Quality of turkeys breast meat affected by white striping myopathy

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ABSTRACT The aim of this study was to characterize the breast meat of turkeys affected by different degrees of severity (normal [**NORM**], moderate [**MOD**], and severe [**SEV**]) of the white striping (**WS**) myopathy, as well as to evaluate the influence of this myopathy on meat quality. Twenty-nine samples of the pectoralis major muscles of each treatment were obtained from Nicholas breed male and female turkeys, reared and slaughtered in the center-west region of Brazil. The whole breasts of the turkeys were used for macroscopic classification, weight evaluation, and morphometric measurements. Then, the pectoralis major muscle was separated for histological evaluation and qualitative physicochemical analyses, namely ventral and dorsal color (L*, a*, and b*), pH value, water holding capacity (**WHC**), cooking loss (**CL**), shear force (**SF**) (Meullenet-Owens Razor Shear [**MORS**] and Warner-Bratzler), sarcomere length, total, soluble, and insoluble collagen contents, proximate composition (protein, lipids, moisture, and ash), cholesterol content, and fatty acid profile. The results showed that muscles affected by myopathy, both MOD and SEV, exhibited larger weights (around 2.8 kg) compared to NORM muscles (1.3 kg) and a significant increase ($P < 0.05$) in the diameter of the fibers. The increase in the degree of severity of the myopathy increased ($P < 0.05$) the value of L* of the dorsal part and ventral part of the muscle. No differences ($P > 0.05$) were observed in the pH, CL, and WHC values of the muscles, whereas the MORS and Warner-Bratzler SF of the SEV fillets resulted in significantly lower shear values ($P < 0.05$) compared to the NORM fillets. In addition, the MOD and SEV fillets presented lower values of protein ($P < 0.05$) than NORM fillets. No significant differences ($P > 0.05$) were observed for moisture and lipid and cholesterol contents. Meat with MOD and SEV severity of WS myopathy had higher ($P < 0.05$) concentrations of total and insoluble collagen. Thus, the presence of WS myopathy in MOD and SEV degrees affected a large part of the histological and quality characteristics evaluated.

Key words: connective tissue, softness, pectoralis major, turkey, white striping

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INTRODUCTION

The turkey meat market has stood out among meat products, according to ABPA (2018); in the year 2017, the production of turkey meat was 390.48 thousand tons, a number that exceeds the production of this sector, in 2016, by 6.1%. Brazilian exports reached 109 thousand tons. The consumption of turkey meat in Brazil occurs especially in the form of ham, smoked or cooked breasts, mortadellas, sausages, and hamburgers (Magdelaine et al., 2008; Kuttappan et al., 2012).

According to the North American Meat Institute, in the year 2017, the total consumption of turkey meat in the United States was 2.7 billion kilograms, being considered one of the most consumed processed meat in America (North American Meat Institute, 2018). A current USDA report proposes that consumption of turkey meat per capita will reach 7.8 kg per person by 2025.

Turkey meat has become universally popular and is widely used in regional cuisines. It has high protein and mineral content, reduced lipid content, and good sensory characteristics (Gálvez et al., 2018). With

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increasing health concerns among consumers, consumption of turkey meat has increased over the past decades, putting more pressure on producers to improve the performance of live poultry production (growth rate and feed conversion). This intense genetic selection of poultry for greater weight gain in a shorter life span has led to abnormal physiological behaviors that cause damage to muscle tissue, such as the white striping (**WS**) myopathy observed in broiler meat (Petracci et al., 2014).

WS myopathy is the occurrence of white striations viewed parallel to the muscle fibers, especially in the pectoralis major (breast fillet) muscle, and may present with varying degrees of severity that can be classified as normal (**NORM**), moderate (**MOD**), and severe (**SEV**). It is directly associated with heavier and/or higher growth rate of poultry (Kuttappan et al., 2013c).

The existence of WS myopathy does not affect the safety of meat as food; however, it may decrease the quality and acceptance by the consumer. In a study of consumer acceptance of the visual appearance of broiler breast meat with varying degrees of WS myopathy, the results suggest that WS affects consumer acceptance based on the appearance of fillets and consumers were more likely to purchase NORM fillets (Kuttappan et al., 2012). Broiler breasts affected by myopathy show increased fat content, reduction in protein content, increased values of monounsaturated fatty acids, and reduced values of eicosapentaenoic and docosahexaenoic acids. The pH value and cooking losses (**CL**) are significantly higher and the shear force (**SF**) and the water holding capacity (**WHC**) are significantly lower in meat with WS (Kuttappan et al., 2012, 2013b; Petracci et al., 2013).

WS myopathy is a reality that negatively affects the production of commercial poultry in Brazil. Although numerous studies have recently addressed the impact of this myopathy on the quality and technological properties of broiler meat, only limited data are available on turkey meat. In this context, studies should be carried out to understand the dynamics of this myopathy, as well as to know its effects on the quality of the meat of this species. Thus, the objective of this study was to characterize the breast meat of turkeys affected by different degrees of severity of WS myopathy, as well as to evaluate the influence of this myopathy on the quality and sensory acceptance of this meat.

MATERIALS AND METHODS

Sample Collection and Preparation

Samples were randomly collected in a commercial slaughterhouse located in the center-west region of Brazil. Eighty-seven samples were obtained from the pectoralis major muscle of Nicholas breed male and female turkeys, aged between 150 and 160 d with an average weight at slaughter of 18.5 kg, affected by WS myopathy in different degrees: NORM (n = 29), MOD (n = 29), and SEV (n = 29). The turkeys were slaughtered in accordance with the routine of the slaughterhouse.

After identification and gathering, the samples were transported to the Laboratory of Technology of Animal Products of the Department of Technology of the Faculty of Agrarian and Veterinary Sciences of UNESP, Jaboticabal Campus, São Paulo, Brazil under controlled temperature conditions (4°C–6°C). Physical analyses were performed immediately after the arrival of the samples in the laboratory, and the samples for further chemical analyses were frozen at −18°C (for a period of not more than 30 d).

Analysis

Classification of Samples According to the Degree of Severity of WS Myopathy Macroscopic classification of the carcasses was initially performed according to the degree of severity of the striations apparent in the muscle, using NORM, MOD, and SEV, according to the methodology used by Kuttappan et al. (2012). The MOD degree was assigned to fillets that exhibited white striations on the surface of the muscle less than 1 mm thick, but visible on the surface of the muscle. Fillets showing white striations, parallel to the muscle fibers, with a thickness greater than 1 mm, easily visible on the surface of the breast fillet, were classified as SEV. Fillets that did not show white striations were classified as NORM. Illustrative images of this classification are presented in Figure 1. Then, each muscle was weighed.

Histological Analysis For the analysis of the morphometric parameters of the muscle fiber, transverse samples of 2 cm of the pectoralis major muscle of 10 turkeys per treatment were removed from the sternal region in the paramedian portion of the lesion to analyze the compromising of the musculature around the area affected by the WS myopathy. Subsequently, the material was fixed in plastic containers having Bouin solution in the course of 24 h. Then, the samples were sanitized in 70% ethanol to remove the fixative, and dehydrated in a series of increasing ethanol concentration (70, 80, 90, and 100%). After dehydrating the material, the samples were diaphanized in xylol and included in paraffin. Semiserial histological sections 5 μm thick were stained with hematoxylin and eosin (Behmer and Tolosa, 2003). The slides were produced with Stellan. The final material was analyzed using an Olympus photomicroscope on 10 and 40× lenses coupled to the Olympus Computerized Image Analysis Software (Olympus Co., Japan). The related images were photographed for subsequent morphometric analysis in the Olympus CellSens Software 1.14 (Olympus Co., Japan). Preliminarily, the structure, shape, size, position of nuclei, and the existence of artifacts or anomalies in histological sections were analyzed. Muscle fiber morphometric analyses included the number of muscle fibers, the perimeter (μm), diameter (μm), area (μm^2) of the fibers, and the thickness of the perimysium that surrounds the muscle fibers.

Chemical Analysis Total, soluble, and insoluble collagen contents were quantified by determination of amino acid hydroxyproline according to the methodology proposed by Woessner (1961) and Cross et al. (1973), adapted by Hadlich et al. (2006) and by the Laboratory of Technology of Animal Products of the Faculty of Agrarian and Veterinary Sciences of UNESP, Jaboticabal Campus. Five grams of frozen raw meat was weighed into 50 mL Falcon tubes and 20 mm of distilled water was added. Subsequently, the tubes were subjected to a water bath (80°C) for 2 h. The samples were then homogenized in Ultra-Turrax at 22,000 rpm for 1 min and centrifuged at 4,000 rpm for 15 min (centrifugation at room temperature, 24°C). The samples were transferred to autoclavable tubes. In this phase, the sediment (solid fraction) and the filtrate (liquid fraction) were separated. Thirty milliliters of 6N HCl were added to the filtrate, and 50 mL of 6N HCl to the sediment (Woessner, 1961). The samples were autoclaved for 4 h (120°C, 1 atm) (Cross et al., 1973), and the next day the pH of all samples was adjusted to 6.0 using 2N NaOH. After that, the samples were filtered in volumetric flasks (sediment in 250 mL flasks and filtered in 100 mL flasks) and the flasks were filled with distilled water. Then, 10 mL was collected from all samples and added to the other volumetric flasks (sediment samples in 100 mL flasks and filtrate in 50 mL flasks), and the flasks were filled with distilled water. Then, 2 mL aliquots of each diluted sample were pipetted into test tubes, and 1 mL of oxidation reagent (Chloramine-T 1.41%) and 1 mL of color reagent (10 g of p-dimethylaminobenzaldehyde in 35 mL of 60% perchloric acid and 65 mL of isopropanol) were added. The sample tubes were kept in a water bath for 15 min at 60°C. Spectrophotometer readings with the wavelength adjusted to 560 nm were taken. Results for soluble collagen concentration were obtained through the filtrate samples, while results for insoluble collagen concentration were obtained through the sediment samples. The standard curve was analyzed using a solution with a known concentration of hydroxyproline. The collagen concentration was estimated at 7.14 times the hydroxyproline concentration (Hadlich et al., 2006). Total, insoluble, and soluble collagen values were calculated using the following equations:

$$\%\ of\ collagen\ in\ sediment\ =\ \frac{absorbance\times F\times 250\times 100\times 7.14\times 10-6\times 100}{10\times 2\times meat\ sample\ weight(g)}$$

$$\%\ of\ collagen\ in\ supernatant=\ \frac{absorbance\times F\times 100\times 50\times 7.14\times 10-6\times 100}{10\times 2\times meat\ sample\ weight(g)}$$

$$\%\ of\ total\ collagen=\%\ of\ collagen\ in\ sediment+\%\ of\ collagen\ in\ supernatant$$

$$\%\ of\ soluble\ collagen\ =\ \frac{\%\ of\ collagen\ in\ supernatant\times 100}{\%\ of\ total\ collagen}$$

The proximate composition were determined by the moisture (950.46, Moisture in Meat), protein (977.14, Nitrogen in Meat), and ash (920.153, Ash of Meat) contents, according to procedures recommended by the Association of Official Analytical Chemists (AOAC, 2005), and lipids by the methodology described by (Bligh and Dyer, 1959).

Cholesterol was determined using the methodology described by Saldanha et al. (2004). In the Falcon tubes, 0.5 g of lyophilized sample was weighed, and 6 mL of ethanol and 4 mL of 50% aqueous KOH solution were added. Then, the tubes were kept in a shaking water bath (40°C) until the samples had completely dissolved. Subsequently, the sample tubes were kept in a water bath (60°C) for 10 min. Five milliliters of distilled water was added and, after refrigerating the samples, 10 mL of hexane was added 3 times for phase separation. From the upper phase, a 3 mL aliquot was collected and evaporated with N_2. After that, 0.5 mL of isopropanol was added and the tubes were vortexed, 3 mL of enzyme reagent (Labtest Cholesterol Analysis Enzyme Kit, Ref: 76 MS: 10009010068) was added, and the samples were kept in a water bath for 10 min (37°C). Finally, the spectrophotometer reading was noted at the wavelength indicated by the enzyme reagent manufacturer (500 nm).

Sarcomere length was determined by the method of Cross et al. (1981), using approximately 0.5 g of the central portion of the muscle of each sample. Then, 15 mL of 0.08 mol/L potassium chloride and 15 mL of 0.08 mol/L potassium iodide were added to the Falcon tube and homogenized in the Ultra-Turrax equipment at 15,000 rpm for 30 s to ease the suspension of muscle myofibrils. One drop of the homogenate was transferred to a slide and covered with a coverslip. The set was read quickly under a phase-contrast microscope at 1,000× magnification (100× objective, 10× eyepiece).

Raw samples were isolated in fatty acids by the method described by Bligh and Dyer (1959), removing the lipid phase from the sample. Fatty acid esterification was performed according to the methodology proposed by Maia and Rodriguez-Amaya (1993), and analyzed by a gas chromatograph (Shimadzu 14 B, Shimadzu Corporation, Kyoto, Japan) equipped with a flame ionization detector, and a fused silica capillary column (Omegawax 250), where H_2 was used as the carrier gas. Peak identification was performed by comparing the retention times of known composition standards.

Physical Analysis Color was determined in triplicate using a Minolta Chroma Meter CR-400 colorimeter through the CIELAB system. The color characteristics of lightness (L*), the intensity of redness (a*), and intensity of yellowness (b*) of the pectoralis major muscle were evaluated. The color was evaluated on the ventral (muscle surface in contact with the skin), and dorsal (internal surface of the muscle in contact with the supracoracoideus muscle and sternal bone) surface so that there was no interference from the slaughter process on this variable. Evaluation was performed at 3 different points of each muscle part and averaged.

The pH value was determined in duplicate using a model 205 Testo digital pH meter equipped with a penetration electrode by direct insertion of the electrode into the pectoralis major muscle.

WHC was determined using the methodology described by Hamm (1961), in which 2 g of pectoralis major muscle sample was placed between 2 filter papers and acrylic plates and subjected to a pressure exerted by a weight of 10 kg for 5 min. Subsequently, the samples were again weighed to determine the WHC, expressed as a percentage, according to the calculation: $\frac{(final\ weight)\times 100}{initial\ weight}$.

CL was determined in pectoralis major muscle samples of similar size and weight using the methodology described by Honikel (1987). The samples were weighed, packaged in waterproof plastic casing, and cooked in a water bath (85°C) for 30 min. After refrigerating at room temperature, they were again weighed to determine CL, expressed as a percentage, according to the calculation: $\frac{(initial\ weight - final\ weight)\times 100}{initial\ weight}$.

SF was analyzed using the Meullenet-Owens Razor Shear method described by Cavitt et al. (2004) in samples of the pectoralis major muscle from the CL analysis. The samples were cut with fibers oriented perpendicular to the blade, which had a straight shape, 0.5 mm thickness, 8.9 mm width, and 30 mm height. Three measurements were taken from each sample. The blade was coupled to a Texture Analyzer TA-XT2i to make the cuts and the force required to shear the sample was expressed in Newtons. The Warner-Bratzler method described by Lyon et al. (1998) was also applied, where the samples were cut into 1 cm^2 cross-sectional strips (with 3 repetitions), which were placed with the fibers oriented perpendicular to the "Warner-Bratzler" device, coupled to the Texture Analyzer TA-XT2i, and cut. The force required to shear the sample was also expressed in Newtons.

Statistical Analysis Data were arranged in a completely randomized design with 3 treatments (NORM, MOD, and SEV) and 29 repetitions per treatment. ANOVA was performed and in case of significance, means were compared by Tukey test, with a significance level defined at $P < 0.05$, using SAS software (SAS Institute Inc., Cary, NC, 2002–2003).

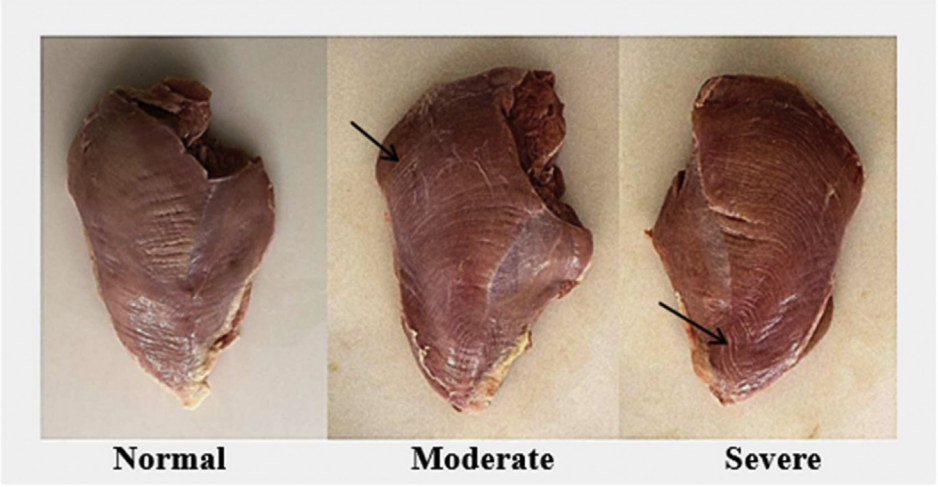

Figure 1. Classification of the white striping myopathy according to the degree of severity (normal, moderate, and severe) of the apparent white striations in the muscle.

RESULTS AND DISCUSSION

General Macroscopic Analysis of Pectoralis Major Muscles of Turkeys Affected by WS Myopathy

In the general macroscopic analysis of the pectoralis major muscles of turkeys, white striations were observed to be arranged in the same direction as the muscle fibers in the MOD and SEV degrees of myopathy. Moderately affected pectoral muscles showed striations less than 1 mm thick in the right and left upper quadrants. White striations in the SEV degree extended to the middle portion of the muscle, with a thickness generally greater than 1 mm, following the classification of Kuttappan et al. (2012). According to Valentine and McGavin (2012), white striations may be due to mineralization or infiltration of collagen or fat as a result of muscle fiber necrosis.

According to Kuttappan et al. (2012), the reduction in protein content in fillets with SEV WS is directly related to the increase in scores for degenerative or necrotic lesions, fibrosis, and lipidosis as the degree of WS myopathy increases.

The results of the pectoralis major muscle classifications and weights are shown in Table 1. There was an increase in the weight of the pectoralis major muscle with the progression of the lesion. This behavior can be expected, as heavier birds tend to present more myopathy problems (Kuttappan et al., 2013c).

The results of the present study confirm those found by Soglia et al. (2018), who observed a 20% increased pectoralis major weight for WS muscles (both MOD and SEV cases). Likewise, Kuttappan et al. (2013a), Russo et al. (2015), and Baldi et al. (2018) found that the WS is more SEV in heavier broilers.

In the pectoralis major muscle of Nicholas turkeys, the fibers were acidophilic and circular in appearance to the cross-section. Nuclei were numerous and basophilic, usually located on the periphery of muscle fibers. Dense unmodified connective tissue characterized as perimysium that gathers skeletal muscle fibers into fascicles was observed (Figure 2). The fibers of the pectoralis major muscle in the region parallel to the lesion in turkeys affected by the WS MOD and SEV degree were hypertrophied and coated with unmodified dense connective tissue thicker than NORM (Figure 2). According to MacRae et al. (2006), when the increase in muscle fiber size is not accompanied by adequate nutritional support, it can lead to intermediate metabolic stress, due to the difficulty of oxygen diffusion in muscle tissue. Figure 2A shows homogeneity in the size of normocolored muscle fibers. Figure 2B shows variations in fiber size. Figure 2C shows the perimysium accompanied by inflammatory infiltrate in the SEV degree of myopathy.

According to Barbut (2019), WS myopathy may be the consequence of damage to muscle fibers that normally do not have enough time for repair, especially in fast growing birds (NORM muscle fibers usually go through injury and repair cycles without presenting lasting effects).

Table 1. Classifications and weights of pectoralis major muscles of turkeys affected by the white striping myopathy.

Classification	Breast weight (g)
Normal	1,350.20 ± 104.08[b]
Moderate	2,778.7 ± 73.00[a]
Severe	2,922.5 ± 107.45[a]
P-value	1.360e-08

[a,b]Means and SE followed by distinct letters (in columns) differ from each other by the Tukey test ($P < 0.05$).

Histomorphometry of Fibers of the Pectoralis Major Muscles of Turkeys Affected by WS Myopathy

Turkeys that did not have WS in the pectoralis major (NORM) had a larger number, smaller area, smaller perimeter, and smaller diameter of muscle fibers, and had thinner interstitial connective tissue (endomysium thickness) than the MOD and SEV groups ($P < 0.05$) (Table 2).

There was no difference between the MOD and SEV groups for the morphometric variables studied. According to Wilson et al. (1990), in a study on muscle structure and blood enzyme activity in turkey breeds selected for rapid growth, muscle dystrophies provided a compensatory increase in fiber diameter, a characteristic also observed in the present study.

Chemical Analysis of Pectoralis Major Muscles of Turkeys Affected by WS Myopathy

The occurrence of the WS myopathy partially affected the results obtained in the chemical analyses (Table 3). In fact, both protein and ash contents were significantly altered within the severity degree (both MOD and SEV). In detail, compared to the NORM muscles, the SEV group presented higher ash content (1.81 vs. 1.67%; $P < 0.05$), while MOD presented lower values ($P < 0.05$). In contrast, regardless of the severity of the myopathy anomaly, the MOD and SEV degrees exhibited considerably lower protein contents compared to NORM (18.27 and 18.26 vs. 20.25%; $P < 0.05$). Kuttappan et al. (2012), and Petracci et al. (2014) reported that protein content decreases as the degree of severity of WS myopathy increases. Similarly, in a study on quantity and functionality of protein fractions in broiler breast fillets, Mudalal et al. (2014) reported that WS fillets had lower protein percentages.

On the other hand, in a study by Soglia et al. (2018), the occurrence of WS partially affected the proximate composition of turkey breast meat. In detail, protein contents did not differ among the groups, if compared with NORM, higher lipid contents were found in SEV muscles, whereas MOD had intermediate values, and lower ash content was observed in MOD and SEV.

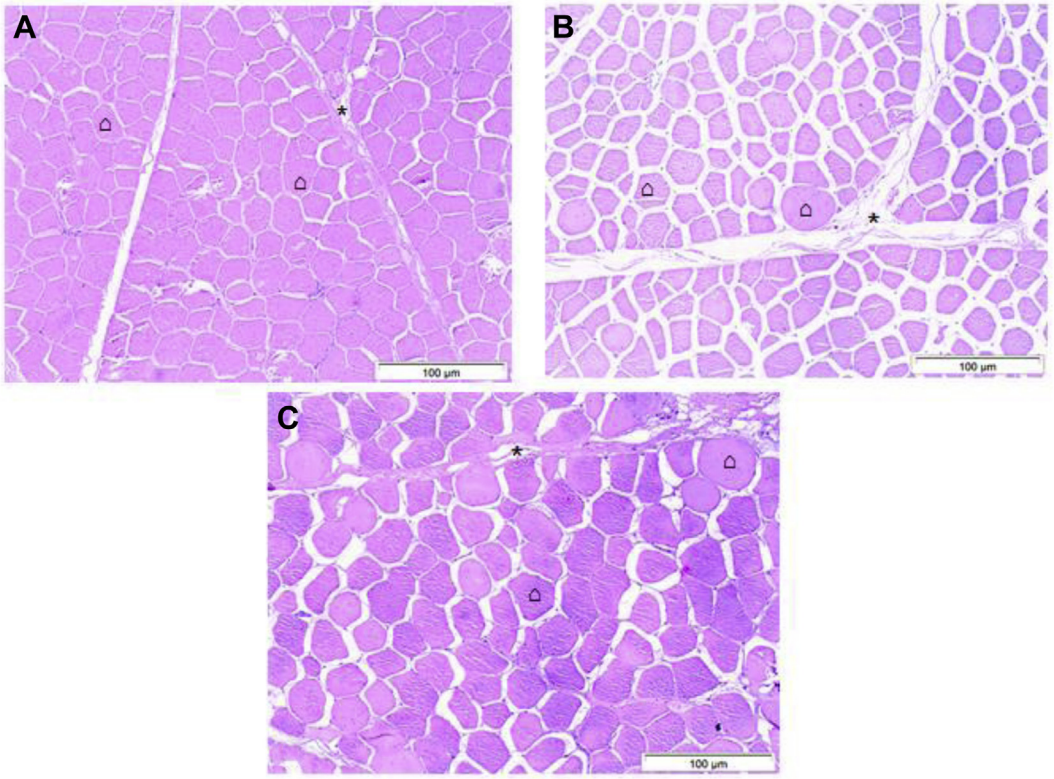

Figure 2. Cross-sectional photomicrograph of the pectoralis major muscle of turkeys affected by the white striping myopathy: (A) normal; (B) moderate aspect of the white striping myopathy; (C) severe aspect of the white striping myopathy. Muscle fiber (⌓), perimysium (*). Hematoxylin and eosin, 100×. Source: the author.

According to Kuttappan et al. (2012), the difference in chemical composition may be a consequence of the myopathic changes observed in higher degrees of WS distribution, and muscle fiber degeneration may have influenced the reduced protein content.

Reduction in protein content (indicative of muscle fiber degeneration or atrophy) could result in more room for adipocytes to expand, favoring increased fat deposition. However, in the present study, no significant differences were observed for moisture, lipid, and cholesterol contents. Likewise, in a study on the effect of WS myopathy on the quality of turkey breast meat, Soglia et al. (2018) did not observe significant differences for moisture between treatments. On the contrary, Salles et al. (2019) observed an increase in lipid and moisture contents in broiler breasts affected by SEV WS myopathy when compared to the control variable (NORM), confirming that other causes may be correlated with WS alterations, apart from the poultry strain and the location of the evaluated samples.

The presence of WS myopathy in different degrees of severity caused increased concentrations of total and insoluble collagen in muscles, respectively ($P < 0.05$; Table 4), except for soluble collagen concentrations that were not significantly different from each other ($P > 0.05$). Increasing the proportion of collagen in meat and meat products may reduce the absolute number of essential amino acids for humans (histidine, leucine, isoleucine, valine, tryptophan, methionine, phenylalanine, threonine, and lysine), the nutritional quality of protein (El, 1995). Similar characteristics were observed when NORM and SEV degree broiler

Table 2. Muscle fiber number, area (µm), perimeter (µm), diameter (µm) of muscle fibers, and endomysium thickness (µm) surrounding the muscle fibers of the pectoralis major muscles of turkeys affected by the white striping myopathy.

	Severity degree			
Variable	Normal	Moderate	Severe	*P*-value
Number	235.69 ± 14.30[a]	151.75 ± 10.97[b]	152.50 ± 7.05[b]	1.68e-05
Fiber area	4,110.90 ± 344.11[b]	5,432.13 ± 526.24[a]	5,255.36 ± 304.25[a]	0.001
Perimeter	254.95 ± 10.71[b]	301.18 ± 14.51[a]	289.45 ± 9.19[a]	0.004
Diameter	70.80 ± 2.92[b]	81.44 ± 3.59[a]	80.16 ± 2.43[a]	0.001
Endomysium thickness	15.470 ± 2.38[b]	18.804 ± 1.69[a]	21.270 ± 2.01[a]	0.009

[a,b]Means and SE followed by distinct letters (in columns) differ from each other by the Tukey test ($P < 0.05$).

Table 3. Chemical composition of the pectoralis major muscles of turkeys affected by the white striping myopathy.

Variable	Severity degree			*P*-value
	Normal	Moderate	Severe	
Protein (%)	20.25 ± 0.34[a]	18.27 ± 0.48[b]	18.26 ± 0.19[b]	0.0003
Lipids (%)	2.79 ± 0.04	2.81 ± 0.06	2.64 ± 0.13	0.2946
Moisture (%)	73.61 ± 0.39	74.11 ± 0.43	73.95 ± 0.19	0.6052
Ash (%)	1.67 ± 0.05[b]	1.27 ± 0.05[c]	1.81 ± 0.10[a]	0.0001
Cholesterol (%)	84.69 ± 1.01	82.86 ± 1.24	81.08 ± 1.13	0.3248

[a–c]Means and SE followed by distinct letters (in columns) differ from each other by the Tukey test ($P < 0.05$).

fillets from WS myopathy were compared, which also demonstrated a higher collagen content and a reduction in the total amount of sarcoplasmic and myofibrillar proteins in broiler breast fillets (Mudalal et al., 2014). No significant differences were observed for sarcomere length, a positive factor demonstrating that there was no shortening of muscle fibers in the pectoralis major muscles of turkeys with increasing severity of WS myopathy. Tijare et al. (2016) reported similar results where non-marinated broiler fillets with WS had sarcomere lengths similar to NORM fillets.

Regarding the fatty acids profile (Table 5), the SEV samples, when compared to NORM and MOD fillets, showed higher levels of capric acid and of long-chain essential n-3 (omega 3) and n-6 (omega 6) polyunsaturated fatty acids, such as linolenic acid, eicosadienoic acid, eicosatrienoic acid, and docosatetraenoic acid. However, in the present study there were no differences for total saturated fatty acids, monounsaturated fatty acids, and saturated fatty acids among all samples. Studies by Kuttappan et al. (2012) demonstrated that NORM broiler fillets had higher ($P < 0.05$) percentages of saturated fatty acids than SEV broiler fillets and the proportions of monounsaturated fatty acids as well as linoleic and linolenic acids were higher ($P < 0.05$) in SEV broiler fillets than in NORM broiler fillets. In a study by Soglia et al. (2016) on the effect of WS and/or wooden breast abnormalities on broiler breast meat, according to the amount of n-3 fatty acids, enveloped as precursors for the synthesis of n-6 and n-3 long-chain polyunsaturated fatty acids, an increasing propensity ($P < 0.05$) was observed going from NORM to WS/wooden breast samples.

Physical Analysis of Pectoralis Major Muscles of Turkeys Affected by WS Myopathy

According to Table 6, L* values increased ($P < 0.05$) in turkey fillets as WS severity increased (NORM vs. MOD or SEV) on both dorsal and ventral sides of the fillet; however, the changes were more pronounced on the ventral side where SEV fillets also had greater L* than MOD fillets ($P < 0.05$), suggesting that WS results in paler fillets. The degree of severity did not influence the intensity of red (a*) on the internal and external surfaces. However, as the degree of severity increased, the intensity of yellow (b*) increased ($P < 0.05$) on the dorsal and ventral sides ($P < 0.05$) in the muscle. Corroborating with these results, Kuttappan et al. (2013a), and Petracci et al. (2013) both showed that the fillets affected by myopathy were more yellow (b*) in comparison to those that were not affected.

In contrast, the results of Soglia et al. (2018) for color characteristics of raw and marinated turkey breast meat did not differ between NORM and WS cases.

No differences ($P > 0.05$) in pH values, CL, and WHC were observed for all treatments (Table 7). Similarly, Kuttappan et al. (2013a) reported that the percentage of CL did not differ significantly between NORM and SEV WS broiler fillets. Birds processed at 6 wk of age showed similar results to those of Tijare et al. (2016) who reported no difference ($P > 0.05$) between fillets with SEV WS and those with NORM WS. However, Petracci et al. (2013) reported higher CL values on SEV broiler fillets when compared to NORM.

Results from the SF Meullenet-Owens Razor Shear and SF Warner-Bratzler analyses (Table 7) showed

Table 4. Sarcomere length and total, soluble, and insoluble collagen contents of the pectoralis major muscles of turkeys affected by the white striping myopathy.

Variable	Severity degree			*P*-value
	Normal	Moderate	Severe	
Total collagen (%)	0.23 ± 0.03[c]	0.35 ± 0.05[b]	0.46 ± 0.05[a]	0.0001
Soluble collagen (%)	0.07 ± 0.01	0.08 ± 0.01	0.10 ± 0.01	0.1525
Insoluble collagen (%)	0.20 ± 0.06[b]	0.33 ± 0.04[a]	0.34 ± 0.05[a]	0.0001
Sarcomere (μm)	1.96 ± 0.02	1.97 ± 0.02	1.98 ± 0.01	0.1085

[a–c]Means and SE followed by distinct letters (in columns) differ from each other by the Tukey test ($P < 0.05$).

Table 5. Fatty acid concentration, in g kg^{-1}, of pectoralis major muscle fat from turkeys affected by the white striping myopathy.

		Severity degree			
Fatty acids	Nomenclature	Normal	Moderate	Severe	*P*-value
Capric	C10:0	0.033 ± 0.00[b]	0.030 ± 0.001[b]	0.053 ± 0.005[a]	0.0051
Lauric	C12:0	0.071 ± 0.003	0.076 ± 0.004	0.068 ± 0.004	0.5904
Myristic	C14:0	0.733 ± 0.009	0.736 ± 0.009	0.775 ± 0.019	0.3737
Myristoleic	C14:1	0.131 ± 0.005	0.118 ± 0.003	0.131 ± 0.004	0.2267
Pentadecanoic	C15:0	0.096 ± 0.001	0.098 ± 0.001	0.101 ± 0.002	0.3381
Palmitic	C16:0	25.93 ± 0.192	26.63 ± 0.270	26.87 ± 0.261	0.232
Palmitoleic	C16:1	5.21 ± 0.144	4.83 ± 0.163	4.51 ± 0.151	0.1442
Heptadecanoic	C17:0	0.140 ± 0.001	0.143 ± 0.002	0.150 ± 0.002	0.0705
Heptadecenoic	C17:1	0.068 ± 0.001	0.066 ± 0.001	0.073 ± 0.002	0.1741
Stearic	C18:0	6.555 ± 0.110	6.586 ± 0.162	7.021 ± 0.087	0.1983
Oleic	C18:1n9c	31.93 ± 0.139	30.64 ± 0.432	30.93 ± 0.401	0.2558
Vaccenic	C18:1n7	2.14 ± 0.011	2.07 ± 0.027	1.98 ± 0.035	0.0574
Linoleic	C18:2n6c	22.45 ± 0.227	22.76 ± 0.270	23.31 ± 0.224	0.2946
γ Linolenic	C18:3n6	0.091 ± 0.002	0.088 ± 0.002	0.103 ± 0.003	0.0656
α Linolenic	C18:3n3	0.776 ± 0.011[b]	0.873 ± 0.019[b]	0.921 ± 0.035[a]	0.0441
Conjugated linoleic	C18:2c9,t11	0.041 ± 0.002	0.036 ± 0.002	0.041 ± 0.002	0.4538
Arachidic	C20:0	0.058 ± 0.002	0.058 ± 0.001	0.061 ± 0.002	0.8645
Eicosenoic	C20:1n9	0.191 ± 0.003	0.185 ± 0.005	0.191 ± 0.005	0.7577
Eicosadienoic	C20:2	0.112 ± 0.003[b]	0.126 ± 0.004[b]	0.145 ± 0.003[a]	0.0183
Eicosatrienoic (cis-8, 11, 14)	C20:3n6	0.083 ± 0.007[b]	0.111 ± 0.004[b]	0.216 ± 0.010[a]	0.0001
Arachidonic	C20:4n6	2.14 ± 0.126	2.39 ± 0.152	1.81 ± 0.011	0.1727
Eicosapentaenoic	C20:5n3	0	0	0	0
Docosatetraenoic	C22:4n6	0.30 ± 0.014[b]	0.24 ± 0.023[b]	0.36 ± 0.010[a]	0.0127
Docosapentaenoic	C22:5n3	0.13 ± 0.008	0.15 ± 0.009	0.11 ± 0.008	0.1172
Docosahexaenoic	C22:6n3	0.54 ± 0.047	0.59 ± 0.043	0.39 ± 0.038	0.1196
ΣSFA	Cn:0	33.62 ± 0.211	34.79 ± 0.405	34.66 ± 0.275	0.2084
ΣMUFA	Cn:1	39.67 ± 0.223	37.58 ± 0.499	38.15 ± 0.454	0.0933
ΣPUFA	Cn:n	26.7 ± 0.227	27.62 ± 0.022	27.17 ± 0.344	0.3211
Total	-	100	100	100	-

[a,b]Means and SE followed by distinct letters (in columns) differ from each other by the Tukey test ($P < 0.05$).

Abbreviations: MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids.

that the SEV degree samples had lower shear values ($P < 0.05$) compared to the NORM degree. According to Petracci et al. (2014), this observation was also confirmed by SF Allo-Kramer evaluated in unmarinated broiler fillets, which was smaller in fillets with the WS myopathy, demonstrating a softer texture after cooking. WS myopathy can be considered to be correlated with muscle degeneration, very similar to that which occurs in muscular dystrophies. This degeneration can cause a large reduction in muscle contractile proteins (myosin and actin) resulting in softer-textured breast meat, which occurred in the present study where protein content decreased as the severity of the WS myopathy increased (Kuttappan et al., 2012; Petracci et al., 2013).

In contrast to the present study, the results of Soglia et al. (2018) for SF Warner-Bratzler analyses of raw and marinated turkey breast meat did not differ between NORM and WS cases.

CONCLUSION

Higher weight of turkey breast meat affected by WS myopathy compared to NORM breast meat can be considered as an additional basis for the principle that selection for growth rate and breast production plays a significant role in the occurrence of this emergent myopathy. Furthermore, the presence of the myopathy resulted in a partial reduction of the histological and

Table 6. Lightness (L*), intensity of redness (a*), and intensity of yellowness (b*) of the external and internal surfaces of the pectoralis major muscles of turkeys affected by the white striping myopathy.

		Severity degree			
Variable		Normal	Moderate	Severe	*P*-value
Ventral surface coloring	L*	54.94 ± 0.66[c]	62.71 ± 0.44[b]	64.15 ± 0.60[a]	0.0001
	a*	3.71 ± 0.18	3.88 ± 0.17	3.41 ± 0.18	0.1408
	b*	0.67 ± 0.26[b]	0.59 ± 0.28[b]	1.77 ± 0.34[a]	0.0127
Dorsal surface coloring	L*	53.26 ± 0.74[b]	60.51 ± 0.41[a]	61.37 ± 0.41[a]	0.0001
	a*	4.21 ± 0.19	3.67 ± 0.30	4.01 ± 0.38	0.2605
	b*	0.00 ± 0.18[a]	0.44 ± 0.20[b]	0.46 ± 0.22[b]	0.0001

[a–c]Means and SE followed by distinct letters (in columns) differ from each other by the Tukey test ($P < 0.05$).

Table 7. pH values, water retention capacity, CL, and shear force (Warner-Bratzler and MORS) of pectoralis major muscles of turkeys affected by the white striping myopathy.

Variable	Severity degree			*P*-value
	Normal	Moderate	Severe	
pH	5.81 ± 0.02	5.77 ± 0.03	5.75 ± 0.03	0.7539
WHC (%)	76.16 ± 1.31	74.19 ± 0.81	73.99 ± 1.03	0.2942
CL (%)	23.57 ± 0.66	24.81 ± 0.77	22.54 ± 0.78	0.3346
MORS (N)	13.59 ± 0.59[a]	9.59 ± 0.38[b]	9.87 ± 0.35[b]	0.0001
Warner-Bratzler (kg/mm^2)	13.43 ± 0.75[a]	12.24 ± 0.82[a]	10.86 ± 0.50[b]	0.0451

[a,b]Means and SE followed by distinct letters (in columns) differ from each other by the Tukey test ($P < 0.05$).

Abbreviations: CL, cooking loss; MORS, Meullenet-Owens Razor Shear; WHC, water holding capacity.

qualititative characteristics of turkey breast meat. Therefore, more studies are needed to investigate the physiological and morphological characteristics of turkey breast meat and to compare them with those of broiler breast meat in order to adequately explain the diversified effect of WS on meat quality characteristics.

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DISCLOSURES

All the authors declare that they do not have any conflict of interest.

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