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Fillet Dimensions and Meat Quality Attributes Associated With Woody Breast in Broilers

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Abstract: Woody breast (WB) is a major myopathy in broilers characterized by hardness of the breast fillet and can be evaluated by human palpation with a severity scale of 0 (normal) to 3 (severe). The objective of this study was to determine fillet dimensions and meat quality factors that are associated with WB scores that may potentially be used for sorting purposes. A total of 206 broiler breast fillets (deboned at 3 h postmortem) were collected and scored for WB. Thickness and length (overall, cranial, caudal, and keel regions) of the *Pectoralis major* (whole butterfly) were measured with a caliper. Compression force (CF), pH, and color were measured. The right side of the butterfly fillet was frozen at −20°C for 48 h and thawed for 24 h, and then CF was measured along with cook loss, Meullenet-Owens Razor Shear, and blunt Meullenet-Owens Razor Shear. Pearson correlation coefficients and nominal logistic regression were determined. Measurement responses were compared for 4 categories of WB. The keel length measurement on the breast showed no difference ($P > 0.05$). However, the thickness was moderately correlated with WB score ($r = 0.67$) and could differentiate between the scores. In addition, CF of right side was higher than left side of fillets ($P < 0.05$). Freezing/storage significantly decreased ($P < 0.05$) CF of thawed fillets compared to chilled (nonfrozen) fillets. Cook loss increased ($P < 0.05$) as severity for WB increased. Peak counts for Meullenet-Owens Razor Shear and blunt Meullenet-Owens Razor Shear were higher ($P < 0.05$) for the severe compared to the lower levels of WB severity. In conclusion, meat quality differences were evident among the WB categories, differences in CF were observed between right and left fillets, and freezing/storage decreased hardness of fillets. Breast fillet dimensions along with L^* value may potentially be used to identify WB, and this model of prediction of WB could be used in the industry to select the different WB categories in the development of sorting methods.

Key words: broiler breast, wooden breast, meat quality, myopathies, thawed meat
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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 have adopted high breast-yielding strains of broilers to better meet the needs of the growing heavy debone market segments. However, the incidence of myopathies such as woody breast (WB) and white striping (WS) in these broiler strains have also increased (Kuttappan et al., 2013a; Kuttappan et al., 2016). Several issues affecting WB and WS, including the sex of the birds, high-yielding genotypes, and higher growth rates, have been reported to increase the incidence and severity of these myopathies (Kuttappan et al., 2012a; Petracci and Cavani, 2012; Kuttappan et al., 2016). These myopathies affect the quality of the poultry meat and consumer acceptability. Specifically, WB is characterized by hard consistency and pale color of the *Pectoralis major* (Sihvo et al., 2014; Tijare et al., 2016).

Histological changes are also associated with myopathy, such as fiber degeneration, fibrosis resulting in lower protein, higher collagen, and higher fat content lipidosis (Sihvo et al., 2014; Soglia et al., 2015; Soglia et al., 2017). In turn, meat quality is impacted; fillets have increased drip loss, pH, and cook loss and decreased water-holding capacity and marinade uptake (Kuttappan et al., 2012b; Russo et al., 2015; Kuttappan et al., 2017). Severe WB fillets are poor quality meat that are often downgraded in the poultry industry, causing economic losses. Kuttappan et al. (2016) reported that the industry could be losing over $200 million a year due to lost yield and downgraded value. Currently, WB meat is graded by plant personnel and sorted when necessary depending on product requirements. Ongoing research is being conducted in the field for potential sorting methods; however, understanding the characteristics of WB fillets would be useful in developing sorting techniques. Therefore, the objective of this study was to determine fillet dimensions and meat quality factors that are associated with WB scores that may potentially be used for sorting purposes. A secondary objective was to determine whether there is a location effect (breast side) or effect of freezing/storage on compression force (CF) of fillets.

Materials and Methods

Animal source and diets

In the present study, male Cobb 700 broiler chicks were obtained from Cobb-Vantress (Siloam Springs, AR). Feed and water were provided *ad libitum*, with all the treatments receiving a commercial feed depending on the phase. Diets were formulated to approximate the nutritional requirements of broiler chickens as recommended by the National Research Council (1994) and were adjusted to breeder recommendations (Cobb-Vantress Inc., Siloam Springs, AR). At 57 d, 206 birds were processed using a commercial in-line system at the University of Arkansas. All animal handling procedures complied with the Institutional Animal Care and Use Committee at the University of Arkansas, Fayetteville.

Processing of birds

About 10 h before slaughter, feed was withdrawn, but the birds were given an *ad libitum* supply of water. A commercial-style processing in-line system was used where the birds were electrically stunned, manually slaughtered by severing the left carotid artery and jugular vein, bled out, soft scalded, and defeathered (Mehaffey et al., 2006). The carcasses were then manually eviscerated, prechilled at 12°C for 15 min followed by chilling for 90 min at 1°C in immersion chilling tanks. While prechilling and chilling, the carcasses were manually agitated frequently to prevent the thermal layer in the tank and to enhance the chilling efficiency. The carcasses were taken out of the tanks, packed in ice, and aged at 4°C until deboning at 3 h postmortem, common industry deboning times. Ready-to-cook weight of each carcass was measured before deboning. The *Pectoralis major* muscle was removed from each carcass by 6 trained people to avoid any alterations in fillet dimensions and other meat quality parameters due to the deboning procedures. The butterfly fillet from each bird was placed in common zip-sealable freezer bags and stored at 4°C until analysis.

Fillet attributes

Woody Breast scoring. Whole breast fillets were evaluated immediately after deboning (day of processing, day 0) for degree of hardness (WB) based on the tactile evaluation scale by Tijare et al. (2016), categorized as follows: 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.

Fillet dimensions. After scoring, keel length (middle of the butterfly fillet), fillet length (at the longest point), fillet width (at the widest point), cranial thickness (height at the thickest portion), and caudal length (one-third of the fillet length) were measured using calipers adapted from Mehaffey et al. (2006) to determine the fillet dimensions.

Compression Force. CF was then measured in 4 regions at the cranial part of the fillet on both the right and left sides on day 0 using methods described by Sun et al. (2018). The right side was measured again after freeze-thaw cycle (described below). Briefly, fillets were compressed to 20% of the fillet height using a 6-mm flat probe on a TA.XT Plus Texture Analyzer

(Texture Technologies Corp., Hamilton, MA/Stable Micro Systems, Godalming, Surrey, UK).

Meat quality parameters

Each butterfly fillet was halved into left and right. The left fillets were used for measuring pH and color, whereas texture analysis was conducted on the right fillets.

Muscle pH and color. Muscle pH was measured using a Testo spear tip probe and meter (Model Testo 205, Testo Inc., Sparta, NJ). Color was assessed on the same day of processing (day 0) by measuring L^*, a^*, and b^* values of fillets using a Minolta colorimeter (CR-300, Konica Minolta, Ramsey, NJ). Settings included illuminant D65, 2° observer, and an 8-mm aperture. An average of 3 readings representing 3 different sites on the dorsal (bone side) of the fillet were recorded.

Cook loss and texture analysis. The right fillets were vacuum packed, stored at 4°C until 24 h postmortem (day 1), and then frozen at −20°C (stored frozen less than 2 wk) until the cook loss and Meullenet-Owens Razor Shear Energy (MORSE) were measured as described below. Before cooking, the frozen fillets were moved to a 4°C cooler for thawing over a 24-h period. Then, CF was determined on thawed fillets as previously described. All fillets were cooked on raised wire racks in covered aluminum-lined pans in an air convection oven to an internal endpoint temperature of 76°C (Mehaffey et al., 2006). The difference between fillet weights before and after cooking was taken, and cooking loss was expressed as percentage with respect to the initial weight. After cooking, the fillets were cooled to room temperature, individually wrapped in aluminum foil, and stored overnight at 4°C, to be used for the determination of tenderness by the Meullenet-Owens Razor Shear (MORS) and Blunt Meullenet-Owens Razor Shear (BMORS) techniques (Cavitt et al., 2004; Lee et al., 2008, 2016) of the cooked samples, and the results are reported in terms of shear energy, or MORSE/Blunt Meullenet-Owens Razor Shear Energy (BMORSE) (Newton millimeter). The method uses the TA.XT Plus Texture Analyzer (Texture Technologies Corp., Hamilton, MA/Stable Micro Systems, Godalming, Surrey, UK) with a 5-kg load cell using a razor blade or blunt blade probe. Four shears at different locations on the cranial region were made perpendicular to the muscle fibers on each fillet, and the mean was calculated. The crosshead speed was 5 mm/s along with a sample shear depth of 20 mm and a trigger force of 0.1 N. The instrumental data were collected using Texture Exponent 32 version 1.0.0.92 (Stable MicroSystems, Godalming, Surrey, UK), and the macro options texture exponent was employed to determine the force and energy values from the force-distance curves. The MORS force (Newton) and MORSE (Newton millimeter) and the BMORS force (Newton) and BMORSE (Newton millimeter) were determined and used as instrumental predictors of meat tenderness.

Statistical analysis

The data were analyzed using an analysis of variance with the WB categories as treatments: normal (score 0), mild (score 1), moderate (score 2), and severe (score 3). Least-squares means were separated with a *t* test when only 2 factors and Tukey's honestly significant difference for more than 2 comparisons at a significance $P < 0.05$ using JMP® Pro 14 (Cary, NC). The Pearson correlation was done using multivariate, and the scores were considered continuous. For the effect of freezing on CF, a mixed model (JMP Pro® 14) was used to analyze repeated measures data. Nominal logistic regression was also conducted; in this case, scores were collapsed into 2 categories: Normal (scores 0 to 1) and Severe (1.5 to 3). The covariates or continuous variables (inputs) included the carcass/meat quality parameters such as ready-to-cook weight, fillet length, fillet width, keel length, thickness, caudal length, pH, L^*, a^*, b^*, CF, cook loss, peak counts, and MORSE. The data were analyzed using nominal logistic regression procedure with JMP® Pro 14. The model will test each one of the inputs and proceed adding the next most significant input until all the significant parameters are included in the model. The results from the analysis are reported mainly as the odds ratio (OR), 95% CI, and the respective *P* values. OR is the ratio of the probability of an event of interest (e.g., probability of Normal) to the probability that the event will not occur (e.g., probability of Severe), and OR is the ratios of 2 odds comparing 2 groups. The OR indicates the increased or decreased chance of a dependent category as a result of an increase in the continuous variable by 1 unit or with a categorical variable in comparison with a reference. OR > 1 indicates an increased chance, whereas OR < 1 denotes a decreased chance. When the OR is equal to 1, there is an equal chance for the category in question and the reference category (Kuttappan et al., 2013a). The estimated probability of occurrence of the 2 degrees of WB was determined for all the categorical variables.

Results

Compression Force

Out of the 206 fillets evaluated, 45 (22%) were normal; 51 (25%) showed mild lesions of WB, 62 (30%) showed moderate lesions of WB, and 48 (23%) showed severe lesions of WB. In both the left and right sides of fillets on day of processing (day 0), CF significantly increased ($P < 0.05$) as WB score increased (Table 1), and CF was highly correlated to WB category ($r = 0.77$; Table 2). However, the right breast side had higher CF on normal, mild, and severe fillets compared to the left side within each WB category ($P < 0.05$; Table 1).

As the WB score increased on chilled or thawed breast fillets, CF also significantly increased ($P < 0.05$; Table 3). Thawed breast fillets for each WB score had a significantly lower CF compared with chilled fillets ($P < 0.05$) and resulted in CF reductions of 51% to 65% due to freezing/storage (Table 3).

Fillet dimensions

A significant increase in thickness of the fillets was observed as the severity of the WB score increased. However, the fillet length was significantly shorter ($P < 0.05$) in fillets with a severe WB score. No significant differences were noted in the cranial width, caudal width fillet, or keel length among the fillets, regardless of the WB score (Table 4). Thickness was highly correlated to WB category ($r = 0.67$), whereas other dimensions had a low and/or nonsignificant correlation to WB category (Table 2).

Table 1. Means (± standard error) of compression force[1] (N) of right and left sides of butterfly fillets varying in severity of WB categories

WB[2] Category	Chilled Left Breast Side	Chilled Right Breast Side
Normal ($n = 45$)	4.9 ± 0.54^{dB}	5.6 ± 0.51^{cA}
Mild ($n = 51$)	7.2 ± 0.51^{cB}	8.6 ± 0.48^{bA}
Moderate ($n = 62$)	9.5 ± 0.46^{bB}	10.1 ± 0.43^{bA}
Severe ($n = 48$)	14.4 ± 0.52^{aB}	15.4 ± 0.50^{aA}

[1]Compression force measured on chilled fillets on day of processing (day 0).

[2]WB = woody breast.

[a–d]Means showing difference between the columns are significantly different ($P < 0.05$).

[A–B]Means showing differences between the rows are significantly different.

Table 2. Pearson's correlation between WB scores and fillet attributes

Variable	WB Score[1]	*P* Value
Compression Force	0.77	0.001
Thickness	0.67	0.001
Cranial Width	−0.06	0.411
Caudal Width	−0.01	0.970
Keel Length	−0.04	0.548
Fillet Length	−0.15	0.031
Breast Yield	0.53	0.001
L*	0.35	0.001
a*	0.09	0.222
b*	0.23	0.001
pH	0.24	0.001
Cook Loss	0.38	0.001
MORS Force	0.03	0.671
MORSE	0.09	0.162
MORS Peak Count	0.37	0.001
BMORS Force	0.36	0.001
BMORSE	0.29	0.001
BMORS Peak Count	0.53	0.001

[1]Woody breast (WB) scores (0 to 3, normal to severe, respectively).

BMORS, Blunt Meullenet-Owens Razor Shear; BMORSE, Blunt Meullenet-Owens Razor Shear Energy; MORS, Meullenet-Owens Razor Shear; MORSE, Meullenet-Owens Razor Shear Energy.

Table 3. Means (± standard error) of compression force of the chilled and thawed breast fillet from the different WB categories

WB[1] Category	Chilled Breast Fillet[2]	Thawed Breast Fillet[3]
Normal ($n = 45$)	5.6 ± 0.51^{cA}	2.7 ± 0.19^{cB}
Mild ($n = 51$)	8.6 ± 0.48^{bA}	3.7 ± 0.18^{bB}
Moderate ($n = 62$)	10.0 ± 0.43^{bA}	3.7 ± 0.16^{bB}
Severe ($n = 48$)	15.4 ± 0.49^{aA}	5.4 ± 0.19^{aB}

[1]WB = woody breast.

[2]Compression force was measured on right fillets on day of processing (day 0).

[3]Compression force was measured on right fillets after frozen storage and 24 h of thawing (thawed breast fillet).

[a–d]Means showing difference between the columns are significantly different ($P < 0.05$).

[A–B]Means showing differences between the rows are significantly different ($P < 0.05$).

Meat quality

Cook loss (percent) of fillets significantly increased as severity of WB increased ($P < 0.05$) (Table 5). No significant differences were observed on MORS force

Table 4. Means (± standard error) of the measurements (mm) of chilled butterfly breast fillet by WB category

WB[1] Category	Thickness (mm)	Cranial Width (mm)	Caudal Width (mm)	Keel Length (mm)	Fillet Length (mm)
Normal (*n* = 45)	39.3 ± 0.62[d]	149.3 ± 1.85	168.2 ± 1.82	143.2 ± 1.66	185.1 ± 1.45[a]
Mild (*n* = 51)	42.8 ± 0.59[c]	149.8 ± 174	166.7 ± 1.71	139.9 ± 1.56	182.5 ± 1.36[ab]
Moderate (*n* = 62)	47.1 ± 0.55[b]	147.6 ± 1.63	168.0 ± 1.60	143.7 ± 1.46	184.1 ± 1.27[ab]
Severe (*n* = 48)	49.6 ± 0.60[a]	147.6 ± 1.79	167.9 ± 1.76	139.5 ± 1.60	179.7 ± 1.40[b]

[1]WB = woody breast.

[a–d]Means showing different letters in each score are significantly different ($P < 0.05$).

Table 5. Evaluation of effect of WB category on meat quality and processing parameters in broiler chickens

WB[1] Category	Normal (n = 45)	Mild (n = 51)	Moderate (n = 62)	Severe (n = 48)	MSE
Meat Quality					
Compression force (N)	5.28[d]	7.89[c]	9.79[b]	15.01[a]	0.73
Cook loss (%)	24.5[c]	26.3[bc]	28.6[ab]	30.2[a]	0.36
MORS force (N)	15.10	14.86	14.90	15.56	1.49
MORSE (N.mm)	210.67[ab]	205.68[b]	209.41[ab]	223.03[a]	5.58
MORS peak count	9.5[b]	9.7[b]	10.7[b]	12.9[a]	1.66
BMORS force (N)	20.00[b]	19.24[b]	20.92[b]	25.46[a]	2.14
BMORSE (N.mm)	267.17[b]	252.63[b]	277.42[b]	331.29[a]	7.81
BMORS peak count	5.1[c]	6.4[b]	7.1[a]	7.7[a]	1.23
pH	5.77[b]	5.82[ab]	5.84[ab]	5.86[a]	0.33
*L**	53.99[c]	54.37[bc]	55.42[ab]	56.41[a]	1.56
*a**	3.16	3.39	3.58	3.76	1.31
*b**	6.06[b]	6.64[ab]	7.73[a]	7.74[a]	1.75
Processing					
Bird weight (kg)	3.78[b]	3.85[b]	4.03[a]	4.08[a]	0.59
Carcass (kg)	3.00[b]	3.06[b]	3.23[a]	3.29[a]	1.71
Breast yield (%)	30.7[b]	31.5[b]	32.9[a]	33.7[a]	1.35

[1]WB = woody breast.

[a–c]Means showing different letters in each score are significantly different ($P < 0.05$).

BMORS, Blunt Meullenet-Owens Razor Shear; BMORSE, Blunt Meullenet-Owens Razor Shear Energy; MORS, Meullenet-Owens Razor Shear; MORSE, Meullenet-Owens Razor Shear Energy; MSE, mean square error.

($P > 0.05$); however, fillets with severe WB score had the highest ($P < 0.05$) MORS peak count, BMORS force, and BMORSE compared to moderate, mild, and normal fillets, which did not differ from each other ($P > 0.05$; Table 5). Severe and moderate fillets also had higher BMORS peak count compared to other categories, and normal fillets had the lowest BMORS peak count ($P < 0.05$). The pH of breast fillets increased as WB severity increased; severe WB had higher pH ($P < 0.05$) than normal fillets, while mild and moderate WB fillets were intermediate (Table 5). Moderate and severe fillets had higher *L** and *b** values ($P < 0.05$) than normal fillets, and mild fillets were intermediate. At processing, broilers with moderate and severe WB had higher live weight, carcass weight, and breast yield compared to broilers with normal or mild WB fillets ($P < 0.05$).

Significant and positive correlations were observed between WB score and CF, thickness, fillet length, breast yield, *L**, *b**, pH, cook loss, MORS peak count, as well as BMORS force, BMORSE, and BMORS peak count (Table 2). All other parameters had nonsignificant correlations.

The nominal logistic model obtained in the present study showed the main carcass and meat quality factors that were significantly ($P < 0.05$; Table 6) associated with severe WB. These factors include cranial thickness, *L** value, fillet length, breast weight, and caudal width. The *L** value (which indicates lightness) had the highest OR value influence on the occurrence of severe fillets (OR 1.30; 95% CI 1.07–1.59), followed by cranial thickness (OR 1.29; 95% CI 1.14–1.49), indicating that, as the *L** value or cranial thickness of the fillets increases, there is a greater probability that it could have a severe degree of WB (Table 6).

Table 6. OR, 95% CI, and the probability (*P*) level for variables in the model of severe WB or normal fillets

Variables	OR	95% CI	P Value
Thickness	1.29	1.14–1.49	<0.0001
Caudal Width	0.91	0.86–0.96	0.0008
Fillet Length	0.84	0.77–0.91	<0.0001
Breast Weight	1.02	1.01–1.03	<0.0001
L*	1.30	1.07–1.59	0.009

OR, odds ratio; WB, woody breast.

Discussion

Compression Force

Subjective scoring of fillets can be done based on a butterfly or single fillet (right or left) in research and in plants for sorting purposes. CF of the left side and right side of the breast fillet were significantly different, with the right side of the breast having higher CF than the left side ($P < 0.05$; Table 1). The reason that the right side was higher than the left side is unknown. However, the differences between each WB category were greater than the differences due to side (left vs. right). With either side, significant differences ($P < 0.05$) between WB categories were still present. The CF was also highly correlated to WB category, which supports the high correlations reported by Sun et al. (2018).

The reduction in CF between chilled (day of processing, day 0) and thawed (after freeze-thaw cycle) (CF chilled > CF thawed; Table 3) may be due to the freezing process and/or due to changes that occur simply because of aging. During freezing, ice crystals form in the meat and can lead to the loss of membrane strength and subsequent structural damage (Leygonie et al., 2012). Though freezing should halt most changes that normally occur in postmortem aging, the time required to freeze and then time to thaw would allow some aging to occur. Substantial changes in CF when fillets were stored multiple days (at 4°C) have been previously reported (Sun et al., 2018; Hasegawa et al., 2020). Sun et al. (2018) reported approximately 30% to 60% reduction from day 0 to days 3 or 4. Accounting for the time to freeze and time to thaw, the fillets in this study would be an equivalent of 3 to 4 days of aging (minus the frozen storage time). In the current study, 51% to 65% reductions in CF were observed, which would be similar to reductions observed by Sun et al. (2018) in a similar aging period. Bowker and Zhuang (2019) also reported that the freeze-thaw cycle resulted in a softening effect on fillets with varying degrees of WB severity. It is important to note that, although a softening effect of the raw fillets may be observed due to freezing and/or aging, the shear characteristics may not be impacted, as was observed with the BMORS results in this study and further supported by results from Bowker and Zhuang (2019). Further research is needed to determine the effect of freezing alone.

Meat quality

WB has negative implications for meat quality (Tijare et al., 2016). The pH was significantly different ($P < 0.05$) between normal and severe WB, and mild and moderate WB fillets were intermediate (similar to both normal and severe, $P > 0.05$; Table 5). This trend was also observed in previous studies (Dalle Zotte et al., 2017; Kuttappan et al., 2017; Xing et al., 2017; Cai et al., 2018), but no differences were reported in many other studies (Mudalal et al., 2015; Trocino et al., 2015; Soglia et al., 2016; Wold et al., 2017; Chen et al., 2018; Dalgaard et al., 2018). However, L^* value in this study increased with WB scores, indicating that paleness increased as WB severity increased (Table 5), which is in agreement with previous research related to WB (Dalle Zotte et al., 2017; Wold et al., 2017; Cai et al., 2018). In this study, the OR was high for L^* value, suggesting that as L^* increases, the chances of WB increase as well (Table 6). Other factors may be involved in increasing L^* values in breast fillets that are not related to WB. Owens et al. (2000) and Woelfel et al. (2002) reported that increased L^* values in poultry meat were related to low pH and to pale, soft, and exudative meat, which has different characteristics than WB (Tijare et al., 2016). Similar to L^* values, the b^* values of fillets increased with WB severity, indicating that yellowness increased (Table 5), which is in agreement with previous research (Tasoniero et al., 2016; Kuttappan et al., 2017; Baldi et al., 2018). Negative effects were also noted with cook loss (percent), such that fillets that had severe WB scores lost more water during the cooking process (Table 5), which is in agreement with previous studies (Mudalal et al., 2015; Trocino et al., 2015; Soglia et al., 2016; Tasoniero et al., 2016; Tijare et al., 2016; Xing et al., 2017; Dalgaard et al., 2018). Overall, the occurrence of different degrees of WB were associated with changes in pH, color L^* and b^* values, cook loss, MORS peak count, BMORS force, BMORSE, and BMORS peak count (assessment of texture quality) (Table 5). These data confirm the negative impact of WB on poultry meat quality.

Fillet dimensions

In recent years, myopathies have caused significant economic losses to the poultry industry due to lost yield and value as a result of consumer complaints and the negative impact on the quality of additional processed poultry meat products (Kuttappan et al., 2016). WS is a disorder characterized by the occurrence of white striations parallel to muscle fibers on breast, thigh, and tender muscles of broilers, whereas WB is characterized by having a distinct hardness of the muscle associated with histological, compositional, and quality changes (Sihvo et al., 2014; Tijare et al., 2016; Griffin et al., 2018; Zhuang and Bowker, 2018). These myopathies have also been moderately to highly correlated to larger broilers (live or carcass weight) and high breast yield (Kuttappan et al., 2012a, 2013b; Mudalal et al., 2015; Alnahhas et al., 2016; Chatterjee et al., 2016; Zambonelli et al., 2016; Dalle Zotte et al., 2017; Xing et al., 2017; Dalgaard et al., 2018). Results from the nominal logistic model indicate that the factors that are most predictive are related to fillet dimensions along with color (Table 6). Thickness (of breast) was highly correlated to WB scores ($r = 0.67$, $P < 0.0001$; Table 2) and had high OR, suggesting that, as thickness increases, the probability of WB increases. Previous research has shown that fillet thickness had a much greater impact on fillet weight compared with length and width of the fillet (Lubritz, 1997; Griffin et al., 2018), and generally, higher degrees of WS and WB are associated with heavier or thicker fillets (Kuttappan et al., 2012a, 2013b; Mudalal et al., 2015; Alnahhas et al., 2016; Kuttappan et al., 2017). Similarly, Griffin et al. (2018) reported that models using breast length, width, thickness, and yield and *P. minor* (tender) width and yield were most predictive of WB in broilers.

Conclusion

Meat quality differences were evident among the WB categories, differences in CF were observed between right and left fillets, and freezing/storage decreased hardness of fillets. Breast fillet dimensions along with L^* value may potentially be used to identify WB, and this model of prediction of WB could be used in the industry to select the different WB categories in the development of sorting methods. In processing plants, the capability of obtaining these breast measurements is feasible, especially using noncontact methods, which would be beneficial. However, more research would be needed to adjust these models based on carcass sizes being processed.

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