Brazilian Journal of Poultry Science
Revista Brasileira de Ciência Avícola

ISSN 1516-635X 2019 / v.21 / n.2 / 001-006

http://dx.doi.org/10.1590/1806-9061-2018-0759

Original Article

Practical Assessment of Spaghetti Breast in Diverse Genetic Strain Broilers Reared under Different Environments

Author(s)

Montagna FS[I] https://orcid.org/0000-0002-3076-0444
Garcia G[I] https://orcid.org/0000-0002-4978-9386
Nääs IA[I] https://orcid.org/0000-0003-0663-9377
Lima NDS[I] https://orcid.org/0000-0002-1284-7810
Caldara FR[I] https://orcid.org/0000-0002-7564-6127

[I] College of Agricultural Sciences, Federal University of Grande Dourados. Dourados, MS, Brazil.
[II] University of Campinas, School of Agricultural Engineering. Campinas, SP, Brazil.

Mail Address

Corresponding author e-mail address
Nilsa Duarte da Silva Lima
Faculdade de Engenharia Agrícola – FEAGRI, Av. Cândido Rondon, 501 - Barão Geraldo 13083-875 - Campinas/SP - Brasil.
Phone: (5567) 3410-2437
Email: nilsa.lima@feagri.unicamp.br

Keywords

Muscle structure. Pectoralis major. Rearing environment. Genetic strain. Myopathy.

Submitted: 18/February/2018
Approved: 23/February/2019

ABSTRACT

Brazilian processing plants have identified the so-calledspaghetti breast myopathy characterized by muscular dystrophy of unknown etiology. This study aimed at estimating the incidence of spaghetti breast myopathyin broilers from three commercial genetic strains (Ross, Cobb, Hubbard) reared in two different housing systems (DH, Dark house, and TS, Tunnel system), presenting different controlled ventilation systems and light availability. Breast meat samples (n=5,580) were collected and macroscopically evaluated for spaghetti breast myopathy according to a 0-2 scale, as 0 = normal, 1 = intermediate or moderate, and 2 = severe. A higher number of broilers reared in DH presented normal breasts and moderate myopathy relative to TS-reared birds. Ross broilers presented a higher incidence of normal breasts compared with Cobb and Hubbard broilers. The risk of presenting spaghetti breast myopathy was higher in broilers reared in DH than those in reared in TS, indicating that the exposure to DH environmental conditions may increase the chance of myopathy incidence. Broilers reared in dark houses presented 26% higher chance and 13% higher risk of showing spaghetti-breast myopathy the than those reared in tunnel-ventilated systems.

INTRODUCTION

Intensive selection of broilers for high growth rate and breast yield over the last 30 years has increased the incidence of breast meat abnormalities, such as deep pectoral myopathy, and pale-soft-and-exudative meat (PSE), and more recently white striping, wooden breast, and spaghetti breast associated with wooden breast (Kuttappan *et al.*, 2013; Petracci *et al.*, 2013a; Petracci *et al.*, 2013b). Myopathies of the muscle *Pectoralis major* are characterized by the disintegration and detachment of the muscle fibers, and the muscle *Pectoralis minor* may also be affected, causing anomalies including deep pectoral myopathy (green muscle disease) and wooden breast (fibrous fillet) of the muscle *Pectoralis major* (Kuttappan *et al.*, 2013; Tijare *et al.*, 2016).

These breast myopathies negatively affect chicken meat quality due to the presence of white streaks in the direction of fiber and by muscle atrophy, causing an undesirable visual aspect that is rejected by consumers and impairing its utilization in further processing (Kuttappan *et al.*, 2009; Kuttappan *et al.*, 2012; Petracci *et al.*, 2013a). The increasing incidence of muscular abnormalities results in economic losses to the processing companies, particularly in smaller parts, such as breast fillets (Bauermeister *et al.*, 2009).

One of the most recent myopathies detected in the poultry processing industry is the so-called spaghetti breast. This myopathy causes macroscopic changes in the Pectoralis major muscle. The structure of the meat is loose in as the muscle fibers present soft texture, pale color, and separation of muscle fiber bundles, which are easily detached when the condition is moderate and severe (Petracci*et al.*, 2012). Myopathy may be associated with white striping and wooden breast, according to Baldi *et al.* (2017). A similar pathology was also described in fresh pork and turkey meat by Voutila *et al.* (2009) and Voutila *et al.* (2008). The meat structure is severely affected, allowing to separate the muscle fibers with the fingers. Such a condition has severe consequences for the broiler meat processing industry (Bowker & Zhuang, 2016).

Researchers have suggested that several factors, such as genotype, sex, incubation process, growth rate, diet, and environment, affect the incidence and severity of myopathies in broilers (Kuttappan *et al.*, 2012; Kuttappan *et al.*, 2013; Lorenzi *et al.*, 2014; Petracci *et al.*, 2013a). The genetic selection pressure for a high carcass and parts yield has led to an increase in the incidence of myopathies. Although virtually all commercial broiler strains present high carcass yield and fast growth rate, slight differences among strains can be detected (Patricio *et al.*, 2012). Another major challenge of broiler production is environmental conditions. New production systems and technologies have been developed to provide better environmental conditions to allow modern high-yield broiler strains to express their full genetic potential, i.e., to achieve the highest market weight with the lowest feed intake (Bailey *et al.*, 2015).

The objective of this study was to determine the incidence of spaghetti breast myopathy of the *Pectoralis major* muscle of broiler and to evaluate the possible influence of the type of rearing/housing, and genetic strain.

MATERIALS AND METHODS

Birds and husbandry

The study was conducted in a broiler commercial processing plant located in the state of Mato Grosso do Sul, Brazil, located at 54°11'6" W longitude and 23°28'26" S latitude, between April and July 2017.

The experiment was approved by the Ethics Committee of the Federal University of Grande Dourados, Brazil, under protocol number 24/2015.

The study evaluated three broiler genetic strains, Hubbard, Cobb, and Ross, from two types of facilities (DH and TS), considered the average of 720 for Hubbard, 660 for Cobb, and 780 for Ross.

A straight-run (males and females) flock of 23,000 broilers was reared in each of eight broiler houses with two different construction and rearing concepts: DH (dark house) or TS (tunnel system). The DH house was 15-m wide, 150-m long and 3.8-m high, with a floor area of 31500 m^2, and equipped with forced-ventilation exhaustion fans (12 fans with 580 m^3 s^{-1} airflow), a high-pressure fogging system, and black-painted internal walls. The heating system for the first weeks of growth was placed in the air inlet and automatically controlled. Flock density in DH was 14 birds m^{-2}. The TS house was 12-m wide, 150-m long and 3.2-m high, with a floor area of 1800 m^2, and equipped with forced-ventilation exhaustion fans (11 fans with 450 m^3 s^{-1}air flow), and a high-pressure fogging system, and lateral open walls closed with yellow polypropylene curtains. The flock density in TS was 13 birds m^{-2}. The lighting system had fluorescent light bulbs, and the manually-controlled heating system was placed in the center of the house and was used from days 1 to 14 of the grow-out period. Both houses were East-West solar-oriented. Light intensity inside both house typeswas set at 25 lx for the first weeks of grow-out (7-21 d), and at 5 lx for the remainder of the grow-out cycle (42 d) using automatic light control-based sensors placed (Table 1). The two rearing concepts had similar ventilation systems with the air inlet at one end, and the outlet at the opposite side. Reflectivity inside was different in each house, as the inner walls of the DH houses were coated with black paint.

Table 1 – Lighting program applied in both HD and TS rearing systems.

Production phases (d)	Photoperiod (h)	Illuminance (lx)
1 - 7	23	25
8 - 21	18	5
22 - 35	20	5
36 - 45	22	5

The difference between the houses were the initial heating system (DH) and the solid black walls (DH) with heat isolation and 32 inlets. The TS house was open-sided closed with yellow polypropylene curtains. Birds had access to water and feed *ad libitum*, and management practices followed the recommendation of the commercial genetic strain manuals. Table 2 shows the basal commercial feed composition fed to the evaluated flocks, according to Rostagno *et al.* (2011).

Table 2 – Ingredient composition of the commercialdiets fed to the studied flocks according to rearing phase.

Ingredients	Pre-starter	Starter	Grower	Finisher
Corn	673.655	673.655	673.655	673.655
Soybean meal	244.596	244.596	244.596	244.596
Corn gluten meal	45.345	45.345	45.345	45.345
Soybean oil	10.000	10.000	10.000	10.000
Limestone	7.461	7.461	7.461	7.461
Meat and bone meal	5.660	5.660	5.660	5.660
Sodium bicarbonate	4.650	4.650	4.650	4.650
L-Lysine	2.760	2.760	2.760	2.760
Vitamin premix	1.929	1.929	1.929	1.929
DL-Methionine	1.663	1.663	1.663	1.663
Salt	1.285	1.285	1.285	1.285
Mineral premix	0.955	0.955	0.955	0.955
Enzyme	0.040	0.040	0.040	0.040
Total (kg)	1000.00	1000.00	1000.00	1000.00

Live performance evaluation

All performance parameters were calculated for 42-d-old broilers, and included final body weight (FBW, kg); feed conversion ratio (FCR, kg kg^{-1}); daily weight gain (DWG, g); feed intake (FI, kg), and mortality (MOR, %). Feed intake (kg $bird^{-1}$) was assessed per experimental unit. The feed conversion (FCR) values were calculated using the equation: FCR = (FCP kg) / (DWG kg). Daily weight gain (DWG) were determined using the equation: DWG (kg) = (average final weight - average initial weight)/bird age in days. The number of dead birds was daily recorded, and mortality was calculated as: MOR (%) = ((final number of dead birds)/(number of birds housed)) x 100. Livability was calculated as mortality minus 100 and expressed as a percentage.

Breast meat sampling and classification

At the commercial processing plant, breast samples of 3% of the slaughtered flock of each house were collected, totaling 5,580 breasts of broilers reared in both two types of the house (DH and TS) and from the three commercial evaluated genetic strains (Hubbard, Cobb, and Ross), from eight broiler houses (from the composition, sample 1: 3% Hubbard, sample 2: 3% Hubbard, sample 3: 3% Cobb, sample 4: 3% Cobb, sample 5: 1.5% Ross, sample 6: 1.5% Ross, sample 7: 1.5% Ross, and sample 8: 1.5% Ross).

The birds selected for the evaluation of spaghetti breast myopathy were identified in the evisceration room, after chilling and deboning. Their breasts were collected, and then 3% of the total number of breasts(n=5,580) were classified by trained professionals, who separated healthy breast from those presenting spaghetti breast characteristics (Figure 1).

Breasts were visually evaluated for the severity of spaghetti breast myopathy according to Bauermeister *et al.* (2009) and Kuttappan *et al.* (2012). A 3-score scale used was applied: 0 = normal, with no lesions, 1 = intermediate or moderate lesions; and 2 = severe lesions, as shown in Figure 1.

Data analysis

The total number of breast samples analyzed (n=5,580) corresponded to 3% of the total number of birds evaluated. The effect of housing type (DH or TS) and genetic strain (Ross, Cobb, Hubbard) on each myopathy score (normal, moderate, and severe) were separately analyzed. This procedure was also

Absence of SB myopathy or normal breast: the muscle presents normal structure, firm texture, and normal color.

Moderate SB myopathy: partially abnormal muscle fiber structure with the tendency to disintegrate, partially loose structure, and abnormal color.

Severe SB myopathy: completely disintegrated and loose muscle fiber structure, pale color.

Figure 1 – Visual classification of spaghetti breast (SB) myopathy in broilers.

adopted for evaluating the production system (house and genetic strain). Data were subjected to a one-way analysis of variance using a completely randomized design and means were compared by Student's t-test for independent samples (n = 5,580) at P < 0.05. The online statistical software VassarStats (Website for Statistical Computation) was used for statistical analyses.

RESULTS AND DISCUSSION

Broiler performance

The feed intake was obtained in DH-reared birds (FI = 5,580 g bird^{-1}) was almost 10% higher (p<0.05) than that of TS-reared ones (FI = 5,060 g). Housing type did not influence (p>0.05) final body weight, feed conversion ratio or mortality (Table 3).

Table 3 – Average final body weight (FBW), feed conversion ratio (FCR), daily weight gain (DWG), feed intake (FI), and mortality (MOR).

	Rearing systems					
Performance parameters	DH	TS	Average	SD	p-value	CV (%)
FBW (kg)	3.18	2.84	2.92	0.34	0.126	11.7
FI (kg)	5.58 a	5.06 b	5.19	0.31	0.012	5.9
FCR (kg/kg)	1.79	1.83	1.82	0.19	0.402	10.4
DWG (g)	62.5	56.8	58.3	6.86	0.176	11.8
MOR (%)	3.3	3.7	3.6	1.46	0.384	40.5

Different letters in the same row differ by Student's t-test using at 95% confidence interval (p < 0.05). CV = coefficient of variation. SD = Standard deviation.

Spaghetti breast myopathy

Housing type did not affect the incidence of severe spaghetti breast myopathy, regardless of the genetic strain (p>0.05). However, a higher number of healthy breasts (p<0.05) were determined for DH- than TS-reared birds presenting normal (DH = 359; TS = 348) and moderate (DH = 334; TS = 320) degrees of spaghetti breast (Table 4).

Table 4 – Degrees of spaghetti-breast myopathy according to rearing system.

	Degree of spaghetti breast		
Rearing system	Normal or Absent	Moderate	Severe
DH (Dark house)	359 a	334 a	27
TS (Tunnel system)	348 b	320 b	22
Average	350	324	23
Standard deviation	112	99	9
p-value	<.0001	<.0001	0.5486
Coefficient of variation (%)	32	30	38

Different letters in the same column differ by Student's t-test using at 95% confidence interval (p < 0.05). CV = coefficient of variation. SD = Standard deviation.

The environmental rearing conditions may influence the incidence of pectoral myopathy since it is influenced by management, nutrition, and health condition, which are related to the construction typology of the houses (Kuttappan *et al.*, 2012). According to Mitchell & Sandercock (2004), pectoral myopathy may also associated to level of stress birds experience during the grow-out phase. Broilers reared under the DH concept (Dark House) usually present superior performance results compared to conventional rearing systems due to the degree of automation, ensuring better broiler thermal comfort. The TS (tunnel rearing system) had a low level of environmental control and, therefore, it is greatly influenced by environmental variables (Miragliotta *et al.*, 2006).

When evaluating the commercial genetic strains, no differences (p>0.05) were observed in the incidence of severe myopathy. However, there was a higher incidence of normal breasts (p<0.05) in Ross broilers, whereas Hubbard broilers had a higher incidence (p<0.05) of moderate myopathy compared with the other evaluated strains (Table 5).

Table 5 – Average incidence of spaghetti-breast myopathy according to commercial genetic strain.

	Degree of myopathy spaghetti breast		
Genetic strain	Normal or Absent	Moderate	Severe
Hubbard	368 b	327 a	25
Cobb	314 c	323 b	23
Ross	433 a	324 b	23
Average	350	324	23
Standard deviation	112	99	9
p-value	<0.0001	<0.0001	0.9900
Coefficient of variation (%)	32	30	38

Different letters in the same column differ by t-Student test using a confidence interval of 95% (p < 0.05).

The presence of breast myopathy lesions was recorded in broilers reared under both housing concepts. Odds ratio (RC=1.26) and relative risk (RR=1.13) results indicated an association between myodegeneration (p<0.05) and housing system concept (Table 6). Broilers reared in DH presented 26% higher chance and 13% higher risk of showing *Pectoralismajor* muscle fiber changes the than those reared in TS. These results indicate that birds reared under DH may present spaghetti breast myopathy more often.

Improvements in the environmental conditions associated with genetic selection have allowed accelerated growth rates in broiler chickens. The Cobb genetic strain is the most frequently used in commercial broiler production due to its adequate final weight gain (Henn *et al.*, 2014), excellent live

Table 6 – Incidence of spaghetti breast myopathy and the Odds Ratio and Relative Risk Ratio of spaghetti breast myopathy prevalence in broilers reared in two different rearing systems.

	Incidence (number of breasts)		
Rearing systems	Present	Absent	Total
DH (Dark house)	723	717	1,440
TS (Tunnel system)	694	866	1,560
Total	1,417	1,583	3,000

	Association measurements	
Factor	Odds Ratio	Relative Risk Ratio
DH *vs.* TS	1.26 (1.09 - 1.45)	1.13 (1.05 - 1.22)
p-value	0.002	

Confidence interval (95%).

performance, and high carcass yield, particularly breast yield. The Ross genetic strain is characterized byslow initial growth rate, which is compensated from 21 d of age, and may reach the same slaughter weight and carcass yield as Cobb broilers when slaughtered at 45 days of age (Kokoszyński *et al.*, 2017). According to Udeh & Ogbu (2011) define that the Hubbard genetic strain underwent a process of adaptation that allowed the birds to have superior production performance compared with other strains. The main characteristic of Hubbard broilers is their resistance to rearing temperature variations and therefore, they perform well when reared in tropical regions. However, their carcass and parts yield are not as good as that of Cobb and Ross broilers.

The genetic selection for the traits high growth rate and yield increases the genetic pressure on birds, resulting in histological and biochemical changes in the muscle tissue (Bauermeister *et al.*, 2009). Kuttappan *et al.* (2012) observed that male broilers present a higher incidence of the white striping myopathy, whichis associated with heavier birds with high growth rates. Genetic selection for weight gain and breast yield has increased muscle fiber size, mainly of the *Pectoralis major* muscle. Studies showed that, compared with traditional broiler breeds, the muscle fibers of broilers from commercial have larger diameter (Macrae *et al.*, 2006; Petracci*et al.*, 2013a).

Considering that the DH system provides a more efficient rearing environment due to its better control of microclimate conditions compared with TS, broiler would probably have better performance, including faster weight gain. Environmental factors may contribute to the incidence of breast muscle myopathy in broilers (Bailey *et al.*, 2015). A study by Kuttappan *et al.* (2013) evaluating the factors associated with the occurrence of white striping in chicken breast fillets showed that heavier birds have higher probability of presenting more severe degree of this myopathy; however, the condition was not related to changes in the quality of cooked meat. Current concerns about the quality of poultry meat are associated with diseases of the *pectoralis* muscle. Such issues impair the appearance of the product and increase the occurrence of problems related to meat water retention capacity, as well as to low resistance and cohesion associated with the immaturity of the intramuscular connective tissue (Alnahhas *et al.*, 2016).

The different types of rearing systems do not ensure performance uniformity during the grow-out period. In addition of the the facilities, management practices, health, nutrition, environment, and the welfare of the birds are important during their development stages (Kuttappan *et al.*, 2009; Kuttappan *et al.*, 2012; Velleman *et al.*, 2003;).

Several studies have found a correlation between high growth rate, high breast yield, and the incidence of lesions affecting the quality of the *Pectoralismajor* muscle (Kuttappan *et al.*, 2012; Lorenzi *et al.*, 2014; Petracci *et al.*, 2014; Sihvo *et al.*, 2014). Growth differences among genetic strain could also influence the incidence of this condition in the muscle (Kuttappan *et al.*, 2013). Carcasses affected with muscular myopathies have undesirable visual appearance, increasing carcass downgrading, and reducing consumer acceptability, resulting in economic losses for the entire broiler production chain (Radaelli *et al.*, 2016; Zambonelli *et al.*, 2016). In addition, white striping substantially deteriorates the nutritional value of broiler breast meat, which may harm future consumer attitude towards poultry meat (Petracci *et al.*, 2014).

CONCLUSIONS

Broilers reared in dark houses presented 26% higher chance and 13% higher risk of showing spaghetti breast myopathy the than those reared in tunnel-ventilated systems.

Broiler strains genetically selected for fast growth rate and high carcass yield showed higher incidence of the studied breast meat myopathy, suggesting high economic losses.

The present study indicated that the visual analysis of broiler breasts during processing allows easy and fast evaluation of the severity of breast lesions.

REFERENCES

Alnahhas N, Berri C, Chabault M, Chartrin P, Boulay M, Bourin MC, *et al.* Genetic parameters of white striping in relation to body weight carcass composition and meat quality traits in two broiler lines divergently selected for the ultimate pH of the *pectoralis major* muscle. BMC Genetics 2016;17:61.

Bailey R, AWatson KA, Bilgili SF, Avendano S. The genetic basis of pectoralis major myopathies in modern broiler chicken lines. Poultry Science 2015;94:2870-2879.

Baldi G, Soglia F, Mazzoni M, Sirri F, Canonico L, Babini E, *et al.* Implications of white striping and spaghetti meat abnormalities on meat quality and histological features in broilers. Animal 2017;22:1-10.

Bauermeister LJ, Morey AU, Moran ET, Singh M, Owens CM, McKee SR. Occurrence of white striping in chicken breast fillets in relation to broiler size. Poultry Science 2009;88(Suppl 1):33.

Bowker B, Zhuang H. Impact of white striping on functionality attributes of broiler breast meat. Poultry Science 2016;95:1957-1965.

Henn JD, Bockor L, Ribeiro AML, Coldebella A, Kessler A de M. Growth and deposition of body components of intermediate and high-performance broilers. Brazilian Journal of Poultry Science 2014;16:319-328.

Kokoszyński D, Bernacki Z, Saleh M, Stęczny K, Binkowska M. Body Conformation and Internal Organs Characteristics of Different Commercial Broiler Lines. Brazilian Journal of Poultry Science 2017;19:47-52.

Kuttappan VA, Brewer VB, Clark FD, McKee SR, Meullenet JF, Emmert JL, Owens CM. Effect of white striping on the histological and meat quality characteristics of broiler fillets. Poultry Science 2009;88:136-137.

Kuttappan VA, Brewer VB, Apple JK, Waldroup PW, Owens CM. Influence of growth rate on the occurrence of white striping in broiler breast fillets. Poultry Science 2012;91:2677-2685.

Kuttappan VA, Brewer VB, Mauromoustakos A, Mckee SR, Emmert JL, *et al.* Estimation of factors associated with the occurrence of white striping in broiler breast fillets. Poultry Science 2013;92:811-819.

Lorenz M, Mudalal S, Cavani C, Petracci M. Incidence of white striping under commercial conditions in medium and heavy broiler chickens in Italy. The Journal of Applied Poultry Research 2014;23:754-758.

MacRae VE, Mahon M, Gilpin S, Sandercock DA, Mitchell MA. Skeletal muscle fiber growth and growth associated myopathy in the domestic chicken (*Gallus domesticus*). British Poultry Science 2006;47:264-272.

Miragliotta M, Y NääsI A, Manzione RL, Nascimento FF. Spatial analysis of stress conditions inside broiler house under tunnel ventilation. Scientia Agricola 2006;63:426-432.

Mitchell MA, Sandercock DA. Spontaneous and stress induced myopathies in modern meat birds: a cause for quality and welfare concerns. Australian Poultry Science Symposium 2004;16:100-107.

Patriciol. S Mendes A. A Ramos A. A. and Pereira D. F. Overview on the performance of Brazilian broilers (1990 to 2009). Brazilian Journal of Poultry Science2012;14:233-238.

Petracci M, Cavani C. Muscle growth and poultry meat quality issues. Nutrients 2012;4:1-12. 2012.

Petracci M Sirri F Mazzon iM. and Meluzzi A. Comparison of breast muscle traits and meat quality characteristics in 2 commercial chicken hybrids. Poultry Science 2013a;92:2438–2447.

Petracci M, Mudalal S, Bonfiglio A, Cavani C. Occurrence of white striping under commercial conditions and its impact on breast meat quality in broiler chickens. Poultry Science 2013b;92:1670-1675.

Petracci M, Mudalal S, Babini E, Cavani C. Effect of white striping on chemical composition and nutritional value of chicken breast meat. Italian Journal of Animal Science 2014;13:179-183.

Radaelli G, Piccirillo A, Birolo M, Bertotto D, Gratta F, Ballarin C, *et al.* Effect of age on the occurrence of muscle fiber degeneration associated with myopathies in broiler chickens submitted to feed restriction. Poultry Science 2016;96:309-319.

Rostagno HS. Tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais. 3rd ed. Viçosa: Universidade Federal de Viçosa; 2011.

Sihvo H, KImmonen K, Puolanne E. Myodegeneration with fibrosis and regeneration in the pectoralis major muscle of broilers. Veterinary Pathology 2014;51:619-623.

Tijare VV, Yang FL, Kuttappan VA, Alvarado CZ, Coon CN, Owens CM. Meat quality of broiler breast fillets with white striping and woody breast muscle myopathies. Poultry Science 2016;92:2167-2173.

Udeh I , Ogbu CC. Principal component analysis of body measurements in three strains of broiler chicken. The Scientific World Journal 2011;6:11-14.

VassarStats. Website for statistical computation [cited 2017 Feb 23]. Available from: http://vassarstats.net/2012.

Velleman S, GAnderson JW, Coy CS, NestorK E. Effect of selection for growth rate on muscle damage during turkey breast muscle development. Poultry Science 2003;82(7):1069-1074.

Voutila L Ruusunen M, Jouppila K, Puolanne E. Thermal properties of connective tissue in breast and leg muscles of chickens and turkeys. Journal of the Science of Food and Agriculture 2009;89:890-896.

Voutila L, Ruusunen M, Puolanne E. Comparison of the thermal characteristics of connective tissue in loose structured and normalstructured porcine M. semimembranosus. Meat Science 2008;80:1024-1030.

Zambonelli P, Zappaterra M, Soglia F, Petracci M, Sirri F, Cavani C, *et al.* Detection of differentially expressed genes in broiler pectoralis major muscle affected by White Striping – Wooden Breast myopathies. Poultry Science 2016;95:2771-2785.