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Allometric coefficient in broilers and development of white striping and wooden breast myopathies

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Abstract: The aim was to study the evolution and severity of white striping and wooden breast myopathies and to carry out a study on the parameters of meat quality and allometric growth of male and female broilers at different ages. The experiment was conducted in a broiler house in a completely randomized design, using 960 one-day-old chicks of the Cobb® strain, with 480 chicks of each sex. 96 birds per treatment were slaughtered weekly at the age of 21 to 49 days. The present study analyses the occurrence of myopathies, their scores, and their evolution over the age of the birds, comparing males and females. Further assessments included the allometric coefficient and meat quality analyses such as physical measurements (breast length, width, and thickness), pH, colour (L*, a*, and b*), drip loss, water-holding capacity, cooking loss, and shear force. The results demonstrate that the sex of birds did not affect the occurrence of white striping and wooden breast myopathies. However, the degree of myopathies evolved with advancing age, suggesting the weight as a predisposing factor for these myopathies. The emergence of white striping myopathy occurred as early as in the third week of the birds' life. Wooden breast did not develop as isolated myopathy, occurring only in the concomitant presence of white striping. The allometric coefficient demonstrated that regardless of the sex and age, broiler breast had positive heterogonic growth, i.e. late growth in relation to the other parts of the body.

Keywords: muscle degeneration; study of relative growth; pectoral myopathy; meat quality

Genetic advances as well as nutritional, sanitary, and technological developments in the poultry sector have increased productivity in poultry farming, especially in broiler production. Despite the occurrence of environmental and nutritional developments, genetic improvement of broilers accounts for 85% to 90% of the progress in poultry farming (Zuidhof et al. 2014).

Notwithstanding, this genetic evolution occurred along with muscle changes in birds. These events,

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called myopathies, lead to macroscopic features easily identified by the consumer, mainly due to colour and consistency aspects. White striping and wooden breast myopathies are the most common changes in prime cuts such as broiler breasts, thighs, and drumsticks (Sihvo 2019). Many studies have been conducted to identify the causes of these muscle changes; however, their aetiology and pathogenesis are currently unknown (Sihvo et al. 2018). Furthermore, it is unclear whether both myopathies share a common aetiology or if one evolves from the other.

According to Joiner et al. (2014), genetic evolution has exacerbated myofibre growth, in which capillaries for gas exchange are marginalized, increasing the diffusion distance of oxygen and various metabolites and thus inducing muscle ischaemia. Moreover, histopathological studies of bird breasts affected by white striping reveal that in addition to myofibre degeneration, this condition increases fatty tissue (lipidosis) and connective tissue content (fibrosis). Both these increases can affect several meat quality traits, mainly colour and tenderness (Kuttappan et al. 2013).

Sihvo et al. (2016) identified that extremely young birds can develop wooden breast. This condition consists of a focal lesion starting in birds at approximately two weeks of age and progressing into a chronic and diffuse phase affecting the entire pectoralis major muscle in approximately five to six weeks (Sihvo et al. 2018).

Kuttappan et al. (2012) found that a high body growth rate increases the occurrence of more severe degrees of white striping in broiler breast fillets. According to Petracci et al. (2019), white striping can result in thicker and heavier breast fillets depending on its severity. In turn, Baldi et al. (2017) correlated the mean breast fillet weight not only with white striping but also with white striping associated with wooden breast.

Although some authors have determined the allometric coefficients of broiler carcass parts over the years (Van der Klein et al. 2017; Tickle et al. 2018), information is lacking on the allometric growth of carcasses affected by breast myopathies. Thus, this study identifies the presence, evolution, and severity of white striping and wooden breast myopathies affecting broilers. In addition, we present meat quality parameters and the study of allometric growth of carcasses.

MATERIAL AND METHODS

Birds and housing system

All procedures for this study were approved by the Ethics Committee on Animal Use (CEUA) of the Federal University of Grande Dourados (UFGD) (Protocol No. 17/2018).

The experiment was conducted in an experimental broiler house. After initial weighing and weight standardization, 960 one-day-old chicks (480 males and 480 females of the Cobb 500® strain) were housed. The experimental design was completely randomized, consisting of two treatments (male and female), with 12 replicates per treatment and 40 birds per replicate, arranged in 24 pens. Experimental rations were provided *ad libitum* following a feeding program. Bird density was 14 birds/m^2. Chicks were vaccinated in the hatchery against Marek's disease and infectious bronchitis. The other practices adopted for bird management followed the recommendations of the Cobb® manual.

Relative growth study and slaughter procedure

All birds were weighed at 21, 28, 35, 42, and 49 days of age. Three birds per replication were selected at each age, with a variation of ± 10% in average weight. These assessments measured live weight, carcass and cut yields for allometric analysis of relative growth, the presence of white striping and wooden breast myopathies, and meat quality.

The birds were slaughtered by cervical dislocation followed by the section of jugular veins and carotid arteries, and bled for three minutes at least. The carcasses were scalded, plucked, and eviscerated. These carcasses were then cooled in a two-stage water immersion in a stainless steel tank (prechiller and chiller). Allometric equations for the study of relative growth were determined from the weight of commercial cuts as described by Castilho et al. (2022).

White striping and wooden breast classification

After cooling the carcasses, the breasts were deboned and weighed. Breast fillets were scored for

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wooden breast and white striping according to the methodologies of Sihvo et al. (2016) and Kuttappan et al. (2016), respectively. A trained person with extensive experience in the studies of both myopathies was responsible for classifying the breasts at all slaughter ages. It was considered for classification in both the right and left breasts.

For determining the degree of wooden breast, fillets were manually palpated according to the methodology of Tijare et al. (2016). Subsequently, a macroscopic score was established based on the degree of myopathy proposed by Sihvo et al. (2016): grade 0 = normal; grade 1 = moderate; grade 2 = severe. Following Kuttappan et al. (2016) white striping myopathy was scaled at 0 = normal (no white stripes); 1 = moderate; 2 = severe; and 3 = extreme.

Meat quality analysis

After deboning, pectoralis major muscles were collected, identified, and placed in a BOD (chamber to keep the sample at a controlled temperature) at 5 °C. After 24 h after death, the following parameters were analysed in the right fillet of the *pectoralis major* muscle: pH, colour, fillet dimensions, water-holding capacity, drip loss. The left fillet was frozen at −18 °C for further analysis of cooking loss and shear force.

The pH value of broiler breast fillets was measured using a Testo 205 digital pH meter (Testo SE & Co. KGaA, Titisee-Neustadt Germany). Breast fillet colour was determined using a portable Minolta CR 400 colorimeter (Konika Minolta Tokyo, Japan), in which the parameters L* (brightness), a* (redness), and b* (yellowness) were evaluated according to the methodology proposed by Van Laack et al. (2000). The breasts were sized with the aid of a digital calliper following the methodology of Mudalal et al. (2014a), measuring fillet width, length, and thickness (cm).

For determining water-holding capacity, 2.0 g of breast muscle were used, and the measurements followed Hamm (1960). Drip loss was measured with 80-gram samples of the pectoralis major muscle according to the methodology described by Mudalal et al. (2014b). For cooking loss, samples of breast fillets were previously thawed at 5 °C, being then packaged in vacuum plastic containers and cooked in a water bath at 85 °C for 30 minutes. After cooking, the fillets were cooled to room temperature and weighed (Honikel 1987).

For determining shear force, TA.XT plus texturometer equipment (Stable Micro Systems, Godalming, UK) was used. The samples were cut into parallelepipeds in quintuplicate. The results were expressed in kg/force/cm^2, and blade descent speed was 200 mm/minute.

Statistical analysis

After obtaining the results of the experiment, the means were determined and the results were statistically analysed through the PROC MIXED procedure of the SAS software v9.4 (SAS Institute, Inc., Cary, NC, USA). The results were previously tested for the normality of residuals studentized by the Shapiro-Wilk test (PROC UNIVARIATE). Variances were compared by Tukey's test adjusted to 5% significance for the results of the analysis of carcass and cut yield and meat quality. The results of the occurrence of myopathies between treatments at each slaughter age were subjected to chi-square analysis at a 5% significance level.

The study of the relative growth of cuts was carried out using the power equation $Y = a X^b$, logarithmically transformed into a linear model $\ln Y = \ln a + b \ln X + \ln ei$ according to Huxley 1932, performed and described by Castilho et al. (2022).

RESULTS

Bird sex did not interfere with the occurrence of white striping and wooden breast myopathies in broiler breast at the ages under study (Table 1).

Wooden breast occurred later than white striping, given the absence of characteristics evidencing the woody breast condition in the 21-day slaughter (Table 1). However, similar to white striping, wooden breast severity also increased over time. In other words, this severity increased with increasing bird age, regardless of the sex. The evolution in percentages from grade 1 to grade 2 wooden breast was evidenced from 28 days of age and increased with advancing age, reaching 100% of samples affected by grade 2 WB in breasts of 49-days-old males. The percentage of grade 2 wooden breast was more evident at 35, 42, and 49 days of age.

When comparing only the presence or absence of isolated or concomitant white striping and wooden breast myopathies regardless of their scores,

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Table 1. Frequency of white striping and wooden breast in male and female broiler breasts at 21, 28, 35, 42, and 49 days of age

Age	Score	WS (%)		WB (%)		*P*-value	
		female	male	female	male	WS	WB
21 days	0	20.0	8.3	100	100	0.765	1.00
	1	80.0	91.7	0	0		
	2	0	0	0	0		
	3	0	0	–	–		
28 days	0	0	0	36.1	33.3	0.151	0.792
	1	100	95.4	58.3	63.8		
	2	0	4.66	5.56	2.78		
	3	0	0	–	–		
35 days	0	0	0	27.7	13.8	0.721	0.275
	1	88.8	86.1	52.7	55.5		
	2	11.1	13.8	19.4	30.5		
	3	0	0	–	–		
42 days	0	0	0	2.78	0	0.170	0.067
	1	88.8	77.7	22.2	5.56		
	2	8.33	22.2	75.0	94.4		
	3	2.77	0	–	–		
49 days	0	0	0	0	0	0.364 8	0.313 9
	1	36.1	27.7	2.78	0		
	2	55.5	52.7	97.2	100		
	3	8.33	19.4	–	–		

WB = wooden breast; WS = white striping

Chi-square ($P < 0.05$); considered 64 samples analysed at each age

wooden breast did not occur as isolated myopathy. This myopathy occurred in broiler breasts only in the presence of white striping characteristics, regardless of the sex and slaughter age (Table 2).

Wooden breast correlated strongly and positively with age, live weight, breast weight, and breast fillet length, width, and thickness. In other words, the higher the value of these variables, the more severe the degree of myopathy (Table 3). However, white striping correlated significantly and moderately with these variables.

The correlation between pH and the presence of white striping was not significant. This factor had a low significant correlation with wooden breast. The L* value had a weak positive correlation with white striping and an average positive correlation with wooden breast, indicating that the greater the severity of both myopathies, the lighter the fillets. Nonetheless, the results demonstrate that the b* value did not correlate with white striping and correlated weakly with wooden breast. Redness (a*) correlated weakly with the two myopathies under study. Drip loss, water-holding capacity, and cooking loss correlated weakly with both myopathies. Shear force did not correlate significantly with the myopathies under study.

Breasts with the presence of white striping only did not change in relation to breasts without the occurrence of myopathy for length, width, and thickness. On the other hand, the simultaneous presence of wooden breast significantly increased these parameters (Table 4).

Fillets with associated wooden breast and white striping myopathies were lighter and less red than fillets without myopathy and fillets with white striping only, which did not differ from each other. However, fillets with associated myopathies had a yellower colour than fillets with white striping only. Moreover, normal fillets had the b* value similar to that of fillets affected by white striping only. The pH values of fillets with associated myopathies were lower than those of fillets without myopathy.

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Table 2. Frequency of white striping, wooden breast, and the two concomitant myopathies in male and female broiler breasts at 21, 28, 35, 42, and 49 days of age

	Without myopathy (%)	WS (%)	WB (%)	WS + WB (%)
21 days				
Female	14.5	85.4	0	0
Male	10.4	89.5	0	0
28 days				
Female	5.56	30.5	0	63.8
Male	0	33.3	0	66.6
35 days				
Female	0	27.7	0	72.2
Male	0	13.8	0	86.1
42 days				
Female	0	2.80	0	97.2
Male	0	0	0	100
49 days				
Female	0	0	0	100
Male	0	0	0	100

WB = wooden breast; WS = white striping
Considered 64 samples analysed at each age

All collected samples were evaluated together for the study of relative growth. The *t*-test to compare allometric coefficients showed that all analysed parts had heterogonic growth ($b \neq 1$), that is, the growth of each analysed part differed from the body growth (Table 5).

The equations showed negative heterogonic growth ($b < 1$), that is, early development for legs, wings, and back. In turn, breasts had positive heterogonic growth ($b > 1$), that is, late growth in relation to carcass development. Late growth occurs when the analysed part grows more slowly than the body as a whole, whereas early growth occurs when the analysed part grows faster than the body of the bird.

The analysis of allometric coefficients as a function of broiler age and sex shows different growth behaviours (Table 6). For birds slaughtered at 21 days, both males and females had heterogonic growth ($b \neq 1$) for all body cuts, with the back and breast showing late growth ($b > 1$), and legs and wings showing early growth ($b < 1$). Male broilers slaughtered at 28 days had the same results as birds slaughtered at 21 days. However, females had nonsignificant b values for wings and back, showing isogonic growth ($b = 1$), that is, the analysed part grew similarly like the whole body.

At 35 days, females showed heterogonic growth ($b \neq 1$) for all analysed parts, where only the breast had late growth ($b > 1$), whereas legs, wings, and back grew early ($b < 1$). Males of the same age showed late growth ($b > 1$) for breast and legs, and early growth for wings ($b < 1$). On the other hand, the back had isogonic growth ($b = 1$).

Birds slaughtered at 42 and 49 days of age had a significant b value, presenting heterogonic growth

Table 3. Pearson correlation coefficient between white striping and wooden breast myopathies and meat quality variables

	White striping	*P*-value	Wooden breast	*P*-value
Bird age	0.561	< 0.000 1	0.848	< 0.000 1
Live weight	0.562	< 0.000 1	0.813	< 0.000 1
Breast weight	0.585	< 0.000 1	0.846	< 0.000 1
Breast fillet length	0.540	< 0.000 1	0.825	< 0.000 1
Breast fillet width	0.540	< 0.000 1	0.825	< 0.000 1
Breast fillet thickness	0.550	< 0.000 1	0.869	< 0.000 1
pH	–0.085	0.104	–0.111	0.033
L*	0.333	< 0.000 1	0.457	< 0.000 1
a*	–0.223	< 0.000 1	0.199	< 0.000 1
b*	0.063	0.232	0.141	0.007
Drip loss	0.313	< 0.000 1	0.487	< 0.000 1
Water holding capacity	0.151	0.004	0.170	0.001 2
Cooking loss	0.302	< 0.000 1	0.275	< 0.000 1
Shear force	–0.064	0.223	–0.080	0.128

$P < 0.05$; considered 320 samples

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Table 4. Meat quality of normal breasts, breasts with white striping, and breasts with white striping associated with wooden breast in male and female broilers

Variable	Treatment			SEM	*P*-value
	without myopathy	WS	WS + WB		
Length (cm)	12.0[b]	13.1[b]	16.8[a]	0.136	< 0.000 1
Width (cm)	6.10[b]	6.63[b]	9.29[a]	0.093	< 0.000 1
Thickness (cm)	2.00[b]	2.31[b]	3.78[a]	0.048	< 0.000 1
L*	45.4[b]	46.2[b]	48.3[a]	0.176	< 0.000 1
a*	3.22[a]	3.20[a]	2.53[b]	0.051	< 0.000 1
b*	7.65[ab]	7.51[b]	7.89[a]	0.082	0.023 2
pH	6.12[a]	6.15[ab]	6.06[b]	0.015	0.024 4
Water holding capacity (%)	34.6	36.2	36.5	0.254	0.386 4
Drip loss (%)	3.76[b]	4.76[b]	6.73[a]	0.154	< 0.000 1
Cooking loss (%)	26.6[b]	27.9[b]	29.6[a]	0.178	< 0.000 1
Shear force (kgf/cm^2)	1.38	1.49	1.43	0.022	0.623 5

SEM = standard error of the mean; WB = wooden breast; WS = white striping
Tukey's test ($P < 0.05$); considered 320 samples
[a,b]Means followed by the same letter do not differ from each other at 5% probability by the Tukey test

Table 5. Allometric equations for breast, legs, wings, and back in relation to carcass weight of broilers slaughtered at 21, 28, 35, 42, and 49 days, and verification of the difference in the allometric coefficient

Carcass cut	Equation	*t*-test (H_0: $b = 1$)	R^2
Breast	ln Breast = –0.919 7 + 1.122 ln PCRaj	< 0.000 1	0.991
Legs	ln Legs = –1.189 3 + 0.947 7 ln PCRaj	< 0.000 1	0.990
Wings	ln Wings = –2.251 7 + 0.880 2 ln PCRaj	< 0.000 1	0.986
Back	ln Back = –1.671 2 + 0.877 4 ln PCRaj	< 0.000 1	0.947

ln = transformation of a logarithm into a linear equation; PCRaj = weight-adjusted chilled carcass; R^2 = adaptation of the equation to the data obtained; *t*-test = indication if the hypothesis (H_0) was accepted or rejected with a significance level of 5%
Considered 64 samples analysed at each age

($b \neq 1$). Noteworthy, 42-day-old females showed late growth for breast and back ($b > 1$), and early growth for legs and wings ($b < 1$), whereas males of the same age presented late growth only for breast ($b > 1$). The analysis of b values at 49 days showed that males and females maintained the same growth behaviour as they had at 42 days of age.

Only the breast showed positive heterogonic growth, that is, late growth at all evaluated ages, regardless of the sex. Legs and wings showed early heterogonic growth, whereas the back showed both growth behaviours depending on age and sex (Table 7).

DISCUSSION

The present study showed early development of white striping in birds, as this myopathy was already present in the 21-day slaughter, which suggests its occurrence even before that age (Table 1). The hypothesis for both this early development and the lack of correlation between bird sex and white striping relies on the intensified muscle development in commercial broiler strains, especially in the pectoralis major muscle. Allometric equations showed positive heterogonic growth of the breast ($b > 1$). This factor may be the physiological factor of animal growth and development, in which the muscle tissue presents its greatest development after birth, showing a later growth compared to bones; it prevails until maturity, then becoming the main constituent of weight gain. The development of bone tissue is characterized by its slow growth after the animal's birth, however, it becomes constant throughout the animal's life until its complete development (Luchiari Filho 2000; Castilho et al. 2022).

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Table 6. Allometric equations of commercial broiler cuts in relation to carcass weight at 21, 28, 35, 42, and 49 days, and allometric coefficient according to the age and sex of birds

Female			Male		
Equation	*t*-test (H_0: b = 1)	R^2	equation	*t*-test (H_0: b = 1)	R^2
21 days					
ln Breast = –0.949 6 + 1.010 8 ln PCRaj	< 0.000 1	0.570	ln Breast = –0.870 2 + 1.273 2 ln PCRaj	< 0.000 1	0.644
ln Legs = –1.802 6 + 0.986 2 ln PCRaj	< 0.000 1	0.660	ln Legs = –1.276 6 + 0.641 3 ln PCRaj	< 0.000 1	0.390
ln Wings = –2.285 8 + 0.814 6 ln PCRaj	< 0.000 1	0.430	ln Wings = –2.355 5 + 0.586 1 ln PCRaj	< 0.000 1	0.268
ln Back = –1.601 7 + 1.094 4 ln PCRaj	< 0.000 1	0.311	ln Back = –1.549 8 + 1.300 4 ln PCRaj	< 0.000 1	0.271
28 days					
ln Breast = –0.980 9 + 1.544 7 ln PCRaj	< 0.000 1	0.622	ln Breast = –0.992 6 + 1.255 8 ln PCRaj	< 0.000 1	0.502
ln Legs = –1.188 6 + 0.626 4 ln PCRaj	< 0.000 1	0.321	ln Legs = –1.109 8 + 0.627 9 ln PCRaj	< 0.000 1	0.354
ln Wings = –2.204 6 + 0.473 9 ln PCRaj	0.044	0.087	ln Wings = –2.181 2 + 0.549 3 ln PCRaj	0.001	0.231
ln Back = –1.576 9 + 0.792 4 ln PCRaj	0.038	0.093	ln Back = –1.673 7 + 1.247 7 ln PCRaj	0.006	0.177
35 days					
ln Breast = –0.998 1 + 1.373 7 ln PCRaj	< 0.000 1	0.787	ln Breast = –1.059 5 + 1.351 4 ln PCRaj	< 0.000 1	0.754
ln Legs = –1.143 3 + 0.815 2 ln PCRaj	< 0.000 1	0.477	ln Legs = –1.620 + 0.925 7 ln PCRaj	< 0.000 1	0.573
ln Wings = –2.072 + 0.474 7 ln PCRaj	0.001	0.262	ln Wings = –2.180 7 + 0.755 7 ln PCRaj	< 0.000 1	0.538
ln Back = –1.627 1 + 0.678 0 ln PCRaj	0.001	0.229	ln Back = –1.384 4 + 0.391 8 ln PCRaj	0.106	0.047
42 days					
ln Breast = –0.938 8 + 1.172 1 ln PCRaj	< 0.000 1	0.726	ln Breast = –1.298 6 + 1.515 ln PCRaj	< 0.000 1	0.845
ln Legs = –1.105 1 + 0.811 2 ln PCRaj	< 0.000 1	0.606	ln Legs = –0.830 1 + 0.577 7 ln PCRaj	< 0.000 1	0.460
ln Wings = –2.080 0 + 0.628 4 ln PCRaj	< 0.000 1	0.397	ln Wings = –2.000 3 + 0.605 4 ln PCRaj	< 0.000 1	0.439
ln Back = –1.840 6 + 1.104 26 ln PCRaj	< 0.000 1	0.369	ln Back = –1.364 7 + 0.556 8 ln PCRaj	0.003	0.198
49 days					
ln Breast = –0.954 5 + 1.177 8 ln PCRaj	< 0.000 1	0.897	ln Breast = –0.782 9 + 1.385 0 ln PCRaj	< 0.000 1	0.812
ln Legs = –1.242 6 + 0.991 7 ln PCRaj	< 0.000 1	0.795	ln Legs = –1.149 7 + 0.933 5 ln PCRaj	< 0.000 1	0.740
ln Wings = –2.213 6 + 0.850 1 ln PCRaj	< 0.000 1	0.732	ln Wings = –2.052 9 + 0.721 4 ln PCRaj	< 0.000 1	0.502
ln Back = –1.465 9 + 0.624 3 ln PCRaj	0.001	0.236	ln Back = –2.195 7 + 1.330 7 ln PCRaj	< 0.000 1	0.594

b = relative growth coefficient or allometric coefficient; ln = transformation of a logarithm into a linear equation; PCRaj = weight-adjusted chilled carcass; R^2 = indicates the adaptation of the equation to the data obtained; *t*-test = indication if the hypothesis (H_0) was accepted or rejected with a significance level of 5%
Considered 64 samples analysed at each age

According to Alnahhas et al. (2016), the white striping condition is genetically more correlated with the development of the pectoralis major muscle than with the overall body growth. In a way this explains the lack of correlation between bird sex and the presence or absence of white striping. Although male broilers have higher live weight than females, what these researchers propose is that breast development and yield are more determinant than bird weight for the occurrence of this myopathy. The present study highlighted this through the relative study of the body, in which birds had early breast growth at all ages, regardless of the sex.

Genetic selection increased the growth rate of birds as well as breast yield. Some authors argue that this increase in the muscle tissue does not necessarily receive the proportional nutritional input required for adequate metabolic exchanges. Joiner et al. (2014), for example, suggested that alterations related to myopathies possibly are a consequence of the reduction of oxygen supply to the affected tissues, resulting from the lower density of blood capillaries. This lower density would reduce vascular support, increasing the incidence of pectoral myopathies in broilers.

The present study highlighted a considerable evolution in the degrees of white striping with ad-

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Table 7. Allometric coefficient (*b* value) of male and female broilers at different ages

Age	Carcass cut			
	breast (*b* ± SD)	legs (*b* ± SD)	wings (*b* ± SD)	back (*b* ± SD)
Female (21 days)	1.01 ± 0.126	0.986 ± 0.102	0.814 ± 0.134	1.09 ± 0.231
P-value	< 0.000 1	< 0.000 1	< 0.000 1	< 0.000 1
Male (21 days)	1.27 ± 0.139	0.641 ± 0.114	0.586 ± 0.137	1.300 ± 0.302
P-value	< 0.000 1	< 0.000 1	< 0.000 1	< 0.000 1
Female (28 days)	1.54 ± 0.201	0.626 ± 0.149	0.473 ± 0.227	0.792 ± 0.149
P-value	< 0.000 1	0.000 2	< 0.000 1	0.038 7
Male (28 days)	1.25 ± 0.208	0.627 ± 0.139	0.549 ± 0.161	1.24 ± 0.426
P-value	< 0.000 1	< 0.000 1	0.001 7	0.006 1
Female (35 days)	1.33 ± 0.120	0.815 ± 0.146	0.474 ± 0.129	0.678 ± 0.200
P-value	< 0.000 1	< 0.000 1	0.000 8	0.001 8
Male (35 days)	1.35 ± 0.129	0.925 ± 0.133	0.755 ± 0.116	0.391 ± 0.236
P-value	< 0.000 1	< 0.000 1	< 0.000 1	0.106 7
Female (42 days)	1.17 ± 0.121	0.811 ± 0.109	0.628 ± 0.128	1.10 ± 0.238
P-value	< 0.000 1	< 0.000 1	< 0.000 1	< 0.000 1
Male (42 days)	1.51 ± 0.109	0.577 ± 0.104	0.605 ± 0.113	0.556 ± 0.178
P-value	< 0.000 1	< 0.000 1	< 0.000 1	0.003 7
Female (49 days)	1.17 ± 0.067	0.991 ± 0.086	0.850 ± 0.086	0.624 ± 0.181
P-value	< 0.000 1	< 0.000 1	< 0.000 1	0.001 5
Male (49 days)	0.985 ± 0.079	0.933 ± 0.092	0.721 ± 0.119	1.33 ± 0.184
P-value	< 0.000 1	< 0.000 1	< 0.000 1	< 0.000 1
OVERALL	1.12 ± 0.005	0.947 ± 0.004	0.880 ± 0.005	0.877 ± 0.010
P-value	< 0.000 1	< 0.000 2	< 0.000 1	< 0.000 1

SD = standard deviation; *t*-test = 0.05 significance
Considered 64 samples analysed at each age

vancing age, regardless of the bird sex. Few studies correlate the age with the appearance and incidence of myopathies. A possible explanation for the non-occurrence of wooden breast myopathies at 21 days of age in the present study is the distribution of the myopathic lesions in lighter degrees (grade 1) in the pectoralis major muscle. According to Bodle et al. (2018), grade 1 wooden breast consists of a mild hardness within the cranial region of the breast muscle of birds. This local, internal feature that is not visually noticeable makes the grade 1 wooden breast characterization subjective. This explains the absence of this myopathy in the breast of birds in the 21-day slaughter.

Wooden breast myopathy did not occur as isolated myopathy, that is, all fillets affected with this myopathy also presented white striping, regardless of the sex and slaughter age. The results of Table 2 suggest that with the worsening of white striping lesions, the traits of the pectoral muscle evolved to a new myopathy, i.e. wooden breast. This explains the non-occurrence of isolated wooden breast, a myopathy that always occurred in the presence of white striping.

To date, there has been no research mentioning that the occurrence of white striping precedes the development of wooden breast. However, Kuttappan et al. (2016) stated that although both myopathies have distinct and well-defined macroscopic features, their histomorphological characteristics and muscle responses are similar.

The present study showed that wooden breast myopathy correlates strongly and positively with live weight as well as breast weight and its physical measurements. In other words, the heavier the bird and consequently the heavier its breast, the higher the degree of this myopathy. Furthermore, the breast develops earlier and faster than the other parts of the body, as evidenced by allometric coefficients.

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Older birds tend to have higher muscle weight and size than younger birds. According to Radaelli et al. (2017), age is a determining factor for weight gain. These authors argue that lesion severity increases with advancing age of birds, as there is a strong reduction in small blood vessels, which reduces capillary density peripheral to the myofibre (Joiner et al. 2014). This change in vascular support hampers satellite cell-mediated repair mechanisms, leading to fibrosis (Siller 1985). These mechanisms precede the occurrence of wooden breast myopathy, which is characterized by a rigid prominence in the cranial part of the fillet. The presence of this condition in the birds justifies its correlation with the variables under study.

The L* value showed weak and medium positive correlation with white striping and wooden breast, respectively, indicating that the greater the severity of both myopathies, the lighter the fillets. According to Dalle Zotte et al. (2016), higher L* and b* values may correlate with fibrotic responses associated with myodegeneration. However, our results demonstrate that the b* value had no correlation with white striping and low correlation with wooden breast. Chartejee et al. (2016) also evaluated the a* value in myopathic and normal breasts and obtained results similar to those of this study. The authors concluded that the higher the degree of wooden breast and white striping, the lower the fillet redness, characterizing a negative correlation.

Drip loss, water-holding capacity, and cooking loss correlated weakly with both myopathies. However, drip loss and cooking loss were significantly higher in breasts with white striping and wooden breast than in breasts with white striping only and breasts without these changes (Table 4). Dalgaard et al. (2018) justified this difference in breasts affected by wooden breast from the increase in water present in the pectoral muscle due to tissue oedema because of inflammatory action and torn muscle tissue. When the muscle is damaged in the inflammatory process, water molecules embedded in the myofibrils are released into the extramyofibrillar space located between the muscle bundles and the sarcoplasm. Extramyofibrillar water molecules are loosely bound to the surrounding matrix in the sarcoplasm and can thus be easily released by lower impact mechanical or physical forces (Huff-Lonergan and Lonergan 2005; Malila et al. 2018).

CONCLUSION

Wooden breast developed later than white striping. The wooden breast condition did not occur as isolated myopathy, but rather always concomitantly with white striping. This suggests that the wooden breast condition occurs to the detriment of an aggravation of the white striping condition. Allometric coefficients from the study of relative body growth showed that the breast develops later than the other parts of the body. Wooden breast associated with white striping interfered with breast meat quality.

Conflict of interest

The authors declare no conflict of interest.

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