However, there are not relevant color changes compared with normal fillets (Mudalal et al., 2014). The cause for this rise in pH because of WS abnormality is not known. As reported by Sihvo et al. (2014), the presence of substantial histological degeneration of muscle fibers in WS fillets may influence the glycogen content or modify the onset of acidification during the post mortem phase and lead to a rise in final pH. However, additional research is needed to corroborate this hypothesis. In this regard, Kuttappan et al. (2009) observed high pH values in fillets with severe WS, but no significant differences WHC (Bauermeister et al., 2009; Kuttappan et al., 2009). On the contrary, Petracci et al. (2013a) found that WS meat has lower WHC and poor texture compared to normal breast. But this effect was not associated with pH because severe WS fillets have a higher pH compared with moderate and normal fillets, which is usually associated with greater water-holding capacity (Petracci et al., 2004).

The reduction in protein content was associated with higher cooking losses and low marinated yields in WS fillets (Petracci et al., 2013). This fraction particularly plays a major role in determination of protein functionality during processing (Mudalal et al., 2014 and Petracci et al., 2014). Therefore, these changes not only affect the meat quality, but also the nutritional value of the chicken meat due to the decrease the protein content. As a result, the energy contribution from protein decreases and the energy from fat increases (Petracci et al., 2014).

The increased ratio between collagen and total protein may lower the protein quality because of low digestibility of the collagen and lack of some essential amino acids in connective tissue with regard to myofibrillar and sarcoplasmic proteins (Boback et al., 2007 and Young and Pellet, 1984). Moreover, changes in texture such as poor cohesion (tendency to separation muscle bundles) in the WS meat could be associated with immaturity of intramuscular connective tissue (Petracci and Cavani, 2012a; Velleman et al., 2003; and Voutila, 2009).

Kuttappan et al. (2012a) also reported differences in the fatty acids composition in severe WS compared to normal breast. Severe WS meat has a lower amount of saturated fatty acids, related with lower levels of essential long-chain n-3 PUFA (i.e. eicosapenaenoic acid), which are part of a healthy diet (Swanson et al., 2012).

These changes in nutritional facts and the macroscopic modifications on the surface of the fillets can influence the purchasing decisions of consumers when buying chicken breast. Kuttappan et al. (2012b) studied the consumer perception of WS meat and showed that 50% of the consumers would probably not buy chicken breast with any degree of WS because they associated it with high-fat content.

For this reason, the poultry industry categorizes the chicken breast fillets showing severe WS could be downgraded in commercial plants and used for further processing products such as deli-loaves, sausages, etc., while moderate WS fillets are usually marketed for fresh retailing (Petracci et al., 2013a).

Woody breast

Recently, research has observed a new type of muscle abnormality accompanying WS meat called woody breast (WB). Woody breast is one of the latest described quality issues affecting the *pectoralis major* in broiler chickens. It is characterized by the abnormal hardness, pale color, and exudate on the surface of the fillet caused by histological changes and necrosis (Sihvo et al., 2014). As with WS, WB is categorized in normal (0), mild (1), moderate (2) and severe (3). *Normal,* is defined as flexible throughout the fillet; *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).

Within the last three years, this novel quality issue has been increasing in several countries around the world. Recent publications showed that no particular ante mortem signs have been associated with this condition, and no other skeletal muscles appear to be affected. In addition, WS and WB showed similar histological changes and can be found in the same breast fillet, however, there is not too much information about what exactly is causing this abnormality in broiler chickens (Sihvo et al., 2014).

Woody breast is an unknown abnormality emerging in broiler chickens and there are different hypothesis that may be associated with it. One of the main factors affecting the broiler performance is nutritional deficiency. It has been widely studied over the years because it causes myodegeneration in the muscle structure (Van Vleet and Valentine, 2007). Previous research in known etiologies, such as exertional myopathy, hypoxia, and genetic vulnerabilities were associated with deficiency of selenium and tocopherol (vitamin E) (Klasing et al., 2007 and Van Vleet and Valentine, 2007). Therefore, Guetchom et al. (2012); Kuttappan et al. (2012c) studied the effect of increasing nutritional vitamin E supplementation in fast growing birds; however, it has been shown to have little to none effect on reducing the myofiber damage or WS in the *pectoralis major* of broilers. The presence of hardness and fibrosis in the fillet makes woody breast a new abnormality compared to the known etiologies (Kuttappan et al., 2012a). The role of selenium in the specific myodegeneration of the pectoralis major remains to be studied (Sihvo et al., 2014). On the other hand, latest research showed that the incidence of WB increases in birds fed with high-energy protein diets (Kuttappan et al., 2013a).

Recent research also has shown that genetic selection for high breast muscles in combination with the increase of total weight and the fast growth rate may increase the susceptibility of the broiler chickens to oxidative stress (Petracci and Cavani, 2012a). Thus, 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.

Moreover, these macroscopic changes following by the histology differences of the muscle greatly affected the meat quality of the chicken breast. Generally, severe fiber hypertrophy and increased the incidence of large and abnormal fibers are considered as 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 interesting fact is that 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).

The latest research by Poulanne and Ruusanen (2014) showed that 15% of WB could be use as a lean meat replacer in chicken sausages and 30% for chicken nuggets. However, more research is needed to know the texture differences between normal and WB chicken meat.

Marination

Marination is the addition of liquids to meat before cooking (Owens et al., 2010). 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). The main objective of marination is to improve sensory properties such as flavor, juiciness, tenderness and color as well as product shelf life (Young and Buhr, 2000; Barbanti and Pasquini, 2005; and Alvarado and McKee, 2007). 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. Specifically, sodium chloride and phosphates are considered important ingredients of marinades, as they improve meat tenderness and flavor (Barbanti and Pasquini, 2005).

Sodium chloride

Sodium chloride (salt) has been widely used since early ages for preservation purposes mostly in meat products. Salt properties include the following: *flavor*, which imparts a unique and desirable flavor while enhancing other flavors in meat products; *texture*, which increases the ability of actin and myosin to bind water and fat, improving the texture and yield of meat products; and *preservation*, which reduce the water activity of the product, inhibiting the growth of pathogenic bacteria (Schroeder, 2013).

Salt is an ionic ingredient widely used by the food industry. It acts to solubilize myosin, thus as the salt concentration increases the solubility of the myosin increases (Siegel and Schmidt, 2006). Research indicates that salt improved the protein binding in meat products because it uses repulsion forces to open the space within protein molecules allowing more water-binding sites to be available. In agreement with this statement, Booren (1980) reported that there was an increase in bind strength with an increase in salt addition.

Phosphates

Phosphates have wide applications in the meat processing industry such as improve WHC, reduce cook loss, improve protein extraction as well as improve color stability and reduce lipid oxidation (Schroeder, 2013). According to Romans et al. (1994), the concentration of phosphates in the meat products ranges between 0.15% and 0.40%. Moreover, the USDA regulates the use of phosphates and requires no more than 0.5% (5000 ppm) total phosphate in finished product. There are several types of phosphates available for food uses; their functionality depends on the chain length, pH, and solubility in water (i.e., monophosphates, pyrophosphates, polyphosphates, and metaphosphates. However, the most common phosphate used in the commercial poultry industry is sodium tripolyphosphate (STPP).

Sodium tripolyphosphate (STPP) is an alkaline phosphate, which increases the protein-to-protein spatial alignments and raising the pH of the meat close to neutral (7.0), therefore increasing WHC (Owens et al., 2010). Young and Buhr (2000) reported an increase of 0.12 pH units when marinating chicken with STPP and salt, compared to just salt, which raised the pH 0.03 units. This increase in pH resulted in lower cook loss (15.4% vs. 16.9%) and lower shear values (5.9kg vs. 6.1kg) indicating more tender meat. The main advantages of STPP are the bulk powder form, which makes it easy to transport, convenient price and its functionality as the enhancement of protein-binding properties (Barbut et al., 1988).

Marination methods

Several methods are used by the meat industry depending on the production scale and the required uptake. In soaking or immersion method, the meat is placed in a container and brine composed of salt and phosphate is added, and allowed to soak for at least 24 h under refrigeration temperatures (<3° C) (Owens et al., 2010). This method depends on the surface area and osmosis. Penetration is limited to a few millimeters into the meat surface. Thus, this method does not provide a homogeneous distribution of ingredients; conversely, it increases the risk of bacteria contamination. In addition, soaking remains inefficient because it requires a long time and storage space (Alvarado and McKee, 2007).

Multineedle injection is a mechanical method, which consists of forcing a marinade with pressure through a needle with multiple holes (Owens et al., 2010). It is the most widely use method because it allows controlling the exact quantity of the marinade and it can be used on a large scale. The amount of injection depends on the pumping pressure of the injector and the speed of the conveyor belt. This method is mainly used for whole birds and bone-in parts because of the benefits of constant pressure and to prevent marinade pockets. However, one of the disadvantages is that physical punctures are visible on the meat surface. In addition, mechanical injection compared to other methods may also produce products with higher drip loss, especially if the system is not managed properly. In order to control the drip loss, some commercial plants allow the product collected from injectors to soak briefly or they use tumble marination practices after injection (Owens et al., 2010).

Vacuum tumbling involves the use of rotating drum with paddles of baffles to transfer kinetic energy to the meat product in order to increase brine uptake, and protein extraction (Price and Schweigert, 1987). This mechanical action disrupts muscle fiber structure allowing the brine solution to be distributed throughout the meat product. The vacuum pulls oxygen from the meat to prevent the foamy appearance and to create a swelling effect, allowing the penetration of the brine within the muscle. A drop of three feet has been recommended for maximum benefit (Price and Schwiegert, 1987). Tumbling and massaging are similar procedures and depending on the time of the mechanical action is shown to produce exudate on the surface of the meat due to more protein binding sites are exposed, permitting protein-water interaction to occur (Bowker et al., 2010). However, extended tumbling periods can result in over-extraction of proteins, which can affect the texture of the product (Heath and Owens, 1987; Bowker et al., 2010; and Petracci et al., 2012b). According to Lin et al. (1990), the total tumbler revolutions showed a significant change in all texture profile analysis (TPA) parameters except for cohesiveness, while the speed of tumbling affected elasticity.

Measuring texture

There are several factors perceived by human senses contributing to the consumer eating experience: Appearance is mainly associated with vision sense and can be related to geometric shape, size, packaging, and color; flavor and aroma are linked to taste, odors, flavor, and other small molecules perceived by the oral and nasal cavities; and texture, which is the response to the tactile senses to physical stimuli and visual sense (Bourne, 2002).

Texture is one is one of the most important attributes that influences the consumer perception of meat quality. In the poultry industry, the determination of texture parameters is of a great importance to improve the live production of the birds and processing conditions to offer the best meat quality for consumers. For example, if the chicken breast is too chewy or mushy and falling apart, it can be deemed unacceptable for consumers (Barbut, 2002).

In this regard, the texture of a food product can be described by either physical instruments or by sensory evaluation. However, the instrumental methods need to be correlated with sensory evaluation tests to validate the relevance of the data with respect to texture (Szczesniak et al., 1963a and Owens et al., 2010).

Since the 1960s, research has been developed to understand the sensory properties of foods in relation to their physical properties (Szczesniak et al., 1963a). Descriptive analysis methods can be used to define the relationship between descriptive sensory, consumer sensory, and instrumental methods (Murray et al., 2001).

Instrumental tenderness

Tenderness has been considered as one of the most important sensory attributes that influence meat palatability. The most common way to express tenderness is how much force is required to bite through a piece of meat. However, tenderness just describes one part of texture. It can also be perceived by many texture attributes such as hardness, fracturability, chewiness etc. Considering the importance of these characteristics several authors found that consumers prefer tender meat and they are willing to pay higher prices for it (Acebrón and Dopico, 2000 and Lusk et al., 2001).

In this regard, an accurate and consistent measurement was necessary to evaluate texture in foods (Dransfield, 1977). Although texture is considered as a sensory attribute, there was a need to use instrumental tools to measure texture (Nollet and Toldrá, 2011). Texture attributes can be measured by several tests, which are classified as chemical, non-invasive (nondestructive tests) and invasive tests (destructive testing). The destructive test included: sarcomere length, shear, penetration, compression, tension, and torsion (Barbut, 2002 and Kerth, 2013).

Chemical, Shear and compression tests have been widely used by the meat industry to measure texture on intact meat samples. Sarcomere length, Warner Bratzler-Shear force and Texture Profile Analysis respectively are the most popular methods used to predict tenderness or texture quality of chicken breast meat (Lyon and Lyon, 2001).

Sarcomere is the smallest contractile unit of a myofibril. It is located between the two Z-disks and appears as repeating units along the myofibril. The length from Z-disk to Z-disk of sarcomeres in muscle is an indicative of the contractile state of the muscle therefore, is related to meat tenderness (Kerth, 2013). In this regard, sarcomere length is not constant and their dimension depends on the contraction state. Herring et al. (1965) were the first authors to demonstrate the direct relationship of sarcomere length to fiber diameter and toughness. Furthermore, there are factors that can influence the dimensions of the sarcomere. Locker (1960) found that relaxed muscles produce more tender meat than the contracted ones. In 1963, Locker and Hagyard reported that rapid freezing before the start of rigor mortis causes cold shortening in muscles, which causes tougher meat. In normal chicken breast meat, the sarcomere length is approximately 1.69 μm (Tijare et al., 2016). While in beef, the sarcomere length ranges from about 1.5 μm for a fully compressed sarcomere to about 2.7 μm for a fully extended sarcomere (Kerth, 2013). One of the disadvantages of the sarcomere test is that it is time-consuming. In this regard, Warner Bratzler shear force and Allo-Kramer have often been used as an objective measurement of meat tenderness.

Warner Bratzler-shear force (WBSF) was the first instrument developed by Warner (1928) to simulate the human bite measuring food texture and since then, it has been the most popular test used by the meat industry. The method consists of taking 6 cylinder cores or 2 to 3 intact pieces (widely used in chicken breast) from the meat sample, parallel to the muscle fiber orientation (Wheeler et al., 1997 and Zhuang and Savage, 2009). Then, the steel thin blade uses the shear force to cut the meat sample during the test and the maximum measurement is recorded as the meat tenderness value. According to Barbut (2002), the instrumental determination of tenderness, is commonly evaluated on intact pieces or cores to ensure representative sampling of the muscle and therefore, to obtain more accurately data. Generally, the WBSF technique has been shown to have some variations; however, despite the years of research and innovation is still used to measure meat tenderness objectively (Nollet and Toldrá, 2011). The Allo–Kramer shear is another instrumental test widely used by many researchers to measure poultry meat tenderness objectively.

The Allo-Kramer shear was first introduced in 1951 by the name of Kramer shear for measurement of texture in peas. In 1962, it was adapted to measure texture in meat products (Bailey et al, 1962). Since then, the device has been mainly used in Poultry products (Sams et al., 1990b). The Allo-Kramer consists of a metal square box, which has a series of 10-13 blades to shear the sample. As for the Warner-Bratzler, the Allo-Kramer shear uses vertical hydraulic pressure and the peak shear force is recorded. In addition, location and fiber orientation are the same for both methods. The only difference is that the Allo-Kramer shear evaluates the samples by weight not by size, which has been beneficial in the poultry industry because the results are more consistent. However, tenderness is not the only attribute to describe texture. Thus, General Foods Corporation developed the Texture Profile method to describe all the attributes that involve texture.

The Texture profile method was first developed by Szczesniak et al. (1963a) to combine rheological parameters and consumer sensory evaluation (Muñoz et al., 1992). Thus, Szczesniak (1963b) developed a classification of textural characteristics based on popular terminology (i.e., soft, crumbly, sticky, etc.) and rheological properties of different products (i.e., elasticity, viscosity, etc.). The textural terms were categorized in solid and semi-solid foods. As a result, the texture attributes are grouped into 3 categories: mechanical, geometrical and moisture and fat attributes. The development of the texture profile methods is applicable to both instrumental (Texture Profile Analysis) and sensory measurements (Descriptive texture profile).

Texture profile analysis (TPA) is a two-cycle compression test to determine the texture attributes in foods by mimicking the human biting action. During the test, the sample is compressed axially between two flat plates to a predetermined percentage deformation in the first cycle, then the pressure is released and the sample is compressed a second time (Bourne, 1978). The compression percentage varied from 20-50% in intact meat pieces (Soglia et al., 2015 and Xiao and Owens, 2016). However, the use of standard conditions can allow meaningful comparison of results among laboratories. The texture parameters evaluated during the compression test are defined as hardness, cohesiveness, springiness, adhesiveness, resilience, chewiness and gumminess. The main advantage between TPA and WBSF is that TPA can quantify several texture attributes in the same time frame. However, besides the efficiency of these methods, is necessary to validate the texture measurements with the human perception. In this respect, the descriptive texture profile was developed.

Sensory descriptive texture profile

Descriptive texture profile method was developed from the principles of the flavor profile method. The product evaluation and texture technology groups at General Foods Corp. developed this method with the objective to define textural attributes of foods (Skinner , 1988). However, the texture profile has been expanded over the years by various authors. This method describes several factors including hardness, viscosity, springiness, and adhesiveness, particle size, moisture, etc. These characteristics are associated with food products from the first bite through the whole mastication process (Szczesniak et al., 1963a). In the texture profile method, the intensity of each texture attribute is based on standard references scales. The original texture profile method used a 13-point intensity scale version of the flavor profile scale. During the last decades, the texture profile panels have been trained using a 15-point intensity scale, where 0 in none and 15 is extremely present (Meilgaard et al., 2007 and Muñoz, 1986). For example, on the hardness scale, 1 is cream cheese and 14.5 is a hard candy (Meilgaard et al., 2007). The texture attributes most widely used to describe meat products are hardness, cohesiveness of mass, springiness, adhesiveness, fracturability, chewiness, crunchiness, moisture, juiciness, etc. The selection and the definition of these attributes depend on the type of food evaluated. The descriptive texture profile method requires a group of 6-10 carefully selected, trained, and maintained panel. The selections of the panelist are based on their interest, availability, general health, discrimination ability, ability to describe a product and ability to work in a group all of these requirements are evaluated by a pre-screening test. During the training, the panel is exposed to several concepts of texture evaluation using appropriate examples and reference samples. The training can last several months, even years depending on the objectives and the type of product. Once the training is done, is important to keep the motivation, interest and objectivity in the group (Meilgaard et al., 2007 and Szczesniak et al., 1963a). Currently, this method is very useful to describe the changes of food products over the time and to develop new products. In the Poultry Industry especially it helps to describe the new emerging meat quality issues such as woody breast and white striping.

CHAPTER III

MATERIALS AND METHODS

Meat preparation

Woody and normal breast fillets were obtained 3 h post mortem from a commercial processing plant and transported (3° C) to the Poultry Science Research Facility at Texas A&M University. The samples were categorized into normal (0) and severe woody (3) breast fillets by tactile evaluation using the classification proposed by Kuttappan et al. (2012b), as following: normal (NOR), flexible throughout the fillet; and severe woody breast (SWB), very hard and rigid throughout the fillet. All the meat was trimmed to remove excess of fat and cartilage, and to standardize the weight of NOR and SWB fillets respectively. Subsequently, the meat was labeled using three random digit codes and sorted depending on the experiment.

Experiment I

The objective of Experiment I was to evaluate the quality traits of marinated SWB and its effect on tenderness using Warner Bratzler shear force and sarcomere length measurements. After meat preparation, a total of 5- 40 lb boxes of NOR and SWB fillets were weighted in bulk. Then, drip loss % was measured after 24, 48 and 72 h. Afterwards, the meat was marinated using a multi-needle injector (Inject-star BI-88 P-VSO, Mountain View, AZ) with a 15 % brine composed of salt (0.55 %) and phosphate (0.48 % STP) (Blend 100, Francee Flavoring and Spice, Ankeny, IA) at constant pressure (10-15psi) (Table 1). After marination, NOR and SWB meat were weighted in bulk to determine marinade retention %, as a result NOR fillets were injected at 15 % and SWB fillets at 14.1 %. Subsequently, NOR (n = 65) and SWB (n = 38) fillets were placed in aluminum covered pans and cooked in an air convection oven (FC-34/1 Sodir Convection Oven, Equipex, Providence, Rhode Island) set at 177° C, until the samples reach 73° C according to the procedures of Sams (1990b). During cooking, internal temperatures were monitored using copper-constant thermocouples (Omega Engineering, Stanford, CT) inserted into the cranial side (thicker part) of the fillet. Following cooking, the samples were cooled according to Sams (1990) prior to calculation of cook loss %. Marinade retention, drip loss and cook loss percentage were calculated as follows:

$$\text{Marinade retention\%} = \frac{\text{Final weight} - \text{Initial weight}}{\text{Initial weight}} \times 100\%$$

$$\text{Drip loss\%} = \left(\frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100\%\right)$$

$$\text{Cook loss \%} = \text{raw weight} - \text{cook weight} \times 100\%$$

For the Warner-Bratzler shear force test, NOR (n = 50) and SWB (n = 50) were cooked and then stored at refrigeration temperatures (3° C) during 24 h. Subsequently, the cranial part of the fillet was cut in 2 pieces of 1.9 × 1.9 × 4 cm parallel to the muscle fibers and evaluated using the Warner- Bratzler shear force (Lyon and Lyon 1990; Zhuang and Savage , 2009). Shear values (N) were determined using the Instron Universal Testing Machine (Model 1011, Canton, MA 02021) using a slice shear device with the 20 lb load cell and 500 mm/min speed (Lyon and Lyon 1990). Maximum force was recorded in N.

For the sarcomere measurements, non-marinated NOR (n = 15) and SWB (n = 15) fillets were used to measure sarcomere length. This tenderness measurement was developed using the helium-neon laser diffraction method as described by Cross et al. (1981) and Koolmees et al. (1986). Sarcomere length was determined using the equation by Cross et al. (1981), where D is the distance from specimen to diffraction pattern screen in millimeters (set to 100 mm), and T was the spacing between diffraction bands in millimeters as described in the following formula:

$$\mu\mathrm{m} = \frac{0.6328 \times D \times \sqrt{\frac{T^2}{D} + 1}}{T}$$

Experiment II

Phase I. Texture profile development

The objective of Experiment II was to develop and validate a descriptive texture profile of marinated SWB meat using 6 trained panelists and two different cooking methods and to evaluate the mechanical and geometrical texture attributes using the texture analyzer. NOR and SWB fillets were weighted in bulk and then injection marinated using a multi-needle injector (Inject-star BI-88 P-VSO, Mountain View, AZ) with 12% brine composed of salt (0.55%) and phosphate (0.48% STP) (Blend 100, Francee Flavoring and Spice, Ankeny, IA) at constant pressure (10-15 psi). Subsequently, the meat was vacuum-packaged individually in Cryovac vacuum-package bags (Model B4173T, Sealed Air Corporation, Simpsonville, SC) and stored in the blast freezer (29 d, -20° C). Prior to use, the meat was thawed at refrigeration temperatures (3° C) for 24 h. Then, normal and woody breast fillets were cooked to an endpoint internal temperature of 73° C using two different cooking methods. A flat top grill (536TGF 36", Star Max, Lancaster, PA), which was set at 177° C and a convection oven (FC-34/1 Sodir Convection Oven, Equipex, Providence, Rhode Island) set at 177° C were used for cooking. During cooking, internal temperatures were monitored using copper-constant thermocouples (Omega Engineering, Stanford, CT) inserted into the middle of the cranial part of the fillet until the sample reach 73° C.

A panel composed by six trained panelists from the sensory laboratory at Texas A&M University was used to determine the texture profile. The panel has 25 years of experience working with The Spectrum™ descriptive analysis method. The texture attributes were selected based on previous studies related to meat products. In addition, resources from Meilgaard et al. (2007) and Barbut (2002) were used to determine attributes, references, and definitions. The panelists participated in 13 d (two-hour sessions) ballot development to determine the texture attributes present in marinated N and SWB fillets. Two scales per day were introduced to the panelists (Table 2) and subsequently, they were served marinated NOR and SWB meat samples cooked in two different methods to create texture differences as explained above. Each panelist tasted the marinated NOR and SWB samples individually and then discussed the texture attributes found in each sample as a group. Once all panelists came to a consensus about attributes, the intensity of each texture attribute was discussed using a 16-point scale (0 = none, 15 = extremely intense).

Phase II. Texture profile validation

Once all the attributes, references, and texture intensities were defined, trained panelists were asked to evaluate the chicken breast samples using the texture profile. Eleven texture attributes were defined as part of the texture profile: springiness, hardness, denseness, cohesiveness, cohesiveness of mass, tooth packing, loose particles, fracturability, fibrousness, and chewiness. NOR (n = 16) and SWB (n = 16) fillets in two replicates were used for the validation process. After meat preparation, quality measurements such as color and pH were taken. Color was measured from the surface of each fillet (bone side) by averaging three readings using the CIE L*= lightness, a*= redness and, b*= yellowness color scale of a calibrated colorimeter (Minolta Chroma Meter Model CL-200; Minolta Corp., Ramsey, NJ). Values of pH were measured with a pH meter (Model IQ 150, IQ Scientific Instruments, Inc.; piercing probe PH77-SS.) from the cranial part of each fillet (Figure 1).

Normal (n = 16) and SWB (n = 16) right halves were weighted in bulk and then injection marinated with 12% brine following the procedure explained in phase I. Marinade retention was calculated 20 min after injection. Subsequently, each fillet was vacuum packaged individually in Cryovac vacuum package bags (Model B4173T, Sealed Air Corporation, Simpsonville, SC) and stored in a blast-freezer (7 d, -20 °C). Prior to use, the meat was thawed at refrigeration temperatures (3° C) for 24 h. Then, NOR (n = 8) and SWB (n = 8) were cooked on a flat top grill (536TGF 36", Star Max, Lancaster, PA) set at 177° C; and NOR (n = 8) and SWB (n = 8) were cooked in a convection oven (FC-34/1 Sodir Convection Oven, Equipex, Providence, Rhode Island) set at 177° C. During cooking, internal temperatures were monitored using copper-constant thermocouples (Omega Engineering, Stanford, CT) inserted into the middle of the cranial part of the fillet until they reach an endpoint internal temperature of 73° C. Cook loss was calculated and the samples were held in a holding oven at 48.8° C on a corelle plate covered in aluminum foil for no more than 20 min or served immediately.

The cranial part of the fillet was used (Figure 1) because the incidence of woody breast in mainly in this area. Approximately 2.0 × 2.0 cm cubes were cut and three cubes were served for evaluation in an odorless plastic cup (56.7 g Solo soufflé plastic cup, Dart Container Corporation, Mason, MI). Each sample was assigned a random three-digit code. All the samples were tested during three days of evaluation. A warm-up sample (normal chicken breast) was provided before each testing day. The panelists were placed in individual breadbox-style booths separated from the preparation area. Each panelist received double distilled deionized water and unsalted saltine crackers for palate cleansing between samples, the scales sheet (Figure 2) and a sensory ballot (Figure 3). Panelists were given a five min break between each sample to reduce sensory fatigue. The texture attributes that the panelist measured were quantified using a 16-point anchored scale (0 = none and 15 = extremely intense) based on references in the texture profile.

Texture profile analysis (TPA)

Thirty-two NOR and SWB fillets in two replicates were used for the Texture profile analysis (TPA). The marination procedure was the same as explained in phase I. Marinade retention was calculated after 20 min and the samples were vacuum packaged in Cryovac bags and stored for 29 d at -29° C. The left fillets were used. Prior to use, the samples were thawed at 3° C during 24 h. The cooking procedure was the same as explained in phase II. Once cooked, the fillets were placed at refrigeration temperature (3° C) over 24 hours. After the allotted time, the cranial part of the fillet was used and cut into three rectangular 4.0 × 2.0 cm samples using a template and a sharp knife (Mudalal et al., 2014). The texture profile analysis (TPA) was developed according to the procedures outlined by Mudalal et al. (2014). The texture measurements were performed using the texture analyzer (TA.XTPlus, Texture Technologies, Hamilton, MA) and a cylinder probe of 76.2 x 10 mm was used to compress the samples. The software was set to a constant compression speed of 3.0 mms^{-1} (pre-test), 1.0 mms^{-1} (test), and 3.0 mms^{-1} (post-test). First, each sample individually was placed under the probe. Once the test started, the probe continued downwards until reached the 50% of the sample thickness. Then, the probe returned to the initial point of contact and stopped for 2 s before the second compression cycle started. During the test run, the resistance of the sample was recorded every 0.01 s and plotted in a force-time (g/s) plot. From the force–time plot, the TPA parameters were interpreted as shown in Table 3.

Experiment III

The objective of Experiment III was to evaluate the effect of storage temperatures on the texture profile analysis of NOR and SWB meat using two cooking methods. Sixty-four NOR and SWB fillets in two replicates were injected marinated with 12 % brine as explained in Experiment II. After marination, the left side from NOR and SWB was vacuum packaged in Cryovac bags and split into two trials. First trial, NOR (n = 16) and SWB (n = 16) were stored at 4° C (24 h) and for the second trial, NOR (n = 16) and SWB (n = 16) were stored at -29° C (29 d). Prior to use, the fillets were thawed at refrigeration temperatures (4° C) during 24 h. Both trials were cooked either on a flat top grill (177° C) or aluminum foil covered pans in a convection oven (177° C) until 73° C internally. The TPA procedure was the same as explained in Experiment II.

Statistical analysis

Data from experiment I, II and III were analyzed by analysis of variance using PROC GLM of SAS (SAS® 9.4, Inc., Cary, NC.) by testing the main effects for type of meat (NOR and SWB). Means were separated using Least squares means using PDIFF function with an alpha-level ($P < 0.05$) to determine significance. Interactions with $P > 0.05$ were not considered. Pearson correlation coefficient *r* was generated using the PROC CORR procedure**.**

CHAPTER IV

RESULTS AND DISCUSSION

Experiment I

The technological properties of normal (NOR) and severe woody breast (SWB) meat, based on drip loss, marinade retention, cook loss and tenderness measurements such as shear force and sarcomere length are shown in Tables 4 and 5, respectively. There were no significant differences in drip loss after 24 h post mortem between NOR and SWB fillets (6.06 vs. 7.36). Whereas, after 48 h (7.30 vs. 9.61) and 72 h post mortem (7.71 vs. 11.22), SWB had significantly higher percentage drip loss compared to NOR fillets. SWB fillets also had a significantly higher cook loss percentage compared to NOR meat samples (20.32 vs. 16.49). Despite the decreased ability to bind water and the greater cooking loss percentage, NOR and SWB were not statistically different in shear force (19.40 vs. 18.30) and sarcomere length values (1.64 vs. 1.70).

Several authors have stated that the selection for muscle growth in broilers has resulted in a reduction in quality traits as well as technological properties of chicken breast meat (Dransfield et al., 1999; Mudalal et al., 2014; Petracci et al 2015; and Tijare et al., 2016). Results from the current study are consistent with those of Mudalal et al. (2014) who found that SWB has lower marinade retention and higher cook loss percentage compared to NOR fillets. In addition, Soglia et al. (2015) evaluated the percent drip loss 24 h post mortem and significant differences were found between NOR and SWB fillets; however, they found no statistical differences between NOR and SWB with white striations. In this regard, it can be attributed that the SWB and NOR meat used in this study can had presence of white striations. There is no data published about percentage drip loss of SWB at 48 and 72 h; however, histological data showed that the presence of SWB with white striping showed more damage in the muscle fibers when compare to SWB. These results can explain the decrease in marinade retention over time. Additionally, the changes in fibers play an important function in binding water molecules during storage and can contribute to this reduction as well (Mazzoni et al., 2015).

Normal and SWB samples were marinated in order to increase the WHC of the meat, thus reducing drip and cooking loss. However, results in this study showed SWB fillets showed higher cooking loss compared to NOR even after marination. Similar results were found in non-marinated SWB fillets (Soglia et al., 2015). Thus, it can be seen that the pH is not playing a major role in binding water. It is likely the higher cook loss in SWB may be attributed to the histological changes in the muscle fibers and fibrosis, which also causes the loss of protein content (Sihvo et al., 2014). Additionally, factors such as genetics, post mortem handling, and store temperatures can greatly influence the pH decline and therefore affect the WHC of the meat. Moreover, cook loss percentage can be attributed to cooking method and cooking time. Barbanti and Pasquini (2005) found that cooking loss was more highly correlated with cooking time compared with cooking method.

Dransfield and Sosnicki (1999) described the breast meat from fast growing genotypes as tough meat while Sihvo et al. (2014) and Mudalal et al. (2014) characterized woody breast as a rigid-like fillet with a contracted appearance. It has been well documented that the contractile state of muscles is a major factor in determining meat tenderness. In this respect, Fennema (1996) reported that tenderness is influenced by sarcomere length. However, the data presented in this study showed that there is no difference in shear force and sarcomere length. A similar approach by Mudalal et al. (2014) found no significant difference in shear force between NOR and SWB. These findings are consistent with Tijare et al. (2016) and Xiao and Owens (2016), who found that sarcomere values collected from the cranial part of SWB fillets have a higher values compare to NOR. Based on these data and the lack of statistical differences between NOR and SWB in both shear and sarcomere length values, it can be conclude that SWB fillets do not have a tenderness problem.

Experiment II

Quality measurements such as pH, color (L*, a*, b*), and cooking loss are outlined in Table 6. Since there was no interaction between replicates for pH, redness (a*), yellowness (b*) and cook loss from experiment II and III, the data were pooled and analyzed together. Fillets affected by SWB showed higher pH values compared to NOR breast (6.07 vs. 5.83). For color measurements, lightness (L*) showed a significant interaction within replicates ($P < 0.05$). Thus, the results are presented in two different columns. For the first replicate, SWB fillets showed higher L* values compared to NOR (55.25 vs. 53.69), and for the second replicate NOR fillets showed significant higher values compared to SWB (58.85 vs. 56.18). Redness (a*) (4.63 vs. 5.21) and yellowness (b*) (3.73 vs. 5.03) showed significantly higher values for SWB than NOR. Cook loss results show that NOR fillets have lower percentage compared to SWB (16.82 vs. 20.86 %). There was no interaction between cooking methods and type of meat; therefore, the data were analyzed together as mentioned above. The results show that grill method has a significant higher cook loss percentage compare to the oven method (23.16 vs. 14.51).

During the normal process of rigor mortis, the pH of the muscle in broiler chickens is about 7.2 and is progressively reduced to approximately 5.8 when it is converted to meat. However, rigor mortis can be affected by several factors such as pre- and post- slaughter handling (Richardson, 1995), heat stress (McKee and Sams, 1997), genetics (Sandercock et al., 2006), nutrition (Guardia et al., 2014), etc. The results of pH obtained in this study are comparable with recent publications. Zotte et al. (2014) found that pH of the cranial region of the SWB fillet is significantly higher compare to NOR. In contrast to this publication, Mudalal et al. (2014) reported that SWB and NOR fillets show no statistical differences in pH values. According to Berri et al. (2001), breast meat from higher breast yield lines had significantly high pH compare with the unselected control. The ultimate high pH in SWB meat observed in this study is comparable with the pH of dark, firm and dry (DFD) meat. However, the SWB fillets are lighter than NOR fillets and the paler color is easy to distinguish by the human eye. Thus, variability in pH can be attributed to the fibrosis and lipidosis shown in the muscle fibers of SWB (Sihvo et al., 2014 and Soglia et al., 2015).

CIE color (L*, a*, b*) has been shown to have a correlation with different technological and quality properties in both raw and cooked poultry breast meat (Zhuang and Savage, 2010). The color data obtained are broadly consistent with Zotte et al. (2014), who reported that SWB fillets show significantly higher lightness (L*), redness (a*), and yellowness (b*). Moreover, Le Bihan-Duval et al. (1999) found that high-yield broiler genotypes showed significant increase in lightness compared to those not selected. These findings can be attributed to alterations in fiber membrane integrity, which contribute to the loss of liquid (Soglia et al., 2015). Therefore, this can explain the higher light reflectance and therefore the higher values in lightness when comparing SWB and NOR fillets.

Cook loss was also assessed in experiment II and III to evaluate an additional aspect of WHC in marinated fillets. According to Heath and Owens (1997) and Owens et al. (2009), the higher the pH is, the higher the WHC of meat and better texture, juiciness and flavor perception of the cooked meat by consumers. However, the results of this study show that SWB fillets have significantly higher cook loss percentage compared to normal. This means that higher cook loss in SWB fillets can affect the juiciness perception in meat samples, and therefore affects the texture. A similar approach reported by Petracci et al. (2013b) found that meat from high-breast yield hybrids showed a significant reduction of WHC and increased cook loss values compare to standard hybrids. In addition, Barbut et al. (2005), Zhang and Barbut (2005) reported that higher L* values in breast fillets have been correlated with lower WHC and therefore, lower cook loss. As explained above, however, poor WHC cannot be linked to the PSE-like condition, because it was not associated with low pH. However, it can be associated with the less protein (Sihvo et al., 2014) content and the increase in fat content, which reduces the ability of the meat to bind water due to the presence of white striping in the SWB fillets (Soglia et al., 2015).

Oven and grill cooking are the most popular methods used in boneless, skinless poultry meat, particularly in foodservice systems. The results consequentially obtained are comparable with previous studies where the cooking methods play a major role in the determination of instrumental and sensory properties in meat products (Lyon and Lyon , 2001). Murphy and Marks (2000) found that cooking loss, tenderness and crust formation could be attributed to both the cooking technique and the time-temperature profiles. On the other hand, Barbanti and Pasquini (2005) reported that the cooking loss was significantly correlated with the cooking time rather than the cooking temperature. In this respect, a Pearson correlation coefficient test was analyzed to determine if there is a direct relationship between cook loss vs. weight and cook loss vs. cooking time. Consequentially, the data showed that there is a moderate correlation between both cook loss vs. weight for oven and grill cooking ($r = 0.59$ vs. $r = 0.51$; respectively) and cook loss vs. time ($r = 0.60$ vs. $r = 0.61$; respectively). Since there is not a strong correlation between these factors, the results of this study can be attributed to histological changes in the muscle fibers found woody breast fillets. 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. Moreover, more water is also held extra cellular which explain the higher L* values and increased drip and cook loss. In addition, Zhuang and Savage (2012) reported that factors such as genotype, age, and further processing technique could influence the sensory quality more than the weight of the fillets.

Sensory texture attributes

Texture has been considered as one of the most important attributes influencing consumer final satisfaction with poultry meats (Fletcher, 2002). Although presence of white striations in woody breast fillets has been previously reported, is important to mention that regardless of the presence of white striations, woody breast fillets showed higher hardness compare to normal fillets.

Eleven texture attributes were determined to be components of the NOR and SWB descriptive texture profile (Figure 2). Hardness, cohesiveness, cohesiveness of mass, fracturability and chewiness have been widely used in previous studies to describe the effects of fillet size in the texture profile of non-marinated and marinated chicken breast (Fanatico et al., 2006; 2007; Zhuangand Savage, 2010; and Zhuangand Savage 2012). During the ballot development, the panelists were asked to describe new texture attributes present in SWB meat. Interestingly, the panelists detected fibrousness and crunchiness attributes present only in SWB samples. Therefore, the panelists developed intensity scales for crunchiness and fibrousness (Table 2).

Table 7 summarizes the results of the 11 attributes present in the descriptive texture profile of marinated NOR and SWB fillets. The results show that SWB fillets had higher significant differences in springiness, hardness, denseness, cohesiveness, crunchiness, fracturability, fibrousness, and chewiness, compare to NOR fillets. In addition, no significant differences were found between SWB and NOR meat in cohesiveness of mass, tooth packing, and loose particles. Table 8 shows the results of the 11 texture attributes base on cooking methods. Grill and oven cooking methods were not affected by type of meat (Table 8). However, no statistical differences were found within cooking methods for all the 11 texture attributes (P <0.05).

The results obtained are compatible with Zhuang and Savage (2010), who developed a descriptive sensory study and reported that fillets with higher lightness (L*) color showed higher intensity scores for cohesiveness, hardness, rate of breakdown (comparable with fracturability), and chewiness, thus demonstrating that higher lightness values in chicken breast can affect texture more than the darker fillets.

Another approach to understanding the change in texture can be the muscle fiber composition. In this regard, Fanatico et al. (2007) found that the size of muscle fibers is associated with genotypes and can influence tenderness in meats. Similar research by Rémingnon et al. (1994) showed that muscle fibers present in fast-growing genotypes have a wider diameter and higher amount of fibers compare to slow-growing genotypes. These findings are comparable with a later publication by Petracci et al. (2013b), who 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) and Soglia et al. (2015) found severe multifocal regenerative myodegeneration and necrosis, with different quantities of interstitial connective tissue accumulation or fibrosis in fillets affected by WB. According to Rehfeldt et al. (2004), extreme hypertrophy of muscle fibers is an indicator of poor meat quality, which is comparable with the results of this study in the quality traits section.

Texture profile analysis

Six attributes were evaluated in the (TPA). The results of the TPA are shown in Table 9. Severe woody breast fillets showed significantly higher hardness, cohesion, springiness, gumminess and chewiness, and lower values for adhesiveness compared to NOR fillets. Table 10 presents the TPA results for grill and oven cooking methods. However, no statistical differences were found between all of the texture attributes.

The results in this study were similar with Mudalal et al. (2015); Soglia et al. (2015), who found significant differences in hardness, gumminess, and chewiness in SWB fillets. In this regard, these studies confirm that the texture of SWB fillets is significantly different than NOR breast fillets.

As previously mentioned, the overall changes in texture profile can be attributed to several histological and chemical changes in the muscle fibers and connective tissues (Sihvo et al., 2014 and Soglia et al., 2015). Moreover, the significant higher differences found in hardness, cohesion, springiness, gumminess and chewiness values in SWB fillets can be explained by the higher cooking loss, which is one of the factors affected by lower WHC.

Pearson correlation coefficient obtained between the instrumental TPA and descriptive sensory parameters are summarized in Table 11. Hardness (r = 0.39), springiness (r = 0.31), cohesiveness (r = 0.30) and chewiness (r = 0.51) showed a positive significant correlation between both methods. Even thought the correlation is not close to 1, it is considered a strong correlation because of the variability of the muscle structure. In this regard, Cavitt (2004) reported that meat is not a homogeneous product, and there is a variation in the tenderness of meat from fillet to fillet. As a result, it can be concluded that the descriptive sensory and TPA were accurate and useful for predicting sensory texture of marinated NOR and SWB meat.

Experiment III

The process of freezing and thawing of fresh meat can have an impact on the amount of moisture loss and the change in texture properties. The results of TPA in frozen and fresh storage are showed in Table 9 and 12. In frozen storage attributes including hardness, cohesion, springiness, gumminess and chewiness showed significantly high differences in SWB compared to NOR fillets. In addition, no statistical differences were found between grill and oven cooking methods. In fresh storage, it has been found that hardness, gumminess, and chewiness showed higher statistical differences in SWB compared to NOR fillets. However, there is no differences in springiness, adhesive and cohesion in both types of meats. Table 13 presents the results of TPA in grill and oven cooking, where the grill method showed significantly higher values in hardness, springiness, gumminess and chewiness compare to oven cooking.

Despite the storage treatment, SWB fillets showed higher values for hardness, gumminess and chewiness. The results obtained in fresh storage were comparable with Soglia et al. (2015), who also found higher differences in hardness, gumminess, and chewiness in SWB compare to NOR fillets. However, the results obtained from the frozen storage were in contrast to the results reported by Xiao and Owens (2016), who found that raw frozen storage fillets are related to lower hardness compared to the fresh storage. In can be concluded that the storage temperature does not influence the texture profile of SWB fillets.

CHAPTER V

CONCLUSIONS

Historically, marination has been considered as a traditional technique to improve the sensorial properties of meat such as tenderness, flavor, and juiciness. In addition, it has been used to increase WHC, thus reducing drip and cooking loss. However, the results of this study showed that even though the pH is higher than 6.0, the technological properties of meat were lower in SWB compared to NOR fillets.

In general, there is a misconception of the characterization of SWB meat. Results in this study suggested that SWB fillets have a texture problem related more with crunchiness and fibrousness other than toughness. In this regard, it is possible to conclude that the texture profile of NOR and SWB was successfully developed and validated as panelists found differences between both types of meats. Trained panelists determined 11 texture attributes as part of the texture profile of chicken breast. Additional research and texture profile validation needs to be done using the texture profile described in this study in order to ensure consistency.

The texture profile analysis (TPA) also showed differences in texture between NOR and SWB fillets. In addition, the significant correlation between sensory texture and TPA showed that TPA is a reliable method to measure texture in chicken breast.

Overall, storage temperature, cooking methods and marination did not influence the texture of SWB meat and quality characteristics. As a results, new alternatives needs to be investigate in order to reduce the economical looses due to this meat quality problem.

The differences in texture can be attributed to the fact that fast growing genotypes showed muscle damage and fibrosis (Sihvo et al., 2014 and Soglia et al., 2015). Another factor influencing the texture change can be the increase in collagen content as a result of the histological changes in the muscle fibers. However, further investigation is needed to understand the origin of this quality issue.

Future investigation should focus on different further processing products to investigate if there are significant differences in texture properties and in consumer perception.

REFERENCES

Acebrón, B. L., and C. D., Dopico. 2000. The importance of intrinsic and extrinsic cues to expected and experienced quality: an empirical application for beef. Food Qual. Pref. 11:229-238.

Allen, C. D., S. M. Russel, and D. L. Fletcher. 1997. The relationship of broiler breast color and pH to shelf-life and color development. Poult. Sci. 76:1042-1046.

Alvarado, C., and S. Mckee. 2007. Marination to improve functional properties and safety of poultry meat. J. Appl. Poult. Res. 16:113-120.

Alvarado, C. Z., and A. R. Sams. 2004. Turkey carcass chilling and protein denaturation in the development of pale, soft, and exudative meat. Poult. Sci. 83:1039-1046.

Bailey, M. E., H. B. Hedrick, F. C., Parrish, and H. D., Naumann. 1962. L. E. E.-Kramer shear force as a tenderness measurement of beek steak. Food Technol. 16:99-101.

Bailey, R. A., K. A. Watson, S. F. Bilgili, and S. Avendano. 2015. The genetic basis of pectoralis major myopathies in modern broiler chicken lines. Poult. Sci. 94:2870-2879.

Barbanti, D., and M. Pasquini. 2005. Influence of cooking conditions on cooking loss and tenderness of raw and marinated chicken breast meat. Food Sci. Technol. 38:895-901.

Barbut, S. 1993. Color measurements for evaluating the pale soft exudative (PSE) occurrence in turkey meat. Food Res. Int. 26:39-43.

Barbut, S. 1997. Problem of pale soft exudative meat in broiler chickens. Poult. Sci. 88:355-358.

Barbut, S. 1998. Estimating the magnitude of the PSE problem in poultry. J. Muscle Foods. 9:35-49.

Barbut, S. 2002. Poultry Products Processing. An Industry Guide. CRC Press Florida.

Barbut, S., A. J. Maurer, and R. C. Lindsay. 1988. Effects of reduced sodium chloride and added phosphates on physical and sensory properties of turkey frankfurters. J. Food Sci. 53:62.

Barbut, S., L. Zhang, and M. Marcone. 2005. Effects of pale, normal, and dark chicken breast meat on microstructure, extractable proteins, and cooking of marinated fillets. Poult. Sci. 84:797-802.

Barbut, S., A. A. Sosnicki, S. M. Lonergan, T. Knapp, D. C. Ciobanu, L. J. Gatcliffe, E. Huff-Lonergan, and E. W. Wilson. 2008. Progress in reducing the pale, soft and exudative (PSE) problem in pork and poultry meat. Meat Sci. 79:46-63.

Bauermeister, L. J., A. U. Morey, E. T. Moran, M. Singh, C. M. Owens, and S. R. McKee. 2009. Ocurrence of white striping in chicken breast fillets in relation to broiler size. Poult. Sci. 88:33.

Berri, C., J. Besnard, and C. Relandeau. 2008. Increasing dietary lysine increases final pH and decreases drip loss of broiler breast meat. Poult. Sci. 87:480-484.

Berri, C., M. Debut, V. Sante-Lhoutellier, C. Arnould, B. Boutten, N. Sellier, E. Baeza, N. Jehl, Y. Jego, M. J. Duclos, and E. Le Bihan-Duval. 2005. Variations in chicken breast meat quality: Implications of struggle and muscle glycogen content at death. Poult. Sci. 46:572-579.

Berri, C., N. Wacrenier, N. Millet, and E. Le Bihan-Duval. 2001. Effect of selection for improved body composition on muscle and meat characteristics of broilers from experimental and commercial lines. Poult. Sci. 80:833-838.

Boback, M. S., L. C. Cox, D. B. Ott, R. Carmody, W. R. Wrangham, and M. S. Secor. 2007. Cooking and grinding reduces the cost of meat digestion. Compar. Biochem. Physio. 148:651-656.

Booren, A. M. 1980. Binding of meat pieces into sectioned and formed beef steaks. Masters Thesis. University of Nebraska, Lincoln, Nebraska.

Boulianne, M., and A. J. King. 1995. Biochemical and color characteristics of skinless boneless pale chicken breast. Poult. Sci. 74:1693-1698.

Boulianne, M., and A. J. King. 1998. Meat color and biochemical characteristics of unacceptable dark-colored broiler chicken carcasses. J. Food Sci. 63:759-762.

Bourne, M. C. 1978. Texture profile analysis. Food Technol. 32:62.

Bourne, M. C. 2002. Food texture and viscosity: concept and measurement. Academic Press, San Diego, CA.

Bowker, B. C., J. A. Callahan, and M. B. Solomon. 2010. Effects of hydrodynamic pressure processing on the marination and meat quality of turkey breast. Poult. Sci. 89:1744-1749.

Brewer, V. B., V. A. Kuttappan, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2012. Big-bird programs: effect of strain, sex, and debone time on meat quality of broilers. Poult. Sci. 91:248-254.

Cavitt, L. C., G. W. Young, J. F. Meullenet, C. M. Owens, and R. Xiong. 2004. Predication of poultry meat tenderness using razor-blade shear, Allo-Kramer shear, and saromere lenght. J. Food Sci. 69:3274-3283.

Cross, H. R., R. L. West, and T. R. Duston. 1981. Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. Meat Sci. 5:261-266.

Dransfield, E. 1977. Intramuscular composition and texture of beef muscles. J. Sci. Food. 28:833.

Dransfield, E., and A. A. Sosnicki. 1999. Relationship between muscle growth and poultry meat quality. Poult. Sci. 78:743-746.

Duclos, M. J., C. Berri, and E. Le Bihan-Duval. 2007. Muscle growth and meat quality. J. Appl. Poult. Res. 16:107-112.

Fanatico, A. C., P. B. Pillai, J. L. Emmert, E. E. Gbur, J. F. Meullenet, and C. M. Owens. 2007. Sensory attributes of slow- and fast-growing chicken genotypes raised indoors or with outdoor access. Poult. Sci. 86:2441-2449.

Fanatico, A. C., P. B. Pillai, L. C. Cavitt, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2006. Evaluation of slower-growing broiler genotypes grown with and without outdoor access: Sensory attributes. Poult. Sci. 85:337-343.

Fennema, R. O. 1996. Food Chemestry. 3rd ed. Marcel Decker, Inc., New York, NY.

Fletcher, D. L. 1999. Color variation in commercially packaged broiler breast fillets. J. Appl. Poult. Res. 8:67.

Fletcher, D. L. 2002. Poultry Meat Quality. World Poult. Sci. J. 58.

Fletcher, D. L. 2004. Further processing of poultry. Pages 108-134 in Poultry Meat processing and quality. G. C. Mead ed. CRC Press, Florida

Froning, D. L. 1995. Color of poultry meat. Poult. Avian Bio. Rev. 6:83.

Garcia, R. G., L. W. Freitas, A. W. Schwingel, R. M. Farias, F. R. Caldara, A. M. Gabriel, J. D. Graciano, C. M. Komiyama, and I. C. L. Almeida. 2010. Incidence and physical properties of PSE chicken meat in a commercial processing plant. Brazilian J. Poult. Sci. 12:233-237.

Gorsuch, V., and C. Z. Alvarado. 2010. Postrigor tumble marination strategies for improving color and water-holding capacity in normal and pale broiler breast fillets. Poult. Sci. 89:1002-1008.

Guardia, S., M. Lessire, A. Corniaux, S. Metayer-Coustard, F. Mercerand, S. Tesseraud, I. Bouvarel, and C. Berri. 2014. Short-term nutritional strategies before slaughter are effective in modulating the final pH and color of broiler breast meat. Poult. Sci. 93:1-10.

Guetchom, B., D. Venne, S. Chenier, and Y. Chorfi. 2012. Effect of extra dietary vitamin E on preventing nutritional myopathy in broiler chickens. J. Appl. Poult. Res. 21:548-555.

Havenstein, G. B., P. R. Ferket, and M. A. Qureshi. 2003. Growth, livability, and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broilers diets. Poult. Sci. 82:1500-1508.

Heath, J. L., and S. L. Owens. 1987. Effect of tumbling solutions containing ethanol on tenderness and yield of broiler breasts. J. Food Proces. Preserv. 11:159-169.

Hedrick, H. B., E. D. Aberle, J. C. Forrest, M. D. Judge, and R. A. Merkel. 1989. Conversion of muscle to meat and development of meat quality. Pages 95-122 in Principles of meat science. Kendal/ Hunt Publishing Co, Dubuque, IA.

Herring, H. K., R. G. Cassesns, and E. J. Briskey. 1965. Further studies on bovine muscle tenderness as influence by carcass position, sarcomere length, and fiber diameter. J. Food Sci. 30:1049-1054.

Honikel, K. O., and R. Hamm. 1994. Measurement of water-holding capacity and juiciness. Pages 125-161 in Advances in meat research. Quality attributes and their measurements in meat, poultry and fish products. A. M. Pearson, and T. R. Dutson ed. Blackie Academic and Professional, London, UK.

Huff-Lonergan, E., and S. E. Lonergan. 2005. Mechanism of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Sci. 71:194-204.

Kennedy, O. B., B. J. Stewart-Knox, P. C. Mitchell, and D. I. Thurnham. 2004. Consumer perception of poultr meat: a qualitative analysis. Nutr. Food Sci. 34:122-129.

Kerth, C. R. 2013. The science of meat quality. Wiley-Blackwell, Oxford, UK.

Klasing, K. C. 2007. Nutrition and the immune system. Br. Poult. Sci. 48:525-537.

Koolmees, P. A., J. Tuinstra-Melgers, J. G. Van Logtestijn, and P. G. Bijker. 1986. Histometrical and chemical analysis of mechanically deboned pork, poultry and veal. J. Anim. Sci. 63:1830-1837.

Kuttappan, V. A., V. B. Brewer, A. Mauromoustakos, S. R. McKee, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2013a. Estimation of factors associated with the occurrence of white striping in broiler breast fillets. Poult. Sci. 92:811-819.

Kuttappan, V. A., G. R. Huff, W. E. Huff, B. M. Hargis, J. K. Apple, C. Coon, and C. M. Owens. 2013b. Comparison of hematologic and serologic profiles of broiler birds with normal and severe degrees of white striping in breast fillets. Poult. Sci. 92:339-345.

Kuttappan, V. A., S. D. Goodgame, C. D. Bradley, A. Mauromoustakos, B. M. Hargis, P. W. Waldroup, and C. M. Owens. 2012c. Effect of different levels of dietary vitamin E (DL-alpha- tocopherol acetate) on the occurence of various degrees of white striping on broiler breast fillets. Poult. Sci. 91:3230-3235.

Kuttappan, V. A., V. B. Brewer, F. D. Clark, S. R. McKee, J. F. Meullenet, J. L. Emmert, and C. M. Owens. 2009. Effect of white striping on the histological and meat quality characteristics of broiler fillets. Poult. Sci. 88:136-137.

Kuttappan, V. A., V. B. Brewer, J. K. Apple, P. W. Waldroup, and C. M. Owens. 2012a. Influence of growth rate on the ocurrence of white striping in broiler breast fillets. Poult. Sci. 91:2677-2685.

Kuttappan, V. A., Y. S. Lee, G. F. Erf, J. F. Meullenet, S. R. McKee, and C. M. Owens. 2012b. Consumer acceptance of visual appearance of broiler breast meat with varying degrees of white striping. Poult. Sci. 91:1240-1247.

Larry, L. 2002. Industry Studies. 3 ed. M.E. Sharpe, Inc. , Washington, DC.

Le Bihan-Duval, E., N. Millet, and H. Rémignon. 1999. Broiler meat quality: effect of selection for increased carcass quality and estimates of genetic parameters. Poult. Sci. 78:822-826.

Lin, G. C., G. S. Mittal, and S. Barbut. 1990. Effects of yumbling speed and cumulative revolutions on restructurated hams' quality. J. Food Proces. Preserv. 14:467-479.

Locker, R. H. 1960. Degree of muscular contraction as a factor in tenderness of beef. Food Res. Int. 25:304.

Locker, R. H., and C. J. Hagyard. 1963. A cold shortening effect in beef muscle. J. Food Agri. 14:787.

Lorenzi, M., S. Mudalal, C. Cavani, and M. Petracci. 2014. Incidence of white striping under commercial conditions in medium and heavy broiler chickens in Italy. J. Appl. Poult. Res. 23:754-758.

Lusk, J. L., J. A., Fox, T. C. Schroeder, J. Mintert, and M. Koohmaraie. 2001. In-store evaluation of steak tenderness. Amer. J. Agri. Econ. 83:539-550.

Lyon, B. G., and C. E. Lyon. 2001. Meat quality: Sensory and instrumental evaluations. Pages 97-120 in Poultry Meat Processing. A. R. Sams ed. CRC Press, Boca Raton, FL.

Lyon, C. E., and B. G. Lyon. 1990. The relationship of objective shear values and sensory tests to change in tenderness of broiler breast meat. Poult. Sci. 69:1420-1427.

Mazzoni, M., M. Petracci, A. Meluzzi, C. Cavani, P. Clavenzani, and F. Sirri. 2015. Relationship between pectoralis major muscle histology and quality traits of chicken meat. Poult. Sci. 94:123-130.

MCKee, S. R., and A. R. Sams. 1997. The effect of seasonal heat stress on rigor development and the incidence of pale, exudative turkey Meat. Poult. Sci. 76:1616-1620.

Meilgaard, M. C., G. V. Civille, and B. T. Carr. 2007. Sensory evaluation techniques.

Mitchell, M. A. 1999. Muscle abnormalities- Pathophysiological mechanism. Pages 65-68 in Poultry Science symposium series. R. I. Richardson, and G. C. Mead ed. CAB International, Oxon, UK.

Mudalal, S., E. Babini, C. Cavani, and M. Petracci. 2014. Quantity and functionality of protein fractions in chicken breast fillets affected by white striping. Poult. Sci. 93:2108-2116.

Mudalal, S., M. Lorenzi, F. Soglia, C. Cavani, and M. Petracci. 2015. Implications of white striping and wooden breast abnormalities on quality traits of raw and marinated chicken meat. Anim. 9:728-734.

Muñoz, A. M. 1986. Development and application of texture reference scales. J. Sens. Stu. 1:55-83.

Murphy, R. Y., and B. P. Marks. 2000. Effect of meat temperature on proteins, texture, and cook loss for ground chicken breast patties. Poult. Sci. 79:99-104.

Murray, J., C. Delahunty, and I. Baxter. 2001. Descriptive sensory analysis: past, present, and future. Food Res. Int. 34:461-471.

NCC 2015a. U.S. Broiler Performance. National Chicken Council. Accessed Jan. 2016. http://www.nationalchickencouncil.org/about-the-industry/statistics/u-s-broiler-performance/.

NCC. 2015b. How broilers are marketed. National Chicken Council. Accessed Jan 2016. http://www.nationalchickencouncil.org/about-the-industry/statistics/how-broilers-are-marketed/.

NCC. 2016. Per capita consumption of poultry and livestock, 1965 to estimated 2016. National Chicken Council. Accessed Jan. 2016. http://www.nationalchickencouncil.org/about-the-industry/statistics/per-capita-consumption-of-poultry-and-livestock-1965-to-estimated-2012-in-pounds/.

Nollet, M. L., and F. Toldra. 2011. Sensory analysis of foods of animal origin. CRC Press, Boca Raton, FL.

Offer, G., and P. Knight. 1988. The structural basis of water-holding capacity in meat. Part 1: general principles and water uptake in meat processing. Pages 61-171 in Developments in meat science. R. Laurie. ed. Elsevier Applied Science, New York.

Owens, C. M., E. M. Hirschler, S. R. Mckee, R. Martinez-Dawson and A. R. Sams. 2000a. The characterization and incidence of pale, soft, exudative turkey meat in a commercial plant. Poult. Sci. 79:553.

Owens, C. M., N. S. Matthews and A. R. Sams. 2000b. The use of halothane gas to identify turkeys prone to developing pale, exudative meat when transported before slaughter. Poult. Sci. 79:553.

Owens, C. M., Z. Alvarado, and A. R. Sams. 2010. Poultry meat processing. 2nd ed. CRC, Press, Boca Raton, FL.

Petracci, M., and C. Cavani. 2012a. Muscle growth and poultry meat quality issues. Nutr. 4:1-12.

Petracci, M., F. Sirri, M. Mazzoni, and A. Meluzzi. 2013b. Comparison of breast muscle traits and meat quality characteristics in 2 commercial chicken hybrids. Poult. Sci. 92:2438-2447.

Petracci, M., L. Laghi, P. Rocculi, S. Rimini, V. Panarese, M. A. Cremonini, and C. Cavani. 2012b. The use of sodium bicarbonate for marination of broiler breast meat. Poult. Sci. 91:526-534.

Petracci, M., M. Betti, M. Bianchi, and C. Cavani. 2004. Color variation and characterization of broiler breast meat during processing in Italy. Poult. Sci. 83:2086-2092.

Petracci, M., S. Mudalal, E. Babini, and C. Cavani. 2014. Effect of white striping on chemical composition and nutritional value of chicken breast meat. Ital. J. Anim. Sci. 13:179-183.

Petracci, M., S. Mudalal, A. Bonfiglio, and C. Cavani. 2013a. Occurrence of white striping under commercial conditions and its impact on breast meat quality in broiler chickens. Poult. Sci. 92:1670-1675.

Petracci, M., S. Mudalal, F. Soglia, and C. Cavani. 2015. Meat quality in fast-growing broiler chickens. World Poult. Sci. J. 71:363-374.

Pietrzak, M., M. L. Greaser, and A. A. Sosnicki. 1997. Effect of rapid rigor mortis processed on protein functionality in pectoralis major muscle of domestic turkeys. J. Anim. Sci. 75.

Poulanne, E., and M. Ruusanen. 2014. The utilization of poultry breast muscle of different quality classes. Accessed Jan 2016. https://prezi.com/yt3v1aavvkbm/copy-of-the-utilization-of-poultry-breast-muscle-of-different-qualit/

Price, J. F., and B. Schweigert. 1987. The science of meat and meat products. 3rd ed. Food and Nutrition Press, Westport, CN.

Rehfeldt, C., I. Fiedler, and N. C. Stickland. 2004. Number and size of muscle fibers in relation to meat production in muscle development of livestock animals: physiology, genetics and meat quality. M. F. W. Te Pas, M. E. Everts, and H. P. Haagsman ed. CABI Publ., Cambridge, MA.

Rémingnon, H., V. Desrosiers, G. Marche, and F. H. Ricard. 1994. Influences of growth rate on muscle fibre characteristics in the chicken. Pages 223-224 in 9th Eur. Poult. Conf.World's Poult. Sci. Assoc., Glasgow, UK.

Richardson, R. I. 1995. Poultry meat for further processing. Pages 351-361 in Proceedings of the XII European Symposium on the Quality of Poultry Meat., Zaragoza, Spain.

Romans, J. R., W. J. Costello, W. C. Carlson, M. L. Greaser, and K. W. Jones. 1994. The Meat We Eat. 13th ed. Interstate, Danville, IL.

Saha, A., V. S. Perumalla, Y. Lee, J. F. Meullenet, and C. M. Owens. 2009. Tenderness, moistness, and flavor of pre- and postrigor marinated broiler breast fillets evaluated by consumer sensory panel. Poult. Sci. 88:1250-1256.

Sams, A. R. 1990a. Electrical stimulation and high temperature conditioning of broiler carcasses. Poult. Sci. 69:1781-1786.

Sams, A. R. 1999. Problems and solutions in deboning poultry meat. Pages 347-357 in Poultry Meat Science. R. I. Richardson, and G. C. Mead ed. CABI Publishing, Oxfordshire, UK.

Sams, A. R., D.M., Janky, and S. A. Woodward. 1990b. Comparison of two shearing methods for objective evaluation and two sampling times for physical characteristics analysis of early harvested broiler breast meat. Poult. Sci. 69:348-353.

Sandercock, D. A., R. R. Hunter, M. A. Mitchell, and P. M. Hocking. 2006. Thermoregulatory capacity and muscle membrane integrity are compromised in broilers compared with layers at the same age or body weight. Poult. Sci. 47:322-329.

Santos, C., L. C. Roserio, H. Goncalves, and R. S. Melo. 1994. Incidence of different pork quality categories in a portuguese slaughterhouse; A survey. Meat Sci. 38:279-287.

Schroeder, D. J. 2013. Effect of vacuum tumbling time, salt level, and phosphate alternatives on processing characteristics of natural deli-style turkey breast. Thesis Master of Science. University of Nebraska, Lincoln, Nebraska.

Siegel, D. G., and G. R. Schmidt. 2006. Ionic, pH, and temperature effects on the binding ability of myosin. Food Sci. 44:1686-1689.

Sihvo, H. K., K. Immonen, and E. Puolanne. 2014. Myodegeneration with fibrosis and regeneration in the pectoralis major muscle of broilers. Vet .Pathol. 51:619-623.

Skinner, E. Z. 1988. The texture profile method. Pages 89-107 in Applied Sensory Analysis of Foods. H. R. Moskowitz ed. CRC Press, Boca Raton, FL.

Smith, G. C., K. E. Belk, J. N. Sofos, J. D. Tatum, and S. N. Williams, S. N. . 2000. Economic implications of improved color stability in beef. . Pages 379-426 in Antioxidants in muscle foods: nutritional strategies to improve quality. E. A. Decker, C. Faustman, and C. J. Lopez-Bote. ed. John Wiley & Sons, Inc. , New York

Soglia, F., S. Mudalal, E. Barbini, M. Di Nunzio, M. Mazzoni, F. Sirri, C. Cavani, and M. Petracci. 2015. Histology, composition, and quality traits of chicken Pectoralis major muscle affected by wooden breast abnormality. Poult. Sci. 00:1-9.

Strasburg, G. M., and W. Chiang. 2009. Pale, soft, exudative turkey: The role of ryanodine receptor variation in meat quality. Poult. Sci. 88:1497-1505.

Swanson, D., R. Block, and S. A. Mousa. 2012. Omega-3 fatty acids EPA and DHA: health benefits throughout life. Adv. Nutr. 3:1-7.

Szczesniak, A. S. 1963b. Classification of textural characteristics. J. Food Sci. 28:385-389.

Szczesniak, A. S. 2002. Texture is a sensory property Food Qual. Pref. 13:215-225.

Szczesniak, A. S., M. A. Brandt, and H. H. Friedman. 1963a. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and sensory methods of texture evaluation. J. Food Sci. 28:397-403.

Texture Technologies. 2015. An overview of texture profile analysis (TPA). Accessed Jan 2016. http://www.texturetechnologies.com/texture-profile-analysis/texture-profile-analysis.php - section-04

Tijare, V. V., F. L. Yang, V. A. Kuttappan, C. Z. Alvarado, C. N. Coon, and C. M. Owens. 2016. Meat quality of broiler breast fillets with white striping and woody breast muscle myopathies. Poult. Sci. 0:1-7.

Valceschini, E. 2006. Poultry meat trends and consumer attitudes. In proceedings of the XII European Poultry Conference Verona, Italia.

Van Vleet, J. F., and B. A. Valentine. 2007. Muscle and Tendon. Pages 185-280 in Pathology of Domestic Animals. M. G. Grant ed. Elsevier, Edinburgh.

Vanderstoep, J., and J. F. Richards. 1974. Post-mortem glycolytic and physical changes in turkey breast meat. Food Sci. Technol. 7:120-124.

Voutila, L. 2009. Properties of instramuscular connective tissue in pork and poultry with reference to weakening of structure. PhD Diss. University of Helsinki, Helsinki, Finland.

Warner, K. F. 1928. Progress report of the mechanical test for tenderness of meat. Proc. Am. Soc. Anim. Prod. 21:114.

Warriss, P. D., and S. N. Brown. 1987. The relationship between initial pH, reflectance and exudation in pig muscle. Meat Sci. 20:65-67.

Wheeler, T. L., S. D. Shackelford, L. P. Johnson, M. F. Miller, R. K. Miller, and M. Koohmaraie. 1997. A comparison of Warner-Bratzler shear force assessment within and among institutions. J. Anim. Sci. 75:2423-2432.

Woelfel, R. L., C. M. Owens, E. M. Hischler, R. Martinez-Drawson, and A. R. Sams. 2002. The characterization and incidence of pale, soft, and exudative broiler meat in commercial processing plant. Poult. Sci. 81:579-584.

Xargayo, M., J. Lagares, E. Fernandez, D. Ruiz, and D. Borrell. 2001. Marination of fresh meats by means of spray effect: influence of spray injection on the quality of marinated products. Pages 118-126 in Metalquimia. Accessed Jan. 2016. http://metalquimia.com/images/doctecnologic/art13.pdf

Xiao, S., and C. M. Owens. 2016. The relationship between instrumental compression forces and meat quality traits of woody breast fillets during short-term storage. Poult. Sci. 64 (E. Suppl.1) (Abstr. P214).

Yam, K. L., and S. E. Papadakis. 2004. A simple digital imaging method for measuring and analysing color of food surfaces. J. Food. Engi. 61:137-142.

Young, L., and R. J. Buhr. 2000. Effect of Electrical stimulation and polyphosphate marination on drip from early-harvested, individually quick-frozen chicken breast fillets. Poult. Sci. 79:925-927.

Young, V. R., and P. L. Pellet. 1984. Amino acid composition in relation to protein nutritional quality of meat and poultry products. Amer. J. Clinic. Nutri. 40:737-742.

Zhang, L., and S. Barbut. 2005. Rheological characteristics of fresh and frozen PSE, normal and DFD chicken breast meat. British Poult. Sci. 46:687-693.

Zhuang, H., E. M. Savage. 2009. Vatiation and Pearson correlation coefficients of Warner-Bratzler shear force meaurements within broiler breast fillets. Poult. Sci. 88:214-220.

Zhuang, H., E. M. Savage. 2012. Effects of fillet weight on sensory descriptive flavor and texture profiles of broiler breast meat. Poult. Sci. 91:1695-1702.

Zotte, A. D., M. Cecchinato, A. Quartesan, J. Bradanovic, G. Tasoniero, and E. Poulanne. 2014. How does "wooden breast" myodegeneration affect poultry meat quality?. Pages 476-479 in 60th International Congress of Meat Science and Technology, Punta del Este, Uruguay.

APPRENDIX A

TABLES

Table 1. Brine formulation

115% Inject/ Phosphate & Salt			
	Batch Formulation		Based on
Ingredients	Percent	Lb.	100%
Meat	100.00%	86.96	86.96%
Brine	15.00%	13.04	13.04%
Total	115.00%	100.00	100.00%
Ingredient Formulation based on batch wt.			
			Meat Wt.
Ingredients	Percent	Lb.	Percentage
Water total	12.01%	12.01	13.82%
water	*85.00%*	*10.21*	85.00%
ice	*15.00%*	*1.80*	15.00%
Salt	0.55%	0.55	0.63%
Phosphate	0.48%	0.48	0.55%
Total	13.04%	13.04	15.00%
Final Brine Formulation			
Brine Formulation	Percent	Lbs.	
Water total	92.10%	55.26	
water	*85.00%*	*46.97*	
ice (15%)	*15.00%*	*8.29*	
Salt	4.217%	2.53	
Phosphate	3.680%	2.21	
Total	100.00%	60.00	

Table 2. Sensory texture attributes for panel training to evaluate NOR and SWB fillets. All definitions, techniques, and references are from Meilgaard et al. (2007) and Barbut (2002).

Universal Scale			
Scale	Reference	Brand/Type manufacturer	Sample Size
2.0	Saltless cracker	Nabisco	1 piece
5.0	Apple flavor in applesauce	Mott's® Applesauce	2 tbsp.
7.0	Orange flavor in orange juice	Minute Maid® Orange Juice	1 oz.

10.0	Grape flavor in grape juice	Welch’s® Grape Juice	1 oz.
12.0	Cinnamon gum	Big Red chewing gum	1 piece

Standard Springiness Scale

Definition: the degree to which sample returns to the original shape or the rate with which sample returns to original shape.

Technique: place sample between molars; compress partially without breaking the sample structure; release.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
0.0	Cream Cheese	Kraft Foods/Philadelphia	½ in. cube
5.0	Frankfurter	Cooked 10 min/Hebrew National	½ in. slice
9.5	Marshmallow	Marshmallow/Kraft	3 pieces
15.0	Gelatin dessert	Jello, Knox	½ in. cube

Standard Hardness Scale

Definition: the force to attain a given deformation, such as force to compress with the molars, as above; force to compress between tongue and palate; force to bite through with incisors.

Technique: place food between the molars and bite down evenly, evaluating the force required to compress the food.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
1.0	Cream Cheese	Kraft Foods/Philadelphia	½ in. cube
2.5	Egg white	Hard cooked	½ in. cube
4.5	Cheese	Yellow American cheese	½ in. cube
6.0	Olives	Goya Foods/ margarite, stuffed	1 olive
7.0	Frankfurter	Cooked 10 min/Hebrew National	½ in. slice
9.5	Peanut	Cocktail type in vacuum/ planters	1 nut, whole
11.0	Carrots	Uncooked, fresh, unpeeled	½ in. slice
14.5	Hard candy	Life savers	3 pieces

Standard Denseness Scale

Definition: the compactness of the cross section.

Technique: place sample between molars and compress.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
0.5	Cool Whip	Kraft foods	2 tbsp
2.5	Marshmallow Fluff	Fluff-Durkee-Mower	2tbsp
4.0	Nougat center	Three Musketeers/Mars	½ in. cube
6.0	Malted milk balls	Whopper, Hershey’s	5 pieces
9.5	Frankfurter	Cooked 5 min, Oscar Mayer	½ in. slice
13.0	Fruit jellies	Chuckles/Farley's and Sathers	3 pieces

Standard cohesiveness of mass scale

Definition: the degree to which chewed sample (at 10-15 chews) holds together in a mass.

Technique: Chew sample with molars for up to 15 chews.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
0.0	Licorice	Shoestring	1 piece
2.0	Carrots	Uncooked, fresh, unpeeled	½ in. slice
4.0	Mushrooms	Uncooked, fresh	½ in. slice
7.5	Frankfurter	Cooked 5 min/Hebrew National	½ in. slice
9.0	Cheese, yellow	American process HEB brand	½ in. slice
13.0	Soft brownie	Little Debbie (frosting removed)	½ in. cube
15.0	Dough	Pillsbury/ Country Biscuit Dough	1 tbsp

Standard Cohesiveness Scale

Definition: the degree to which sample deforms rather than crumbles, cracks, or breaks.

Technique: place the sample between molars; compress fully (can be done with incisors).

Scale Value	Reference	Brand/Type manufacturer	Sample Size
1.0	Corn muffin	Jiffy	½ in. cube
5.0	Cheese	Yellow American Land/O'lakes	½ in. cube
8.0	Pretzel	Soft pretzel	½ in. piece
10.0	Dried fruit	Sun-dried seedless raisins/sun-maid	1 tsp
12.5	Candy chews	Starburst/Mars	1 piece
15.0	Chewing gum	Freedent/Wrigley	1 stick

Standard Crispness scale

Definition: The force and noise with which product breaks or fractures.

Technique: Place sample between molar teeth and bite down evenly until the food breaks, crumbles, cracks or shatters.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
3.0	Granola Bar	Quaker Low Fat Chewy Chunk	1/3 bar
5.0	Club Cracker	Keebler	½ cracker
6.5	Graham Cracker	Honey Maid	1 in. sq.
7.0	Oat cereal	Cheerios	1 oz.
9.5	Bran Flakes	Kellogg’s	1 oz.
14.0	Corn flakes	Kellogg’s	1 oz.

Standard Slipperiness Scale

Definition/ Technique: The amount in which the product slides across the tongue.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
2.0	Baby food-beef	Gerber	1 oz.
3.5	Baby food-peas	Gerber	1 oz.
7.0	Vanilla yogurt, low fat	Dannon	1 oz.

11.0	Sour cream	Breakstone	1 oz.
13.0	Miracle Whip	Kraft foods	1 oz.

Crunchiness Scale

Definition: Amount of noises present in the sample during the firs bite.
Technique: Place sample between molar teeth and bite down evenly until the food breaks, crumbles, cracks or shatters.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
2.0	Green grapes	Fresh fruit	2 grape
4.0	Rice crispy	Kellogg’s	1/3 bar
5.0	Kit-kat	Nestle	½ bar
10.0	Celery	Uncooked, fresh	½ in. slice
12.0	Carrots	Uncooked, fresh, unpeeled	½ in. slice

Standard Gritty Scale

Definition: The fundamental texture associated with grit or sand.

Scale Value	Reference	Brand	Sample Size
0.0	Miracle whip	Kraft foods	1 oz.
5.0	Instant cream of wheat and sour cream	Daisy	1 oz.
10.0	Mayo and corn meal	Hellman’s	1 oz.

Standard Tooth packing Scale

Definition: The degree to which product sticks on the surface of teeth.
Technique: after the sample is swallowed, feel the tooth surfaces with tongue.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
0.0	Mini-clams	Geisha/Nozaki America	3 pieces
1.0	Carrots	Uncooked, fresh, unpeeled	½ in. slice
3.0	Mushrooms	Uncooked, fresh, unpeeled	½ in. slice
7.5	Graham cracker	Nabisco	½ in sq.
9.0	Yellow cheese	Land O’ Lakes	½ in. cube
11.0	Cheese snacks	Wise-Borden Cheese Doodles	5 pieces
15.0	Jujubes candy	Jujubes	3 pieces

Standard Loose particles Scale

Definition: Amount of particles remaining in and on the surface of mouth after swallowing.
Technique: chew samples 8 times with molars, swallow, and evaluate.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
0.0	Peanut butter	Brand available	1 oz.
2.0	Hot dogs	Oscar Mayer	½ in. slice
3.0	Pound cake	Sarah Lee	1 slice
5.0	Bordeaux cookies	Bordeaux	½ in sq.

10.0	Carrots	Uncooked, fresh, unpeeled	½ in. slice

Standard Moisture Absorption Scale

Definition: The amount of saliva absorbed by the sample during chew down.
Technique: Chew sample with molars for up to 15-20 chews.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
0.0	Licorice	Shoestring	1 piece
4.0	Licorice red	Twizzlers/Hershey’s	1 piece
7.5	Popcorn	Bagged popcorn	2 tbsp.
10.0	Potato chips	Wise	2 tbsp.
13.0	Pound cake	Sara Lee	1 slice
15.0	Saltines	Nabisco	1 cracker

Standard Fracturability Scale

Definition: The force with which the sample breaks.
Technique: Place food between molars and bite down evenly until the food crumbles, cracks, or shatters.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
1.0	Corn muffin	Jiffy	½ in. cube
4.2	Graham crackers	Honey maid	½ in. cube
6.7	Melba toast	Devonsheer	½ in. sq.
8.0	Ginger snaps	Nabisco	½ in. sq.
10.0	Rye wafers	Finn Crisp	½ in. sq.
13.0	Peanut brittle	Brand available	½ in. sq. candy
14.5	Hard candy	Life savers	1 piece

Fibrousness Scale

Definition: Amount of fibers present in the sample.
Technique: Place the sample between the molars, and evaluate during the first two bites.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
0.0	Marshmallow	Marshmallow/Kraft	2 pieces
3.0	Zucchini	Uncooked, fresh, unpeeled	½ in. sq.
5.0	Kiwi	Fresh, peeled	½ in. sq.
8.0	Pineapple	Fresh, peeled	½ in. cube
12.0	Asparagus	Uncooked, fresh, unpeeled	½ in. sq.
15.0	Skirt steak	Cook on the grill (177° F), 137° F	3 (2.54 cm) pieces

Chewiness Scale

Definition: Number of chews necessary for food to be swallowed
Technique: Place the sample between the molars, and chew 3 to 5 times.

Scale Value	Reference	Brand/Type manufacturer	Sample Size
0.0	Yellow cheese	Land O’ Lakes	½ in. sq.
3.0	Marshmallow	Marshmallow/Kraft	2 pieces

4.0	Granola bar	Quaker chewy granola bar	1/3 bar
5.0	Candy bar	Milky way	1/3 bar
8.0	Twizzler	Twizzler licorice	1 piece
13.0	Jujubes	Jujubes fat-free	5 pieces
15.0	Gummy bear	Haribo Gold Bears	3 pieces

Table 3. Texture profile analysis (TPA) parameters. References from Texture Technologies Corp.

Parameters	Definitions
Hardness	The maximum force during the first compression
Fracturability	The force at the first peak
	The area of work during the second compression divided by the area of work during the first compression.
Springiness	The ratio of percentage of a product's original height. Is measured by the distance of the detected height during the second compression divided by the original compression distance.
Gumminess	Hardness × Cohesiveness (Area2/Area1)
Chewiness	Gumminess × Springiness (Distance2/Distance1)

Table 4. Experiment I, marinade retention % measured at 24h, 48h, and 72h post mortem and cook loss % of marinated normal and woody breast fillets.

Treatment	24 h	48 h	72 h	Cook loss %
Normal	93.94 ± 0.54	92.70 ± 0.62	92.29 ± 0.68	16.49 ± 0.01
Woody breast	92.64 ± 0.54	90.39 ± 0.62	88.37 ± 0.68	20.32 ± 0.01
P-value	0.13	0.03	0.01	0.002

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

Table 5. Experiment I, Warner Bratzler shear force and sarcomere length means of marinated normal and woody breast fillets.

Treatment	Shear force (N)	Sarcomere length (μm)
Normal	19.89 ± 0.67	1.64 ± 0.03
Woody breast	18.93 ± 0.63	1.70 ± 0.04
P-value	0.16	0.18

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

Table 6. Experiment II and III, pH, color (L*, a*, b*) and cook loos% of normal and woody breast fillets.

		Color			
Treatment	pH	Lightness (L*)[1]	Lightness (L*)[2]	Redness (a*)	Yellowness (b*)
Normal	5.83±0.03	53.69±0.52	58.85±0.52	4.63±0.20	3.73±0.29
Woody	6.07±0.03	55.25±0.52	56.18±0.52	5.21±0.20	5.03±0.29
P-value	<.0001	0.04	0.0005	0.04	0.0021

Values are expressed as means ±SE. *P*-values <0.05 are significantly different.

[1] Experiment II

[2] Experiment III

Table 6 Continued

Treatment	Cooking loss %
Normal	16.82 ± 0.87
Woody Breast	20.86 ± 0.87
P-value	0.003
Interaction[1]	
P-value	0.71
Grill	23.16 ± 0.84
Oven	14.51 ± 0.90
P-value	<.0001

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

[1] Interaction= type of meat × cooking method

Table 7. Experiment II, sensory texture attributes of normal and woody breast fillets (0=none, 15=extremely intense).

Attributes	Springiness	Hardness	Denseness	Cohesiveness	Cohesiveness of mass	Crunchiness
Normal	3.87 ± 0.12	4.56 ± 0.13	4.77 ± 0.12	4.96 ± 0.10	6.74 ± 0.09	1.88 ± 0.19
Woody	4.32 ± 0.13	4.97 ± 0.13	5.38 ± 0.12	5.31 ± 0.10	6.52 ± 0.09	2.78 ± 0.20
P-value	0.01	0.02	0.0005	0.02	0.08	0.002

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

Table 7 Continued

Attributes	Tooth packing	Loose particles	Fracturability	Fibrousness	Chewiness
Normal	3.36 ± 0.08	2.88 ± 0.08	2.83 ± 0.11	2.01 ± 0.21	1.62 ± 0.13
Woody	3.36 ± 0.08	2.81 ± 0.08	3.23 ± 0.12	3.19 ± 0.21	2.41 ± 0.13
P-value	0.98	0.56	0.02	0.0001	<.0001

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

Table 8. Experiment II, effect of grill and oven cooking methods on the sensory texture attributes of normal and woody breast fillets (0=none, 15=extremely intense).

Attributes	Springiness	Hardness	Denseness	Cohesiveness	Cohesiveness of mass	Crunchiness
Grill	4.13 ± 0.12	4.76 ± 0.12	5.04 ± 0.12	5.17 ± 0.10	6.64 ± 0.09	2.42 ± 0.19
Oven	4.06 ± 0.13	4.77 ± 0.13	5.11 ± 0.13	5.10 ± 0.10	6.62 ± 0.09	2.23 ± 0.20
P-value	0.67	0.95	0.70	0.64	0.87	0.50
Interaction[1]						
P-value	0.74	0.98	0.99	0.89	0.47	0.61
Interaction[2]						
P-value	0.92	0.77	0.17	0.92	0.29	0.06

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

[1] Interaction: type of meat × cooking method

[2] Interaction: panelist × type of meat

Table 8 Continued

Attributes	Tooth packing	Loose particles	Fracturability	Fibrousness	Chewiness
Grill	3.30 ± 0.07	2.88 ± 0.08	2.97 ± 0.11	2.68 ± 0.20	1.95 ± 0.13
Oven	3.41 ± 0.07	2.81 ± 0.08	3.09 ± 0.12	2.55 ± 0.21	2.08 ± 0.14
P-value	0.31	0.55	0.42	0.66	0.47
Interaction[1]					
P-value	0.65	0.87	0.71	0.84	0.80
Interaction[2]					
P-value	0.33	0.17	0.36	0.25	0.23

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

[1] Interaction: type of meat × cooking method

[2] Interaction: panelist × type of meat

Table 9. Experiment II, texture profile analysis (TPA) of marinated normal and woody breast fillets based on frozen storage.

Attributes	Hardness (g)	Adhesive (g/s)	Cohesion	Springiness (%)	Gumminess	Chewiness
Normal	8127.89 ± 654.91	-10.62 ± 2.81	0.46 ± 0.01	65.69 ± 0.81	3787.9 ± 501.09	2502.76 ± 388.71
Woody	13946.31 ± 654.91	-9.46 ± 2.81	0.56 ± 0.01	68.49 ± 0.81	8275.88 ± 501.09	5846.60 ± 388.70
P-value	<.0001	0.77	<.001	0.02	<.0001	<.0001

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

Table 10. Experiment II, effect of grill and oven cooking methods on the Texture Profile (TPA) of marinated normal and woody breast fillets based on frozen storage.

Attributes	Hardness (g)	Adhesive (g/s)	Cohesion	Springiness (%)	Gumminess	Chewiness
Grill	11022.4 ± 654.9	-11.96 ± 2.81	0.51 ± 0.01	66.97 ± 0.81	5879.14 ± 501.09	4019.65 ± 388.70
Oven	11051.8 ± 654.91	-8.12 ± 2.81	0.51 ± 0.01	67.20 ± 0.81	6184.72 ± 501.09	4329.70 ± 388.70
P-value	0.97	0.34	0.97	0.84	0.67	0.57
Interaction[1]						
P-value	0.28	0.61	0.65	0.85	0.25	0.23

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

[1] Interaction: type of meat × cooking method

Table 11. Experiment II, Pearson correlation coefficient (*r*) between sensory texture attributes and texture profile analysis (TPA).

Attributes	Hardness	Springiness	Cohesion	Chewiness
Hardness	1			
r	0.40			
P-value	<.0001			
Springiness		1		
r		0.31		
P-value		0.004		
Cohesion			1	
r			0.31	
P-value			0.002	
Chewiness				1
r				0.51
P-value				<.0001

r= Pearson correlation coefficient. *P*-value <0.05 is significant.

Table 12. Experiment III, texture profile analysis (TPA) of marinated normal and woody breast fillets based on fresh storage.

Attributes	Hardness (g)	Cohesion	Springiness (%)	Chewiness
Fresh storage				
Normal	8448.31 ± 403.82	0.51 ± 0.01	65.21 ± 0.59	2819.19 ± 234.28
Woody	12534.91 ± 403.82	0.56 ± 0.01	67.67 ± 0.59	5194.80 ± 234.28
P-value	<.0001	<.0001	0.003	<.0001
Frozen storage				
Normal	8127.89 ± 654.91	0.46 ± 0.01	65.69 ± 0.81	2502.76 ± 388.71
Woody	13946.31 ± 654.91	0.56 ± 0.01	68.49 ± 0.81	5846.60 ± 388.70
P-value	<.0001	<.001	0.02	<.0001

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

Table 13. Experiment III, effect of grill and oven cooking methods on the texture profile analysis (TPA) of fresh marinated normal and woody breast fillets based on fresh storage.

Attributes	Hardness (g)	Adhesive (g/s)	Cohesion	Springiness (%)	Gumminess	Chewiness
Grill	8106.47 ± 393.93	-8.94 ± 1.66	0.55 ± 0.01	64.21 ± 0.83	4512.00 ± 305.64	2957.07 ± 236.77
Oven	11785.77 ± 393.93	-8.13 ± 1.66	0.57 ± 0.01	67.34 ± 0.83	6878.57 ± 305.64	4525.63 ± 236.77
P-value	<.0001	0.73	0.23	0.008	<.0001	<.0001
Interaction[1]						
P-value	0.19	0.41	0.06	0.12	0.08	0.05

Values are expressed as means ± SE. *P*-values <0.05 are significantly different.

[1] Interaction: type of meat × cooking method

APPRENDIX B

FIGURES

Figure 1. Distribution of the locations for determination of pH, instrumental texture (shear force, sarcomere length, and TPA) and sensory texture profile.

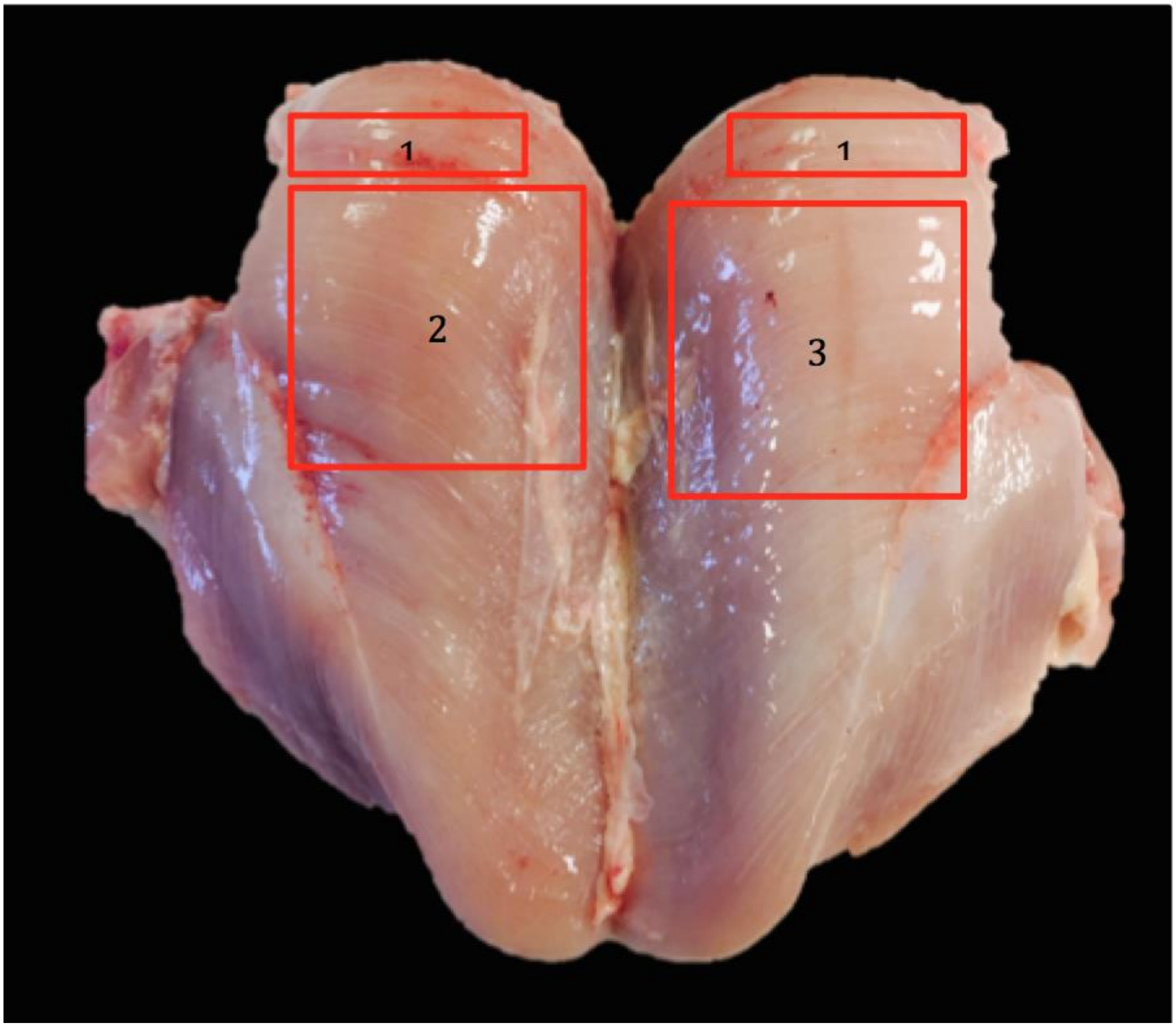
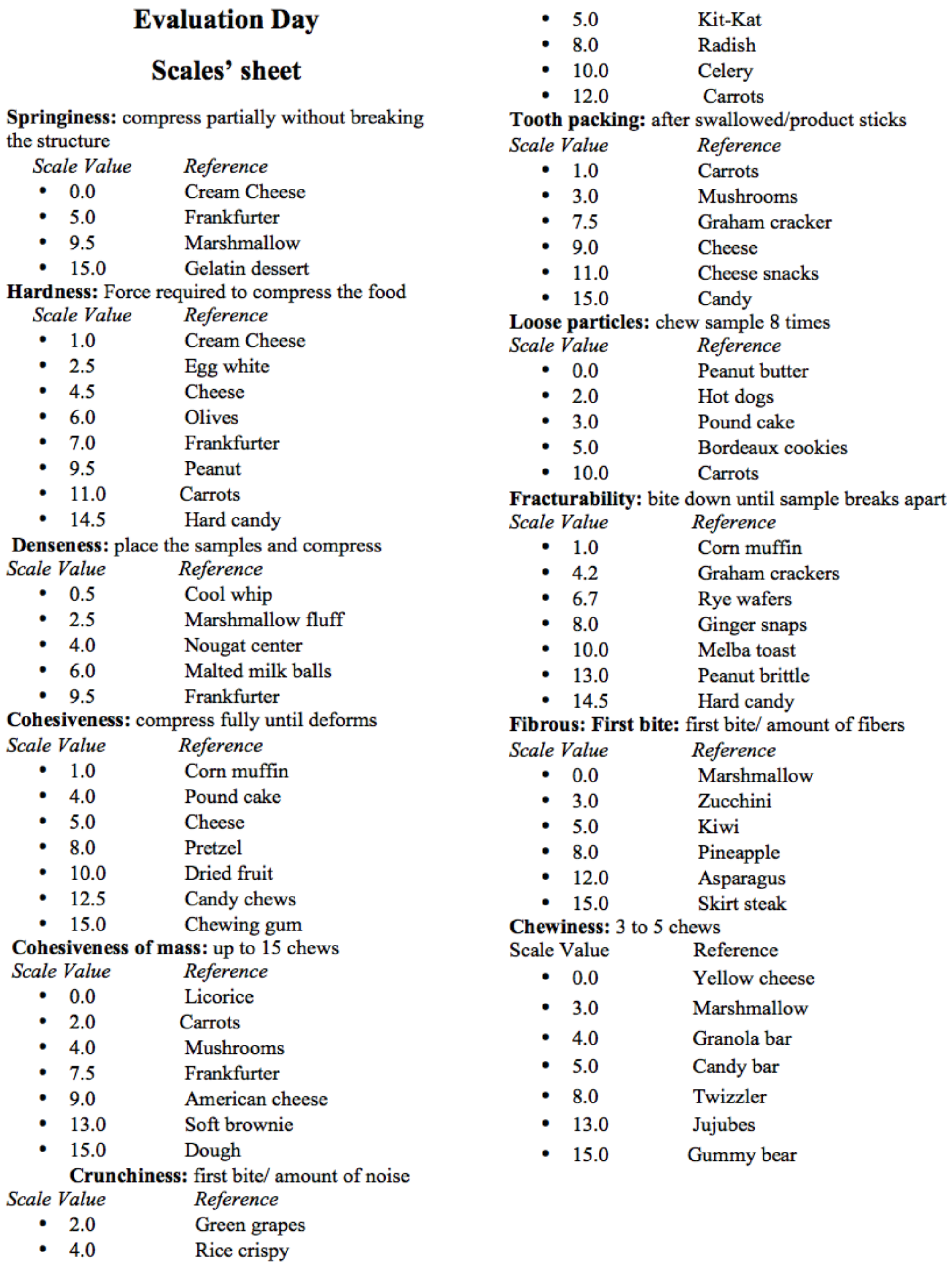


Figure 2. Scale's sheet, used by the trained panel on the validation days, where 0=none; 15=extremely intense.



Evaluation Day

Scales' sheet

Springiness: compress partially without breaking the structure

Scale Value	*Reference*
0.0	Cream Cheese
5.0	Frankfurter
9.5	Marshmallow
15.0	Gelatin dessert

Hardness: Force required to compress the food

Scale Value	*Reference*
1.0	Cream Cheese
2.5	Egg white
4.5	Cheese
6.0	Olives
7.0	Frankfurter
9.5	Peanut
11.0	Carrots
14.5	Hard candy

Denseness: place the samples and compress

Scale Value	*Reference*
0.5	Cool whip
2.5	Marshmallow fluff
4.0	Nougat center
6.0	Malted milk balls
9.5	Frankfurter

Cohesiveness: compress fully until deforms

Scale Value	*Reference*
1.0	Corn muffin
4.0	Pound cake
5.0	Cheese
8.0	Pretzel
10.0	Dried fruit
12.5	Candy chews
15.0	Chewing gum

Cohesiveness of mass: up to 15 chews

Scale Value	*Reference*
0.0	Licorice
2.0	Carrots
4.0	Mushrooms
7.5	Frankfurter
9.0	American cheese
13.0	Soft brownie
15.0	Dough

Crunchiness: first bite/ amount of noise

Scale Value	*Reference*
2.0	Green grapes
4.0	Rice crispy
5.0	Kit-Kat
8.0	Radish
10.0	Celery
12.0	Carrots

Tooth packing: after swallowed/product sticks

Scale Value	*Reference*
1.0	Carrots
3.0	Mushrooms
7.5	Graham cracker
9.0	Cheese
11.0	Cheese snacks
15.0	Candy

Loose particles: chew sample 8 times

Scale Value	*Reference*
0.0	Peanut butter
2.0	Hot dogs
3.0	Pound cake
5.0	Bordeaux cookies
10.0	Carrots

Fracturability: bite down until sample breaks apart

Scale Value	*Reference*
1.0	Corn muffin
4.2	Graham crackers
6.7	Rye wafers
8.0	Ginger snaps
10.0	Melba toast
13.0	Peanut brittle
14.5	Hard candy

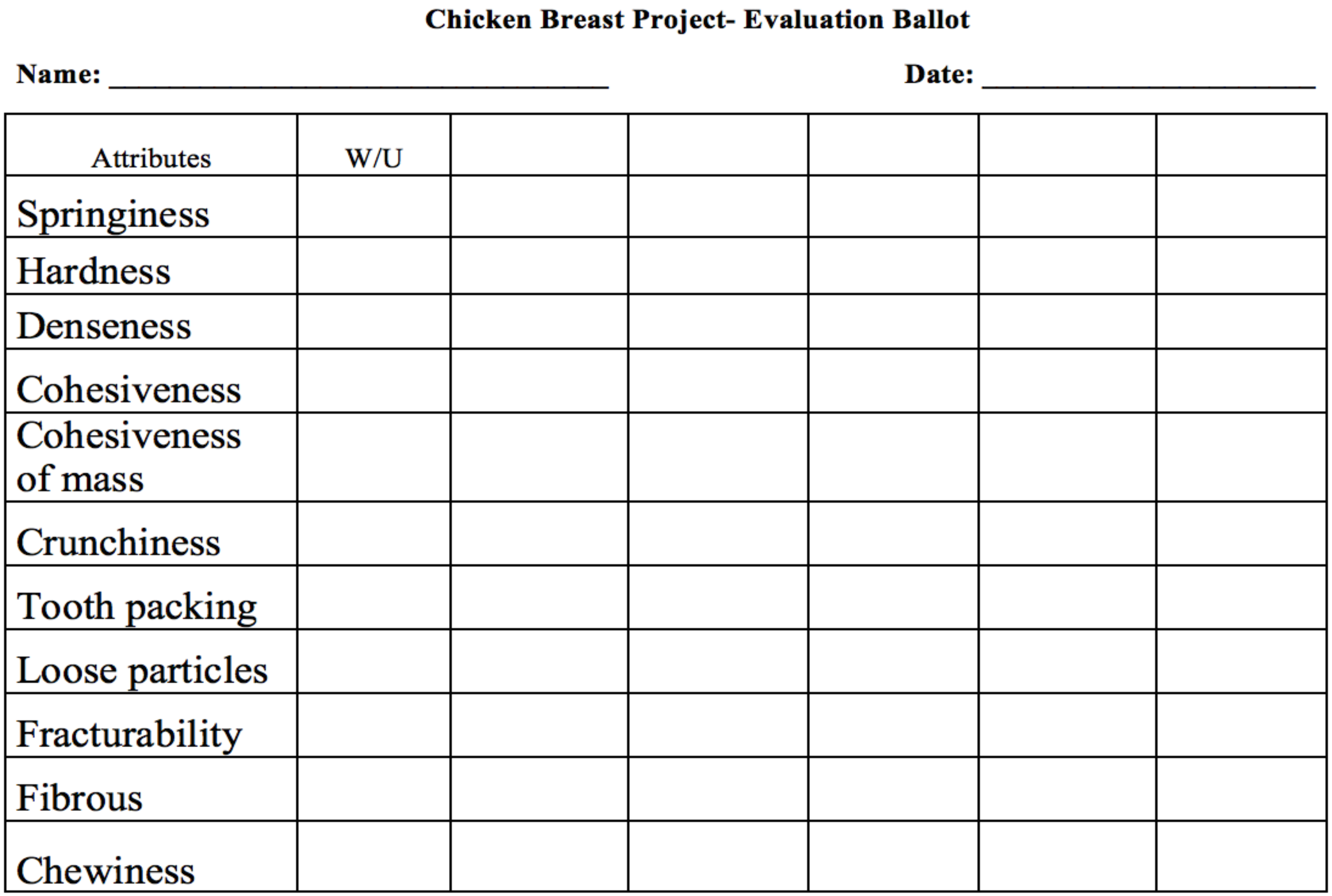
Fibrous: First bite: first bite/ amount of fibers

Scale Value	*Reference*
0.0	Marshmallow
3.0	Zucchini
5.0	Kiwi
8.0	Pineapple
12.0	Asparagus
15.0	Skirt steak

Chewiness: 3 to 5 chews

Scale Value	Reference
0.0	Yellow cheese
3.0	Marshmallow
4.0	Granola bar
5.0	Candy bar
8.0	Twizzler
13.0	Jujubes
15.0	Gummy bear

Figure 3. Sensory ballot used to evaluate the descriptive texture profile of normal and woody breast fillets.



Chicken Breast Project- Evaluation Ballot

Name: ______________________________ **Date:** ____________________

Attributes	W/U					
Springiness						
Hardness						
Denseness						
Cohesiveness						
Cohesiveness of mass						
Crunchiness						
Tooth packing						
Loose particles						
Fracturability						
Fibrous						
Chewiness						