

AN INVESTIGATION OF POSSIBLE CONTRIBUTORS TO AND
CHARACTERISTICS OF WHITE STRIATIONS IN BROILER BREAST FILLETS

by

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(Under the Direction of GENE M. PESTI)

ABSTRACT

White breast striations have become a widespread problem in the poultry industry over the past several decades. Previous research has demonstrated the relationship striations have to the increasingly fast growth rate of modern broiler strains. The purpose of this study was to evaluate the relationship between white striations and broiler strain, gender, fat quality, or vitamin/trace nutrient levels and how they affect meat quality and cooking parameters. Three broiler strains were evaluated; 2 modern strains (M1 and M2) and a 1990's randombred strain (RB). Dietary treatments differed in fat quality and levels of vitamin/trace nutrient mix. Broilers were processed on day 41 and breast fillets scored for white striping severity on a 0 – 4 scale indicating no, slight, moderate, considerable, and severe striations, respectively. Results demonstrated that strain, gender, and live weight are significantly related to white striations. After compensating for live weight differences, strain and gender remained significant factors. Dietary treatments, tenderness measurements, cook loss, collagen content, and pH were not significant to striping. Factors significantly correlated included fillet thickness, yellowness color value, and lipid content.

INDEX WORDS: White Striations, Muscular Dystrophy, Quality Defects, Muscle Myopathy, Occurrence, Broiler, Striping, Breast Meat, Growth Rate, Dietary Deficiency, Oxidized Fat

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DEDICATION

This thesis is dedicated to my mother, Mary Louise Landrum, father, Gerald Glenn Landrum, and the late Arthur Randy Cliett. With every roadblock life threw my way, they remained by my side. My mother is the ultimate role model of strength and determination. I consider myself lucky if I become even half the woman that she is. She is more than just a mother; she is my very best friend and inspiration. She supported me in every way possible, and was eager to tell everyone how proud she was of her daughter. My father has helped to encourage me and ensure that I keep my ultimate goal in mind through the hard times experienced in graduate school. He helped to give me the drive I needed to want these accomplishments and prove that I was able to achieve them. He always reminded me of how proud he was of me, which gave me the extra push I often needed. Mr. Randy demonstrated the meaning of hard work and how important it is to put your heart into everything you do. Through him I learned how strong of a person I am and what I am truly capable of. He made sure I understood that no one can stop me from reaching my dreams. Having them in my life made me the woman I am today and I wouldn't trade a single memory for anything.

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CHAPTER 1

INTRODUCTION

Purpose of the Study

The purpose of this study is to better understand factors related to the prevalence and severity of white striations in broiler breast fillets and their effects on cooking parameters and meat quality. Fast growing, modern broilers were compared to slower growing, 1990's randombreds in cooking parameters and meat quality. The study focuses on white striations, a quality defect in breast fillets that has become a wide spread problem to the broiler industry. The prevalence and severity of striations continues to rise and negatively affect consumer acceptance, resulting in downgrading or economic losses (Kuttappan et al., 2012b). The idea is that genetic selection for faster growth rates has produced a bird whose muscles are pushed beyond their anatomical limits, leading to severe muscle damage (Dransfield and Sosnicki, 1999).

Modern breast fillets are found to have higher fat content and lower protein content than previous decades, which are displayed in the form of white striations (Wang et al., 2010; Kuttappan et al., 2012a). The overall factor causing white striations remains unknown, although studies indicate they are positively related to live weight and the increasingly faster growth rate of modern broiler strains (Dransfield and Sosnicki, 1999; Ferreira et al., 2010; Bauermeister et al., 2011). As severity levels rise, it has become imperative that the industry better understand factors associated with white striations,

their affects on meat quality and cooking parameters, and the steps required to find a solution to the problem.

How This Study is Original

Many influential factors are evaluated in this study that affect meat quality, so an overall representation of the effects white striations have on broiler breast fillets can be demonstrated. Evaluating the incidence and severity of differing genders has not been researched in depth in past studies. The purpose of the four dietary treatments is to find the relationship vitamin/trace nutrient mix and fat quality has with white striations. This will assist in finding whether a dietary influence is present on the progression of white striping. Growth rates have been evaluated in past research of white striping but the effects of strain itself remain unclear. Comparing 2 modern, fast growing, strains and a slower growing 1990's strain demonstrate whether genetic modifications have influenced white breast striations. Past studies evaluated the relationships live, carcass, and parts weights have with white striations, to which results can be compared to those of this study (Ferreira et al., 2010; Bauermeister et al., 2011; Kuttappan et al., 2012a)

Although the striations effects on visual appearance are crucial, it is necessary to understand the correlations white striping has to cooking properties and meat quality. Cooking parameters include measurements such as cooking losses, tenderness, and fillet thickness, while colorimeter scores, pH values, lipid content, and collagen content are measured to evaluate meat quality.

Expected Results

As past studies have shown, it may be expected that a significant positive relationship will exist between live weight and striation severity. The increasingly higher growth rate of modern broilers may be related to higher white striation severity, suggesting a significant strain effect present. As gender has not been extensively researched in relation to striations, there are no expectations on results. Contrasting data in previous research on relationships between white striping and cooking/meat quality parameters gives no indicating of possible results in this study.

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CHAPTER 2

LITERATURE REVIEW

Overview of the Commercial Broiler Industry

Industry Evolution

The commercial broiler industry has shifted dramatically over the last century, as consumer demand has risen significantly. In 1934, the broiler industry generated 65 million pounds of meat within year, an amount the industry can currently produce in one day of production (Martinez, 1998). The tremendous growth can be attributed to multiple factors; such as availability, convenience, lower prices, vertical integration, technological advancements, or genetic improvements. Prior to World War II, poultry was a highly valued product, consumed only on special occasions. Following World War II, technological advancements allowed the industry to improve its production strategies. By 1985, the poultry industry led all other meat industries in consumption rates and consumer demand (Havenstein et al., 2006). Vertical integration was adopted, allowing a single firm control over all aspects of production and processing. This meant broilers were no longer passed from one production point to another, which had made the final distribution of products very time consuming (Anthony, 1998; Ferrara, 2005; Havenstein et al., 2006).

Conveniences associated with poultry products are another factor to its rapid growth. Time constraints are not allowing consumers to prepare and cook family meals as in the past (Kuttappan et al., 2012b). Further processed products attract consumers for

their ease of preparation and versatility of products. Consumers previously purchased whole carcasses, but the industry achieved significant success when increasing its product profile to further processed products (Anthony, 1998).

Genetic modifications are attributed with 85-90% of the improvements in modern broiler strains (Havenstein et al., 2003). The largest and most uniform birds are selected for breeding, allowing favorable heritable qualities to be passed down to offspring (Petracci and Cavani, 2012). Selection is achieved by culling flocks, only keeping birds with desirable traits (Anthony, 1997). Nutritionists have been under intense pressure to maximize broiler size, minimize feed efficiency, and reduce abdominal fat using different feedstuffs (Petracci and Cavani, 2012).

Broilers have shown a three-fold decrease in the amount of feed required to grow them to market weight, which is doubling the weight of broiler strains were 50 years ago (Havenstein et al., 2003). Attention to specific dietary needs within feed ingredients allowed these changes to occur.

Genetic Modifications

Geneticists play a key role in progression of the poultry industry over the last several decades. Companies can select qualities to produce birds suiting specific needs. Desirable traits include rapid growth rate, low feed conversion ratios, lean meat, heavy carcass weights, and high processing yields (Barbut et al., 2007). In the last decade, the main focus was increasing growth rates in modern broiler strains and selecting characteristics within these birds to produce optimal qualities (Havenstein et al., 2003). In the past 45 years, 85-90% of the progress in the poultry industry was the result of intense

genetic selection (Anthony, 1998; Havenstein et al., 2003). The practice of overlapping generations is used by breeders to allow an accelerated selection process, rather than waiting extended periods of time to see recognizable differences (Anthony, 1998). Geneticists utilize the benefits associated with natural genetic variation to help with intense selection and use heritable traits to their advantage (Anthony, 1998). It is believed growth rate and meat quality are genetically linked. Meat quality traits are heritable, which allows breeders to select specific features without altering the progression of a strain's growth rate (Duclos et al., 2007).

The practice of culling is used to eliminate undesirable traits and select qualities of interest throughout the entire growth period of a flock (Anthony et al., 1998). Commonly, geneticists select the top 1% of males and 10% of females to ensure only birds with the highest genetic merit are used in producing future generations. Female birds are selected based on traits such as early growth, egg production, fertility, and hatchability (Anthony, 1998). Important traits in male birds includes growth rate, market age, body weight, carcass conformation, and feed efficiency.

Importance of Visual Appearance

After World War II, consumer demand shifted from traditional family meals to compensate for the increasingly busier lifestyles. Consumer's needs of the poultry industry changed. The time and preparation required to cook whole carcasses was no longer an option to the average consumer, increasing the demand of further processed products (Kuttappan et al., 2012c). Further processing enables customers to be more

selective in making purchase decisions; therefore quality defects are more noticeable and can be highly influential to sales (Kuttappan et al., 2012c).

Presently, 88% of U.S. broilers are sold in further processed products (National Chicken Council, 2011), while 65% of purchases are boneless, skinless breast fillets (Kuttappan et al., 2012c). Kuttappan et al. (2012c) observed that consumers found raw meat more appealing than cooked products, because it allowed more control over preparation techniques and cooking times. This directs the poultry industry to pay closer attention to meat quality in marketed products (Duclos et al., 2007). Other quality issues may include decreased tenderness, poor cohesiveness, varied coloration, and negative water-holding properties (Sosnicki and Wilson, 1991).

Nutritional Values of Poultry

One of the main consumer attractions to the poultry industry is the health benefits associated with poultry compared to other meat industries. Poultry has thrived off its low fat, sodium, and cholesterol (Petracci and Cavani, 2012). Poultry is also well known for being high in unsaturated fatty acids. In the 1970's, poultry was attractive because of its beneficial health characteristics, known for being the better choice compared to beef and pork (Wang et al., 2009). The Royal College of Physicians and the British Cardiac Society reported in 1976 that increasing the consumption of poultry and limiting red meat would have positive benefits to an individual's health (Wang et al., 2009). Fat content in chicken versus red meat differs due to the location of lipid accumulation (Petracci et al., 2014). Lipids build up under poultry skin, detaching it from the meat and largely reducing fat content (Sams and Alvarado, 2010; Petracci et al., 2014). Red meat contains

intramuscular fat, commonly known as marbling, which makes it difficult to separate from the muscle (Petracci et al., 2014).

It was recently found that poultry might no longer hold the nutritional benefits it is well known for (Wang et al., 2009). Studies show it contains triple the energy from fat and higher lipid contents than in previous decades (Wang et al., 2009; Petracci et al., 2014). Such findings can have dramatic effects on the poultry industry, being the health benefits that attract consumers may no longer be factual.

Organic, Free-Range, and Pasture Raised Poultry

Sales of natural and organic food have grown tremendously in the last decade, as consumer interest in the health and processing methods of food industry animals has increased (Holcomb et al., 2004). Organic poultry, commonly sold as whole birds, exceeds other standard industry meats in price. Poultry advertised as “All Natural” includes birds not given any dietary hormone supplements or antibiotics. Many consumers are prepared to pay more for organic meats, feeling the health benefits outweigh the extra costs (Holcomb et al., 2004). The entire organic food industry is led by sales of organic poultry over other meats, because poultry has such a fast growing cycle. Sales of organic meat rose from \$33 million in 2002, to a staggering \$121 million by 2004. Sales of organic poultry alone reached \$46 million in 2003 and remained the most popular organic meat, preferred by 73.2% of shoppers (Holcomb et al., 2004).

Organic meat sales have maintained a position in supermarkets and mass producers, where 58% of organic products are sold (Holcomb et al., 2004). In a study on consumer preferences, 63% of shoppers stated they would choose to purchase organic or

natural products if price wasn't a factor (Holcomb et al., 2004). Some consumers are unable to spend extra to purchase organic meat, but would prefer it to conventional meat.

Consumer Concerns

Although product quality is important to consumers, they are also concerned with other aspects of production. One concern is the handling of food products prior to purchase (Groom, 1990). Consumer's expectations include purchasing meat that has been properly handled and transported. Poultry must be stored in appropriate temperatures for a certain amount of time to ensure adequate shelf life. Customers expect quality meat free of bruises or broken bones. They expect products free of feathers and fully eviscerated at the time of purchase (Groom, 1990). It is imperative the industry maintains a positive image over other meat industries. Any bad experience by consumers may cause negative feelings to the industry as a whole. Major companies within the industry maintain close watch over competing companies, looking for niches or customer dissatisfaction (Holcomb et al., 2004).

Consumers are interested in the welfare of industry animals, a topic popular to the media. Data by Holcomb et al. (2004) suggested 30% of American consumers consider social justice when making a purchase. Holcomb et al. (2004) found 85% of consumers are concerned about the quality of life of farm animals and 75% agree that animals used for consumption should not feel physical pain prior to slaughter. Slaughter methods vary by location and often become a main focus of media coverage (Groom, 1990). Numerous groups and organizations are focused solely on the treatment of food industry animals and propose changes that will better the animal's quality of life.

Diseases concern consumers, especially when they can affect human health. Media attention often focuses on health related issues, being such a serious concern to consumers. Diseases, such as Avian Influenza, require drastic measures for treatment and prevention. When infected birds are discovered, standard protocol includes euthanizing the entire flock to prevent the spread of disease into other flocks or farms (Holcomb et al., 2004). Careful attention to imports or exports is important in preventing new diseases from entering or leaving the country (Holcomb et al., 2004).

Health concerns facing the food industry are important to consumers, for the welfare of themselves and their families. Ferrara (2005) demonstrated that households with children are more health conscious and often limit the amount of fresh meat provided to their family. The study concluded that a correlation exists between the amount of meat intake and the attention given to media coverage on the topic. Packaging labels displaying nutrition and product safety of meat can influence a consumer's purchasing decision (Ferrara, 2005). Companies within the industry must take customer concerns into account and build consumer relationships so customer loyalty will remain high.

Brand Recognition and Packaging

Since the industry's significant sales increase in the 1980's, product branding and advertising has become important to product sales (Brester and Schroeder, 1995). With technology and product demand increasing, it became necessary for consumers to differentiate between products (Ferrara, 2005). In 1993, meat industries spent over \$120 million on branding and advertising expenses (Brester and Schroeder, 1995). Brands that

focused on advertising important consumer topics in a positive manner increased brand loyalty and recognition. When customers have loyalty to a company and a sense of trust they become repetitive buyers. Well-known brands are thought to have better product quality, while new or unfamiliar brands can deter consumers from purchasing (Groom, 1990). Popular brands have the financial capabilities of researching and developing new products (Holcomb et al., 2004). It is common practice for large firms to merge to increase market shares (Ferrara, 2005). They can then charge higher prices to remove large competitors from the market (Ferrara, 2005).

Many customers are willing to pay higher prices for branded products (Holcomb et al., 2004). Brand campaigns use advertisements to increase product consumption, rather than marketing strategies to instill product need (Brester and Schroeder, 1995). Large firms often focus on building interactive relationships with customers, by providing samples or cooking demonstrations (Holcomb et al., 2004; Ferrara, 2005). Interaction with customers builds clientele and gives the ability to show product worth and gain sales. Retailers often develop in-store brands to influence the idea of good product quality and fair price.

Packaging can be a valuable tool in market strategies and can attract customers to certain brands (Groom, 1990). Packaging can also be a tool to preserve product quality, display detailed product information, or give preparation instructions. Many companies choose to pre-package products in individual processing facilities before shipping them to retail stores, also known as “case-ready” (Ferrara, 2005). This allows companies to better record sale records and inventory counts.

Meat Quality Issues

Rapid Growth Leading to Muscle Myopathies

Muscle myopathies have become a serious problem affecting meat quality in the poultry industry. In 1968, Deep Pectoral Muscle Disease (DPM) was described as degenerative myopathy, occurring in modern broilers genetically bred for fast growth and increased muscle mass (Petracci and Cavani, 2012). Petracci and Cavani (2012) observed the disease affects approximately 1% of carcasses. Studies then focused on whether DPM was harmful if affected meat was consumed (Petracci and Cavani, 2012). Results indicated there are no negative consequences to human health. DPM was, however, visually undesirable to consumers and may result in excessive trimming of meat. This can lead great economic losses to the industry, especially because DPM affects the most valuable part of the carcass, breast fillets (Petracci and Cavani, 2012). The inelastic fascia and sternum that surround the breast do not increase when breast muscle size increases from growth. This physiological alteration results in muscle damage from excessive movement, such as wing flapping (Petracci and Cavani, 2012). Such movement causes extreme blood flow into the muscle, increasing the supracoracoid size by 20%. Therefore, muscle damage is unavoidable to birds faced with stressful situations.

The main factor causing muscle myopathies in broilers is rapid growth, because it results in excessive carcass fat (Anthony, 1998). Genetic modifications to the histological and biochemical properties of muscle tissues occur in birds selected for rapid growth (Duclos et al., 2007). Broilers fed high-energy diets for increased weight gain exhibit increased muscle fat from inadequate exercise (Kuttappan et al., 2012a). Fast growth has led to muscle abnormalities and the inability to obtain the required support from the body

(Dransfield and Sosnicki, 1999). When the muscles attempt to keep up with demand they become overworked, which leads to serious muscle damage. Dransfield and Sosnicki (1999) conclude this damage results in higher instances of leg weakness and edema, focal myopathy, or deep pectoral myopathy. As muscle mass continue to rise, there is an increase in the size of muscle fibers. Duclos et al. (2007) showed the large fibers that accompany breast muscles lead to decreased lightness colorimeter values. The larger the muscle fibers, the more blood present which leads to visually darker meat. Lower drip rates, cooking losses, and increased tenderness post cook are characteristic of breasts with large fibers (Duclos et al., 2007).

Pale, Soft, and Exudative (PSE)

In the past decade, research turned to finding a solution for an emerging quality issue in the industry; Pale, Soft, and Exudative (PSE) meat (Barbut et al., 2008). Meat classified as PSE appears pale in color, has lower water holding capacity, and is softer in texture (Woelfel et al., 2002). The cause of PSE is not fully understood but it can effect as much as 28% of a flock (Qiao et al., 2001). One report proposed that 37% of breasts examined in a particular processing plant had qualities classifying them as PSE (Woelfel et al., 1998). Studies have attributed PSE as an effect of pre-slaughter stress in birds. Such stress causes the metabolism to accelerate, dropping the pH, affecting the fillet tenderness (Anthony, 1998; Barbut et al., 2007). A fillet with PSE would appear to have a soggy texture, but excessive exudation causes it to be tougher than a fillet not affected by PSE (Duclos et al., 2007).

Several solutions are suggested to lessen the PSE problem, including lower stress prior to slaughter, different transport and/or unloading methods, rest periods after transport, or alternative methods to stunning birds in a less stressful manner (Barbut et al., 2008). Long-term solutions for PSE include genetic selection against it in future broiler generations (Barbut et al., 2008). One study proposed the addition of non-meat ingredients into poultry products to increase meat texture and provide better water-holding capacity (Barbut et al., 2008).

Intramuscular Connective Fibers

Broiler breast fillets are made up of connective fibers that may change aspects of meat quality. Dransfield and Sosnicki (1998) explained that increasing growth rate stimulates muscle fibers to increase in diameter, making a greater number of glycolytic fibers. These histological changes can affect breast fillet tenderness, an important quality to consumers. Increased fiber diameter decreases tenderness among high yield broilers and male broilers (Brewer et al., 2012). The number of fibers present in the muscle is dependent upon growth rates (Dransfield and Sosnicki, 1998). Strains bred for fast growth have larger, more prevalent fibers. Slow growing strains are constructed of fewer fibers that are smaller in diameter.

Muscle strength depends on the amount of collagen fibrils and cross-bridges within the meat (Petracci and Cavani, 2012). The older the bird, the more cross-bridges within the muscle. Having more cross-bridges equates to greater physical strength and heat stability (Petracci and Cavani, 2012). Meat tenderness is reduced as the number of cross-bridges increases. Intramuscular connective tissue can influence another serious

quality defect of poor cohesiveness. Cohesiveness of the meat relates to the maturity of the connective tissue (Petracci and Cavani, 2012). Birds slaughtered at an earlier age have immature connective tissues and exhibit poor cohesiveness. Poor cohesiveness leads to degeneration, making the texture soggy and negative acceptance from consumers (Petracci and Cavani, 2012).

Breast Meat Spoilage and Shelf life

Product shelf life is imperative to ensuring consumers can purchase quality products. Producers want to distribute a product that stays fresh as long as possible, pushing them above their competitors. Meat pH has been found to play a role in shelf life and microbial growth (Pooni and Mead, 1984; Allen et al., 1997). The lower the pH of the meat, the longer it may be stored (Allen et al., 1997). Type of packaging, storage temperature, and initial bacteria counts are related to meat spoilage (Allen et al., 1997). Consumers immediately reject meat with abnormal odors from amino acid metabolism (Pooni and Mead, 1984).

Overview of Variables Tested

Broiler Strain Differences

Throughout past several decades, geneticists paid close attention to the modifications of broiler strains and that they are favorable for the industry. The strain used by the industry in 1957, Athens-Canadian Randombred (ACRB), is maintained at the University of Georgia's Poultry Breeding Laboratory (Havenstein et al., 2003). This strain gives scientists the ability to compare present and future strain performance to a

past strain. Bouwkamp et al. (1972) demonstrated significant differences in the parts yield of different strains. This was attributed to selection for rapid growth, which allowed modern strains to produce higher yields. A similar study, by Lopez et al. (2011), showed significant strain differences in the breast yield and dressing %, but no relationship to pH drop, cooking loss, shear force values, or proximate composition.

In contrast, Brewer et al. (2012) reported a significant strain effect on fillet yield, dimension, and tenderness. It was concluded that there is variation in rigor development in different strains. No significant strain differences were found in breast muscle color (Brewer et al., 2012). Xiong et al. (1993) reported that strain affects characteristics of cooked breast fillets. Overall, no significant differences existed in consumer acceptance or the appeal of broiler meat from different strains (Lopez et al., 2011).

Broiler Gender Differences

Breeders select different characteristics for male and female broilers, which may have influenced other traits from each gender. Male broilers have significantly greater live weights than female broilers (Lopez et al., 2011; Brewer et al., 2012). The breast fillet conformation also varies significantly by gender; male fillets being longer, wider, and thicker compared to females (Brewer et al., 2012). Although fillets are larger in male birds, studies have observed female broilers have a higher proportion of breast to body weight (Moran and Orr, 1970; Bouwkamp et al., 1973). Males have a significantly higher drumstick yield than females (Moran and Orr, 1970; Bouwkamp et al., 1973). No gender significances were reported relating to shear force (Brewer et al., 2012) or back yield (Bouwkamp et al., 1973).

Factors Affecting Parts Yield

A major factor in the success of a company is the ability to produce higher yield broilers. Seemingly small increases in yield can equate to huge financial gains considering the massive amount of broilers processed daily. Therefore, it is vital to know the factors that positively influence broiler-processing yields. Geneticists select specific characteristics of importance to the industry, including yields, health, nutritional value, and low abdominal fat (Kijowski, 1997; Young et al., 2001). It is important to find a balance between consumer demands for lean poultry meat and processor demands for maximum profit (Kijowski, 1997). Processors focus on collecting the maximum amount of meat to use in further processing sales, where the industry collects the most revenue (Summers et al., 1992).

Bouwkamp et al. (1973) found no significant differences in the yield of parts from broilers differing in sex or age. Moran and Orr (1970) indicated that when carcass grade was constant, no significant differences existed in the parts yield of different broiler strains. Young et al. (2001) indicated a positive relationship between broiler age and the yields of thighs, forequarters, breasts, and fillets. Data also suggested female broilers yield larger forequarters, breasts, and fillets, while males to yield larger drumsticks.

Dietary Influences in Broilers

Nutritionists play a critical role in the poultry industry and have assisted breeders in the development of the modern broiler. Feeding the proper diet maximizes bird performance (Dale, 2014). A nutritionist's job includes finding a reliable source for resources required in a diet and providing them to the bird (Dale, 2014). Ingredient cost

must be considered when constructing diets and 60% of production costs are spent on feed.

During the first week after hatch, the diet includes high levels of and chicks triple their body weight during this time (Dale, 2014). After the first week, nutritionist focus is on supplying ingredients for growth, because energy requirements are low. During the first several weeks of life, chicks grow rapidly and energy requirements increase to maintain steady growth rates. If broiler breeders are allowed free access to feed obesity will occur; therefore, feed must be restricted to ensure good health (Dale, 2014).

Health conditions can suffer when a diet is deficient in ingredients required by the body (Dale, 2014). Diets meeting Methionine and Lysine requirements are shown to provide optimal weight gain (Summers et al., 1992). Diets with low levels of dietary energy can result in broilers with high carcass fat. Myopathies on breast fillets are common in birds consuming vitamin E deficient diets (Kuttappan et al., 2012b). Supplementing essential amino acids can change the overall protein content of meat (Summers and Leeson, 1985).

If incorrect or deficient diets are fed If the correct diet is not fed, it can reflect in bird's growth performance (Havenstein et al., 2003). Birds consuming a vitamin deficient diet can exhibit increased cholesterol levels within their muscles (Chupukcharoen et al., 1985). Broiler diet influences many areas of production including health, growth, feed intake, or yields and should be monitored to ensure maximum performance. This explains how significant nutritionists are to the poultry industry and how massive their role is in ensuring performance.

Factors Affecting Cooking Loss

Product quality is vital to consumer acceptance and consumers making repeat purchases. Cook loss is an important quality to the industry, because it greatly affects the worth and value of a product. Customers expect minimal product loss when cooking meat because retail prices are based on weight. Cook loss refers to the measured percentage of weight lost from a product as a result of cooking (Woelfel et al., 2002). The water holding capacity was related to other characteristics, such as color and tenderness (Brewer et al., 2012). Woelfel et al. (2002) indicated the presence of a positive correlation between lightness colorimeter values and cooking losses. A study by Lyon et al. (2004) found the yield remaining after cooking significantly correlated to broiler diet.

Three key reasons to guarantee proper cooking of poultry products are palatability, preservation, and protection (Boback et al., 2007). Palatability refers to the tenderness of cooked meat, a very important quality to consumers. Tenderness is achieved from the increased solubility of the muscle's connective tissues, while reducing the structural integrity within (Boback et al., 2007). When the internal temperature of the meat reaches 40°C, muscle fibers begin to denature causing meat to become tougher. Muscle collagen denatures at approximately 50-60°C, making connective tissues within the muscle become more soluble (Boback et al., 2007).

Meat preservation is key to product quality, and pH is suggested to affect the shelf life of poultry meat (Allen et al., 1997). Spoilage of raw meat depends on refrigeration and storage temperatures, prevalence and type of bacteria present, and type of packaging (Springer, 2010). Some microorganisms are capable of survival and even growth in low temperatures, making preservation largely dependent on storage techniques.

Contaminations in cooked products are often the cause influencing spoilage rates.

Freezing meat has been shown to be effective in safely preserving poultry products (Springer, 2010).

The dangers and risks of consuming undercooked poultry are seemingly well known. Although cooking destroys pathogens, it often leaves spores unharmed that have the ability to cause serious sicknesses (Springer, 2010). Anaerobic pathogens can become harmful after a product is cooked and held over 10°C for a period of time. Low spore levels still exist post cook, and many food-borne illnesses result from the mishandling of food after cooking. It is often incorrect temperatures or number of days meat is stored that lead to problems (Springer, 2010).

Importance of Breast Meat Color

Any changes in the uniformity of a product can lead to decrease in consumer acceptance. One quality defect that has been shown to alter the functionality of meat is color variations (Qiao et al., 2001). Customers respond negatively to any color variations in a product, and can cause economic losses in sales (Qiao et al., 2001). Fletcher (1999) explained there is a negative response given by consumers when color varies within packages of breast fillets. Qiao et al. (2002) observed approximately 7% of packages contained breast fillets having noticeable color variation. Pale, soft, and exudative meat can affect up to 28% of birds and is responded negatively to by consumers (Barbut, 1997).

The color of meat can assist in predicting meat quality. Allen et al. (1998) explained that dark breast meat has a higher pH, reduced shelf life, but better marinade

uptake abilities. Qiao et al. (2002) demonstrated that dark fillets absorb less marinade than lighter fillets. Allen et al. (1997) found that dark breast fillets produce negative odors faster than lighter colored fillets. There was increased moisture in packages containing lighter fillets, which led to excess fluid within the package (Fletcher, 1999). Woelfel et al. (2002) reported L* colorimeter values could predict the functionality of meat, and was related to the water-holding capacity. Microbial growth was higher in darker fillets and excessive growth was not found in lighter colored fillets (Woelfel et al., 2002).

Myoglobin levels in the muscle increase as bird's age, and cause meat to become darker and redder in color (Fletcher, 2002). A study by Nishida and Nishida (1985) found that myoglobin changes were significantly related to meat coloration. In contrast, Smith et al. (2002) found no significant relationship in broiler age and muscle coloration. Broiler strain has been reported to effect breast color, which suggests genetic differences lead to varied characteristics (Berri et al., 2001). Research by Fletcher (1999) concluded that significantly different meat coloration can be found in birds from different commercial processing plants (Fletcher, 1999).

Stress levels have also been found to affect meat coloration (Bianchi et al., 2006). Heat stress is positively correlated to L* colorimeter values and turkey's display higher L* values during the summer season (Bianchi et al., 2006). Since transportation was suggested to be a stressor for broilers, a study was conducted to evaluate meat color in birds that were and were not transferred to processing plants (Bianchi et al., 2006). No significant transportation differences were found in breast color, although temperature in the holding area prior to processing was significant (Bianchi et al., 2006).

Lightness (L^*) colorimeter values are negatively correlated to the total pigment, myoglobin, and iron concentrations of meat (Boulianne, 1995). Lightness increased as total pigment within the fillet decreased (Fletcher, 1999). Fletcher (1999) noted significant pH differences exist between dark and light meat. When pH increased, meat had significantly lower lightness (L^*) and yellowness (b^*) values (Allen et al., 1997). Pigment, myoglobin, iron, pH, and redness values were higher in darker compared to lighter fillets (Boulianne and King, 1998). Lower lightness and yellowness values were displayed in darker fillets. Lighter fillets had less myoglobin, iron, total pigment, and redness. Higher lightness, yellowness, and pH values were characteristic of lighter fillets (Boulianne and King, 1998).

pH of Broiler Breast Meat

There are multiple studies that demonstrate a significant relationship exists between pH and colorimeter values in poultry meat (Ngoka and Froning, 1982; Allen et al., 1997; Barbut, 1997; Fletcher, 1999). As pH increases, breast fillets become darker in appearance (Bianchi et al., 2006). Replications of this study showed higher pH values exist in darker fillets that display a pink, undercooked appearance when cooked (Bianchi et al., 2006). Fletcher (1999) also conducted research that observed a significant relationship between fillet color and pH level.

The pH of a breast fillet is approximately 6.2 to 6.5 within 15 minutes of slaughtering a bird (Duclos et al., 2007). When pH drops below 6.0, proteins begin to denature, which causes meat to become discolored in appearance and have a lower water holding capacity (Duclos et al., 2007). The ultimate pH of meat is commonly around 5.8

(Duclos et al., 2007), and relates to glycogen levels within the meat (Ngoka and Froning, 1982). When birds are stressed, glycogen levels decrease and correlate to the pH within the muscle (Ngoka and Froning, 1982). When a stressor is introduced meat increases in lightness (L^*) values (Bianchi et al., 2006). Allen et al. (1997) proposed that a correlation is present between pH and microbial spoilage counts. Since color is such an important characteristic to consumers, it has become a serious factor to classifying meat quality.

Lipid Content in Poultry Meat

In 1970, poultry was considered a healthy alternative to other meats and was well known as lean and low fat (Wang et al., 2009). Fat levels are rising, as growth rates of modern broilers continue to dramatically increase. Production changes, such as genetic selection for fast growth, are attributed to the increasing fat content within poultry meat (Wang et al., 2009). Other production changes that have occurred include animal confinement, selection for weight gain, nutritional improvements, growth promoters, and exercise restriction. The industry must consider these issues to avoid mislabeling, consumer uproar, and health consequences from higher fat content (Wang et al., 2009).

Increased fat content, or adipose tissue growth, resulted from increased number of adipocytes present and the growth of those cells (Hermier et al., 1989). This can be seen in studies evaluating abdominal fat pad weights of lean versus modern broilers. Abnormal levels of adipose tissue growth are caused by hyperplasia and/or hypertrophy and can lead to obesity starting as early as two weeks of age (Hermier et al., 1989). Obese birds have increased levels of adipose tissue uptake, which determine fattiness of meat.

Significant differences were found between fat in the breast, thigh, and skin of male versus female broilers (Intarapichet et al., 2008). Histology samples showed female broilers have a higher fat content in their breast fillets than males. Lawrie (1998) concluded that females contain more intramuscular fat than male broilers. Such findings are supported by Intarapichet et al. (2008), who showed female broiler meat contains more monounsaturated fatty acids, but less polyunsaturated fatty acids than males. The overall consensus of past research found fat content is higher in female than male broilers.

Collagen Content in Poultry Meat

Connective tissues within broiler meat are largely composed of collagen, a common protein (Warriss, 2000). Collagen affects the toughness and/or tenderness of meat and is measured by the total collagen level or insoluble collagen (Intaraichet et al., 2008). Toughness of meat is associated with gender and broiler age. Intarapichet et al. (2008) found significant differences in the collagen content of male and female broilers, as well as different broiler strains. The collagen content within the thigh muscle increases as a bird ages and solubility of meat decreases (Warriss, 2000). When consuming high-energy diets the level of insoluble collagen deposits within birds increases (Roy et al., 2006).

The strength of collagen is dependent on the number of cross-links present, which increase in diameter and stabilize as the bird ages (Warriss, 2000). Meat tenderness decreases as the amount of collagen increases (Intaraichet et al., 2008). Collagen cross-links are greater in tendons than in the cartilage of the bird's organs. When cooking an

older bird, cross-links weaken and decrease in solubility, making the meat tougher (Warriss, 2000). Younger birds form a soft, soluble gelatin when cooked from the decreased presence of cross-links.

Warner-Bratzler Shear Force

Methods for evaluating meat tenderness within food industry animals vary. Tenderness is important to the increasing industry sales on boneless, skinless meat (Sams, 1999). Consumer expectations are to purchase quality products that are tender and stay consistent when cooked (Brewer et al., 2012). Multiple factors are considered influential to meat tenderness, including temperature and length of scald, feather removal, chilling, aging, and cut up of meat prior to rigor mortis (Lyon and Lyon, 1990). Other studies listed broiler diet as a factor to meat tenderness variations (Lyon et al., 2004).

Warner-Bratzler shear force measurements, introduced in 1932, are the most popular way to measure tenderness (Lyon and Lyon, 1991). Shear force refers to the strength required to cut through muscle fibers on a specific piece of meat, replicating chewing (Lyon and Lyon, 1991). Alternative techniques to measure tenderness include Allo-Kramer and razor blade shears, although they are not commonly used (Xiong et al., 2006). Although Warner-Bratzler is most popular, it does have negative features. A large sample size is required and the ability to perform accurate, specific cuts on test fillets (Xiong et al., 2006). This causes the method to be time consuming and often difficult to compare with results of other laboratories.

Multiple factors are influential to shear force values within poultry meat. Lyon and Wilson (1986) reported that cooking methods and rigor mortis condition significantly

affect shear force values. Xiong et al. (2006) showed that post slaughter deboning time has a significant influence on shear force values. Results by Qiao et al. (2002) observed no correlations between pH and shear force values. A lower proteolytic potential, resulting from increasing glycolytic fibers, was another factor affecting the meat tenderness (Dransfield and Sosnicki, 1999). The presence of glycolytic fibers rises from larger fiber diameter, resulting from increased growth rate of modern broilers. Zhuang and Savage (2009) found tenderness values change within an individual breast fillet from intramuscular variation.

White Striations in Broiler Breast Fillets

General Information

The primary goals in production and sales within the poultry industry have focused on meat quality over the past several decades. Studies have examined the importance of visual appearance to consumer acceptance and purchasing decisions (Kuttappan et al., 2012c). It was estimated that by the year 2020 the world's demand for poultry would increase to an astonishing 122.5 million metric tons (Best, 2011). With such an increase in demand, the industry's focus on quality and production time will be essential to producing enough products to meet demand.

One visual defect becoming a widespread problem to the poultry industry is white striations in broiler breast fillets. These striations run parallel to the muscle fibers within fillets. Although most commonly focused on in the pectoralis major, they can also be found on the pectoralis minors and thighs (Petracci and Cavani, 2012). Petracci et al. (2013) conducted a survey and found that 12% of the fillets being sold by retailers are

moderate or severely affected by white striations. Kuttappan et al. (2012b) found incidence rates as high as 50% in retail settings. Although the factor causing white striations remains unclear, it has become crucially important to find the source of this growing problem.

Muscular Dystrophy

Since scientists began concentrating on causes of white striations, they have been compared to another condition called hereditary muscular dystrophy (Asmundson and Julian, 1956). Some similarities do exist between muscular dystrophy in poultry and the condition in humans (Julian, 1973). In 1956, it was first reported as a hereditary condition that initially affected the proximal muscles of the bird (Julian, 1973). The condition was very widespread and was not found solely in particular strains of broilers (Kuttappan et al., 2013a). The most severe lesions occurred at the cranial end, or thickest portion, of the breast (Kuttappan et al., 2013c). Julian (1973) suggested that hereditary muscular dystrophy was caused by changes in the vascular system of a bird, making muscles become oxygen deficient. Fat content increased when muscle fibers were lost and replaced by fat (Julian, 1973). The onset of muscular dystrophy sparked an increased number of nuclei, variations in fiber size, vacuolization, and fiber damage.

Nutritional muscular dystrophy also caused white striations that run parallel to muscle fibers within breast fillets (Dam et al., 1952). Birds affected by this condition weighed 30% less than control birds, and had 16% less protein (Bunyan et al., 1967). Studies demonstrated the condition was caused by a dietary deficiency in Vitamin E, Selenium, or Cystine (Machlin and Shalkop, 1955; Nesheim et al., 1959; Klasing, 2008).

Nutritional muscular dystrophy was instigated by peroxidative tissue damage (Bunyan et al., 1967). Machlin and Shalkop (1955) showed that adding a sufficient supply of vitamin E to the diet would cease all findings of white striations, although the requirement to do so was extremely high. Vitamin E deficiencies also caused muscular dystrophy in rabbits, very similar to the condition in poultry (Chupukcharoen et al., 1985). Nesheim et al. (1959) found that increasing Methionine and Cystine levels was also effective in preventing signs of muscular dystrophy. Netke et al. (1999) also found positive results by adding Cystine to the diet in the prevention of muscular dystrophy.

Although the current condition of white striations is similar to nutritional muscular dystrophy, some important differences exist between the two (Kuttappan et al., 2012b). When affected by nutritional muscular dystrophy, breast fillets appeared to have united white areas and were overall paler in color (Kuttappan et al., 2012b). Current white striations are characteristic of white lines with a somewhat clear appearance, while the breast fillet otherwise appears normal. Nutritional muscular dystrophy involved several adjacent muscle fasciculi, giving the overall appearance of thick white areas along the fillet surface. Studies have concluded that supplementing vitamin E into the diets of birds with current white striations is not an effective prevention technique (Kuttappan et al., 2012b). Compared to hereditary muscular dystrophy, modern white striations have a different etiology (Kuttappan et al., 2013a). Although there are similar characteristics between modern white striations and both hereditary and nutritional muscular dystrophy occurrences from the past, there are many differences that make finding the solution difficult.

Progression of White Striping

White striations have progressed throughout the broiler industry, increasing rapidly over recent decades. Interestingly, the problem does not affect a particular area or an individual company within the industry. It is a widespread problem, rapidly increasing in severity. Kuttappan et al. (2009) conducted a study concluding 55.75% of breast fillets were affected with white striations to some degree. By 2012, incidence rates rose to 85.45% of fillets showing visual signs of white striations (Kuttappan et al., 2012b). The condition is not found in a particular strain or gender, as the 4 strains Kuttappan et al. (2012c) evaluated were affected by some level of severity. Therefore this is a serious problem quickly increasing in prevalence throughout each level of the broiler industry and may have serious consequences to product quality and customer acceptance (Kuttappan et al., 2012c).

Importance to the Industry

There are several reasons for the industry's concern of finding a solution to white striations in broiler breast fillets. White striations are visual defects to consumers and cause negative quality characteristics (Kuttappan et al., 2012c). The progression of white striations throughout the broiler industry has begun causing product rejection and lower consumer acceptance of meat (Petracci et al., 2013). More than 50% of fillets were moderately or severely striped in 2009, which has since risen to 75% in 2014 (Owens, 2014). These stripes can cause economic losses within the poultry industry. Kuttappan et al. (2012c) conducted a consumer acceptance study, demonstrating that purchases decrease as striping severity increased. Consumers display great dislike for fillets with

higher severity of white striations, and 50% of consumers surveyed stated they would not purchase moderate or severely striped meat (Kuttappan et al., 2012c).

Compared to red meat, poultry is well known as a healthy, low fat choice for consumers (Wang et al., 2009). Consumers have indicated concern that white striations are made up of fat. A study by Petracci et al. (2014) showed that birds affected by white striping do contain significantly higher fat contents and lower protein contents than birds with no visual striations. Other meat industries have experienced great economic losses due to decreased purchases and consumption, because higher fat content led to health concerns among consumers (Resurreccion, 2004). Poultry products could therefore considerable losses, being well known for positive health benefits (Resurreccion, 2004). Therefore, it is beneficial that the industry identify factors leading to white striations and make a valid attempt in correcting the visual defect.

Possible Explanations

Many explanations to the origin and cause of white striations in broiler breast fillets have been suggested. Valentine and McGavin (2012) explained one probable explanation being myofiber necrosis occurring in the muscle, leading to a buildup of collagen. The collagen was then infiltrated into the pale, white streaks over the surface of the muscle. Other studies concluded the condition was a result of the increasing size of modern broilers, leading to a reduced oxygen supply within the muscles (Kuttappan et al., 2013c). This was supported by evidence that fast growing broilers have lower capillary densities. Decreased blood supply can produce metabolic wastes, which put oxidative stress on the muscles and lead to tissue damage.

Vitamin E deficiency has also been a probable cause of white striations in broiler fillets (Jenkins et al., 1962; Kuttappan et al., 2009). An inadequate amount of vitamin E in the diet can lead to muscle degeneration, visually seen as white striations. Kuttappan et al. (2012b) explained that the vitamin E requirements of fast growing birds are higher than slower growing strains used in the past. Although numerous studies have pinpointed reasons for white striations, the ultimate cause has not yet been identified. Further research is required to better understand of the causation behind white striations.

Scoring System

Striation severity is assessed by a visual scoring system used throughout many studies on white striping. Striation scores are given to boneless, skinless breast fillets after standard processing procedures have been implemented. Kuttappan et al. (2009) thoroughly explained how striping scores are appointed to individual breast fillets. A breast was classified as normal (NORM) when no visual striations were present on the outer surface of the fillet (Kuttappan et al., 2012c). Moderate (MOD) severity included fillets displaying white lines running parallel to the muscle fibers, and are <1-mm in thickness. Fillets described as severe (SEV) displayed the same characteristics as MOD fillets, although stripes were >1-mm thick and were visually very noticeable. The guidelines explaining characteristics for categorizing striping severity were used in several white striation studies (Ferreira et al., 2010; Kuttappan et al., 2009; Kuttappan et al., 2012c; Kuttappan et al., 2012b; Kuttappan et al., 2013a; Kuttappan et al., 2012a; Kuttappan et al., 2013b; Kuttappan et al., 2013c; Petracci et al., 2013; Petracci et al., 2014)

An alternate method for scoring striping severity involves using numbers to score the fillet's visual characteristics. Bauermeister et al. (2011) appointed scores 1 – 4 to individual fillets based striping severity. A striation score of 1 indicate the fillet was free of any visual white striations on its surface, and was considered normal. Fillets with mild striping were designated as score 2. Moderate striping on a fillet surface were given a score of 3, while the presence of severe striping is appointed a score of 4.

Relationship to Broiler Live Weight

Many studies concluded that rapid weight gain plays a key role in the growing prevalence of white striations within broiler breast fillets (Dransfield and Sosnicki, 1999; Ferreira et al., 2010). White striations are associated with heavier, modern broiler strains (Bauermeister et al., 2011) and are an indication of serious muscle damage (Kuttappan et al., 2013a). There has been a dramatic increase in the average live weight of broilers over the last century. Over 50% of broilers are now grown to exceed 6 pounds, while only 23% were this large in year 2000 (Owens, 2014). Kuttappan et al. (2012a) found that broilers exhibiting fast growth showed lower incidence of normal (NORM) fillets and greater presence of severe (SEV) fillets. It was further concluded that increased growth rate leads to overstretching, or ischemia, in the muscle tissues of the broiler (Kuttappan et al., 2013c). This causes the muscle to become damaged and attempt to internally repair itself. One study showed broilers under higher levels of stress from enhanced growth were more likely to exhibit striations of greater severity at time of processing (Kuttappan et al., 2013a).

Influences of Strain on Striping Severity

Striation severity has been correlated to broiler strain, as significant differences exist between the characteristics of modern versus past broilers. Genetic variation allowed modern strains to demonstrate immensely fast growth, as previous slow growing strains were not affected by white striations (Kuttappan et al., 2013a). Kuttappan et al. (2013a) showed that significant correlations between white striation severity and broiler strain were present, although all strains exhibited some striations. Another study showed significant differences in the striping severity between strains, but live weight averages differed between strains (Bauermeister et al., 2011). Strains that averaged higher live weights were more severely striped, which suggests that live weight is still the overall determining factor of striping severity.

Influences of Gender on Striping Severity

Gender is another suspected cause of white striations in broiler breast fillets. Owens (2014) explained the condition was more prevalent in male birds and broilers that exhibited higher breast yields. Kuttappan et al. (2013a) also demonstrated male broilers show greater incidences of white striations. These results may be explained by the differences in live weight and fillet thickness between genders. Males average thicker, wider breast fillets compared to females (Brewer et al., 2012), which supports the idea that gender differences could be attributed to live weight differences.

Correlation Between Diet and Striation Severity

Studies have suggested that diet plays a key role in the occurrence and severity of white striations. Nutritional myopathies have been found in the muscles of birds being fed vitamin E deficient diets (Kuttappan et al., 2013a). Kuttappan et al. (2012b) explained that no obvious visual effects of a vitamin E deficient diet on muscle striations do not necessarily mean no effect is present. Conditions within a bird may block the full amount of vitamin E from reaching the breast muscles. In contrast, other studies found no effects of vitamin E levels on the severity of striping in broilers (Kuttappan et al., 2012b).

There was not a significant difference between the white striations of birds fed a high-energy diet compared to those fed a low-energy diet (Kuttappan et al., 2012a). Jenkins et al. (1962) found a significant correlation between the amount of fat in the diet and the severity of muscle striations. It was observed that the amount of Methionine and Cystine required for optimal growth was also what was needed to prevent muscle striations (Machlin and Shalkop, 1955). A study by Kuttappan et al. (2013a) demonstrated white striations were found in all dietary treatments. Petracci et al. (2013) supported the findings, showing dietary influence on white striping severity.

Chemical Composition of Striped Fillets

The chemical composition within a breast fillet at different levels of striation severity may help in understanding their origin. As growth rates increase, muscle fibers within the meat increase, decreasing the capillary density (Kuttappan et al., 2013a). Low capillary density results in muscle damage from inadequate nutrient supplies, low oxygen levels, and inability to remove lactic acid. Kuttappan et al. (2013b) confirmed muscle

damage was present after finding increased levels of serum enzymes (Kuttappan et al., 2013b). Histology analysis showed that severe myopathic lesions were present on the muscle tissue of fillets affected by white striping (Kuttappan et al., 2013c).

Proximate analysis and fatty acid profiles showed a positive correlation between striation severity and the fat content within the breast muscle (Kuttappan et al., 2012a). Other studies concluded similar results that indicated fat content increases as striation severity becomes more severe (Kuttappan et al., 2013c; Petracci et al., 2014). Petracci et al. (2014) demonstrated the negative correlation between white striation severity and protein content of breast fillets. It was explained that as the muscle loses protein, fat replaces it, appearing as white striations (Kuttappan et al., 2013c). The conclusion was that increased energy signifies higher striping severity seems rational, since energy is a product of fat and is used to fuel the bird (Petracci et al., 2014).

Correlation Between Fillet Thickness and Striping Severity

Many studies have indicated a positive correlation exists between breast fillet weight and striping severity (Bauermeister et al., 2011; Kuttappan et al., 2012a; Kuttappan et al., 2013a; Kuttappan et al., 2013b). Kuttappan et al. (2013a) and Brewer et al. (2012) observed similar results, in that a significant relationship is present between fillet thickness and severity of striations. Fillet thickness is determined by measurements taken from the thickest portion of the cranial region, referring to the area where a wing would attach.

Kuttappan et al. (2013a) proposed the possibility that increased breast thickness raises stress levels within a broiler, causing severe muscle damage. Libritz (1997)

explained that cranial thickness is significantly correlated to fillet weight, when evaluating length and width. Regardless of strain, the thicker the cranial region on a breast fillet, the greater the probability that higher degrees of white striations are present (Kuttappan et al., 2013a). These results support the findings that broiler body weight influences striation severity in breasts. Heavier birds would indicate larger, thicker breast fillets, therefore the presence of more severe striations.

Relationship of pH and Colorimeter Values on Striping Severity

Several studies have evaluated the relationship colorimeter and pH values have with the severity of white striations in breast fillets. Data demonstrated yellowness (b^*) colorimeter measurements are significantly correlated to striation severity (Kuttappan et al., 2009; Kuttappan et al., 2012c; Kuttappan et al., 2013a; Petracci et al., 2013). As striping severity increases, yellowness (b^*) values also increase, indicating a positive correlation (Kuttappan et al., 2009; Kuttappan et al., 2013a). Petracci et al. (2013) found that striping severity significantly correlated to redness (a^*) and yellowness (b^*) colorimeter values, but not with lightness (L^*) values. The idea was that yellowness (b^*) values were greater in severely striped fillets due to the presence of increased levels of fat content (Kuttappan et al., 2012c).

Boulianne and King (1998) presented work showing that darker breast fillets have higher pH values than lighter fillets. In relation to striping, data suggested pH values are significantly higher in severely striped breast fillets than the pH of normal or moderately striped fillets (Petracci et al., 2013). In contrast, other studies found no significant

correlations between pH and striping severity (Kuttappan et al., 2009; Kuttappan et al., 2013a).

Relationship of Shear Force Values and Striping Severity

Fillet texture is important to quality and effects consumer purchases. Consumers highly value certain characteristics of meat including visual appearance, texture, and shelf life. The increased fat content that accompanies the presence of white striations is assumed to influence tenderness and texture of the meat (Kuttappan et al., 2012c). Meat tenderness is measured using shear force values, a popular method to compare tenderness differences (Lyon and Lyon, 1990). Petracci et al. (2013) found that higher the shear force values are related to increased striping severity. These results could have severe negative consequences to consumer purchases, being that tenderness is important to buyers. Less tender meat may decrease consumer attraction to poultry products and cause economic losses.

White Striations Effecting Cooking Loss

White striations not only affect visual appearance, they alter meat quality parameters. Cooking losses occur from increased lipidosis and fibrosis with the meat that is affected by white striations (Kuttappan et al., 2013a). Petracci et al. (2013) suggested that increased striping severity is accompanied by greater cooking losses and a lower overall yield. It was also found that increased striping severity leads to decreased marinade uptake (Petracci et al., 2013). The idea is that striations cause the muscle to lose its binding ability and have difficulty holding water during marinating (Petracci et al.,

2013). Although correlations between striping severity and cook loss were found, contrasting data suggesting no relationship makes it difficult to find a conclusion (Kuttappan et al., 2009; Kuttappan et al., 2013a).

Relationship of Collagen Values and White Striation Severity

Collagen, the main protein in muscles, is the major component of connective tissue (Warriss, 2000). Research has found that collagen levels rise as growth rate increases, and high-energy diets boost the deposit of insoluble collagen within the muscle (Roy et al., 2006). Birds exhibiting higher degrees of striping severity have higher ratios of collagen to total protein, attributed to low digestibility of collagen within the connective tissues (Petracci et al., 2014). The positive relationship between collagen and striation severity may be due to histological changes that occur within meat caused by white striations (Petracci et al., 2014). Such changes in nutritional characteristics may become a problem to the industry in labeling or marketing strategies claiming low fat and low calories.

Relationship of Lipid Content and White Striation Severity

In a study on consumer acceptance, it was indicated that striations are viewed as higher fat content within meat by consumers (Kuttappan et al., 2012c). Therefore, it is important to evaluate the relationship between striping severity and lipid content. Recent studies demonstrated that higher degrees of striation severity are correlated to higher fat and protein contents (Kuttappan et al., 2012a; Petracci et al., 2014). Breasts contained more calories than fillets not as heavily affected by striations. These results can cause

tremendous losses within the poultry industry, as a main attraction for consumers are the healthier, low-fat option poultry gives them (Kuttappan et al., 2012a).

Higher fat content may be caused by increased lipogenesis in the liver or hyperplasia of adipocytes causing increased fat circulation in the muscle (Kuttappan et al., 2012a). Hermier et al. (1989) suggested that enhanced lipoprotein lipase causes hyperplasia of adipocytes that results in increased fat uptake. Petracci et al. (2014) supports this idea by showing increased lipid content in fillets of higher striping severity. A negative correlation between striping severity and protein content of meat was found (Kuttappan et al., 2012a). When protein level decreases, more space is available for adipocytes expansion, possibly explaining the increase in fat of severely striped broilers.

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CHAPTER 3

THE INFLUENCES OF BROILER STRAIN, GENDER, AND DIETARY FACTORS ON THE INCIDENCE AND SEVERITY OF BREAST MUSCLE STRIATIONS

Abstract

A study was conducted to evaluate whether white striations on the surface of broiler breast fillets are related to broiler strain, gender, fat quality, or trace nutrient levels, and the relationship white striations have with broiler live, carcass, and parts weights. Two modern broiler strains (M1 and M2) and a 1990's Randombred strain (RB) were compared. There were 4 dietary treatments differing in fat quality and supplemental trace nutrient levels. Broilers were processed on day 41 and breast fillets scored for striation severity based on a 0 – 4 scale. Scores 0 – 4 indicated no, slight, moderate, considerable, and severe striations, respectively.

No visible white striations were present in 85.9% of RB broilers, and the remaining 14.1% scored a 1 indicating only slight striations. The modern strains exhibited all levels of striation severity. Moderate and severe striping occurred in 15.2% of M1 and 21.4% of M2 broilers. Strain ($p < 0.001$) and gender ($p = 0.035$) were significant contributors to white striation severity. An analysis of covariance was used to compensate for live differences weight between genders and results indicated gender remained significant to striation severity. Therefore, the observed differences in gender were not merely a manifestation of differences in live weight. Male broilers displayed significantly greater ($p < 0.001$) striation severity on breast fillets than females of the same

age and weight. Modern broiler strains had significantly higher striation scores, and there were positive correlations between striation severity and carcass weight in females from the 1990's RB and one modern broiler strain.

Introduction

Vertical integration, technological advancements, and genetic improvements allowed the poultry industry to meet the rapid increase in consumer demand throughout recent decades. Genetic modifications are accredited with 85-90% of the industry's improvements to the modern broiler strain, carefully selecting desired heritable traits to be passed on (Havenstein et al., 2003). Boneless, skinless breast fillets are most popular to consumers, moving the industry to production of heavy, high yield broilers (Owens, 2014). Havenstein et al. (2003) observed broilers reach double market weight in half the time it required 50 years ago. More than 50% of U.S. poultry sales are currently in the big bird market (broilers > 6 lbs), 20% of which weigh >7.5 lbs (Owens, 2014).

The rising demand for further processed products made visual appearance and quality control essential factors to consumer acceptance. Approximately, 65% of sales in the USA are boneless, skinless breast fillets, giving customers the ability to closely inspect products for visual defects prior to purchasing (Duclos et al., 2007; Kuttappan et al., 2012c) opposed to earlier eras when live birds were marketed.

White striations on the surface of broiler breast fillets are a growing concern within the industry (Kuttappan et al., 2013c). Predominately affecting breast fillets, striations might also develop on thighs and tenders. With increasing prevalence, striations continue to increase in severity, ranging from very mild to extremely prominent. They

run parallel to fibers within the pectoralis major, and appear at higher concentrations in the cranial end of the fillet (Petracci and Cavani, 2012; Owens, 2014). Overall factors causing striping remains unknown, but they are linked to muscle degeneration and myopathies (Kuttappan et al., 2009). Kuttappan et al. (2013a) found striping to be an indication of severe muscle damage.

Numerous studies have proposed that white striping is associated with the rapid growth rates in modern broiler strains (Dransfield and Sosnicki, 1999; Ferreira et al., 2010; Bauermeister et al., 2011). When the muscle mass rapidly increases, tissues stretch beyond their limits and result in inadequate blood supply to the muscle (Kuttappan et al., 2013c). Once damaged, a muscle attempts to repair the striations itself. Superficially, white striations in modern broilers are similar to striations that occur from dietary deficiencies of Vitamin E, Selenium, or Cystine (Machlin and Shalkop, 1956; Nesheim et al., 1959; Klasing, 2008). Contrasting data explains similarities and differences between the two conditions (Klasing, 2008; Kuttappan et al., 2012b; Kuttappan et al., 2013a).

In 2009, 55.75% of broiler breast fillets exhibited white striations in some degree of severity (Kuttappan et al., 2009). By 2012, the incidence rate had risen to 85.45% of breasts being affected by striations to some degree (Kuttappan et al., 2012b). Currently, the severity of striping has increased and 75% of fillets exhibit very serious striations that are moderate or severe (Owens, 2014). Kuttappan et al. (2012c) demonstrated that 50% of consumers decline purchase of moderate or severely striped fillets. The objectives of this study were to test the hypotheses that 1) The influence of body weight on striping is not dependent on gender; 2) The incidence of striping is dependent on genetics independent of body weight; 3) The incidence of striping is related to parts weights, as

well as body weights; 4) The incidence of striping is dependent on dietary rancidity; and 5) The incidence of striping is dependent on trace nutrient levels in the feed.

Materials and Methods

There were 3 broiler strains used in this study; 2 modern (M1 and M2) and 1 1990's randombred strain (RB). A total of 1,120 straight run, 1-d-old chicks were placed, which included 480 of each modern strain and 160 RB chicks. Chicks were randomly distributed by strain into 48 floor pens, split between 2 window-less rooms. Thirty M1 and M2 chicks were placed in each 1.22 x 3.05 m pen and 10 RB chicks were placed in each 1.22 x 1.52 m pen. The rooms were environmentally controlled to maintain uniform conditions. The initial temperature 1 - 3 d was 90 - 93° C, and reduced 1° C each day until 75° C was achieved. Lighting was from 27 Paragon EC40005 incandescent light fixtures providing lighting levels on floor of 0 - 2 foot candles. Approximately 0.6 meters of clean pine shavings were spread throughout the floor of each pen. There were 1 hanging feeder and 10 nipple drinkers per pen. There were 4 dietary treatments (Tables 3.1 and 3.2), 3 broiler strains, and 48 pens. Each dietary treatment was replicated in 12 pens, within which there were 4 replicate pens of each broiler strain.

Weights and feed conversion ratios (FCR) were determined by pen on days 0, 18, and 40. All mortalities and/or culled birds were weighed and recorded, including any obvious cause of death. FCR was reported as total feed consumed/total weight of birds produced.

Dietary Treatments

There were 4 dietary treatments with a 2 x 2 factorial design; each based on an industry corn and soybean diet (Tables 3.1 and 3.2) either normal or oxidized fat, and standard or doubled vitamin/trace mineral mix.

Oxidizing Poultry Fat

One hundred kg of standard poultry fat was poured into a Legion Steam Jacketed Kettle equipped with a Campbell Hausfeld 26 gallon air system running at 5 HP, 15 amps, and 6.8 at 90 PSI. The kettle was fitted with 2 m of 1 cm copper tubing with 47 - 10 mm holes. Air was pumped through the fat at 10 L/min for 107 hours, 66 hours at 20°C and 51 hours at 98-105°C.

Processing of Birds

At day 7, 10 birds were randomly selected from each pen and fitted with wing tags with identification numbers. On d 41, 3 male and 3 female tagged birds were randomly selected, weighed live, immediately following evisceration (pre-chill) and after carcasses were iced at 1°C for 240 min (post-chill). Carcasses were subsequently deboned at 4.5 h postmortem. The breast fillets of each bird were scored on a 0 – 4 scale for the severity of white striations present (Figures 3.1, 3.2, and 3.3).

Striation Scores

Breast striation scores were based on a 5-point scale. Scores 0 – 4 indicated the presence of no striations, slight, moderate, considerable, and severe striations, respectively (Figure 3.1, 3.2, and 3.3).

Statistical Analysis

Data was subjected to ANOVA testing on the main effects of white striping, as well as interaction terms, using the general linear model (GLM) (SAS Institute, Inc.). The independent variables were strain, gender, fat quality, and trace nutrient level. An analysis of covariance, live weight as the covariant, was performed accounting for gender weight differences in the relationship to white striations. ANOVA was conducted on the weight gain and feed conversion ratio, using GLM, to evaluate differences between the independent variables and their interactions. Means and standard deviations were analyzed using ANOVA with $p < 0.05$ considered significant. Data was considered by pen as the experimental unit for the entire analysis.

Results

The FCR of RB broilers (1.83 g:g) exceeded that of modern strains, M1 (1.54 g:g) and M2 (1.53 g:g; Table 3.3). Modern broilers gained significantly ($p < 0.001$) more body weight (BWG) than the 1990's RB broilers (Table 3.4). Over the 40 d grow out period, modern broiler strains gained an average of 1.03 kg more than RB broilers (Table 3.5).

Factors significantly related to white striations were strain ($p < 0.001$), gender ($p = 0.035$), and the interaction of strain, gender, and diet ($p = 0.048$; Table 3.6). When live

weight differences between genders were accounted for, gender remained significantly ($p=0.035$) related to white striations (Table 3.7). At d 41, male broilers were an average of 0.39kg heavier than females (Table 3.8 and 3.9). Striation severity in the breast fillets of male broilers (1.095) was significantly more severe than found in female broilers (0.797; Figure 3.4).

Strain significantly affected the prevalence and severity of white striations in modern broiler strains compared to RB broilers (Figure 3.5). No visual striations were present in the breast fillets of 85.9% of RB broilers, while the remaining RB birds were affected at the mildest degree (Score 1; Figure 3.6). Both modern strains demonstrated varied levels of striations, 25% of M1 and 44% of M2 scored a 2 or higher (Figure 3.6). Strain remained significantly related to white striping ($p<0.001$) once live weight was accounted for (Table 3.7). M2 broilers exhibited the most severe striations and the heaviest body weight (Figure 3.7). Figure 3.8 shows the dramatic increase in the striping severity of M1 broilers once they reach a certain weight.

A significant relationship was present between broiler live weight and white striation severity (Table 3.7). The live weight of modern broilers was higher than RB broilers, with similar trends appearing in carcass and parts weight (Table 3.9, 3.10, and 3.11). Breast fillets were heaviest in M2 broilers, who demonstrated the highest live weight and most severe white striations (Figure 3.8). RB broilers had the lightest breast fillets and displayed the lowest level of striping severity (Figure 3.8).

Fat quality and vitamin/trace mineral mix were significantly related to the prevalence and severity of white striations (Table 3.6). There was a significant

relationship ($p=0.048$) between white striping and the interaction of strain, gender, and diet (Table 3.6). The possibility remains that it may, however, be due to chance.

Discussion

The performance objectives of modern broilers, M1 and M2, exceeded those in their breeder management guides. The FCR of M1 and M2 broilers were lower than those specified for the strain in the breeder performance standards. The FCR of RB broilers was significantly higher than modern broilers; supporting previous research on advancements the industry has made by lowering the FCR throughout recent decades (Anthony, 1998).

The results (Table 3.7) indicated the null hypothesis that body weight and gender independently affect striping should be accepted. Brewer et al. (2012) described the conformational differences in male versus female broilers and these may relate to differences in striping severity due to gender. Since gender remained significant to white striations incidence and severity after accounting for gender weight differences, the gender effect was not a manifestation of differences in live weight (Table 3.7). Results showing the higher striping severity in male broilers compared to females (Figure 3.4) supports previous studies concluding that males have increased prevalence and severity (Kuttappan et al., 2013a; Owens, 2014). The statistical tests that indicated significant gender differences was vague.

The data (Table 3.6) indicated the null hypothesis that striping is dependent on genetics, independent of body weight, should be accepted. Previous research found significant correlations between broiler strain and white striping, but indicated

differences in live weight between strains may be the overall determining factor (Bauermeister et al., 2011). It has been concluded that intense genetic selection allowed modern broilers to have exceedingly fast growth rates (Anthony, 1998; Havenstein et al., 2003). Modern strains are specifically selected for a low FCR, while maintaining very accelerated growth rates that produce the maximum yield in a minimal grow out time (Barbut et al., 2007). This study demonstrated that strain remained a significant contributor ($p < 0.001$) to the variation in white striations once live weight was accounted for (Table 3.7). The striation severity of modern broilers was 9X higher than found in RB strain fillets (Figure 3.5). Owens (2014) described the rising prevalence that white striping has undergone in past decades.

The results (Table 3.7) demonstrate the hypothesis that the incidence of striping is related to parts weights, as well as body weights, should be accepted. Past research has shown positive correlations exist between live weight and striping severity (Bauermeister et al., 2011; Kuttappan et al., 2012a; Kuttappan et al., 2013a; Kuttappan et al., 2013b). The predominant theory is the capillary system in the muscle tissues cannot support the requirements of such rapid growth rates, which leads to severe muscle damage appearing as white striations (Mahon, 1999). Kuttappan et al. (2013a) proposed the thicker, heavier fillets cause increased stress levels in the bird, resulting in severe muscle damage. Results of this study support previous research showing the positive relationship between white striping and live weight (Figure 3.7).

Results (Table 3.6) demonstrated the hypothesis that the incidence of striping is dependent on dietary rancidity or trace nutrient level should be rejected. They are, at least, not large contributors to any variations in striping and not practically important.

Kuttappan et al. (2013a) found myopathies in the breast fillets of birds consuming diets deficient in vitamin E. Similar myopathies accompany a condition called nutritional muscular dystrophy, that are superficially like modern white breast striations (Kuttappan et al., 2012b; Kuttappan et al., 2013a). Further investigation on the two conditions determined they have different etiologies and dissimilar histology (Kuttappan et al., 2012b). There were some indications, in this study, that fat quality or vitamin/trace mineral level were significant to white striations, but the magnitude was very small. Kuttappan et al. (2013a) and Petracci et al. (2013) also found no significant dietary effects to white breast striations, only that dietary changes cause differences in growth rates.

Conclusion

Modern, fast growing broiler strains displayed higher incidences of white striations at greater severity than 1990's RB broilers. Gender remained a significant contributor to variation in white striations even after live weight differences between genders were accounted for. Male broilers were more severely affected by white striations than female broilers. This study demonstrated a significant positive relationship between broiler body weight and white striations. Although TN and fat quality may have been significant to striping variation, by showing a significant interaction, their effects were very small.

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Table 3.1. Composition of starter diets (0 - 17 d) with differing levels of vitamin/trace nutrient mix, standard (1 x) or doubled (2 x), and fat quality, normal or oxidized.

Fat Quality	Normal	Oxidized	Normal	Oxidized
Trace Nutrient Level	1x	1x	2x	2x
Ingredient	-----%-----			
Ground yellow corn	51.36	51.36	51.36	51.36
Soybean meal (dehulled)	39.20	39.20	39.20	39.20
Standard poultry fat	6.013	0.000	6.013	0.000
Oxidized poultry fat	0.000	6.013	0.000	6.013
Salt	0.400	0.400	0.400	0.400
L-Lysine HCl	0.175	0.175	0.175	0.175
DL-Methionine	0.307	0.307	0.307	0.307
L-Threonine	0.063	0.063	0.063	0.063
Limestone	0.175	0.175	0.175	0.175
Defluorinated P	1.882	1.882	1.882	1.882
Vitamin Mix ¹	0.250	0.250	0.500	0.500
Trace Mineral Mix ²	0.075	0.075	0.150	0.150
Coban ³	0.050	0.050	0.050	0.050
BMD ⁴	0.050	0.050	0.050	0.050

¹Vitamin mix provided the following (per kilogram of diet): thiamin-mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B₁₂ (cobalamin), 12.0g; pyridoxine-HCl, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-reinyl acetate, 2,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

²Trace mineral mix provides the following (per kilogram of diet): manganese (MnSO₄.H₂O), 101 mg; iron (FeSO₄.7H₂O), 20 mg; zinc (Zn), 80 mg; copper (CuSO₄.5H₂O), 3 mg; iodine (ethylene diamine dihydroiodide), 0.75 mg; magnesium (MgO), 20 mg; selenium (sodium selenite), 0.3 mg.

³Coban (Type A) provides (per pound of diet): Monensin, USP 90.7g; aids in prevention of coccidiosis.

⁴BMD (Bacitracin Methylene Disalicylate - Type A) provides (per pound of diet): feed grade bacitracin methylene disalicylate equivalent to 50 g bacitracin.

Table 3.2. Composition of grower diets (18 - 41 d) with differing levels of vitamin/trace nutrient mix, standard (1 x) or doubled (2 x), and fat quality, normal or oxidized.

Fat Quality	Normal	Oxidized	Normal	Oxidized
Trace Nutrient Level	1x	1x	2x	2x
Ingredient	-----%-----			
Ground yellow corn	55.74	55.74	55.74	55.74
Soybean meal (dehulled)	35.20	35.20	35.20	35.20
Standard poultry fat	5.900	0.000	5.900	0.000
Oxidized poultry fat	0.000	5.900	0.000	5.900
Salt	0.400	0.400	0.400	0.400
L-Lysine HCl	0.148	0.148	0.148	0.148
DL-Methionine	0.267	0.267	0.267	0.267
L-Threonine	0.041	0.041	0.041	0.041
Limestone	0.197	0.197	0.197	0.197
Defluorinated P	1.679	1.679	1.679	1.679
Vitamin Mix ¹	0.250	0.250	0.500	0.500
Trace Mineral Mix ²	0.075	0.075	0.150	0.150
Coban ³	0.050	0.050	0.050	0.050
BMD ⁴	0.050	0.050	0.050	0.050

¹Vitamin mix provided the following (per kilogram of diet): thiamin-mono-nitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B₁₂ (cobalamin), 12.0g; pyridoxine-HCl, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-reinyl acetate, 2,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

²Trace mineral mix provides the following (per kilogram of diet): manganese (MnSO₄.H₂O), 101 mg; iron (FeSO₄.7H₂O), 20 mg; zinc (Zn), 80 mg; copper (CuSO₄.5H₂O), 3 mg; iodine (ethylene diamine dihydroiodide), 0.75 mg; magnesium (MgO), 20 mg; selenium (sodium selenite), 0.3 mg.

³Coban (Type A) provides (per pound of diet): Monensin, USP 90.7g; aids in prevention of coccidiosis.

⁴BMD (Bacitracin Methylene Disalicylate - Type A) provides (per pound of diet): feed grade bacitracin methylene disalicylate equivalent to 50 g bacitracin.

Table 3.3. Effects of feed conversion ratio (FCR) on strain and diet during days 0 - 18, 18 - 40, and 0 - 40.

Source	df	FCR (g•g) Days 0 - 18	FCR (g•g) Days 18 - 40	FCR (g•g) Days 0 - 40
		Pr > F	Pr > F	Pr > F
Strain ¹	2	0.412	<0.001	<0.001
Fat ²	1	0.475	0.312	0.767
Strain*Fat	2	0.119	0.960	0.589
TN ³	1	0.938	0.182	0.331
Strain*TN	2	0.637	0.397	0.367
Fat*TN	1	0.639	0.517	0.480
Strain*Fat*TN	2	0.568	0.099	0.188
R-Square		0.203	0.632	0.550

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, either standard or doubled

Table 3.4. Analysis of Variance in effects of strain and diet on body weight gain (BW G) during days 0 - 18, 18 - 40, and 0 - 40.

Source	df	BWG (kg) Days 0 - 18	BWG (kg) Days 18 - 40	BWG (kg) Days 0 – 40
		Pr > F	Pr > F	Pr > F
Strain ¹	2	<0.001	<0.001	<0.001
Fat ²	1	0.623	0.077	0.098
Strain*Fat	2	0.396	0.760	0.876
TN ³	1	1.000	0.083	0.085
Strain*TN	2	0.524	0.945	0.935
Fat*TN	1	0.071	0.109	0.173
Strain*Fat*TN	2	0.966	0.098	0.096
R-Square		0.965	0.902	0.935

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix, either standard (1 x) or doubled (2 x)

Table 3.5. Effects of strain and diet on the body weight gain (BW G) and feed conversion ratio (FCR) at days 0 – 18, 18 – 40, and 0 – 40. Mean \pm Standard Error.

Strain ¹	Trace Nutrients ²	Fat Quality ³	n	Body Weight Gain (kg)			Feed Conversion Ratio (g:g)		
				0-18 d	18-40 d	0-40 d	0-18 d	18-40 d	0-40 d
RB	1 \times	Normal	4	0.44 \pm 0.02	1.25 \pm 0.15	1.69 \pm 0.17	1.43 \pm 0.08	1.95 \pm 0.10	1.83 \pm 0.09
RB	1 \times	Oxidized	4	0.45 \pm 0.02	1.27 \pm 0.10	1.72 \pm 0.11	1.43 \pm 0.18	1.92 \pm 0.15	1.79 \pm 0.09
RB	2 \times	Normal	4	0.46 \pm 0.02	1.37 \pm 0.14	1.82 \pm 0.16	1.47 \pm 0.10	1.87 \pm 0.19	1.79 \pm 0.16
RB	2 \times	Oxidized	4	0.43 \pm 0.03	1.27 \pm 0.18	1.70 \pm 0.20	1.59 \pm 0.16	2.03 \pm 0.28	1.92 \pm 0.20
M1	1 \times	Normal	4	0.67 \pm 0.01	2.20 \pm 0.08	2.86 \pm 0.08	1.26 \pm 0.01	1.60 \pm 0.04	1.52 \pm 0.03
M1	1 \times	Oxidized	4	0.69 \pm 0.03	1.96 \pm 0.33	2.65 \pm 0.30	1.52 \pm 0.57	1.67 \pm 0.28	1.64 \pm 0.36
M1	2 \times	Normal	4	0.69 \pm 0.02	2.16 \pm 0.08	2.84 \pm 0.07	1.32 \pm 0.11	1.56 \pm 0.08	1.51 \pm 0.09
M1	2 \times	Oxidized	4	0.69 \pm 0.04	2.17 \pm 0.10	2.86 \pm 0.12	1.23 \pm 0.02	1.57 \pm 0.11	1.49 \pm 0.08
M2	1 \times	Normal	4	0.64 \pm 0.02	2.15 \pm 0.06	2.79 \pm 0.06	1.57 \pm 0.59	1.54 \pm 0.02	1.55 \pm 0.12
M2	1 \times	Oxidized	4	0.66 \pm 0.02	1.92 \pm 0.19	2.57 \pm 0.19	1.25 \pm 0.02	1.74 \pm 0.17	1.62 \pm 0.12
M2	2 \times	Normal	4	0.64 \pm 0.01	2.09 \pm 0.09	2.73 \pm 0.10	1.59 \pm 0.65	1.56 \pm 0.11	1.57 \pm 0.18
M2	2 \times	Oxidized	4	0.64 \pm 0.02	2.16 \pm 0.05	2.79 \pm 0.06	1.24 \pm 0.02	1.44 \pm 0.19	1.40 \pm 0.14
RB			8	0.44 \pm 0.02	1.29 \pm 0.14	1.73 \pm 0.16	1.48 \pm 0.14	1.94 \pm 0.18	1.83 \pm 0.14
M1			8	0.68 \pm 0.03	2.12 \pm 0.19	2.80 \pm 0.18	1.33 \pm 0.28	1.60 \pm 0.15	1.54 \pm 0.18
M2			8	0.65 \pm 0.02	2.08 \pm 0.14	2.72 \pm 0.14	1.41 \pm 0.43	1.57 \pm 0.17	1.53 \pm 0.15
	1 \times		12	0.59 \pm 0.11	1.79 \pm 0.43	2.38 \pm 0.52	1.41 \pm 0.33	1.73 \pm 0.21	1.66 \pm 0.19
	2 \times		12	0.59 \pm 0.11	1.87 \pm 0.41	2.46 \pm 0.52	1.40 \pm 0.29	1.67 \pm 0.26	1.61 \pm 0.23
		Normal	12	0.59 \pm 0.10	1.87 \pm 0.42	2.45 \pm 0.52	1.44 \pm 0.35	1.68 \pm 0.19	1.63 \pm 0.17
		Oxidized	12	0.59 \pm 0.12	1.79 \pm 0.42	2.38 \pm 0.52	1.37 \pm 0.27	1.73 \pm 0.27	1.64 \pm 0.24

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrients = Level of vitamin/trace mineral mix, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

Table 3.6. General Linear Model (GLM) for the effect of strain, gender, fat, trace nutrient supplementation (TN), and all interactions on white striations in broiler breast fillets.

Source	df	Pr > F
		Type III
Strain ¹	2	<0.001
Gender	1	0.035
Strain*Gender	2	0.074
Fat ²	1	0.357
Strain*Fat	2	0.577
Gender*Fat	1	0.617
Strain*Gender*Fat	2	0.061
TN ³	1	0.883
Strain*TN	2	0.853
Gender*TN	1	0.938
Strain*Gender*TN	2	0.946
Fat*TN	1	0.255
Strain*Fat*TN	2	0.386
Gender*Fat*TN	1	0.748
Strain*Gender*Fat*TN	2	0.048
R-Square = 0.599		

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, either standard (1 x) or doubled (2 x)

Table 3.7. Analysis of Covariance, using live weight as the covariant, on the effects of strain, gender, and their interactions on white striations in broiler breast fillets.

Source	df	Pr > F
		Type III
Strain	2	<0.001
Gender	1	0.035
Strain*Gender	2	0.073
Live Weight	1	0.001
R-Square = 0.498		

Table 3.8. Effect of strain, gender, fat quality, and trace nutrient supplementation on the live, unchilled carcass, and chilled carcass weights of broilers. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Live Weight (kg)	Carcass Weight (kg)	
						Unchilled	Chilled
RB	1 \times	Normal	Male	4	1.94 \pm 0.03	1.35 \pm 0.03	1.41 \pm 0.03
RB	1 \times	Normal	Female	4	1.59 \pm 0.12	1.10 \pm 0.08	1.15 \pm 0.08
RB	1 \times	Oxidized	Male	4	1.91 \pm 0.10	1.33 \pm 0.08	1.38 \pm 0.07
RB	1 \times	Oxidized	Female	4	1.61 \pm 0.05	1.12 \pm 0.05	1.17 \pm 0.06
RB	2 \times	Normal	Male	4	2.06 \pm 0.13	1.43 \pm 0.07	1.48 \pm 0.07
RB	2 \times	Normal	Female	4	1.60 \pm 0.12	1.11 \pm 0.07	1.17 \pm 0.07
RB	2 \times	Oxidized	Male	4	1.91 \pm 0.11	1.31 \pm 0.06	1.36 \pm 0.07
RB	2 \times	Oxidized	Female	4	1.63 \pm 0.04	1.11 \pm 0.04	1.16 \pm 0.04
M1	1 \times	Normal	Male	4	3.07 \pm 0.13	2.27 \pm 0.07	2.33 \pm 0.07
M1	1 \times	Normal	Female	4	2.67 \pm 0.15	1.97 \pm 0.14	2.06 \pm 0.18
M1	1 \times	Oxidized	Male	4	3.09 \pm 0.14	2.27 \pm 0.10	2.34 \pm 0.10
M1	1 \times	Oxidized	Female	4	2.63 \pm 0.19	1.95 \pm 0.12	2.01 \pm 0.13
M1	2 \times	Normal	Male	4	3.06 \pm 0.16	2.29 \pm 0.10	2.36 \pm 0.12
M1	2 \times	Normal	Female	4	2.70 \pm 0.10	2.00 \pm 0.11	2.05 \pm 0.11
M1	2 \times	Oxidized	Male	4	3.01 \pm 0.07	2.22 \pm 0.07	2.28 \pm 0.07
M1	2 \times	Oxidized	Female	4	2.61 \pm 0.09	1.92 \pm 0.07	2.01 \pm 0.07
M2	1 \times	Normal	Male	4	3.05 \pm 0.11	2.27 \pm 0.09	2.34 \pm 0.10
M2	1 \times	Normal	Female	4	2.55 \pm 0.09	1.90 \pm 0.07	1.98 \pm 0.07
M2	1 \times	Oxidized	Male	4	2.98 \pm 0.04	2.21 \pm 0.05	2.30 \pm 0.05
M2	1 \times	Oxidized	Female	4	2.71 \pm 0.07	1.91 \pm 0.06	1.98 \pm 0.06
M2	2 \times	Normal	Male	4	2.95 \pm 0.17	2.21 \pm 0.12	2.27 \pm 0.11
M2	2 \times	Normal	Female	4	2.64 \pm 0.30	1.96 \pm 0.23	2.01 \pm 0.22
M2	2 \times	Oxidized	Male	4	3.07 \pm 0.09	2.26 \pm 0.04	2.33 \pm 0.04
M2	2 \times	Oxidized	Female	4	2.62 \pm 0.30	1.94 \pm 0.24	1.99 \pm 0.25

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace nutrient mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

Table 3.9. Main effect means of broiler strain, gender, fat quality, and trace nutrient supplementation on live, unchilled carcass, and chilled carcass weights. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Live Weight (kg)	Carcass Weight (kg)	
						Unchilled	Chilled
RB				8	1.78 \pm 0.20	1.23 \pm 0.14	1.29 \pm 0.14
M1				8	2.85 \pm 0.24	2.11 \pm 0.18	2.18 \pm 0.18
M1				8	2.80 \pm 0.27	2.08 \pm 0.20	2.15 \pm 0.21
	1 \times			12	2.47 \pm 0.56	1.80 \pm 0.45	1.87 \pm 0.46
	2 \times			12	2.49 \pm 0.55	1.81 \pm 0.45	1.87 \pm 0.45
		Normal		12	2.49 \pm 0.55	1.82 \pm 0.45	1.88 \pm 0.45
		Oxidized		12	2.47 \pm 0.55	1.80 \pm 0.45	1.86 \pm 0.46
			Male	12	2.67 \pm 0.53	1.95 \pm 0.43	2.01 \pm 0.44
			Female	12	2.28 \pm 0.51	1.67 \pm 0.41	1.73 \pm 0.42

¹Strain = 1990's Rando-bred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace nutrient mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidize

Table 3.10. Effects of strain, gender, fat quality, and trace nutrient supplementation on the weight of broiler parts. Mean \pm Standard Error

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Parts Weight (kg)			
					Breasts	Wings	P. Minor	Back
RB	1 \times	Normal	Male	4	0.27 \pm 0.01	0.17 \pm 0.00	0.07 \pm 0.01	0.60 \pm 0.03
RB	1 \times	Normal	Female	4	0.21 \pm 0.02	0.14 \pm 0.01	0.06 \pm 0.00	0.49 \pm 0.04
RB	1 \times	Oxidized	Male	4	0.25 \pm 0.01	0.16 \pm 0.01	0.07 \pm 0.01	0.60 \pm 0.04
RB	1 \times	Oxidized	Female	4	0.22 \pm 0.03	0.14 \pm 0.02	0.06 \pm 0.00	0.54 \pm 0.06
RB	2 \times	Normal	Male	4	0.28 \pm 0.01	0.17 \pm 0.01	0.08 \pm 0.00	0.64 \pm 0.04
RB	2 \times	Normal	Female	4	0.22 \pm 0.01	0.14 \pm 0.01	0.06 \pm 0.00	0.48 \pm 0.06
RB	2 \times	Oxidized	Male	4	0.27 \pm 0.02	0.16 \pm 0.01	0.07 \pm 0.00	0.55 \pm 0.06
RB	2 \times	Oxidized	Female	4	0.22 \pm 0.01	0.13 \pm 0.01	0.06 \pm 0.00	0.48 \pm 0.03
M1	1 \times	Normal	Male	4	0.58 \pm 0.03	0.24 \pm 0.01	0.12 \pm 0.01	0.90 \pm 0.02
M1	1 \times	Normal	Female	4	0.49 \pm 0.04	0.20 \pm 0.01	0.11 \pm 0.00	0.77 \pm 0.03
M1	1 \times	Oxidized	Male	4	0.59 \pm 0.01	0.25 \pm 0.02	0.13 \pm 0.01	0.91 \pm 0.06
M1	1 \times	Oxidized	Female	4	0.50 \pm 0.03	0.21 \pm 0.03	0.11 \pm 0.02	0.81 \pm 0.10
M1	2 \times	Normal	Male	4	0.59 \pm 0.03	0.24 \pm 0.01	0.12 \pm 0.01	0.89 \pm 0.05
M1	2 \times	Normal	Female	4	0.51 \pm 0.04	0.20 \pm 0.01	0.12 \pm 0.00	0.78 \pm 0.05
M1	2 \times	Oxidized	Male	4	0.59 \pm 0.05	0.24 \pm 0.01	0.12 \pm 0.01	0.89 \pm 0.02
M1	2 \times	Oxidized	Female	4	0.51 \pm 0.04	0.20 \pm 0.01	0.12 \pm 0.01	0.77 \pm 0.03
M2	1 \times	Normal	Male	4	0.63 \pm 0.05	0.23 \pm 0.01	0.13 \pm 0.01	0.87 \pm 0.02
M2	1 \times	Normal	Female	4	0.54 \pm 0.02	0.19 \pm 0.01	0.12 \pm 0.01	0.74 \pm 0.02
M2	1 \times	Oxidized	Male	4	0.63 \pm 0.04	0.22 \pm 0.01	0.13 \pm 0.01	0.88 \pm 0.05
M2	1 \times	Oxidized	Female	4	0.53 \pm 0.04	0.19 \pm 0.01	0.11 \pm 0.01	0.73 \pm 0.06
M2	2 \times	Normal	Male	4	0.59 \pm 0.04	0.22 \pm 0.01	0.12 \pm 0.02	0.90 \pm 0.05
M2	2 \times	Normal	Female	4	0.54 \pm 0.05	0.21 \pm 0.03	0.12 \pm 0.02	0.77 \pm 0.16
M2	2 \times	Oxidized	Male	4	0.63 \pm 0.03	0.22 \pm 0.01	0.13 \pm 0.00	0.87 \pm 0.04
M2	2 \times	Oxidized	Female	4	0.55 \pm 0.08	0.19 \pm 0.03	0.12 \pm 0.02	0.76 \pm 0.15

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace mineral mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

Table 3.11. Main effect means of strain, gender, fat quality, and trace nutrient supplementation on the weight of broiler parts. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Parts Weights (kg)			
					Breast	Wings	P. Minor	Back
RB				8	0.24 \pm 0.03	0.15 \pm 0.02	0.07 \pm 0.01	0.55 \pm 0.07
M1				8	0.55 \pm 0.05	0.22 \pm 0.02	0.12 \pm 0.01	0.84 \pm 0.08
M2				8	0.58 \pm 0.06	0.21 \pm 0.02	0.12 \pm 0.01	0.82 \pm 0.10
	1 \times			12	0.45 \pm 0.16	0.19 \pm 0.04	0.10 \pm 0.03	0.74 \pm 0.16
	2 \times			12	0.46 \pm 0.20	0.19 \pm 0.04	0.10 \pm 0.03	0.72 \pm 0.17
		Normal		12	0.46 \pm 0.16	0.19 \pm 0.04	0.10 \pm 0.03	0.73 \pm 0.16
		Oxidized		12	0.46 \pm 0.16	0.19 \pm 0.04	0.10 \pm 0.03	0.73 \pm 0.16
			Male	12	0.49 \pm 0.16	0.21 \pm 0.04	0.11 \pm 0.03	0.79 \pm 0.15
			Female	12	0.42 \pm 0.15	0.18 \pm 0.03	0.10 \pm 0.03	0.67 \pm 0.15

¹Strain = 1990's Rando-bred Broilers, Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace nutrient mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

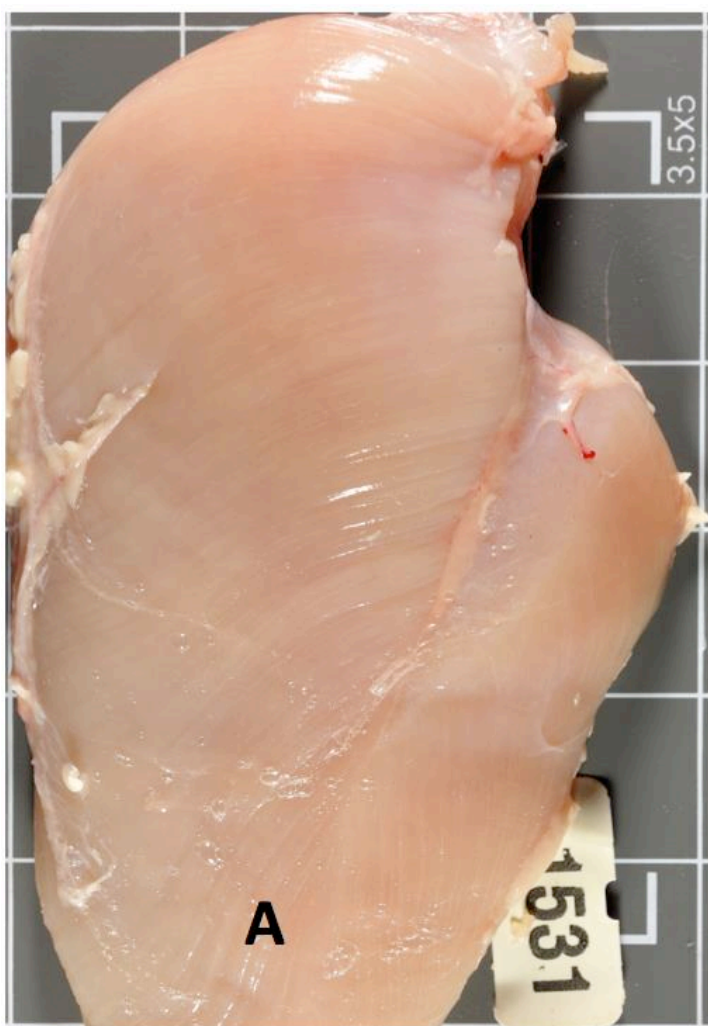


Figure 3.1. White Striation Scoring System: A) Score 0: Breast fillet has no visual white striations & B) Score 1: Breast fillet has thin lines of striping not covering the entire fillet.

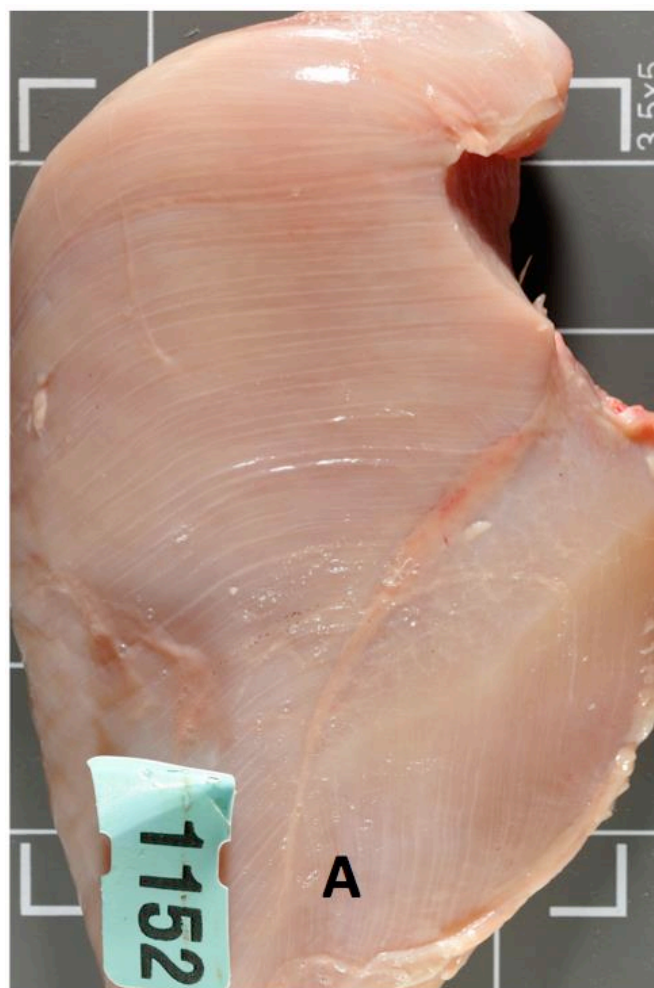


Figure 3.2. White Striation Scoring System: A) Score 2: Breast fillet with thin striations that cover the entire fillet or thin striations accompanied by <10 medium striations & B) Score 3: Breast fillet with medium striations covering the entire fillet and/or accompanied by <10 thick striations.



Figure 3.3. White Striation Scoring System: Score 4: Breast fillet with thick striations that cover throughout the fillet, considered an extreme case.

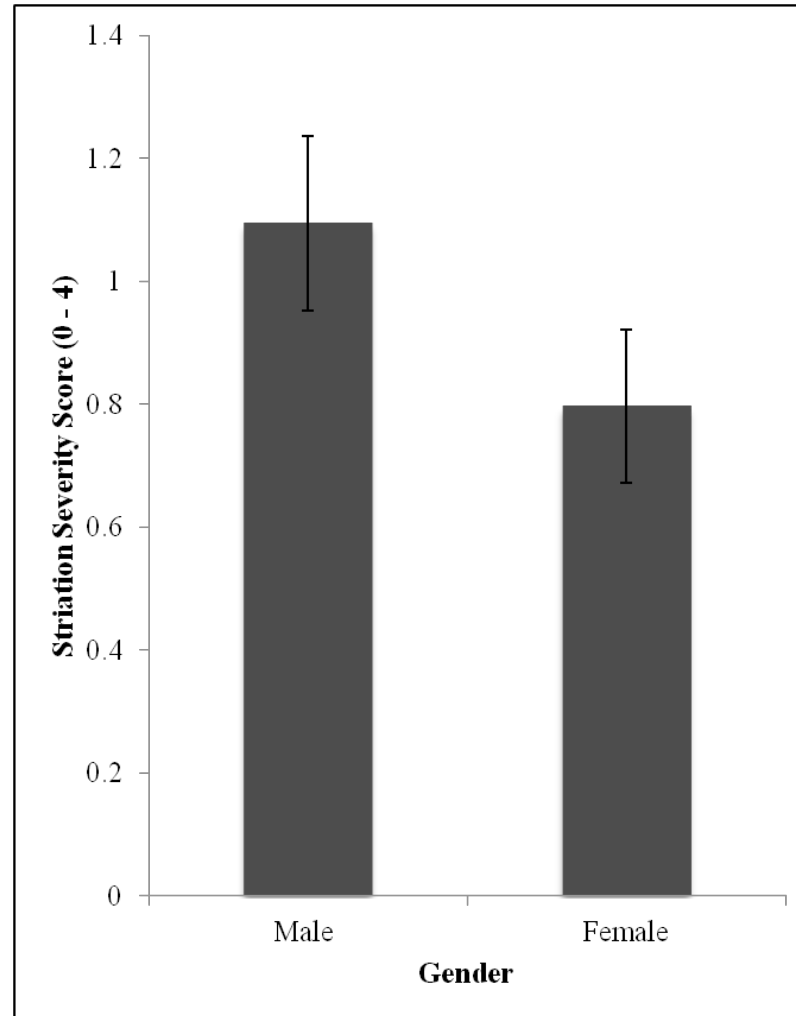


Figure 3.4. The average striation severity score (0-4) of male (1.095) versus female (0.797) broiler breast fillets.

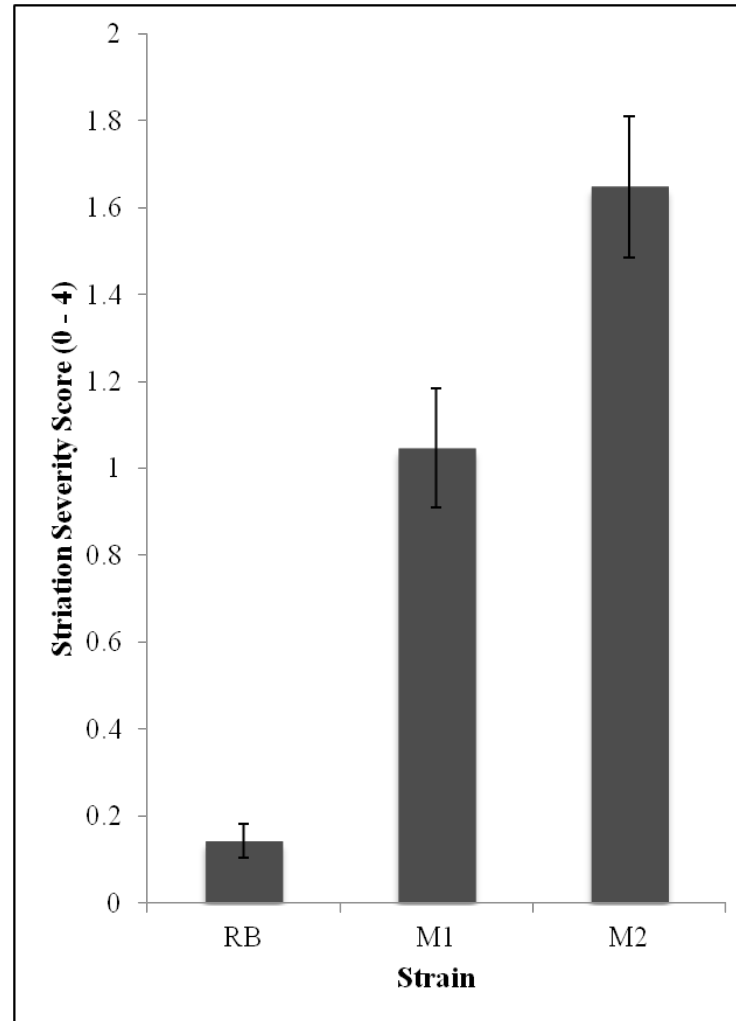


Figure 3.5. The average striation severity score (0–4) of M1 (1.05), M2 (1.65), and RB (0.14) of broiler breast fillets.

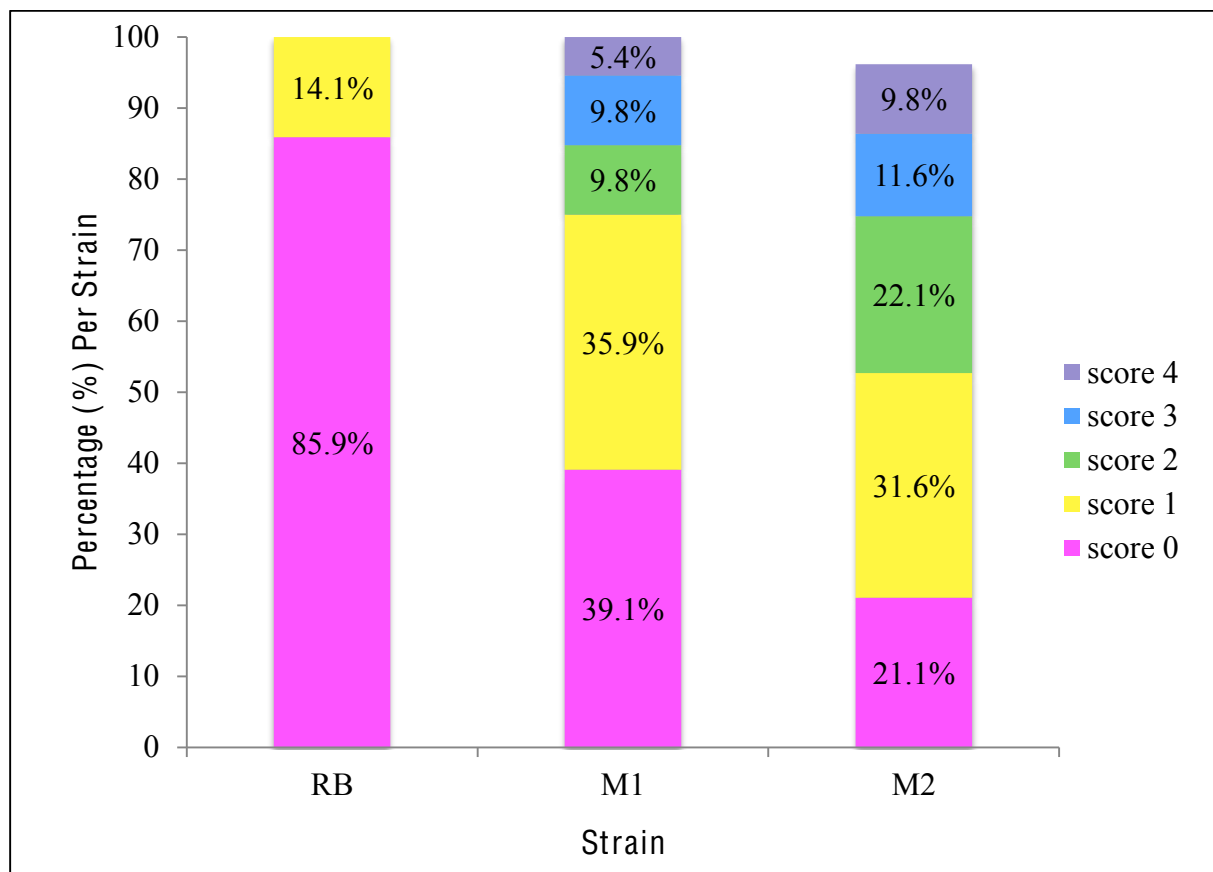


Figure 3.6. The percentage of each strain displaying each level (0 – 4) of striation severity.

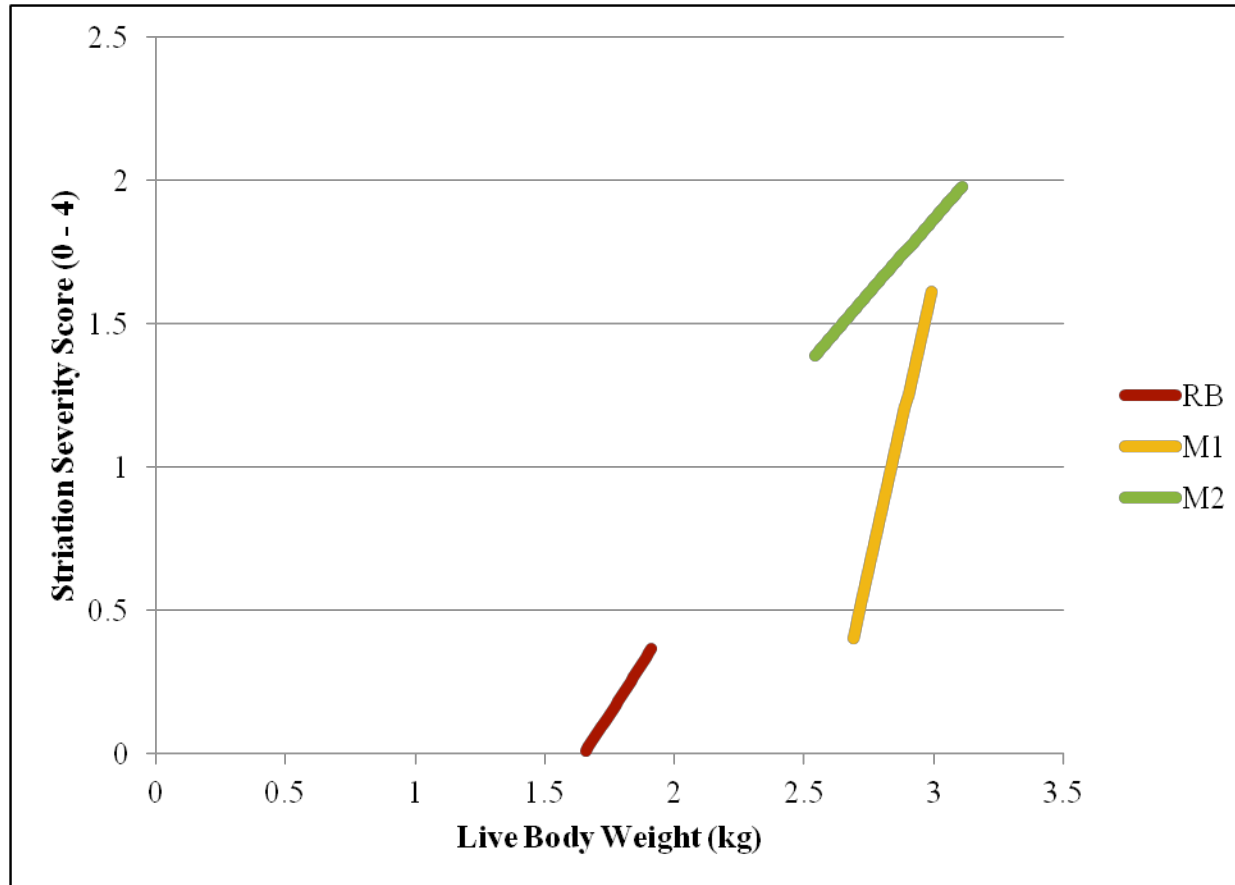


Figure 3.7. Striation severity score (0-4) in relation to broiler live weight (kg) by strain.

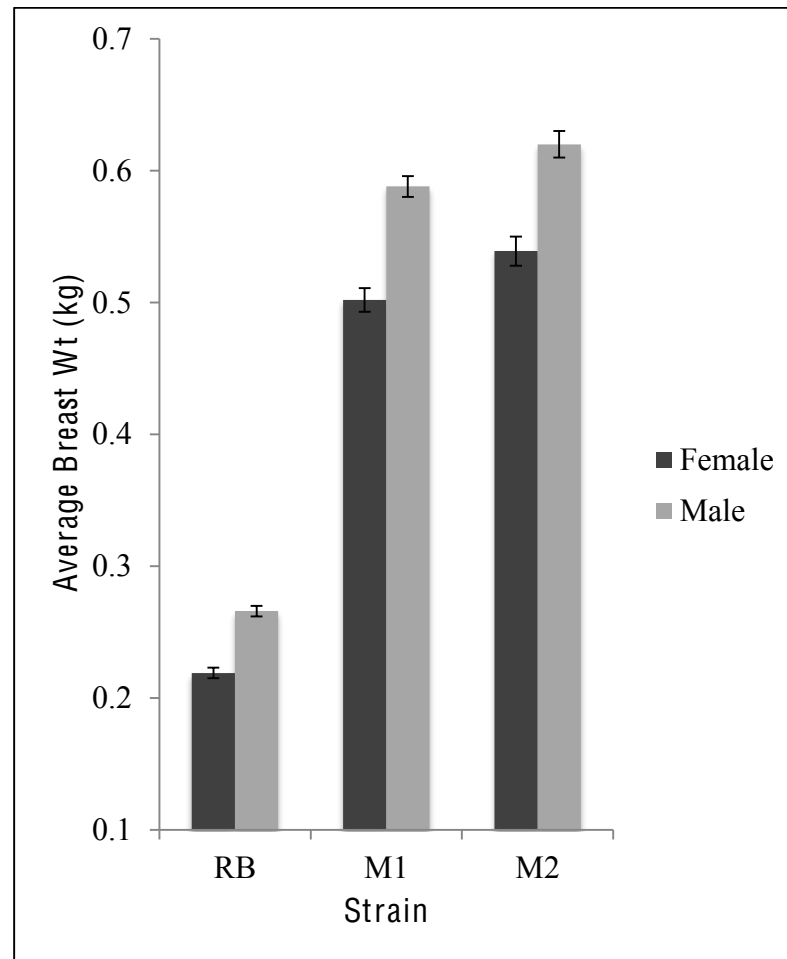


Figure 3.8. The average breast fillet weight (kg) by gender in each of the 3 broiler strains.

CHAPTER 4

AN INVESTIGATION OF THE CORRELATIONS BETWEEN WHITE STRIATIONS ON BROILER BREAST FILLETS AND COOKING PARAMETERS

Abstract

A study was conducted to determine whether correlations exist between white striations on broiler breast fillets and cooking parameters including cook loss, thickness, and tenderness. Two modern broiler strains (M1 and M2) and a 1990's Randombred strain (RB) were compared. Four dietary treatments were evaluated. Treatments differed in fat quality, normal or oxidized, and vitamin/trace mineral level, standard or doubled. Six broilers, 3 male and 3 female, were processed on d 41 and breast fillets scored for white striation severity based on a 0 – 4 scale. Scores 0 - 4 indicate no, slight, moderate, considerable, and severe striations, respectively.

The prevalence and severity of white striations was related to breast fillets in the frozen, thawed, and cooked state. No significant correlations existed between cooking losses and white striations. Data on the correlation between white striations and breast fillet thickness were inconsistent, but a positive relationship was present between fillet thickness and white striations. No correlations were found between the tenderness of breast fillets and white striation severity. Modern broilers had significantly greater cooking losses than RB broilers. Breast fillets of modern broilers were significantly larger than RB broilers. Shear force, or tenderness, values were significantly higher in modern, fast-growing strains compared to slow-growing RB broilers.

Introduction

A consumer's initial perception of a product's quality relies heavily on visual appearance and highly impacts purchasing decisions. Because more further processed products are sold presently than in the past, consumers have the ability to closely inspect meat (as opposed to the bird's skin) for abnormalities (Kuttappan et al., 2012b). Visual abnormalities may include muscle myopathies, bruises, hemorrhages, and discoloration (Allen et al., 1997; Anthony, 1998; Barbut et al., 2008; Petracci and Cavani, 2012). Such quality defects may cause a product to be downgraded or rejected, possibly leading to large economic losses. Previous research has demonstrated qualities important to consumers include texture, tenderness, juiciness, shelf life, and cooking loss (Allen et al., 1998; Brewer et al., 2012). The term "meat quality" refers to alterations to a product's appearance, texture, nutritional value, or overall consumer acceptability (Petracci and Cavani, 2012).

One major attraction to consumers is the health benefits associated with poultry meat. The perception that poultry has low fat and high protein content gives it an advantage over other meat products (Petracci and Cavani, 2012). Recently, studies have shown that modern broilers contain higher lipid content than in the past (Wang et al., 2010; Kuttappan et al., 2012a). A quality defect shown to contribute to the increasing fat content is white striations within broiler breast fillets (Petracci et al., 2014).

White striations have become a widespread quality defect that affects multiple strains and both genders. Striations run parallel to muscle fibers within the breast and vary in severity levels (Kuttappan et al., 2012b). Although focused on mainly in the highly demanded breast fillets, striations may appear on thighs and tenders (Petracci et

al., 2013). Kuttappan et al. (2012b) demonstrated white striping negatively affects consumer acceptance and 50% of consumers stated they would decline purchasing moderately or severely striped fillets. Therefore, these fillets are subject to be downgraded and used only in the manufacturing of further processed products (Petracci et al., 2014). The main factor causing white striations remains unknown, although research has attributed them to the immensely fast growth rates of modern broilers (Dransfield and Sosnicki, 1999; Ferreira et al., 2010). The objectives of this study were to test the hypotheses that 1) No correlation exists between white striations and the weight of broiler breast fillets in the frozen, thawed, and cooked form; 2) No correlations exist between white striations and cooking losses; 3) The incidence of striping is not correlated to tenderness and fillet thickness; 4) No variations exists in cooking properties between modern broiler strains and the 1990's randombred strain.

Materials and Methods

There were 12 treatments with a 3 x 2 x 2 factorial design; 3 broiler strains were fed 4 dietary treatments. All measurements were taken by gender.

General Husbandry

The chicks were placed in 2 window-less rooms, environmentally controlled to maintain uniform conditions. There was 1 hanging feeder and 10 nipple drinkers per pen. During d 0 – 3, temperature remained between 90-93° C and was reduced 1° C each day until 75° C was achieved. Lighting was from 27 Paragon EC40005 incandescent light fixtures providing floor lighting levels of 0.15 – 0.61 m and 5 – 18 lumen candles. The

floor of each pen was covered with 0.05 m of clean pine shavings. Pens for M1 and M2 broilers were 1.22 x 3.05 m with 30 chicks placed in each. Pens for RB were 1.22 x 1.52 m with 10 chicks placed in each. Distributed through the 48 pens were 4 dietary treatments (Tables 4.1 and 4.2) and 3 broiler strains.

Weight and feed conversion ratio (FCR) were determined by pen on days 0, 18, and 40. All mortalities and/or culled birds were weighed and recorded, including any obvious cause of death. FCR was reported as the total feed consumed/total weight of birds produced.

Genetic Strains

There were three genetic strains: 2 modern (M1 and M2) and a 1990's randombred strain (RB). A total of 1,120 straight run, 1-d-old chicks were distributed into 48 floor pens by strain; 480 of each modern strain and 160 RB chicks.

Dietary Treatments

There were 4 dietary treatments with a 2 x 2 factorial design; each based on an industry corn and soybean diet (Tables 4.1 and 4.2) with normal or oxidized fat, and standard or doubled vitamin/trace mineral mix.

Oxidizing Poultry Fat

One hundred kg of standard poultry fat was poured into a Legion Steam Jacketed Kettle equipped with a Campbell Hausfeld 26 gallon air system running at 5 HP, 15 amps, and 6.8 at 90 PSI. The kettle was fitted with 2 m of 1 cm copper tubing with 47 –

10 mm holes. Air was pumped through the fat at 10 L/min for 117 hours, 66 hours at 20°C and 51 hours at 98-105°C.

Processing & Scoring

At day 7, 10 birds were randomly selected from each pen and fitted with wing tags with identification numbers. On d 41, 3 male and 3 female tagged birds were randomly selected and weighed live, post evisceration (pre-chill) and after carcasses were iced at 1°C for 240 min (post-chill). Carcasses were subsequently deboned at 4.5 h postmortem and breast fillets scored for severity of white striations.

Striation Severity Scoring

Striation scores were determined based on a 5-point scale. Scores of 0 – 4 were given by the severity of white striations. Scores indicated the presence of no striations, slight, moderate, considerable, and severe, respectively (Figure 4.1, 4.2, and 4.3).

Cooking Procedures

Breast fillet weights were determined in the frozen, thawed, and cooked form. Thaw and cook loss were calculated for each fillet. Prior to cooking, fillets of similar weight were vacuum-sealed individually into cryovac bags (Sealed Air Corporation, Elmwood Park, NJ). One fillet per tray was temperature monitored by the insertion of a thermocouple into the thickest portion of the fillet. A multimeter (Cole-Palmer, Eutech Instruments, Vernon Hills, IL, USA) determined the internal temperature and the tray

was removed from the oven after reaching 75°C. Fillets were stored overnight at 4°C for shear force analysis.

Warner-Bratzler Shear Force

Shear force measurements were taken to evaluate tenderness using the Warner-Bratzler method (Zhuang and Savage, 2009). Measurements were taken at 4 locations (Figure 4.4). A 1.9 – cm wide template was placed ½” from the muscle seam on the cranial end of the fillet, parallel to the muscle fibers. Two strips of meat were removed using the template and two notches made onto each strip, designated B1, B2, C1, and C2. Height measurements were recorded at the 4 locations (cm). Tenderness measurements were taken at each location using an Instron Shear Force machine that displayed the maximum force (N) required to slice through the fillet. Averages were calculated for shear force and height measurements at the 2 locations.

Results

Breast Fillet Weights

There was a significant positive correlation between the frozen ($p=0.006$), thawed ($p=0.003$), and cooked ($p=0.017$) breast fillet weights and white striations in M2 female broilers (Table 4.3). No other significant correlations to white striations were found.

Strain and gender were significantly ($p<0.001$) related to the frozen, thawed, and cooked breast fillet weights (Table 4.4). The fillet weight of modern broilers more than doubled those of RB broilers (Table 4.5 and 4.6).

Cooking Loss

No correlations were present between striation severity and cook loss (Table 4.3). Thaw loss was significantly ($p=0.011$) related to broiler strain, gender, and vitamin/trace nutrient mix. Strain ($p<0.001$), gender ($p=0.003$), and a strain, gender, vitamin/trace nutrient mix interaction ($p=0.018$) was significantly related to cook loss (Table 4.7). Modern broiler strains, M1 (19.19%) and M2 (19.84%), had significantly greater cook loss than the RB (13.91%) strain (Table 4.8 and 4.9).

Striation Severity Scores

Strain ($p<0.001$), gender ($p=0.035$), and a strain, gender, fat, vitamin/trace nutrient mix interaction ($p=0.048$) were significant contributors to white striations in broiler breast fillets (Table 4.10). Modern broilers, M1 (mean score (SS) = 1.05 of 4.00) and M2 (SS = 1.65), displayed significantly more severe striations than RB broilers (SS = 0.014) (Table 4.11 and 4.12). Male broilers (SS = 1.09) had significantly more severe striations than females (SS = 0.80) (Table 4.11 and 4.12).

Breast Fillet Thickness

Breast fillet thickness was significantly correlated to white striations at both measurement locations, B ($p=0.013$) and C ($p=0.019$), in M2 female broilers (Table 4.13). M1 female broilers exhibited a positive correlation ($p=0.046$) between fillet thickness and white striping only in location C (Table 4.13). There were no other significant correlations with white striations.

Strain and gender were significantly ($p<0.001$) related to fillet thickness at the 2 measurement locations (Table 4.14). M2 broilers had the thickest fillets (2.84 cm), followed by M1 broilers (2.57 cm) (Table 4.11). RB birds were significantly less thick (1.55 cm) than the modern strains (Table 4.11 and 4.12).

Warner-Bratzler Shear Force

Results found no significant correlations present between white striations and shear force measurements at the 2 locations (Table 4.13). Strain ($p<0.001$), gender ($p=0.033$), and fat ($p=0.044$) were significant factors to the shear force measurements at location B (Table 4.15). At location C, strain was significantly ($p<0.001$) related to shear force (Table 4.15). Shear force, or tenderness, measurements were highest in M1 broilers, followed by M2 broilers, at both locations (Table 4.16 and 4.17). Modern broilers had an average shear force 1.46 N higher at location B and 1.76 N higher at location C than RB broilers (Table 4.16).

Statistical Analysis

Data was subjected to correlation testing, using the proximate correlation analysis (PROC CORR) to determine significant correlations between white striation severities and cooking parameters (SAS Institute, Inc.). Independent variables were broiler strain, gender, fat quality, and vitamin/trace nutrient level and their interaction terms. The dependent variables included breast fillet weight in the frozen, thawed, and cooked state, cook losses, fillet thickness, and tenderness/shear force measurements. ANOVA was conducted using the general linear model (GLM) to evaluate the factors significantly

related to the dependent variables, specifically significant differences between modern and RB strains (SAS Institute, Inc.). Means and standard deviations were analyzed using ANOVA and $p < 0.05$ significance level. Main effect means were displayed (Mean \pm Standard Error) for all dependent variables. Data was considered by pen for the entire experimental analysis.

Discussion

The data (Table 4.3) indicated the null hypothesis that no correlation exists between white striations and the frozen, thawed, and cooked weight of breast fillets should be accepted. Results contrast those of Petracci et al. (2013) suggesting breast fillets exhibit greater losses at higher levels of striation severity, leading to an overall lower product yield. As striping severity increased, the muscles experience a decrease in binding abilities, causing difficulties to water holding capacity during marinade (Petracci et al., 2013). Other research indicated no relationship exists between breast fillet losses and white striations (Kuttappan et al., 2009; Kuttappan et al., 2013). Although broilers in this study and the one conducted by Petracci et al. (2013) were relatively similar in size, there were contrasting results in cook loss, which may be from the different cooking methods. Petracci et al. (2013) cooked fillets in a water bath at 80°C for 45 minutes, while a convection oven was used to achieve internal temperatures of 75°C in the present study. Research showing consistent results followed similar cooking methods (Kuttappan et al., 2009; Kuttappan et al., 2013). Therefore, the method used to cook breast fillets may be significant to cook loss.

The data (Table 4.13) indicated the null hypothesis that the incidence of striping is not correlated to the tenderness of breast fillets should be accepted. Contrasting results were demonstrated by Petracci et al. (2013), who found greater shear force values in breast fillets that were more severely affected by white striations. Differences between the two studies, contributing to the confounding results, may be the size of meat strip being evaluated. A plastic template (1.9 cm wide) was used in the present study to ensure consistency, while Petracci et al. (2013) made no mention of a template used when measurements were taken. Kuttappan et al. (2012b) suggested that alterations to tenderness and texture by white striations were due to increasing fat content within the fillet. It is known that consumers place high value on product texture, making it important to industry sales.

Due to the lack of consistency in the data (Table 4.13), the null hypothesis that the incidence of striping is not correlated to breast fillet thickness should be further evaluated. It has been demonstrated through previous research that significant correlations exist between white striping and breast fillet thickness (Bauermeister et al., 2011; Brewer et al., 2012; Kuttappan et al., 2012a; Kuttappan et al., 2013). Although there were some strain and gender combinations significant to the data, a general overall trend was not established (Table 4.13). Figure 4.5 illustrates that as striping severity increased, the average height of breast fillets increased at both locations of measurement. Kuttappan et al. (2013) proposed that birds with larger, thicker breast fillets had higher levels of stress, which caused severe muscle damage. Fillet thickness is significantly correlated to overall broiler body weight, supporting the idea that a positive relationship between striping severity and body weight is present (Kuttappan et al., 2013).

The data (Tables 4.4, 4.7, 4.14, and 4.15) indicated the null hypothesis that cooking properties do not vary between modern broilers and RB broilers should be rejected. Since strain and gender were significant factors to breast fillet weights in all cooking states, the apparent differences between fast and slow growing birds are further supported. The breast fillets of modern broilers more than doubled the weight of the RB broilers (Table 4.5). Differences in body composition between male and female broilers assist in explaining the effect gender has with breast weight (Lopez et al., 2011; Brewer et al., 2012). Male broilers typically have larger, thicker breast fillets than female broilers (Brewer et al., 2012).

“Cook loss” refers to the weight a product loses resulting from the act of cooking (Woelfel et al., 2002). Xiong et al. (1993) explained the different characteristics in the cooking properties of broiler strains. Lopez et al. (2011) found contrasting results showing that no relationship exists between the cook loss or shear force value breasts in modern broilers compared to past industry strains. However, this study demonstrated that modern broilers lost significantly more than RB broilers upon cooking (Table 4.8 and 4.9). Strain and gender were significant ($p < 0.001$) factors to the percentage of cook loss in this study (Table 4.7). Brewer et al. (2012) supported these findings indicating that breast yield is significantly affected by broiler strain.

Boback et al. (2007) explained that meat tenderness arises from increased solubility of connective tissues within the muscle. The present study supported results found by Intaraichet et al. (2008), indicating that strain and gender were significant to the tenderness and thickness of breast at location B (Table 4.14 and 4.15). The strain and gender effects may be explained by the positive relationship between fillet thickness and overall live weight.

Conclusion

Because there were no significant correlations between cook loss or fillet tenderness and the presence or severity of white striations, processors should not have to make adjustments in cooking based on striping severity. Fillet thickness was significantly correlated to white striping in some of the strain/gender combinations, but overall data was inconsistent so a trend was not established. As fillet thickness increases, striping severity rises, obviously a result of overall live weight. The cooking properties of modern broilers vary significantly from the slower growing RB strain of ~20 years ago, suggesting that cooking parameters should also be different. However, a better comparison should be made using birds of similar body weight (different ages). Modern strains displayed significantly higher cook losses, shear force values, and fillet thickness than RB broilers.

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Table 4.1. Composition of starter diets (0 - 17 d) with differing levels of vitamin/trace standard (1 x) and doubled (2 x) and fat quality, normal or oxidized.

Fat Quality	Normal	Oxidized	Normal	Oxidized
Trace Nutrient Level	1x	1x	2x	2x
Ingredient	-----%-----			
Ground yellow corn	51.36	51.36	51.36	51.36
Soybean meal (dehulled)	39.20	39.20	39.20	39.20
Standard poultry fat	6.013	0.000	6.013	0.000
Oxidized poultry fat	0.000	6.013	0.000	6.013
Salt	0.400	0.400	0.400	0.400
L-Lysine HCl	0.175	0.175	0.175	0.175
DL-Methionine	0.307	0.307	0.307	0.307
L-Threonine	0.063	0.063	0.063	0.063
Limestone	0.175	0.175	0.175	0.175
Defluorinated P	1.882	1.882	1.882	1.882
Vitamin Mix ¹	0.250	0.250	0.500	0.500
Trace Mineral Mix ²	0.075	0.075	0.150	0.150
Coban ³	0.050	0.050	0.050	0.050
BMD ⁴	0.050	0.050	0.050	0.050

¹Vitamin mix provided the following (per kilogram of diet): thiamin-mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B₁₂ (cobalamin), 12.0g; pyridoxine-HCl, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-reinyl acetate, 2,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

²Trace mineral mix provides the following (per kilogram of diet): manganese (MnSO₄.H₂O), 101 mg; iron (FeSO₄.7H₂O), 20 mg; zinc (Zn), 80 mg; copper (CuSO₄.5H₂O), 3 mg; iodine (ethylene diamine dihydroiodide), 0.75 mg; magnesium (MgO), 20 mg; selenium (sodium selenite), 0.3 mg.

³Coban (Type A) provides (per pound of diet): Monensin, USP 90.7g; aids in prevention of coccidiosis.

⁴BMD (Bacitracin Methylene Disalicylate - Type A) provides (per pound of diet): feed grade bacitracin methylene disalicylate equivalent to 50 g bacitracin.

Table 4.2. Composition of grower diets (18 - 41 d) with differing levels of vitamin/trace nutrient mix, standard (1 x) and doubled (2 x) and fat quality, normal or oxidized.

Fat Quality	Normal	Oxidized	Normal	Oxidized
Trace Nutrient Level	1x	1x	2x	2x
Ingredient	-----%-----			
Ground yellow corn	55.74	55.74	55.74	55.74
Soybean meal (dehulled)	35.20	35.20	35.20	35.20
Standard poultry fat	5.900	0.000	5.900	0.000
Oxidized poultry fat	0.000	5.900	0.000	5.900
Salt	0.400	0.400	0.400	0.400
L-Lysine HCl	0.148	0.148	0.148	0.148
DL-Methionine	0.267	0.267	0.267	0.267
L-Threonine	0.041	0.041	0.041	0.041
Limestone	0.197	0.197	0.197	0.197
Defluorinated P	1.679	1.679	1.679	1.679
Vitamin Mix ¹	0.250	0.250	0.500	0.500
Trace Mineral Mix ²	0.075	0.075	0.150	0.150
Coban ³	0.050	0.050	0.050	0.050
BMD ⁴	0.050	0.050	0.050	0.050

¹Vitamin mix provided the following (per kilogram of diet): thiamin-mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B₁₂ (cobalamin), 12.0g; pyridoxine-HCl, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-reinyl acetate, 2,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

²Trace mineral mix provides the following (per kilogram of diet): manganese (MnSO₄.H₂O), 101 mg; iron (FeSO₄.7H₂O), 20 mg; zinc (Zn), 80 mg; copper (CuSO₄.5H₂O), 3 mg; iodine (ethylene diamine dihydroiodide), 0.75 mg; magnesium (MgO), 20 mg; selenium (sodium selenite), 0.3 mg.

³Coban (Type A) provides (per pound of diet): Monensin, USP 90.7g; aids in prevention of coccidiosis.

⁴BMD (Bacitracin Methylene Disalicylate - Type A) provides (per pound of diet): feed grade bacitracin methylene disalicylate equivalent to 50 g bacitracin.

Table 4.3. The correlation analysis on the relationship between white striations and frozen, thawed, cooked breast fillet weights, percentage of thaw loss, and percentage of cook loss; r = Pearson Correlation Coefficients, p = Prob > | r | under H0:Rho=0, N = Number of Observations.

		Randombred		Modern Strain 1		Modern Strain 2	
		Female	Male	Female	Male	Female	Male
Frozen Weight (kg)	r	-0.094	0.077	0.239	0.350	0.653	-0.095
	p	0.730	0.778	0.373	0.183	0.006	0.726
	N	16	16	16	16	16	16
Thawed Weight (kg)	r	-0.115	-0.087	0.099	0.339	0.695	-0.218
	p	0.672	0.758	0.716	0.199	0.003	0.436
	N	16	15	16	16	16	15
Cooked Weight (kg)	r	-0.074	0.326	0.109	0.227	0.588	-0.105
	p	0.787	0.218	0.687	0.397	0.017	0.698
	N	16	16	16	16	16	16
Thaw Loss ¹ (%)	r	-0.050	0.352	0.316	-0.205	-0.070	0.029
	p	0.866	0.238	0.234	0.446	0.797	0.922
	N	16	13	16	16	16	14
Cook Loss ² (%)	r	-0.237	-0.224	-0.041	0.199	0.025	0.019
	p	0.394	0.442	0.882	0.461	0.926	0.947
	N	16	14	16	16	16	15

¹Thaw Loss = (frozen breast weight (kg) – thawed breast weight (kg)) / (frozen breast weight (kg)) * 100

²Cook Loss = (thawed breast weight (kg) – cooked breast weight (kg)) / (thawed breast weight (kg)) * 100

Table 4.4. General Linear Model (GLM) for the effect of strain, gender, fat quality, trace nutrient supplementation, and all interactions on the frozen, thawed, and cooked weight of broiler breast fillets.

Source	df	Pr > F – Type III		
		Frozen	Thawed	Cooked
Strain ¹	2	<0.001	<0.001	<0.001
Gender	1	<0.001	<0.001	<0.001
Strain*Gender	2	0.012	0.049	0.302
Fat ²	1	0.724	0.499	0.139
Strain*Fat	2	0.896	0.777	0.770
Gender*Fat	1	0.662	0.374	0.925
Strain*Gender*Fat	2	0.544	0.534	0.518
TN ³	1	0.557	0.987	0.830
Strain*TN	2	0.870	0.860	0.572
Gender*TN	1	0.931	0.902	0.740
Strain*Gender*TN	2	0.560	0.142	0.752
Fat*TN	1	0.876	0.659	0.438
Strain*Fat*TN	2	0.030	0.053	0.242
Gender*Fat*TN	1	0.176	0.337	0.105
Strain*Gender*Fat*TN	2	0.479	0.566	0.787
R-Square		0.957	0.934	0.939

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, either standard (1 x) or doubled (2 x)

Table 4.5. Main effect means of white striation severity on the frozen, thawed, and cooked weight of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Breast Fillet Weight (kg)		
					Frozen Wt ⁴	Thawed Wt ⁵	Cooked Wt ⁶
RB				8	0.12 \pm 0.01	0.12 \pm 0.03	0.10 \pm 0.01
M1				8	0.27 \pm 0.03	0.26 \pm 0.03	0.21 \pm 0.02
M2				8	0.29 \pm 0.03	0.28 \pm 0.03	0.22 \pm 0.02
	1 \times			12	0.23 \pm 0.08	0.22 \pm 0.08	0.18 \pm 0.06
	2 \times			12	0.23 \pm 0.08	0.22 \pm 0.08	0.18 \pm 0.06
		Normal		12	0.23 \pm 0.08	0.22 \pm 0.08	0.18 \pm 0.06
		Oxidized		12	0.23 \pm 0.08	0.22 \pm 0.07	0.18 \pm 0.06
			Male	12	0.24 \pm 0.08	0.24 \pm 0.08	0.19 \pm 0.06
			Female	12	0.21 \pm 0.07	0.20 \pm 0.07	0.17 \pm 0.05

¹Strain = 1990's Rando-bred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace nutrient mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

⁴Frozen Weight (kg) = Breast fillet weight immediately after removal from freezer

⁵Thawed Weight (kg) = Breast fillet weight after thawed 10 hours in cooler

⁶Cooked Weight (kg) = Breast fillet weight after removed from oven

Table 4.6. Effects of strain, gender, fat quality, and trace nutrient supplementation on the frozen, thawed, and cooked breast fillet weights. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Breast Fillet Weight (kg)		
					Frozen ⁴	Thawed ⁵	Cooked ⁶
RB	1 \times	Normal	Male	4	0.13 \pm 0.01	0.13 \pm 0.01	0.12 \pm 0.01
RB	1 \times	Normal	Female	4	0.11 \pm 8.71	0.10 \pm 8.98	0.09 \pm 6.13
RB	1 \times	Oxidized	Male	4	0.12 \pm 0.01	0.12 \pm 0.01	0.11 \pm 0.01
RB	1 \times	Oxidized	Female	4	0.13 \pm 44.10	0.13 \pm 64.69	0.11 \pm 29.27
RB	2 \times	Normal	Male	4	0.14 \pm 0.01	0.14 \pm 0.01	0.11 \pm 0.01
RB	2 \times	Normal	Female	4	0.12 \pm 13.15	0.11 \pm 2.29	0.10 \pm 7.80
RB	2 \times	Oxidized	Male	4	0.13 \pm 0.01	0.13 \pm 0.01	0.11 \pm 0.01
RB	2 \times	Oxidized	Female	4	0.11 \pm 5.47	0.10 \pm 8.89	0.09 \pm 5.94
M1	1 \times	Normal	Male	4	0.29 \pm 0.02	0.28 \pm 0.02	0.22 \pm 0.01
M1	1 \times	Normal	Female	4	0.25 \pm 0.03	0.23 \pm 0.03	0.20 \pm 0.03
M1	1 \times	Oxidized	Male	4	0.29 \pm 0.03	0.28 \pm 0.03	0.22 \pm 0.02
M1	1 \times	Oxidized	Female	4	0.24 \pm 0.03	0.23 \pm 0.03	0.19 \pm 0.03
M1	2 \times	Normal	Male	4	0.29 \pm 0.02	0.28 \pm 0.02	0.22 \pm 0.02
M1	2 \times	Normal	Female	4	0.26 \pm 0.03	0.25 \pm 0.03	0.20 \pm 0.03
M1	2 \times	Oxidized	Male	4	0.29 \pm 0.04	0.27 \pm 0.04	0.22 \pm 0.03
M1	2 \times	Oxidized	Female	4	0.25 \pm 0.03	0.23 \pm 0.03	0.19 \pm 0.02
M2	1 \times	Normal	Male	4	0.32 \pm 0.04	0.32 \pm 0.04	0.25 \pm 0.03
M2	1 \times	Normal	Female	4	0.27 \pm 0.02	0.26 \pm 0.03	0.21 \pm 0.03
M2	1 \times	Oxidized	Male	4	0.30 \pm 0.03	0.29 \pm 0.03	0.23 \pm 0.03
M2	1 \times	Oxidized	Female	4	0.26 \pm 0.03	0.25 \pm 0.02	0.21 \pm 0.02
M2	2 \times	Normal	Male	4	0.30 \pm 0.03	0.29 \pm 0.03	0.23 \pm 0.03
M2	2 \times	Normal	Female	4	0.27 \pm 0.02	0.26 \pm 0.03	0.21 \pm 0.03
M2	2 \times	Oxidized	Male	4	0.32 \pm 0.03	0.31 \pm 0.03	0.24 \pm 0.02
M2	2 \times	Oxidized	Female	4	0.28 \pm 0.05	0.26 \pm 0.04	0.21 \pm 0.04

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace nutrient mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

⁴Frozen Weight (kg) = Breast fillet weight immediately after removal from freezer

⁵Thawed Weight (kg) = Breast fillet weight after thawed 10 hours in cooler

⁶Cooked Weight (kg) = Breast fillet weight after removal from oven

Table 4.7. General Linear Model (GLM) for the effect of strain, gender, fat quality, trace nutrient supplementation, and all interactions on the percentage of thaw and cook loss of broiler breast fillets.

Source	df	Pr > F – Type III	
		% Thaw Loss ⁴	% Cook Loss ⁵
Strain ¹	2	0.320	<0.001
Gender	1	0.143	0.003
Strain*Gender	2	0.208	0.915
Fat ²	1	0.376	0.402
Strain*Fat	2	0.354	0.939
Gender*Fat	1	0.858	0.153
Strain*Gender*Fat	2	0.652	0.869
TN ³	1	0.112	0.527
Strain*TN	2	0.558	0.641
Gender*TN	1	0.945	0.580
Strain*Gender*TN	2	0.011	0.018
Fat*TN	1	0.811	0.694
Strain*Fat*TN	2	0.551	0.313
Gender*Fat*TN	1	0.427	0.476
Strain*Gender*Fat*TN	2	0.758	0.817
R-Square		0.302	0.434

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, either standard (1 x) or doubled (2 x)

⁴Thaw Loss = (Frozen Breast Weight (kg) – Thawed Breast Weight (kg)) / (Frozen Breast Weight (kg)) * 100

⁵Cook Loss = (Thawed Breast Weight (kg) – Cooked Breast Weight (kg)) / (Thawed Breast Weight (kg)) * 100

Table 4.8. Main effect means of the percentage of thaw loss and percentage of cooking loss by strain, gender, fat quality, and trace nutrient supplementation of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Breast Fillet Losses (%)	
					% Thaw Loss ⁴	% Cook Loss ⁵
RB				8	3.46 \pm 4.91	13.91 \pm 6.08
M1				8	4.72 \pm 3.23	19.19 \pm 4.90
M2				8	4.00 \pm 2.68	19.84 \pm 3.97
	1 \times			12	2.52 \pm 1.90	17.49 \pm 6.06
	2 \times			12	4.66 \pm 4.40	18.00 \pm 5.22
		Normal		12	3.55 \pm 2.70	17.46 \pm 5.39
		Oxidized		12	4.51 \pm 3.27	18.03 \pm 5.90
			Male	12	3.56 \pm 3.41	19.36 \pm 4.68
			Female	12	4.59 \pm 3.85	16.20 \pm 6.06

¹Strain = 1990's Rando-bred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²TN = Level of vitamin/trace mineral mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

⁴Thaw Loss = (frozen breast weight (kg) – thawed breast weight (kg)) / (frozen breast weight (kg)) * 100

⁵Cook Loss = (thawed breast weight (kg) – cooked breast weight (kg)) / (thawed breast weight (kg)) * 100

Table 4.9. Effects of strain, gender, fat quality, and trace nutrient supplementation on the percentage of thaw and cook loss in broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Breast Fillet Losses (%)	
					% Thaw Loss ⁴	% Cook Loss ⁵
RB	1 \times	Normal	Male	4	3.63 \pm 4.92	12.27 \pm 1.86
RB	1 \times	Normal	Female	4	1.65 \pm 0.72	12.60 \pm 2.57
RB	1 \times	Oxidized	Male	4	0.74 \pm 0.20	12.47 \pm 2.67
RB	1 \times	Oxidized	Female	4	2.26 \pm 2.49	15.90 \pm 13.53
RB	2 \times	Normal	Male	4	1.08 \pm 0.72	18.65 \pm 5.49
RB	2 \times	Normal	Female	4	8.63 \pm 10.18	9.04 \pm 2.80
RB	2 \times	Oxidized	Male	4	1.40 \pm 0.77	16.33 \pm 4.09
RB	2 \times	Oxidized	Female	4	6.86 \pm 2.98	12.04 \pm 4.24
M1	1 \times	Normal	Male	4	2.50 \pm 1.05	21.59 \pm 3.03
M1	1 \times	Normal	Female	4	5.65 \pm 3.89	15.43 \pm 5.85
M1	1 \times	Oxidized	Male	4	3.57 \pm 1.72	23.50 \pm 4.24
M1	1 \times	Oxidized	Female	4	5.43 \pm 3.92	17.32 \pm 6.94
M1	2 \times	Normal	Male	4	3.96 \pm 3.53	20.40 \pm 5.06
M1	2 \times	Normal	Female	4	3.57 \pm 0.97	16.96 \pm 5.19
M1	2 \times	Oxidized	Male	4	8.32 \pm 5.19	17.69 \pm 2.80
M1	2 \times	Oxidized	Female	4	4.75 \pm 1.71	20.62 \pm 2.87
M2	1 \times	Normal	Male	4	2.26 \pm 0.69	22.23 \pm 1.83
M2	1 \times	Normal	Female	4	3.23 \pm 1.20	18.18 \pm 5.63
M2	1 \times	Oxidized	Male	4	4.14 \pm 2.17	19.25 \pm 2.22
M2	1 \times	Oxidized	Female	4	5.76 \pm 1.90	16.62 \pm 2.15
M2	2 \times	Normal	Male	4	4.81 \pm 5.37	21.71 \pm 3.18
M2	2 \times	Normal	Female	4	3.16 \pm 1.86	17.03 \pm 4.93
M2	2 \times	Oxidized	Male	4	4.99 \pm 4.62	23.88 \pm 2.57
M2	2 \times	Oxidized	Female	4	4.10 \pm 3.24	20.85 \pm 3.97

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1, Modern Strain 2 (M2)

²Trace Nutrient Level = level of vitamin/trace mineral mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

⁴% Thaw Loss = (frozen breast weight (kg) – thawed breast weight (kg)) / (frozen breast weight (kg)) * 100

⁵% Cook Loss = (thawed breast weight (kg) – cooked breast weight (kg)) / (thawed breast weight (kg)) * 100

Table 4.10. General Linear Model (GLM) for the effects of strain, gender, fat quality, trace nutrient supplementation, and all interactions on white striations in broiler breast fillets.

Source	df	Pr > F
		Type III
Strain ¹	2	<0.001
Gender	1	0.035
Strain*Gender	2	0.074
Fat ²	1	0.357
Strain*Fat	2	0.577
Gender*Fat	1	0.617
Strain*Gender*Fat	2	0.061
TN ³	1	0.883
Strain*TN	2	0.853
Gender*TN	1	0.938
Strain*Gender*TN	2	0.946
Fat*TN	1	0.255
Strain*Fat*TN	2	0.386
Gender*Fat*TN	1	0.748
Strain*Gender*Fat*TN	2	0.048
R-Square = 0.599		

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, either standard (1 x) or doubled (2 x)

Table 4.11. Main effect means of the shear force height measurements by strain, gender, fat quality, and trace nutrient supplementation of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Striping Score	Shear Force - Thickness	
						B - Height ⁴ (cm)	C-Height ⁵ (cm)
RB				8	0.14 \pm 0.22	1.72 \pm 0.22	1.38 \pm 0.21
M1				8	1.05 \pm 0.75	2.73 \pm 0.19	2.40 \pm 0.24
M2				8	1.65 \pm 0.92	3.01 \pm 0.23	2.67 \pm 0.25
	1 x			12	0.94 \pm 0.90	2.47 \pm 0.56	2.13 \pm 0.59
	2 x			12	0.96 \pm 0.98	2.50 \pm 0.63	2.17 \pm 0.63
		Normal		12	1.01 \pm 1.00	2.48 \pm 0.62	2.14 \pm 0.64
		Oxidized		12	0.88 \pm 0.87	2.50 \pm 0.58	2.16 \pm 0.58
			Female	12	0.80 \pm 0.87	2.40 \pm 0.58	2.05 \pm 0.58
			Male	12	1.09 \pm 0.99	2.57 \pm 0.60	2.25 \pm 0.62

¹Strain = 1990's Rando-bred Broilers (RB), Modern Strain 1(M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace mineral mix in the diet, either standard (1 x) or doubled (2 x)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

⁴B – Height = Breast fillet height/thickness (cm) at location designated B

⁵C – Height = Breast fillet height/thickness (cm) at location designated C

Table 4.12. Effects of strain, gender, fat quality, and trace nutrient supplementation on the height measurements of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Striping Score	Shear Force - Thickness	
						B-Height ⁴ (cm)	C-Height ⁵ (cm)
RB	1 \times	Normal	Male	4	0.13 \pm 0.25	1.80 \pm 0.21	1.38 \pm 0.14
RB	1 \times	Normal	Female	4	0.06 \pm 0.13	1.52 \pm 0.22	1.22 \pm 0.09
RB	1 \times	Oxidized	Male	4	0.33 \pm 0.24	1.89 \pm 0.21	1.55 \pm 0.31
RB	1 \times	Oxidized	Female	4	0.08 \pm 0.17	1.81 \pm 0.34	1.37 \pm 0.32
RB	2 \times	Normal	Male	4	0.17 \pm 0.34	1.77 \pm 0.02	1.44 \pm 0.08
RB	2 \times	Normal	Female	4	0.19 \pm 0.24	1.61 \pm 0.07	1.24 \pm 0.14
RB	2 \times	Oxidized	Male	4	0.13 \pm 0.25	1.69 \pm 0.12	1.39 \pm 0.13
RB	2 \times	Oxidized	Female	4	0.06 \pm 0.13	1.70 \pm 0.27	1.43 \pm 0.30
M1	1 \times	Normal	Male	4	1.42 \pm 1.40	2.88 \pm 0.12	2.58 \pm 0.22
M1	1 \times	Normal	Female	4	1.17 \pm 1.14	2.62 \pm 0.16	2.31 \pm 0.29
M1	1 \times	Oxidized	Male	4	0.79 \pm 0.37	2.79 \pm 0.16	2.44 \pm 0.19
M1	1 \times	Oxidized	Female	4	0.92 \pm 0.42	2.60 \pm 0.10	2.21 \pm 0.05
M1	2 \times	Normal	Male	4	1.33 \pm 0.47	2.80 \pm 0.22	2.58 \pm 0.17
M1	2 \times	Normal	Female	4	0.42 \pm 0.42	2.67 \pm 0.22	2.25 \pm 0.27
M1	2 \times	Oxidized	Male	4	0.75 \pm 0.50	2.85 \pm 0.11	2.53 \pm 0.14
M1	2 \times	Oxidized	Female	4	1.58 \pm 0.74	2.63 \pm 0.27	2.31 \pm 0.28
M2	1 \times	Normal	Male	4	2.33 \pm 0.27	3.08 \pm 0.12	2.81 \pm 0.11
M2	1 \times	Normal	Female	4	1.38 \pm 0.29	2.86 \pm 0.06	2.50 \pm 0.10
M2	1 \times	Oxidized	Male	4	1.54 \pm 1.08	2.97 \pm 0.18	2.64 \pm 0.28
M2	1 \times	Oxidized	Female	4	1.08 \pm 0.74	2.88 \pm 0.18	2.50 \pm 0.15
M2	2 \times	Normal	Male	4	1.79 \pm 0.46	3.04 \pm 0.27	2.71 \pm 0.29
M2	2 \times	Normal	Female	4	1.75 \pm 1.57	3.07 \pm 0.25	2.72 \pm 0.29
M2	2 \times	Oxidized	Male	4	2.43 \pm 0.80	3.34 \pm 0.19	3.00 \pm 0.16
M2	2 \times	Oxidized	Female	4	0.88 \pm 0.85	2.82 \pm 0.16	2.50 \pm 0.22

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace mineral mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

⁴B – Height = Average breast fillet height/thickness (cm) at location designated B

⁵C – Height = Average breast fillet height/thickness (cm) at location designated C

Table 4.13. The correlation analysis on the relationship between white striations and the average height (cm), shear force, and shear/cm at locations B and C by gender in the 3 broiler strains; r = Pearson Correlation Coefficients, p = Prob > | r | under H0:Rho=0, N = Number of Observations.

		Randombred		Modern Strain 1		Modern Strain 2	
		Female	Male	Female	Male	Female	Male
Average B Height (cm)	r	-0.195	0.484	0.232	0.346	0.606	0.083
	p	0.468	0.058	0.386	0.189	0.013	0.759
	N	16	16	16	16	16	16
Average C Height (cm)	r	-0.371	0.437	0.504	0.402	0.577	0.025
	p	0.157	0.091	0.046	0.123	0.019	0.928
	N	16	16	16	16	16	16
Average B Shear Force (N)	r	-0.183	0.196	-0.280	-0.238	0.020	0.145
	p	0.497	0.467	0.294	0.375	0.943	0.591
	N	16	16	16	16	16	16
Average C Shear Force (N)	r	-0.087	0.051	-0.267	-0.116	0.025	0.063
	p	0.748	0.852	0.317	0.670	0.928	0.818
	N	16	16	16	16	16	16
Shear/cm - B	r	-0.074	0.074	-0.278	-0.338	-0.171	0.116
	p	0.785	0.785	0.297	0.201	0.527	0.670
	N	16	16	16	16	16	16
Shear/cm - C	r	0.078	-0.108	-0.317	0.200	-0.175	0.054
	p	0.773	0.692	0.231	0.457	0.517	0.843
	N	16	16	16	16	16	16

Table 4.14. General Linear Model (GLM) for the effect of strain, gender, fat quality, trace nutrient supplementation, and all interactions on the average height at location B and C of broiler breast fillets.

Source	df	Pr > F – Type III	
		Height - Location B ⁴	Height - Location C ⁵
Strain ¹	2	<0.001	<0.001
Gender	1	<0.001	<0.001
Strain*Gender	2	0.680	0.434
Fat ²	1	0.636	0.748
Strain*Fat	2	0.368	0.227
Gender*Fat	1	0.908	0.980
Strain*Gender*Fat	2	0.147	0.374
TN ³	1	0.535	0.269
Strain*TN	2	0.175	0.485
Gender*TN	1	0.766	0.857
Strain*Gender*TN	2	0.578	0.860
Fat*TN	1	0.757	0.560
Strain*Fat*TN	2	0.325	0.495
Gender*Fat*TN	1	0.066	0.519
Strain*Gender*Fat*TN	2	0.208	0.079
R-Square		0.920	0.905

¹Strain = 1990's Randombred Broilers (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, either standard (1 x) or doubled (2 x)

⁴Height – Location B = Average breast fillet height/thickness (cm) at location designated B

⁵Height – Location C = Average breast fillet height/thickness (cm) at location designated C

Table 4.15. General Linear Model (GLM) for the effect of strain, gender, fat quality, trace nutrient supplementation, and all interactions on the shear force height measurements (N) of broiler breast fillets.

Source	df	Pr > F – Type III	
		Shear Force (N) Location B ⁴	Shear Force (N) Location C ⁵
Strain ¹	2	<0.001	<0.001
Gender	1	0.033	0.122
Strain*Gender	2	0.209	0.656
Fat ²	1	0.044	0.120
Strain*Fat	2	0.485	0.273
Gender*Fat	1	0.896	0.785
Strain*Gender*Fat	2	0.863	0.553
TN ³	1	0.131	0.324
Strain*TN	2	0.547	0.597
Gender*TN	1	0.271	0.134
Strain*Gender*TN	2	0.097	0.169
Fat*TN	1	0.340	0.624
Strain*Fat*TN	2	0.102	0.052
Gender*Fat*TN	1	0.467	0.701
Strain*Gender*Fat*TN	2	0.844	0.849
R-Square		0.686	0.672

¹Strain = 1990's Rando-bred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, either standard (1 x) or doubled (2 x)

⁴Shear Force – Location B = Average shear force measurement (N) at location designated B

⁵Shear Force – Location C = Average shear force measurement (N) at location designated C

Table 4.16. Main effect means of the shear force measurements by strain, gender, fat quality, and trace nutrient supplementation of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Shear Force (N)			
					B Shear Value ⁴ (N)	C Shear Value ⁵ (N)	B Force per cm ⁶	C Force per cm ⁷
RB				8	2.13 \pm 0.55	1.97 \pm 0.60	1.25 \pm 0.34	1.45 \pm 0.48
M1				8	3.95 \pm 0.78	4.31 \pm 1.20	1.46 \pm 0.35	1.84 \pm 0.67
M2				8	3.22 \pm 0.70	3.15 \pm 0.66	1.08 \pm 0.26	1.19 \pm 0.29
	1 \times			12	3.00 \pm 0.98	3.06 \pm 1.22	1.21 \pm 0.29	1.44 \pm 0.47
	2 \times			12	3.20 \pm 1.04	3.23 \pm 1.35	1.31 \pm 0.40	1.54 \pm 0.65
		Normal		12	2.96 \pm 0.94	3.01 \pm 1.17	1.21 \pm 0.29	1.43 \pm 0.50
		Oxidized		12	3.24 \pm 1.07	3.28 \pm 1.39	1.31 \pm 0.40	1.55 \pm 0.63
			Female	12	3.24 \pm 1.09	3.28 \pm 1.40	1.36 \pm 0.36	1.63 \pm 0.64
			Male	12	2.96 \pm 0.91	3.01 \pm 1.16	1.17 \pm 0.32	1.36 \pm 0.45

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace mineral mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

⁴B – Shear Value = Shear force value (N) at location designated B

⁵C - Shear Value = Shear force value (N) at location designated

Table 4.17. Effects of strain, gender, fat quality, and trace nutrient supplementation, on the shear force measurements in broiler breast fillets. Mean \pm Standard Error.

Strain ₁	TN ₂	Fat Quality ³	Gender	n	Shear Force (N)			
					B Shear Value ⁴ (N)	C Shear Value ⁵ (N)	B Force per cm	C Force per cm
RB	1 X	Normal	Male	4	1.97 \pm 0.61	2.03 \pm 0.80	1.11 \pm 0.38	1.48 \pm 0.62
RB	1 X	Normal	Female	4	2.05 \pm 0.62	1.88 \pm 0.61	1.33 \pm 0.26	1.52 \pm 0.41
RB	1 X	Oxidized	Male	4	1.90 \pm 0.36	1.66 \pm 0.31	1.01 \pm 0.17	1.09 \pm 0.23
RB	1 X	Oxidized	Female	4	1.90 \pm 0.54	1.73 \pm 0.54	1.05 \pm 0.25	1.25 \pm 0.24
RB	2 X	Normal	Male	4	2.24 \pm 0.33	2.03 \pm 0.22	1.27 \pm 0.18	1.40 \pm 0.11
RB	2 X	Normal	Female	4	1.87 \pm 0.51	1.69 \pm 0.53	1.16 \pm 0.31	1.36 \pm 0.33
RB	2 X	Oxidized	Male	4	2.46 \pm 0.85	2.01 \pm 0.71	1.47 \pm 0.54	1.47 \pm 0.61
RB	2 X	Oxidized	Female	4	2.64 \pm 0.10	2.72 \pm 0.66	1.58 \pm 0.23	2.00 \pm 0.75
M1	1 X	Normal	Male	4	3.53 \pm 0.58	3.66 \pm 0.62	1.22 \pm 0.18	1.42 \pm 0.22
M1	1 X	Normal	Female	4	3.34 \pm 0.12	3.48 \pm 0.31	1.28 \pm 0.08	1.52 \pm 0.26
M1	1 X	Oxidized	Male	4	4.32 \pm 0.73	4.92 \pm 1.62	1.56 \pm 0.31	2.06 \pm 0.85
M1	1 X	Oxidized	Female	4	4.09 \pm 0.34	4.59 \pm 0.59	1.58 \pm 0.18	2.08 \pm 0.30
M1	2 X	Normal	Male	4	3.49 \pm 0.76	3.75 \pm 0.77	1.24 \pm 0.19	1.45 \pm 0.25
M1	2 X	Normal	Female	4	4.44 \pm 0.66	5.04 \pm 1.87	1.67 \pm 0.29	2.31 \pm 1.11
M1	2 X	Oxidized	Male	4	3.75 \pm 0.51	4.00 \pm 0.69	1.32 \pm 0.14	1.58 \pm 0.25
M1	2 X	Oxidized	Female	4	4.61 \pm 1.34	5.07 \pm 1.64	1.80 \pm 0.69	2.28 \pm 1.02
M2	1 X	Normal	Male	4	2.96 \pm 0.71	3.16 \pm 0.60	0.96 \pm 0.22	1.13 \pm 0.20
M2	1 X	Normal	Female	4	3.73 \pm 0.70	3.59 \pm 0.66	1.31 \pm 0.27	1.44 \pm 0.30
M2	1 X	Oxidized	Male	4	2.90 \pm 0.74	2.89 \pm 0.68	0.98 \pm 0.26	1.10 \pm 0.25
M2	1 X	Oxidized	Female	4	3.31 \pm 0.47	3.12 \pm 0.50	1.14 \pm 0.10	1.25 \pm 0.13
M2	2 X	Normal	Male	4	2.79 \pm 0.58	2.76 \pm 0.57	0.93 \pm 0.22	1.02 \pm 0.21
M2	2 X	Normal	Female	4	3.18 \pm 0.66	3.05 \pm 0.58	1.03 \pm 0.20	1.14 \pm 0.27
M2	2 X	Oxidized	Male	4	3.16 \pm 0.66	3.24 \pm 0.75	0.95 \pm 0.22	1.09 \pm 0.32
M2	2 X	Oxidized	Female	4	3.77 \pm 0.89	3.41 \pm 1.04	1.34 \pm 0.30	1.38 \pm 0.46

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace mineral mix in the diet, either standard (1 X) or doubled (2 X)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

⁴B – Shear Value = Shear force value (N) at location designated B

⁵C - Shear Value = Shear force value (N) at location designated C

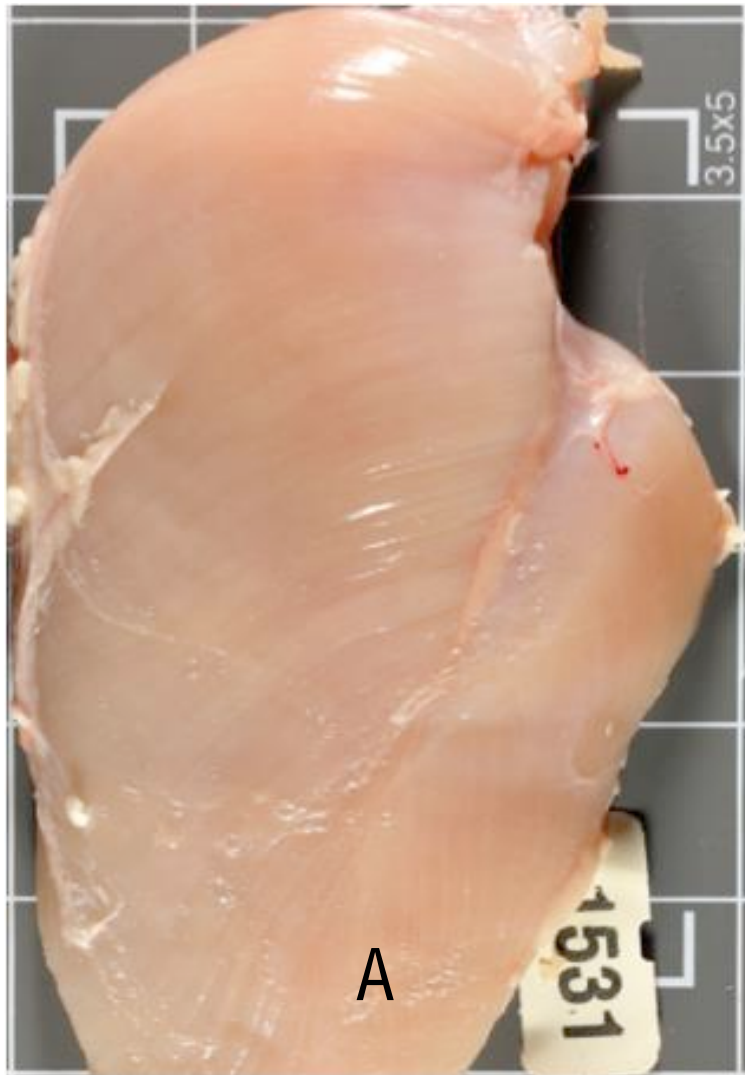


Figure 4.1. White striping classification of broiler breast fillets: A) Complete absence (no striping) and B) Slight.



Figure 4.2. White striping classification of broiler breast fillets: A) Moderate and B) Considerable striations.



Figure 4.3. White striping classification of broiler breast fillets: Severe striations.

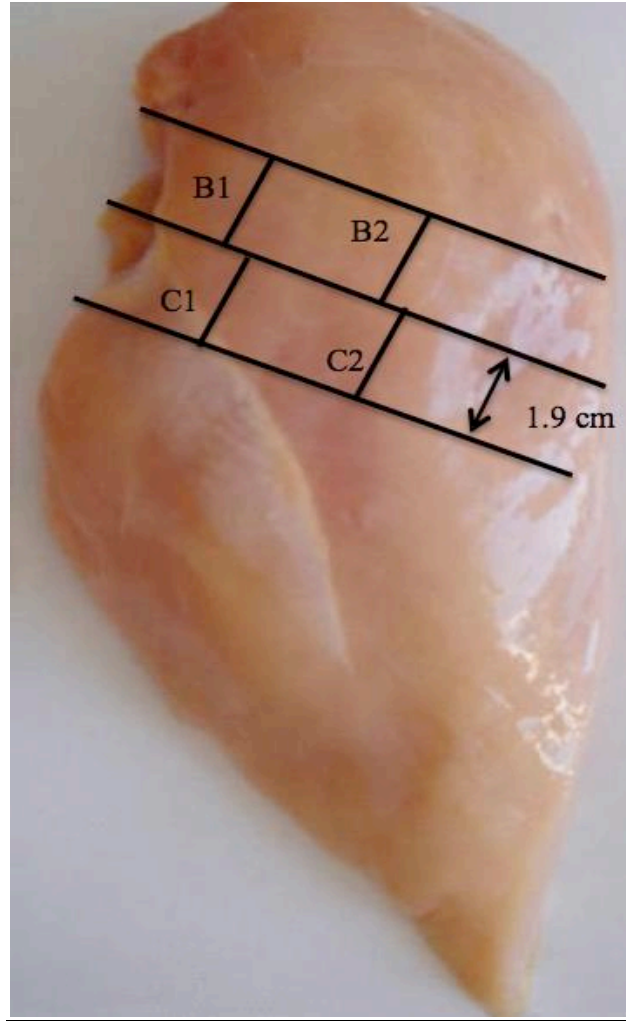


Figure 4.4. Diagram of the template used to cut the 4 locations of height (cm) and shear force (N) measurement in each of the broiler breast fillets.

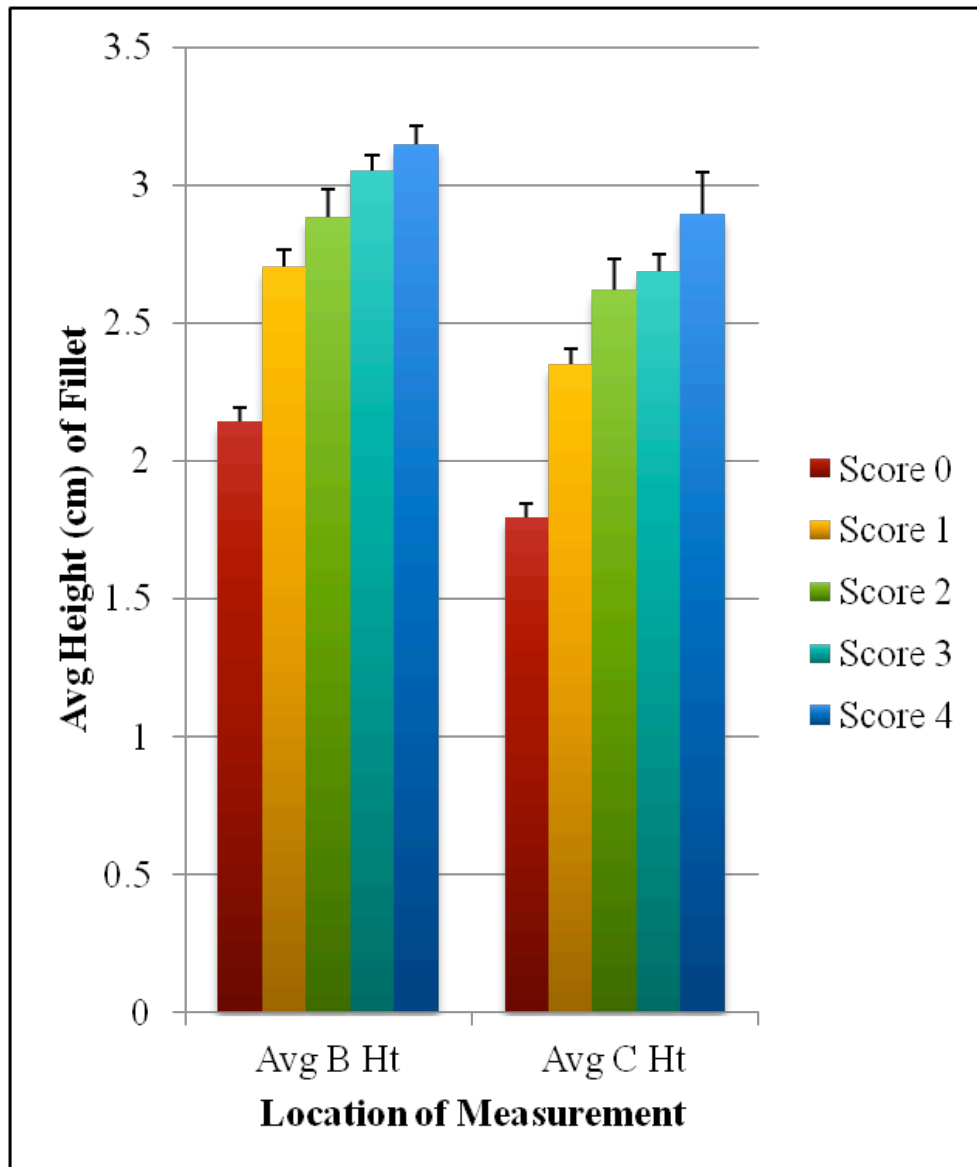


Figure 4.5. Average thickness (cm) of each level of striation severity at the 2 locations of measurement.

CHAPTER 5

AN INVESTIGATION OF THE RELATIONSHIP BETWEEN WHITE STRIATIONS IN BROILER BREAST FILLETS AND MEAT QUALITY

Abstract

A study was conducted to evaluate whether white striations on the surface of broiler breast fillets are correlated to meat quality parameters. Two modern broiler strains (M1 and M2) were compared to a slower growing 1990's randombred strain (RB). There were 4 dietary treatments differing in fat quality and supplemental vitamin/trace nutrient level. At day 41, broilers were processed and breast fillets scored on a 0 – 4 scale indicating no, slight, moderate, considerable, and severe striations, respectively.

Inconsistent data allowed no overall correlations between white striations and meat quality parameters. A positive correlation existed between white striations and yellowness (b^*) colorimeter scores, as well as lipid content within breast fillets. Meat quality parameters varied significantly ($p < 0.001$) between modern and RB broilers. The breast fillets of modern broilers had significantly ($p < 0.001$) higher yellowness colorimeter values and lipid content, but lower collagen content and pH values.

Introduction

Product quality is a critical factor to the success of the poultry industry and is affected by the industry's efforts to meet the dramatic increase of consumer demand over recent decades. Consumer expectations have risen with their newfound ability to closely

inspect products prior to purchasing, making visual appearance a serious component to sales (Kuttappan et al., 2012b). This is attributed to the shift in consumer demand from whole carcasses to further processed products (Brewer et al., 2012). Today's consumers value the convenience and selection that further processed products allow. Supplying this fast growing market has required geneticists to use precise genetic modifications to select only desirable qualities such as better feed efficiency, increased growth rate, and higher yield (Petracci and Cavani, 2012).

The increasingly fast growth rate of modern broilers has allowed the industry to meet the growing consumer demands, but have increased the prevalence of quality defects in the meat including muscle myopathies, PSE (pale, soft, and exudative) breast meat, color abnormalities, and white striations in broiler breast fillets (Petracci and Cavani, 2012). Muscle tissues undergo histological and biochemical modifications from such rapid development, leaving them unable to support themselves and with severe muscle damage (Dransfield and Sosnicki, 1999).

Such damage is shown in breast fillets exhibiting white striations, which have become a serious widespread quality defect to the poultry industry throughout recent decades. White striations run parallel to muscle fibers within the breast and vary in severity levels. Although focused mainly on their presence in the highly valued breast fillets, these striations may also be found on broiler thighs and tenders. Meat acquires a fatty appearance as the level of striation severity increases, and has been shown to negatively affect consumer acceptance (Kuttappan et al., 2012c). Moderate or severe striations can lead to downgrading or having to be used in only further processed products where visual appearance is not a concern.

Although visual appearance is affected, striations also alter the nutritional benefits of poultry by increasing fat content and decreasing protein content of the meat (Kuttappan et al., 2012a). These changes can lead to serious economic losses, because the health benefits of poultry are a serious quality to its growing popularity. The purpose of this study was to test the hypotheses that 1) The incidence and severity of white striations are not correlated to color variations within the fillet; 2) No correlation exists between white striations and pH values; 3) White striping is not correlated to the collagen content within breast fillets; 4) No correlation exists between white striations and lipid content in the breast; 5) No variation exists in the meat of modern broiler strains compared to 1990's randombred broilers.

Material and Methods

This study consisted of a 3 x 2 x 2 factorial design including 12 treatments, 3 broiler strains, and 4 diets.

General Husbandry

The chicks were placed in 2 window-less rooms, environmentally controlled to maintain uniform conditions. There was 1 hanging feeder and 10 nipple drinkers per pen. During d 0 – 3, temperature was set between 90-93° C and reduced 1° C each day until 75° C was achieved. Lighting was from 27 Paragon EC40005 incandescent light fixtures providing lighting levels on floor of 0.15 – 0.61 m, 5 – 18 lumen candles. The floor of each pen was covered with 0.05 m of clean pine shavings. Pens for M1 and M2 broilers were 1.22 x 3.05 m with 30 chicks placed in each. Pens for RB were 1.22 x 1.52 m with

10 chicks placed per pen. Distributed through the 48 pens were 4 dietary treatments (Tables 5.1 and 5.2) and 3 broiler strains.

Weights and feed conversion ratios (FCR) were determined by pen on days 0, 18, and 40. All mortalities and/or culled birds were weighed and recorded, including any obvious cause of death. FCR was reported as total feed consumed/total weight of birds produced.

Genetic Strains

There were three genetic strains: 2 modern (M1 and M2) and a 1990's randombred strain (RB). A total of 1,120 straight run, 1-d-old chicks were distributed by strain into 48 floor pens; 480 of each modern strain and 160 RB chicks.

Dietary Treatments

There were 4 dietary treatments with a 2 x 2 factorial design; each based on an industry corn and soybean diet (Tables 5.1 and 5.2) with normal or oxidized fat, and standard or doubled vitamin/trace mineral mix (TN).

Oxidizing Poultry Fat

One hundred kg of standard poultry fat was poured into a Legion Steam Jacketed Kettle equipped with a Campbell Hausfeld 26 gallon air system running at 5 HP, 15 amps, and 6.8 at 90 PSI. The kettle was fitted with 2 m of 1 cm copper tubing with 47 – 10 mm holes. Air was pumped through the fat at 10 L/min for 117 hours, 66 hours at 20°C and 51 hours at 98-105°C.

Processing & Scoring

At day 7, 10 birds were randomly selected from each pen and fitted with wing tags with identification numbers. On d 41, 3 male and 3 female tagged birds were randomly selected, weighed live, immediately following evisceration (pre-chill) and after carcasses were iced at 1°C for 240 min (post-chill). Carcasses were subsequently deboned at 4.5 h postmortem and the breast fillets scored for severity of white striations.

Striation Severity Scoring

Striation scores were determined from a 5-point scale. A score of 0 – 4 was given based on the severity of white striations. Scores indicated severity levels as no striations, slight, moderate, considerable, and severe, respectively (Figure 5.1, 5.2, and 5.3).

Color Measurement

CIE color values were measured using a Minolta Chroma Meter (Model CR-310, wide-area illumination, 50 mm-diameter measuring area, C Illuminant; Minolta Co., Ltd.; Ramset, NJ, USA). Lightness (L*), redness (a*), and yellowness (b*) measurements were recorded from the internal surface on the cranial end of the fillet. Standardized black and white tiles were used to calibrate the colorimeter prior to use.

pH

The pH measurements were recorded from two locations on the breast, as depicted in Figure 5.4, using a spear-tipped probe portable pH 11 meter (Eutech Instruments Pte Ltd/Oakton Instruments, Vernon Hills, IL, USA).

Collagen

Right breast fillets were homogenized in a commercial blender (Waring Commercial, model 51BL31, 120V, Torrington, Connecticut) using liquid nitrogen. All procedures prior to autoclaving were as described by Hill (1966). Post autoclaving procedures were as followed by other studies evaluating intramuscular collagen (Bergman and Loxley, 1963; Cross et al., 1973). Soluble and insoluble collagen content procedures were completed and are expressed as milligrams of collagen per gram of skeletal muscle (mg/g).

Lipid Content

Right breast fillets were trimmed of any excess fat or connective tissue. Fillets were powder homogenized in a blender (Waring Commercial, model 51BL31, 120V, Torrington, Connecticut) and prepared in duplicate as described by Folch et al. (1957), with only slight modifications. Aluminum pans dried overnight in a 90°C oven and were equilibrated 5 – 10 minutes in a desiccator. Homogenized fillet samples (2.5 ± 0.1 g) were measured into 50 mL conical tubes and 15 mL of a (2:1) methanol:chloroform mixture was added to each. Samples were homogenized (Polytron homogenizer) at medium speed for 30 seconds. Samples sat for 1 hour at room temperature before 5 mL of chloroform and 5 mL of 1M KCl were added to each tube. Tubes were vortexed, placed into an ice bath for 5 minutes, and centrifuged (2,000 rpm; 0°C) for 10 minutes. The top layer of each sample was aspirated off without disturbing the bottom pellet. Pellets were dislodged by thumping and poured into the pre-weighed aluminum pans. Tubes were discarded and pans left overnight in the hood (fan on). Pans were placed into the 90°C

drying oven for 15 minutes and a desiccator for 5 minutes before being weighed. The percentage of lipid content was calculated using the formula:

$$(\text{pan with lipid wt} - \text{pan wt}) / \text{sample wt} \times 100\%$$

Statistical Analysis

Data was subjected to correlation testing against white striation severity, using the proximate correlation analysis (PROC CORR) (SAS Institute, Inc.). Independent variables were broiler strain, gender, fat quality, vitamin/trace nutrient mix level and their interaction terms. Parameters analyzed to evaluate meat quality of broiler breasts were CIE colorimeter measurements, pH values, collagen content (soluble and insoluble), and lipid content. ANOVA was conducted using the general linear model (GLM), to evaluate differences between independent variables and their interactions, specifically modern broilers versus RB broilers, to the test parameters. Mean and standard deviations were analyzed using ANOVA with a $p < 0.05$ considered significant (SAS Institute, Inc.). Main effect means were displayed (Mean \pm Standard Error) for all dependent variables.

Results

A significant ($p=0.023$) correlation between white striations and the lightness (L^*) colorimeter value of M1 female broilers was found (Table 5.3). There were no significant correlations between redness (a^*) colorimeter measurements and white striation severity. Yellowness (b^*) measurements were significantly correlated to the prevalence and severity of white striations in male ($p=0.034$) and female ($p=0.020$) M2 broilers (Table 5.3). Strain ($p < 0.001$), fat ($p=0.026$), gender/fat interaction ($p=0.045$), and strain/TN

interaction were significantly related to lightness (L^*) colorimeter values ($p=0.035$) (Table 5.4). Modern broilers, M1 ($L^*=61.10$) and M2 ($L^*=61.56$), displayed significantly greater lightness values (L^*) than RB broilers ($L^*=58.11$) (Table 5.5 and 5.6). Factors significant to redness (a^*) were strain ($p<0.001$) and a gender/fat interaction ($p=0.019$) (Table 5.4). Redness in RB fillets ($a^*=15.60$) was higher than in modern strains, M1 ($a^*=14.30$) and M2 ($a^*=15.09$) (Table 5.5). Yellowness (b^*) was significant to broiler strain ($p<0.001$), gender ($p<0.001$), vitamin/trace nutrient level (TN) ($p<0.001$), strain/gender/TN interaction ($p=0.034$), and fat/TN interaction ($p=0.007$) (Table 5.4).

The correlation between the pH measurement at location B and white striation severity was significant ($p=0.050$) in M1 female broilers (Table 5.3). There were no other strain/gender correlations significant to pH and white striping. Factors significantly related to the pH measurements at both locations were strain ($p<0.001$), fat (loc. A - $p=0.014$; loc. E - $p=0.002$), and strain/TN interaction (loc. A - $p=0.026$; loc. E - $p=0.002$) (Table 5.7). RB broilers had the highest pH values at both locations, A (pH=6.29) and E (pH=6.34) (Table 5.8). Broilers fed diets containing normal poultry fat had significantly higher pH values at locations A (pH=6.16) and E (pH=6.22) than broilers fed diets containing oxidized fat (Table 5.8 and 5.9).

Significant correlations ($p=0.002$) were found between white striations and the soluble ($p=0.002$) and insoluble ($p<0.001$) collagen content of M2 female broilers (Table 5.10). Strain and gender were significant ($p<0.001$) factors to soluble and insoluble collagen content (Table 5.13). Fat quality ($p<0.001$) and strain/gender/fat interaction ($p=0.044$) were significant factors related only to insoluble collagen content. RB broilers

had significantly higher collagen content compared to modern strains, M1 and M2 (Table 5.11 and 5.12). Male broilers exceeded females in collagen content (Table 5.11 and 5.12).

The lipid content within the breast was significantly correlated to white striations in M1 male ($p=0.033$) and M2 female broilers ($p=0.017$) (Table 5.14). Breast fillet weight was significantly ($p<0.001$) correlated to white striping in M2 female broilers (Table 5.14). No correlations were found between white striations and the total grams of lipid present in breast fillets (Table 5.14).

Strain ($p<0.001$), gender ($p<0.001$), and a strain/gender interaction ($p=0.042$) were significant to broiler breast weight (Table 5.15). Fillets of modern broilers, M1 (0.55 kg) and M2 (0.58 kg), more than doubled the weight of RB (0.24 kg) broilers (Table 5.16 and 5.17). The breast fillets of male broilers were significantly heavier (0.49 kg) compared to females (0.42 kg) (Table 5.16). Strain ($p<0.001$), strain/gender interaction ($p=0.003$), strain/gender/TN interaction ($p=0.043$), and a gender/fat/TN interaction ($p=0.030$) were factors significant to the lipid content present within a breast fillet (Table 5.15). RB broilers had significantly lower lipid content (1.31%) in their breast fillets than modern strains, M1 (1.55%) and M2 (1.62%) (Table 5.16).

Discussion

The null hypothesis that the incidence and severity of white striations in breast fillets are not correlated to colorimeter measurements should be further evaluated due to inconsistent data (Table 5.3). Previous research has demonstrated the positive relationship between yellowness (b^*) values and striation severity (Kuttappan et al., 2009; Kuttappan et al., 2012c; Kuttappan et al., 2013a; Petracci et al., 2013). Kuttappan

et al. (2012c) proposed the higher yellowness values were caused by higher fat content within fillets more severely affected by white striations. Although results showed strain and gender combinations that were significant to white striations, an overall trend could not be established. Figure 4.5 illustrates how the yellowness values increased in fillets more severely striated. The two studies may have contrasting results due to different grow out periods (41 versus 61 days) or dissimilar locations of measurements.

Data (Table 5.3) indicated the null hypothesis that no correlations exist between white striations and pH values in breasts should be further evaluated due to inconsistent data. Previous research has been unclear, giving contrasting results on pH and striping severity. Petracci et al. (2013) demonstrated that significantly higher pH values are present in severely striped fillets compared to normal or moderate fillets. In contrast, Kuttappan et al. (2009; 2013a) found no significance between pH and striation severity. Differences in the two studies included 1) grow out period (Petracci et al., 2013 - 49 d-old; Kuttappan et al., 2013a - 59-63 d-old) and 2) strain and gender (Petracci et al., 2013 - Ross 708 broilers, straight run; Kuttappan et al., 2013a - 4 modern broilers strains, equal genders).

The data (Table 5.10) indicates the null hypothesis that collagen content is not correlated to the severity or incidence of white striations should be further evaluated, as no consistent trends existed. Petracci et al. (2014) demonstrated that more heavily striped fillets contain higher levels of collagen than fillets unaffected or moderately striped. The two studies differed in 1) different testing methods (Petracci et al., 2014 - colorimeter method; current study - spectrophotometric determination) and 2) strain and age (Petracci

et al., 2014 - 49 d-old, Ross 708 broilers; present study - 2 modern broiler strains and 1 1990's RB strain, 41 d-old).

Inconsistent data (Table 5.14) indicates the null hypothesis that no correlations exist between white striations and lipid content in the breast should be further evaluated. Previous research has shown that a positive correlation exists between white striation severity and the lipid content within breast fillets (Kuttappan et al., 2012a; Petracci et al., 2014). Kuttappan et al. (2012a) suggested that the increase in lipid content may be due to a decrease in the protein level within the breast caused by white striations allowing room for adipocytes to expand, which increases the fat content. There were no trends in the results of this study to indicate a significant correlation, however there was a positive relationship between striping and lipid content as shown in Figure 4.6.

The data (Table 5.4, 5.8, 5.11, 5.13, and 5.15) indicates the null hypothesis that no variations exist in the meat quality of modern compared to RB broilers should be rejected. Strain was a significant ($p < 0.001$) factor to the colorimeter values (L^* , a^* , b^*). Santiago et al. (2005) found a positive correlation between breast meat yield and lightness (L^*) values, supporting results in the present study showing significantly higher lightness values in the modern broiler strains. Mehaffey et al. (2006) did find variation in the lightness values between strains, but no relationship between lightness and breast yield or body weight. The differences in the two studies may be the strain of broiler used for the study. Bihan-Duval et al. (1999) indicated no strain differences in lightness (L^*) measurements. Duclos et al. (2007) proposed that increased breast muscle indicates larger muscle fibers present, which leads to decreased lightness values.

Supporting the effect of strain on pH in this study, Mehaffey et al. (2006) also determined that strain is a significant factor related to muscle pH. Bihan-Duval et al. (1999) found slightly higher pH measurements in strains selected for decreased abdominal fat, concluding that genetic strain is a sizeable factor in meat quality traits.

The data (Table 5.13) indicated that there are statistically significant differences ($p < 0.001$) in the soluble and insoluble collagen content of broiler strains. Intarapichet et al. (2008) also found that collagen content differed between breeds and genders. Insoluble collagen is an important factor to meat tenderness, making it an important part of meat quality (Intarapichet et al., 2008). Roy et al. (2006) reported that high-energy diets increase the insoluble collagen content, supported by the present study showing fat quality is significant ($p < 0.001$) to insoluble collagen (Table 5.13). However, Roy et al. (2006) found no significant relationship between strain and collagen content, possibly due to the strains used in the studies being different.

Data (Table 5.15) indicated strain ($p < 0.001$) is significant to lipid content in breast fillets. Wang et al. (2010) explained the precise genetic selection that allowed for faster growth rates in modern broiler strains. This study also found significantly more lipid in the breasts of modern broilers compared to RB broilers. Hermier et al. (1989) demonstrated the significantly larger abdominal fat pads in modern broilers that far exceeded those found in leaner broiler strains.

Conclusion

No significant overall trends were established showing correlations between white striations and the parameters surrounding meat quality. Yellowness values (b^*) were

positively related to striation severity, possibly caused by higher fat contents within the meat. This was supported by the positive relationship shown between white striation severity and lipid content within the breasts. Significant variations in meat quality were found between modern and RB broilers. Breasts of modern broilers had a lighter, yellower color, that were lower in pH and collagen, but higher in lipid content than the slower growing RB broilers.

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Table 5.1. Composition of starter diets (0 - 17 d) with differing levels of vitamin/trace nutrient mix, standard (1 x) and doubled (2 x) and fat quality, normal or oxidized.

Fat Quality	Normal	Oxidized	Normal	Oxidized
Trace Nutrient Level	1x	1x	2x	2x
Ingredient	-----%-----			
Ground yellow corn	51.36	51.36	51.36	51.36
Soybean meal (dehulled)	39.20	39.20	39.20	39.20
Standard poultry fat	6.013	0.000	6.013	0.000
Oxidized poultry fat	0.000	6.013	0.000	6.013
Salt	0.400	0.400	0.400	0.400
L-Lysine HCl	0.175	0.175	0.175	0.175
DL-Methionine	0.307	0.307	0.307	0.307
L-Threonine	0.063	0.063	0.063	0.063
Limestone	0.175	0.175	0.175	0.175
Defluorinated P	1.882	1.882	1.882	1.882
Vitamin Mix ¹	0.250	0.250	0.500	0.500
Trace Mineral Mix ²	0.075	0.075	0.150	0.150
Coban ³	0.050	0.050	0.050	0.050
BMD ⁴	0.050	0.050	0.050	0.050

¹Vitamin mix provided the following (per kilogram of diet): thiamin-mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B₁₂ (cobalamin), 12.0g; pyridoxine-HCl, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-reinyl acetate, 2,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

²Trace mineral mix provides the following (per kilogram of diet): manganese (MnSO₄.H₂O), 101 mg; iron (FeSO₄.7H₂O), 20 mg; zinc (Zn), 80 mg; copper (CuSO₄.5H₂O), 3 mg; iodine (ethylene diamine dihydroiodide), 0.75 mg; magnesium (MgO), 20 mg; selenium (sodium selenite), 0.3 mg.

³Coban (Type A) provides (per pound of diet): Monensin, USP 90.7g; aids in prevention of coccidiosis.

⁴BMD (Bacitracin Methylene Disalicylate - Type A) provides (per pound of diet): feed grade bacitracin methylene disalicylate equivalent to 50 g bacitracin.

Table 5.2. Composition of grower diets (18 - 41 d) with differing levels of vitamin/trace nutrient mix, standard (1 x) and doubled (2 x) and fat quality, normal or oxidized.

Fat Quality	Normal	Oxidized	Normal	Oxidized
Trace Nutrient Level	1x	1x	2x	2x
Ingredient	-----%-----			
Ground yellow corn	55.74	55.74	55.74	55.74
Soybean meal (dehulled)	35.20	35.20	35.20	35.20
Standard poultry fat	5.900	0.000	5.900	0.000
Oxidized poultry fat	0.000	5.900	0.000	5.900
Salt	0.400	0.400	0.400	0.400
L-Lysine HCl	0.148	0.148	0.148	0.148
DL-Methionine	0.267	0.267	0.267	0.267
L-Threonine	0.041	0.041	0.041	0.041
Limestone	0.197	0.197	0.197	0.197
Defluorinated P	1.679	1.679	1.679	1.679
Vitamin Mix ¹	0.250	0.250	0.500	0.500
Trace Mineral Mix ²	0.075	0.075	0.150	0.150
Coban ³	0.050	0.050	0.050	0.050
BMD ⁴	0.050	0.050	0.050	0.050

¹Vitamin mix provided the following (per kilogram of diet): thiamin-mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B₁₂ (cobalamin), 12.0g; pyridoxine-HCl, 2.7 mg; D-biotin, 0.11 mg; folic acid, 0.55 mg; menadione sodium bisulfate complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 1,100 IU; trans-reinyl acetate, 2,500 IU; all-rac-tocopherol acetate, 11 IU; ethoxyquin, 150 mg.

²Trace mineral mix provides the following (per kilogram of diet): manganese (MnSO₄.H₂O), 101 mg; iron (FeSO₄.7H₂O), 20 mg; zinc (Zn), 80 mg; copper (CuSO₄.5H₂O), 3 mg; iodine (ethylene diamine dihydroiodide), 0.75 mg; magnesium (MgO), 20 mg; selenium (sodium selenite), 0.3 mg.

³Coban (Type A) provides (per pound of diet): Monensin, USP 90.7g; aids in prevention of coccidiosis.

⁴BMD (Bacitracin Methylene Disalicylate - Type A) provides (per pound of diet): feed grade bacitracin methylene disalicylate equivalent to 50 g bacitracin.

Table 5.3. Correlation analysis on the correlation between white striations and the colorimeter measurements (L^* , a^* , b^*) and pH values (location A and E); r = Pearson Correlation Coefficients, p = Prob $> |r|$ under $H_0: \rho=0$, N = Number of Observations.

		Randombred		Modern Strain1		Modern Strain 2	
		Female	Male	Female	Male	Female	Male
L - Front	r	-0.157	-0.419	0.563	-0.321	0.401	0.273
	p	0.561	0.106	0.023	0.225	0.124	0.307
	N	16	16	16	16	16	16
a* - Front	r	0.188	0.197	-0.228	-0.131	0.354	-0.245
	p	0.486	0.465	0.396	0.630	0.178	0.361
	N	16	16	16	16	16	16
b* - Front	r	-0.336	0.104	0.332	0.338	-0.574	0.531
	p	0.204	0.702	0.209	0.201	0.020	0.034
	N	16	16	16	16	16	16
L - Back	r	-0.171	-0.396	0.192	-0.411	0.127	-0.015
	p	0.526	0.129	0.477	0.114	0.639	0.955
	N	16	16	16	16	16	16
a* - Back	r	0.274	0.014	-0.020	-0.234	-0.330	-0.378
	p	0.304	0.959	0.941	0.383	0.212	0.149
	N	16	16	16	16	16	16
b* - Back	r	-0.223	-0.073	0.058	0.256	-0.314	0.108
	p	0.406	0.787	0.831	0.338	0.236	0.690
	N	16	16	16	16	16	16
pH – Location A	r	-0.265	0.074	-0.471	-0.326	0.305	-0.049
	p	0.321	0.785	0.065	0.217	0.251	0.857
	N	16	16	16	16	16	16
pH – Location B	r	-0.240	-0.072	-0.497	-0.134	0.249	0.039
	p	0.370	0.791	0.050	0.621	0.353	0.886
	N	16	16	16	16	16	16

Table 5.4. General Linear Model (GLM) for the effect of strain, gender, fat quality, trace nutrient supplementation, and all interactions on the colorimeter measurements (L^* , a^* , b^*).

Source	df	Pr > F – Type III		
		L^* ⁴	a^* ⁵	b^* ⁶
Strain ¹	2	<0.001	<0.001	<0.001
Gender	1	0.839	0.140	<0.001
Strain*Gender	2	0.119	0.756	0.151
Fat ²	1	0.026	0.967	0.115
Strain*Fat	2	0.810	0.413	0.194
Gender*Fat	1	0.045	0.019	0.933
Strain*Gender*Fat	2	0.343	0.494	0.280
TN ³	1	0.335	0.240	<0.001
Strain*TN	2	0.035	0.313	0.369
Gender*TN	1	0.482	0.886	0.914
Strain*Gender*TN	2	0.381	0.678	0.034
Fat*TN	1	0.510	0.698	0.007
Strain*Fat*TN	2	0.995	0.380	0.763
Gender*Fat*TN	1	0.886	0.970	0.809
Strain*Gender*Fat*TN	2	0.931	0.770	0.218
R-Square		0.667	0.367	0.573

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, standard (1 \times) or doubled (2 \times)

⁴ L^* = lightness value (0 = white; 100 = black)

⁵ a^* = redness value (-a = green; +a = red)

⁶ b^* = yellowness value (-b = blue; +b = yellow)

Table 5.5. Main effect means of colorimeter measurements by strain, gender, fat quality, and trace nutrient supplementation of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Colorimeter Scores		
					L ⁴	a* ⁵	b* ⁶
RB				8	58.11 \pm 1.86	15.60 \pm 1.27	13.23 \pm 1.38
M1 ²				8	62.10 \pm 1.31	14.30 \pm 0.84	14.54 \pm 1.28
M2 ³				8	61.56 \pm 1.62	15.09 \pm 1.10	14.40 \pm 1.22
	1 \times			12	60.44 \pm 2.68	15.13 \pm 1.31	14.51 \pm 1.24
	2 \times			12	60.75 \pm 2.07	14.86 \pm 1.07	13.60 \pm 1.44
		Normal		12	60.23 \pm 2.27	15.00 \pm 1.13	14.23 \pm 1.54
		Oxidized		12	60.95 \pm 2.47	14.99 \pm 1.27	13.88 \pm 1.25
			Male	12	60.62 \pm 2.59	14.83 \pm 1.37	13.62 \pm 1.55
			Female	12	60.56 \pm 2.20	15.16 \pm 0.98	14.49 \pm 1.10

¹Strain = 1990's Rando-bred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace mineral mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

⁴L* = lightness value (0 = white; 100 = black)

⁵a* = redness value (-a = green; +a = red)

⁶b* = yellowness value (-b = blue; +b = yellow)

Table 5.6. Effects of strain, gender, fat quality, and trace nutrient supplementation on the colorimeter measurements (L^* , a^* , b^*) of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	TN ²	Fat quality ³	Gender	n	Colorimeter Scores - Front		
					L^4	a^{*5}	b^{*6}
RB ¹	1 X	Normal	Male	4	57.64 \pm 2.69	15.48 \pm 1.92	13.38 \pm 0.93
RB	1 X	Normal	Female	4	56.68 \pm 1.67	16.26 \pm 0.95	14.81 \pm 0.39
RB	1 X	Oxidized	Male	4	56.76 \pm 1.04	16.52 \pm 1.01	13.62 \pm 1.51
RB	1 X	Oxidized	Female	4	58.48 \pm 0.90	15.62 \pm 1.26	13.73 \pm 1.10
RB	2 X	Normal	Male	4	58.32 \pm 0.95	14.29 \pm 1.37	11.45 \pm 0.92
RB	2 X	Normal	Female	4	58.37 \pm 0.58	15.57 \pm 0.75	13.27 \pm 0.42
RB	2 X	Oxidized	Male	4	58.02 \pm 1.48	15.77 \pm 1.49	11.58 \pm 0.87
RB	2 X	Oxidized	Female	4	60.60 \pm 2.50	15.25 \pm 0.73	14.02 \pm 0.83
M1 ²	1 X	Normal	Male	4	61.74 \pm 0.43	14.00 \pm 0.58	15.20 \pm 0.53
M1	1 X	Normal	Female	4	61.61 \pm 0.83	15.03 \pm 0.53	15.88 \pm 0.94
M1	1 X	Oxidized	Male	4	62.31 \pm 0.83	14.01 \pm 0.91	12.98 \pm 0.36
M1	1 X	Oxidized	Female	4	62.58 \pm 2.36	14.21 \pm 1.43	15.21 \pm 0.98
M1	2 X	Normal	Male	4	62.22 \pm 0.91	14.17 \pm 0.71	14.55 \pm 2.01
M1	2 X	Normal	Female	4	60.87 \pm 0.93	14.69 \pm 0.69	14.31 \pm 0.56
M1	2 X	Oxidized	Male	4	62.79 \pm 1.61	13.91 \pm 0.96	13.97 \pm 0.39
M1	2 X	Oxidized	Female	4	62.70 \pm 1.48	14.40 \pm 0.69	14.20 \pm 1.64
M2 ³	1 X	Normal	Male	4	62.50 \pm 1.75	14.45 \pm 0.97	15.12 \pm 1.14
M2	1 X	Normal	Female	4	60.91 \pm 1.07	15.32 \pm 0.99	15.49 \pm 0.77
M2	1 X	Oxidized	Male	4	62.54 \pm 2.52	15.23 \pm 1.89	14.07 \pm 1.51
M2	1 X	Oxidized	Female	4	61.48 \pm 1.47	15.43 \pm 0.64	14.63 \pm 0.51
M2	2 X	Normal	Male	4	61.10 \pm 1.67	15.01 \pm 1.29	13.10 \pm 1.47
M2	2 X	Normal	Female	4	60.79 \pm 2.08	15.75 \pm 0.84	14.17 \pm 1.64
M2	2 X	Oxidized	Male	4	61.55 \pm 1.78	15.13 \pm 1.31	14.41 \pm 0.92
M2	2 X	Oxidized	Female	4	61.62 \pm 0.39	14.43 \pm 0.67	14.19 \pm 0.53

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace mineral mix in the diet, either standard (1 X) or doubled (2 X)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

⁴ L^* = lightness value (0 = white; 100 = black)

⁵ a^* = redness value (-a = green; +a = red)

⁶ b^* = yellowness value (-b = blue; +b = yellow)

Table 5.7. General Linear Model (GLM) for the effect of strain, gender, fat quality, trace nutrient supplementation level, and all interactions on pH measurements at location A and E.

Source	df	Pr > F – Type III	
		Location A	Location E
Strain ¹	2	<0.001	<0.001
Gender	1	0.117	0.996
Strain*Gender	2	0.370	0.477
Fat ²	1	0.014	0.002
Strain*Fat	2	0.256	0.099
Gender*Fat	1	0.184	0.169
Strain*Gender*Fat	2	0.875	0.858
TN ³	1	0.884	0.865
Strain*TN	2	0.026	0.002
Gender*TN	1	0.824	0.558
Strain*Gender*TN	2	0.170	0.150
Fat*TN	1	0.934	0.985
Strain*Fat*TN	2	0.627	0.398
Gender*Fat*TN	1	0.330	0.156
Strain*Gender*Fat*TN	2	0.401	0.716
R-Square		0.631	0.676

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, standard (1 x) or doubled (2 x)

Table 5.8. Main effect means of pH measurements by strain, gender, fat quality, and trace nutrient supplementation level of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	pH	
					Location A	Location E
RB				8	6.29 \pm 0.13	6.34 \pm 0.14
M1				8	5.98 \pm 0.15	6.03 \pm 0.14
M2				8	6.12 \pm 0.14	6.16 \pm 0.12
	1 \times			12	6.13 \pm 0.21	6.18 \pm 0.21
	2 \times			12	6.13 \pm 0.16	6.17 \pm 0.15
		Normal		12	6.16 \pm 0.17	6.22 \pm 0.16
		Oxidized		12	6.09 \pm 0.20	6.14 \pm 0.20
			Male	12	6.15 \pm 0.21	6.18 \pm 0.20
			Female	12	6.11 \pm 0.17	6.18 \pm 0.17

¹Strain = 1990's Rando-bred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, standard (1 \times) or doubled (2 \times)

Table 5.9. Effects of strain, gender, fat quality, and trace nutrient supplementation level on pH measurements in broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	pH	
					Location A	Location E
RB	1 X	Normal	Male	4	6.43 \pm 0.13	6.48 \pm 0.07
RB	1 X	Normal	Female	4	6.30 \pm 0.05	6.38 \pm 0.03
RB	1 X	Oxidized	Male	4	6.40 \pm 0.15	6.44 \pm 0.21
RB	1 X	Oxidized	Female	4	6.26 \pm 0.10	6.32 \pm 0.12
RB	2 X	Normal	Male	4	6.19 \pm 0.13	6.22 \pm 0.15
RB	2 X	Normal	Female	4	6.28 \pm 0.13	6.34 \pm 0.14
RB	2 X	Oxidized	Male	4	6.30 \pm 0.10	6.30 \pm 0.07
RB	2 X	Oxidized	Female	4	6.18 \pm 0.04	6.23 \pm 0.06
M1	1 X	Normal	Male	4	6.00 \pm 0.22	6.09 \pm 0.15
M1	1 X	Normal	Female	4	6.06 \pm 0.04	6.12 \pm 0.04
M1	1 X	Oxidized	Male	4	5.85 \pm 0.10	5.87 \pm 0.11
M1	1 X	Oxidized	Female	4	5.94 \pm 0.23	5.98 \pm 0.23
M1	2 X	Normal	Male	4	6.03 \pm 0.10	6.08 \pm 0.11
M1	2 X	Normal	Female	4	6.06 \pm 0.09	6.13 \pm 0.07
M1	2 X	Oxidized	Male	4	6.01 \pm 0.07	6.03 \pm 0.07
M1	2 X	Oxidized	Female	4	5.86 \pm 0.13	5.93 \pm 0.12
M2	1 X	Normal	Male	4	6.10 \pm 0.16	6.10 \pm 0.11
M2	1 X	Normal	Female	4	6.09 \pm 0.19	6.12 \pm 0.15
M2	1 X	Oxidized	Male	4	6.11 \pm 0.08	6.13 \pm 0.06
M2	1 X	Oxidized	Female	4	6.02 \pm 0.12	6.10 \pm 0.11
M2	2 X	Normal	Male	4	6.24 \pm 0.15	6.21 \pm 0.10
M2	2 X	Normal	Female	4	6.16 \pm 0.12	6.29 \pm 0.13
M2	2 X	Oxidized	Male	4	6.13 \pm 0.19	6.15 \pm 0.16
M2	2 X	Oxidized	Female	4	6.06 \pm 0.06	6.16 \pm 0.08

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, standard (1 X) or doubled (2 X)

Table 5.10. Correlation analysis on the correlation between white striations and soluble and insoluble collagen content of broiler breast fillets; r = Pearson Correlation Coefficients, p = Prob > | r | under H0:Rho=0, N = Number of Observations.

		Ranombred		Modern Strain 1		Modern Strain 2	
		Female	Male	Female	Male	Female	Male
Soluble Collagen Content (mg/g)	r	-0.168	-0.112	-0.005	-0.056	0.466	-0.141
	p	0.306	0.595	0.980	0.736	0.002	0.411
	N	16	16	16	16	16	16
Insoluble Collagen Content (mg/g)	r	-0.093	-0.331	0.012	-0.192	0.551	0.021
	p	0.574	0.106	0.949	0.242	0.000	0.903
	N	16	16	16	16	16	16

Table 5.11. Main effect means of soluble and insoluble collagen content by strain, gender, fat quality, and trace nutrient supplementation level of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Collagen Content (mg/g)	
					Soluble	Insoluble
RB				8	1.77 \pm 0.06	4.36 \pm 0.08
M1				8	1.24 \pm 0.06	3.56 \pm 0.11
M2				8	1.40 \pm 0.08	3.82 \pm 0.16
	1 \times			12	1.48 \pm 0.06	3.89 \pm 0.09
	2 \times			12	1.44 \pm 0.07	3.92 \pm 0.13
		Normal		12	1.51 \pm 0.06	4.09 \pm 0.11
		Oxidized		12	1.42 \pm 0.06	3.73 \pm 0.10
			Male	12	1.68 \pm 0.06	4.26 \pm 0.09
			Female	12	1.27 \pm 0.05	3.57 \pm 0.11

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, standard (1 \times) or doubled (2 \times)

Table 5.12. Effects of strain, gender, fat quality, and trace nutrient supplementation level on soluble and insoluble collagen content (mg/g) in broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Collagen Content (mg/g)	
					Soluble	Insoluble
RB	1 \times	Normal	Male	4	1.95 \pm 0.18	4.65 \pm 0.26
RB	1 \times	Normal	Female	4	1.47 \pm 0.17	3.87 \pm 0.20
RB	1 \times	Oxidized	Male	4	2.01 \pm 0.12	4.63 \pm 0.11
RB	1 \times	Oxidized	Female	4	1.59 \pm 0.16	4.11 \pm 0.19
RB	2 \times	Normal	Male	4	2.13 \pm 0.15	4.90 \pm 0.10
RB	2 \times	Normal	Female	4	1.65 \pm 0.04	4.59 \pm 0.11
RB	2 \times	Oxidized	Male	4	1.90 \pm 0.13	4.48 \pm 0.15
RB	2 \times	Oxidized	Female	4	1.58 \pm 0.11	3.87 \pm 0.11
M1	1 \times	Normal	Male	4	1.37 \pm 0.14	3.91 \pm 0.19
M1	1 \times	Normal	Female	4	1.27 \pm 0.18	3.95 \pm 0.30
M1	1 \times	Oxidized	Male	4	1.52 \pm 0.16	3.94 \pm 0.14
M1	1 \times	Oxidized	Female	4	1.01 \pm 0.09	3.06 \pm 0.15
M1	2 \times	Normal	Male	4	1.63 \pm 0.21	4.03 \pm 0.33
M1	2 \times	Normal	Female	4	0.89 \pm 0.14	2.94 \pm 0.17
M1	2 \times	Oxidized	Male	4	1.36 \pm 0.09	3.81 \pm 0.24
M1	2 \times	Oxidized	Female	4	1.00 \pm 0.12	2.98 \pm 0.21
M2	1 \times	Normal	Male	4	1.74 \pm 0.07	4.58 \pm 0.19
M2	1 \times	Normal	Female	4	1.15 \pm 0.10	3.04 \pm 0.21
M2	1 \times	Oxidized	Male	4	1.63 \pm 0.24	3.64 \pm 0.12
M2	1 \times	Oxidized	Female	4	1.19 \pm 0.10	3.45 \pm 0.24
M2	2 \times	Normal	Male	4	1.92 \pm 0.19	4.98 \pm 0.27
M2	2 \times	Normal	Female	4	1.26 \pm 0.20	3.94 \pm 0.51
M2	2 \times	Oxidized	Male	4	1.18 \pm 0.16	3.83 \pm 0.36
M2	2 \times	Oxidized	Female	4	1.12 \pm 0.24	3.10 \pm 0.59

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace mineral mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

Table 5.13. General Linear Model (GLM) for the effect of strain, gender, fat quality, trace nutrient supplementation level, and all interactions on soluble and insoluble collagen (mg/g) content of broiler breast fillets.

Source	df	Pr > F – Type III	
		Soluble Collagen	Insoluble Collagen
Strain ¹	2	<0.001	<0.001
Gender	1	<0.001	<0.001
Strain*Gender	2	0.736	0.245
Fat ²	1	0.086	0.001
Strain*Fat	2	0.400	0.183
Gender*Fat	1	0.317	0.539
Strain*Gender*Fat	2	0.385	0.044
TN ³	1	0.678	0.565
Strain*TN	2	0.544	0.161
Gender*TN	1	0.828	0.428
Strain*Gender*TN	2	0.400	0.454
Fat*TN	1	0.056	0.083
Strain*Fat*TN	2	0.557	0.075
Gender*Fat*TN	1	0.101	0.489
Strain*Gender*Fat*TN	2	0.663	0.150
R-Square		0.411	0.409

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, standard (1 x) or doubled (2 x)

Table 5.14. Correlation analysis on the correlation between white striations with lipid content and fillet weight in broiler breast fillets; r = Pearson Correlation Coefficients, p = Prob > | r | under H0:Rho=0, N = Number of Observations.

		Randombred		Modern Strain 1		Modern Strain 2	
		Female	Male	Female	Male	Female	Male
Breast Weight (g)	r	0.173	0.138	0.362	0.343	0.626	0.117
	p	0.521	0.624	0.168	0.194	0.001	0.665
	N	16	16	16	16	16	16
% Lipid Content	r	0.177	-0.150	0.429	0.535	0.588	0.104
	p	0.513	0.593	0.097	0.033	0.017	0.701
	N	16	16	16	16	16	16

Table 5.15. General Linear Model (GLM) for the effect of strain, gender, fat quality, trace nutrient supplementation level, and all interactions on the breast weight and percentage of lipid content in broiler breast fillets.

Source	df	Pr > F – Type III	
		Breast Wt	% Lipid
Strain ¹	2	<0.001	<0.001
Gender	1	<0.001	0.060
Strain*Gender	2	0.061	0.003
Fat ²	1	0.885	0.424
Strain*Fat	2	0.581	0.810
Gender*Fat	1	0.969	0.672
Strain*Gender*Fat	2	0.543	0.841
TN ³	1	0.425	0.219
Strain*TN	2	0.636	0.995
Gender*TN	1	0.637	0.756
Strain*Gender*TN	2	0.450	0.043
Fat*TN	1	0.803	0.763
Strain*Fat*TN	2	0.398	0.128
Gender*Fat*TN	1	0.481	0.030
Strain*Gender*Fat*TN	2	0.837	0.096
R-Square		0.964	0.536

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Fat = Quality of fat in the diet, either normal or oxidized

³TN = Level of vitamin/trace mineral mix in the diet, standard (1 x) or doubled (2 x)

Table 5.16. Main effect means of the breast weight and lipid content by strain, gender, fat quality, and trace nutrient supplementation level of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Lipid Content	
					Breast Weight (kg)	% Lipid
RB				8	0.24 \pm 0.03	1.31 \pm 0.22
M1				8	0.55 \pm 0.06	1.55 \pm 0.19
M2				8	0.58 \pm 0.06	1.62 \pm 0.23
	1 \times			12	0.46 \pm 0.16	1.52 \pm 0.25
	2 \times			12	0.46 \pm 0.16	1.47 \pm 0.24
		Normal		12	0.46 \pm 0.16	1.51 \pm 0.24
		Oxidized		12	0.45 \pm 0.17	1.48 \pm 0.25
			Male	12	0.49 \pm 0.16	1.53 \pm 0.29
			Female	12	0.42 \pm 0.15	1.46 \pm 0.20

¹Strain = 1990's Rando-bred Strain (RB), Modern Strain 1(M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace mineral mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidize

Table 5.17. Effects of strain, gender, fat quality, and trace nutrient supplementation level on the breast weight and lipid content of broiler breast fillets. Mean \pm Standard Error.

Strain ¹	Trace Nutrient Level ²	Fat Quality ³	Gender	n	Lipid Content	
					Breast Weight (kg)	% Lipid
RB	1 \times	Normal	Male	4	0.27 \pm 0.01	1.55 \pm 0.27
RB	1 \times	Normal	Female	4	0.21 \pm 0.02	1.26 \pm 0.06
RB	1 \times	Oxidized	Male	4	0.25 \pm 0.01	1.18 \pm 0.06
RB	1 \times	Oxidized	Female	4	0.23 \pm 0.03	1.38 \pm 0.31
RB	2 \times	Normal	Male	4	0.28 \pm 0.01	1.11 \pm 0.04
RB	2 \times	Normal	Female	4	0.23 \pm 0.01	1.50 \pm 0.21
RB	2 \times	Oxidized	Male	4	0.25 \pm 0.02	1.25 \pm 0.19
RB	2 \times	Oxidized	Female	4	0.21 \pm 0.01	1.34 \pm 0.23
M1	1 \times	Normal	Male	4	0.58 \pm 0.03	1.66 \pm 0.15
M1	1 \times	Normal	Female	4	0.49 \pm 0.04	1.58 \pm 0.19
M1	1 \times	Oxidized	Male	4	0.59 \pm 0.01	1.47 \pm 0.16
M1	1 \times	Oxidized	Female	4	0.50 \pm 0.03	1.61 \pm 0.10
M1	2 \times	Normal	Male	4	0.59 \pm 0.03	1.55 \pm 0.23
M1	2 \times	Normal	Female	4	0.51 \pm 0.04	1.43 \pm 0.27
M1	2 \times	Oxidized	Male	4	0.59 \pm 0.05	1.70 \pm 0.23
M1	2 \times	Oxidized	Female	4	0.51 \pm 0.04	1.44 \pm 0.09
M2	1 \times	Normal	Male	4	0.63 \pm 0.05	1.72 \pm 0.25
M2	1 \times	Normal	Female	4	0.53 \pm 0.02	1.50 \pm 0.16
M2	1 \times	Oxidized	Male	4	0.63 \pm 0.04	1.82 \pm 0.32
M2	1 \times	Oxidized	Female	4	0.53 \pm 0.04	1.54 \pm 0.24
M2	2 \times	Normal	Male	4	0.59 \pm 0.04	1.78 \pm 0.15
M2	2 \times	Normal	Female	4	0.54 \pm 0.05	1.53 \pm 0.09
M2	2 \times	Oxidized	Male	4	0.62 \pm 0.06	1.64 \pm 0.06
M2	2 \times	Oxidized	Female	4	0.55 \pm 0.07	1.41 \pm 0.20

¹Strain = 1990's Randombred Strain (RB), Modern Strain 1 (M1), Modern Strain 2 (M2)

²Trace Nutrient Level = Level of vitamin/trace mineral mix in the diet, either standard (1 \times) or doubled (2 \times)

³Fat Quality = Quality of fat in the diet, either normal or oxidized

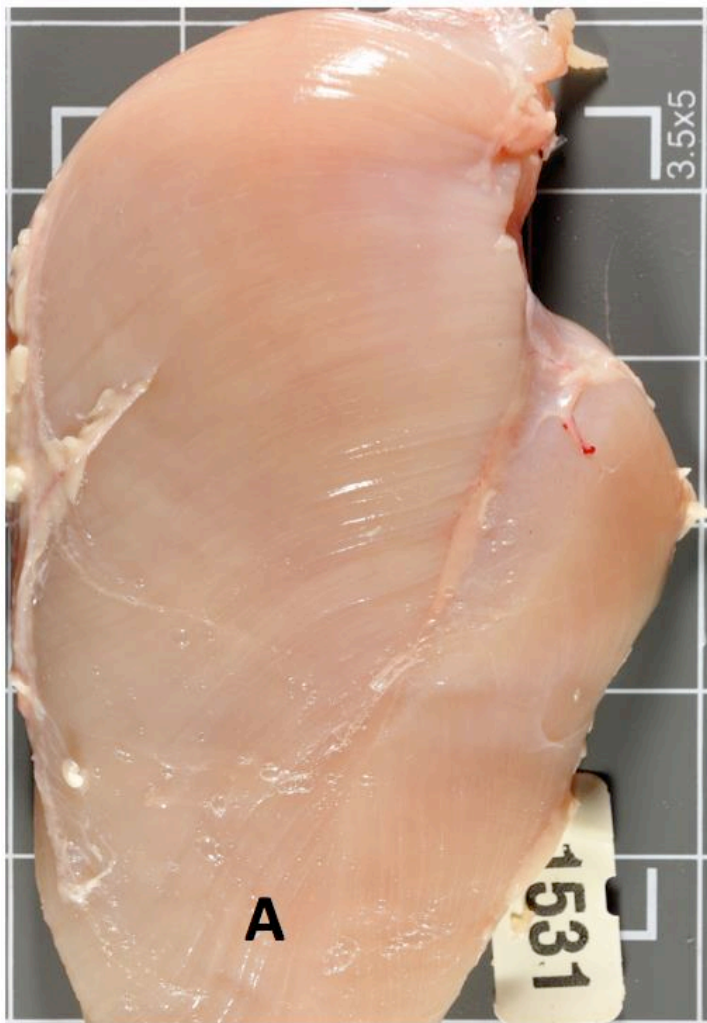


Figure 5.1. White striping classification of broiler breast fillets: A) Complete Absence and B) Slight striations.

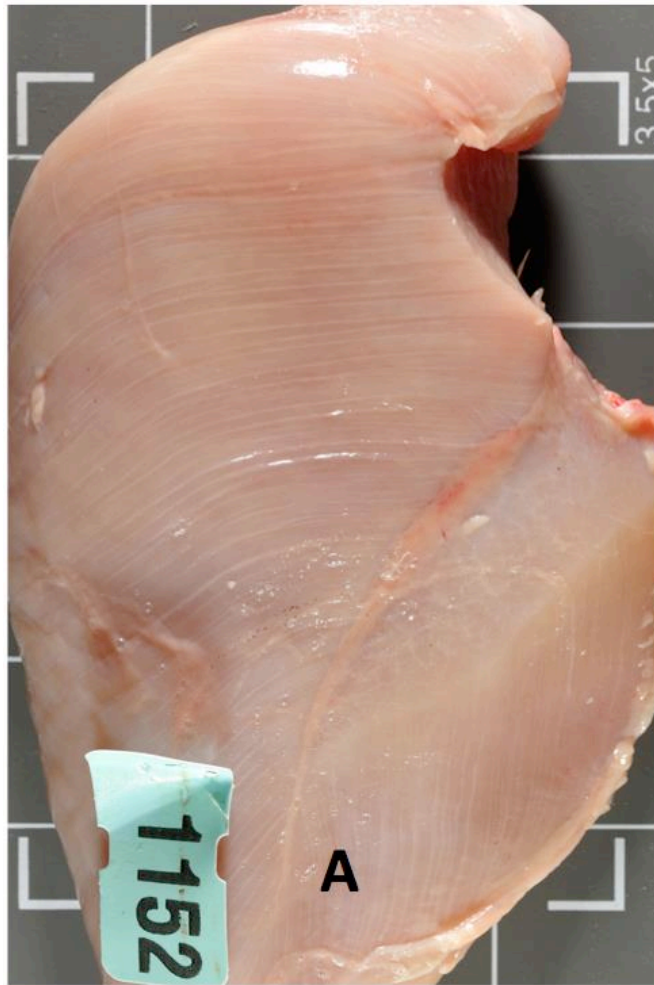


Figure 5.2. White striping classification of broiler breast fillets: A) Moderate and B) Considerable striations.



Figure 5.3. White striping classification of broiler breast fillets: Severe striations.

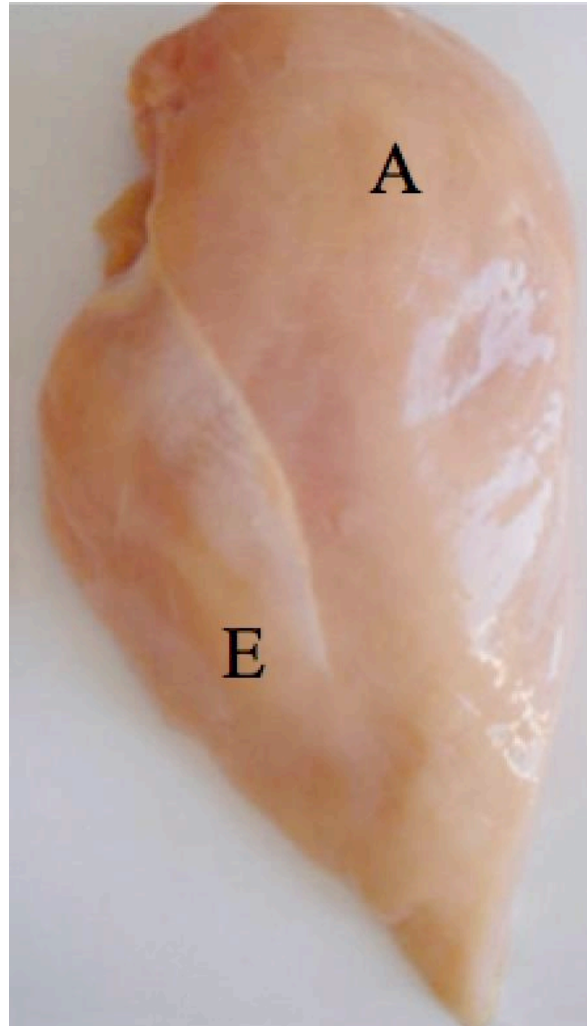


Figure 5.4. Diagram of pH measurement locations A and E.

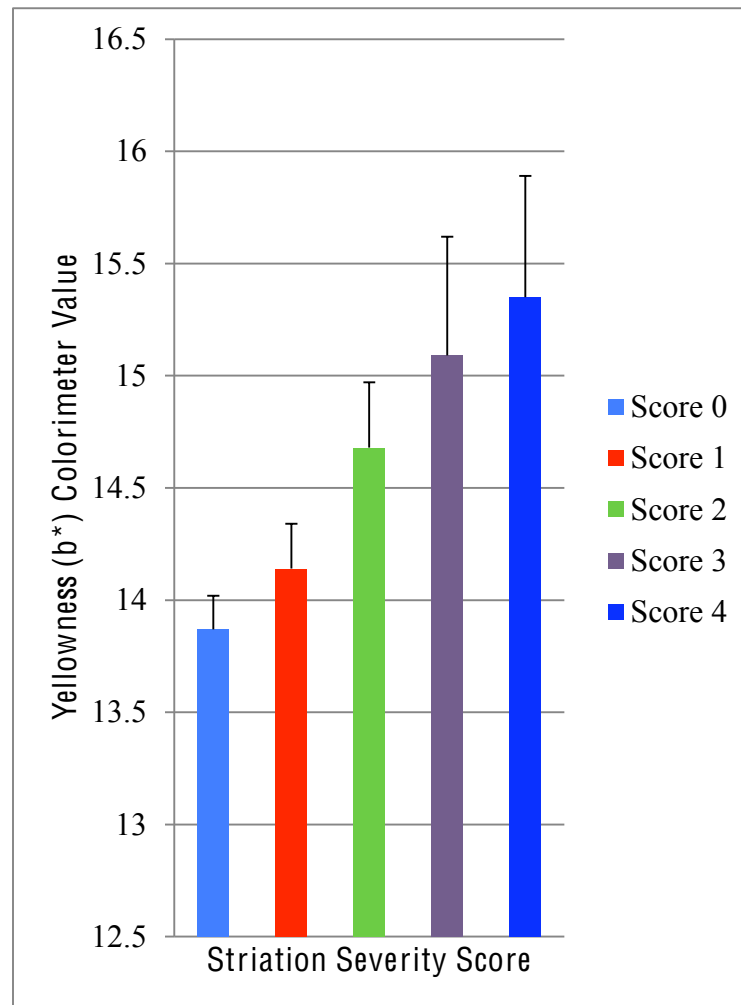


Figure 5.5. Average yellowness (b^*) colorimeter value for each level of stripping severity.

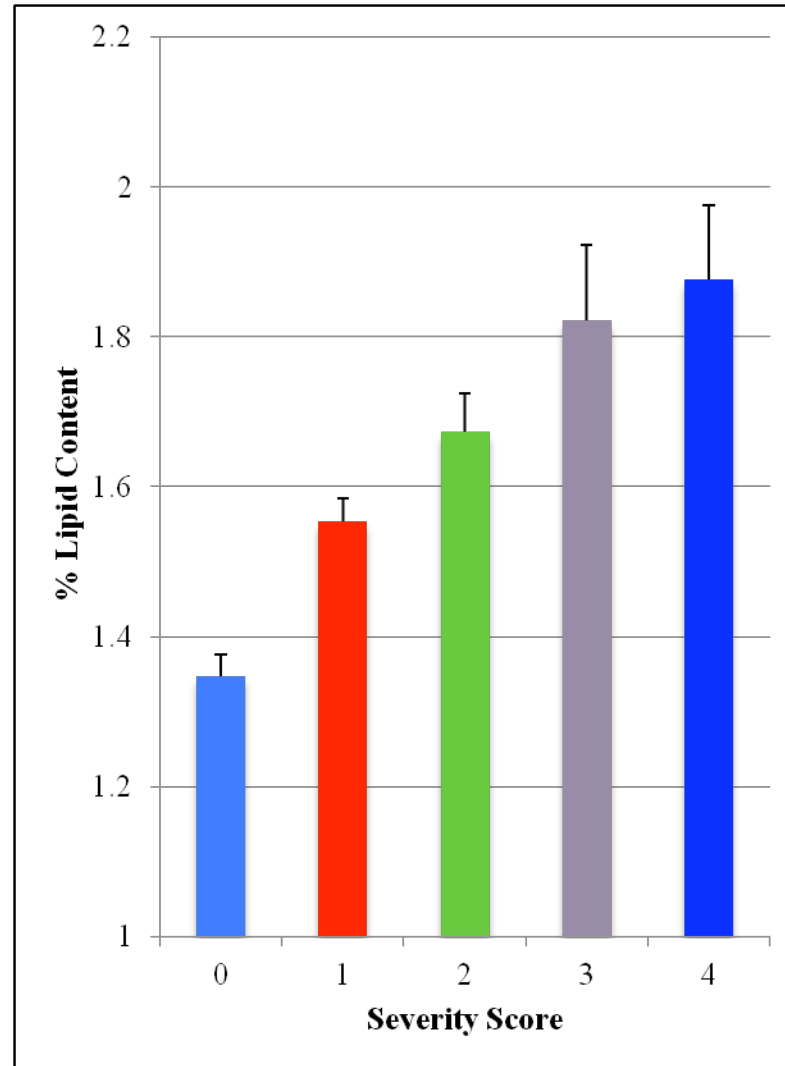


Figure 5.6. Average percentage of lipid content in each level of striation severity (0 – 4).

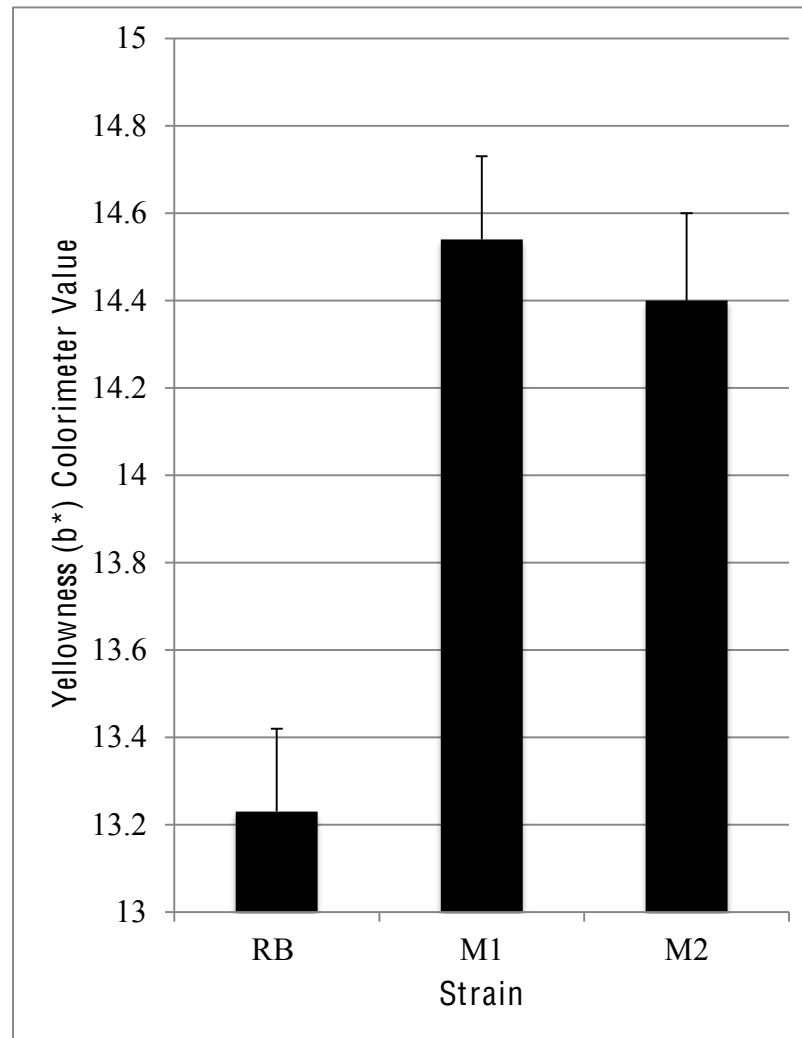


Figure 5.7. Average yellowness (b*) colorimeter value for each of the 3 broiler strains.

CHAPTER 6

CONCLUSIONS

White striations have become a widespread issue within the poultry industry and prevalence continues to rise. Results of this study found severity is higher in modern, fast growing birds, rather than the slow growing, 1990's randombred strain. Gender and strain remain significant factors in the prevalence and severity of white striations after live weight differences between genders was accounted for. Therefore, the strain and gender effects were not a manifestation of live weight differences, although live weight was significant to white striations. Male broilers showed higher degrees of striation severity compared to females. Dietary treatments differing in fat quality and level of vitamin/trace mineral mix indicated that the influence of diet on the variation of white striations was quite small.

When examining correlations between white striping and cooking parameters, no factors were significantly correlated to cook loss or tenderness of breast fillets. Breast thickness was significant to the prevalence of striping, obviously an influence of overall live weight. Investigation on meat quality parameters demonstrated there was not enough evidence to draw overall conclusions. A positive relationship existed between white striations and the yellowness (b^*) colorimeter score, a possible indication of higher fat content. This was supported by the positive relationship striation severity had to the overall lipid content within the fillet. Soluble and insoluble collagen content were not significant to the prevalence and severity of white striations.

CHAPTER 7

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