Comparison of 2 commercial turkey hybrids: productivity, occurrence of breast myopathies, and meat quality properties

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ABSTRACT This study was undertaken to compare productive performance, occurrence of breast myopathies, chemical composition, and technological properties of the meat in 2 dominant commercial turkey hybrids. A total of 972 1-day-old male turkey poults (equally divided in hybrid A and B) were randomly distributed in 18 floor pens.

Overall, productive performance resulted similar between the genotypes, although they showed different growth profile (turkeys from group B grew up faster up to 84 d). Regarding the occurrence of myopathies, the percentage of breasts affected by white striping was markedly higher in both genotypes (46 vs. 60% of severe lesions, respectively for A and B; $P < 0.05$), while the occurrence of spaghetti meat-like condition was negligible. The histological features of the different categories of meat abnormalities resulted similar to those previously described for chicken hybrids.

The technological traits such as ultimate pH, lightness, redness, marinade uptake, cooking losses, and shear force were not significantly affected by the genotype. However, turkeys from group B exhibited lower yellowness (b[*], 0.50 vs. 1.04; $P < 0.05$) and higher drip losses (1.34 vs. 1.26%; $P < 0.05$). The shelf-life test on thigh meat showed no significant changes in meat color over the storage time in both hybrids, whereas thigh meat from group A showed absolute lower values of lightness (L[*]) and yellowness (b[*]) ($P < 0.05$). Lipid oxidation of thigh meat significantly increased during storage, although no significant difference was found between the hybrids. Proximate composition and intramuscular collagen properties resulted similar between genetic lines with the exception of total fat content (1.55 vs. 1.21%, respectively for A and B; $P < 0.05$). The genotype had a moderate effect on fatty acid families of breast meat as only monounsaturated fatty acid content was significantly affected (31.7 vs. 29.8%, respectively for A and B). In conclusion, the overall productive traits of commercial turkeys, including the occurrence of muscle myopathies, as well as quality attributes of fresh and refrigerated meat were only slightly affected by the genotype.

Key words: turkey, growth, meat quality, chemical composition, myopathies

INTRODUCTION

Throughout the world, consumers are increasingly attracted to poultry meat. Turkey meat is the second most consumed poultry meat worldwide (Remignon, 2004), and it is highly appreciated for its delicate taste and texture, but also for its modest levels of total lipids, saturated fatty acids (**SFA**), and cholesterol content (USDA, 2011), which influence the perceived healthfulness of turkey meat. Much of the world's increase in turkey production is powered by continued genetic progress resulting from the work of primary breeders (Strasburg and Chiang, 2009). In addition, the increasing demand for further-processed products, coupled with a preference for breast meat in Western countries, has shifted selection toward birds with high breast development (Fletcher, 2004; Remignon, 2004). This selection pressure has greatly increased growth rate and edible meat yield of commercial turkeys while reducing feed conversion ratio (**FCR**) and slaughter age. Havenstein et al. (2007), summarizing the changes that have taken place in the turkey industry from 1966 through 2003, reported that the 2003 turkeys were twice as heavy as 1966 turkeys at the same slaughter age. Feed efficiency was 50% higher in 2003 toms in comparison to the 1966 counterpart. Total edible carcass yield increased by 6.5% over this 37-yr period. However, as observed in broiler chickens, a great number of scientific evidences suggest that the intense genetic

selection could be associated with impaired meat quality and increased incidence of stress-induced myopathies (Petracci et al., 2015; Kuttappan et al., 2016; Patterson et al., 2017; Baldi et al., 2018). Typical muscle fiber defects observed in turkeys selected for increased growth rate include deep pectoral myopathy (Wilson et al., 1990; Sosnicki and Wilson, 1991), focal myopathy (Sosnicki, 1993), and pale, soft, and exudative meat (Barbut, 1997; Owens and Sams, 2000; Strasburg and Chiang, 2009), and more recently white striping (**WS**) condition (Soglia et al., 2018). Swatland (1990) observed an abnormality affecting both raw and cooked turkey breast muscles, which exhibited a loose in structure (i.e., disintegrated) with the tendency of muscle fiber bundles to separate. The author observed an increased cross-sectional area in muscle fibers from disintegrated meat, suggesting that these fibers have outgrown their connective tissue leading to the formation of large intracellular spaces. Wilson et al. (1990) found more fragmenting muscle fibers and higher plasma creatine-kinase concentration in fast-growing lines compared to slow-growing ones and hypothesized that the selection for growth rate in turkeys has resulted in muscles that have outgrown their life-support systems. Recently, a new abnormality termed 'spaghetti meat (**SM**)' has been observed in broiler chickens. Being characterized by an altered structural integrity of the cranial surface of the P. major muscle (Baldi et al., 2018), this defect seems to be analogous to the abnormality observed in turkey breast muscles by Swatland (1990). Furthermore, the growing concern of the poultry industry regarding these new emerging meat quality issues has heightened the need for extending knowledge not only on broiler chickens but also on turkeys.

The current study was undertaken to compare productive performance, occurrence of breast myopathies, and quality traits of meat, both fresh and after refrigerated storage, in 2 dominant commercial turkey hybrids currently available for the poultry industry and raised under the same farming conditions.

MATERIALS AND METHODS

Birds, Diets and Experimental Design

All procedures including the use of birds, management, and care were in compliance with the European parliament and the European Council Directive regulation on the protection of animals used for scientific purposes (European Commission, 2010).

A total of 972 1-day-old male turkey poults belonging to 2 modern fast-growing hybrids (486 birds of hybrid A and 486 of hybrid B), both currently available and used in worldwide commercial practices, was housed in an environmental controlled shed and randomly distributed in 18 floor pens (9/genotype) of 18 m^2 each (54 toms/pen). The turkey lines tested in this study belong to 2 different breeding companies and are not genetically related. The birds were raised on fresh pinewood shavings litter and fed a common commercial diet (Table 1). Feed was provided according to a 6-phase feeding program (starter, 0 to 16 d; grower I, 17 to 35 d; grower II, 36 to 56 d; grower III, 57 to 84 d; finisher I, 85 to 112 d; finisher II, 113 to 140 d). Coccidiostats (monensin) was included in starter, grower I, and grower II feed.

Housing, management, feeding, and husbandry conditions were representative for current commercial operations in Europe. The temperature and lighting programs were consistent with the recommendations provided by the genetic companies. Water and feed were supplied on ad libitum basis. The physical form of the feed was as follows: starter, crumbled; grower I, pellet (diameter 2.5 mm); grower II to slaughter, pellet (diameter 3.5 mm).

Productive Performance

Turkeys were weighed on a pen basis at placement (0 d), at the end of each feeding phase (16, 35, 56, 84, and 112 d) and at slaughter (140 d), and body weight (**BW**) and daily weight gait (**DWG**) were determined accordingly. Similarly, feed intake was recorded on a pen basis at 16, 35, 56, 84, 112, and 140 d. FCR was calculated according to these measurements in each feeding phase and in the overall period of trial. Dead or culled turkeys were weighed and recorded on a daily basis, and their BW was taken into consideration for the calculation of productive parameters. All the birds were slaughtered at the end of the experiment (140 d) in a commercial processing plant. Feed withdrawal was about 9 h, of which 6 on farm and 3 on loading, transport, and lairage.

Slaughtering Evaluations

Processing yields, consisting of eviscerated carcass, skinless breast, thighs, and wings, were measured on all the slaughtered birds and results reported on a group basis. Yield determination was made after air-chilling. The incidence and severity of WS and SM-like conditions were assessed on 100 randomly collected breasts/group approximately 24 h after processing. As for WS, the dimension of white striations was used to classify the severity of the defect into 4 classes (0: no lesions; 1: mild lesions—few stripes; 2: marked lesions—up to 50% of surface; 3: severe lesions—more than 50% of surface). A 3 point-scale evaluation system (0: no lesions; 1: mild lesions; 2: severe lesions) was applied to rank the severity of SM-like defect according to the tendency of the breasts to show muscle deconstruction in response to finger pinching, as previously described by Sirri et al. (2016) in broilers.

Table 1. Composition of the different diets supplied in each feeding phase to both the turkey genotypes (A and B).

	Starter 0-16 d	Grower I 17-35 d	Grower II 36-56 d	Grower III 57-84 d	Finisher I 85-112 d	Finisher II 113-140 d
Ingredients, g/100 g						
Wheat	22.3	27.1	30.0	39.3	39.2	41.1
Corn	18.3	16.1	17.5	15.0	14.6	15.7
Soybean meal 48%	36.5	32.9	30.0	26.0	12.8	8.32
Full-fat soybean	10.0	10.0	10.0	10.0	21.0	22.5
Sunflower meal	3.00	3.00	3.00	0.00	0.00	0.00
Protein hydrolysate	2.00	2.00	0.00	0.00	0.00	0.00
Wheat bran	0.00	0.00	0.00	0.00	3.00	3.00
Beef tallow	0.51	0.51	0.51	0.00	5.93	6.41
Poultry fat	2.35	3.09	4.08	5.53	0.00	0.00
Lysine	0.66	0.63	0.62	0.51	0.45	0.38
DL-Methionine	0.37	0.35	0.40	0.35	0.33	0.27
L-Threonine	0.16	0.15	0.15	0.13	0.11	0.08
Premix vit.-min.[1]	0.45	0.45	0.40	0.33	0.35	0.30
Calcium carbonate	0.95	0.92	0.83	0.87	0.68	0.64
Dicalcium phosph.	2.25	2.16	1.86	1.44	0.91	0.65
Sodium chloride	0.25	0.22	0.28	0.23	0.19	0.22
Sodium bicarb.	0.00	0.00	0.05	0.10	0.17	0.15
Choline chloride	0.10	0.10	0.10	0.10	0.10	0.00
Phytase	0.30	0.30	0.30	0.20	0.20	0.20
β-gluc./xylanases	0.08	0.08	0.08	0.08	0.08	0.08
Coccidiostat[2]	0.04	0.04	0.04	0.03	0.00	0.00
Calculated composition						
Dry matter, %	88.8	88.9	88.6	88.6	88.6	88.6
Crude protein, %	26.8	25.4	23.4	21.1	19.2	17.8
Total lipid, %	6.26	6.95	7.90	8.76	10.8	11.6
Crude fiber, %	3.29	3.23	3.17	2.66	2.75	2.72
Ash, %	7.52	7.18	6.54	5.83	4.90	4.43
Lysine, %	1.79	1.68	1.55	1.36	1.20	1.08
Met. + Cyst., %	1.19	1.13	1.09	0.98	0.87	0.80
Arginine, %	1.81	1.70	1.57	1.37	1.23	1.13
Ca (total), %	1.21	1.17	1.03	0.91	0.71	0.62
P (total), %	0.83	0.79	0.71	0.61	0.50	0.45
AME, kcal/kg	2,810	2,890	2,980	3,130	3,280	3,360

[1]Provided the following per kg of diet: vitamin A (all trans-retinol acetate), 13,500 IU; vitamin D3 (cholecalciferol), 3,000 IU; vitamin E (DL-α_tocopheryl acetate), 100 mg; vitamin K (menadione sodium bisulfite), 5 mg; riboflavin, 9.0 mg; pantothenic acid, 30 mg; niacin, 30 mg; pyridoxine, 7 mg; folic acid, 3 mg; biotin, 0.35 mg; thiamine, 4 mg; cyanocobalamin, 40 μg; Mn, 100 mg; Zn, 85 mg; Fe, 50 mg; Cu, 15 mg; I, 2 mg; Se, 0.3 mg; ethoxyquin, 100 mg
[2]Monensin.

Technological Traits of Breast Meat

At 24 h postmortem, 15 P. major muscles per group showing no macroscopic defects were collected at the processing plant and used for determining the chemical composition and technological traits of the breast meat. After trimming from visible fat, cartilage, and connective tissue, color (Lightness—L*, Redness—a*, Yellowness—b*; CIE, 1976) was measured in triplicate on the bone-side surface of the cranial portion of the muscle with a Chroma Meter CR-400 (Minolta Corp., Milan, Italy). A subsample was excised from the cranial portion of the muscle to assess ultimate pH following the iodoacetate method proposed by Jeacocke (1977). Then, quality traits of raw meat (drip loss, cooking loss, and Allo-Kramer shear force) were evaluated on a parallelepiped meat cut (8 × 4 × 3 cm, weighing about 80 g) sampled according to our previous study (Soglia et al., 2018). Raw meat cuts were placed in covered plastic boxes over sieved plastic racks and stored for 48 h at 4 ± 1°C in order to assess drip loss. Subsequently, samples were individually packaged under vacuum and cooked in a water bath at 80°C for 45 min (80°C at

the core thus avoiding any temperature gradient between the inner and the outer portion of the samples). After cooking, shear force was assessed on a subsample (4 × 2 × 1 cm) by using a TA.HDi heavy duty texture analyzer (Stable Micro Systems Ltd., Godalming, Surrey, UK) equipped with a 25 kg loading cell and an Allo-Kramer shear cell (10 blades) (Smith and Fletcher, 1988). Subsequently, to determine marinade uptake and cooking losses of marinated meat, a further parallelepiped meat cut (8 × 4 × 2 cm, weighing about 75 g) was excised and vacuum-tumbled used by using a small-scale tumbler (model MGH-20; Vakona Qualitat, Lienen, Germany) with a 20% (wt/wt) aqueous solution containing sodium tripolyphosphate (1.8%) and sodium chloride (6.0%). The samples were then weighed (to estimate marinade uptake), individually packaged under vacuum and cooked (80°C, 25 min) in order to calculate cooking losses.

Moreover, deboned thigh muscles (skin-on) were also obtained from each carcass at 24 h postmortem, individually packed under ordinary atmosphere and stored for 7 d at 3 ± 1°C in a cooler. At 0, 3, and 7 d of storage, 5 samples (Ilio-tibial muscle) for each group

per sampling time were used to monitor pH and color (L^*, a^*, b^*) evolution by using the same methods described above. In addition, to evaluate lipid oxidation, the thiobarbituric acid-reactive substances (**TBARS**) were quantified following the procedure proposed by Bao and Ertbjerg (2015) and the results expressed as mg MDA/kg of meat.

Proximate and FA Composition

With regard to proximate composition, moisture and ash contents were determined in duplicate on the same 15 breasts/group according to the procedure described by the Association of Official Analytical Chemists (AOAC, 1990). Crude protein content was assessed by Kjeldahl method from the ammonia ions neutralized by sodium hydroxide (AOAC, 1990). Finally, the chloroform–methanol extraction procedure reported by Folch et al. (1957) was used to determine the total fat content of breast meat.

After extracting the intramuscular fat by chloroform–methanol, the FA profile was determined as methyl esters, using a gas chromatograph ThermoQuest TRACE 2000 (SAC^{tm}-5 column 3000 cm × 0.25 mm, Supelco, USA). Helium was used as the carrier gas at a flow rate of 1.5 mL/min with constant flow compensation. GC inlets and the detector were held at a temperature of 240 and 250°C, respectively. The oven temperature was programmed from 150°C and followed by a ramp at a rate of 5°C/min till 240°C with a final hold of 15 min (the total analysis time was 33.00 min). The identification of individual FA was carried out by using polyunsaturated fatty acid (**PUFA**-2 FA) methyl ester standards (Matreya, Pleasant Gap, PA). Results were expressed as percentage of the total FA identified. To assess the nutritional implications, the n-6/n-3 FA ratio and the PUFA/SFA (**P/S**) ratio were calculated. Moreover, in order to evaluate the risk of atherosclerosis and the potential aggregation of blood platelets, the atherogenic index (**AI**) and the thrombogenic index (**TI**) were respectively calculated according to the formulas suggested by Ulbricht and Southgate (1991).

Intramuscular Collagen Analysis

At analysis, 15 muscle samples were thawed at room temperature, trimmed of fat and epimysium, and lyophilized for 48 h. 100 mg of each lyophilized sample was weighed and hydrolyzed in Duran tubes in 5 mL 6N HCl at 110°C for 18 to 20 h for the determination of hydroxyproline (Woessner, 1961) and crosslinking. The analyses were carried out in duplicate. Intramuscular collagen (**IMC**) concentration was calculated according to Eastoe and Leach (1958) and expressed as μg hydroxyproline/mg of lyophilized tissue, assuming that collagen weight was 7.25 times the measured hydroxyproline weight. Hydroxylysylpyridinoline (**HLP**) concentration, the principal non-reducible crosslink of

muscle collagen which is highly correlated with the thermal stability of collagen (McCormick, 1999), was determined using the procedure described by Eyre et al. (1984). A Kontron HPLC (Kontron Instruments, Milan, Italy) model 535, equipped with a Luna C18 column (250 × 4.6 mm × 5 μm; Phenomenex, Torrance, CA), was used. The concentration of HLP residues in the samples was calculated based on the concentration of collagen in each hydrolysate by assuming that the molecular weight of collagen was 300,000 and the molar fluorescence yield of pyridoxamine (internal standard) was 3.1 times that of HLP (Eyre et al., 1984). The HLP was expressed as moles of HLP per mole of collagen and also as micrograms of HLP per milligram of lyophilized tissue.

Histological Features

The histological evaluations were performed on a total of 10 P. major muscles representative of abnormality and degree of severity adopted for testing the occurrence of these myopathies (WS 0, 1, 2, and 3 and SM 0 and 1). Each sample was cut in order to separate the superficial from the deep layer according to the sampling protocol previously described by Soglia et al. (2017). To prevent muscle contraction, the ends of the muscle samples were pinned on the balsa wood as previously described by Velleman et al. (2013). Subsequently, the samples were immediately fixed in a 10% buffered formalin solution for 24 h at room temperature. After that, specimens were oriented for transverse fiber sectioning, dehydrated in a graded series of ethanol, and embedded in paraffin. From each sample, transverse sections (6 μm thick) were obtained, mounted on polylysine-coated slides and stained with Masson's trichrome.

Statistical Analyses

Productive performance data were analyzed through the Student-T test by considering the genotype as the experimental factor. The experimental unit was the pen. Similarly, Student's t-test used to analyze the data regarding technological traits, IMC, and proximate and FA composition of breast meat. Two-way ANOVA was used to test the effect of genotype and storage and their interactions on pH, color, and oxidative stability of turkey thigh meat. Chi-square test was applied for the statistical analysis of the data regarding the occurrence of breast myopathies (SAS Institute, 1988). For these parameters, the bird was considered as the experimental unit.

RESULTS AND DISCUSSION

Productive Performance

The productive performance of both the genetic lines is reported in Table 2. At housing (0 d), poults A

Table 2. Effect of the genotype (A and B) on productive performance of male turkeys in each feeding phase.

	A	B	SE	P value
n	9	9		
0 to 16 d				
Poults body weight (g)	62.8[B]	67.4[A]	0.001	<0.001
Body weight (g)	500[B]	522[A]	4.40	<0.001
Daily weight gain (g/bird/d)*	27.4[B]	28.5[A]	0.28	<0.01
Daily feed intake (g/bird/d)*	36.5[B]	38.3[A]	0.001	<0.001
Feed conversion rate*	1.306	1.328	0.01	0.10
Mortality (%)	0.00	0.00	0.01	-
17 to 35 d				
Body weight (g)	2,074[B]	2,204[A]	21.7	<0.001
Daily weight gain (g/bird/d)*	82.5[B]	88.4[A]	1.05	<0.001
Daily feed intake (g/bird/d)*	115.5[B]	121.5[A]	1.27	<0.001
Feed conversion rate*	1.401[A]	1.376[B]	0.01	<0.01
Mortality (%)	0.97	0.39	0.03	0.26
36 to 56 d				
Body weight (g)	5,345[B]	5,535[A]	41.8	<0.001
Daily weight gain (g/bird/d)*	155.4	157.4	1.48	0.20
Daily feed intake (g/bird/d)*	251.5[B]	256.7[A]	1.48	<0.01
Feed conversion rate*	1.619	1.632	0.01	0.31
Mortality (%)	0.78	1.56	0.04	0.23
57 to 84 d				
Body weight (g)	9,486[B]	10,309[A]	284.5	<0.01
Daily weight gain (g/bird/d)*	146.5	168.7	11.4	0.07
Daily feed intake (g/bird/d)*	367.8	368.3	7.46	0.95
Feed conversion rate*	2.658	2.186	0.25	0.08
Mortality (%)	1.78	2.18	0.04	0.66
85 to 112 d				
Body weight (g)	15,174[b]	15,610[a]	209.1	<0.05
Daily weight gain (g/bird/d)*	195.6	179.4	14.4	0.28
Daily feed intake (g/bird/d)*	470.1	454.2	9.00	0.10
Feed conversion rate*	2.487	2.535	0.14	0.68
Mortality (%)	6.88	6.92	0.03	0.97
113 to 140 d				
Body weight (g)	20,016	19,850	156.1	0.32
Daily weight gain (g/bird/d)*	168.6	156.6	8.42	0.19
Daily feed intake (g/bird/d)*	510.6	487.5	9.88	<0.05
Feed conversion rate*	3.040	3.129	0.14	0.54
Mortality (%)	4.74	2.66	0.06	0.32

Means within a row not sharing a common superscript are significantly different (A, B: $P < 0.01$; a, b: $P < 0.05$).

*Corrected for mortality.

Table 3. Effect of the genotype (A and B) on productive performance of male turkeys during the overall period of trial (0–140 d).

	A	B	SE	P value
n	9	9		
Chick body weight (g)	62.8[B]	67.4[A]	0.001	<0.001
Body weight (g)	20,016	19.850	156.1	0.32
Daily weight gain (g/bird/d)	136.9	138.4	1.66	0.39
Daily feed intake (g/bird/d)*	318.3	316.7	5.18	0.78
Feed intake (kg/bird)*	45.47	44.54	0.62	0.18
Feed conversion rate*	2.324	2.288	0.02	0.11
Mortality (%)	15.1	11.6	0.04	0.20

Means within a row not sharing a common superscript are significantly different (A, B: $P < 0.01$).

*Corrected for mortality.

$P < 0.001$) and shower lower DFI (251.5 vs. 256.7 g/bird/d, respectively for A and B; $P < 0.01$). DWG, FCR, and mortality were not significantly affected by the genetic line during this feeding phase. BW resulted significantly lower in group A also at 84 d (9,486 vs. 10,309 g, respectively for A and B; $P < 0.01$). From 57 to 84 d, DWG resulted lower in group A (146.5 vs. 168.7 g/bird/d, respectively for A and B; $P = 0.07$) while FCR was higher (2.658 vs. 2.186, respectively for A and B; $P = 0.08$). DFI and mortality only showed slightly differences between the groups. Toms A reported lower BW at 112 d (15,174 vs. 15,610 g, respectively for A and B; $P < 0.05$), even if DWG and DFI resulted numerically higher in group A from 85 to 112 (195.6 vs. 179.4 g/bird/d, respectively for A and B, $P = 0.28$; and 470.1 vs. 454.2 g/bird/d, respectively; $P = 0.10$). The 2 groups reached similar BW at slaughter (140 d) and only DFI showed significant differences between the groups during the finisher II phase (510.6 vs. 487.5 g/bird/d, respectively for A and B; $P < 0.05$). Considering the overall period of trial (Table 3), no significant difference in terms of productive performance was observed between the 2 genotypes. Taken together, these results seem to indicate that the 2 turkey hybrids are characterized by different growth pattern while showing similar performance at the end of the rearing cycle. Indeed, turkeys belonging the B line showed a greater precocity than the A ones, as indicated by the higher DWG from 0 to 84 d. On the other hand, toms A grew more during the later stages of the study, as supported by the numerically higher DWG observed in this group from 85 to 140 d. Except from 17 to 35 d, feed efficiency was similar between the 2 hybrids, suggesting that the increased growth rate showed by the toms respectively in the earlier or later stages of the trial was accompanied by a proportional increase in feed intake. Similar to our findings, Roberson et al. (2003, 2004), comparing 3 commercial turkey lines, observed different growth patterns but similar feed conversion rate at the age of slaughter. No significant difference between the tested turkey lines was observed for mortality. Previous works reported either similar (Roberson et al., 2003) or different (Roberson et al., 2004) livability among commercial turkey strains.

showed lower BW than B ones (62.8 vs. 67.4 g, $P < 0.001$). A significant effect of the genotype on hatching weight was previously reported by Roberson et al. (2004). In the present trial, fertile eggs were obtained from breeder flocks of the same age for both the genotypes. Therefore, the differences observed in 1-day-old poult weight may reflect a different egg weight and consequently its embryo development. After 16 d, turkeys belonging to the group A reported lower BW (500 vs. 522 g, respectively for A and B; $P < 0.001$), DWG (27.4 vs. 28.5 g/bird/d, $P < 0.001$) and DFI (36.5 vs. 38.3 g/bird/d, $P < 0.001$). However, no significant difference between the groups was observed for FCR and mortality during the starter phase. From 17 to 35 d of trial, toms A exhibited lower BW (2,074 vs. 2,204 g, $P < 0.001$), DWG (82.5 vs. 88.4 g/bird/d, $P < 0.001$), and DFI (115.5 vs. 121.5 g/bird/d, $P < 0.001$) than B ones. FCR resulted higher in group A (1.401 vs. 1.376, respectively for A and B, $P < 0.01$) while mortality was similar. After 56 d, toms A were lighter than the counterpart (5,345 vs. 5,535 g, respectively for A and B;

Table 4. Effect of the genotype (A and B) on the occurrence (%) of turkey breast myopathies at slaughter age (140 d) (n = 100).

	A	B	χ^2
White striping			
Score 0 (no lesions)	1	1	
Score 1 (mild lesions—few stripes)	17	5	<0.05
Score 2 (marked lesions—up to 50% of surface)	36	34	
Score 3 (severe lesions—more than 50% of surface)	46	60	
Poor cohesion			
Score 0 (no lesions)	100	96	
Score 1 (mild lesions)	0	4	0.12
Score 2 (severe lesions)	0	0	

Slaughtering Performance and Occurrence of Breast Myopathies

At slaughter, the 2 genotypes reported similar eviscerated carcass yield (76.3 vs. 76.4%, respectively for A and B), as well as breast (32.9 vs. 33.0%), thighs (32.0 vs. 31.6%), and wings (10.2 vs. 9.9%) yield, respectively.

The occurrence of breast myopathies in both the experimental groups is reported in Table 4. Overall, albeit the percentage of breasts affected by WS was markedly higher in both the tested lines, turkey from group A showed a significant lower incidence of breasts with severe lesions (46 vs. 60%, respectively for A and B; $P <$ 0.05), while the percentage of those with mild lesions was higher (17 vs. 5%; $P < 0.05$). The overall occurrence of SM-like condition was negligible and no significant difference was detected between the 2 turkey genotypes. Although the presence of white striation on the superficial layer of Pectoralis major muscle of turkey has been observed for several years, there are no studies regarding the incidence of this myopathy on turkey meat, contrary to the large amount of scientific evidences reported for broiler chickens (Petracci et al., 2015; Velleman, 2015; Kuttapan et al., 2016). In broilers, the presence of WS negatively impacted on visual appearance and reduced the consumer willingness to buy this kind of meat (Kuttappan et al., 2012). However, it should be considered that turkey breast meat is generally sold in the European market as further-processed products (i.e., sliced raw meat or ready-to-eat preparations) and this may limit the impact of the WS presence on consumers' perception and thereby product acceptability (Soglia et al., 2018).

Proximate Composition and Technological Traits

The results concerning proximate composition and technological traits of breast meat are shown in Table 5. Although no significant differences were found between the groups in terms of moisture (74.5 vs. 75.0%, respectively for A and B), crude protein (24.3 vs. 24.0%), and ash (1.36 vs. 1.26%), a higher total fat content was observed in P. major belonging to group A (1.55 vs 1.21%, respectively for A and B; $P < 0.05$). Similarly,

Table 5. Effect of the genotype (A and B) on proximate composition and technological traits of turkey breast meat.

	A	B	SE	P value
Proximate composition				
Moisture (%)	74.5	75.0	0.23	0.39
Crude protein (%)	24.3	24.0	0.31	0.36
Total fat (%)	1.55[A]	1.21[B]	0.12	<0.01
Ash (%)	1.36	1.26	0.08	0.12
Technological traits				
pHu	5.74	5.77	0.01	0.20
Lightness (L*)	52.8	53.6	0.35	0.29
Redness (a*)	3.09	3.26	0.12	0.48
Yellowness (b*)	1.04[a]	0.50[b]	0.13	0.04
Drip loss (%)	1.26[b]	1.34[a]	0.02	0.05
Marinade uptake (%)	11.0	10.3	0.60	0.54
Cooking loss—raw meat (%)	19.1	19.1	0.36	0.98
Cooking loss—marinated meat (%)	21.2	21.1	0.34	0.97
Shear force—raw meat (kg/g)	3.62	3.41	0.11	0.36

Means within a row not sharing a common superscript are significantly different (A, B: $P < 0.01$; a, b: $P < 0.05$).

also Roberson et al. (2003) and Werner et al. (2008) showed significant differences in total fat content of breast muscles belonging to different turkey genotypes. On the other hand, similar works showed no or limited effect of the genotype on crude protein, ash, and moisture content of turkey breast meat (Roberson et al., 2003; Werner et al., 2008; Sarica et al. 2011).

Overall, the technological traits were poorly affected by the genotype. Indeed, no significant differences were found for ultimate pH, lightness, redness, marinade uptake as well as cooking losses and shear force (of both raw and marinated meat). Otherwise, if compared to A, turkeys from group B exhibited lower yellowness (b*, 0.50 vs. 1.04; $P < 0.05$) and higher drip losses (1.34 vs. 1.26%; $P < 0.05$). However, in absolute terms, these differences appear of a relatively little practical and industrial importance. Regarding color, the slightly less yellowness measured in breast meat belonging to group B can be associated with the lower fat content observed in these muscles, as found in previous studies carried out on broilers (Funaro et al., 2014). When comparing turkey genotypes having a very different genetic background, also Werner et al. (2008) did not result in clear differences in meat quality between the fast- and slow-growing strains, even if the selection for increased growth rate and breast muscle yield was previously associated with decreased meat functionality in modern commercial turkeys (Updike et al., 2005).

As for the shelf-life test on thigh meat (Table 6), genotype did not significantly modify the pH onset. Although no significant changes in meat color were found over the storage time in both hybrids, differences were observed in absolute lightness (L*) and yellowness (b*) which were lower ($P < 0.05$) in thigh meat from group A. As expected, TBARS values significantly increased during storage even if no significant differences were found between the hybrids. It is well known that, having a high PUFA and heme iron content, thigh meat is particularly prone to oxidation leading to negative implications on chemico-physical shelf life and sensory

Table 6. Effect of the genotype (A and B) on pH, color (L*a*b*), and oxidative stability (TBARS) of turkey thigh meat packaged under ordinary atmosphere during refrigerated storage (7 d at 2 to 4°C).

		Storage time (ST)				P value		
	Hybrid (H)	0 d	3 d	7 d	SE	H	ST	H × ST
pH	A	5.96[a,b]	5.93[a,b]	5.98[a]	0.01	0.42	0.05	0.54
	B	5.98[a]	5.89[b]	5.94[a,b]				
L*	A	52.2[a,b]	52.6[a]	50.4[a,b]	0.64	0.03	0.84	0.41
	B	49.4[a,b]	47.6[b]	49.5[a,b]				
a*	A	14.0	13.5	15.0	0.31	0.65	0.52	0.76
	B	13.8	13.7	14.0				
b*	A	6.87[a]	6.50[a,b]	6.63[a,b]	0.40	0.02	0.67	0.84
	B	5.51[a,b]	4.57[a,b]	4.17[b]				
TBARS (mg MDA/kg)	A	0.55[c]	1.47[b,c]	3.28[a]	0.23	0.47	<0.001	0.71
	B	0.63[c]	1.27[c]	2.80[a,b]				

Means within a row not sharing a common superscript are significantly different (a, b: $P < 0.05$).

properties of both raw and cooked meat products (Estevez, 2015). However, according to previous studies, dietary treatments, meat composition, product formulation as well as packaging and storing conditions are more relevant on this issue (Mielnik et al., 2006; Contini et al., 2014; Estevez, 2015) if compared with genetic background of the birds.

Overall, from meat quality evaluations it appears that even if modern turkey strains are rather prone to develop meat quality defects (Carvalho et al., 2014; Patterson et al., 2017; Soglia et al., 2018), no negative implications on breast meat quality among turkey hybrids exist.

FA Composition

FA composition of turkeys' breast muscle is presented in Table 7. Overall, turkey genotype had only a marginal effect on the FA composition of breast meat. Considering the general FA profile, total SFA were the most abundant (35.5%), followed in descending order by PUFA (33.7%) and monounsaturated fatty acids (**MUFA**, 30.7%). These findings are consistent with those found by Mikulski et al. (2012). In the present study, significant differences between the 2 genotypes were only observed for MUFA content, which was higher in group A (31.7 vs. 29.8%, respectively; $P < 0.01$). This difference is likely attributable to the greater concentration of oleic acid (C18:1) (27.3 vs. 25.6%, respectively; $P < 0.01$), which is quantitatively the most abundant FA in turkey breast meat. Total SFA content tended to be higher in group B (34.7 vs. 36.4%, respectively; $P = 0.07$) mainly due to the greater ($P < 0.01$) content of stearic acid (C18:0). Overall, the proportion of the single SFA found in this study is consistent with those reported in literature (Mikulski et al., 2012; Skiepko et al., 2016). Although the total PUFA content was not affected by the genotype, linolenic acid (C18:3 n-3) concentration was higher in group A (2.12 vs. 1.71%, respectively; $P < 0.01$). In addition, breasts belonging to

Table 7. Effect of the genotype (A and B) on fatty acid composition (% of total fatty acids) and nutritional ratios in turkey breast meat.

	A	B	SEM	P value
C 14:0	1.11[A]	0.91[B]	0.03	0.01
C 14:1	0.13[A]	0.09[B]	0.01	0.01
C 16:0	22.7	22.9	0.33	0.75
C 16:1 n-7	1.48	1.38	0.08	0.53
C 18:0	10.8[B]	12.6[A]	0.30	0.01
C 18:1 cis9	27.3[A]	25.6[B]	0.31	0.01
C 18:1 cis11	2.59	2.60	0.06	0.95
C 18:2 n-6	25.7	25.0	0.27	0.14
C 18:3 n-3	2.12[A]	1.71[B]	0.07	0.01
C 20:0	0.05	0.04	0.00	0.37
C 20:1 n-9	0.16	0.15	0.00	0.13
C 20:2 n-6	0.22	0.24	0.01	0.17
C 20:3 n-3	0.05	0.09	0.02	0.29
C 20:4 n-6	4.01	5.00	0.27	0.06
C 20:5 n-3	0.11	0.12	0.00	0.24
C 22:4 n-6	0.16	0.20	0.01	0.12
C 22:5 n-3	0.67	0.76	0.04	0.25
C 22:6 n-3	0.53	0.72	0.06	0.11
Partial sum				
ΣSFA	34.7	36.4	0.48	0.07
ΣMUFA	31.7[A]	29.8[B]	0.33	0.01
ΣPUFA	33.7	33.8	0.40	0.83
Σn-6	30.2	30.4	0.31	0.68
Σn-3	3.48	3.39	0.10	0.69
Nutritional index				
n-6/n-3	8.81	9.16	0.19	0.38
P/S	0.98	0.94	0.02	0.36
Aterogenic index	0.42	0.42	0.01	0.89
Trombogenic index	0.84	0.91	0.02	0.13

Means within a row not sharing a common superscript are significantly different (A, B: $P < 0.01$; a, b: $P < 0.05$).

the group A showed higher amount of myristic (C14:0; $P < 0.01$) and myristoleic (C14:1; $P < 0.01$) acid.

The precursor of the n-6 family, the linoleic acid (C18:2), which was quantitatively the most concentrated n-6 PUFA (25.3%), was not affected by the genotype. Long-chain FA were found in very small amount, evidencing no significant difference between the 2 strains. In general, the total content of n-6 PUFA and n-3 PUFA was not affected by genotype. The ratio of n-6 PUFA to n-3 PUFA (n-6/n-3) found in this study (8.81 to 9.16), though not significantly different

Table 8. Mean values for intramuscular collagen properties of turkey breast muscle.

Item[1]	A	B	SEM	P value
IMC (μg/mg)[2]	14.7	15.4	0.58	0.55
HLP (mol/mol of collagen)	0.18	0.17	0.01	0.56
HLP (μg/mg)	3.79	3.82	0.17	0.94

[1]IMC = intramuscular collagen; HLP = hydroxylylpiridonline.
[2]μg/mg of lyophilized muscular tissue.

between the groups, is quite similar to those reported by Delezie et al. (2010) for 16-wk-old turkeys fed different dietary oils and by Mikulski et al. (2012) in turkeys fed diets containing rapeseed meal. However, the values of n-6/n-3 ratio obtained in the present study are higher than the recommended value (1 to 4). This shift is likely driven by the high linoleic acid content and the low proportion of PUFA observed in breast meat. In addition, other parameters such as the P/S, as well as the AI and TI, were similar among groups.

IMC Properties

There is an increasing interest to characterize the IMC properties of turkey hybrids in relation to the increasing occurrence of meat abnormalities in meat-type poultry. It has been reported that in fast-growing birds, collagen is immature, resulting in low heat stability. Consequently, poultry meat is usually tender, but it may turn fragile and even mushy if these collagen conditions are exacerbated, leading to raw turkey breast meat that can be peeled in strips (reviewed in Voutila et al. 2008). The results of IMC properties (Table 8) showed a similar collagen content in the breast muscle of the 2 turkey strains (14.7 vs. 15.4 μg/mg, respectively, for A and B). Similarly, muscle HLP concentration (3.79 vs. 3.82 μg/mg, respectively for A and B) and collagen maturation (0.18 vs. 0.17 mol of HLP/mol of collagen, respectively for A and B) did not differ between groups. In general, HLP values are inversely proportional to the amount of collagen (Maiorano et al., 2009). In fact, the steady increase in mature collagen crosslinking is due to the progressive and ongoing crosslinking reactions that occur within fibrillar collagen coupled with the slowing of collagen synthesis rates as animals approach maturity. Less collagen synthesis and turnover provide existing fibrillar collagen time to progressively crosslink or mature (McCormick, 1994). Regardless the genotype, the present findings on crosslinks (mol of HLP/mol of collagen) reveal a good level of collagen maturation which can be associated with a proper meat structure as previously proven in English White quails (Maiorano et al., 2011). This could also explain the overall low occurrence and severity of SM-like condition in breast muscle of turkeys from both the genetic lines as previously discussed.

Histological Features

Overall, histological observations in pectoral muscle showed correlations with the gross lesions used as selection criteria during sampling. Breast muscles not showing either white striations or tendency towards the separation of the fiber bundles on the surface (i.e., WS = 0) show myofibers with a normal profile and endo- and perimysial connective tissues without remarkable alterations (Figure 1A). The breasts that macroscopically exhibit minor WS lesions (i.e., WS = 1) generally show, both in the superficial and deep part, some necrotic fibers intermingled with apparently normal fibers that have lost their normal polygonal profile (Figure 1B). In other cases, when superficial WS striations markedly occurred (i.e., WS = 2 and 3), nuclear internalization, vacuolar and hyaline degeneration, necrosis and lysis of the fibers, inflammatory cells infiltration, variable cross-sectional area (degenerating and regenerating fibers), lipidosis and fibrosis (Figure 1B and C) were observed. Similar histological features such as degenerative changes included scattered and focal necrosis, hypercontraction of muscle fibers, strong proliferation of connective and fat tissues in the endo- and perimysium, as well as infiltration of the necrotic areas by mononuclear cells, have been previously described in fast-growing turkey Pectoralis major muscle (Sosnicki et al., 1988; Sosnicki and Wilson, 1991). Moreover, these results are consistent with earlier studies on commercial chicken hybrids (Kuttappan et al., 2016; Radaelli et al., 2017; Baldi et al., 2018). In our WS samples (i.e., WS = 2 and 3), an increase in the deposition of adipocytes within the connective tissue (fat infiltrations) was observed (Figure 1C–E). Similar histological features such as abundant adipose tissue deposition infiltrating the endo- and perimysial spaces were observed in commercial chicken hybrids (Kuttappan et al., 2013; Radaelli et al., 2017). These morphological features were found both in the superficial and deep part of the Pectoralis major muscle sample, although the magnitude of the histological lesions appears more severe in the superficial part rather than in the deep portion in agreement with Baldi et al. (2018).

A distinctive progressive rarefaction of the endomysial and perimysial connective tissue leading to muscle fibers detaching from each other, resulting in fibers presenting poor cohesiveness (Figure 2A and B), was observed in muscles affected by the SM defect in agreement with that reported in broilers (Baldi et al., 2018). In addition, this compromised connective tissue is generally accompanied by degenerate and necrotic (up to lysis) fibers, fat and inflammatory infiltrations and the presence of small-caliber fibers associated with large-caliber ones (degenerate and regenerate muscle fibers) (Figure 2B). In turkey, this myopathy has not been described yet. Sosnicki and Wilson (1991), describing the "focal myopathies of the turkey", stated that the excrescence of the sinus muscle fibers on the supporting connective tissue may also predispose the products to
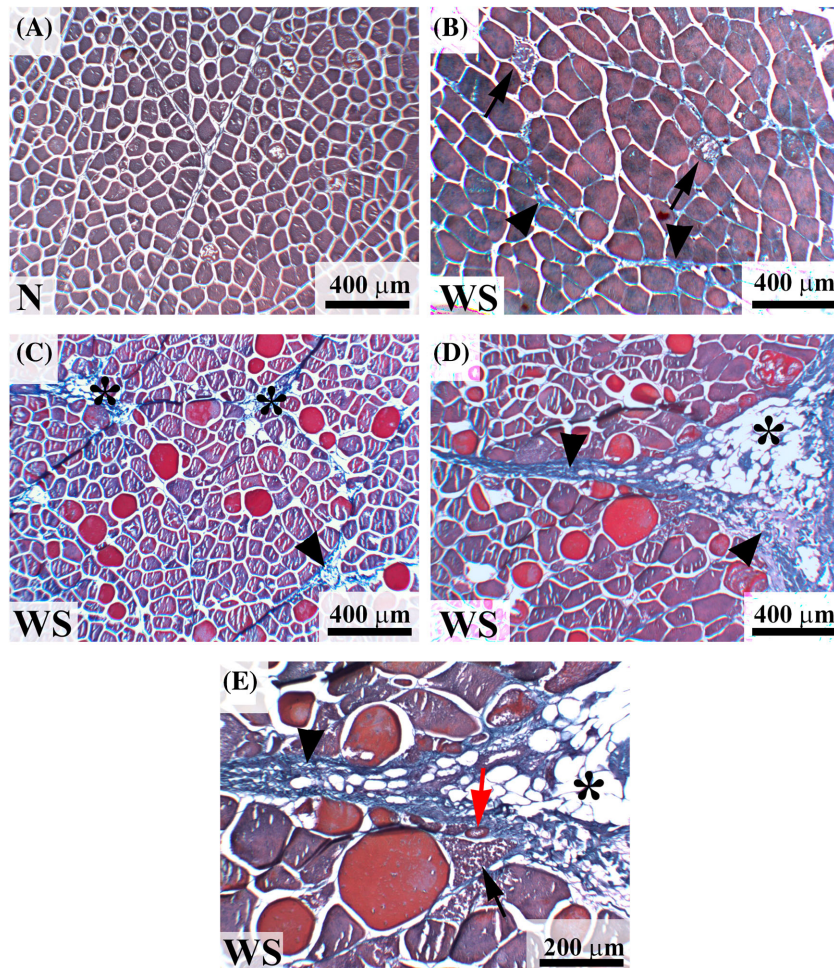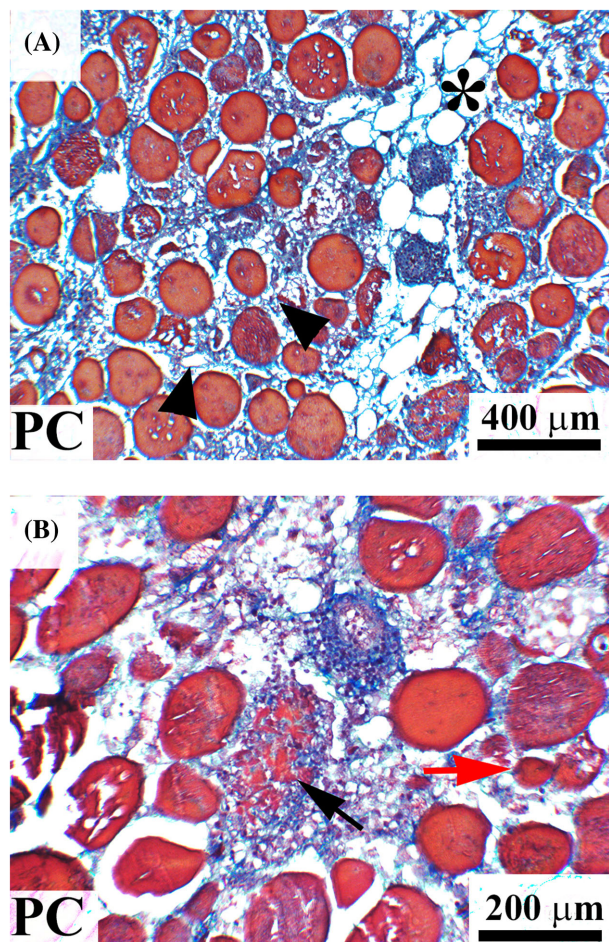
Figure 1. Turkey Pectoralis major muscle, Masson's trichrome. Representative images of transversal (A–E) histological sections of normal (N) and white striping (WS) affected fillets. In N samples, skeletal muscle fibers show a regular polygonal profile, compact and normal shape and size: also, perimysial and endomysial spaces are normal (A). The breasts that macroscopically exhibit minor WS lesions (B); some necrotic fibers (arrows) intermingled with apparently normal fibers that have lost their normal polygonal profile: also, the perimysial connective is altered (arrowheads). In samples affected by WS where the striations occur more marked (moderate and severe scored) is peculiar abundant endomysial fatty tissue infiltrated and, above all, perimysial: fatty infiltration in some cases result very abundantly (C and D, asterisks). In this case, there were observed rounded fibers of different dimensions and altered connective tissue (arrowheads). The image (E) represents a magnification of the image (D). In (E), to the aforementioned aspects of connective tissue proliferation (arrowhead) and infiltration of adipose tissue (asterisk), tiny fibers (red arrow) that surround greater caliber fibers (degenerating and regenerating fibers) (red arrow) close to a necrotic fibers (arrow) were observed.

fragmentation and SM-like condition. In the Pectoralis major muscle of chicken, Baldi et al. (2018) observed a progressive rarefaction of the endo- and perimysium connective tissue and an inflammatory infiltration in the SM histological sections. Interestingly, the same authors observed severe histological features in the superficial part of the Pectoralis major sample, while the deep part exhibited normal appearance. On the contrary, in our samples, both superficial and deep parts resulted severely compromised (Figure 2A and B).

In conclusion, the present study provided an update of the main productive traits and quality attributes of 2 representative commercial turkey hybrids used worldwide for meat production. The growth pattern of the 2 lines was different although they reached similar results at the end of the rearing cycle and at slaughtering. For the first time, a detailed description of the occurrence of WS- and SM-like conditions, as well as the histological features associated with the different degrees of severity of these myopathies, were reported. The histological analysis evidenced that the muscle alterations associated with the observed meat abnormalities are similar to those described for fast-growing chicken hybrids. However, the relatively high occurrence of WS in both the genetic lines tested herein had no negative effects on breast meat quality traits. Similarly, the shelf life of thigh meat, which is particularly prone to oxidation leading to negative implications on chemico-physical and sensory properties of the meat, was not influenced by the genotype. Overall, the results obtained in this study highlight the limited effect of the genetic line on productive traits of commercial turkeys including occurrence of breast myopathies and quality attributes of meat, either fresh or after refrigerated storage.

Figure 2. Turkey Pectoralis major muscle, Masson's trichrome. Representative images of transversal (A and B) histological sections of poor cohesiveness (PC) affected fillets. In the PC samples, muscle fibers were reduced in number and spaced apart (sometimes almost isolated) from each other; such fibers have a rounded profile and very variable dimensions. The perimysial and endomysial connective tissue result compromised (arrowheads) and particularly rarefied around some fibers (A), whereas adipose tissue infiltrates the space between the muscle fibers (A, asterisk). At higher magnification (B), it is possible to observe degenerate fiber (arrow), surrounded and infiltrated by inflammatory cells. Furthermore, it is possible to observe some regenerative fibers (red arrow).

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