Characteristics and incidence of broiler chicken wooden breast meat under commercial conditions in China

T. Xing,[*,1] X. Zhao,[†,1] L. Zhang ⬡,[*] J. L. Li,[*] G. H. Zhou,[†] X. L. Xu ⬡,[†] and F. Gao[*,2]

[*]*College of Animal Science and Technology; Key Laboratory of Animal Products Processing, Ministry of Agriculture; Key Laboratory of Meat Processing and Quality Control, Ministry of Education; Jiangsu Collaborative Innovation Center of Meat Production and Processing, Quality and Safety Control, Nanjing Agricultural University, Nanjing 210095, China; and [†]College of Food Science and Technology, Nanjing Agricultural University, Nanjing 210095, China*

ABSTRACT Wooden breast (WB) has emerged as a dramatically increasing myopathy in the poultry industry over the past few years. The objective of this study was to investigate the incidence of WB in a Chinese commercial broiler processing plant, and the consequences on quality attributes, textural properties, and sensory traits. A total of 1,135 breast fillets were collected at the deboning line and assigned to normal, mild, moderate, and severe WB categories by tactile evaluation. The proportion affected by WB was approximately 61.9%. WB fillets appeared heavier and thicker than normal fillets. The degree of WB myopathy was highly correlated with fillet weight and thickness. The meat quality characteristics of cooking loss and purge loss increased along with increasing severity of WB myopathy. Compression tests of raw meat revealed higher cutting strength and shear values for WB. In cooked meat, only severe WB fillets exhibited elevated hardness and chewiness. Finally, moderate and severe WB fillets affected the sensory evaluation by consumers owing to their impaired general appearance, texture, and drip loss. The results suggested that a high proportion of WB broiler fillets would cause detrimental losses to the poultry meat retailing and processing industry.

Key words: broiler, wooden breast, meat quality, sensory evaluation

INTRODUCTION

Driven by the growing demand for poultry meat, intensive genetic selection and feeding optimization in broiler production have resulted in a faster growth rate and increased breast yields worldwide over past decades (Petracci et al., 2015). However, this selection has been generally recognized to cause defects in the appearance and functionalities of individual breast fillets, leading to huge economic losses to the modern poultry industry. Wooden breast (**WB**) myopathy has been identified as an emerging quality defect. Macroscopically, WB is characterized by palpably hard, pale ridge-like bulges at the caudal end, along with clear viscous fluid, small hemorrhages, and white striping, that may occur separately or together. Histologically, WB lesions show polyphasic myodegeneration characterized by degenerative and atrophic fibers, vacuolar degeneration, occasional regeneration, mononuclear cell infiltration, interstitial inflammation, and accompanied fibrosis and lipidosis (Sihvo et al., 2014).

Due to the visual defects and unpleasant texture, consumers have a low acceptance of WB fillets as raw meat products. Moreover, the impaired functional properties caused by the increased fat and connective tissue and the loss of functional proteins limit its utilization in manufacturing valuable products (Mudalal et al., 2015; Xing et al., 2017a). Therefore, WB fillets are usually downgraded to use for ground products or even for animal feed (Kuttappan et al., 2016).

Wooden breast myopathy has been reported around the world, and the occurrence has increased dramatically over the past few years. Dalle Zotte et al. (2017) observed WB in 53.2% of 474 carcasses of high-breast-yield chickens at a poultry-meat cutting facility in Italy. Owens (2014) also reported that up to 50% of individuals were affected in the United States (**US**). The recent occurrence of WB in flocks raised using commercial diets was observed to be as high as 96.1% (Tijare et al., 2015). By conservative estimates, the incidence of severe WB could lead to an annual economic loss of more than $200 million in the US (Kuttappan et al., 2016). Based on a 0.8% incidence rate of WB resulting in condemned meat, the loss in the Brazilian poultry industry

is estimated to be in excess of $70,000 per day (Zanetti et al., 2018).

To date, the occurrence of WB in broilers in China has not been established. Therefore, this study was designed to evaluate the incidence and characteristics of WB in a major Chinese commercial broiler processing plant.

MATERIALS AND METHODS

Experiment I

Pectoralis Major Selection and Scoring A total of 1,135 broiler breast fillets (pectoralis major muscles) from the right side were collected over 3 replicate samplings from a single major processing plant (Yike Inc., Suqian, Jiangsu, China) in China on the day of slaughter. Broilers were slaughtered according to standard industrial practices. Briefly, slaughter consisted of electrical stunning, bleeding, scalding, evisceration, chilling, and deboning. Fillets were randomly collected from a deboning line (at approximately 3 h postmortem) and subjectively assessed for degree of hardness (WB) based on tactile evaluation according to the criteria of Tijare et al. (2015) as follows: 0 = fillets that were flexible throughout (normal), 1 = fillets that were hard primarily in the cranial region but otherwise flexible (mild); 2 = fillets that were hard throughout but flexible in the mid to caudal region (moderate); 3 = fillets that were extremely hard and rigid throughout from cranial region to caudal tip (severe). Immediately after scoring, each fillet was individually weighed, and subjected to morphometry measurements, assessment of meat color, and pH analyses.

Morphometric Measurements Morphometric measurements of fillets were determined using an electronic caliper according to Mudalal et al. (2015) with slight modifications. Briefly, the longest distance from the cranial to the caudal end of the fillet was measured as length, whereas width as taken to be the longest dimension from side to side in the middle of the fillet. Top height (H_1) was measured at the highest area in the cranial area, middle height (H_2) was measured at the midpoint of the fillet's length, and the bottom height (H_3) was determined as the vertical distance from the caudal area by 25 mm in the dorsal direction. All the geometrical measurements were recorded in mm.

Meat Color and pH Measurements Meat color (lightness, redness, and yellowness) was assessed in triplicate at the cranial section of the dorsal surface using a chromameter (Minolta CR400; Konica Minolta Company, Tokyo, Japan) as described in our previous study (Xing et al., 2017b). Subsequently, we measured pH value by inserting a probe electrode into the cranial part of the fillet using a portable glass electronic pH meter (Hanna Instrument Company, Porto, Portugal) as reported previously by Xing et al. (2015).

Experiment II

For the purpose of characterization analysis, a total of 96 fillets (24 fillets in each severity category) were categorized based on their WB scores. Samples were tagged, placed in polyethylene bags packed on ice, transported to the laboratory, and held at 4°C. At 24 h postmortem, the fillets were subjected to meat quality assessment, instrumental analysis, and sensory evaluation. Meat color and pH value were measured as described above.

Purge Loss Fillets from each severity category were weighed before vacuum packaging. After 24 h of refrigerated storage, fillets were patted dry using a Whatman filter paper and reweighed. Purge loss was measured by calculating the percentage of weight loss during storage.

Cooking Loss Cooking loss was measured using the whole fillets according to Brambila et al. (2018) with slight modifications. All fillets were weighed before wrapping in individual retort pouches and cooking. Samples were cooked ventral side up in a water bath at 83°C until the thickest part of the fillet reached 76°C. 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 on the following day.

Warner–Bratzler Shear Force After the cooking loss measurement, the meat samples were further used for a shear force value test using the Warner–Bratzler shear method according to Maxwell et al. (2018). Briefly, duplicate strips (1 cm × 1 cm × 3 cm) were taken from the cranial section of each fillet, with fibers parallel to the long axis, and each strip was sheared perpendicular to the axis of muscle fibers twice using a texture analyzer (C-LM3B; Northeast Agricultural Univ., Harbin, China). The peak force (N) was recorded as the shear value.

Compression Force Compression force was determined using the methods of Soglia et al. (2017) and Sun et al. (2018) with modifications. This method was accommodative for analysis on a whole fillet rather than a cut of a fillet. Briefly, fillets were compressed to 40% of the initial height with a speed of 4 mm/s using a 6 mm flat probe on a texture analyzer (XT plus, Stable Micro Systems Ltd., Godalming, UK). The trigger force was set at 5 g, probe height was set at 55 mm (higher than the thickest fillet sample), pre- and post-probe speeds were both 10 mm/s, and the test speed of the probe was 5 mm/s. The probe was oriented perpendicular to the muscle fiber direction. Compression analysis was performed 3 times on different areas of the cranial section, the average value was taken as the result.

Textural Profile Analyses Cooked samples were subjected to textural profile analyses using a texture analyzer (XT Plus, Stable Micro Systems Ltd., Godalming, UK). A 25 mm diameter core, perpendicular to the fillet surface, was removed from the cranial portion according to Chatterjee et al. (2016). Portions corresponding to the ventral (surface-side) sides of all

Table 1. Effect of wooden breast condition on morphological characteristics and meat quality attributes of broiler breast fillets evaluated at the deboning line (experiment I, n = 1135).

Parameter	Breast meat category				s.e.m.	Significance
	Score 0	Score 1	Score 2	Score 3		
n.	432	353	264	86		
Weight (g)	190[d]	230[c]	251[b]	276[a]	2	<0.001
Length (mm)	155.6[b]	162.1[a]	162.9[a]	163.4[a]	0.6	<0.001
Width (mm)	83.6[c]	87.2[b]	87.8[a,b]	88.9[a]	0.5	<0.001
Top height (H$_1$, mm)	27.9[d]	32.8[c]	35.9[b]	38.7[a]	0.3	<0.001
Middle height (H$_2$, mm)	22.6[d]	24.9[c]	30.5[b]	33.7[a]	0.2	<0.001
Bottom height (H$_3$, mm)	14.4[d]	17.0[c]	21.1[b]	23.8[a]	0.2	<0.001
Lightness (L*$_{3h}$)	48.99[b]	49.39[a,b]	49.32[a,b]	49.65[a]	0.18	0.010
Redness (a*$_{3h}$)	3.14[b]	3.32[b]	3.23[b]	3.87[a]	0.07	<0.001
Yellowness (b*$_{3h}$)	6.80	7.16	6.87	7.16	0.14	ns
pH$_{3h}$	6.22[c]	6.25[b,c]	6.28[b]	6.39[a]	0.02	<0.001

[a–d]Means within the same row followed by different superscript letters differ significantly ($P < 0.05$).

samples were trimmed to a height of 20 mm. A double compression cycle test was set to 50% compression of the original height, and the elapsed time was set to 1 s. The speed used for the test was 5 mm/s with the trigger force of 5 g.

Sensory Evaluation To assess consumer acceptability and purchase intention of normal and WB fillets, a sensory evaluation was carried out according to the modified procedures of Droval et al. (2012), but based on the Chinese standard GB/T 22210–2008 (criterion for sensory evaluation of meat and meat products) and GB 16869–2005 (Fresh and frozen poultry product). The sensory evaluation was carried out with 3 replications. For each replicate, we chose between 30 and 40 consumers of different ages and sexes at the point of purchase in local supermarkets in Nanjing to evaluate the samples for sensory attributes and purchase intention. Raw breast fillets were conditioned in polyethylene trays, covered with plastic film, and refrigerated. Each fillet was randomly encoded with a 3 digit number and presented in a random order. All panelists were asked to evaluate the following attributes: general appearance, color, texture, and drip loss. In addition, they were asked to indicate their degree of acceptance for the fillet and to give reasons for their purchasing decisions. A 9-point hedonic scale was used to score these attributes: 1, dislike extremely; 2, dislike very much; 3, dislike moderately; 4, dislike slightly; 5, neither like nor dislike; 6, like slightly; 7, like moderately; 8, like very much; 9, like extremely (Meilgaard et al., 2007).

Statistical Analysis

For experiment I, data were analyzed as a completely as a completely randomized design using the GLM procedure (SAS Inst. Inc., Cary, NC, 2003), with WB score as the main effect and individual fillets as the experimental unit. Pearson correlation coefficients were used to characterize the relationship among variables, and the results were presented as a heat map using the Heml Heatmap Illustrator software 1.0 (Wuhan, Hubei, China). For experiment II, data analysis was carried out with 1-way ANOVA and a Duncan's multiple range test using SAS 9.12 (SAS Institute Inc., Cary, NC, 2003). Wooden breast score was included in the model as the main effect; individual fillets and experimental replication were treated as random effects. Differences were considered significant at $P < 0.05$, and the results are presented as the mean and SEM.

RESULTS AND DISCUSSION

Experiment I: WB Incidence, Morphological Characteristics, and Meat Quality Attributes at the Deboning Line

The numbers of fillets in each breast meat category from a total 1,135 broiler breast right fillets are presented in Table 1. The incidence of WB was 61.9%, with 31.1% scored as 1 (mild), 23.2% scored as 2 (moderate), and 7.6% of fillets scored as 3 (severe). The results of the morphometric analysis indicated that breast fillet weights differed significantly between severity categories of WB ($P < 0.05$), with the heaviest fillets in group 3. This was in agreement with previous studies, which demonstrated that WB affected fillets exhibited higher weights than normal fillets (Mudalal et al., 2015; Tasoniero et al., 2016). Genetic selection of broilers for high growth rate and breast yield exceeds physiologically sustainable parameters, leading to myodegeneration and increased risk of myopathies. It has been extensively documented that heavier broilers exhibit a higher incidence of myodegeneration. Kuttappan et al. (2017) showed that the severe WB was associated with increased weight and age of broilers. The occurrence and the severity of WB observed in this study were lower than previously reported by Tijare et al. (2015). However, it should be noted that broilers used in the current study were raised in commercial houses, and the average live weight was 2.56 kg at the slaughter age of 42 D. We speculated that the incidence and severity of WB might be increased as the broilers grew heavier and older.
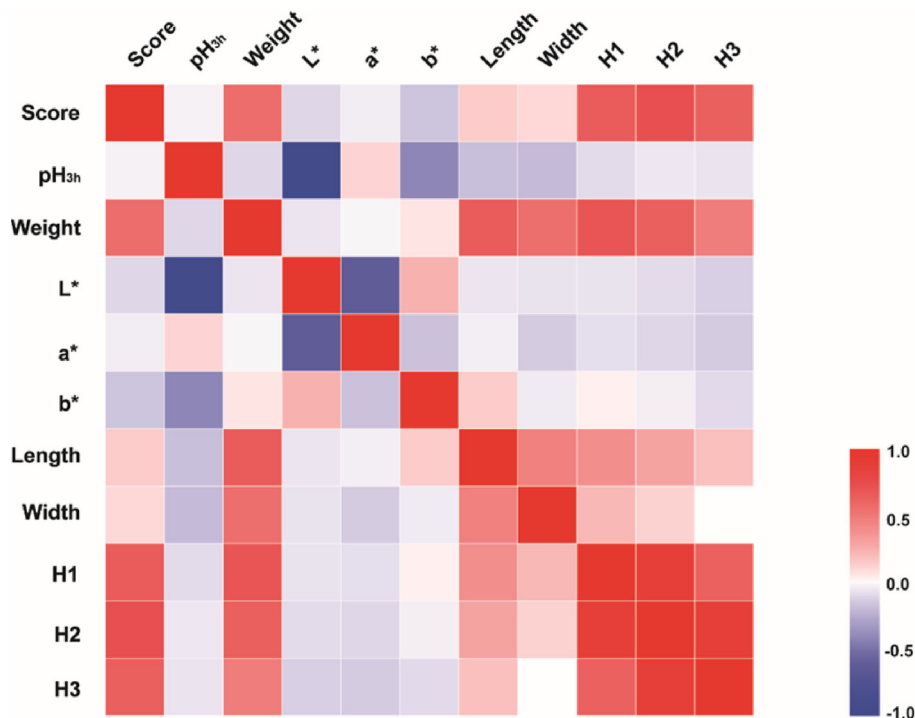
Figure 1. Heat map illustrating correlation coefficient between wooden breast scores, morphological characteristics, and meat quality attributes. Red means positive correlation, whereas blue represents negative correlation.

Wooden breast fillets appeared to be longer and wider than normal fillets, and they also had greater thickness at the top (H_1), middle (H_2), and bottom (H_3) positions ($P < 0.05$). Our results support the previous report of Lubritz (1997), who found increased length, width, and thickness in heavier fillets. Thickness increased significantly with the severity of WB myopathy ($P < 0.05$). Only fillets affected by severe WB myopathy exhibited a higher lightness (L^*) and redness (a^*) value compared with normal fillets ($P < 0.05$); similar results were found by Aguirre et al. (2018). Mutryn et al. (2015) found that the myoglobin gene was overexpressed in individuals with the WB myopathy caused by fiber-type switching in response to myodegeneration, which might contribute to the red appearance of the meat. Whereas the paler color observed in some fillets with severe WB was not consistently observed due to the concomitant effects of white striping (Soglia et al., 2015). We also found higher pH3h values in moderate and severe WB fillets than in normal ones ($P < 0.05$), which could be ascribed to reduced glycogen content and decreased levels of glycolytic enzymes (Abasht et al., 2016).

Experiment I: Correlation Coefficient Analysis

Correlation coefficients for WB scores, morphological characteristics, and meat quality attributes are illustrated in Figure 1 using a heat map. There was a significant positive correlation ($r = 0.64$) between WB score and fillet weight ($P < 0.01$). We further investigated the distribution of fillet weights in broiler breasts used in our current study. The range of the fillet weight varied greatly from 110 to 352, and the distribution was almost normal (Figure 2A). There were increases in the incidence of WB, and the severity of WB as fillet weight increased (Figure 2B). This observation demonstrates that the level of association between the occurrence of WB myopathy and the severity degree appears to increase with the body weight of the broilers. Meanwhile, broilers with high weight gain at the same slaughter age may have a predisposition to develop WB myopathy. These results further support the viewpoint that increased fillet weight and body weight are the main predisposing factors for high incidence and severity of WB myopathy (Kuttappan et al., 2017). In addition, WB score had significant positive correlations with fillet thickness ($P < 0.01$), which was consistent with the findings of Kuttappan et al. (2013), who indicated that myodegeneration was associated with thicker fillets. These results further supported the hypothesis that selection for rapid growth and breast muscle yield increases the risk of emerging myopathies (Petracci et al., 2015).

Currently, the detecting and sorting of fillets affected by WB rely primarily on visual and palpatory inspection, though the lack of standardized scoring scales or criterion makes it difficult to compare the worldwide reports of this myopathy. This constitutes an urgent challenge for the modern industry as the incidence of WB continues to grow (Kuttappan et al., 2016). Herein, we found that WB score was significantly correlated
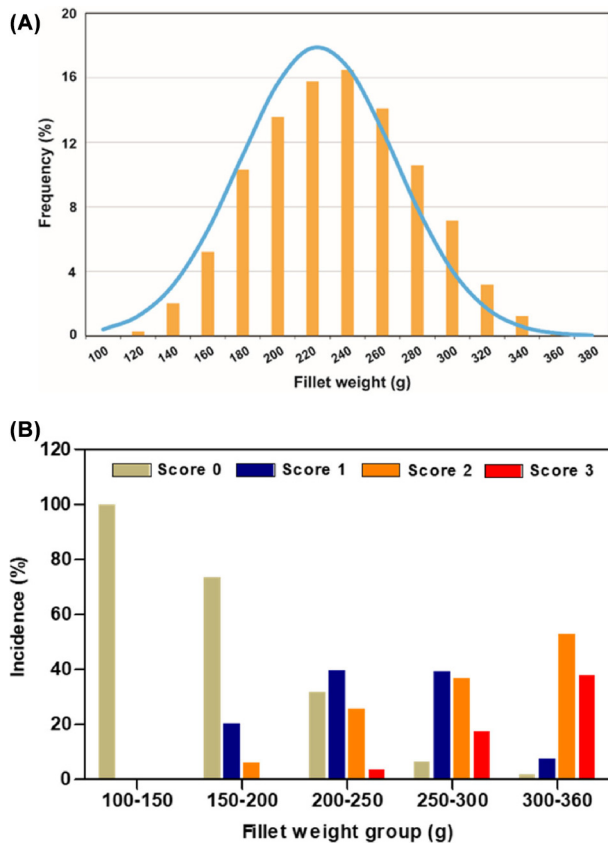
Figure 2. (A) Distribution of fillet weights in broiler breasts. (B) Incidence of wooden breast condition categories by fillet weight (n = 1135).

with weight and thickness of fillets; these parameters have potential for predicting and discriminating WB fillets. Therefore, we further evaluated the relationship between fillet weight and thickness. It was noticed that weight and thickness had a strong linear relationship with each other and with the 4 score variables describing the severity of WB myopathy (Figure 3). Brewer et al. (2012) suggested that weight had a much greater impact on thickness than did length and width of fillets. By examining the thickness distribution and the WB scores, we demonstrated that fillets with greater thickness, regardless of the measurement position, have a greater incidence of WB and more severe WB myopathy. However, we also found varied correlation coefficients between fillet weight and thickness among the different WB scores. H_1, in the cranial position, had the greatest correlation coefficient, followed by H_2, in the central position. H_3, in the caudal position, had the lowest correlation coefficient that was only significant in fillets with moderate or severe WB. Previous work demonstrated that, due to the inconsistency of myodegeneration and nonuniform regeneration and fibrosis, the muscle architecture of fillets with WB is not homogeneous (Clark and Velleman, 2016); this finding could partially explain our results. However, the low correlation coefficient observed suggests that use of fillet weight and thickness alone is insufficient for WB scoring or sorting.

Experiment II: Meat Quality, Measurements of Textural Properties and Sensory Evaluation

Meat quality attributes of broiler breast fillets are indicated in Table 2. Wooden breast occurs in differing levels of severity, which has implications for meat quality (Tijare et al., 2015; Chatterjee et al., 2016). Meat color and pH measured at 24 h postmortem were in accordance with those evaluated at the deboning line, with higher redness and pH values in severe WB fillets than normal fillets ($P < 0.05$). However, we failed to find consistently greater lightness in severe WB fillets, which might be caused by the concomitant effects of white striping (Soglia et al., 2015). The cooking loss of WB fillets was significantly greater than in normal fillets; similar results have been found in previous studies (Mudalal et al., 2015; Xing et al., 2017a). Cooking loss increased as the severity of WB increased ($P < 0.05$). Furthermore, we observed a higher purge loss in WB fillets compared with normal fillets ($P < 0.05$), supporting the results of Sun et al. (2018), who also indicated that the cumulative drip loss of a whole fillet was higher for WB. Tenderness is one of the most important eating qualities for Chinese consumers (Zhang et al., 2017). The Warner–Bratzler shear force was similar between normal and WB fillets in the current study, regardless of WB severity ($P > 0.05$); this finding is similar to those of previous studies (Dalgaard et al., 2018; Maxwell et al., 2018). However, it should be noted that the conclusions of studies regarding the shear force of WB are inconsistent. Tasoniero et al. (2016) observed a higher shear force in WB fillets, whereas Brambila et al. (2018) found that shear force of WB fillets was lower than that of normal fillets. The irregular and diffuse accumulation of connective tissue and intramuscular fat in the interstitial fraction are thermally labile which contributes to the comparable shear force values of cooked samples (Soglia et al., 2017). More importantly, we speculate that WB mainly occurs during the initiation stage of myopathic lesion development; therefore, the deposition and remodeling of extracellular matrix is not strong and has little impact on meat tenderness (Velleman and Clark, 2015; Griffin et al., 2018). The discrepancy of shear force might also be caused by differences in meat status (i.e., fresh vs. frozen) of raw fillets or cooking procedures (Tasoniero et al., 2016).

The results of the compression test of raw meat and the textural profile analysis of cooked meat are shown in Table 3. Compression tests have been widely used to study the mechanical properties of raw meat, single muscle fibers, and perimysial connective tissue (Christensen et al., 2000; Soglia et al., 2015; Sun et al., 2018). Cutting strength (maximum rupture force by the cross-section of the fillet) and work of shear (area under the deformation curve) gradually increased with increasing severity of WB myopathy, with the highest values in group 3 ($P < 0.05$). Wooden breast fillets had
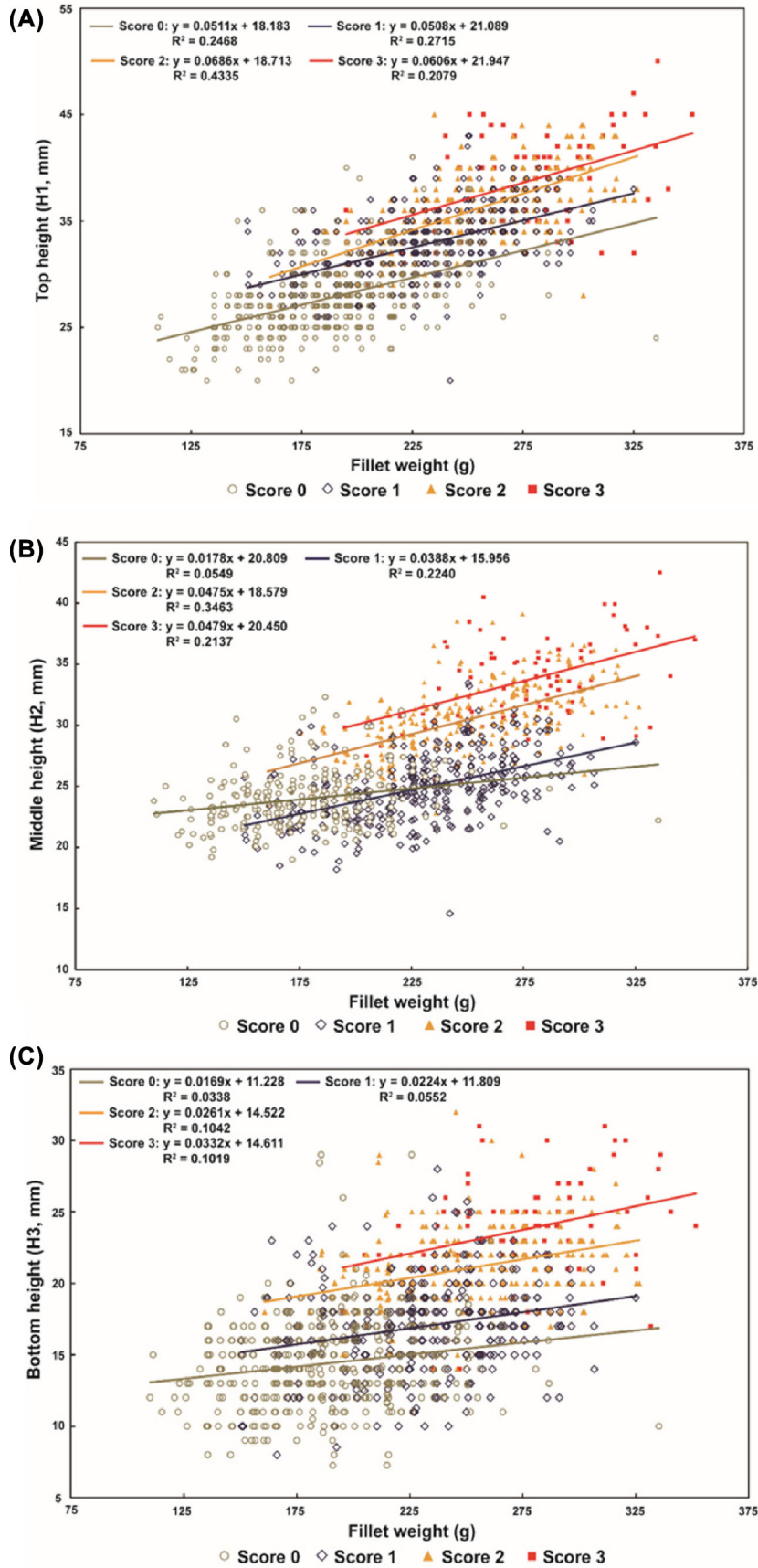
Figure 3. Relationships between fillet weight and top height (A), middle height (B), and bottom height (C).

Table 2. Effect of wooden breast condition on meat quality attributes of broiler breast fillets evaluated at 24 h postmortem (experiment II, n = 24 each).

	Breast meat category					
Parameter	Score 0	Score 1	Score 2	Score 3	s.e.m.	Significance
Lightness ($L^*_{24 h}$)	50.91	50.28	50.32	50.93	0.61	ns
Redness ($a^*_{24 h}$)	1.34[b]	1.96[a,b]	1.9[a,b]	2.29[a]	0.21	0.046
Yellow ($b^*_{24 h}$)	7.16	7.18	7.27	7.74	0.41	ns
pH_{24h}	5.86[b]	5.95[a,b]	5.98[a,b]	6.05[a]	0.04	0.025
Purge loss (%)	0.57[c]	0.82[b]	1.33[a]	1.43[a]	0.07	<0.001
Cooking loss (%)	19.81[d]	21.83[c]	24.81[b]	27.10[a]	0.57	<0.001
Shear value (N)	29.2	29.0	27.9	28.8	1.4	ns

[a–d]Means within the same row followed by different superscript letters differ significantly ($P < 0.05$).

Table 3. Effect of wooden breast condition on textural properties of raw and cooked broiler breast fillets (experiment II, n = 24 each).

	Breast meat category					
Parameter	Score 0	Score 1	Score 2	Score 3	s.e.m.	Significance
Raw meat						
Cutting strength (N)	10.0[c]	11.7[b,c]	15.5[a,b]	16.5[a]	1.3	0.019
Distance at failure (mm)	11.6[b]	22.0[a]	22.6[a]	24.6[a]	0.9	<0.001
Work of shear (Nsec)	16.3[c]	26.5[b]	31.9[a,b]	36.5[a]	2.0	<0.001
Cooked meat						
Hardness (N)	5,309[c]	5,954[b,c]	6,491[a,b]	7,139[a]	323	0.003
Springiness	0.53	0.57	0.57	0.60	0.03	ns
Cohesiveness	0.47	0.43	0.43	0.49	0.02	ns
Gumminess	2,403	2,959	2,811	3,182	224	ns
Chewiness	1,280[b]	1,590[a,b]	1,721[a,b]	2,004[a]	160	0.048
Resilience	0.21	0.18	0.18	0.23	0.02	ns

[a–d]Means within the same row followed by different superscript letters differ significantly ($P < 0.05$).

higher distance at failure values (maximum peak height resisted by the fillet) than normal fillets ($P < 0.05$). The collagenous structures of WB fillets, caused by fibrosis, possess a high degree of inherent strength, which contributes to the tactile hardness (Sihvo et al., 2014). In addition, Clark and Velleman (2016) indicated that myodegeneration tends to affect the anterior portion of the fillets; therefore, the fibrotic response leads to the nonhomogeneous structure of WB fillets. We note that we performed the compression test in the cranial region. In addition, we confirmed the potential use of instrumental compression force for identifying and categorizing WB, similar to the suggestions of Mudalal et al. (2015) and Sun et al. (2018). For the textural properties of cooked fillets, there were significant differences in hardness and chewiness between normal and WB fillets, with the highest values in severe WB samples ($P < 0.05$). Similar characteristics were also observed by Chatterjee et al. (2016). These differences were associated with the severe histological, chemical changes in muscle fibers, and the accumulation of interstitial connective tissue (Soglia et al., 2015; Aguirre et al., 2018).

In assessing consumer acceptability and purchase intention for normal and WB fillets, the sensory evaluation of raw fillets was a more direct and reliable approach to discriminating among the effects of various
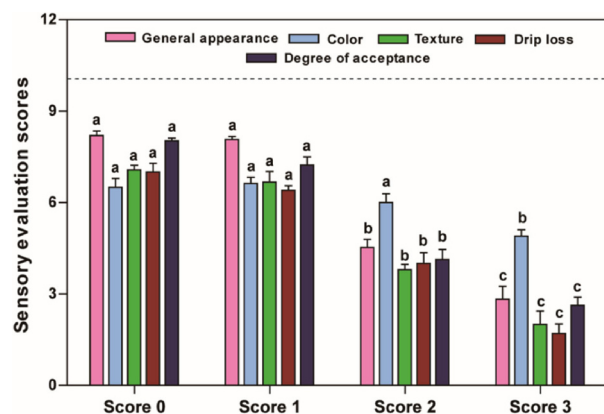
Figure 4. Sensory attributes of broiler breast fillets varied in wooden breast scores. All measurements are expressed as the mean ± SEM (n = 3) with different superscripts (a, b, c) differ significantly ($P < 0.05$).

WB levels for consumption. No significant difference evaluated was observed between score 0 and score 1 groups for all sensory attributes ($P > 0.05$), indicating mild WB myopathy would not attenuate sensory evaluation scores (Figure 4). When buying raw meat, the general appearance of the product is particularly important for consumers (Kuttappan et al., 2016). Moderate or severe WB fillets are irregularly shape, present ridge-like bulges at the caudal end, and are often

accompanied by varying degrees of white striping, viscous fluid, or even small hemorrhages (Sihvo et al., 2014). As expected, moderate and severe WB fillets had lower scores than normal and mild ones for general appearance ($P < 0.05$). Scores for texture and drip loss also decreased significantly in groups 2 and 3 ($P < 0.05$); these findings were in agreement with the above results. The undesirable visual appearance and the deteriorated quality traits contributed to the lower degree of acceptance, which further verified that the occurrence of myopathies negatively affects consumer purchases and even increases concerns about nutritional value and animal welfare of poultry products (Petracci et al., 2015).

CONCLUSIONS

Approximately 30.8% of the poultry population presented moderate to severe WB myopathies. The incidence and severity of WB myopathy was highly correlated with fillet weight and thickness. Wooden breast abnormality resulted in a deterioration in quality traits and reduced consumer acceptability. In general, these results suggest that a substantial portion of commercially processed broiler fillets can be affected by WB myopathy in China, which is likely to cause detrimental losses to the poultry meat retailing and processing industry due to the impaired water holding capacity and textural properties. Compression tests in the cranial portion of fillets have potential in identifying and categorizing WB. Further studies are needed to control these myopathies in poultry and for the development of processing strategies that can alleviate inferior quality attributes.

ACKNOWLEDGMENTS

REFERENCES

Abasht, B., M. F. Mutryn, R. D. Michalek, and W. R. Lee. 2016. Oxidative stress and metabolic perturbations in wooden breast disorder in chickens. PLoS One. 11:e0153750.

Aguirre, M. E., C. M. Owens, R. K. Miller, and C. Z. Alvarado. 2018. Descriptive sensory and instrumental texture profile analysis of woody breast in marinated chicken. Poult. Sci. 97:1456–1461.

Brambila, G. S., B. C. Bowker, D. Chatterjee, and H. Zhuang. 2018. Descriptive texture analyses of broiler breast fillets with the wooden breast condition stored at 4°C and −20°C. Poult. Sci. 97:1762–1767.

Brewer, V. B., V. A. Kuttappan, J. L. Emmert, J. F. Meullenet, and C. M. Owens. 2012. Big-bird programs: Effect of strain, sex, and debone time on meat quality of broilers. Poult. Sci. 91:248–254.

Chatterjee, D., H. Zhuang, B. C. Bowker, A. M. Rincon, and G. Sanchezbrambila. 2016. Instrumental texture characteristics of broiler pectoralis major with the wooden breast condition. Poult. Sci. 95:2449–2454.

Christensen, M., P. P. Purslow, and L. M. Larsen. 2000. The effect of cooking temperature on mechanical properties of whole meat, single muscle fibres and perimysial connective tissue. Meat Sci. 55:301–307.

Clark, D., and S. Velleman. 2016. Spatial influence on breast muscle morphological structure, myofiber size, and gene expression associated with the wooden breast myopathy in broilers. Poult. Sci. 95:2930–2945.

Dalgaard, L. B., M. K. Rasmussen, H. C. Bertram, J. A. Jensen, H. S. Møller, M. D. Aaslyng, E. K. Hejbøl, J. R. Pedersen, D. Elsser-Gravesen, and J. F. Young. 2018. Classification of wooden breast myopathy in chicken pectoralis major by a standardised method and association with conventional quality assessments. Poult. Sci. 53:1744–1752.

Dalle Zotte, A., G. Tasoniero, E. Puolanne, H. Remignon, M. Cecchinato, E. Catelli, and M. Cullere. 2017. Effect of "Wooden Breast" appearance on poultry meat quality, histological traits, and lesions characterization. Czech J. Anim. Sci. 62:51–57.

Droval, A. A., V. T. Benassi, A. Rossa, S. H. Prudencio, F. G. Paião, and M. Shimokomaki. 2012. Consumer attitudes and preferences regarding pale, soft, and exudative broiler breast meat. J. Appl. Poult. Res. 21:502–507.

Griffin, J. R., L. Moraes, M. Wick, and M. S. Lilburn. 2018. Onset of white striping and progression into wooden breast as defined by myopathic changes underlying pectoralis major growth. Estimation of growth parameters as predictors for stage of myopathy progression. Avian Pathol. 47:2–13.

Kuttappan, V., B. Hargis, and C. M. Owens. 2016. White striping and woody breast myopathies in the modern poultry industry: a review. Poult. Sci. 95:2724–2733.

Kuttappan, V. A., C. M. Owens, C. Coon, B. M. Hargis, and M. Vazquez-Añon. 2017. Incidence of broiler breast myopathies at 2 different ages and its impact on selected raw meat quality parameters. Poult. Sci. 96:3005–3009.

Kuttappan, V. A., H. L. Shivaprasad, D. P. Shaw, B. A. Valentine, B. M. Hargis, F. D. Clark, C. M. McKee, and C. M. Owens. 2013. Pathological changes associated with white striping in broiler breast muscles. Poult. Sci. 92:331–338.

Lubritz, D. L. 1997. A statistical model for white meat yield in broilers. J. Appl. Poult. Res. 6:253–259.

Maxwell, A. D., B. C. Bowker, H. Zhuang, D. Chatterjee, and K. Adhikari. 2018. Descriptive sensory analysis of marinated and non-marinated wooden breast fillet portions. Poult. Sci. 97:2971–2978.

Meilgaard, M. C., G. V. Civille, and B. T. Carr. 2007. Sensory Evaluation Techniques. 4th ed. CRC, Press, Boca Raton, FL.

Mudalal, S., M. Lorenzi, F. Soglia, C. Cavani, and M. Petracci. 2015. Implications of white striping and wooden breast abnormalities on quality traits of raw and marinated chicken meat. Animal. 9:728–734.

Mutryn, M. F., E. M. Brannick, W. Fu, W. R. Lee, and B. Abasht. 2015. Characterization of a novel chicken muscle disorder through differential gene expression and pathway analysis using RNA-sequencing. BMC Genomics. 16:1–19.

Owens, C. M. 2014. Identifying Quality Defects in Poultry Processing. Watt Poult. USA. 42–50.

Petracci, M., S. Mudalal, F. Soglia, and C. Cavani. 2015. Meat quality in fast-growing broiler chickens. World Poult. Sci. J. 71:363–374.

Sihvo, H. K., K. Immonen, and E. Puolanne. 2014. Myodegeneration with fibrosis and regeneration in the pectoralis major muscle of broilers. Vet. Pathol. 51:619–623.

Soglia, F., S. Mudalal, E. Babini, M. Di Nunzio, M. Mazzoni, F. Sirri, C. Cavani, and M. Petracci. 2015. Histology, composition, and quality traits of chicken Pectoralis major muscle affected by wooden breast abnormality. Poult. Sci. 95:651–659.

Soglia, F., J. Gao, M. Mazzoni, E. Puolanne, C. Cavani, M. Petracci, and P. Ertbjerg. 2017. Superficial and deep changes of histology, texture and particle size distribution in broiler wooden breast muscle during refrigerated storage. Poult. Sci. 96:3465–3472.

Sun, X., D. A. Koltes, C. N. Coon, K. Chen, and C. M. Owens. 2018. Instrumental compression force and meat attribute changes in woody broiler breast fillets during short-term storage. Poult. Sci. 97:2600–2606.

Tasoniero, G., M. Cullere, M. Cecchinato, E. Puolanne, and Z. A. Dalle. 2016. Technological quality, mineral profile, and sensory attributes of broiler chicken breasts affected by white striping and wooden breast myopathies. Poult. Sci. 95:2707–2714.

Tijare, V. V., F. L. Yang, V. A. Kuttappan, C. Z. Alvarado, C. N. Coon, and C. M. Owens. 2015. Meat quality of broiler breast fillets with white striping and woody breast muscle myopathies. Poult. Sci. 95:2167–2173.

Velleman, S. G., and D. L. Clark. 2015. Histopathological and myogenic gene expression changes associated with wooden breast in broiler breast muscles. Avian Dis. 59:410–418.

Xing, T., X. Xu, G. Zhou, P. Wang, and N. Jiang. 2015. The effect of transportation of broilers during summer on the expression of heat shock protein 70, postmortem metabolism and meat quality. J. Anim. Sci. 93:62–70.

Xing, T., X. Zhao, M. Han, L. Cai, S. Deng, G. Zhou, and X. Xu. 2017a. A comparative study of functional properties of normal and wooden breast broiler chicken meat with NaCl addition. Poult. Sci. 96:3473–3481.

Xing, T., X. Zhao, P. Wang, H. Chen, X. Xu, and G. Zhou. 2017b. Different oxidative status and expression of calcium channel components in stress-induced dysfunctional chicken muscle. J. Anim. Sci. 95:1565–1573.

Zanetti, M. A., D. C. Tedesco, T. Schneider, S. T. F. Teixeira, L. Daroit, F. Pilotto, E. L. Dickel, S. P. Santos, and L. R. dos Santos. 2018. Economic losses associated with wooden breast and white striping in broilers. Semina: Ciências Agrárias. Londrina. 39:887–892.

Zhang, W., B. M. Naveena, C. Jo, R. Sakata, G. Zhou, R. Banerjee, and T. Nishiumi. 2017. Technological demands of meat processing—an Asian perspective. Meat Sci. 132:35–44.