Technological quality, mineral profile, and sensory attributes of broiler chicken breasts affected by White Striping and Wooden Breast myopathies

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ABSTRACT The aim of the research was to study the impact of white striping and wooden breast myopathies on the technological quality, mineral, and sensory profile of poultry meat. With this purpose, a total of 138 breasts were selected for a control group with normal breasts (N), a group of breasts characterised by white striping (WS) myopathy, and a group of breasts having both white striping and wooden breast myopathies (WSWB). Data revealed that the simultaneous presence of the two myopathies, with respect to the WS lesion individually considered, had a further detrimental effect on pH (6.04 vs. 5.96; $P < 0.05$), yellowness (11.4 vs. 10.3; $P < 0.01$), cooking losses (30.4 vs. 27.6%; $P < 0.05$), toughness instrumental values (22.8 vs. 20.0 N; $P < 0.01$), and perception (6.22 vs. 5.56; $P < 0.01$). In addition, mineral contents suggest that a defective ions regulation is also present in white striping and wooden breast myopathies.

Key words: chicken breast, white Striping, wooden Breast, physicochemical analyses, sensory profile

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INTRODUCTION

An ever-increasing demand for chicken meat has made the poultry industry focus on high-energy diets and intensive selection of genotypes exhibiting faster growth with higher breast yields. However, this trend happened at the same time as the onset of two emerging meat quality issues: White striping (**WS**) and wooden breast (**WB**). Macroscopically, WS appears as white striations running parallel to the muscle fibers (Bauermeister et al., 2009; Kuttappan et al., 2012a,b; Kuttappan et al., 2013a), which give a fatty, marbled, and abnormal appearance to the fillets (Kuttappan et al., 2012b). In addition, fiber bundles beneath the striated area can display a tendency towards separation (Petracci et al., 2013). On the other hand, WB condition is characterized by remarkable palpatory hardness and paleness, along with a fluid and clear exudate, bulges, small hemorrhages, and white striping, as well as areas with separated muscle bundles, particularly within the deep layers of the muscle (Dalle Zotte et al., 2014; Sihvo et al., 2014). Histologically, both WS and WB lesioned areas show myodegeneration along with variable amount of interstitial connective tissue accumulation (Kuttappan et al., 2011, 2013a; Sihvo et al., 2014). Moreover, WS is also characterized by lipidosis (Kuttappan et al., 2013a; 2011). The triggering factors of WS are: heavier birds (Bauermeister et al., 2009; Kuttappan et al., 2013b), increased growth rate (Kuttappan et al., 2012a; Mudalal et al., 2014), and breast yields (Lorenzi et al., 2014; Mudalal et al., 2014), as well as thicker fillets (Kuttappan et al., 2013b) have all a role in WS condition development. As for WB condition, the etiology is still obscure, however, similarly to WS, the greatest suspicions seems to fall on the fast growth rate and the ever-increasing breast meat yield (Dalle Zotte et al., 2014; Mudalal, et al., 2015). The onset of the two defects seems to be also influenced by the part considered: the maximum thickness observed in the cranial part could produce overstretching or ischemia resulting in tissue damage and reparative responses (Kuttappan et al., 2013a) due to an impaired blood supply (Hoving-Bolink et al., 2000). The muscle considered could also play a significant role, suggesting that red muscles are less sensitive than white muscles. Indeed, *Pectoralis major* and *Iliotibialis* exhibited higher WS incidence than *Gastrocnemius* (Kuttappan et al., 2013a); WB has been described in the breast fillet (Sihvo et al., 2014) and *Anterior latissimus dorsi* muscle has been reported to exhibit similar lesions (Zimermann et al., 2012). Genetic selection for broiler traits could also involve a defective cations regulation, especially of calcium, which seems to be associated to myopathic changes and meat quality problems (Sandercock et al., 2009). Interestingly, some farming practices could be of importance in myopathies breaking out. A recent study of Dalle Zotte, et al. (2015b) revealed that the use of ionophores against

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coccidiosis have a predisposing action towards WS; indirectly, due to their positive effect on intestinal integrity and live performances, and directly, due to their proven myotoxicity (Novilla, 1992; Chapman et al., 2010; Markiewicz et al., 2014). The average frequencies observed so far under commercial and experimental conditions are higher than 50% both for WS (Kuttappan et al., 2012a; Petracci et al., 2013; Lorenzi et al., 2014; Dalle Zotte et al., 2015b) and WB (Dalle Zotte et al., 2015a). The high percentages achieved, together with the negative impact on the various meat quality aspects, demonstrate how this myopathy is becoming an issue of great relevance for the poultry industry. Indeed, meat is less suitable for processing (Kuttappan et al., 2012a; Petracci et al., 2013; Petracci et al., 2014; Mudalal et al., 2015) enforcing producers to manufacture processed products instead of offering breasts for fresh retailing, and the visual acceptability at purchase is compromised (Kuttappan et al., 2012b; Petracci et al., 2013). Nevertheless, no information is currently available on WS and WB myopathies related to sensory analysis; attributes of affected breasts different from the visual appearance have not been tested so far. Therefore, the aim of the present study was to outline a sensory profile of affected cooked breasts, investigating a possible negative impact exerted by WS and WS+WB beyond the visual appearance using a trained panel. Additional information on the technological quality traits of breast meat simultaneously affected by the two myopathies is provided; moreover, researchers chose to investigate the mineral profile to give a contribution in affirming that an altered cellular ions balance could be one of the triggering factors.

MATERIALS AND METHODS

Sample Collection

For this study, breast muscles belonging to a batch of 500 carcasses of 51-day-old Ross 708 male chickens were used. Birds were processed in an authorized commerical slaughterhouse by electrical stunning (120 V, 200 Hz). Subsequently, they were soft-scalded (53°C for 2 min) and air-chilled after evisceration (precooling at 5°C for 60 min, followed by chilling at 0°C for 90 min). Carcasses were then transported to a poultry cut-up plant and stored at 4°C; there, breasts were deboned and sorted, then collected by the working team members forty-eight hours postmortem. Sorting procedure consisted in a visual and palpatory inspection to detect the presence on breasts (M. *Pectoralis major*) of lesions attributable to WS (Kuttappan et al., 2013a) and WB (Sihvo et al., 2014). The WS selection criteria included the presence of visible white striations on the surface. A grid arranged according to the scheme proposed by Puolanne (personal communication) and recently used by Dalle Zotte et al. (2015a), helped the researchers to identify WB samples. WB detection considered first the presence of hard areas at palpation of both the left and right breast muscles, then, detection and characteristics of other descriptors (color, bulges, exudate, hemorrhage, and concomitant presence of WS) were taken into account (Table 1). Initially, four experimental groups of 60 breasts each were planned: a group with no macroscopic lesions (Normal group, **N**), a group exhibiting WS myopathy (WS), a group with WB myopathy (WB), and a fourth group having the both lesions (**WSWB**). As only eighteen N and no WB samples were found, only three experimental groups were formed and a total number of 138 whole breast muscles (18 N, 60 WS, and 60 WSWB) were collected and weighed.

Instrumental Analysis

At the Department of Animal Medicine, Production and Health (MAPS) laboratory, *Pectoralis major* muscles were subjected to instrumental analyses. A total of 137 right breasts (17 of the N group; 60 belonging to WS; and 60 of the WSWB group) were used to measure pH and $L^*a^*b^*$ color values. On 108 of them (8 Normal, 50 WS, and 50 WSWB) the cooking losses and the Warner-Bratzler shear force (**WBSF**) were determined. A total of 113 left breasts (10 Normal, 52 WS, 51 WSWB) were used for thawing and cooking losses determination after a six-month storage. The remaining 24 left *Pectoralis major* muscles (8 samples per treatment) were considered for the mineral profile analysis.

On the cranial and caudal ends, ultimate pH was measured with Mettler Toledo FE20 and color values (CIE 1976 $L^*a^*b^*$) were detected with RM200QC (X-Rite, Co, Neu-Isenburg, Germany) colorimeter provided with multidirectional LED illumination set at D65 10°. The color measurements were taken

Table 1. Scheme used to evaluate *Pectoralis major* muscles.

Descriptors	Wooden breast			
Consistency	Hard	Very hard		
Color	Normal	Pale	Pink	Other
Bulge presence and diffusion	Not present	Cranial	Caudal	Longitudinally diffuse
Exudate presence and consistency	Not present	Fluid	Turbid	
Exudate color	Clear	Gray	Yellow	
Hemorrhage presence and diffusion	Not present	Cranial	Caudal	Longitudinally diffuse
Hemorrhage width	pinpoint	3 to 5 mm	≥5 mm	
White Striping presence and diffusion	Not present	Cranial	Caudal	Longitudinally diffuse
White Striping presence and width	Not present	≤ 1 mm	≥ 1 mm	

with the instrument resting on samples kept in the horizontal plane. Fillets were then individually vacuum-packed in polypropylene bags, put in a water bath set at 80°C, and cooked until a core temperature of 78°C was reached. At each cooking round, the fillets were divided into two main groups according to weight, and core temperature was controlled by inserting the probe of two digital thermometers (Checktemp 1 Digital Thermometer, Mod. HI98509, Hanna Instrument, Limena, Padova, Italy) in the thickest part of the heaviest and of the lightest fillet. Once cooked, samples were cooled by immersing bags in cold water added with crushed ice until room temperature was reached; then bags were removed and breasts were reweighed to determine the cooking losses as a percentage of the initial sample weight. WBSF was assessed on cylindrical cooked meat pieces (1.25-cm diameter × 2 cm length) obtained by coring the muscle with a mechanical coring device (Perlo et al., 2010) oriented parallel to the fibers direction (Wheeler et al., 1996). Six cylindrical samples (3 from the cranial portion and 3 from the medial caudal portion) were attained from each breast, by cutting the muscle through the whole breast thickness; therefore, surface and deep layers were both included. Thereafter, cylinders were cut perpendicularly to the muscle fiber direction with a Warner-Bratzler cell (100 kg load cell, 2 mm/s crosshead speed) fitted on a TA-HDi Texture Analyzer (Stable Macro System, London, UK), following the procedure described by Sams et al. (1990). Reported WBSF data represent an average of the six measurements.

Left breast samples and 30 right breasts (10 per treatment) were individually vacuum-packed and frozen at –20°C. Breast muscles were first thawed at 4°C for 16 h, then left at room temperature until 4°C was reached, and then dried and weighed. Thawing losses were calculated as percentage of the frozen weight. Then fillets were vacuum-packed again, cooked following the same above-mentioned procedure and weighed again to determine the cooking losses as percentage on the thawed weight.

Mineral profile considered Calcium, Iron, Sodium, Potassium, and Phosphorus content. Inductively coupled plasma optical emission spectrometry (ICP-OES) was performed with Spectro Arcos (SPECTRO Analytical Instruments, GmbH, Kleve, Germany) after microwave digestion with Milestone rotor at 64-bar pressure, according to AOAC 2000 (Method no. 999.10). Data were expressed as mg/kg as is.

Sensory Analysis

After three months of frozen storage, the 30 right breast meat samples were subjected to a descriptive conventional profiling sensory analysis (as defined by ISO 13299, 2003), following the method suggested by Meilgaard et al. (1999) and O'Sullivan et al. (2003) on warm samples. The analysis was carried out in five consecutive days in order to avoid panel sensory fatigue, given the high number of samples to be tested. A panel of ten staff members of the MAPS Department was involved, after a 1.5 hour training session. During this session, several purchased and frozen breast samples were served to be evaluated as reference materials; all the descriptors to be used were developed, discussed, and selected, as intensity scores were assimilated (according to ISO 13299, 2003). Sensory analysis was carried out in a testing room with temperature set at 21°C, neutral colored wall and furniture, and standard lighting conditions. Permanent individual testing booths (76 cm wide × 51 cm depth) were arranged with two sets of six, facing each other across a central corridor and provided with a vertical sliding door to receive samples. Each day of analysis, six frozen half breasts randomly chosen between the three treatments were thawed (16 h at 4°C), identified with a random three-digit code, and cooked following the above-mentioned specification. Samples were served one by one whilst still warm and cut to have ten numbered and equally sized pieces, each corresponding to a specific panelist. First, breasts were cut in half in the thickness direction; then, a cranial, a medium, and a caudal portion were obtained from each half and the first two areas were further divided in two parts. The same ten people were employed in all five sessions; each person always tested the same breast portion throughout the single session and the whole test. Each assessor was equipped with plastic cutlery, plastic dish and glass, expectorant cup, water, unsalted crackers, and six paper ballots (one per sample), and had no knowledge about the samples history. Off-odors and off-flavor perceptions (overall intensity, rancid, fishy, wet cardboard), taste (sourness and bitterness), aroma intensity (as described by Rizzi et al., 2007), and texture (tenderness, juiciness, and fatness) were taken into account and ranked on a 150-mm unipolar continuous-line scale. Scores put nearby 0-mm indicated the lowest value for each considered attribute and scores put nearby 150-mm indicated the highest value (Table 2). Marks left on the line scales were measured with a ruler as distances from 0-mm anchors and the absolute values considered as scores.

Statistical Analysis

SAS (2004 version 9.3) statistical software package was used. Breast weight data were evaluated by using ANOVA and processed by choosing a general linear model that considered treatment as fixed effect (PROC GLM). Instrumental analyses (pH, color traits, WBSF, thawing, and cooking losses) and mineral profile data were also analyzed using the same model, with breast weight as covariate. A mixed model (PROC MIXED) was used to detect any myopathies influence on sensory analysis scores considering treatment and panelist as fixed and random effects, respectively. Single tasting was considered as experimental unit and sensory scores

Table 2. List of the sensory attributes and scales anchors.

Attributes	Scores	
	0 mm anchor	150 mm anchor
Off-odor		
Overall intensity	Extremely poor	Extremely strong
Rancid	Not rancid	Extremely rancid
Fishy	Not fishy	Extremely fishy
Wet cardboard	Not wet cardboard	Extremely wet cardboard
Other off-odours	Not perceived	Extremely strong
Off-flavor		
Overall intensity	Extremely poor	Extremely strong
Rancid	Not rancid	Extremely rancid
Fishy	Not fishy	Extremely fishy
Wet cardboard	Not wet cardboard	Extremely wet cardboard
Other off-flavors	Not perceived	Extremely strong
Taste		
Sourness	Not sour	Extremely sour
Bitterness	Not bitter	Extremely bitter
Aroma intensity	Extremely poor	Extremely strong
Texture		
Tenderness	Extremely tender	Extremely tough
Juiciness	Extremely dry	Extremely juicy
Fatness	Extremely poor	Extremely strong

deviating more than ± 5 (mm or absolute value) were considered as outliers and removed from the dataset. Post hoc pairwise contrasts were evaluated by Bonferroni adjustments and three significance levels were assigned: $P < 0.05$; $P < 0.01$; and $P < 0.001$. In addition, Pearson correlation was performed considering $P < 0.05$ as significance level and principal component analysis (PCA) graphic art was obtained based on the treatment effect, after Varimax rotation.

RESULTS AND DISCUSSION

As expected, breasts of the WSWB group were the heaviest ($P < 0.001$) (Figure 1) and exhibited the highest pH values ($P < 0.05$), which was strongly influenced by both treatment ($P < 0.05$) and breast weight ($P < 0.05$) (Table 3). In fact, previous results showed that WS, WB, and the simultaneous presence of the two degenerative conditions generally increase pH values (Petracci et al., 2013; Dalle Zotte et al., 2014, 2015b; Mudalal et al., 2015).

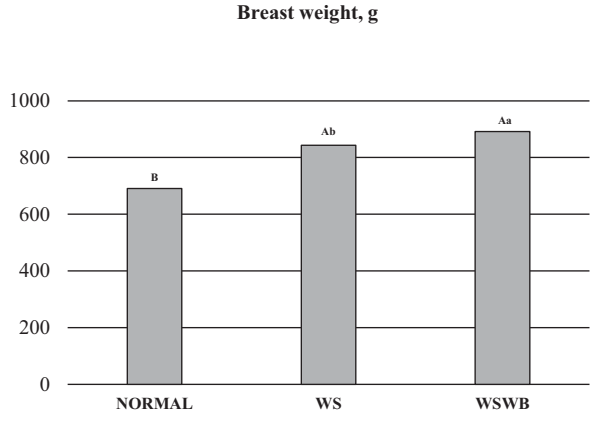

Figure 1. Differences in breast weights among NORMAL, WS, and WSWB groups (A, B: $P < 0.001$; a, b: $P < 0.05$).

Le Bihan-Duval et al. (2008) obtained a high heritability for ultimate pH and glycogen storage (determined as glycolytic potential). A strong negative correlation between glycogen store and breast muscle weight was found; on the contrary, a strong positive correlation between breast weight and high ultimate pH of meat was noticed. It seems that the physiological functions in the lesion area are not normal. In addition, microscopic studies show that there are large areas of connective tissue in the muscle, meaning that the lesion itself causes swelling and therefore the increase in muscle volume.

Fillets of the WSWB group also had the greatest a^* and b^* values ($P < 0.001$ and $P < 0.01$, respectively) whereas WS group did not differ from the N one; on the contrary, L^* value did not differ among the three experimental groups. A work by Mutryn et al. (2015) found that fiber-type switching could occur in WB condition, thus leading to a high expression of myoglobin genes and thus to redder muscles, which was detected in the present survey considering WSWB group and also by Dalle Zotte et al. (2014). Interestingly, Petracci et al. (2013) showed that WS condition was already sufficient to determine higher redness of meat compared to normal chicken breasts. Previous studies demonstrated that fillets affected by WS or WB are more yellow than non-affected ones, probably due to the strong fibrotic response (Petracci et al., 2013; Dalle Zotte et al., 2014). In our study, a different scenario was observed: WS alone did not affect the yellowness of the meat, whereas a probable additive effect of the simultaneous presence, WSWB, increased the b^* value. As for L^* value, other studies showed that WS, as well as WSWB conditions did not increase the paleness of the meat and this was in accordance with our study (Petracci et al., 2013; Mudalal et al., 2015).

Cooked *Pectoralis major* muscle samples belonging to WSWB group were tougher ($P < 0.01$) than both N and WS ones (22.8 vs. 17.5 and 20.0 N, respectively). However, our findings were not confirmed by previous studies, as cooked WB (Dalle Zotte et al., 2014) and WSWB (Mudalal et al., 2015) meat samples exhibited the same toughness of the normal meat. However, meat samples analyzed by Dalle Zotte et al. (2014) had been previously frozen for 3 months. In general, tenderness of meat is known to increase with freezing and thawing, as the formation of large extracellular ice crystals breaks down myofibrils, thus resulting in physical structure disruption (Leygonie et al., 2012). Differently, Mudalal et al. (2015) applied a different cooking procedure than that of the present study, thus possibly explaining different shear force results (Jeremiah and Gibson, 2003; Garcia-Segovia et al., 2007). WSWB breast meat samples displayed also the worst water cooking losses at 48 h postmortem ($P < 0.01$) as well as after six months of frozen storage ($P < 0.05$), thus supporting previous results (Dalle Zotte et al., 2014; Mudalal et al., 2015; Petracci et al., 2015). Differently, thawing losses remained unaffected.

Table 3. Meat quality traits of *Pectoralis major* muscle.

Physical quality traits	Experimental groups			Significance	COV Breast weight
	Normal	WS	WSWB		
pH[1]	5.92 ± 0.04^{a,b}	5.96 ± 0.02^{b}	6.04 ± 0.02^{a}	*	*
L*,[1]	56.1 ± 0.8	55.8 ± 0.4	55.9 ± 0.4	NS	NS
a*,[1]	−3.10 ± 0.28^{B}	−2.38 ± 0.13^{A,B,b}	−1.84 ± 0.14^{A,a}	***	NS
b*,[1]	9.27 ± 0.56^{B}	10.3 ± 0.3^{A,B,b}	11.4 ± 0.3^{A,a}	**	*
WBSF (N)[2]	17.5 ± 1.7^{A,B,b}	20.0 ± 0.6^{B}	22.8 ± 0.6^{A,a}	**	NS
Cooking losses, 48 h *post mortem* (%)[2]	25.4 ± 2.1^{a,b}	27.6 ± 0.7^{b}	30.4 ± 0.8^{a}	*	NS
Thawing losses (%) at 6 months[3]	5.43 ± 0.82	6.02 ± 0.31	6.44 ± 0.33	NS	NS
Cooking losses (%) at 6 months[3]	22.9 ± 2.0^{b}	25.9 ± 0.7^{b}	29.1 ± 0.8^{a}	**	NS

^{a,b}means within row with different superscripts differ at $P \leq 0.05$ (*).
^{A,B}means within row with different superscripts differ at $P \leq 0.01$ (**) and $P \leq 0.001$ (***).
[1]137 right breast muscles (17 N, 60 WS, 60 WSWB).
[2]108 right breast muscles (8 N, 50 WS, 50 WSWB).
[3]113 left breast muscles (10 N, 52 WS, 51 WSWB).

Table 4. Mineral profile of *Pectoralis major* muscle.

Minerals (mg/kg as is)[1]	Experimental groups			SE	Significance	COV Breast weight
	Normal	WS	WSWB			
Ca	47.9	55.8	57.0	3.8	NS	NS
Fe	3.23^{B}	4.45^{A,b}	5.25^{A,a}	0.18	***	NS
Na	498^{B}	566^{A,B}	631^{A}	23	**	NS
K	2,705^{A}	2,685^{A}	2,478^{B}	42	**	NS
P	2,033^{A}	1,984^{A}	1,822^{B}	29	***	NS

^{a,b}means within row with different superscripts differ at $P \leq 0.05$.
^{A,B}means within row with different superscripts differ at $P \leq 0.01$ (**) and $P \leq 0.001$ (***).
[1]24 left breast muscles (8 N, 8 WS, 8 WSWB).

In WS meat, the overall connective tissue increases to the detriment of the protein amount, which was found to be lower than normal meat (Petracci et al., 2014). Such structural change implies a marked reduction of actin and myosin contents, which are responsible of meat water holding capacity, in favor of collagen that does not bind water (Dalle Zotte et al., 2014; Petracci, et al., 2015). This replacement results in a significant impairment of protein functionality, which is not pH-dependent but linked to the muscle degeneration, since the greatest losses were seen in correspondence to the highest pH values (Petracci et al., 2013) (Table 3).

The WSWB fillets significantly differed from the N and WS groups also in terms of mineral profile: iron and sodium levels increased ($P < 0.001$ and $P < 0.01$, respectively), whereas potassium and phosphorus levels followed the opposite trend ($P < 0.01$ and $P < 0.001$, respectively) (Table 4).

Recently Petracci et al. (2015) observed that WS condition reduced total ash percentage leading to a higher sodium concentration and lower potassium and phosphorus levels, however, this was not statistically revealed in our study.

Even if no statistical difference was detected among groups, probably due to the small number of samples analyzed, calcium content exhibited a growing trend going from N to WSWB meat samples (47.9, 55.8, and 57.0 mg/kg meat for N, WS, and WSWB, respectively). This partially supports the suggestion of Petracci et al. (2015), who hypothesized a connection between the two myopathies and an imbalance of calcium regulation. In fact, an uncontrolled and prolonged overload of intracellular calcium from extracellular sources or due to its mobilization from the sarcoplasmic reticulum can originate muscle tissue degeneration (Jones et al., 1984; Duncan and Jackson, 1987; Jackson, 1993; Sandercock and Mitchell, 2003, 2004). Muscle damage is triggered by the alteration of the cell membrane integrity (Mitchell, 1999) mediated by Ca^{2+}- activated proteases and lipases, such as phospholipase A_2 (Jackson et al., 1984; Jackson, 1993; Sandercock and Mitchell, 2003). Sandercock and Mitchell (2004) hypothesized that calcium uptake into muscle cells might be mediated by an increased muscle sodium level, which was observed also by Sandercock et al. (2009) in chicken selected for broiler traits. Therefore, sodium homeostasis disturbances may have a significant role in the development of cell injury, through the involvement of the Na^{+}/Ca^{2+} exchanger (Sandercock and Mitchell, 2004).

In dogs, skeletal muscle cell damage is also associated to moderate phosphorus depletion, which results in abnormally increased intracellular sodium and chloride ions levels, along with the decline of normal potassium concentration and transmembrane potential. The triggering factor seems to be a lowered synthesis of adenosine triphosphate (ATP); in effect, the lack of energy

Table 5. Sensory analysis scores of *Pectoralis major* muscle.

Attributes[1]	Experimental groups			SE	Significance
	Normal	WS	WSWB		
Off-odor					
Overall intensity	1.86[b]	2.70[a]	2.20[a,b]	0.31	*
Rancid	0.84	0.91	0.98	0.23	NS
Fishy	0.36	0.29	0.42	0.14	NS
Wet cardboard	0.74	0.84	0.76	0.17	NS
Other off-odors	0.00	0.00	0.00	-	-
Off-flavor					
Overall intensity	1.57	1.48	1.76	0.28	NS
Rancid	0.79	0.80	1.03	0.25	NS
Fishy	0.33	0.24	0.38	0.16	NS
Wet cardboard	0.67	0.80	0.68	0.21	NS
Other off-flavors	0.64	0.45	0.62	0.23	NS
Taste					
Sourness	2.06	1.74	1.71	0.33	NS
Bitterness	1.56	1.98	1.82	0.37	NS
Aroma intensity	4.76	4.45	4.14	0.57	NS
Texture					
Toughness	4.70[B]	5.56[A,B]	6.22[A]	0.40	**
Juiciness	5.14	4.98	4.58	0.44	NS
Fatness	1.26	1.32	1.25	0.39	NS

[a,b]means within row with different superscripts differ at $P \leq 0.05$ (*).
[A,B]means within row with different superscripts differ at $P \leq 0.01$ (**) and $P \leq 0.001$ (***).
[1]30 right breast muscle (10 N, 10 WS, 10 WSWB).

may interfere in the activity of the $Na^+ - K^+ - ATPase$ in maintaining a high concentration of potassium ions within the cell. Phosphorus decrease may also result in greater myofiber permeability to sodium and compromised sarcolemma integrity, as consequences of lowered ATP availability for sarcolemma metabolic processes as well as the depletion or alteration of certain lipid compounds (Fuller et al., 1976).

Chronic WB may be linked to localized hypoxia, oxidative stress, as well as the possible presence of muscle fiber-type switching, as demonstrated by the work of Mutryn et al. (2015) on RNA-sequence analysis. The last phenomenon consists in the change from fast to slow twitch fibers in response to muscle degeneration, with the consequent unexpected high expression of myoglobin (Mutryn et al., 2015), which could explain the greatest iron content and a^* color value in our WSWB breasts.

The sensory profile analysis revealed that off-odors were more intense in fillets of the WS group compared to the N ones, whereas WSWB fillets reached intermediate scores ($P < 0.05$). Nevertheless, panelists did

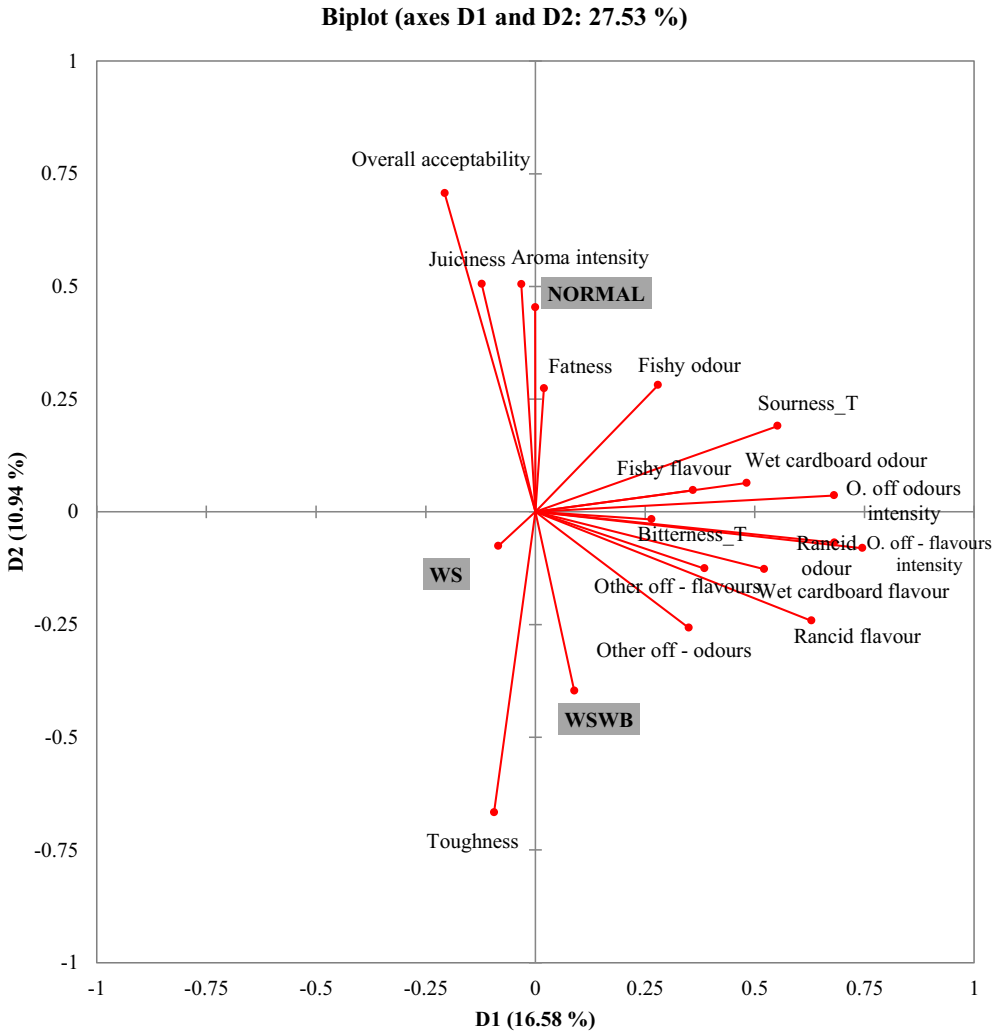

Figure 2. Plot of the sensory attributes based on the two variables that mainly explain the PCA model variability: overall off-odor intensity (D1) and rancid odor (D2).

not find any difference concerning specific off-odor perception among groups (Table 5). Even if no statistical difference was observed, panelists seemed to perceive a certain decreasing trend going from N to WSWB meat samples for sourness, aroma intensity, and juiciness. Such tendencies were opposite to that of pH value (Table 3), probably because pH is a key factor in sourness perception. Therefore, it is involved in aroma perception (Madruga and Mottram, 1995; Meynier and Mottram, 1995) and the experience of juiciness (Hoffman et al., 2007). Regarding overall and specific off-flavor intensity, bitterness, juiciness, and fatness, neither differences nor trends were detected among the three groups. WSWB group received the highest toughness scores ($P < 0.01$), thus supporting the greatest instrumental shear force values previously discussed.

PCA was performed to evaluate the relationships among sensory variables. The first two principal components accounted for 27.5% of the total variance (Figure 2). The first PC (16.6% of the total variance) was positively loaded by overall off-odor intensity (0.68), rancid odor (0.68), overall off-flavor intensity (0.75), and rancid flavor perception (0.63). The second PC (10.9% of the total variance) was positively loaded by juiciness (0.51), but negatively loaded by toughness (-0.67). The PCA plot shows that the WSWB condition is the most positively linked to toughness (0.16). It is worthy to be noticed that the fatness attribute is located in the opposite position from WS and WSWB but near the N group. This could be explained by considering that the slight fat perception is related to juiciness (0.31). Given that the visual aspect of WS affected meat led to product rejection at purchase (Kuttappan et al., 2012b), the present work tried to describe a sensory profile of the cooked meat, avoiding the negative influence of raw meat appearance prior to tasting. Macroscopic lesions characterizing WS and WB were not detected after cooking; despite this, the hedonic quality of WSWB meat was lower than that of normal samples due to a harder texture feeling in the mouth.

In our material, it was impossible to find breast muscles affected only by WB myopathy, contrary to previous findings of Mudalal et al. (2015). In addition, WS prevalence appears to have increased dramatically in a few years when comparing to the study of Petracci et al. (2013) and that of Lorenzi et al. (2014), Dalle Zotte et al. (2015b) and Russo et al. (2015).

In conclusion, this investigation demonstrated that the simultaneous presence of WS and WB exerted an additional detrimental effect on technological traits, nutritional quality, and toughness perception respect to the single lesions individually considered. A strict connection and common causative basis may be hypothesized between the two conditions, even if they still need to be elucidated. Thus, further studies should elucidate the link existing between the two myopathies and their development involving biochemical and genic analysis, in order to better understand the pathological pathways.

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