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ARTICLE

Influence of Slaughter Age on the Occurrence and Quality Characteristics of White Striping and Wooden Muscle Abnormalities

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Abstract The aim of this study was to assess the occurrence of white striping (WS), wooden breast (WB), and WS combined with WS/WB muscle abnormalities in broilers (Ross 500) at different slaughter ages (34, 41, and 48 d). In addition, the influence of these muscle abnormalities at different slaughter ages on quality characteristics (physical dimensions, pH, color index, and chemical composition) was studied. Overall occurrence of muscle abnormalities was 45%, 92%, and 100% at slaughter ages of 34, 41, and 48 d, respectively. It was found that about 39% from the occurrence of muscle abnormalities was not similar in the same bird (left and right fillets). Breast fillets affected by muscle abnormalities had significantly ($p<0.05$) higher weight than normal fillets. At slaughter age of 34 d, normal fillets had significantly higher L* (67.37 vs. 61.73 and 63.05, $p<0.05$), lower a* (3.25 vs. 4.87 and 5.18, $p<0.05$) and b* (4.02 vs. 5.20 and 5.99, $p<0.05$) than WS and WS combined with WB fillets; respectively. The changes in chemical composition due to muscle abnormalities were more significant at high slaughter age than at low slaughter age. In conclusion, the occurrence of muscle abnormalities was strongly influenced by slaughter age. Moreover, breast fillets affected by muscle abnormalities had different quality characteristics (proximate composition, color traits, and dimensions) in comparison to normal fillets.

Keywords white striping, wooden, occurrence, quality, slaughtering age

Introduction

Optimization of housing conditions and genetic selection have resulted in dramatic improvements in broiler growth rates in recent decades. This success has been effective in increasing of poultry meat production and meeting the growing demand for poultry meat (Petracci et al., 2019). On the other hand, genetic selection to improve growth rate has been associated with occurrence of several muscle abnormalities (Dransfield and Sosnicki, 1999; Mahon, 1999). Deep pectoral muscle disease, PSE-like meat (pale, soft, and exudative-like condition), white striping (WS), wooden breast (WB), and spaghetti meat are good examples of these muscle abnormalities (Bianchi et al., 2006; Petracci et al., 2019).

WS and WBs are considered the newest muscle abnormalities threatening the poultry industry because of their effect on meat quality. WS was first studied by Bauermeister et al. (2009) and Kuttappan et al. (2009) and identified by the appearance of white striation on the surface of chicken fillets parallel to the fiber directions. WB abnormality was described by the appearance of hardened and pale areas in the caudal part of the pectoral muscles in combination with polyphasic myodegeneration with fibrosis (Sihvo et al., 2014).

Previous studies generally agreed that WS and WB muscle abnormalities have negative effects on meat quality, such as a reduction in water holding capacity, color changes, a reduction in sensory perception, changes in chemical composition, and changes in texture characteristics (Kato et al., 2019; Kuttappan et al., 2009; Mudalal et al., 2014; Mudalal et al., 2015; Sihvo et al., 2014; Tasoniero et al., 2016).

The incidence of WS varied depending on different farming factors such as genotype, gender, growth rate, feed composition, and slaughter age. Petracci et al. (2013) found that high-breast yield hybrids exhibited higher incidence of WS than standard-breast yield hybrids. Birds fed with high energy diet had higher incidence of WS than birds fed with standard diet while male broilers had higher incidence of WS than females (Kuttappan et al., 2013a). Several studies evaluated the incidence of WS and WB abnormalities under different farming conditions. In this context, Petracci et al. (2013) found that the incidence of WS in some slaughterhouses in Italy was 12%. Alnahhas et al. (2016) showed that the average incidence of WS was about 50% in examined birds' population. Ahsan and Cengiz (2020) revealed that the incidence of WS was lowered by reducing the level of lysine in the grower feed. It was found that low level of lysine in the feed lowered the feed intake as well as the growth rate of the birds, therefore, the severity and incidence of WS reduced.

Several researchers investigated the possibility of using different tools and instruments to distinguish between normal and abnormal meat. It was found that visible/near infrared spectroscopy was able to differentiate between normal and white striped meat (Zaid et al., 2020). Kato et al. (2019) found that there was possibility to classify muscle abnormalities based on a computer vision system, exploring different machine learning algorithms and the most important image features. Hyperspectral imaging in visible and near-infrared range (400–1,000 nm) was a good tool to differentiate between normal and white striped meat (Jiang et al., 2019).

Even WS and WBs were investigated by several researchers (Kato et al., 2019; Mudalal et al., 2014; Mudalal et al., 2015; Sihvo et al., 2014; Tasoniero et al., 2016; Zaid et al., 2020). Further studies are needed to evaluate the effect and complications of these muscle abnormalities on the quality traits of meat under different farming conditions. There is limited knowledge about the effect of slaughter age on the incidence and the quality traits of WS and WB muscle abnormalities at different slaughter ages as well as for different commercial chicken breeds. This study aims to evaluate the occurrence and the effect of WS and WB muscle abnormalities on quality characteristics of chicken breast fillets at different slaughter ages.

Materials and Methods

A total of approximately 600 one-d old male chicks (Ross 500) were purchased from a local hatchery. The chicks were reared under continuous lighting throughout period. The internal temperature of the farm was gradually lowered from 32℃ on day 1 to 24℃ on day 21 and then kept constant.

The chemical composition of the feed is shown in Table 1. In the first three weeks, chicks were fed with the starter diets and for the remaining time (48 d), they were fed with the grower diet.

Table 1. Composition of the basal diets fed to broilers in feeding trial

Ingredient	Starter (g/kg)	Grower (g/kg)
Yellow corn	560	620
Soybean meal	360	306
Oil	40	40
Dicalcium phosphate	15	12
Limestone	15	15
NaCl	3.5	3.5
Premix[1)]	5	5
DL-Methionine	1	1
L-Lysine	0.5	0.5
Calculate analysis		
Crude protein	220	200
Lysine	110	110
Methionine	55	56
Calcium	100	110
Available P	46	47
ME, MJ/ kg ration	704	718

[1)] Vitamin premix/kg diet: vitamin A, 12,000 IU; vitamin D_3, 1,500 IU; vitamin E, 50 mg; vitamin K_3, 5 mg; vitamin B_1, 3 mg; vitamin B_2, 6 mg; vitamin B_6, 5 mg; vitamin B_{12}, 0.03 mg; niacin, 25 mg; Ca-D-pantothenate, 12 mg; folic acid, 1 mg; D-biotin, 0.05 mg; apo-carotenoic acid ester, 2.5 mg; choline chloride, 400 mg.

At 34 d of age, 200 broilers were slaughtered and the same number of birds were slaughtered at 41 and 48 d of age. After approximately 6 h of slaughter, chicken fillets were classified into several levels of muscle abnormalities based on criteria previously described by Kuttappan et al. (2012) and Sihvo et al. (2014). The total number of fillets that exposed to muscle abnormalities assessment at each slaughtering time was 400 fillets (200 birds×2 fillets/bird). Fillets were classified into four levels of muscle abnormalities [Normal (N), WS, WB and WS/WB]. Fillets were classified as normal when there were no any white striations or hardened areas over the surface. Fillets that showed white striations (thin to thick striations) on the surface, were classified as white striped fillet (WS). When fillets had pale ridge-like bulges and diffuse hardened areas, they were classified as WBs. Fillets were classified as WS combined with WB when they had pale ridge-like bulges and diffuse hardened areas, combined with white striations in different thickness. For each pair of breast fillets in the same bird, they were classified as similar when both fillets are normal or abnormal (either both WS or WB or WS/WB) and when both fillets are N/WS or WS/WB or WS/WS+WB, they were classified as different.

At each slaughter age, 36 fillets were selected and divided into 3 groups: normal (n=12), WS (n=12), and WS combined with WB (n=12) to evaluate the quality characteristics [pH, physical dimensions (length, width, and height at three points), color index (L*, a*, and b*), and chemical composition (moisture, protein, fat, ash, and collagen)]. Meat pH was measured using a calibrated handheld pH/temperature meter (IQ150, IQ Scientific Instruments, San Diego, CA, USA) according to the method described by Jeacocke (1977).

The longest dimension of the fillet was measured and recorded as length (L). The longest distance from side to side in the middle of fillet was measured and recorded the width (W). The first height (H3) was measured as vertical distance far from the end of caudal part by 1 cm toward dorsal direction. At the half distance of the breast length (L), the second height (H2) was measured. At the highest point in the cranial part, the third height (H1) was measured.

Color characteristics (L*, a*, and b*) were measured using the Minolta Chroma Meter (CR-410, Konica Minolta, Osaka, Japan). Color values were recorded according to the Commission International de l'Eclairage (CIE) system. The system consists of three dimensions: One for luminance (L*-lightness) and two for color (a*-green to red; b*-blue to yellow). The color values for each meat type were measured at three different locations (at the top of cranial part, middle, and peripheral of caudal part), and the mean value was considered. Any abnormal area (containing blood splash, or connective tissues, or visible fat tissues) was excluded during measuring the color values.

Twelve samples were selected to determine proximate composition (moisture, protein, ash, and lipid contents) for each meat type according to official methods of AOAC (AOAC, 1990). The moisture content was determined based on weight differences due to losses during air oven drying. The Kjeldahl method was used to determine total crude protein content. In addition, fat content was determined using the solvent extraction method. For ash content, dry ashing technique by employing muffle furnace has been used. Collagen content was determined by measuring hydroxyl proline content using a colorimetric method (Kolar, 1990).

Statistical analysis

The results of the study were analyzed using the ANOVA (GLM procedure SPSS Statistical Analysis Software, 2002). It was used to evaluate the influence of slaughter age on the occurrence and the quality properties of WS and WB muscle abnormalities. Duncan test was used to separate the means of the dependent variables in case of statistical differences ($p<0.05$).

Results and Discussion

The incidence of muscle abnormalities (normal, WS, and WB) at different slaughter ages of 34, 41, and 48 d is shown in Table 2. At slaughter age of 34 d, it was found that 55% of fillets were normal while 29% were WS. Moreover, about 14% of chicken fillets were affected by WS combined with WB. A small proportion (about 2%) of chicken fillets had WB abnormality. In general, the incidence of muscle abnormalities at this age was relatively high, but to some extent, it was in consistent with previous studies. In this context, Lorenzi et al. (2014) found that the incidence of WS in medium- sized birds (1.5–2 kg) was 24.3% in females and 33.9% in males. Mudalal et al. (2021) found that the incidence of WS in broilers fed standard feed was 38.5% while it was 28%–30% in broiler fed herb extract enriched feed at slaughter age of 34 d.

Table 2. The incidence of muscle abnormalities (normal, white striping, and wooden) in chicken fillets at different slaughter ages of 34, 41, and 48 d

Slaughtering age	Incidence, n (%)			
	Normal	WS	WS/WB	WB
34 D (n=400)	219 (55)	114 (29)	58 (14)	8 (2)
41 D (n=400)	31 (8)	87 (22)	264 (66)	18 (5)
48 D (n=400)	0 (0)	104 (26)	296 (74)	0 (0)

WS, white striping; WB, wooden breast.

At slaughter age of 41 d, the percentage of normal fillets at this age was 8%, which is considered relatively low compared with previous studies. The percentage of normal fillets decreased by 47% (55% from 8%) when the slaughter age was increased to 41 d. The proportion of fillet with WS in combination with WB was 66% while the proportion of WB fillet was 4%. In addition, 22% of fillets were affected by WS abnormality. Lorenzi et al. (2014) found that broiler flocks slaughtered at 41–50 d of age had average of 43% WS. Malila et al. (2018) found that broilers slaughtered at 42 d (>2.5 kg) of age had 3% normal fillets, 89% white striped fillets, and 7% WB combined with WS fillets.

At slaughter age of 48 d, there were no normal cases of chicken fillets. Chicken fillets had 26% WS and 74% WS combined with WB. Similar results were obtained by Trocino et al. (2015). At slaughter 46 d of age, it was found that overall incidence of WS was about 75%. Lorenzi et al. (2014) revealed that the incidence of moderate and severe WS in heavy flocks slaughtered at 3.0–4.2 kg live weight (50 to 58 d old) was 46.9% and 9.5%, respectively. In other studies, it was found that the incidence of WS was in range 50.7%–55.8% at slaughter 59–63 d of age (Kuttappan et al., 2009; Kuttappan et al., 2013b). Oral Toplu et al. (2021) showed that the incidence of normal, moderate, and severe WS in broiler fed with standard diet and slaughtered at 49 d of age were 2.5%, 40%, 57.5%, respectively. At slaughter 49 d of age (weight>2.5 kg), Malila et al. (2018) showed that there were no normal fillets. In the same study, the incidence of WS (mild, moderate, and severe) was 92% while WS combined with WB reached to 8%. About 5% to 10% of produced chicken fillets by industry had WB abnormality (Gee, 2016). In the USA, it was found that 98% of chicken breasts obtained from 9-wk-old birds were found to be affected by WS (Kuttappan et al., 2017).

The incidence of muscle abnormalities in both fillets (left and right) of the same bird at different slaughter ages (34, 41, 48 d) is shown in Table 3. This part of the results was used to understand whether the two fillets of the same bird have the same pattern of occurrence of muscle abnormalities or not. It was observed that at the same slaughter age, not all fillets (left and right) of the same bird showed the same type of muscle abnormalities. The study showed that the percentage of fillets (left and right) that had similar abnormalities increased with age. At 34 d of age, about 39.2% of fillets had different muscle abnormalities between left and right. About 13.5% of the left and right fillets of the same bird exhibited normal and WS combined with WB. At 48 d of age, it was clear that the differences in muscle abnormalities in the same pairs of fillets was related to WS and WS combined with WB.

The weights, physical dimensions (L, W and, T1, T2, and T3), color traits (L*, a*, and b*), and pH of chicken fillets affected by different muscle abnormalities at slaughter 34 d of age are shown in Table 4. The incidence of muscle abnormalities had no effect on T3 and T2. Normal fillets had significantly lower T1 (5.99 vs. 8.56 and 8.43, $p<0.05$) compared to WS and WS combined with WB fillets, respectively. There were no significant differences in T1 between WS

Table 3. The incidence of muscle abnormalities in each individual pairs of breast fillets in the same bird at different slaughtering ages (34, 41, 48 d)

Age	Similar[1)]	Different[2)]	Distribution of muscle abnormalities in breast pairs with different abnormalities between left and right breast					
			WS/WS+WB	WB/WS+WB	N/WB	N/WS	WS/WB	N/WS+WB
34	60.81	39.19	6.08	2.03	2.03	15.54	0.00	13.51
41	63.56	36.44	21.19	5.93	0.85	3.39	0.85	4.24
48	68.71	31.29	29.93	1.36	0.00	0.00	0.00	0.00

[1)] This result represents the percentage of breast fillet pairs (left and right) that had the same muscle abnormalities.
[2)] This result represents the percentage of breast fillet pairs (left and right) that had the different muscle abnormalities.
WS, white striping; WB, wooden breast; N, normal.

Table 4. Weights, physical dimensions, color traits, pH of chicken breast fillets affected by different muscle abnormalities at slaughtering age 34 d

Muscle abnormalities	Normal	WS	WS/WB	p-value
T3 (mm)[1)]	21.02±3.07	24.18±6.51	22.38±1.49	0.136
T2 (mm)[2)]	13.74±3.81	15.74±6.72	16.50±2.21	0.253
T1 (mm)[3)]	5.99±1.17^{b}	8.56±4.55^{a}	8.43±2.25^{a}	<0.05
Width (mm)[4)]	67.17±5.17^{b}	66.78±6.22^{b}	73.83±7.42^{a}	<0.05
Length (mm)[5)]	141.53±10.54^{b}	154.40±14.62^{a}	144.20±13.87^{b}	<0.05
CIE L*	67.37±4.09^{a}	61.73±3.32^{b}	63.05±2.91^{b}	<0.05
CIE a*	3.25±1.18^{b}	4.87±1.77^{a}	5.18±2.34^{a}	<0.05
CIE b*	4.02±1.97^{b}	5.20±2.28^{a}	5.99±1.13^{a}	<0.05
pH	5.67±0.09^{c}	5.74±0.08^{b}	5.84±0.09^{a}	<0.05
Weight (g)	106.16±22.85^{b}	123.48±27.90^{a}	135.47±21.04^{a}	<0.05

[1)] T3 is the height at the highest point of cranial part.
[2)] T2 is the height at the mid of breast length.
[3)] T1 is the height measured from 1 cm far a way of the end of caudal part.
[4)] Width is the distance of widest area in the middle of breast.
[5)] Length represents the longest distance of the breast.
[a–c] Means within a row followed by different superscript letters differ significantly ($p<0.05$).
WS, white striping; WB, wooden breast.

and WS combined with WB fillets. Fillets affected by WS combined with WB showed significantly higher width than normal and white striped fillets. White striped fillets had significantly higher length when compared normal fillets and fillets affected by WS combined with WB. Normal fillets had significantly higher L* (67.37 vs. 61.73 and 63.05, $p<0.05$) and lower a* (3.25 vs. 4.87 and 5.18, $p<0.05$) and b* (4.02 vs. 5.20 and 5.99, $p<0.05$) than WS and WS combined with WB fillets; respectively. Moreover, the weight of fillets affected by muscle abnormalities were higher than normal fillets. Normal fillets had significantly lower pH-values than fillets affected by WS or both abnormalities. Fillets affected by WS had significantly lower pH than fillets affected by both muscle abnormalities.

The physical and chemical characteristics of the chicken breast affected by different muscle abnormalities at slaughter 41 d of age are shown in Table 5. In contrast to age 34 d, there were no significant differences between muscle abnormalities in height at T1. Normal fillets had significantly lower T3 values (23.28 vs. 26.41 and 26.75, $p<0.05$) and T2 values (17.17 vs. 21.25 and 22.22; $p<0.05$) than WS and WS combined with WB fillets; respectively. The incidence of muscle abnormalities at both levels did not affect the width of the fillets. Fillets affected by both abnormalities had significantly higher length (74.97 vs. 71.88, $p<0.05$) than normal fillets while white striped fillets exhibited moderate values. In contrast to the results obtained at age 34, the incidence of muscle abnormalities did not show any effect on color characteristics (L*, a*, and b*). Similar to the results obtained at age 34, normal fillet had a lower pH-value than fillets affected by WS or fillets affected by both muscle abnormalities. Fillets affected by WS or by both abnormalities had significantly higher fillet weights than normal fillets.

The quality characteristics of normal and abnormal chicken breasts obtained at slaughter age of 48 d are shown in Table 6. Normal fillets had significantly lower T3-values (24.78 vs. 28.87, $p<0.05$) and T1-values (7.97 vs. 11.88; $p<0.05$) than WS combined with WB fillets; respectively. There were no significant differences in T2, width, and length between groups. Normal fillets had significantly lower L* than fillets affected by both abnormalities while WS exhibited moderate values. Muscle abnormalities did not show any effect on a* and b*. Normal fillets exhibited lower pH-values than fillet affected by

Table 5. Weights, physical dimensions, color traits, pH of chicken breast affected by different muscle abnormalities at slaughtering age 41 d

Muscle abnormalities	Normal	WS	WS/WB	p-value
T3 (mm)[1)]	23.28±2.23[b]	26.41±6.51[a]	26.75±3.47[a]	<0.05
T2 (mm)[2)]	17.17±3.81[b]	21.25±4.83[a]	22.22±3.40[a]	<0.05
T1 (mm)[3)]	10.52±3.90	11.59±4.65	12.64±3.42	0.337
Width (mm)[4)]	71.88±7.81	75.64±6.21	74.97±5.52	0.09
Length (mm)[5)]	141.16±11.00[b]	147.60±10.14[ab]	152.53±14.23[a]	<0.05
CIE L*	64.71±2.13	65.51±2.29	65.45±2.57	0.40
CIE a*	1.88±1.01	2.33±1.44	2.75±2.36	0.20
CIE b*	5.76±1.44	6.03±1.61	6.08±1.75	0.76
pH	5.73±0.09[b]	5.83±0.11[a]	5.88±0.12[a]	<0.05
Weight (g)	132.49±26.25[b]	168.90±40.90[a]	156.26±22.68[a]	<0.05

[1)] T3 is the height at the highest point of cranial part.
[2)] T2 is the height at the mid of breast length.
[3)] T1 is the height measured from 1 cm far a way of the end of caudal part.
[4)] Width is the distance of widest area in the middle of breast.
[5)] Length represents the longest distance of the breast.
[a,b] Means within a row followed by different superscript letters differ significantly ($p<0.05$).
WS, white striping; WB, wooden breast.

Table 6. Weights, physical dimensions, color traits, pH of chicken breast affected by different muscle abnormalities at slaughtering age 48 d

Muscle abnormalities	Normal	WS	WS/WB	p-value
T3 (mm)[1)]	24.78±1.47[b]	27.14±5.14[ab]	28.87±3.83[a]	<0.05
T2 (mm)[2)]	20.31±2.43	20.53±5.76	23.24±3.60	0.10
T1 (mm)[3)]	7.97±2.88[b]	9.02±2.77[b]	11.88±3.94[a]	<0.05
Width (mm)[4)]	78.56±5.65	83.89±9.20	82.83±6.42	0.10
Length (mm)[5)]	161.26±12.74	166.40±10.55	167.86±16.91	0.37
CIE L*	62.79±3.73[b]	64.64±3.98[ab]	65.57±3.47[a]	<0.05
CIE a*	1.51±1.19	2.18±1.28	1.94±1.18	0.43
CIE b*	5.67±1.44[b]	6.48±1.63[ab]	6.69±1.90[a]	0.76
pH	5.73±1.07[b]	5.80±0.09[a]	5.86±0.12[a]	<0.05
Weight (g)	176.57±23.78[b]	215.870±38.56[a]	220.28±41.55[a]	<0.05

[1)] T3 is the height at the highest point of cranial part.
[2)] T2 is the height at the mid of breast length.
[3)] T1 is the height measured from 1 cm far a way of the end of caudal part.
[4)] Width is the distance of widest area in the middle of breast.
[5)] Length represents the longest distance of the breast.
[a,b] Means within a row followed by different superscript letters differ significantly ($p<0.05$).
WS, white striping; WB, wooden breast.

muscle abnormalities. Moreover, normal fillets had lower weight when compared to white striped fillets or fillets affected by both abnormalities.

The high ultimate pH of abnormal fillets in comparison to normal fillets may be attributed due to the strong negative correlation between glycogen storage and breast muscle weight (Le Bihan-Duval et al., 2008). Abnormal and high weighed fillets may exhibit low glycolytic potential resulting in a higher pH than normal fillets (Soglia et al., 2016b). Mudalal (2019) found that white striped turkey breast had a higher pH than normal turkey breast.

Mudalal et al. (2014, 2015) showed that there were no differences in the length of normal and white striped fillets while Baldi et al. (2018) found differences. There were no significant differences in the length of fillets between normal and WB fillets or WS combined with WB (Mudalal et al., 2015; Zambonelli et al., 2016). Several studies revealed that the width of normal fillets was not significantly different from the width of WS and WB fillets (Baldi et al., 2018; Mudalal et al., 2014; Mudalal et al., 2015). On the other hand, fillets affected by both striping and WB abnormalities had a greater width than normal fillets (Zambonelli et al., 2016).

The proximate composition (moisture, proteins, fat, ash, and collagen) of normal, white striped, and white striped combined with WB chicken fillets at different slaughter ages is shown in Table 7. In general, there were significant differences in proximate compositions due to the incidence of muscle abnormalities. Overall, the results showed that chicken fillets affected by muscle abnormalities had higher fat content and lower protein content than normal fillets. At slaughter ages of 34 and 48 d, there were no significant differences in ash and collagen content between normal and abnormal fillets. Chicken fillets affected by both muscle abnormalities (WS and WB) had higher moisture content compared to normal and white striped fillets. There were no significant differences in protein, ash and collagen content between normal and abnormal

Table 7. Proximate composition (moisture, proteins, fat, ash, and collagen) of normal, white striped, and white striped combined with wooden chicken fillets at different slaughtering ages (34, 41, and 48 d)

Muscle abnormalities	Normal	WS	WS/WB	p-value
Slaughtering age 34 d				
Moisture	73.46±0.19[b]	73.47±0.16[b]	74.31±0.42[a]	<0.05
Proteins	24.20±0.14	24.23±0.22	24.02±0.37	0.21
Fat	1.76±0.17[b]	1.99±0.10[a]	1.65±0.14[b]	<0.05
Ash	1.44±0.03	1.45±0.07	1.43±0.5	0.58
Collagen	0.82±0.16	0.78±0.16	0.66±0.13	0.11
Slaughtering age 41 d				
Moisture	74.46±0.23	74.47±0.18	74.27±0.21	0.09
Proteins	23.83±0.2[a]	22.93±0.14[b]	22.73±0.17[c]	<0.05
Fat	1.40±0.12[c]	1.95±0.30[b]	2.25±0.19[a]	<0.05
Ash	1.31±0.04[b]	1.36±0.06[ab]	1.39±0.07[a]	<0.05
Collagen	0.55±0.10	0.72±0.20	0.64±0.22	0.17
Slaughtering age 48 d				
Moisture	73.62±0.19[c]	74.11±0.19[a]	73.83±0.29[b]	<0.05
Proteins	24.07±0.8[a]	22.92±0.05[c]	23.29±0.11[b]	<0.05
Fat	1.55±0.08[b]	2.10±0.18[a]	2.02±0.15[a]	<0.05
Ash	1.42±0.04	1.44±0.07	1.41±0.07	0.52
Collagen	0.84±0.22	0.87±0.08	0.87±0.22	0.89

[a,b] Means within a row followed by different superscript letters differ significantly ($p<0.05$).
WS, white striping; WB, wooden breast.

fillets at slaughtering age 34 d. Moreover, white striped meat had higher fat content (1.99 vs. 1.75 and 1.65%, $p<0.05$) when compared to normal and meat affected by both abnormalities. Our results suggest that the effect of muscle abnormalities on the proximate composition became more evident with increasing slaughter age.

Several researchers investigated the effect of WS and WB muscle abnormalities (either separately or combined) on proximate chemical composition (moisture, protein, fat, collagen, and ash), mineral profile, fatty acids profile, and protein functionality. Zambonelli et al. (2016) found that meat affected by WS and WB had higher moisture, fat, and collagen contents as well as lower contents of proteins and ash if compared to normal meat. In another study, there were significant differences in the proximate composition between normal and white striped meat (Petracci et al., 2015). Chicken fillet affected by severe WS exhibited significantly higher fat content and lower protein content than normal chicken fillets (Mudalal et al., 2020). Soglia et al. (2016a) showed that the presence of both muscle abnormalities (WS and WB) had greater effect on the chemical composition than the presence of single muscle abnormality. This result was consistent with our results in particular at slaughtering age 41 d. Our study showed that meat affected by both muscle abnormalities (WB and WS breast) had significantly lower protein content (22.73 vs. 22.93%, $p<0.05$) and higher fat content (2.25 vs. 1.95, $p<0.05$) in comparison to meat affected only by WS. In general, the studies agreed on the effect of muscle abnormalities on protein and fat content.

Several authors showed that there were no significant differences in moisture content between normal and white striped fillets (Baldi et al., 2018; Kuttappan et al., 2012; Petracci et al., 2014; Soglia et al., 2016a; Soglia et al., 2016b; Soglia et al., 2018). In contrast, several studies showed that WB fillets had significantly higher moisture content than normal (Cai et al., 2018; Soglia et al., 2016a; Soglia et al., 2016b; Wold et al., 2017). Most of studies agreed that white striped meat had lower protein content than normal meat (Baldi et al., 2018; Kuttappan et al., 2012; Mudalal et al., 2014; Petracci et al., 2014; Soglia et al., 2016a). On the contrary, Soglia et al. (2018) revealed that there were no significant differences in protein content between white striped and normal fillets. WB fillets and WS combined with WB fillets had significantly lower protein contents than normal fillets (Cai et al., 2018; Soglia et al., 2016a; Soglia et al., 2016b; Wold et al., 2017). For the effect of muscle abnormalities (WS and WBs) on lipid content, most of studies were generally in agreement. Meat affected by severe cases of WS or WB or WS combined with WBs exhibited higher fat content than normal meat (Baldi et al., 2018; Cai et al., 2018; Kuttappan et al., 2012; Soglia et al., 2016a; Soglia et al., 2016b; Soglia et al., 2018; Wold et al., 2017). Some researchers indicated that in moderate cases of WS and WB muscle abnormalities, there were no significant differences in fat content in comparison to normal (Kuttappan et al., 2012; Soglia et al., 2018; Wold et al., 2017). In respect to ash content, Baldi et al. (2018) and Kuttappan et al. (2012) did not find any significant effect for WS, while Soglia et al. (2018) found that white striped meat had lower ash content than normal.

In conclusion, the incidence of WS and WB muscle abnormalities was highly affected by slaughtering age. The muscle abnormalities did not occur in the same pattern at left and right fillets of the same bird. The effect of muscle abnormalities on quality characteristics was stronger at high slaughter age. Accordingly, it is important to differentiate between slaughter age for fillets dedicated for fresh retail use and for fillets dedicated for processing in order to mitigate the implications of muscle abnormalities on consumer perception.

Conflicts of Interest

The authors declare no potential conflict of interest.

Author Contributions

Conceptualization: Mudalal S. Data curation: Mudalal S, Zaazaa A. Formal analysis: Mudalal S. Methodology: Mudalal S, Zaazaa A. Software: Mudalal S. Validation: Mudalal S, Zaazaa A. Investigation: Mudalal S, Zaazaa A. Writing - original draft: Mudalal S. Writing - review & editing: Mudalal S, Zaazaa A.

Ethics Approval

This research was approved by the Animal Welfare Committee of the An-Najah National University in Palestine.

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