Running Title: Lessening of Woody Broiler Breast Severity

Impact of Refrigerated Storage Time on Woody Broiler Breast Severity and Instrumental Quality

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ABSTRACT:

Chicken breast samples (n = 90; n = 30 normal, n = 30 moderate woody breast (WB), n = 30 severe WB) were collected from a commercial processing plant on 5 separate occasions and were evaluated for severity from day 0 through day 5. A 3 × 6 two-way factorial structure (meat quality treatment × storage time) with 5 replications within a randomized complete block design (replications as blocks) with subsamples was utilized to evaluate the effects of treatment (normal (NOR), moderate (MOD), severe (SEV) and storage time (days 0-5) on pH, color, cook loss, shear force and proximate analysis (days 0 and 5). After 5 days of storage at 2-4°C, 84% of SEV WB fillets were evaluated as MOD WB, which was greater (P < 0.05) than all other storage times. In comparison, 40-52% of the moderate WB fillets were rated as slight WB or NOR after 3 to 5 days of storage. Cook loss was less (P < 0.05) for NOR compared to MOD and SEV breast meat at all storage times. Shear force was greater (P < 0.05) for NOR breast meat than MOD and SEV WB meat on day 0. After 2, 3, 4, and 5 days of storage the upper position (cranial part) of SEV WB had greater (P < 0.05) shear force than NOR fillets. Therefore, the lessening of severity that occurred in WB meat over refrigerated storage was apparent through palpation but did not result in improved texture in the cranial portion of the breast, based on shear force and water-holding capacity results. These results are important since they indicate that even though muscle softening occurred over refrigerated storage time, meat quality did not improve.

Keywords: Chicken Breast, Woody Breast Meat, Meat Quality, Water-Holding Capacity, Shear Force
Introduction

The United States poultry industry, inclusive of broilers, turkeys, and eggs, had a combined total value of $42.7 billion in 2018 (USDA-NASS, 2018). Of this total, 71% or $30.3 billion was attributed to the broiler industry (USDA-NASS, 2018). Boneless chicken breast meat is a source of high-quality protein that is low-fat (Hoffman and Falvo, 2004; Brambila et al., 2017). With the continued increase in demand for chicken meat, the U.S. poultry industry has adopted the use of high-yielding broiler genetic strains and the implementation of big bird programs. These broilers grow in half the time and weigh twice as much at the time of slaughter when compared to broilers from 50 years ago (Barbut et al., 2008). Along with the increased production of higher yielding birds, especially those that weigh greater than 4.2 kg at the time of slaughter, producers have noticed an increased incidence of myopathies that affect the pectoralis major muscle such as woody breast (WB) (Owens, 2016). Woody breast has been characterized as normal (0), mild (1), moderate (2) and severe (3) (Tijare et al., 2016). The characterization definitions are: normal (0) is defined as flexible throughout the breast fillet; mild (1) is defined as hard, mainly in the cranial region and flexible at the caudal region; moderate (2) is hard throughout the fillet with some flexibility in the mid to caudal region; and, severe (3) WB meat is extremely hard throughout the fillet (Tijare et al., 2016). White striping is characterized by white striated lines running parallel to the muscle fibers (Kuttappan et al., 2013).

The United States Department of Agriculture Food Safety and Inspection Service (USDA-FSIS, 2018) has reissued dispositions instruction for broiler breast meat that is affected by WB and WS. The disposition instructions state that inflammatory tissue that accompanies the WB condition is considered adulterated and unwholesome and must be trimmed as with other defects (USDA-FSIS, 2018). The WB myopathy results in an excess of $200 million in losses per year (estimated) due to decreased yield (e.g., trimming, drip loss, cook loss, etc.) and/or lost
value if product is downgraded or discarded (Kuttappan et al., 2016; Owens, 2016). According to Cai et al. (2018), WB meat has a higher pH, is lighter, less red and more yellow than normal breast fillets. Mudalal et al. (2015) reported that WB fillets had lower marinade pickup and greater cooking loss in both unprocessed and marinated meat in comparison to normal broiler breast meat. Sensory results indicate that severe WB is also crunchier and more fibrous as compared to normal breast meat (Aguirre et al., 2018). According to personal communication with poultry companies, the severity of the WB condition may lessen after storing the meat under refrigeration temperature for a few days (Billingsley, 2017). Sun et al. (2018) and Soglia et al. (2017) also noticed a softening effect of woody breast meat over cold storage time. The objective of this research was to evaluate and compare the instrumental quality traits (color, pH, purge and cook loss, proximate composition, and shear force) of normal and WB fillets (MOD and SEV) from a local broiler plant over storage time and determine if the condition diminishes over storage time at 2-4 ºC. The goals of this research are to determine the following: 1) does softening of WB from a local broiler strain occur over refrigerated storage time, 2) if softening does occur, is it related to any above-mentioned instrumental attributes, and 3) if softening does occur, does the softening result in improved meat quality.

Materials and Methods

Broiler Breast Meat

Ninety chicken breast samples, 30 from each of the following three breast meat categories (normal – NOR, moderate - MOD and severe - SEV) were evaluated (Tijare et al., 2016) and collected on 5 separate occasions (n=5 replications) by a plant employee and two members of our research team at the time of deboning, approximately 4 h postmortem, from the deboning line of a commercial processing plant that processed 9-week-old Ross 708 broilers that weighed approximate 4 to 4.2 kg and sent to Mississippi State University on ice. After arriving at
Mississippi State University, the breasts were confirmed again for the degree of hardening and flexibility within the muscle by a member of our research team that did not evaluate the samples at the plant using a method reported by Tijare et al. (2016). A breast was considered normal when it did not contain any regions of hardening and was flexible throughout the entire muscle (Tijare et al., 2016). Mild was defined as hard, mainly in the cranial region and flexible at the caudal region (only evaluated in diminishment or less of severity analysis). Moderate was hard throughout the fillet with some flexibility in the mid to caudal region (Tijare et al., 2016). Severe WB meat was extremely hard throughout the fillet (Tijare et al., 2016). Each breast was given a score between 0 and 3 (0 = normal or no expression of the trait evaluated; 1 = mild woody; 2 = moderate woody; 3 = severe woody chicken breast. The chicken breast samples (n=30) from each category (NOR, MOD, SEV) were randomly assigned to 6 groups on d 0 postmortem (storage time: days 0, 1, 2, 3, 4, and 5) with 5 breast samples in each group that were individually packaged in 0.908 L Ziploc bags (S.C. Johnson & Son, Inc. Racine, WI, USA) for analysis from day 0 through day 5. Woody breast scoring, instrumental color, pH, cooking loss, and shear force were evaluated for all samples. In addition, 6 chicken breast samples of each category were randomly selected for proximate analysis on day 0 and day 5. All chicken breast samples were stored in a cooler at 2 ± 1°C prior to analysis.

**Color**

Color measurements were taken from 5 chicken breasts (n=5 replications with 5 breast subsamples within each replication) from each of the three categories (NOR, MOD, SEV) on each day (day 0 through day 5). Color was evaluated and expressed as CIE \( L^* \) (lightness), \( a^* \) (redness), \( b^* \) (yellowness) at three different locations (cranial, medial, and caudal, n=3 subsamples within each breast) on the ventral side of each fillet (Figure 1) using a HunterLab MiniScan EZ spectrophotometer (Model 4500L, Hunter Associates Laboratory, Inc. Reston, VA,
with a 31.8 mm port size, a 0° observer angle and a 45° circumferential illumination). The instrument calibration was carried out using a standard white Hunter MiniScan calibration plate.

**pH Analysis**

pH measurements were taken from two locations in the cranial region and two from the caudal region (4 sub-subsamples) from 5 chicken breasts (n = 5 replications with 5 breast subsamples within each replication) from each of the three categories (NOR, MOD, SEV) on each day (day 0 through day 5) (Figure 1). Breast fillets were analyzed for pH using a pH meter (Model Accumet 61, Fisher Scientific, Hampton, NH, USA) with a meat penetrating probe (Model FlexipHet SS Penetration tip, Cole Palmer, Vernon Hills, IL). Prior to analyzing chicken breast fillets, the pH probe was standardized using calibration buffer solutions (pH 4 and 7). Additionally, after 10 pH measurements, the pH meter was re-calibrated to ensure measurement accuracy.

**Purge Loss**

Purge loss percentages were calculated from day 1 through day 5. Broiler breast fillets (n = 5 replications with 5 breast subsamples per replication) were individually sealed in 0.908 L Ziploc bags (S.C. Johnson & Son, Inc. Racine, WI, USA) and stored at 2-4 °C for a total of 6 days. Starting on day 1 (day after slaughter), each breast fillet was weighed with any purge that remained in the Ziploc bag. Breast fillets were then removed from the bag to allow any excess purge to drip back into the weighing container and re-weighed. The difference in weight was used to determine purge loss.

**Cooking Loss**

Following pH and color evaluations, the same breast fillets (n = 5 replications with 5 breast subsamples per replication) were used to determine cook loss and shear force. Each breast was trimmed to 220 ± 10 g for even cooking and cooling. Each breast was weighed, placed on
aluminum foil wrapped baking sheets and baked in a preheated oven at 177 °C (Viking, Greenwood, MS, USA) to a final internal temperature of 77 °C. The internal temperature of the chicken samples was monitored using a meat thermometer (Model 14709, Digital Meat Thermometer (2311 W. 22nd Street Oak Brook, IL). Cooked breast fillets were cooled to room temperature (22±2°C). Excess moisture was drained, and the cooked weight was measured. Cooking loss was reported as a percentage and calculated as follows:

\[
\text{Cooking loss} = \left(\frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}}\right) \times 100
\]

**Warner Bratzler Shear Force Determination**

Warner-Bratzler shear force is an objective measurement of the amount of shear force that is necessary to cut through meat, which as an indicator of tenderness. Woody breast is often localized to the top and bottom part of the breast. Therefore, Warner-bratzler shear force was used measure shear force of the top, middle, and bottom of the breast meat to determine if shear force values differed over storage time between woody and normal breast meat samples in the top, middle, and bottom parts of the breast. The samples used to determine cook loss were used to evaluate shear force (n = 5 replications with 5 breast subsamples per replication). Six adjacent 1 cm (width) × 1 cm (thickness) × 2 cm (length) pieces were cut from each cooked breast, parallel to the muscle fiber. Two pieces (sub-subsamples) were cut from the cranial (upper), two (sub-subsamples) from the middle, and two (sub-subsamples) from the caudal (lower) region (Figure 2). Samples were sheared using a Warner-Bratzler shear attachment that was mounted to an Instron Universal Testing Center (Model 3345, Instron, Norwood, MA), and shear force was reported as the maximum amount of force (N) required to shear through the piece of chicken.
**Proximate Analysis**

On day 0 and day 5 (n = 5 replications with 3 breast subsamples per replication), chicken breast samples from each category (NOR, MOD, SEV) were analyzed for fat, protein, moisture and collagen content, with duplicate measurements per chicken breast. Each sample was homogenized using a food processor (3 cup mini chopper, Sunbeam-Oster 200 E Las Olas Blvd, Fort Lauderdale, FL) and packed tightly in a 140-mm diameter sample cup prior to analysis. Proximate composition (protein, fat, collagen and moisture) was measured using a near-infrared spectrometer (Food Scan Lab Analyzer, Model 7880, Foss Analytical, Eden Prairie, MN) that is AOAC approved (AOAC, 2007).

**Diminishment**

On day 0 through day 5, fillets were tactiley evaluated by the same person for degree of woodiness according to grading criteria from previous research (Tijare et al., 2016). Woody breast characterization was performed to determine the percentage of fillets out of 25 (n = 5 replications with 5 breast subsamples) at each storage time to evaluate the diminishment or lessening of woody breast severity. Diminishment was defined as the change of severe woody breast fillets to moderate/mild woody breast or normal breast, and the change of moderate woody breast to mild woody breast or normal breast meat. The diminishment percentage was calculated by the number of woody breast samples that lessened in severity divided by the total number of chicken breast evaluated (n=25).

**Statistical Analysis**

A 3 × 6 two-way factorial structure (meat quality treatment × storage time) with 5 replications within a randomized complete block design (replications as blocks) with subsamples (5 breast samples) was utilized to test the effects of treatment (NOR, MOD, SEV) and storage
time (days 0 through day 5) (P<0.05) on color, pH, purge loss, cook loss, and shear force (SAS version 9.4, NC, USA). When differences existed (P < 0.05) among treatments, Duncan’s Multiple Range Test was used to separate treatment means.

A 3 × 2 two-way factorial structure (meat quality treatment × storage time) with 5 replications within a randomized complete block design (replications as blocks) with subsamples (3 breast samples) was utilized to test the effects of treatment (NOR, MOD, SEV) and storage time (day 0 and day 5) (P < 0.05) on proximate analysis (SAS version 9.4, NC, USA). When differences existed (P < 0.05) among treatments, Duncan’s Multiple Range Test was used to separate treatment means. For both experimental designs, a two-way ANOVA was used to determine if statistical differences existed (P < 0.05) for main effects and interaction.

Results and Discussion

Color

CIE L* (lightness)

There was no interaction (P>0.05) present between severity and storage time for CIE L*. When averaged over day, MOD and SEV WB were lighter (P < 0.05) than NOR breast fillets (Table 1). On day 0, there was no difference (P>0.05) in lightness (L*) between NOR, MOD and SEV WB fillets (Table 1). On days 1 through 5, SEV WB fillets had greater L* values (P < 0.05) than NOR breast fillets at every storage time but day 4, and MOD WB had greater L* values (P < 0.05) than NOR breast fillets on days at 1, 2, 4, and 5. Normal breast fillets became darker as storage time increased to days 4 and 5, since L* was greater (P < 0.05) at day 0 and day 1 than at day 4 and day 5. For MOD WB fillets, there was not a difference (P > 0.05) in lightness over storage time, with the exception that L* values of MOD WB fillets were less (P < 0.05) on day 4 than on day 1. Severe WB fillets had greater L* (P < 0.05) on days 0, 1, 2, and 3 than on day 4.
Lightness at day 5 did not differ from any other storage times for SEV WB other than day 1.

Normal breast fillets had a L* value range from 60.5 to 63.0 and an overall average of 61.7.

Moderate WB fillets had a L* value range from 62.5 to 63.8 with an overall average of 63.3.

Severe WB fillets had a L* value range from 62.0 to 64.5 and an overall average of 63.6. These results are similar to the difference in L* values reported by Baldi et al. (2017) and Cai et al. (2018). These researchers reported that L* values for NOR breast fillets were on average 3 units less than that of WB meat. In contrast, Chatterjee et al. (2016) reported no difference in L* value between woody and normal broiler breasts. This lack of difference may have been due to these researchers measuring color on the dorsal portion of the breast in comparison to the current research in which the ventral portion of the breast was evaluated. It is likely that the greater lightness in WB meat is due to a higher percentage of moisture in the product in WB meat in comparison to normal meat, which would cause greater light reflectance and a lighter color (Qiao et al., 2001).

**CIE a* (redness)**

There was no interaction ($P > 0.05$) present between severity and storage time for CIE a*. On day 0 and day 4, redness (CIE a*) values were higher ($P < 0.05$) for SEV WB fillets than NOR breast fillets (Table 2). On days 1, 2, 3 and 5, there was no difference ($P > 0.05$) in redness among NOR, MOD WB, and SEV WB fillets. Normal and MOD breast fillets had lower a* values ($P < 0.05$) on day 0 than at days 1 through 5, which did not differ in redness. Severe WB fillets had greater a* values ($P < 0.05$) on day 4 than on days 1 and 2. Normal breast fillets had a CIE a* value range from 4.0 to 5.6 and an overall average of 5.0. Moderate WB fillets had a CIE a* value range from 4.2 to 5.5 and an overall average of 5.1, and SEV WB fillets had a CIE a* value range from 4.7 to 5.9 and an overall average of 5.2. Mudalal et al. (2014) and Baldi et al.
(2017) also reported no difference in a* values between NOR breast meat and WB meat. In contrast, Cai et al. (2018), Cando (2016) and Dalle Zotte et al. (2014) reported that WB meat has a slightly redder (higher a*) color than NOR breast meat. Though these researchers reported statistical differences, there was very little numerical or practical difference between treatments. Lack of difference in a* value is likely due to a low concentration of the meat pigment, myoglobin in broiler breast meat (Kim et al., 2008).

**CIE b* (yellowness)**

Interaction was present (P < 0.05) between severity and storage time with respect to CIE b*. This was due to NOR increasing in CIE b* over time and the MOD and SEV treatments remaining relatively constant over storage time. On day 0, NOR breast fillets had lower b* values (P < 0.05) than SEV WB fillets. One day 1, however, NOR breast fillets had greater b* values (P < 0.05) than MOD WB fillets. On days 2 through 4, there was no difference (P > 0.05) in b* values among NOR breast fillets, MOD WB fillets and SEV WB fillets (Table 3). On day 5, NOR breast fillets had greater b* values (P < 0.05) than SEV WB fillets. On days 1 through 5 there was no difference (P > 0.05) in b* values among NOR breast fillets, but NOR breast meat had lower b* values (P < 0.05) on day 0 than on other days. The MOD WB fillets on day 0 had lower b* values (P < 0.05) than on day 3, but no other differences existed (P > 0.05). For SEV WB, breast fillets had lower b* values on day 5 than on days 1-4. This is opposite to the trend for NOR breast fillets in which b* was greater after day 0. Normal breast fillets had b* values range from 14.1 to 17.0 with an overall average of 16.1. Moderate WB fillets had b* values range from 14.9 to 16.2 with an overall average of 15.6. Severe WB fillets had b* values range from 14.6 to 16.3 and had an overall average of 15.8. Overall there were minimal practical differences in b* values among NOR, MOD WB, and SEV WB fillets. In contrast, it has been reported that WB
meat is more yellow than NOR breast meat (Cando, 2016; Baldi et al., 2017; Cai et al., 2018).

Reasons for differences in $b^*$ values between the current research and previously reported research may be due to instrumental differences since a Hunter Colorimeter was used in the current study and Minolta chroma meters were used in the previous research, which may also have differed in calibration tiles, observer angle and light source. Differences may also be due to evaluating CIE $b^*$ over storage time in the current study in comparison to other studies in which CIE $b^*$ was only measured at 24 h postmortem.

**pH Values**

There was no interaction ($P > 0.05$) present between severity and storage time for pH. Severe and MOD WB fillets had higher pH values than NOR breast fillets ($P < 0.05$) on all days (Table 4). Severe WB fillets had higher pH values ($P < 0.05$) than MOD WB on days 1, 3, 4, and 5. For NOR fillets, there was no difference ($P > 0.05$) in pH values on days 0, 2, 3 and 4. In addition, pH values of NOR breast fillets on days 1 and 5 were higher ($P < 0.05$) than on days 0 and 3. Even though slight differences existed between pH values for NOR breast fillets, all pH values were very similar to each other over storage time with average values between 5.76 and 5.84. For MOD WB fillets, no difference ($P < 0.05$) existed in pH values over storage time.

Severe WB fillets had greater pH values ($P < 0.05$) on day 5, than on days 2 and 4, but no other differences ($P > 0.05$) existed among storage time. Average pH values ranged from 5.76 to 5.84 for NOR breast fillets, 5.92 to 5.98 for MOD WB fillets and 5.96 to 6.07 for SEV WB fillets over five days of storage at 2 ºC. Dalle Zotte et al. (2014), Baldi et al. (2017), and Cai et al. (2018) also reported that the pH of WB meat was greater than that of normal meat, with similar values to the current study. In contrast, Soglia et al. (2015) reported no difference between the pH values of NOR breast fillets and WB fillets. Current results are similar to previous research
and indicative that there were minimal changes in pH differences over storage time for NOR, MOD, or SEV breast fillets. The higher pH in the WB meat may be due to the presence of less ATP and creatine phosphate in the muscle at the time of death (Cai et al., 2018). Since greater oxidative stress has occurred in muscle that becomes WB (Abasht et al., 2016), there is less energy available in the muscle to convert to lactic acid, which results in a greater pH (Sihvo, 2019). A greater pH is usually indicative of better color, greater water-holding capacity in normal meat, and better sensory tenderness and juiciness since the pH is further away from the isoelectric points of myosin and actin (Pearson and Gillett, 1996). However, in WB meat, this is not the case since there is less protein, the protein is partially denatured, and there is often more fat and collagen present in WB meat in comparison to NOR breast meat (Soglia et al., 2016).

**Purge Loss**

There was no interaction \( (P > 0.05) \) present between severity and storage time for purge loss. Purge loss increased throughout storage time for NOR, MOD, and SEV breast fillets (Table 5). In addition, purge loss was less \( (P < 0.05) \) for NOR breast fillets than SEV WB fillets after 1 and 2 days of storage. However, after 3-5 days of storage, no difference \( (P > 0.05) \) existed in purge among NOR, MOD, and SEV WB fillets. In previous research conducted by Sun et al. (2018), the cumulative drip loss over storage was greater for severe WB than normal chicken breasts, which is in agreement with the current study. However, Mudalal et al. (2014) reported that there was no difference in purge loss percentage between NOR breast meat and WB meat with an average purge loss of 1.3% for both NOR and WB meat after 48 h of storage at 2-4 °C. The most significant implications of this data are that SEV WB fillets had greater purge loss than NOR breast fillets and that NOR, MOD, and SEV WB samples all had significant increases in purge loss over storage time, which is indicative of decreased meat quality over storage time.
The greater initial purge loss in SEV WB fillets may be due to less protein, greater moisture, and more protein degradation, specifically with the z-line and desmin in WB in comparison to NOR breast fillets (Soglia et al., 2015; Petracci et al., 2019).

**Cooking Loss**

There was no interaction ($P > 0.05$) present between severity and storage time for cook loss. Severe and MOD WB had greater cook loss ($P < 0.05$) than NOR breast fillets at every storage time (Table 6). Severe WB had greater cooking loss than MOD WB on day 0, but there were no differences between MOD and SEV WB from day 1 to 5 of storage (Table 6). Normal breast fillets had greater ($P < 0.05$) cooking loss on day 0 and 3 than on day 4. This difference may be partially due to an increase in purge loss over storage time. There was no difference ($P > 0.05$) in cook loss percentages for MOD and SEV WB fillets on day 0 through day 5. Cook loss percentages ranged from 22.3% to 26.0% for NOR, 28.3% to 30.2% for MOD, and 29.5% to 32.3% for SEV WB. Results from this research confirm results from previous research. Dalle Zotte et al. (2014), Soglia et al. (2015), Tijare et al. (2016), and Cai et al. (2018) all reported less cooking loss for NOR breast fillets than WB fillets, regardless of whether the sample was fresh or previously frozen or baked or sous vide cooked. Similar to purge loss, the greater cooking loss for SEV and MOD WB fillets in comparison to NOR breast fillets may be due to less protein, greater moisture, and more extensive protein degradation (Soglia et al., 2016). In addition, WB meat has greater desmin and z-line degradation, which contributes to lower water-holding capacity and cook yields in WB than in NOR meat (Soglia et al., 2015). Velleman and Clark (2015) used fluorescent microscopy to show that WB lacked both muscle fiber bundle organization and well-defined spacing in the endomysium and perimysium. These authors also reported that extracellular matrix glycosaminoglycans that are covalently bound to myofibrillar
proteins were more abundant in NOR breast meat. These molecules ionically interact with water. A lower abundance of glycosaminoglycans and lack of fiber bundle and connective tissue organization may contribute to lower water-holding capacity and greater cook loss.

**Shear Force**

There was no interaction ($P > 0.05$) present between severity and storage time for shear force for the upper, middle and lower portions of the breast meat (Table 7). On day 0, NOR breast fillets had greater ($P < 0.05$) shear force than SEV WB and MOD WB fillets for the upper, middle and lower portions of the breast (Table 7). By day 1, the shear force of NOR breast fillets did not differ ($P > 0.05$) from MOD and SEV WB fillets for the upper and middle portion of the breast. For the lower portion of the breast, there was no difference ($P > 0.05$) in shear force between NOR and SEV WB fillets, but the MOD WB fillets required less ($P < 0.05$) shear force to cut through it than the NOR breast fillets. For the upper, middle and lower portion of the breasts, SEV WB fillets had a greater shear force ($P < 0.05$) on day 4 than MOD WB and NOR breast fillets (Table 7). NOR breast fillets required less shear force than SEV WB to cut through the upper region of the breast on days 2, 3, 4, and 5, which indicates the NOR breast fillets were more tender than the SEV WB in the upper portion of the breast. This is logical since WB is most commonly associated with the upper portion of the breast (Soglia et al., 2015). Soglia et al. (2019) reported that the muscle fiber bundle separation, rigidity, and hardness associated with WB primarily affects the cranial, upper portion of the breast fillet. Normal breast meat fillets increase in tenderness over storage time due to myofibrillar protein degradation (Takahashi, 1996), most specifically with the z line and desmin. In contrast, the shear force of the upper portion of the SEV WB fillets did not decrease ($P > 0.05$) over storage time, which was different than what was observed with SEV WB fillets in the middle and lower portions of
the breast. This may be due to extreme myopathy in the upper part of the muscle (Soglia et al., 2015), in which z line and desmin degradation occur earlier postmortem than in NOR breast fillets and the lack of well-defined muscle and connective tissue structure in the WB fillets (Velleman and Clark, 2005). Previous research determined that broiler breast meat with a Warner-Bratzler shear force value of up to 45 N are considered acceptable in tenderness to greater than 70 % of consumers (Schilling et al., 2003). This portion of muscle is not extremely tough, according to shear values, but has a crunchy texture that is undesirable to consumers (Von Staden et al., 2019). For the lower part of the breast, shear force decreased over storage time from day 0 to day 5 for NOR, MOD and SEV WB fillets. This indicates that the meat became softer over storage time, which is similar to results previously reported by Sun et al. (2018). These researchers noticed muscle softening, which indicates that woody breast severity, as determined by palpation and appearance was lessened. For the middle portion of the breast, the shear force also decreased ($P < 0.05$) over storage time for NOR and MOD WB fillets. For SEV WB fillets, the lower portion of the middle section decreased ($P < 0.05$) in shear force over time for SEV WB fillets, but the decrease was less than that of MOD and NOR WB fillets. The decrease in shear force was 17.8 N for NOR breast fillets, 9.7 N for MOD WB fillets and 5.2 for SEV WB fillets. In contrast to the lower and upper regions of the breast, the shear force of the MOD and SEV WB fillets did not decrease ($P > 0.05$) over storage time in the upper portion of the breast, which indicates that aging the meat did not increase tenderness of upper portion of SEV WB fillets, which generally does occur during aging for normal broiler chicken breast meat.

**Proximate Analysis**

There was no interaction ($P > 0.05$) present between severity and storage time for fat, protein, collagen and moisture percentage in the breast fillets. There was no difference ($P >
0.05) in fat percentage between NOR, MOD WB, and SEV WB fillets on day 0 and day 5 (Table 8). Protein percentages were greater ($P < 0.05$) for NOR breast fillets than MOD and SEV WB fillets. In addition, on day 0, the MOD WB fillets had a higher protein percentage ($P < 0.05$) than SEV WB fillets (Table 8). There was no difference ($P > 0.05$) in collagen percentage between NOR, MOD WB, and SEV WB fillets on day 0 and day 5 (Table 8). Moisture percentages were greater ($P < 0.05$) in SEV and MOD WB fillets when compared to NOR breast fillets on day 0 and day 5. In addition, SEV WB fillets had more moisture ($P < 0.05$) on day 0 than MOD WB fillets. These proximate composition results are similar to previous research results by Cai et al. (2018), Soglia et al. (2015) and Baldi et al. (2017), but differ with respect to a higher fat percentage in WB fillets when compared to NOR breast fillets. Cai et al. (2018) reported fat, protein and moisture percentages of 1.9%, 21.7% and 74.4% for WB fillets and 1.2%, 23%, and 73.8% for NOR breast fillets. Soglia et al. (2015) reported fat, protein and moisture percentages of 1.25%, 21.4% and 75.3% for WB fillets and 0.87%, 22.8% and 74.1% for NOR breast fillets. Baldi et al. (2017) reported, average fat, protein and moisture percentages of 2.12%, 20.5%, and 77.1% for WB fillets and 1.51%, 22.9%, and 75% for NOR breast fillets. These authors reported WB fillets have decreased protein percentages and increased moisture and fat percentages when compared to NOR breast fillets. Soglia et al. (2015) reported that WB fillets that were affected with white striping simultaneously had greater fat percentages than NOR breast fillets and WB fillets without white striping. These researchers may have reported higher fat percentages in WB fillets compared to NOR breast fillets because the WB fillets had white striping as well. The lower protein concentration in WB fillets is probably due to myodegeneration and responded upregulation of protein metabolism and the regenerative process to repair the degenerative changes (Sihvo et al., 2014; Kuttappan et al., 2017). In addition, the
moisture percentage is greater in WB fillets due to the pooling of water in the area where the myopathy is present in the breast muscle to help with protein repair (Velleman and Clark, 2015).

**Diminishment**

In this study, separate fillets were manually evaluated each day for degree of diminishment and softening using appearance and palpation according to Tijare et al. (2016). For MOD WB fillets, 52% (13 out of 25) of fillets diminished to slight WB, but there were no differences over storage time (P=0.057), largely due to a large amount of variability from replication to replication (Table 9). After 5 days of storage at 2-4 °C, 84% of SEV WB fillets (21 out of 25 samples) lessened to MOD WB, which was greater (P < 0.05) than days 1-3. Diminishment percentage was also greater for SEV WB after 4 and 5 days of storage in comparison to 1 and 2 days of storage. Even though a large percentage of SEV WB diminished over time, breast fillets only diminished to MOD, not slight or NOR. In comparison, only 40-52% (10 out of 25 breast samples and 13 out of 25 breast samples) of MOD WB fillets diminished to slight or NOR after 3 to 5 days of storage. The softening effect in WB during cold storage was observed by other researchers, which they attributed to the loss of moisture, postmortem proteolysis as indicated by increased activity of autolyzed μ/m-calpain, and other mechanisms that have yet to be determined (Soglia et al., 2015, 2017; Sun et al., 2018). As described by Soglia et al. (2015), myofibrillar and sarcoplasmic protein breakdown did occur. The proximate composition of WB included more moisture and less protein content. In previous research by Sun et al. (2018), the same fillets were evaluated for softening using compression force and a softening effect was reported. Another potential cause of the softening over time may be a decrease in the amount of intact desmin and an increase in the autolyzed form of desmin, a 39-kDa fragment during storage (Soglia et al., 2018).
Conclusions

Even though some diminishment (palpation and visual) of the WB myopathy occurred over time, this did not impact the shear force of the meat from the upper portion of the chicken breast, indicating that there are some tough tissue parts within this portion of the breast. Results also indicated that instrumental measurements including pH, instrumental color, proximate analysis, and cooking loss differed between severe, moderate, and normal breast meat but did not change over storage time. Therefore, the diminishment that occurred was mainly tactile and did not lead to improved meat quality as determined by color, purge loss, cooking loss, shear force, and proximate composition. Therefore, refrigerating WB meat for an extended amount of time will not improve its quality or increase its functionality in processed meat products. These results are important since they indicate that even though it was substantiated that muscle softening occurred over refrigerated storage time, meat quality did not improve. This substantiates the need to reduce the incidence of WB meat in the broiler industry. Future research is needed to minimize WB incidence and determine technical solutions to incorporate WB meat into processed products such as chicken nuggets, chicken patties and other products in which a portion of WB meat can be used with minimal impacts on eating quality and product yields.

Acknowledgements

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Literature Cited


Table 1. Instrumental color CIE L* (lightness) measurements of normal breast meat, moderate and severe woody breast meat that were stored from day 0 (day of processing) through day 5 at 2-4 °C (n=25).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Average</th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOR</td>
<td>63.0</td>
<td>62.7</td>
<td>61.5</td>
<td>61.8</td>
<td>60.7</td>
<td>60.5</td>
<td>61.7</td>
<td>0.19</td>
<td>0.0004</td>
</tr>
<tr>
<td>MOD</td>
<td>63.6</td>
<td>64.3</td>
<td>63.2</td>
<td>62.8</td>
<td>62.5</td>
<td>63.5</td>
<td>63.3</td>
<td>0.16</td>
<td>0.032</td>
</tr>
<tr>
<td>SEV</td>
<td>64.1</td>
<td>64.5</td>
<td>64.1</td>
<td>64.0</td>
<td>62.0</td>
<td>62.7</td>
<td>63.6</td>
<td>0.19</td>
<td>0.001</td>
</tr>
<tr>
<td>SEM</td>
<td>0.32</td>
<td>0.25</td>
<td>0.23</td>
<td>0.24</td>
<td>0.24</td>
<td>0.26</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>0.392</td>
<td>0.01</td>
<td>&lt;0.0001</td>
<td>0.0018</td>
<td>0.0086</td>
<td>&lt;0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
NOR = Normal breast meat, MOD = Moderate woody breast meat, SEV = Severe woody breast meat, SEM = Standard error of the mean
a-b: means with the same letter by column are not different (P > 0.05).
A-C: means with the same letter by row are not different (P > 0.05).
Table 2. Instrumental color CIE a* (redness) measurements of normal breast meat, moderate and severe woody breast meat that were stored from day 0 (day of processing) through day 5 at 2-4 °C (n=25).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Average</th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOR</td>
<td>3.96 bB</td>
<td>4.92 aA</td>
<td>5.06 aA</td>
<td>5.51 aA</td>
<td>4.94 bA</td>
<td>5.55 aA</td>
<td>5.0</td>
<td>0.08</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>MOD</td>
<td>4.15 abB</td>
<td>5.04 aA</td>
<td>5.45 aA</td>
<td>5.48 aA</td>
<td>5.34 abA</td>
<td>5.12 aA</td>
<td>5.1</td>
<td>0.08</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SEV</td>
<td>4.69 aC</td>
<td>4.81 aBC</td>
<td>5.15 aBC</td>
<td>5.06 aBC</td>
<td>5.90 aA</td>
<td>5.34 aAB</td>
<td>5.2</td>
<td>0.09</td>
<td>0.001</td>
</tr>
<tr>
<td>SEM</td>
<td>0.12</td>
<td>0.11</td>
<td>0.12</td>
<td>0.10</td>
<td>0.13</td>
<td>0.01</td>
<td>0.12</td>
<td>0.195</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
NOR = Normal breast meat, MOD = Moderate woody breast meat, SEV = Severe woody breast meat, SEM = Standard error of the mean
a-b: means with the same letter by column are not different (P > 0.05).
A-C: means with the same letter by row are not different (P > 0.05).
Table 3. Instrumental color CIE b* (yellowness) measurements of normal breast meat, moderate and severe woody breast meat that were stored from day 0 (day of processing) through day 5 at 2-4 ºC (n=25).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Average</th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOR</td>
<td>14.1 bB</td>
<td>16.5 aA</td>
<td>16.5 aA</td>
<td>17.0 aA</td>
<td>16.0 aA</td>
<td>16.5 aA</td>
<td>16.1</td>
<td>0.202</td>
<td>0.001</td>
</tr>
<tr>
<td>MOD</td>
<td>14.9 abB</td>
<td>15.3 bAB</td>
<td>15.8 aAB</td>
<td>16.2 aA</td>
<td>15.6 aAB</td>
<td>15.5 abAB</td>
<td>15.6</td>
<td>0.171</td>
<td>0.292</td>
</tr>
<tr>
<td>SEV</td>
<td>15.7 aAB</td>
<td>16.3 abA</td>
<td>16.0 aA</td>
<td>16.2 aA</td>
<td>16.1 aA</td>
<td>14.6 bB</td>
<td>15.8</td>
<td>0.142</td>
<td>0.005</td>
</tr>
<tr>
<td>SEM</td>
<td>0.25</td>
<td>0.20</td>
<td>0.27</td>
<td>0.22</td>
<td>0.28</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>0.038</td>
<td>0.043</td>
<td>0.573</td>
<td>0.246</td>
<td>0.738</td>
<td>0.008</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
- NOR = Normal breast meat, MOD = Moderate woody breast meat, SEV = Severe woody breast meat, SEM = Standard error of the mean
- a-b: means with the same letter by column are not different (P > 0.05).
- A-B: means with the same letter by row are not different (P > 0.05).
Table 4. pH measurements from normal breast meat, moderate and severe woody breast meat that were stored from day 0 (day of processing) through day 5 at 2-4 °C (n=25).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOR</td>
<td>5.76 bB</td>
<td>5.84 cA</td>
<td>5.80 bAB</td>
<td>5.76 cB</td>
<td>5.80 cAB</td>
<td>5.83 cA</td>
<td>0.01</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>MOD</td>
<td>5.98 aA</td>
<td>5.96 bA</td>
<td>5.92 aA</td>
<td>5.93 bA</td>
<td>5.92 bA</td>
<td>5.97 bA</td>
<td>0.01</td>
<td>0.089</td>
</tr>
<tr>
<td>SEV</td>
<td>6.03 aAB</td>
<td>6.03 aAB</td>
<td>5.96 aB</td>
<td>6.00 aAB</td>
<td>5.98 aB</td>
<td>6.07 aA</td>
<td>0.01</td>
<td>0.001</td>
</tr>
<tr>
<td>SEM</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P value   
<0.0001   <0.0001 <0.0001 <0.0001 <0.0001 <0.0001

Notes:

NOR = Normal breast meat, MOD = Moderate woody breast meat, SEV = Severe woody breast meat, SEM = Standard error of the mean.

a-c: means with the same letter by column are not different (P > 0.05).

A-B: means with the same letter by row are not different (P > 0.05).
Table 5. Purge loss (%) from normal breast meat, moderate and severe woody breast meat that were stored from day 0 (day of processing) through day 5 at 2-4 ºC (n=25).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOR</td>
<td>0.54 bC</td>
<td>0.84 bBC</td>
<td>1.61 aAB</td>
<td>1.56 aB</td>
<td>2.56 aA</td>
<td>0.11</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>MOD</td>
<td>0.50 bB</td>
<td>1.46 aBA</td>
<td>1.69 aA</td>
<td>2.40 aA</td>
<td>1.85 aA</td>
<td>0.12</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SEV</td>
<td>1.05 aB</td>
<td>1.43 aB</td>
<td>1.90 aAB</td>
<td>2.48 aA</td>
<td>2.49 aA</td>
<td>0.10</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SEM</td>
<td>0.08</td>
<td>0.10</td>
<td>0.16</td>
<td>0.18</td>
<td>0.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>0.0160</td>
<td>0.01580</td>
<td>0.7157</td>
<td>0.0740</td>
<td>0.1302</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
NOR = Normal breast meat, MOD = Moderate woody breast meat, SEV = Severe woody breast meat, SEM = Standard error of the mean
a-b: means with the same letter by column are not different (P > 0.05).
A-C: means with the same letter by row are not different (P > 0.05).
Table 6. Cook loss (%) from normal breast meat, moderate and severe woody breast meat that were stored from day 0 (day of processing) through day 5 at 2-4 °C (n=25).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOR</td>
<td>25.9 cA</td>
<td>23.7 bAB</td>
<td>23.4 bAB</td>
<td>26.0 bA</td>
<td>22.3 bB</td>
<td>23.5 bAB</td>
<td>0.31</td>
<td>0.003</td>
</tr>
<tr>
<td>MOD</td>
<td>29.5 bA</td>
<td>28.3 aA</td>
<td>28.8 aA</td>
<td>29.8 aA</td>
<td>28.4 aA</td>
<td>30.2 aA</td>
<td>0.37</td>
<td>0.610</td>
</tr>
<tr>
<td>SEV</td>
<td>32.1 aA</td>
<td>29.5 aA</td>
<td>31.6 aA</td>
<td>31.6 aA</td>
<td>30.1 aA</td>
<td>32.3 aA</td>
<td>0.36</td>
<td>0.160</td>
</tr>
<tr>
<td>SEM</td>
<td>0.14</td>
<td>0.54</td>
<td>0.50</td>
<td>0.16</td>
<td>0.50</td>
<td>0.51</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:

NOR = Normal breast meat, MOD = Moderate woody breast meat, SEV = Severe woody breast meat, SEM = Standard error of the mean.

a-c: means with the same letter by column are not different ($P > 0.05$).
A-B: means with the same letter by row are not different ($P > 0.05$).
Table 7. Warner-Bratzler shear force values of normal breast meat, moderate and severe woody breast meat that were stored from day 0 (day of processing) through day 5 at 2-4 ºC (n=25 with 2 subsamples in each position).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Position</th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOR</td>
<td>Upper</td>
<td>32.6 aA</td>
<td>24.4 aB</td>
<td>22.5 bBC</td>
<td>18.6 bD</td>
<td>18.3 cD</td>
<td>19.9 bCD</td>
<td>0.45</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>MOD</td>
<td>Upper</td>
<td>25.7 bAB</td>
<td>27.3aA</td>
<td>23.9 abABC</td>
<td>22.5 aBC</td>
<td>23.0 bABC</td>
<td>20.8 bC</td>
<td>0.60</td>
<td>0.032</td>
</tr>
<tr>
<td>SEV</td>
<td>Upper</td>
<td>28.0 bA</td>
<td>26.7 aA</td>
<td>26.7 aA</td>
<td>24.7 aA</td>
<td>26.4 aA</td>
<td>26.3 aA</td>
<td>0.47</td>
<td>0.485</td>
</tr>
<tr>
<td>SEM</td>
<td></td>
<td>0.73</td>
<td>0.86</td>
<td>0.73</td>
<td>0.64</td>
<td>0.63</td>
<td>0.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td></td>
<td>0.0006</td>
<td>0.344</td>
<td>0.057</td>
<td>0.001</td>
<td>&lt;0.0001</td>
<td>0.0004</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| NOR       | Middle   | 41.1 aA   | 26.4 aB   | 23.0 aBC  | 19.7 aC   | 19.6 bC   | 21.0 abC  | 0.60   | <0.0001  |
| MOD       | Middle   | 28.1 bA   | 24.0 aB   | 23.2 aBC  | 20.0 aCD  | 19.0 bD   | 17.9 bD   | 0.52   | <0.0001  |
| SEV       | Middle   | 27.9 bA   | 24.8 aABC | 24.5 aBC  | 21.7 aC   | 25.6 aAB  | 22.4 aBC  | 0.44   | 0.001    |
| SEM       |          | 1.03      | 0.72      | 0.79      | 0.54      | 0.61      | 0.66      |        |          |
| P value   |          | <0.0001   | 0.378     | 0.695     | 0.258     | <0.0001   | 0.019     |        |          |

| NOR       | Lower    | 45.7 aA   | 27.0 aB   | 23.9 aBC  | 19.6 aC   | 19.7 bC   | 21.0 aC   | 0.65   | <0.0001  |
| MOD       | Lower    | 30.3 bA   | 22.6 bB   | 24.8 aB   | 18.7 aC   | 19.1 bC   | 16.3 bC   | 0.46   | <0.0001  |
| SEV       | Lower    | 29.0 bA   | 25.5 abB  | 23.5 aB   | 20.4 aC   | 25.4 aB   | 19.7 aC   | 0.41   | <0.0001  |
| SEM       |          | 1.08      | 0.70      | 0.78      | 0.59      | 0.05      | 0.62      |        |          |
| P value   |          | <0.0001   | 0.041     | 0.789     | 0.485     | <0.0001   | 0.009     |        |          |

Notes:
- NOR = Normal breast meat, MOD = Moderate woody breast meat, SEV = Severe woody breast meat, SEM = Standard error of the mean
- a-c: means with the same letter by column are not different (P > 0.05).
- A-D: means with the same letter by row are not different (P > 0.05).
Table 8. Proximate analysis (NIR) of normal breast meat, moderate and severe woody breast meat that were from day 0 (day of processing) and day 5 that were stored at 2-4 °C (n=15).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
<th>Collagen (%)</th>
<th>Moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 0</td>
<td>Day 5</td>
<td>SEM</td>
<td>P value</td>
</tr>
<tr>
<td>NOR</td>
<td>1.9 a</td>
<td>2.2 a</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>MOD</td>
<td>2.2 a</td>
<td>2.1 a</td>
<td>0.10</td>
<td>0.574</td>
</tr>
<tr>
<td>SEV</td>
<td>2.1 a</td>
<td>2.1 a</td>
<td>0.11</td>
<td>0.788</td>
</tr>
<tr>
<td>SEM</td>
<td>0.08</td>
<td>0.09</td>
<td>0.12</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Notes:
- NOR = Normal breast meat, MOD = Moderate woody breast meat, SEV = Severe woody breast meat, SEM = Standard error of the mean
- a-c: means with the same letter by column are not different (P > 0.05)
Table 9. Diminishment (%) of woody breast severity of moderate and severe woody breast meat that were stored from day 1 through day 5 at 2-4 °C (n=25).

<table>
<thead>
<tr>
<th>Diminishment</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOD</td>
<td>4 A</td>
<td>16 A</td>
<td>40 A</td>
<td>48 A</td>
<td>52 A</td>
</tr>
<tr>
<td>SEV</td>
<td>8 D</td>
<td>24 CD</td>
<td>52 BC</td>
<td>56 AB</td>
<td>84 A</td>
</tr>
</tbody>
</table>

Notes:
1 Diminishment is the percentage of moderate woody breast that lessened in severity to mild woody breast or normal breast meat, and
2 the percentage of severe woody breast fillets that diminished or lessened to moderate woody breast diminished.
3 MOD = Moderate woody breast meat, SEV = Severe woody breast meat.

A-D: means with the same letter by row are not different ($P > 0.05$).
Figure 1. Sampling positions for color (circles) and pH (squares) measurements
Figure 2. Sampling positions for shear force measurements