Meat quality of broiler breast fillets with white striping and woody breast muscle myopathies

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ABSTRACT The global poultry industry has been faced with emerging broiler breast meat quality issues including conditions known as white striping (WS, white striations parallel to muscle fibers) and woody breast (WB, hardness of raw fillet). Experiments were conducted to evaluate effects of WS and WB hardness on meat quality traits in broiler breast fillets. In Exp. 1, birds were processed at approximately 9 wk of age and deboned at 4 h postmortem (PM); in Exp. 2, birds were processed at approximately 6 and 9 wk of age and deboned at 2 h PM. Fillets were categorized as: normal for both white striping and woody breast (NORM); moderate for white striping and mild for woody breast (MILD); severe for white striping and mild for woody breast (WS); severe for woody breast and moderate for white striping (WB); or severe for both white striping and woody breast (BOTH). Sarcomere length, gravimetric fragmentation index, marination uptake, cook loss, and Meullenet-Owens razor shear energy (MORSE) values on non-marinated and marinated fillets were assessed. Sarcomeres tended to be longer ($P = 0.07$) with increasing severity of WS and WB in both experiments and gravimetric fragmentation index did not differ ($P > 0.05$) among categories. Marinade uptake decreased ($P < 0.05$) with increasing severity of WS and WB. Cook losses of non-marinated and marinated fillets were greatest ($P < 0.05$) in the BOTH category. Even though MORSE values did not differ ($P > 0.05$) in non-marinated fillets, the marinated BOTH fillets had greater MORSE values ($P < 0.05$) than other categories of fillets in Exp. 1. Non-marinated NORM fillets had greater ($P < 0.05$) MORSE values than the other categories at 6 wk age; however, MORSE values did not differ ($P > 0.05$) among categories of marinated breasts. At 9 wk, WS and BOTH were higher ($P < 0.05$) in MORSE compared to NORM for non-marinated fillets, but similar to NORM marinated fillets. Results suggest that severe degrees of white striping and woody breast, individually or in combination, negatively impact meat quality, especially water holding capacity attributes such as marinade uptake and cook loss.

Key words: white striping, woody breast, broiler, meat quality, defect

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INTRODUCTION

Boneless breast meat is a popular meat choice in the United States and is considered a premium product. To meet the demand of this fast growing industry, processors are adopting high breast-yielding strains of broilers that meet the needs in the growing heavy debone market segments. Today, chickens and turkeys are marketed in about half the time and at about twice the body weight compared to 50 years ago (Barbut et al., 2008). Challenging birds to attain high body weight within a short period of time can cause various meat quality problems (Kuttappan et al., 2012a). Because these rapid-growing broilers are now grown for longer times to achieve high meat yield, broiler myopathies, like white striping and more recently, woody breast, are severely affecting meat appearance and other meat quality attributes (Kuttappan et al., 2012a; Petracci et al., 2014)

The severity of white striping has increased in recent years and is characterized by white striations parallel to muscle fibers in which muscle fiber degeneration takes place with infiltration of fat and connective tissue (Kuttappan et al., 2012a; 2013b; 2013c). White striping is associated with heavier birds (Kuttappan et al., 2013a) and can be observed in varying degrees of severity. On the other hand, woody breast is a more recent myopathy characterized as pale expansive areas of substantial hardness accompanied with white striations (Sihvo et al., 2014) and by hard, rigid fillets in which muscle fiber degeneration takes place with infiltration of connective tissue (Sihvo et al., 2014; Mazzoni et al., 2015). Woody breast is also observed in varying degrees of severity and often observed with white striping. According to Sihvo et al. (2014), fast growth rate, along with increased breast meat yield plays a significant role

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in development of woody breast in chicken, and abnormal fibers were observed in high-yielding breast in a study conducted by Petracci et al. (2013b). Researchers have investigated a number of factors affecting white striping, including that males have higher incidences than females (Kuttappan et al., 2013a), high yielding genotypes show higher incidences of white striping than low yielding genotypes (Petracci et al., 2013a), and higher growth rates are also associated with greater incidence of white striping (Kuttappan et al., 2012a). In a study of histology of abnormal fibers, Mazzoni et al. (2015) reported severe myodegeneration and fibers with divergent diameters and shapes associated with woody breast characteristics, which are very similar to the histological characteristics associated with white striping (Sihvo et al., 2014). Apart from the aforementioned results of Mazzoni et al. (2015), limited information is available concerning the occurrence of woody breast and associated meat quality defects.

The occurrence of white striping and woody breast is negatively impacting the poultry processing industry, and the industry is facing great economic losses due to customer complaints about fillets affected by these myopathies. According to a study, consumers are more likely to buy normal fillets without any white striations and over 50% of consumers indicated that they will probably not or definitely not buy moderate or severely white striped fillets (Kuttappan et al., 2012c). Consumers also indicated that fillets with severe white striping look fattier and have a marbled appearance (Kuttappan et al., 2012c). Inclusion of such meat in further processed products can impact the final product quality. Kuttappan et al. (2012a) reported that there is an increase in fat content and decrease in protein content of white striped fillets which can be a concern in further processed products due to a decrease in functionality of proteins. In Italy, Petracci et al. (2013a) reported increased cook loss and decreased marinade uptake in fillets with white striping whereas, woody breast fillets had lower marinade uptake and greater cooking losses than white striped fillets for both unprocessed and marinated meat (Mudalal et al., 2014).

With evidence that white striping and woody breast myopathies can occur simultaneously in a single chicken breast fillet, it is important to study the effects of these myopathies on meat quality. Therefore, two experiments were conducted to determine the effects of white striping and woody breast, individually or in combination, on meat quality of broiler breast fillets, and to determine incidence of these myopathies in research flocks raised using commercial practices including variations in age at processing and postmortem debone times.

MATERIALS AND METHODS

Experiment 1

All research was approved by the Institutional Animal Care and Use Committee at the University of Arkansas. A total of 285 high breast-yielding male broilers with a live weight of approximately 3.97 kg were processed at the age of 61 d (referred to as 9 wk) using a commercial inline system at the university pilot processing plant. Birds were electrically stunned (11 V, and 11 mA for 11 s), manually slaughtered and bled out, scalded (53.8°C, 2 min), and picked using inline commercial defeathering equipment (Mehaffey et al., 2006). The carcasses were then manually eviscerated and rinsed. Following evisceration, birds were pre-chilled at 12°C for 15 min and chilled for 90 min at 1°C in immersion chilling tanks with manual agitation at regular intervals to enhance the efficiency of chilling. After chilling time, the birds were aged at 4°C in a walk-in cooler until the debone time of 4 h postmortem (**PM**).

The *Pectoralis major* muscle was deboned and scored for white striping using normal (0), moderate (1), or severe (2) as described by Kuttappan et al. (2012c) as well as an additional category of extreme (3), which was defined as striations greater than 3 mm throughout the fillet. Whole breast fillets were evaluated for degree of hardness (woody breast) based on tactile evaluation and categorized as: 0 = fillets that were flexible throughout (normal); 1 = fillets that were hard mainly in the cranial region but flexible otherwise (mild); 2 = fillets that were hard throughout but flexible in mid to caudal region (moderate); 3 = fillets that were extremely hard and rigid throughout from cranial region to caudal tip (severe). Additionally, fillets were scored in 0.5 increments, when necessary, and rounded down for classification purposes. To minimize variability in scoring, one person carried out all scoring of fillets. For the purpose of meat quality analysis, based on incidence, 115 whole breast fillets were categorized into multiple categories described in Figure 1. Only those fillets that had the same score for each side (i.e., right and left fillets) were selected for analysis.

The whole butterfly fillets were packed in zip-sealed bags and stored overnight at 4°C. At 24 h PM, fillets were removed from cooler and split into halves. Samples were cut from the medial-caudal region of the left side and then held at −80°C until analysis of sarcomere length (**SL**) and gravimetric fragmentation index (**GFI**). Cranial region of the left side fillet was vacuum packed in plastic bags and stored at −20°C for later determination of cook loss and texture analysis (non-marinated fillets). The right sides of breast fillets were vacuum packed in plastic bags and stored at −20°C for later determination of marinade uptake, cook loss, and texture analysis (marinated fillets). Fillets were frozen due to study logistics and all samples were treated the same so that treatment effects may still be observed. Zhuang and Savage (2013) reported that cooking from a thawed state resulted in better meat quality (e.g., lower cook loss, lower shear force) than those cooked from a frozen state so fillets were thawed in this study prior to analysis. Fillets were removed from the freezer 24 h prior to cooking to ensure adequate thawing. Right

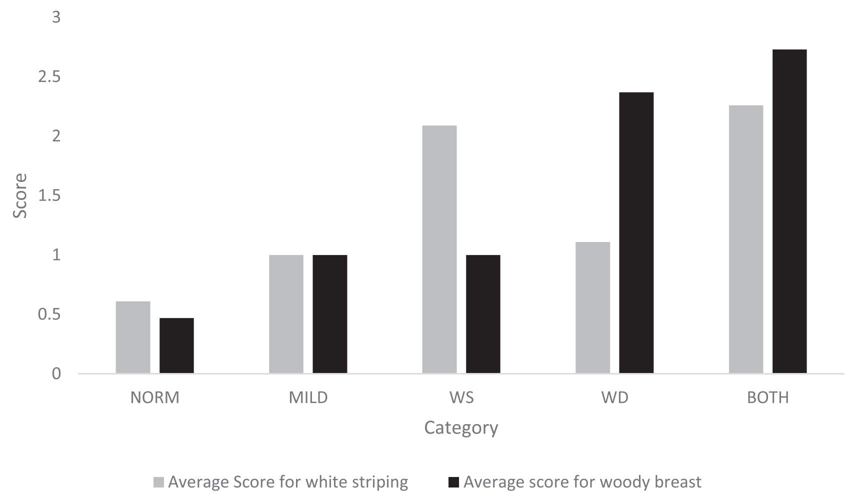

Figure 1. Description of categories analyzed for meat quality based on the average scores of white striping (WS) and woody breast (WB) myopathies (Exp. 1). NORM = normal for WS and WB; MILD = moderate for WS and mild for WB; WS = severe for WS but mild for WB; WB = severe for WB but moderate for WS; BOTH = severe for WS and WB.

side breast fillets which were to be marinated were portioned horizontally with a target height of 40 mm in the cranial region to reduce effect of fillet thickness on marination properties. Fillets were then tagged and tumble marinated in a salt (NaCl)−phosphate (STP) solution for 20 min and a target of 15% marinade pickup and final concentration of 0.75% NaCl and 0.45% phosphate (Carnal 822; Budenheim USA Inc., Plainview, NY). Marination was carried out in replicates where each category was subjected to two replications. The fillets were allowed to rest 15 minutes after vacuum tumbling and weighed to compute marination uptake percentage. Both left and right side breast fillets were weighed before cooking in aluminum foil covered pans on raised wire racks in an air convection oven to an internal temperature of 76°C (Cavitt et al., 2004). After cooking, the fillets were cooled to room temperature and weighed to calculate cook loss percentage. Individual fillets were wrapped in aluminum foil and stored overnight at 4°C before texture analysis the following day. Fillets were kept at 4°C for shear analysis. Texture analysis was carried out using Meullenet-Owens razor shear technique (Cavitt et al., 2004) to indirectly assess the tenderness of non-marinated and marinated fillets by measuring total energy (**MORSE**). This technique uses a texture analyzer (model TAX-T2, Texture Technologies, Scarsdale, NY). Three shear readings were taken perpendicular to the muscle fibers at different locations of each fillet and the razor blade was changed after every 99 shears so the blade did not become dull (Cavitt et al., 2004).

GFI measurement was carried out to assess PM proteolysis according to the protocol described by Sams et al. (1991). Samples were homogenized in iodoacetate solution, vacuum filtered through a 250 μm nylon screen, and the residue was dried and weighed. Sarcomere length was measured using laser diffraction method described by Voyle (1971) and Cross et al. (1980).

Experiment 2

All research was approved by the Institutional Animal Care and Use Committee at the University of Arkansas. High breast-yielding broilers were processed at the age of 40 and 42 d (referred to as 6 wk) and 61 d (referred to as 9 wk) of age using previously described commercial practices. Because fewer birds were available at 9 wk, birds were only processed on one day for that age period. The average live weight of birds processed 6 and 9 wk of age was approximately 2.66 and 4.62 kg, respectively. Processed broilers were aged on ice in a walk-in cooler at 4°C until time of deboning.

Fillets were deboned at 2 h PM and scored for severity of white striping by visual evaluation as described by Kuttappan et al. (2012c) and woody breast by tactile evaluation as described previously. For meat quality analyses, 160 fillets and 87 were collected at 6 (four collections of each category) and 9 wk of age (two collections of each category), respectively, due to availability. Availability of normal fillets was a limiting factor for the 9 wk treatment. In this study, fillets were categorized into 3 classes (normal [**NORM**], severe for white striping and moderate for woody breast [**WS**], or severe for white striping and woody breast [**BOTH**]; Table 1). Based on limited availability, there was no category for severe woody breast and moderate white striping or for moderate for white striping and mild woody breast.

After storing for 24 h, fillets were split into halves and samples were collected for sarcomere length from the medial-caudal region of left side and then held at −80°C until analysis. Cranial region of the left side fillet was vacuum packed in plastic bags and stored at −20°C for determination of cook loss and texture analysis (non-marinated fillets). The right sides of breast fillets were vacuum packed in plastic bags and stored at −20°C for determination of marinade uptake, cook loss, and texture analysis (marinated fillets). Right side breast fillets were portioned horizontally to 40 mm height and

Table 1. Description of categories analyzed for meat quality based on the average scores of white striping (WS) and woody breast (WB) myopathies in 6 and 9 week age birds (Exp. 2).

Category[1]	WS score[2]	WB score[2]	n
6 Weeks			
NORM	0.46	0.13	64
WS	2.00	0.91	46
BOTH	2.05	2.30	50
9 Weeks			
NORM	0.95	0.40	32
WS	2.00	0.75	23
BOTH	3.20	3.07	32

[1]NORM = normal for white striping and woody breast; WS = severe for white striping but mild for woody breast; and BOTH = severe for white striping and woody breast.
[2]Average score for white striping or woody breast in each category.

marinated as described in Exp. 1. After marination, fillets were allowed to rest 20 minutes after vacuum tumbling and weighed to compute marination uptake percentage. Left and right side breast fillets were then cooked and sheared in four locations according to methods previously described to determine cook loss and MORSE.

Statistical Analysis

Data were analysed as a completely randomized design using the GLM procedure in JMP (SAS, 2015), with the main effect of the category (e.g., NORM, MILD, WS, WD, BOTH), in each experiment. Because the treatment was the classification of the defect (i.e., category) identified at time of deboning, the experimental unit was the bird in each experiment. The experimental unit was replicated multiple times (Table 2 and Table 3). In a separate analysis, age was considered the main effect within each category of EXP. 2. Additionally, non-marinated and marinated fillets were analyzed separately for cook loss and MORSE values. Means were separated by Tukey's HSD or Student t test, as appropriate, and significance level was set at $P < 0.05$.

RESULTS AND DISCUSSION

Experiment 1

The incidence of white striping from the total number of 285 birds was 96.1%, with 63.8% of breast fillets receiving a score of 1 (moderate), which is similar to previous studies (Kuttappan et al., 2012a; 2012b; 2013b), whereas 32.3% of breast fillets received a score of 2 (severe). Furthermore, about 2% were considered 3 (extreme), a category of severity not previously observed in this laboratory. The incidence of woody breast was also 96.1%, with 48% scored as 1 (mild), 28% scored as 2 (moderate), and 20% of fillets scored as 3 (severe). It should be noted that the flocks used in this study were raised in controlled research settings (pen trial) using commercial diets allowing for good growth performance and uniformity. Therefore, the high incidence of higher degrees of severity of white striping and woody breast was not surprising and is likely higher than would be found in flocks in commercial houses. Following scoring for white striping and woody breast abnormalities, the fillets were placed into treatment categories of NORM, MILD, WS, WB, and BOTH. The average scores for white striping and woody breast in each category were reported in Table 1.

Woody breast is characterized by hardness of the fillet and is often described as a fillet with outbuldge or a ridge (Sihvo et al., 2014; Mudalal et al., 2014), having a contracted muscle appearance. Thus, sarcomere lengths of muscle samples from each category were assessed, and, interestingly, the sarcomeres of BOTH and WB fillets tended to be longer ($P = 0.07$) than NORM fillets (Table 2). Xiao and Owens (2016) reported that sarcomeres, collected from the cranial region, were longer ($P < 0.05$) in severe woody breast than in normal breast fillets, supporting the trend observed in this experiment. These results suggest that

Table 2. Effect of white striping (WS) and woody breast (WB) on quality attributes of non-marinated breast meat (Exp. 1).

	Category[1]					
Attribute	NORM	MILD	WS	WB	BOTH	Pooled SEM
n	17	28	16	28	22	
Non-marinated						
Cook loss (%)	27.8^{c}	30.8^{b,c}	37.1^{a}	34.8^{a,b}	38.1^{a}	0.62
MORSE (N.mm)	191.8	205.6	222.2	219.9	210.1	4.10
Sarcomere Length (μm)	1.69	1.73	1.79	1.80	1.80	0.010
GFI[2]	160.6	167.0	143.8	166.5	173.4	4.73
Marinated						
Marinade uptake (%)	10.6^{a}	8.3^{b}	7.2^{b,c}	6.3^{c}	5.9^{c}	0.24
Cook loss (%)	16.9^{b,c}	15.6^{c}	22.0^{a,b}	18.5^{a-c}	22.6^{a}	0.52
MORSE (N.mm)	127.0^{b}	129.2^{b}	140.0^{a,b}	139.1^{a,b}	165.9^{a}	3.41

[a–c]Means within a row followed by different superscript letters differ significantly ($P < 0.05$).
[1]NORM = normal for white striping and woody breast; MILD = moderate for white striping and mild for woody breast; WS = severe for white striping but mild for woody breast; WB = severe for woody breast but moderate for white striping; and BOTH = severe for white striping and woody breast.
[2]Gravimetric fragmentation index.

Table 3. Effect of white striping (WS) and woody breast (WB) on quality attributes of non-marinated and marinated breast meat from broilers 6 and 9 weeks of age (Exp 2).

Attribute	Category[1] NORM	WS	BOTH	Pooled SEM
n				
6 weeks	64	46	50	
9 weeks	32	23	32	
Non-marinated				
Sarcomere length, nm				
6 weeks	1.59[b,x]	1.63[b]	1.66[a]	0.007
9 weeks	1.54[b,y]	1.63[a]	1.64[a]	0.100
Pooled SEM	0.009	0.009	0.009	
Cook loss, %				
6 weeks	28.2[b]	28.5[a,b,y]	30.9[a,y]	0.46
9 weeks	28.3[c]	32.2[b,x]	35.5[a,x]	0.58
Pooled SEM	0.43	0.73	0.72	
MORSE (N.mm)				
6 weeks	196.7[a]	180.2[b,y]	181.1[b,y]	2.49
9 weeks	193.8[b]	214.9[a,x]	206.9[a,b,x]	2.68
Pooled SEM	2.63	3.93	3.74	
Marinated				
Marination Uptake, %				
6 weeks	14.0[a,x]	10.3[b,x]	7.5[c,x]	0.30
9 weeks	8.6[a,y]	7.2[b,y]	4.9[c,y]	0.26
Pooled SEM	0.37	0.32	0.25	
Cook loss, %				
6 weeks	20.0[b,x]	19.8[b]	24.7[a,y]	0.39
9 weeks	17.4[b,y]	19.2[b]	30.4[a,x]	0.85
Pooled SEM	0.39	0.65	0.71	
MORSE, N*mm				
6 weeks	131.9[y]	124.5	136.7[y]	2.14
9 weeks	148.9[a,b,x]	135.3[b]	156.8[a,x]	2.67
Pooled SEM	2.60	3.02	3.29	

[a–c]Means within row with no common superscript differ ($P < 0.05$).
[x–y]Means within column within attribute with no common superscript differ ($P < 0.05$).
[1]NORM = normal for white striping and woody breast; WS = severe for white striping but mild for woody breast; and BOTH = severe for white striping and woody breast.

the hardness in woody breast is not due to an overall decrease in contractile state (i.e., sarcomere shortening). However, further research is needed to determine if location (e.g., ventral to dorsal) has an effect on these muscle fiber characteristics (e.g., sarcomeres).

As marination is a common method for adding value through improving yield and quality, fillets classified as NORM had the greatest ($P < 0.05$) marinade uptake, whereas MILD fillets had greater ($P < 0.05$) marinade uptake percentages than WB and BOTH fillets (Table 2). Mudalal et al. (2014) conducted a similar study on effects of white striping and woody breast on meat quality, and these results support the finding of Mudalal et al. (2014) who reported a decrease in marinade uptake in the WB and WS+WB categories when compared to normal breast meat. A possible reason for lower marinade uptake and higher cook loss (non-marinated) in WS, WB, and BOTH can be attributed to a greater loss of protein from woody breast with fibrosis (Sihvo et al., 2014) and white striped breast with lipidosis (Kuttappan et al., 2012a).

Cook loss was assessed to evaluate one aspect of water holding capacity in both non-marinated and marinated fillets. Non-marinated breast fillets categorized as NORM had the least ($P < 0.05$) cook loss, whereas those classified as WS and BOTH had greater ($P < 0.05$) cook losses than fillets categorized as MILD (Table 2). There have been varied reports on cook loss in severe white striped fillets in comparison to normal fillets. Kuttappan et al. (2013a) reported that cook loss percentage did not differ between normal and severe white striped fillets; however, Petracci et al. (2013a) reported higher cook losses in severe white striped fillets compared with normal. In the marinated fillets, only the BOTH treatment had greater cook loss than NORM ($P < 0.05$; Table 2). These results are supported by Mudalal et al. (2014) who reported higher cook loss in marinated fillets with severe woody breast category and severe both abnormalities category compared to normal and severe white striped category fillets.

Among non-marinated fillets, MORSE values did not ($P > 0.05$) differ among the 5 categories, indicating that the shearing properties did not change with either of the abnormalities (Table 2). In contrast, where the right side breast were vacuum marinated, BOTH fillets had greater ($P < 0.05$) MORSE values than those categorized as NORM and MILD (Table 2). The increased MORSE values in BOTH fillets maybe due to the low marinade pickup which reduced the effectiveness of ingredients at tenderizing meat, which is consistent with Mudalal et al. (2014). Interestingly, GFI did not differ ($P > 0.05$) among categories in non-marinated breast fillets suggesting similar status of postmortem proteolysis in the first 24 h.

Experiment 2

Due to the results observed in Exp. 1., sarcomere length was measured in Exp. 2 to confirm the trend for longer sarcomeres in fillets with severe myopathies. For birds processed at 6 wk of age, BOTH fillets had longer ($P < 0.05$) sarcomeres than NORM and WS fillets, whereas fillets categorized as WS and BOTH had longer ($P < 0.05$) sarcomeres than NORM fillets when birds were processed at 9 wk of age (Table 3). Interestingly, sarcomeres were shorter ($P < 0.05$) in the NORM fillets at 9 wk compared to those at 6 wk, but no differences ($P > 0.05$) were observed in sarcomere length in the WS or in the BOTH fillets between the ages. These data support and confirm the trend observed in Exp. 1 where sarcomeres were longer in WB fillets compared to normal fillets ($P = 0.07$). Xiao and Owens (2016) reported similar results where severe woody breast fillets had longer ($P < 0.05$) sarcomeres (cranial region) than normal fillets. Data suggests that sarcomeres are longer as the severity of white striping and woody breast increases, however, the reason of increase in length is unknown. It may be possible that that the increased collagen and/or loss of myofibrillar structure (due to fiber degeneration) associated with white striping and woody breast is preventing shortening from occurring, thereby resulting in longer sarcomeres than in normal fillets. It is not likely that the rigidness and contracted appearance of severe woody breast is related to a general sarcomere shortening. However, a much deeper investigation of muscle at the cellular level will be needed to elucidate the reason of differences in sarcomere length with these myopathies.

When marinating, regardless of the age at processing, NORM fillets had the greatest ($P < 0.05$) marinade uptake, and fillets categorized as WS had greater ($P < 0.05$) marinade uptake than those categorized as BOTH (Table 3). These findings support the results of Exp. 1 where NORM had greater ($P < 0.05$) marinade uptake percentages compared to rest of the categories. Mudalal et al. (2014) and Petracci et al. (2013a) reported similar results where marinade uptake percentage decreased with increasing severity of white striping and woody breast. The age of the bird also impacted marination uptake as fillets from 6 wk broilers had greater ($P < 0.05$) marinade pickup than fillets from 9 wk broilers, in all categories. All fillets were portioned to approximately 40 mm in thickness to minimize the impact of fillet dimensions between the ages. More research is needed to elucidate reasons for these differences.

Cook loss of non-marinated breast fillets was assessed in Exp. 2 as well. When processed at 6 wk of age, non-marinated BOTH fillets had greater ($P < 0.05$) cook loss percentages than NORM fillets; however, fillets categorized as WS and BOTH had greater ($P < 0.05$) cooking loss than NORM fillets in birds processed at 9 wk (Table 3). With regard to white striping only, 6 wk fillets had similar results to Kuttappan et al. (2013a) who reported no difference ($P > 0.05$) between severe white striped fillets and normal fillets. On the other hand, 9 wk non-marinated cook loss % results were similar to Petracci et al. (2013a), Mudalal et al. (2014), and Exp. 1 where severe white striped fillets had higher ($P < 0.05$) cook loss than normal fillets.

In the marinated fillets, fillets classified as BOTH had greater ($P < 0.05$) cook loss percentages than either WS or NORM fillets, regardless of the bird age at processing (Table 3). These results are consistent with findings of Mudalal et al. (2014) and Exp. 1; however Petracci et al. (2013a) reported that severely white striped fillets had higher cook loss than normal fillets. For the fillets with both defects (BOTH), cook loss (non-marinated or marinated) significantly increased ($P < 0.05$) from 6 to 9 wk of age. For the NORM and WS fillets, the effect of age was inconsistent between cook loss of non-marinated and marinated fillets. Overall, these results suggest that these myopathies negatively impact water holding capacity of broiler fillets. Reduced water holding capacity negatively impacts yield and product quality.

When processed at the age of 6 wk, non-marinated fillets categorized as NORM had greater ($P < 0.05$) MORSE values than WS fillets and BOTH fillets (Table 3), but the trend was opposite at 9 wks where MORSE values of WS and BOTH fillets were greater ($P < 0.05$) than NORM fillets. Furthermore, at 9 wk, both the WS and BOTH fillets had greater ($P < 0.05$) MORSE values than at 6 wk, but age did not impact MORSE values of non-marinated NORM fillets as indicated by no significant differences ($P > 0.05$). The reason for this is unclear since sarcomeres were actually generally longer in these WS and BOTH fillets relative to NORM fillets at both 6 and 9 wk. Therefore, it is unlikely that the differences in MORSE were related to contractile state.

MORSE values were not significantly different ($P > 0.05$) among categories when fillets from 6 wk old birds were marinated (Table 3) but at 9 wk, the BOTH fillets had greater ($P < 0.05$) MORSE values than WS fillets and were not different ($P > 0.05$) from the NORM fillets. In this study, the marinated BOTH and NORM fillets had greater MORSE values at 9 wk than those at 6 wk, but no differences were observed due to age in the marinated WS fillets. Petracci et al. (2013a) reported white striped fillets had greater shear values than normal fillets while Kuttappan et al. (2013a) reported that WS did not significantly impact MORSE values. The variations in results from past studies and this experiment may be attributed to the differences in strain (high breast yielding and moderate breast yielding broilers used in previous studies), age (range from 49 to 63 d in previous studies), and debone time (range of 2 to 6 h PM in previous studies) of broiler birds as well as differences in shearing methodologies, all of which have been shown to have impact on shear values (Thompson et al., 1987; Northcutt et al., 2001; Cavitt et al., 2004; Mehaffey et al., 2006; Brewer et al., 2012; Petracci et al., 2013a; Kuttappan et al., 2013a). Traditional shear methodologies have typically assessed meat for indirectly for tenderness related to contractile state, but the histological differences (i.e., fiber degeneration, fat, and connective tissue infiltration) related to white striping and woody breast relative to normal fillets may impact the meaning of the shear results. More research is needed in the future to assess the relationship of shear values of woody breast and/or white striping and sensory properties.

CONCLUSION

The results of this study suggest that severe degrees of white striping and woody (hardness), together or alone, negatively impact some aspects of meat quality, especially water holding capacity attributes such as cook loss and marinade uptake of whole muscle fillets. Both of these abnormalities have potential to greatly affect the poultry industry, especially in further processing and/or food service where breast meat from heavy deboned broilers is often used. Future research should include sensory analysis to determine acceptability of meat with such abnormalities and to determine the usability of white striping and woody breast meat in further processed products.

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