

SPAGHETTI MEAT'S IMPACT ON TEXTURE AND QUALITY PARAMETERS
WHEN INCORPORATED INTO GROUND CHICKEN PATTIES

by

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(Under the Direction of T. Dean Pringle)

ABSTRACT

Spaghetti Meat (SM) myopathy causes fiber integrity loss, muscle bundle separation, and endomysium and perimysium rarefaction in broiler *pectoralis major* muscle resulting in breast meat which resembles stands of spaghetti. Irreversible quality defects render SM breast meats unable to be sold in whole breast form. Therefore, the objective of this study was to benchmark and examine textural and quality parameters of ground SM when incorporated into chicken patties. Color, shear force, texture profile, myofibrillar water properties, ultimate pH, moisture content, and fat content of chicken patties were negatively impacted by SM addition. Cook yields were positively impacted by SM incorporation. Sensory analysis indicated SM did not influence patty texture or flavor. This study confirmed deficiencies present in whole-breast SM do not persist through grinding. Future research could focus on ground SM performance with incorporation of functional ingredients; however, SM can be incorporated into ground products without consumer impact.

INDEX WORDS: Spaghetti meat, Chicken myopathy, Quality, Texture, Color,

Processing

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DEDICATION

I would like to dedicate my thesis to my beautiful fiancé, Danica, and to my beloved black lab, Charlotte.

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CHAPTER 1

INTRODUCTION

In the United States, poultry processing accounted for 32.6% of the nation's total meat processing in 2022, with increased demand for poultry products predicted for 2023 (Seiler et al., 2023). In the past decade alone, chicken consumption has increased 17.7% per capita to 51.3 kg in the United States with an expected 0.85% increase in the next five years (IBIS World, 2022). To meet the growing consumer demand, broiler size has increased over 364% with a 1957 broiler weighing 905 g at slaughter, compared to a 2005 broiler weighing 4,202 g (Zuidhof et al., 2014). Moreover, broilers average market age in 2021 was 47 d, a 65 d decrease from 1925 (National Chicken Council, 2022). Modern broilers' breast muscle grew 3.8 times faster and accounted for 15.37% more body mass than a 1950's heritage breed (Schmidt et al., 2009, Orłowski et al., 2020). Advancements in broiler genetics, nutrition, and management have allowed for the modern industry to fulfill consumer demand; however, the unforeseen development of chicken breast myopathies has plagued US poultry producers with an estimated \$0.2 to \$1 billion annual economic loss (Huang & Ahn, 2018).

Chicken breast myopathies are associated with fast-growing broilers that reach market at, or prior to 8 weeks of age and whose breast meat is physically and biochemically altered (Bordignon et al., 2022). Myopathic breast meat can result in poor eating experiences, diminished visual appeal, and altered nutritional composition. Woody Breast (WB) and White Striping (WS) are two prevalent chicken breast myopathies with

substantial research into their functional properties for use in further processed chicken products. Researchers have investigated their functionality in sausages, hotdogs, meatballs, marinated products, patties, and more without a concrete solution for the industry's growing problem (Bowker et al., 2018, Rigdon et al., 2021, Sun et al., 2021, McDonald et al., 2023). Woody Breast incidence rates are increasing from 1.4% to 8.7% in 2012, to 25.7% to 32.3% in 2015, and recently 36% to 56% prevalence (Kuttappan et al., 2016, Che et al., 2022a). A newer chicken myopathy is being studied that will add to producers', processors', and consumers' growing concerns over broiler breast meat quality.

Spaghetti Meat (SM) myopathy, first described in 2015 (Bilgili, 2015), is the latest myopathy to affect breast muscle. Spaghetti Meat myopathy's etiology, like other chicken breast myopathies, is still unknown, but SM has been characterized by muscle fiber integrity loss, endomysium, and perimysium rarefaction, resulting in thin cylindrical muscle tissue resembling spaghetti pasta (Che et al., 2022b, Petracci et al., 2019, Tasoniero et al., 2020). The incidence rate of SM in US poultry production has yet to be reported; however, Canadian, and Italian researchers reported SM to affect roughly one in three high-yielding breast broilers (Pascual et al., 2020, Che et al., 2022b). Wang et al. (2023) reported SM and WB were not mutually exclusive and are often present together. Spaghetti Meat presenting with other myopathies could limit US researchers' ability to accurately determine true SM incidence rate. Spaghetti Meats' incidence rate may be unknown, but the effect SM has on meat quality is known. Spaghetti Meat directly affects meat quality regarding ultimate pH, objective color, proximate composition, myofibrillar water properties, textural properties, and collagen structure (Baldi et al., 2021).

Mir et al. (2017) reported consumer purchasing habits for chicken meat are influenced by multiple factors, but these authors stated appearance, texture, and flavor to have the greatest impact. Spaghetti Meat directly affects consumers perception of quality with increased muscle yellowness, greater ultimate pH, decreased protein content, increased moisture and fat, and softened meat texture (Baldi et al., 2021, Mir et al., 2017). Due to their compromised physical appearance and structural integrity, breast fillets exhibiting the SM myopathy are not sold as intact muscle products. Available data suggests that the altered biochemical and compositional changes observed in SM may potentially affect its functionality in further-processed meat products. However, little if any data has been reported on the direct incorporation of SM into processed meat products and its potential impact on processing and final product quality.

Therefore, the object of the current research was to determine quality and textural characteristics of chicken patties when ground SM was incorporated in at varying levels. The experiment evaluated raw, intact SM breasts and normal breast meat to identify whole-breast defects. Once ground, chicken patties were formed with 0, 25, 50, 75, and 100% replacement of normal breast meat with SM, for five treatment levels. Spaghetti Meat was incorporated into patties to benchmark any defects present after particle size reduction and to determine a potential threshold where SM noticeably affects final product quality.

CHAPTER 2

LITERATURE REVIEW

Modern Chicken Broilers

The modern poultry industry has made tremendous strides in increasing broiler production efficiency. Modern broilers have an average market age of 47 days, down from 112 days in 1925 (National Chicken Council, 2022). The reduction in days to market can be attributed to improved genetics, nutrition, and management practices. These improvements not only produce broilers faster, but also produce more uniform broilers for processing. Broilers growth has increased 400%, with a 50% reduction in feed consumption and a 124% *pectoralis major* yield increase from 1957 to 2005 in the United States (Zuidhof et al., 2014). Innovative processing technology has allowed poultry processors to efficiently process broilers faster with modern poultry lines processing 15,000 head per hour, a 600% increase from 2,500 head an hour in 1962 (Barbut et al., 2022). In-line automatic splitting, de-boning, skinning, and sorting machines have allowed processors to handle the increased broiler volume while producing a consistent product. Alnahhas et al. (2015) reported selectively breeding broilers based on breast pH for five generations had detrimental effects on blood capillary density, which resulted in muscles with impaired oxidative capacity, and increased use of glycogen as an energy source. The previous study purposely single-trait selected for an increase in breast pH, but the study demonstrates how single-trait breeding can drastically alter meat quality (Alnahhas et al., 2015).

Poultry Consumption

In the United States, 2023 chicken consumption per capita was 51.3 kg (Seiler et al., 2023). To meet this demand, the United States produced 26.9 billion kg of chicken from 9.13 billion broilers worth \$31.5 billion in 2021 (USDA, 2022). In the first week of February 2023, chicken consumption by part was 49.0% breast meat, 22.8% drums, 14.3% thighs, 8.3% tender, and 5.6% other (USDA, 2023).

Consumers view chicken as healthier, better value, more convenient, and more versatile compared to red meat (Kennedy et al., 2004). US consumers who regularly buy chicken value organic chicken at a 35% premium, and a 104% premium for USDA organic (Loo et al., 2011). Habitual clean label chicken buyers are willing to pay a 244.3% premium for USDA certified organic chicken (Loo et al., 2011). Research involving consumers willing to pay for free-range, organic, cage-free, and other programs indicate that consumers concern for animal health and welfare are increasing; however, research also indicates consumers prefer to be disconnected from the animal their meat originates from, and prefer cut-up skinless, trimmed chicken portions (Kennedy et al., 2004; Barbut et al., 2022). Thus, consumers purchase chicken because they believe it is healthier, and are willing to pay more for value-added programs which they believe increases broilers quality of life.

Meat Biochemistry

Meat is postmortem muscle tissue from livestock and poultry that is intended for consumption (Seman et al., 2018). Many biochemical changes occur as muscle is converted into meat and these changes directly affect meat quality and functionality.

Ultimate pH, meat composition, Water Holding Capacity (**WHC**), and myofibrillar water activity are closely related biochemical factors that affect meat.

pH

Muscle pH is neutral between 7.0 and 7.2 while chicken breast meat ultimate pH is between 5.7 and 6.0 (Fletcher et al., 2000). pH values will change as muscle is converted to meat; thus, the term ultimate pH refers to pH after the conversion process is complete. Muscle acidification occurs during exsanguination as oxygen is depleted and the rapid burn of stored glycogen occurs via anaerobic respiration (glycolysis). Briefly, glycolysis occurs when glycogen phosphorylase catalyzes glycogen breakdown into glucose, glucose is converted in a 10-step reaction to pyruvate while using the free energy realized in the process to synthesize ATP from ADP and inorganic phosphate (Matarneh et al., 2017). In the absence of oxygen, the pyruvate in muscle tissue is reduced to lactate via lactate dehydrogenase which would normally be converted back into glucose in the liver; however, lack of blood flow following exsanguination causes lactate and free hydrogen accumulation in muscle tissue resulting in acidification (Matarneh et al., 2017). Once glycogen stores are depleted, ATP production ceases, and myosin can no longer release from actin causing rigor mortis to develop (Offer et al., 1989). Chicken rigor mortis onset phase begins less than 30 minutes after harvest, and rigor mortis is completed 2-4 h postmortem (Nusairat et al., 2022). The amount of stored glycogen in muscle tissue directly affects meat's ultimate pH, which in turn affects color, tenderness, Water Binding Capacity (**WBC**), and muscle protein.

Meat Structure

Protein abundance and functional properties present in meat are essential for meat quality and practical use in further processed products. Muscle is held together with connective tissue surrounding myofibers, fasciculus, and the entire muscle called endomysium, perimysium, and epimysium, respectively (Aberle et al., 2012). These connective tissue networks ensure muscle integrity during fabrication. Myofibrillar proteins are long fibrous proteins organized in repeated sarcomeres for contraction by sliding the thick and thin filaments along each other (López-Bote, 2017). Myosin and actin, primary proteins of the thick and thin filament respectively, are the two most abundant myofibrillar proteins accounting for a combined 70% of myofibrillar proteins (López-Bote, 2017). These proteins use ATP to form a reversible bond during contraction that results in sarcomere shortening and muscle contraction. During rigor mortis, depleted ATP stores cause myosin to no longer detach from actin and the actomyosin bond becomes permanent resulting in meat toughening. Permanent actomyosin bonds reduce meats' microstructure space for water infiltration; however, myofibrillar proteins are soluble in salt. For comminuted products, the addition of salt can solubilize myofibrillar proteins allowing for greater protein activation which will allow more water to bind, thus increasing water retention (Warner, 2017).

WHC and Myofibrillar Water Properties

Water holding capacity can be defined as meat's ability to retain water when external forces are applied, such as cutting, or heating (Warner, 2017). Muscle water can be classified into three categories: bound, immobilized, and free water. Bound water will bind to charged hydrophilic side chains on proteins and will not freeze under normal

conditions. Immobilized, or intramyofibrillar, water is contained within the muscle microstructure, which is between actin and myosin. An increase in immobilized water can be considered swelling. Free, or extramyofibrillar, water is found outside the muscle microstructure, is easily expressed from meat, and is commonly referred to in uncooked meat products as purge or weep.

Meat's ability to hold water or changes in myofibrillar properties can be altered with functional ingredients that move its isoelectric point. As rigor mortis progresses, divalent calcium and magnesium cations from the sarcoplasm are released and can reduce negative anion electrostatic repulsion resulting in decreased space for intramyofibrillar water, forcing water to the extramyofibrillar matrix. (Wismer-Perdersen, 1986). The addition of salt, specifically chloride anions, can increase electrostatic repulsion and allow water to move into the muscle microstructure (Offer et al., 1989). Offer et al. (1989) reported phosphate in the presence of magnesium ions will weaken actin and myosin binds, allowing chloride to extract myosin at lower concentrations and increase water swelling.

Factors Affecting Meat Quality

The aforementioned biochemical properties have a direct effect on consumers perception of meat quality. Meat's appearance, based primarily on color, and palatability, based on texture, juiciness and flavor, impact consumers' initial willingness to purchase meat, and their likelihood to continue purchasing meat, respectively.

Appearance and Color

Chicken meat's appearance can be argued as the most important quality attribute as consumers associate appearance and color with product freshness (Mir et al., 2017).

Chicken breast meat has minimal concentrations of heme pigment myoglobin, and when exposed to oxygen does not bloom, form oxymyoglobin, causing chicken to appear whiter than beef, lamb, pork, and chicken thigh meat (Millar et al., 1994). Delayed, or slow, carcass chilling can promote postmortem glycolysis, leading to a faster and (or) greater pH decrease, and ultimately reducing muscle protein functionality (Faustman, 2017). The lower pH accelerates protein denaturation, which in turn causes meat paleness, and loss of water holding capacity (Hultin et al., 1984). Meat with slight surface moisture can be viewed as fresh; however, excessive surface moisture, or extreme lack of surface moisture is perceived as not fresh and, thus undesirable to consumers (Mir et al., 2017). Surface moisture relates to meat's WHC and with an increase in extramyofibrillar water seen as producing a less juicy eating experience and reduced desirability to consumers.

Texture and Sensory Evaluation

USDA cooking guidelines state chicken meat's internal temperature should reach at least 74°C for complete bacterial lethality (USDA, Appendix A). At 74°C, myosin, actin, and collagen are denatured, and sarcoplasmic proteins are unfolded. Once unfolded, sarcoplasmic proteins can be resolubilized to form a network which can contribute to increased WHC. However, when chicken is cooked to 70°C or higher, the greatest moisture loss is seen (Aberle et al., 2012; Warner, 2017). Cooking to 70°C results in inferior tenderness ratings and increasing hardness from denaturation, coagulation, and dehydration of the myofibrils (Aberle et al., 2012). Objective and subjective texture parameters can be measured by texture profile analysis (TPA), Warner-Bratzler shear, Allo-Kramer shear, and sensory panelist valuations, respectively.

Sensory evaluation and TPA combined can be used to indicate consumer acceptance of meat. Sensory evaluations can be conducted with trained sensory panelists, or with consumer panelists. Trained sensory panels are thought to give more objective measurements, as these panelists are trained to reduce preference during the eating experience (AMSA, 2016). While consumer panels present their own set of challenges, they can give a more accurate representation of any differences present that a typical consumer would notice. Texture Profile Analysis uses a double compression method measuring downward force, force applied back onto the machine as it raises for each compression. Common texture parameters gathered are hardness, adhesiveness, resilience, cohesion, springiness, gumminess, and chewiness.

Meat Processing

Whole muscle meat products, steaks, roasts, etc., are prepared from large, intact pieces of the carcass, while further-processed products reduce whole muscle particle size by comminution (grinding), blending, or emulsification (Aberle et al., 2012). During grinding, ordered myofibrillar structures and connective tissue are disrupted, or broken apart, by an external mechanical force. Utilizing beef flank meat, Berger et al. (2022) reported non-intact muscle fibers, soluble protein content, lactate dehydrogenase, and drip loss increased when whole muscle was initially ground through a 13 mm plate with further differences after a second grind through a 2.4 mm plate. Warner (2017) reported comminuted meat exudes more fluid due to the physical forces retaining water in whole muscle are destroyed during grinding. These findings indicate muscle microstructure fragmentation releases intramyofibrillar water, creates additional open-ended sarcomeres, and may increase myofibrillar protein surface area. Blending refers to additional meat

mixing for the purpose of solubilizing and swelling myofibrillar proteins prior to further processing (Aberle et al., 2012). An emulsion is a mixture of two immiscible liquids, one is dispersed in the form of small droplets in the other liquid (Aberle et al., 2012).

Emulsified meat batters have spherical fat particles coated with soluble proteins, myofibrillar or sarcoplasmic, that are suspended in an aqueous solution (Aberle et al., 2012). Salt is essential to meat emulsion products for its ability to solubilize myofibrillar proteins that form connections between proteins and lipids, and when heated, form a gel increasing water retention (Warner 2017).

Broiler Breast Myopathies

Selecting broilers for faster growth, higher feed efficiency, and larger *pectoralis major* muscle (**PM**) has led to the development of breast muscle myopathies. Three primary myopathies have emerged affecting US chicken producers: Woody Breast (**WB**), White Striping (**WS**), and Spaghetti Meat (**SM**). The etiologies of these myopathies are not fully understood, but some preliminary “causes” have been suggested. Chicken breast myopathies share some histological changes characterized by degeneration and necrosis of myofibers, changes in connective tissue network and abundance, and increased amounts of fat. These myopathies have an undesirable appearance, flavor, and texture resulting in processors having to trim or portion out the affected fillets or discounting the entire fillet. Shivo et al. (2014) suggested WB to be the result of multifocal regenerative myodegeneration, necrosis, and fibrosis within broiler PM resulting in the characteristic hardness of the affected tissue. Similarly, WS breasts can be the result of degenerating and regenerating muscle fibers with infiltration of connective tissue, and accumulation of adipose tissues forming white strips across the muscles surface (Huang & Ahn, 2018).

Spaghetti Meat is an emerging myopathy, with research published on its biochemical changes in whole breast form (Tasoniero et al., 2022). Woody Breast and WS have been well characterized in whole breast form, with research into their functionality in processed products. While SM is different from WB and WS, understanding deficiencies that persist through processing in WB and WS may help better utilization of SM in further processing.

Woody Breast

Woody Breast is characterized by PM hardness, swollen and pale sections, scattered hemorrhages, and clear viscous fluid present on its surface (Caldas-Cueva and Owens, 2021). Woody Breast meat has greater levels of fat, collagen, and moisture with decreased levels of protein and ash (Shivo et al., 2013). In a 2022 Canadian study, 9250 broilers were examined with 82.0% WB prevalence regardless of severity (Che et al., 2022). Griffin et al. (2018) reported WB onset is an inflammatory response, with primary damage resulting from hemorrhaging. These authors support previous research stating ischemia, hypoxia, and eventual necrosis seen in WB worsens as PM size increases. Woody Breast meat has been incorporated into meatballs, sausage, chicken patties, and emulsified hotdogs that is not indistinguishable from NB products for processors to recapture lost revenue utilizing WB fillets (Sun et al., 2021, Rigdon et al., 2021, Brambila et al., 2017, McDonald et al., 2023). Sun et al. (2021) reported WB inclusion into chicken meatballs resulted in negative effects on cook loss, color, subjective and objective sensory evaluation, and water distribution. Although, these authors did suggest a WB inclusion percent of less than or equal to 30% may be possible. Similarly, Rigdon et al (2021) reported low-level inclusion of WB into fresh chicken sausage may be a viable

option; however, these authors did not conduct a sensory analysis to determine if WB inclusion would affect sensory characteristics. Brambila et al (2017) reported WB inclusion into chicken patties determinately altered patty texture. McDonald et al (2023) reported low-level WB inclusion into an emulsified hotdog positively affected cook yield, but sensory analysis confirmed WB negatively impacted flavor. Muscle fiber degeneration associated with WB negatively impacts binding capacity, WHC, and texture in intact fillets. Current available data suggests that the quality challenges presented by WB are not completely overcome through further-processing. Recent research has indicated incorporating functional ingredients, and forming an emulsion may be an avenue for adding value to WB (Xing et al., 2017, McDonald et al., 2023). Xing et al. (2017) reported that WB meat gels with less than 3% salt had an increased cook loss compared to unaffected breast meat gels. McDonald et al. (2023) reported emulsified hotdogs containing 25% WB and 75% normal breast meat had an increased cook yield of 1.45% compared to chicken hotdogs without WB. These authors also reported trained sensory panelists scored WB hotdogs to have decreased meatiness flavor when compared to normal hotdogs. Cooked WB fillets were harder, less springy, and chewier than normal breast meat (Chatterjee et al., 2016). Using cooked chicken patties, Caldas-Cueva et al. (2021) reported severe WB patties were softer, less cohesive, less springy, and less chewy compared to chicken patties with only unaffected breast meat. Brambila et al. (2017) reported WB had no effect on Warner-Bratzler Shear Force (**WBSF**) values (cooked whole breasts) or Allo-Kramer (cooked patties) shear force values. Overall, WB continues to be a significant problem for the poultry industry because of the reduction in

value of affected meat and because minimal processing alternatives exist to overcome the value reduction.

White Striping

White Striping is characterized by white striations parallel to muscle fibers, and usually appears near the cranial wing attachment portion on the ventral surface of the fillet (Petracchi et al., 2019). White Striping meat has increased fat and decreased protein compared to unaffected breast meat (Kuttappan et al., 2012a). In a Canadian study published in 2022, 9,250 broilers were examined with 93.8% WS prevalence regardless of WS severity. While the exact etiology of WS is unknown, Pampouille et al. (2018) reported WS gene mapping showed a polygenic inheritance and identified several candidate genes. White Striping affected broilers have increased concentrations of long and medium-chain fatty acids suggesting a defect in beta-oxidation (Boerboom et al., 2018). Oxygen deprivation may be the cause of fatty acid accumulation and can diminish TCA cycle activity. White striped breasts had elevated citrulline levels and decreased arginine levels, suggesting arginine was converted to citrulline to increase nitric oxide production to enhance blood flow to breast tissue (Boerboom et al., 2018). This suggests hypoxic conditions in the breast muscle, with the vascular system unable to support muscle development under stress, to be the cause of the disrupted metabolomics. Kuttappan et al. (2012b) reported consumer acceptance of WS decreased 8-fold for severe WS breasts, with WS breasts scoring inferior to unaffected breasts in nearly all visual evaluations. Bowker and Zhuang (2016) reported WS breasts to have decreased sarcoplasmic protein solubility, decreased thaw loss, greater pH, and decreased myofibrillar emulsifying activity compared to unaffected breast meat.

Spaghetti Meat

Spaghetti Meat was first identified by Bilgili et al. (2015) as a breast myopathy with poor cohesive properties and lack of muscle structure. Currently, SM is characterized by PM muscle fiber integrity loss and separation, and endomysium and perimysium progressive rarefaction leading to long, thin, cylindrical muscle tissue resembling spaghetti pasta (Che et al., 2022, Petracchi et al., 2019, Mazzoni et al., 2020). Spaghetti Meat can affect one in three broilers with SM incidence rate increasing as live weight increases; however, SM is often present with other myopathies, making an exact incidence rate difficult to determine (Che et al., 2022, Zampiga et al., 2018). Furthermore, Che et al. (2022) reported SM incidence rate was 2.25 times greater in female broilers. This agreed with previous research which reported female broiler SM occurrence was 8 times greater than male broilers (Pascual, 2020). Neither author presents a reason as to why female broilers are more susceptible to the SM condition. Spaghetti Meat incidence rate increased 20.9% in the summer months compared to winter months which could be the result of increased heat stress and affected broilers unable to supply oxygen to the affected tissue (Che et al., 2022). Feeding female broilers sodium-butyrate decreased SM incidence rate, with some research reporting sodium-butyrate to have antimicrobial, anti-inflammatory, and antioxidant properties when fed to broilers (Lan et al., 2020, Pascual et al., 2020).

Similar to WB and WS, SM has decreased protein content, with increased moisture and fat compared to normal breast meat (Baldi et al., 2019, Tasoniero et al., 2020). Spaghetti Meat fillets did not exhibit more pronounced ageing-related muscle protein degradation when compared to normal fillets during postmortem storage with no

difference in titin, myosin, actin, desmin, or calpain abundance (Tasoniero et al., 2022). Altered myofibrillar water properties in SM are likely not due to more extensive cytoskeletal muscle protein breakdown. Tasoniero et al (2020) reported SM lower myofibrillar protein solubility compared to unaffected breast meat. Spaghetti Meat's protein profile has minor shifts in myofibrillar protein abundance and a decrease in myofibrillar protein solubility suggesting SM does not cause an increase in cytoskeletal muscle protein breakdown. Spaghetti Meat's decreased myofibrillar protein solubility could negatively affect its ability to form stable bonds when incorporated into further-processed products. Spaghetti Meat had less mature collagen than unaffected breast meat, with significantly more glycosaminoglycan (**GAG**) to collagen ratio (Sanden et al., 2021). Riemer et al. (2012) reported in juvenile animal tissue, GAG tends to absorb huge quantities of water, and stiff collagen limits the swelling ability in the extracellular matrix. Spaghetti Meat's endomysium and perimysium network breakdown could suggest an increase in immature collagen, resulting in an altered immunoreactivity to procollagen type III (Mazzoni et al., 2020). Spaghetti Meat had an increase in the concentration of nearly all free amino acids, with the exception of beta-alanine compared to unaffected breast meat (Sogila et al., 2019). Increased free amino acids agree with the hypothesis from Boerboom et al. (2018), in WS breasts, that insufficient vascularization of muscle tissue results in inadequate waste removal from muscle degeneration.

Spaghetti Meat myopathy had no effect on L*, a*, and b* (Baldi et al., 2019, Campo et al., 2020, Bordignon et al., 2022). In contrast, Tasoniero et al. (2020) reported b* values for SM skin side were greater than unaffected breast meat b* skin side values, and Sogila et al. (2019) reported SM b* values were greater than unaffected breast meat

b* values. While reported b* differs, it is generally accepted that SM yellowness is greater than unaffected breasts. Spaghetti Meat's ultimate pH can vary depending on the study, Baldi et al. (2018) reported SM superficial and deep pH was greater than unaffected breast meat, while Baldi et al (2019) reported SM superficial and deep pH did not differ from unaffected breast meat. Soglia et al (2019) and Tasoniero et al. (2020), reported SM pH was greater than unaffected breast meat pH. Bordignon et al. (2022) and Campo et al. (2020) reported SM and unaffected breast meat pH did not differ. Spaghetti Meat severity could influence the differences seen between researchers with some studies having a greater proportion of severely affected SM than others.

Spaghetti Meat has less bound water and intramyofibrillar water and no difference in extramyofibrillar water than unaffected breast meat (Baldi et al., 2018, Soglia et al., 2019, Tasoniero et al., 2022). Baldi et al. (2018) reported superficial SM breasts had the greatest proportion of extramyofibrillar water compared to unaffected and WS breast fillets. These authors also reported myofibrillar water properties in deep PM tissue were not affected by SM. Sogila et al. (2019) reported myofibrillar water properties were not different between frozen SM and frozen unaffected breast meat. Tasoniero et al. (2022) reported altered myofibrillar water properties are clearly ascribable to histological lesions observed in SM such as fiber necrosis and lysis, immature collagen, and fiber architecture loss.

Spaghetti Meat Allo-Kramer shear force values were 21.64% softer than unaffected breast meat (Pascual et al., 2021). These authors also reported SM to have 5.40% greater cook loss compared to unaffected breast meat. Campo et al. (2020) reported raw and cooked whole SM breasts did not differ in TPA hardness, adhesiveness,

cohesiveness, springiness, gumminess, chewiness, or resilience values compared to normal breast meat. These authors also reported that SM had no effect on WBSF values. Meat gels with SM had greater cook loss and decreased TPA hardness values than normal breast meat (Wang et al., 2022). Spaghetti Meat incorporated into a meat gel with 2% milk powder had greater springiness, cohesiveness, chewiness, and resilience values compared to meat gels with unaffected breast meat without milk powder (Wang et al., 2022). It should be noted that in Wang et al. (2022) whey protein isolate, caseinate, milk powder, or whey protein concentrate increased all TPA attributes regardless of whether SM or unaffected breast meat was used compared to only normal breast meat gels. Wang et al. (2022) does prove that SM can perform similarly to unaffected breast meat when functional ingredients are added. No sensory evaluations have been conducted on SM incorporated into further processed chicken products; thus, how comminuted SM will perform when consumed remains unknown.

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CHAPTER 3

Spaghetti Meat's impact on textural and quality parameters when incorporated into
ground chicken patties¹

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ABSTRACT: Spaghetti Meat (SM) myopathy affects broilers *pectoralis major* muscle and is characterized by fiber integrity loss, fiber separation, and endomysium and perimysium rarefaction resulting in meat which resembles spaghetti pasta strands. Current literature has focused on biochemical changes caused by SM; however, research focused on SM functional properties when incorporated into processed products is limited. Therefore, the study objective was to determine quality and textural characteristics of chicken patties when normal breast (NB) was replaced with SM. Severe SM was formulated into chicken patties at 0, 25, 50, 75, 100% replacement of NB for 5 treatment levels. Objective color, texture, shear force, yields, and sensory evaluations were collected during various stages of production. Spaghetti Meat fillets sides were yellower (skin and bone side) than NB ($P < 0.01$). Average cook yield for SM patties was 3.8% greater ($P < 0.01$) compared to NB patties. Despite SM fillets having decreased intramyofibrillar water ($P < 0.01$), SM75 patties had 9.9% greater intramyofibrillar water abundance than NB patties. Spaghetti Meat patties were softer, less cohesive, gummier, and chewier than NB patties ($P < 0.01$). Normal Breast patties required an additional 0.72 kgf/g, on average, to shear ($P < 0.01$). These textural differences were not apparent to sensory panelist with no difference noted between treatments for all sensory attributes ($P > 0.15$), except for visual sear ($P = 0.01$) which NB patties had less sear than SM25 and SM50 patties ($P < 0.01$). These results indicate SM could be incorporated into chicken patties at any level of incorporation with minimal detectable impact for consumers. Future research should focus on ground SM shelf life.

KEY WORDS: spaghetti meat, myopathy, texture, sensory, chicken, quality

Introduction

The United States produced 26.9 billion kg of chicken in 2021 with chicken breast sales accounting for 57.5% of consumer purchases (USDA, 2022; Statista, 2023). Poultry production over the past 50 years has transformed broiler composition through improved production techniques, nutrition, and genetic selection; however, in recent decades chicken breast meat has been burdened by the increased prevalence of myopathic diseases (Zuidhof et al., 2014). Myopathic breast meat are not the result of an infectious agent and do not pose a food safety risk, rather their unsavory appearance paired with an unpleasant eating experience can cause affected breast meat to not be sold in whole breast form (Barbut et al., 2019). This results in an estimated 5.4 billion kg and \$0.2 to \$1 billion annual loss for US producers as well as decreased availability of high quality animal protein to consumers (Huang and Ahn, 2018). An emerging myopathy, Spaghetti Meat (**SM**), poses a distinct set of challenges to overcome, and has limited research published on its functional properties in further processed meat products. Che et al. (2022b) reported more than one-third of Canadian broilers presented breast fillets affected by SM. These authors concluded SM prevalence to be complex and affected by multiple factors, but an overall prevalence range of 10% - 30%. Zampiga et al. (2018) reported Italian broilers had a 35% SM occurrence with 29% mild and 6% severe SM. The authors did not state SM prevalence in the US, but US broiler production may have a similar SM prevalence.

Spaghetti Meat is characterized by *pectoralis major* muscle (**PM**) with impaired integrity, muscle fiber loss and separation, and endomysium and perimysium progressive rarefaction leading to long, thin, cylindrical muscle tissue resembling spaghetti pasta

(Petracci et al., 2019; Tasoniero et al., 2020; Che et al., 2022a). Spaghetti Meat in whole breast form is reported to have increased moisture and fat, decreased protein, increased ultimate pH, greater cook loss, increased bound and extramyofibrillar water, and negative textural properties when compared to normal breast meat (Baldi et al., 2019; Soglia et al., 2019; Tasoniero et al., 2020). Tasoniero et al. (2020), reported SM to have decreased protein in its superficial layer which could result in decreased protein to protein bind during emulsion stabilization; however, Tasoniero et al. (2022) reported no difference in myofibrillar protein, calpain activity, or protein degradation in whole breast analysis. In contrast, Pascual Guzmán et al. (2021) reported lower total protein in whole SM compared to unaffected breast meat. Soglia et al. (2019) reported SM breasts to have an increased ultimate pH compared to unaffected breast meat. Wang et al. (2023) reported SM to have decreased compression forces and decreased Water Holding Capacity (**WHC**). The differences present in whole SM may or may not persist through particle size reduction, but whole breast classification can give an idea on SM functional properties in processed products.

Incorporating SM into further processed products is imperative to keep high-quality meat proteins commercially available and affordable to US consumers. A potential avenue for the poultry industry to recapture lost revenue associated with SM and produce high-quality animal protein for consumers is incorporation of SM into ground chicken breast. With no literature published on SM functionality when ground, this study hypothesizes SM breasts could be incorporated into ground chicken with limited differences noticeable to consumers. Therefore, the objective of this study was to

examine and benchmark quality and textural characters of comminuted SM incorporated into patties.

Material and Methods

Sample Collection and Patty Formation

Pectoralis major muscles were collected 3 h postmortem from 52 day-old mixed-sex Ross 708 birds from a local abattoir. Trained University of Georgia personnel selected breast fillets (approximately 46 kg) with severe SM from those identified by plant personnel as having various defects that required trimming or alternative marketing. Severe SM was identified by extensive superficial lacerations on the breasts surface, and abundant separation of muscle fiber bundles, resembling spaghetti pasta (Baldi et al., 2021). Additionally, normal breast (**NB**) fillets (approximately 45 kg) were obtained from the plant. Fillets (NB and SM) were boxed with ice and transported approximately 37 km to the University of Georgia's Meat Science Technology Center (**MSTC**, Athens, GA). Upon arrival at the MSTC, breast muscles were removed from boxes and placed on wire racks for 15 min to allow any excess moisture obtained during processing to drain. Fillets were then re-evaluated by trained experts to remove any samples exhibiting the woody breast condition and to ensure that only those fillets with severe SM were used in this study. Excess extra-muscular fat and skin were removed from fillets. Nine individual, intact fillets were randomly selected from each category, sealed in oxygen impermeable bags, and immediately stored in a -29°C walk in freezer for subsequent analysis.

The remaining breast fillets from each category were transferred to a grinder and ground separately through a 9.53-mm grinder plate (Model 7552, Biro, Lakeside Marblehead, OH). Ground breast meat was used to formulate five 11.34-kg batches: **NB**,

containing 100% unaffected breast meat; **SM25**, 25% SM and 75% unaffected breast meat; **SM50**, 50% of both SM and unaffected breast meat; **SM75**, 75% SM and 25% unaffected breast meat, and **SM100**, 100% SM. Batches were transferred to a paddle mixer (Model A-80; KOCH Equipment LLC., Kansas City, MO) and mixed for one minute in the forward direction, and then immediately one minute in the reverse direction. Once mixed, each batch was ground a second time through a 4.78-mm grinder plate and subsequently transferred to a vacuum filler (Model 500; Vemag Maschinenbau GmbH, Verden, Germany) with a patty former attachment (Model Single Slot die 3/8"; Colosimo's Original Inc., Magna, Utah). Batches were formed into 61-cm long by 10.2-cm wide by 9.5-mm thick strips and placed onto trays. Treatments were separated by tray and placed into a -40°C blast freezer for 20 min. Upon exiting the blast freezer, strips were cut every 10.2-cm to form 10.2-cm × 10.2-cm × 9.5-mm square patties. Once patties were formed, four patties, with wax paper on the bottom, were sealed in oxygen impermeable bags and stored in a -29°C walk in freezer until subsequent analysis. Three replications were formulated on separate days.

Thaw and Cook

After two days of frozen storage, patty samples were removed from the walk-in freezer, removed from the vacuum bag, and weighed (Model BD1201; METTLER TOLEDO, Greifensee, Switzerland) to obtain a frozen weight. Samples were then replaced in a vacuum bag without vacuum, transferred to a 3°C walk-in cooler on wire racks, and allowed to thaw for 24 h. After thawing, samples were reweighed (Model BD1201; METTLER TOLEDO) to obtain a thaw weight. Thaw yield was calculated using the following equation: $(\text{Thaw wt} \div \text{Frozen wt}) \times 100\%$.

Patties were cooked at 149°C on a flat top griddle (Model Griddler Elite; Cuisinart, Stamford, Connecticut) for 3 min 15 sec, flipped and cooked for additional 3 min 15 sec to an internal temperature of 73°C. Cooked patties were placed on a tray, allowed to cool for 21 min to an internal temperature of $25 \pm 1.5^\circ\text{C}$, and then weighed (Model BD1201; METTLER TOLEDO). Cook yield was calculated using the following equation: $(\text{Cook wt} \div \text{Thaw wt}) \times 100\%$.

Proximate Composition

Proximate composition was analyzed in triplicate on 3 breasts per treatment and replication after homogenization in a food processor. Patty proximate composition was analyzed in triplicate on 3 patties per treatment level and replication. Protein was analyzed using a rapid protein analyzer (Model Sprint; CEM Corporation, Matthews, NC). Moisture and fat contents were analyzed using a rapid microwave moisture analyzer (Model Smart Profat 6; CEM Corporation) and an NMR-based fat analyzer (Model ORACLE; CEM Corporation).

Time Domain-Nuclear Magnetic Resonance Measurements

Muscle water properties were assessed using transverse relaxation time (T_2) measurements with a LF90II minispec NMR (Bruker Biospin, Rheinstetten, Germany). For each replication, three intact raw breast fillets from each category (NB and SM) and four raw patties per treatment level were analyzed for T_2 properties. Transverse relaxation time data were acquired using Minispec NF software (Bruker Biospin) with $\tau = 0.15$ and 500 total number of acquired echoes. Contin software (Bruker Biospin) was used to determine the relative proportions of three identified water populations (bound, intra-myofibrillar, extra-myofibrillar). For intact raw breast fillets, 500 points of decay, 300

points of relaxation spectrum, and a relaxation interval of 2 ms to 661 ms were used for data collection and to calculate the three water peaks. For raw patties, 500 points of decay to fit, 500 points of relaxation spectrum, and a relaxation interval of 0.41 ms to 350 ms were used for data collection and to calculate the three water peaks. From each peak position, the percent relative area was calculated by the proportion of protons expressed during relaxation times by their respective area under each peak.

pH

After thawing, pH was measured in triplicate from equal thirds of raw intact breast fillets and raw patties with a spear tip probe (Model Orion 8163BNWP ROSS; ThermoFisher Scientific Inc., Waltham, MA) and a calibrated pH meter (Model Orion Star A321; ThermoFisher Scientific Inc.). pH was expressed as the average of the 3 measurements.

Instrumental Color Evaluation

Instrumental color (CIE L*, a*, b*) measurements were collected using a colorimeter set to illuminate D65 with a 10° viewing angle through an 8 mm aperture (Model Miniscan EZ 4500L; Hunter Associates Laboratory, Inc., Reston, VA). Twenty-five randomly selected intact raw breast fillets, per category (NB and SM) and replication, were measured in triplicate on the ventral and dorsal surfaces and expressed as skin and bone side respectively. Twenty-four randomly selected raw patties per treatment level and replication, were measured in triplicate subsequent to formation, and prior to freezing. Twelve cooked patties per treatment level and replication, were measured once samples cooled to $25 \pm 1.5^{\circ}\text{C}$ following cooking.

Allo-Kramer Shear Force Analysis

Allo-Kramer Shear force was analyzed on 4 patties per treatment level and replication. Once patties were cooled after cooking, a 4 cm × 3.5 cm section was removed from the patty's center, sections were weighed, then placed in an Allo-Kramer shear attachment, and analyzed on a Universal Testing Machine (Model Instron Dual Column 3365; Instron Corp., Norwood, Massachusetts). A 5K N load cell with a 25 cm/min crosshead speed was used to record peak shear force (Bluehill software, Instron Corp.) and shear force values are expressed as kgf/g.

Texture Profile Analysis

Texture Profile Analysis was analyzed in triplicate on 6 patties per treatment level and replication. Patties were divided into thirds from the center, and a 2.5 cm core was removed from each third. A 10.2 cm diameter cylinder probe (Model TA-40; Texture Technologies Corp., Hamilton, Massachusetts) compressed samples 40% of their height following the double compression method (Model TA-XT; Texture Technologies Corp.) with a pre-test speed of 1 mm/sec, test speed of 2 mm/sec, post-test speed of 2 mm/sec, and a 5 g trigger force. Textural parameter data were analyzed by Exponent Connect (Texture Technologies Corp.) for hardness, adhesiveness, resilience, cohesiveness, springiness, gumminess, and chewiness, where gumminess is the product of hardness and cohesiveness, and chewiness is the product of gumminess and springiness.

Sensory Evaluation

Sensory evaluations were conducted on chicken patties using a Quantitative-Descriptive Analysis (**QDA**) by trained culinary panelists (DragonFly SCI., Emeryville, California). Panelists completed one 75-minute language development session to identify and define sensory attributes. Chicken patties were thawed and cooked by replication

following the thaw and cook methods outlined above, covered, and kept warm in a 37°C oven until panelist evaluation. Half patties were served to panelist using a balanced block design with three replicate measurements per sample. Panelist scores were recorded using sensory data collection software (RedJade, Martinez, California), with a two-minute break between samples, unsalted crackers and water used as palate cleansers. Panelists evaluated each sample on appearance, aroma, flavor, and texture/mouthfeel. Sensory attribute descriptions are shown in Table 1.

Statistical Analysis

Data for intact raw breast fillets objective color were analyzed as a split-plot design. The whole plot consisted of breast category and skin or bone side within breast category served as the subplot. Fixed effects were category, side, and their interaction, and random effects were replication and replication \times treatment. Proximate composition, TD-NMR, yield, pH, Allo-Kramer shear, and TPA data were analyzed as a complete randomized block design. Either breast category, or patty treatment level served as the fixed effect, replication was included as the blocking factor, and raw breast or chicken patty was the experimental unit. Sensory data were analyzed as a complete randomized block design. Treatment served as the fixed effect, patty evaluated by panelist served as the experimental unit, replication was included as the blocking factor, and panelist was included as a random effect. All models were analyzed using the MIXED procedure of SAS 9.4 (SAS Institution Inc., Cary, North Carolina). Least square means were generated, and means were separated using the PDIFF option in the LSMEANS statement. Significance was determined at $\alpha \leq 0.05$.

Results

Proximate Composition

For intact raw breast fillets, there were no category (NB vs SM) effects for proximate composition ($P > 0.11$; Table 2), except for moisture percent ($P < 0.01$). Spaghetti Meat fillets had greater moisture than NB fillets ($P < 0.01$).

There were treatment effects for raw patty proximate composition ($P < 0.01$; Table 2), except for protein percent ($P = 0.59$). Moisture percent did not differ between SM100, SM75 or SM25 ($P > 0.10$); however, SM100 patties had greater moisture percent than SM50 and NB patties ($P < 0.01$), which did not differ from each other ($P = 0.28$). Spaghetti Meat 25, SM50, and SM75 did not differ in moisture percent ($P > 0.07$). Spaghetti Meat 100, SM75, and SM50 did not differ in fat percent ($P > 0.49$) and had greater fat percent than SM25 ($P < 0.03$). Spaghetti Meat 50 and NB patties did not differ in fat percent ($P = 0.06$), and NB patties did not differ from SM25 patties in fat percent ($P = 0.74$).

Thaw and Cook Yield

There were no treatment effects for intact breast thaw yield ($P = 0.54$; Figure 1), or for patty thaw yield ($P = 0.60$).

There were treatment effects for patty cook yield ($P < 0.01$; Figure 1). Spaghetti Meat 25 patties had greater cook yields than SM100 and NB patties ($P < 0.01$), and SM25 patties cook yield did not differ from SM50 or SM75 patties ($P > 0.08$). Spaghetti Meat50, SM75, and SM100 patties' cook yields did not differ ($P > 0.16$). Normal Breast patties had the lowest cook yield compared to all other treatments levels ($P < 0.01$).

pH

There were treatment effects for breast fillet pH values ($P = 0.04$; Table 2). Intact SM breasts had greater pH values than NB fillets ($P = 0.04$).

There were also treatment effects for patty pH values ($P < 0.01$; Table 2). Spaghetti Meat 100 patties had the greatest pH values ($P < 0.01$), which did not differ from SM75 patties ($P = 0.08$). The pH values of SM75 patties did not differ from SM50 patties ($P = 0.45$), and SM75 had greater pH values than NB and SM25 patties ($P < 0.01$). Spaghetti Meat 50 patties pH value did not differ from SM25 ($P = 0.06$) and SM50 patties had a greater pH than NB patties ($P < 0.01$). Spaghetti meat 25 patties and NB patties pH values did not differ ($P > 0.05$).

Water Properties

There were treatment effects on the intramyofibrillar and extramyofibrillar water properties of raw intact breast fillets ($P < 0.01$; Table 2), but no effect on the bound water ($P = 0.79$). Fillets from NB had greater intramyofibrillar water than SM fillets ($P < 0.01$), but SM fillets had greater extramyofibrillar water than NB fillets ($P < 0.01$).

There were treatment effects for raw patty intramyofibrillar and extramyofibrillar water properties ($P < 0.02$; Table 2), but no effect for bound water activity ($P = 0.31$). Spaghetti Meat 75 patties had greater intramyofibrillar water than NB and SM25 patties ($P < 0.04$), and SM75 patties' intramyofibrillar water did not differ from SM50 and SM100 patties ($P > 0.27$). The proportion of intramyofibrillar water in SM100, SM50, and NB patties did not differ ($P > 0.07$). Intramyofibrillar water in SM25 patties did not differ from NB or SM50 patties ($P > 0.06$). Spaghetti Meat 25 patties had greater extramyofibrillar water than SM75 and SM100 patties ($P < 0.01$), and SM25 patties

extramyofibrillar water did not differ from NB or SM50 patties ($P > 0.06$). Normal Breast patties extramyofibrillar water did not differ from SM50 or SM100 patties ($P > 0.07$). Spaghetti Meat 75 patties extramyofibrillar water did not differ from SM50 or SM100 patties ($P > 0.27$).

Objective Color

There were side by side interactions for intact breast fillet L^* and b^* values ($P < 0.01$; Figure 2), except for a^* ($P = 0.10$). Normal Breast skin side and SM skin side had greater L^* values than NB bone side and SM bone side ($P < 0.01$) and did not differ from each other ($P = 0.25$). Normal Breast bone side L^* value was less than SM bone side ($P < 0.01$). Spaghetti Meat bone side had the greatest b^* values ($P < 0.01$). Spaghetti Meat skin side had greater ($P < 0.01$) b^* values than NB bone side. Normal Breast skin side had the lowest b^* values ($P < 0.01$).

There were treatment effects across all objective color measurements for raw patties ($P < 0.01$; Table 3). Spaghetti Meat 100 patties' L^* values did not differ ($P = 0.12$) from SM50 patties, and SM100 patties had greater L^* compared to all remaining treatments ($P < 0.01$). Spaghetti Meat 50 patties' L^* values did not differ from SM25 and SM75 patties ($P > 0.17$). Normal Breast patties had lower L^* values than SM50 patties ($P = 0.04$) and did not differ from SM25 or SM75 patties in L^* value ($P > 0.10$). Normal Breast, SM50, and SM100 a^* values did not differ ($P > 0.08$) and had greater a^* values than SM25 and SM75 patties ($P < 0.01$), which did not differ ($P = 0.90$) from each other. Spaghetti Meat 100 patties had the greatest b^* values compared to all other treatments ($P < 0.01$). Spaghetti Meat 25, SM50, and SM75 b^* values did not differ from each other (P

> 0.20). Normal Breast patties had the smallest b^* value and differed from all other treatments ($P < 0.01$).

There were no treatment effects for objective color measurements in cooked patties ($P > 0.14$; Table 3), except for a^* values ($P = 0.04$). Normal Breast, SM25, SM50, and SM75 cooked patties a^* values did not differ ($P > 0.05$). Spaghetti Meat 100 patties had lower a^* values than NB and SM50 patties ($P < 0.02$) but did not differ from SM25 and SM75 cooked patties ($P > 0.52$).

Allo-Kramer Shear Force

There were treatment effects for Allo-Kramer shear force values ($P < 0.01$; Figure 3). Normal Breast patties had the greatest shear force value compared to all other treatments ($P < 0.01$) which did not differ from each other ($P > 0.08$).

Texture Profile Analysis

There were treatment effects for textural attributes ($P < 0.01$; Table 4), except for adhesiveness, resilience, and springiness ($P > 0.18$). Normal Breast patties had greater hardness values compared to all other treatment levels ($P < 0.01$). Spaghetti Meat 25 patties had greater hardness values than SM100 patties ($P = 0.03$). Spaghetti Meat 50 and SM75 patties did not differ from each other ($P = 0.47$) and did not differ from SM25 or SM100 ($P > 0.11$). Normal Breast patties had greater cohesion values than all other treatment levels ($P < 0.01$) which did not differ from each other ($P > 0.11$). Normal Breast patties had greater gumminess and chewiness values than all other treatment levels ($P < 0.01$). Spaghetti Meat 25 gumminess and chewiness values were greater than SM100 patties ($P < 0.04$). Spaghetti Meat 50 and SM75 gumminess and chewiness values did not differ ($P > 0.42$) from each other, or from SM25 and SM100 independently ($P > 0.10$).

Sensory Evaluation

There were no treatment effects for sensory texture or flavor attributes ($P > 0.15$; Table 5); however, there was a treatment effect for visual Sear ($P = 0.01$). The visual sear values in SM25 and SM50 patties did not differ ($P > 0.05$) from each other but were greater than scores in NB patties ($P < 0.01$). Spaghetti Meat 75 and SM100 visual sear values did not differ from all treatment levels ($P > 0.08$).

Discussion

Composition and Myofibrillar Water Properties

The objective of this study was to identify quality differences between SM and normal breast fillets and determine whether differences persist in raw and cooked chicken patties made with varying degrees of SM. Spaghetti Meat breasts had 1.4% greater total moisture than normal breasts, which persisted through processing with a linear moisture increase as SM percent incorporation increased with SM100 patties having nearly 1% greater moisture than NB patties. These findings agree with previous literature where SM was reported to have increased moisture (Baldi et al., 2019; Tasoniero et al., 2020) to a degree, but this study utilized the entire breast rather than sectioning off superficial or deep portions of the muscle. While identifying SM effect on different portions of afflicted fillets is important to understand the development and progression of the myopathy, this study's goal was to identify defects when the entire afflicted breast was used such that processors can understand if any quality defects become present after incorporating SM into a further processed product. Fat percentage in previous literature was not different in deep portions of muscle between SM and NB fillets, with one study finding superficial fat to differ between SM and NB (Tasoniero et al., 2020). The current study found no

difference between SM and NB fillet fat percentage; however, once formulated into patties, SM75 and SM100 patties had, on average, 0.13% greater fat content than NB patties. Protein percentage did not differ for breast fillet or patty treatments, but Tasoniero et al. (2020) reported whole SM breast myofibrillar protein was less soluble and formed a less stable emulsion than NB, but no difference in salt-induced water uptake. Therefore, while SM has no difference in protein abundance, SM does alter myofibrillar intrinsic properties.

In the current study, intact SM breast fillets had 11.2% less intramyofibrillar water, and 10.9% more extramyofibrillar water. Differences were present after particle size reduction, but SM had a positive impact on water properties as SM replacement of NB increased. Spaghetti Meat 75 patties had 6.6% greater intramyofibrillar water, and 6.6% less extramyofibrillar water with no difference in bound water percent compared to NB patties. Neither freezing, nor storage time was reported to have an effect on myofibrillar water properties (Soglia et al., 2019; Tasoniero et al., 2022). Spaghetti Meat's positive impact might be attributed to its effect on pH. Ultimate pH increased as SM percent replacement increased, with SM100 patties having a 0.06 pH units greater ultimate pH. Particle size reduction had no effect on NB pH, with fillet pH and NB patties having the same pH, but SM pH was 0.04 pH units' lower ground than in breast form.

Spaghetti Meat's slight increase in pH, and patty moisture could be attributed to SM having a greater amount of free amino acids found in the extra-cellular matrix resulting from SM fillets inability to properly dispose of cellular waste (Boerboom et al., 2018; Soglia et al., 2019). This theory could be supported by SM patties 11.8%

extramyofibrillar water decrease from fillet to patty form, and subsequent free amino acids present in the extra-cellular matrix are lost in purge during processing. Free amino acid concentrations were not analyzed prior to and after processing, but future research should identify if free amino acids are lost during particle size reduction.

It is important to note that myofibrillar water properties in the present study were expressed as relative abundances rather than total amount present in fillets or patties. This distinction could provide a simpler reason for myofibrillar water property differences seen from intact fillets to formed patties. Intact fillets were comminuted, thus disrupting, or destroying, muscle microstructure. In porcine longissimus, Bertram et al. (2003) reported muscle structure and sarcomere length had a direct affect on myofibrillar water mobility with more compact muscle structure and shorter sarcomere length resulting in additional drip loss. These authors reported a strong positive correlation of shorter sarcomere lengths expelling water in meats' microstructure and increasing drip loss (Bertram et al., 2003). Utilizing beef flank meat, Berger et al. (2022) reported muscle fiber structure destruction, soluble protein content, and drip loss increased when intact muscle was subjected to grinding. The present study's findings suggest that during patty processing SM fillets may have expelled greater amounts of extramyofibrillar water than NB fillets, thus increasing the relative abundance of intramyofibrillar water seen in patties. While treatments containing SM did not visually appear to have excess water accumulation during processing and no apparent batter consistency differences amongst treatments, it is logical to conclude SM myofibrillar water property differences from intact fillet to ground patty could be the result of comminution.

Yields and Color

Spaghetti Meat positively affected cook yield with SM chicken patties cook yield averaging 76.38% compared to NB patties 72.62% cook yield, a 3.78% increase. These findings disagree with current literature which reported SM breast cook loss to be 4.5% greater than unaffected breasts, and minced SM used in meat gels cook loss was approximately 1.5% greater than minced unaffected breast meat gels (Pascual Guzmán et al., 2021; Wang et al., 2022). It should be noted in Pascual Guzmán et al. (2021) SM breasts were 20.9% heavier than unaffected breasts, which could have contributed to cook loss, although this may not be a consideration when incorporating SM into ground products. Despite NB and SM25 chicken patties having similar levels of extramyofibrillar water, intramyofibrillar water, pH, protein percent, fat percent, and thaw yield, SM25 patties yielded 5.16% more than NB patties after cooking. Moreover, SM100 patties lost 2.64% more weight after cooking compared to SM25 patties. This study can conclude ground SM will increase cook yield in chicken patties; however, this study cannot conclude a reason as to why a 25% replacement of normal breast meat with SM resulted in 5.16% increase in cook yield. This study can suggest that SM shifts in myofibrillar water properties during processing could have contributed to the difference in cook yield. This is no clear trend, as SM75 patties were the only difference in myofibrillar water properties from NB patties, but, again, that is relative abundance. Further research should investigate myofibrillar water absolute amounts of SM from fillet to ground product.

In agreement with some literature, this study found SM breasts were yellower than NB (Baldi et al., 2018; Tasoniero et al., 2020). Baldi et al. (2018) reported the increased b^* values could be due to myopic breasts increased fat deposition. Moreover,

these authors and the present study found no difference in fat percent between NB and SM fillets, suggesting SM fillets deposit fat at the muscles surface where the epimysium and perimysium network breakdown occurs. The present study also found SM bone side tissue to be lighter than NB bone side tissue, which was not found in a previous study (Tasoniero et al., 2020). Differences seen in this study and others may be due to this study's strict selection of only severe SM affected fillets removing any moderate SM fillets from the study. Severely affected fillets were characterized by extensive superficial lacerations on its cranial and caudal surface, where moderately affected breasts presenting SM only on its cranial surface (Baldi et al., 2021). When only SM cranial portion is used, greater objective color measurements are seen compared to differences seen in the present study (Wang et al., 2023). Objective color measures reported in the current study are expressed as the average of 3 measurements each taken from a third of the breast; thus, it is feasible that objective color measures from SM head, main myopathy location, would differ. Lighter and yellower colors observed in fillet form did translate when SM was ground. Spaghetti Meat 100 patties were lighter and yellower than NB patties; however, the differences seen are less than 7 units and won't be noticeable to the consumer (Fletcher, 1999). Minor objective color variations should not concern processors or consumers, in the raw product as it will have little effect on cooked color; however, extreme color variations present in raw product can have adverse effects on final product color (Fletcher et al., 2000). The present study supports these findings as objective color differences in raw patties lightness and yellowness did not translate to differences in cooked patty object color. Cooked NB patties were 0.40 a* units redder compared to SM100 patties. Statistical differences in a* values for cooked patties may

not be noticeable to consumers. Consumer concerns for chicken redness are in blood spots present on the muscles surface, and consumers expect chicken to possess a characteristic pink color which, to consumers, indicates a fresh product (Kennedy et al., 2004). Overall, this study found SM to alter breast fillet color that is undesirable to the consumer, but SM incorporation into ground products will not affect consumers perception of quality.

Texture Characteristics of Chicken Patties

Texture is deemed one of the most important quality factors for chicken products as it relates to consumers acceptance and overall satisfaction (Mir et al., 2017). This study found SM to negatively impact objective texture and quality measurements if NB patties were used as standard, or control. Current literature reported cooked SM fillets did not affect TPA hardness, adhesiveness, cohesiveness, springiness, gumminess, chewiness, or resilience attributes (Campo et al., 2020). The previous study utilized sous vide cookery to achieve an internal temperature of 70°C that can create a softer surface compared to direct heat cookery which can directly affect texture values. Moreover, due to complete muscle fiber separation, some authors have determined utilizing SM fillets in some analysis apparatuses to be impossible (Wang et al., 2023). In the present study, SM incorporation, at any level, negatively affected TPA hardness (maximum force of first compression), cohesiveness (how well a product withstands a second compression), gumminess (how hard and cohesive a product is), and chewiness (how hard, cohesive, and springy a product is). At 25% replacement, SM caused patties to be 17.1% softer than NB patties, and SM100 patties were 27.7% softer than NB patties. Objective TPA hardness differences reported in the present study are confirmed with SM incorporated

patties having, on average, 0.72 kgf/g less Allo-Kramer (**AK**) shear force values compared to NB patties. Pascual Guzmán et al. (2021) reported SM breasts AK values were 2.9 N/g, or 0.296 kgf/g, softer than NB AK values. Spaghetti Meat incorporated patties were less cohesive than NB patties, consistent with lower shear force values found in AK testing suggesting when SM is incorporated into a further processed product it is more likely to fragment. Drastic differences in objective texture measurements could suggest an inferior product; however, if less shear force is interrupted as more tender, then SM may positively impact objective texture. Future research should investigate consumer ground chicken texture preferences and how it correlates to changes in TPA and AK values.

Spaghetti Meat has yet to be analyzed by a sensory panel in either whole breast form or when incorporated into a further processed product. Despite SM negative effects on objective texture analysis, the present studies sensory evaluation found no textural or flavor differences. Panelists were able to determine NB patties had less visual browning, or sear, on patties surface than SM25 and SM50 patties. Spaghetti Meat has increased free amino acids (Soglia et al., 2019) which could attribute to a more intense Maillard reaction resulting in more surface sear. The present study's sensory evaluation suggests SM might have less hurdles to full incorporation in products at the processing plant than Woody Breast whose effect on flavor and texture have yet to be overcome (Brambila et al., 2017; McDonald et al., 2023).

Conclusion

Spaghetti Meat had a direct impact on objective quality factors when formulated into chicken patties. Spaghetti Meat patties had minor differences in proximate

composition, pH, and objective color following particle size reduction. Key determining factors for utilizing SM in processed products are its effects on texture, WHC, and sensory evaluation. This study found that TPA and AK shear force values were impacted when SM was incorporated into a chicken patty; however, differences were not noticeable to panelists during sensory evaluation. Spaghetti Meat positively impacted intramyofibrillar water, extramyofibrillar water, and cook yields perhaps providing processors a method to maximize yields whilst using a previously discounted product. The data from the present study can provide evidence for poultry processors to incorporate all previously removed SM breast fillets into their ground chicken. Poultry processors can confidently incorporate SM into their ground chicken breast due to this studies use of only severely affected SM breast fillets. It is reasonable to assume processor will have varying degrees of SM present and will not formulate a 100% severe SM grind: thus, having a ground chicken breast formulation within this studies treatments. Future research should focus on SM performance when functional ingredients such as salt and phosphates are added, ground SM shelf life, and sensory evaluation to correlate consumer texture preferences with objective texture values.

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Table 1. Sensory Attribute Definitions

Sensory attribute	Definition
Visual ¹	
Sear	Measure of the amount of searing, or browning due to cooking, on the surface of the patty.
Moisture	Measure of the amount of visible moisture on the surface of the patty.
Flavor ²	
Chicken	Intensity of cooked chicken meat flavor.
Chicken Fat	Intensity of chicken fat flavor, characteristic of chicken skin.
Umami	Intensity of umami taste, includes savory tastes.
Texture ³	
Crumbles	Overall impression of how much the product crumbles on first bite, ranging from low or stays intact, to high or breaks into many pieces.
Chewy	Overall impression of the chewiness of the product while breaking down. A product with a high chewy rating would take many chews to break down.
Adhesive	Degree to which the product adheres or sticks to the mouth.
Cohesive	Degree to which the product forms a ball and sticks to itself inside the mouth.
Moisture	Degree to which the product feels moist and wet in the mouth; a dry patty would be low in moistness.

¹Visual evaluation scored when patty was initially placed in front of panelist. ²Flavor evaluation scored during panelists initial patty bite. ³Texture evaluation scored as panelist chewed patties.

Table 2. Proximate composition, pH, and Myofibrillar water properties of Normal Breast and Spaghetti Breast fillets, and chicken patties with varying levels of Spaghetti Meat incorporated

Parameters	Breast category ¹		SEM	<i>P</i> value	Patty category ²					SEM	<i>P</i> value
	NB	SM			NB	SM25	SM50	SM75	SM100		
Myofibrillar water, %											
Bound	0.09	0.09	0.006	0.79	0.15	0.15	0.14	0.14	0.18	0.02	0.31
Intra	71.47 ^a	60.28 ^b	5.83	<0.01	66.32 ^{b,c}	63.60 ^c	69.48 ^{a,b,c}	72.90 ^a	71.94 ^{a,b}	4.86	0.02
Extra	28.76 ^b	39.62 ^a	5.67	<0.01	33.53 ^{a,b}	36.25 ^a	30.37 ^{a,b,c}	26.94 ^c	27.87 ^{b,c}	4.84	0.01
pH	5.88 ^b	5.98 ^a	0.056	0.04	5.88 ^d	5.89 ^{c,d}	5.91 ^{b,c}	5.92 ^{a,b}	5.94 ^a	0.009	<0.01
Proximate composition											
Protein, %	25.12	24.37	0.37	0.11	24.31	23.77	24.04	24.16	24.07	0.25	0.59
Moisture, %	73.94 ^b	75.14 ^a	0.23	<0.01	74.00 ^c	74.48 ^{a,b}	74.23 ^{b,c}	74.63 ^{a,b}	74.84 ^a	0.15	<0.01
Fat, %	0.90	1.09	0.10	0.21	1.20 ^{b,c}	1.17 ^c	1.35 ^{a,b}	1.41 ^a	1.38 ^a	0.08	0.01

^{a,b,c,d} Means within a category and row without common superscript differ ($P < 0.05$). ¹Normal Breast is unaffected breast meat. Spaghetti Meat is breast meat affected by spaghetti meat myopathy. ²Normal Breast patty formulated with unaffected breast as the primary protein source. Spaghetti Meat 25 patty formulated with 25% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 50 patty formulated with 50% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 75 patty formulated with 75% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 100 patty formulated with 100% replacement of unaffected breast meat with spaghetti meat.

Table 3. Objective color measurements of raw and cooked chicken patties with varying levels of Spaghetti Meat incorporated

Parameters	Patty Category ¹					SEM	P value
	NB	SM25	SM50	SM75	SM100		
Raw ²							
L* ³	57.26 ^c	57.82 ^{b,c}	57.96 ^{a,b}	57.49 ^{b,c}	58.50 ^a	1.07	<0.01
a* ⁴	9.58 ^a	9.19 ^b	9.59 ^a	9.24 ^b	9.76 ^a	0.82	<0.01
b* ⁵	27.63 ^c	28.41 ^b	28.68 ^b	28.58 ^b	29.31 ^a	1.08	<0.01
Cooked ⁶							
L*	78.48	78.57	78.58	78.72	78.45	0.50	0.78
a*	3.90 ^a	3.81 ^{a,b}	3.95 ^a	3.61 ^{a,b}	3.50 ^b	0.26	0.04
b*	26.18	26.14	26.79	26.27	26.10	0.23	0.14

^{a,b,c} Means within a row without common superscript differ ($P < 0.05$). ¹Normal Breast patty formulated with unaffected breast as the primary protein source. Spaghetti Meat 25 patty formulated with 25% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 50 patty formulated with 50% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 75 patty formulated with 75% replacement of unaffected breast meat with spaghetti. Spaghetti Meat 100 patty formulated with 100% replacement of unaffected breast meat with spaghetti meat. ²Uncooked, thawed, raw patties. ³0 is black and 100 is white. ⁴-60 to 60 color scale. ⁵-60 to 60 color scale. ⁶Cooked patties were allowed to cool to 25°C and then objective color was collected.

Table 4. Texture profile analysis of cooked chicken patties with varying levels of spaghetti breast meat incorporation

Attribute	Patty category ¹					SEM	<i>P</i> value
	NB	SM25	SM50	SM75	SM100		
Hardness	4507 ^a	3735 ^b	3455 ^{b,c}	3616 ^{b,c}	3260 ^c	293	<0.01
Adhesiveness	-9.24	-9.27	-11.31	-7.61	-4.12	2.26	0.18
Resilience	0.20	0.19	0.22	0.19	0.19	0.016	0.47
Cohesion	0.64 ^a	0.61 ^b	0.61 ^b	0.61 ^b	0.59 ^b	0.008	<0.01
Springiness	0.71	0.69	0.68	0.69	0.68	0.013	0.23
Gumminess	2891 ^a	2321 ^b	2110 ^{b,c}	2227 ^{b,c}	1962 ^c	188	<0.01
Chewiness	2056 ^a	1628 ^b	1446 ^{b,c}	1552 ^{b,c}	1350 ^c	141	<0.01

^{a,b,c}. Means within a row without common superscripts, differ ($P < 0.05$).¹Normal Breast patty formulated with unaffected breast as the primary protein source. Spaghetti Meat 25 patty formulated with 25% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 50 patty formulated with 50% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 75 patty formulated with 75% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 100 patty formulated with 100% replacement of unaffected breast meat with spaghetti meat.

Table 5. Sensory evaluation of chicken patties incorporated with SM

Attribute	Patty Category ¹					SEM	P value
	NB	SM25	SM50	SM75	SM100		
Visual ²							
Sear	28.73 ^b	36.60 ^a	42.34 ^a	34.70 ^{a,b}	35.70 ^{a,b}	3.68	0.01
Moisture	19.27	18.57	19.50	22.23	21.80	4.61	0.59
Flavor ³							
Chicken	58.23	59.70	57.53	60.53	56.90	5.56	0.15
Chicken	17.27	16.57	16.23	17.90	14.43	5.00	0.91
Fat							
Umami	33.13	33.43	33.73	33.47	34.17	7.05	0.99
Texture ⁴							
Crumbles	44.97	49.70	45.97	44.73	46.10	5.28	0.43
Chewy	50.97	52.20	54.27	49.97	50.60	4.64	0.43
Adhesive	34.67	35.43	34.93	32.20	34.33	4.41	0.61
Cohesive	28.30	28.80	27.37	26.50	26.03	5.80	0.54
Moisture	21.40	19.90	20.67	24.90	23.20	4.65	0.35

^{a,b} Means within a row without common superscript differ ($P < 0.05$). ¹Normal Breast patty formulated with unaffected breast as the primary protein source. Spaghetti Meat 25 patty formulated with 25% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 50 patty formulated with 50% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 75 patty formulated with 75% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 100 patty formulated with 100% replacement of unaffected breast meat with spaghetti meat. ²Visual evaluation scored when patty was initially placed in front of panelist. ³Flavor evaluation scored during panelists initial patty bite. ⁴Texture evaluation scored as panelist chewed patties.

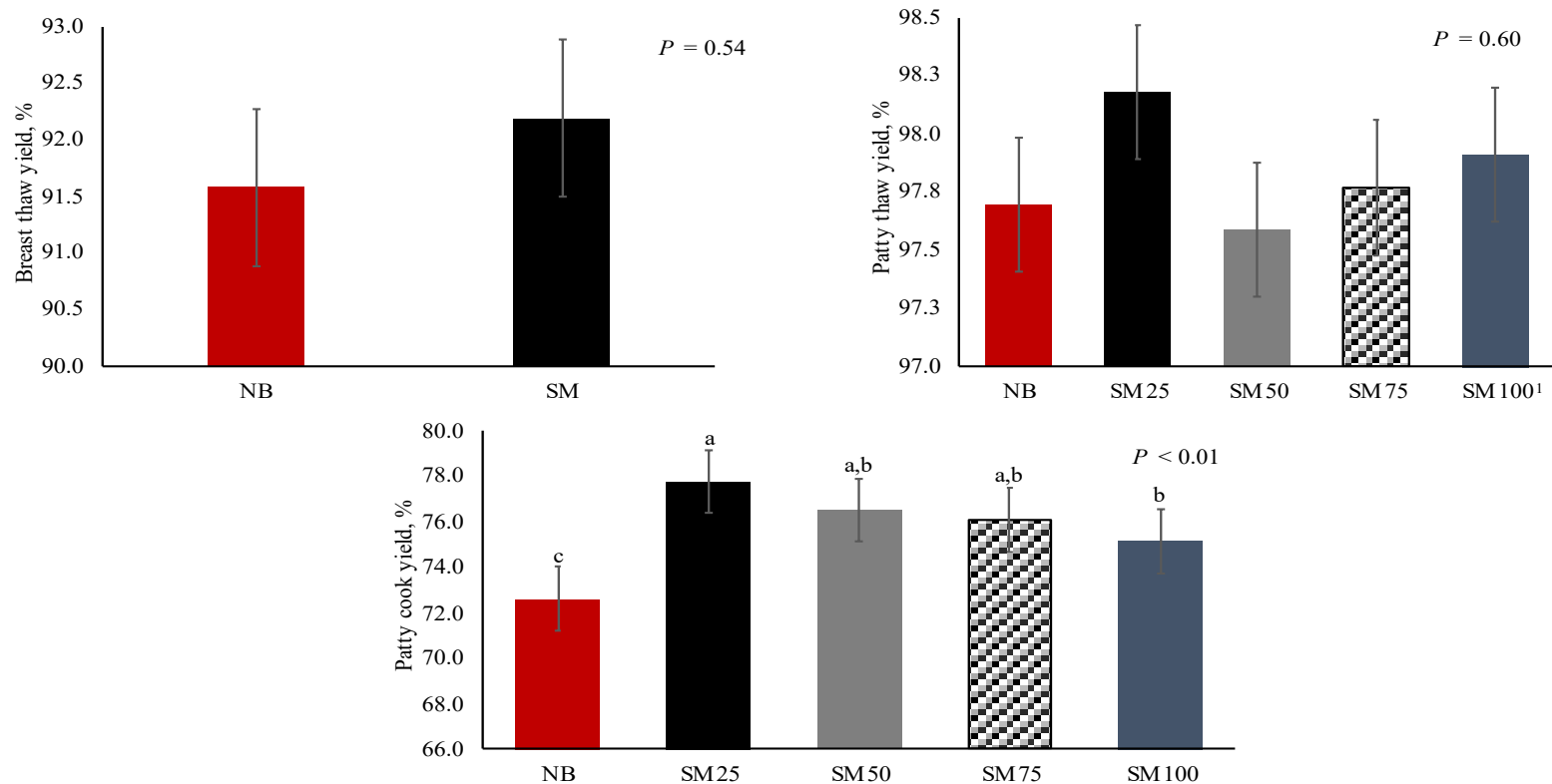


Figure 1. Thaw and Cook Yields for Normal Breast, Spaghetti Breasts, and Chicken Patties with varying levels of Spaghetti Meat Incorporated. ^{a,b,c,d} Means without common superscripts, differ ($P < 0.05$). ¹ Normal Breast patty formulated with unaffected breast as the primary protein source. Spaghetti Meat 25 patty formulated with 25% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 50 patty formulated with 50% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 75 patty formulated with 75% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 100 patty formulated with 100% replacement of unaffected breast meat with spaghetti meat.

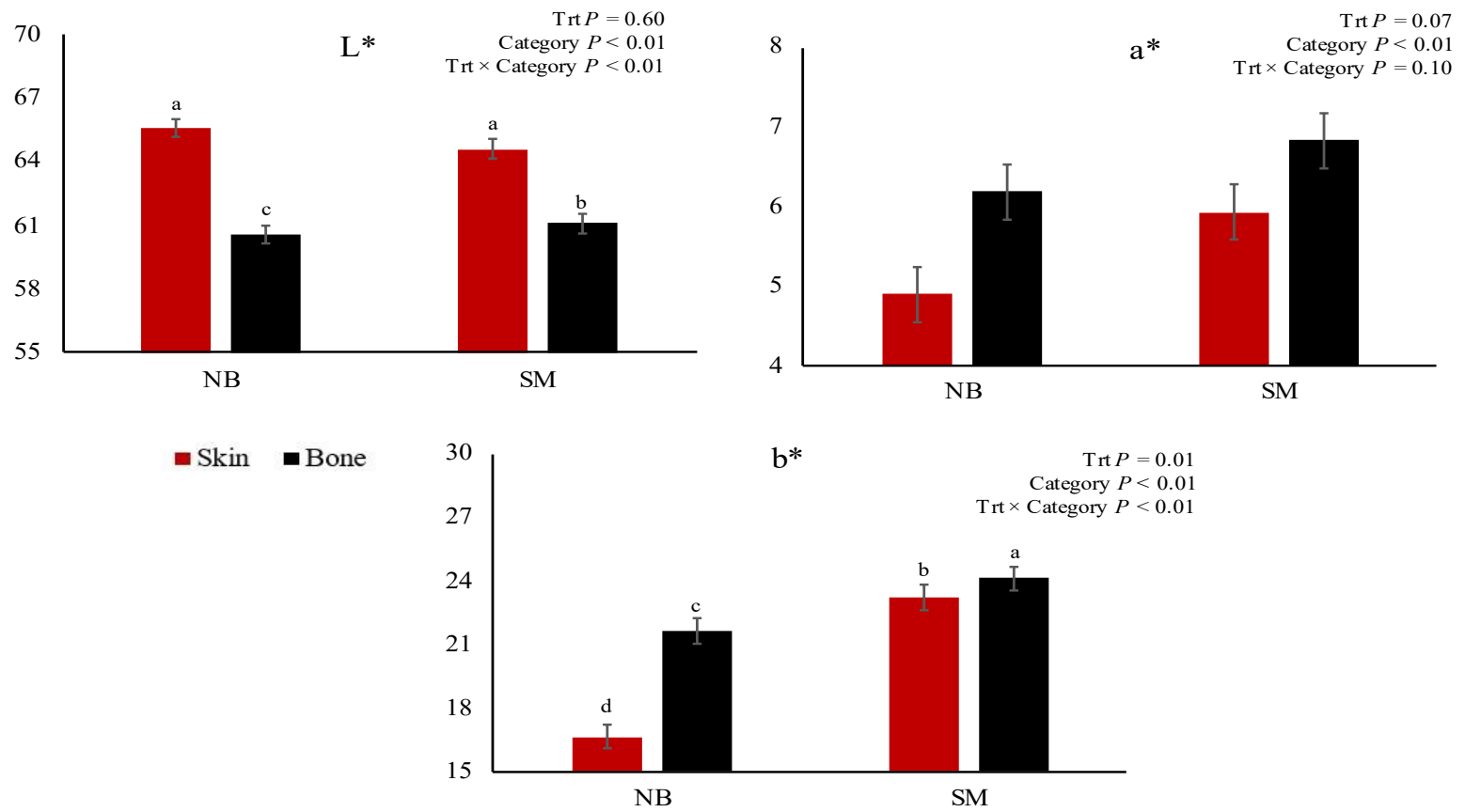


Figure 2. Objective Color Measurement of Raw Normal and Spaghetti Breasts.^{a,b,c,d} Means without common superscripts, differ ($P < 0.05$). L* measure of lightness to darkness, 0 is black and 100 is white. a* measure of red to green, -60 to 60 color scale. b* measure of blue to yellow, -60 to 60 color scale.

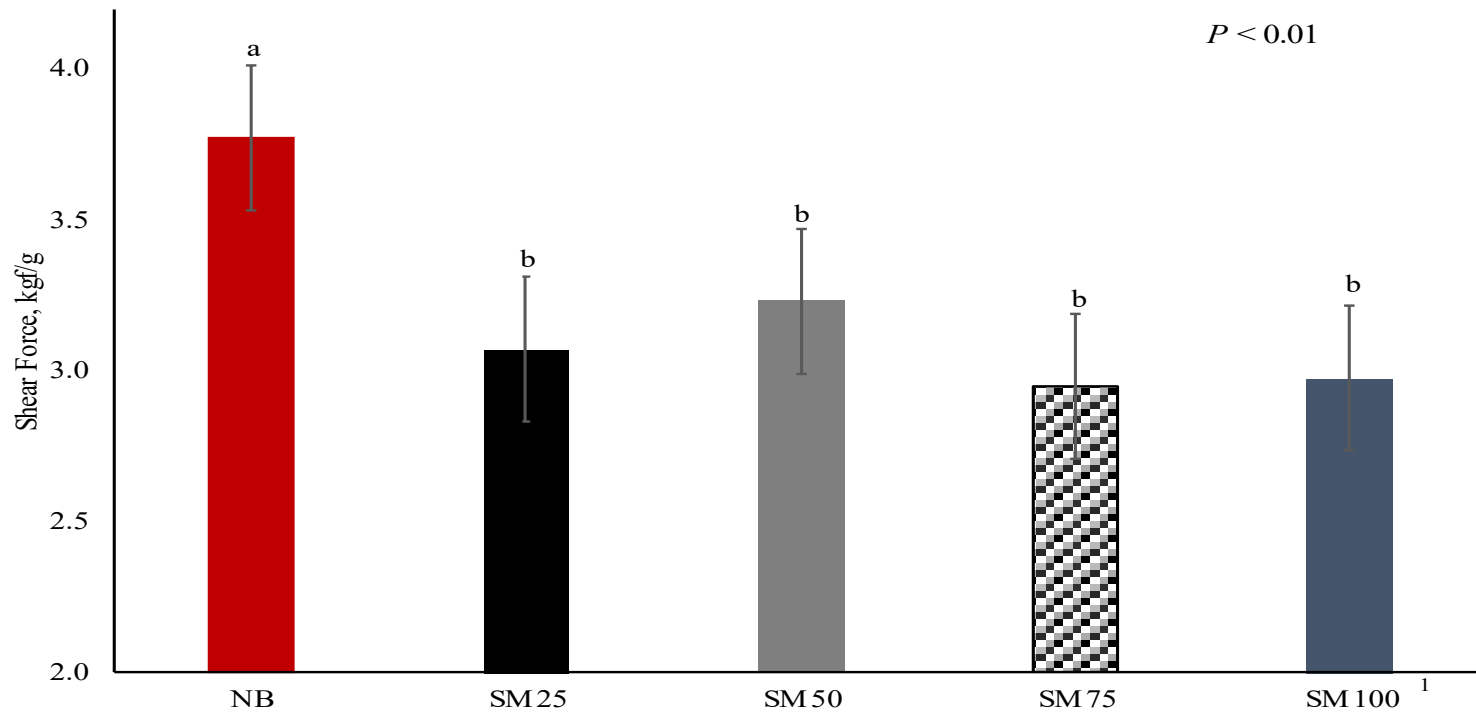


Figure 3. Allo-Kramer Shear Force of Cooked Chicken Patties with varying levels of Spaghetti Meat Incorporated. ^{a,b} Means without common superscripts, differ ($P < 0.05$). ¹ Normal Breast patty formulated with unaffected breast as the primary protein source. Spaghetti Meat 25 patty formulated with 25% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 50 patty formulated with 50% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 75 patty formulated with 75% replacement of unaffected breast meat with spaghetti meat. Spaghetti Meat 100 patty formulated with 100% replacement of unaffected breast meat with spaghetti meat.