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LONGISSIMUS LUMBORUM QUALITY OF LIMOUSIN SUCKLER BEEF IN RELATION TO AGE AND POSTMORTEM VACUUM AGEING*

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Abstract

The aim of the research was to evaluate the influence of calf age on proximate composition, fatty acid composition and mineral contents, as well as postmortem ageing under vacuum on the inherent properties of *musculus longissimus lumborum* of Limousin suckler beef aged to 6, 7 or 8 months. The moisture, protein, fat, and ash content, fatty acid composition, mineral concentrations and intrinsic properties (pH, electrical conductivity, drip and cooking loss, shear force, and CIE colour parameters) were determined. The calf age significantly ($P \leq 0.05$) correlated with an increased protein content and energy value of meat and decreased water:protein proportion. Moreover, increased age correlated with higher concentrations of Mg ($P \leq 0.01$), Zn and Fe ($P \leq 0.05$) and reduced concentrations of Cu ($P \leq 0.05$). The fatty acid composition was similar irrespective of calf age, with the exception of CLA content, which was significantly ($P \leq 0.01$) reduced in older animals. Muscles of calves aged 6 months were significantly lighter, less red, and showed the most significant drip loss compared to the muscles of older animals. There was no significant ($P > 0.05$) interaction between calf age and postmortem ageing for the intrinsic properties analysed. Postmortem ageing under vacuum resulted in a significant decrease ($P \leq 0.05$) in the shear force of meat (irrespective of the age of the calves). The lack of significant differences, especially with regard to the meat pH, shear force, fatty acid composition, and with the significantly higher content of protein and major elements (Fe, Mg and Zn) in relation to the slaughter age, indicates the validity of increasing the duration of fattening of the Limousin calves reared with their mothers on the pasture until the age of 8 months, which is a maximum in this category.

Key words: suckler beef, veal, nutritional quality, inherent properties, vacuum ageing

Meat quality is a complex concept and can be defined as the characteristics of meat that satisfy customers (Hocquette et al., 2012). The total value of meat is determined by the intrinsic and extrinsic qualities required by consumers to form expecta-

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tions about beef quality (Grunert et al., 2004). The majority of the world's beef is produced with the utilisation of grazing pastures based on extensive rearing systems. These are low-cost solutions because the natural and animal-friendly meat production, in particular, meets the requirements of retailers and consumers. In addition to these idealistic aspects, a key determinant of food quality is its health and nutritional value for the customer (Schor et al., 2008). The fatty acid composition of meat has been extensively studied because of its implications for human health. Due to the relationship between high-fat diets and heart disease, consumer interest in the fat content and fatty acid composition of foods has been increasing. The production system can, therefore, be used to manipulate the fatty acid content of muscle in an attempt to improve the nutritional balance (Scollan et al., 2006). The colour of meat is influenced at all stages of the production chain from the breed, sex, diet, age at antemortem inspection of animals, stunning, bleeding, and it is also affected by the temperature and the length of time in storage. Moreover, the meat colour is also affected by packaging, marketing and distribution; therefore it is a key sensory feature of red meat that is associated with its appearance and freshness (Mancini and Hunt, 2005). Despite unfavourable changes (e.g., darker colour), vacuum packaging and ageing of wholesale beef is mostly used in industrial range (Lindahl, 2011) mainly due to a significant improvement of beef tenderness (Oliete et al., 2006; Revilla and Vivar-Quintana, 2006).

In the European Union, veal is described as the meat of bovine animals aged less than 8 months at slaughter; however, the management systems and meat features are not regulated. The term beef is equally used for the meat of older (i.e., aged from 12 months) male and female bovine animals (EU, 2013). According to Ripoll et al. (2013), identifying and producing products of distinctive quality is a priority for beef producers. Moreover, different products could be obtained depending on the management of veal calf rearing, which can affect the resultant colour and texture.

In Poland, young calves are traditionally fed only with whole milk for 50–60 days up to the weight of 80 kg. The successive feeding diet for white meat calves or "baby beef" (live weight of more than 120 kg) is solely based on milk replacers. A significant popularity of the Limousin breed in Poland derives from its excellent carcass and meat qualities (Litwińczuk et al., 2006, 2013; Nogalski et al., 2014). Therefore, veal production in Poland also involves suckler beef to a limited extent, consisting mainly of Limousin calves reared by their dams on the pasture. Usually, these animals are slaughtered at weights ranging from 250 to 350 kg, shortly after weaning (Florek et al., 2012). Litwińczuk et al. (2013) reported that the slaughter age of calves (6, 7 or 8 months) had no significant effect on the dressing percentage. Moreover, the carcass conformation and fatness were not significantly affected by the slaughter age. This indicates a possibility of calves fattening with their mothers on pasture until the age of 8 months, which is a maximum in this category. High quality slaughter material may be obtained at the end of the grazing period (October to November) by adjusting the calving for the late winter or early spring season (February to March).

The present study was designed to determine the nutritional properties of *musculus longissimus lumborum* from Limousin suckler beef (i.e., calves of beef breeds reared in a pasture-based management system with dams up to 6, 7 or 8 months), as well as the inherent properties after different times of postmortem ageing under vacuum.

Material and methods

Animal management

The investigations included 18 Limousin breed calves (intact males) from the central-eastern region of Poland. Calves stayed with their mothers on pasture during the vegetative season from birth until the slaughter. Three groups of animals (each of six heads) were distinguished depending on age: I – up to 6 months (161–180 days), II – approximately 7 months (181–220 days), and III – approximately 8 months (221–245 days). Under the extensive conditions, the diet of the suckler calves consisted exclusively of pasture from the beginning of May to the end of October. The mother's milk contained on average 2.62% fat, 3.54% protein, 4.95% lactose and 11.76% total solids (Florek et al., 2013). The value of the pasture yield (MJ net energy ha^{-1}) was evaluated twice a season using the Różycki's standard control parcel method (Borowiec, 2001). The first evaluation was performed in May before putting animals out to pasture and the other in October before grazing the last feedlots. The pasture value in May (valued in food units) was very good (average of 49.7 thous. MJ of net energy), while in October it was weak (average of 22.3 thous. MJ of net energy). The botanical evaluation share of grass in the pasture sward was 70%, legumes were 23%, and herbs and weeds were 7%.

Meat sampling

Approximately 3–4 hours prior to slaughter, the animals were weaned and transported directly from the pasture to the slaughterhouse in which they were weighed. The stunning and slaughter operations of calves were performed in compliance with the technology obligatory in the meat industry and under supervision of veterinary inspection. The carcass weight was measured before and after the chilling, and the dressing (hot and cold) values were calculated. During the technological partition of the carcass (after chilling for 24 h at 2ºC, and relative moisture of 85%) the samples of *musculus longissimus lumborum* (MLL) were cut out from the lumbar region, divided into three sections of the same length, and then weighed and vacuum-packed in the PA/PE foil bags. The samples were stored at 2ºC until 2, 5 and 12 d postmortem and then were analysed.

Intrinsic measurements

The PQM I-KOMBI (INTEK GmbH, Aichach, Germany) meter was employed to determine the values of pH and electrical conductivity (EC), which was expressed in mS cm^{-1}. Both measurements were determined directly in muscle tissue 1 h (pH_1, EC_1), and 2 (pH_2, EC_2), 5 (pH_5, EC_5), and 12 days (pH_{12}, EC_{12}) after the slaughter.

The meat colour was measured using a Minolta CR-310 (Minolta Camera Co., Ltd., Osaka, Japan) portable chroma meter (illuminant D65, geometry 0° and 50 mm of measure aperture) after the muscle sample had been removed from the vacuum bag, cut off to create a fresh surface and then bloomed for 30 min at 4°C. The measurements were taken on days 5 and 12. Values were given in the CIE colour space (CIE, 2004), where L* denotes metrical lightness on a scale of 0 (black) to 100 (white); a* indicates red (+) or green (–), and b* yellow (+) or blue (–). The hue angle (h°) was calculated as h = arctan (b*/a*), where h = 0° for red hue and h = 90° for yellowish hue. A result for a sample was computed as an arithmetic mean from two replications on the muscle surface.

Drip and cooking loss were determined according to Honikel (1998). Drip loss (DL) was expressed as a percentage of the initial weight of the meat sample (before packaging) to samples stored for 5 and 12 d. Cooking loss (CL) after 5 and 12 d postmortem was expressed as a percentage of the initial weight of the meat sample (about 100 g) to samples after thermal treatment in the water bath at 70ºC for 60 min, then cooled for 30 min in running tap water and stored at 4°C until analysis.

The filter paper press method (Grau and Hamm, 1952) was used to measure the amount of loose water (mg) from meat (0.3 g) held under pressure (2-kg for 5 min). The 'ring zone' (difference between total area and meat area) was measured using imaging software (MultiScan Base ver. 14). The area of 'ring' of expressed juice absorbed by the filter paper is inversely proportional to the meats' water-holding capacity. Duplicate measurements per sample were taken for analysis.

Shear force (SF, N) measurement was carried out using a Zwick/Roell universal testing machine Proline BDO125 FB0.5TS (Zwick GmbH & Co., Ulm, Germany) and a Warner-Bratzler device (V-blade), after thermal treatment of the samples 5 and 12 d postmortem. From each meat sample (at room temperature), a minimum of six stripes (10 × 10 × 50 mm) of a 1 cm^2 area were cut perpendicular to the fibre direction, at a crosshead speed of 100 mm min^{-1}. Results of measurements were obtained using TestXpert® II software (Zwick GmbH & Co.).

Chemical analyses

The reference methods were employed to determine the proximate composition of MLL. The moisture content was determined according to PN-ISO 1442:2000 by the drying method using a hot air oven (103°C); total ash by incineration in a muffle furnace (550°C) as described in PN-ISO 936:2000; a crude protein content (N × 6.25) with the Kjeldahl method by a Büchi B-324 (Flawil, Switzerland) apparatus according to PN-A-04018:1975; and total fat content by Soxhlet lipid extraction method using Büchi-B-811 (Flawil, Switzerland) equipment and n-hexane as a solvent presented by PN-ISO 1444:2000. The energy value of the meat was calculated on the basis of the content of crude protein and fat. The computations were based on the physiological (Atwater) energy equivalents (for protein 4.0 kcal = 16.76 kJ, while for fat 9.0 kcal = 37.66 kJ) and expressed as kJ per 100 g^{-1} of fresh tissue.

Fatty acid levels were analysed following fat extraction according to Folch et al. (1957). Further steps were carried out according to PN-EN ISO 5509:2001 and PN-EN ISO 5508:1996. Fatty acids were separated in a Varian CG 3900 (Walnut Creek, USA) gas chromatograph with a flame ionization detector (FID). The capillary column CP 7420 (Agilent Technologies, USA) was used that had the following specifications: 100 m in length, inner diameter of 0.25 mm and film thickness of 0.25 μm. The initial oven temperature was 50°C, and the final temperature was 260°C. The injector and detector temperature was 270°C, the carrier gas (hydrogen) flow rate was 2 ml/min, the size of the injected samples was 1 μl, and the split ratio was 1:50. Identification of fatty acids was based on retention times corresponding to reference standard – Supelco® 37 Component FAME Mix (Supelco Inc., Bellefonte, PA, USA) and Conjugated Linoleic Acid Methyl Ester – CLA (Sigma-Aldrich, St. Louis, MO, USA). Fatty acids were expressed as percentages of the sum of total identified fatty acid methyl esters (FAME) (wt %) using a Star GC Workstation Version 5.5. software (Varian Inc., Walnut Creek, USA).

The samples of MLL were wet digested with concentrated nitric acid using a MarsXpress microwave oven (CEM Corporation, Matthews, NC, USA). The concentration of major elements (potassium, sodium, calcium, magnesium) and minor elements (zinc, iron, manganese, copper) was determined by means of the flame atomic absorption spectrometry (FAAS; air-acetylene flame) with the use of a Varian Spectra 240FS spectrometer. The method accuracy was evaluated by means of trace metals determined in DORM-3 and 1546C Standard Reference Material. Analyses were performed in triplicate. The content of macro- and microelements in the samples was expressed in mg kg^{-1} wet mass.

Statistical analysis

The analyses were performed using the SAS Enterprise Guide 6.1 software (SAS, 2013). Based on one-way analysis of variance, the influence of calf age (6, 7 or 8 months) on the proximate composition, fatty acid and mineral contents of MLL was estimated. For inherent properties the GLM model for analyses of variance included calf age and duration of ageing. Tukey's test was applied for the multiple comparisons among means, considering $P \leq 0.05$ or $P \leq 0.01$ as significant.

Results

The increase of slaughter value traits concurrent with increasing calf age are shown in Table 1. Such significant ($P \leq 0.05$) dependence referred to animal weight before slaughter, and weight of carcasses before (hot) and after chilling (cold), which are obvious. On the other hand, a pronounced impact of calf age on hot and cold dressing percentage was not confirmed.

This study showed that the meat of calves aged 7 and 8 months contained significantly ($P \leq 0.05$) more protein and it was more caloric than that from 6-month-old animals (Table 2). This tendency (not significant, $P > 0.05$) was also found in the case of ash, and intramuscular fat content, which undoubtedly contributed to the higher energy content of older calves' veal. The protein content varied while the water content remained the same, which caused significant ($P \leq 0.05$) differences in the water to protein proportion in the meat. With the age of calves, the hydration of muscle proteins decreased by 10% (6 months vs. 7 and 8 months).

Table 1. Slaughter value of Limousin suckler beef in relation to age (mean±s.e.)

Item	Calf age (months)		
	6	7	8
Age (days)	163±8	202±9	230±8
Slaughter weight (kg)	230.0 a±10.69	287.4 b±9.18	307.2 c±8.71
Weight of carcasses (kg)			
before chilling	144.7 a±4.86	178.3 b±5.75	193.4 c±6.05
after chilling	141.9 a±4.93	175.1 b±5.67	189.7 c±5.74
Dressing percentage			
before chilling	63.02±0.97	62.06±0.51	62.93±0.67
after chilling	61.75±0.94	60.94±0.47	61.74±0.59

a, b, c – values in rows with different letters differ significantly ($P \leq 0.05$).

Table 2. Proximate composition and energy value of *musculus longissimus lumborum* of Limousin suckler beef in relation to age (mean±s.e.)

Item	Calf age (months)		
	6	7	8
Moisture (g 100 g^{-1})	76.39±0.40	75.64±0.31	76.07±0.22
Crude protein (g 100 g^{-1})	21.13 a±0.23	23.11 b±0.57	23.49 b±0.60
W:P	3.62 b±0.05	3.28 a±0.09	3.24 a±0.08
Intramuscular fat (g 100 g^{-1})	0.67±0.16	0.79±0.12	0.93±0.18
Ash (g 100 g^{-1})	1.2±0.09	1.28±0.14	1.37±0.14
Net energy (kJ 100 g^{-1})	376.2 a±8.7	415.1 b±10.2	421.4 b±13.4

a, b, c – values in rows with different letters differ significantly ($P \leq 0.05$).
W:P – water:protein proportion.

Table 3. Fatty acid composition (% total fatty acids) of *musculus longissimus lumborum* of Limousin suckler beef in relation to age (mean±s.e.)

Fatty acid	Calf age (months)		
	6	7	8
C12:0	0.18±0.01	0.22±0.02	0.18±0.01
C14:0	5.90±0.26	6.13±0.76	5.51±0.24
C16:0	28.14±0.69	30.51±1.65	30.65±1.18
C18:0	15.95±0.44	15.27±1.03	15.89±1.02
C20:0	0.12±0.01	0.10±0.00	0.14±0.01
SFA	50.31±1.35	52.24±1.79	52.40±0.57
C16:1c9	4.12±0.08	4.51±0.42	4.24±0.48
C18:1c9	36.66±0.73	34.94±1.56	37.67±0.18
MUFA	40.87±0.74	39.54±1.89	42.00±0.63
C18:2c9c12n6 (LA)	3.38±0.31	3.24±1.23	2.45±0.54
C18:3c9c12c15n3 (ALA)	1.57±0.09	1.39±0.52	0.90±0.22
CLA (C18:2c9t11/t10c12)	1.49 B±0.02	1.14 B±0.17	0.75 A±0.07
C20:4n6 (AA)	1.43±0.18	1.46±0.77	0.72±0.24
C22:5n3 (DPA)	0.78±0.05	0.74±0.35	0.34±0.16
PUFA	8.79±0.65	8.20±2.86	5.58±1.12
UFA	49.67±1.34	47.74±1.79	47.59±0.57
PUFA/SFA	0.17±0.01	0.16±0.06	0.10±0.02

A, B – values in rows with different letters differ significantly ($P \leq 0.01$).

The skeletal muscles of the young bulls had the highest percentages of oleic (C18:1c9), palmitic (C16:0) and stearic (C18:0) acid, as expected in beef (Table 3). Oleic acid (C18:1c9) was dominant among monounsaturated fatty acids (MUFA), accounting for over one-third of all of the acids determined in the intramuscular fat of the suckler beef. The age only influenced the CLA concentration. The MLL of calves aged 6 and 7 months had a significantly ($P\leq0.01$) higher CLA content (1.49 and 1.14%, respectively) in relation to animals at the age of 8 months (0.75%). Similar, but insignificant, decreasing tendencies were reported for linoleic acid (LA), α-linolenic acid (ALA), docosapentaenoic acid (DPA), total PUFAs and PUFA/SFA ratio. Whereas, increasing contents of palmitic acid and total SFA were also observed.

Table 4. Mineral contents (mg kg^{-1}) of *musculus longissimus lumborum* of Limousin suckler beef in relation to age (mean±s.e.)

Mineral	Calf age (months)		
	6	7	8
K	3374.23±200.71	3176.25±185.00	3386.77±310.37
Na	369.38±25.67	420.67±41.76	385.29±48.99
Mg	279.83 A±3.93	312.89 B±7.10	388.60 C±5.50
Ca	16.10±4.94	20.72±5.41	28.43±6.93
Fe	16.32 a±3.02	29.20 b±2.90	32.56 b±4.09
Zn	22.97 a±0.21	29.72 b±0.43	32.67 b±1.27
Mn	2.45±0.83	1.74±0.49	1.11±0.31
Cu	0.91 b±0.03	0.23 ab±0.02	0.13 a±0.03

a, b, c – values in rows with different letters differ significantly ($P\leq0.05$).
A, B, C – as above for $P\leq0.01$.

Table 5. Changes in pH and specific electrical conductivity of *musculus longissimus lumborum* of Limousin suckler beef in relation to postmortem ageing (mean±s.e.)

Item	Calf age (months)				P-value		
	6	7	8	Average	CA	PA	CA × PA
pH							
1 h	6.74±0.19	6.57±0.13	6.87±0.10	6.72 B±0.08	0.073	0.000	0.875
2 d	5.70±0.07	5.57±0.06	5.67±0.14	5.64 A±0.05			
5 d	5.55±0.06	5.46±0.02	5.58±0.07	5.52 A±0.03			
12 d	5.51±0.09	5.51±0.05	5.60±0.08	5.54 A±0.04			
EC (mS cm^{-1})							
1 h	2.93±0.48	3.10±0.80	1.96±0.43	2.67 A±0.37	0.076	0.000	0.383
2 d	2.98± 0.80	2.42±0.34	2.30±0.47	2.54 A±0.29			
5 d	8.30±1.53	6.55±1.68	6.14±0.82	6.88 B±0.81			
12 d	11.13±1.76	13.02±0.67	9.00±0.85	11.17 C±0.72			

CA – calf age; PA – postmortem ageing; CA × PA – interaction.
A, B, C – values in columns with different letters differ significantly ($P\leq0.01$).

The content of mineral elements in MLL from Limousin calves is shown in Table 4. A significant impact of calf age was observed mainly for minor elements. An increase in Mg ($P\leq0.01$), Zn and Fe ($P\leq0.05$) and a decrease in Cu ($P\leq0.05$) were observed. Similar but insignificant (related to considerable variability) tendencies were observed for Ca (increased concentration), and for Mn (decreased concentration).

Table 6. Changes in water holding capacity and shear force of *musculus longissimus lumborum* of Limousin suckler beef in relation to postmortem ageing (mean±s.e.)

Item	Calf age (months)				P-value		
	6	7	8	Average	CA	PA	CA × PA
Drip loss (%)							
5 d	1.7±0.2	1.6±0.2	1.5±0.2	1.6 A±0.1	0.036	0.000	0.118
12 d	4.5±0.4	2.9±0.5	2.2±0.2	3.1 B±0.5	(6–7, 6–8)		
Cooking loss (%)							
5 d	30.3±1.9	29.9±2.0	34.6±0.7	31.6±1.1	0.008	0.581	0.907
12 d	29.1±0.8	29.9±1.5	33.8±0.7	31.0±0.8	(6–8, 7–8)		
Expressible juice (mg)							
5 d	55.4±7.3	53.7±7.2	45.4±6.0	51.4±3.9	0.559	0.215	0.680
12 d	44.7±1.7	47.5±3.6	45.0±3.7	45.9±1.9			
Shear force (N)							
5 d	73.6±7.12	84.7±12.97	81.8±11.38	81.0 b±6.45	0.988	0.035	0.710
12 d	63.2±4.05	55.0±6.71	54.9±13.54	56.8 a±5.56			

CA – calf age; PA – postmortem ageing; CA × PA – interaction.
a, b – values in columns with different letters differ significantly (P≤0.05).
A, B – as above for P≤0.01.

Table 7. Changes in CIE L*a*b* colour parameters of *musculus longissimus lumborum* of Limousin suckler beef in relation to postmortem ageing (mean±s.e.)

Item	Calf age (months)			Average	P-value		
	6	7	8		CA	PA	CA × PA
L*							
5 d	40.29±0.86	38.57±0.44	36.57±1.11	38.37 a±0.58	0.003	0.032	0.561
12 d	42.45±1.57	39.19±0.27	38.84±1.08	39.94 b±0.65	(6–7, 6–8)		
a*							
5 d	21.19±0.21	22.13±0.45	22.55±0.33	22.02 A±0.25	0.007	0.003	0.552
12 d	22.05±0.83	23.87±0.48	24.15±0.15	23.48 B±0.38	(6–7, 6–8)		
b*							
5 d	3.62±0.38	3.64±0.43	4.05±0.45	3.77 A±0.24	0.404	0.009	0.511
12 d	4.53±0.46	5.30±0.42	4.96±0.72	4.98 B±0.31			
h°							
5 d	9.6±1.0	9.2±0.9	8.4±0.8	9.0 A±0.5	0.685	0.004	0.770
12 d	11.6±1.1	12.4±0.7	11.5±1.6	11.8 B±0.6			

CA – calf age; PA – postmortem ageing; CA × PA – interaction.
a, b – values in columns with different letters differ significantly (P≤0.05).
A, B – as above for P≤0.01.

The interaction between calf age and postmortem ageing on the inherent properties of MLL was not significant (P>0.05) (Table 5). Moreover, there was no noted effect of the different calf ages on the meat pH and electrical conductivity (EC). A significantly (P≤0.01) higher meat pH was found 1 h after the slaughter of calves regardless of their age. It was also shown that the pH value of the meat of all calves measured in consecutive measurements (2, 5 and 12 d postmortem) was within the desired range (i.e., from 5.5 to 5.6). It has been shown that, regardless of the age of calves, along with the postmortem ageing of MLL stored at 2°C, the EC value increased significantly ($P \leq 0.01$) from 2 d up to 12 d after slaughter (Table 5). The MLL of calves aged 6 months had a significantly ($P \leq 0.05$) higher drip loss than muscles from animals aged 7 and 8 months (Table 6). The significant ($P \leq 0.01$) influence of calf age was confirmed also for cooking loss (Table 6). The highest drip after thermal treatment was determined for meat of calves aged 8 months compared with younger animals. The amount of expressible juice was not different ($P > 0.05$) between an age group of animals and between the 5 and 12 days of ageing. There was no significant difference in shear force designated for MLL of calves at the age of 6, 7 and 8 months (Table 6). However, a significant ($P \leq 0.05$) influence of postmortem ageing on improvement of meat tenderness regardless of calf age was observed. On the 12th day postmortem, it was found that the shear force required to break the fibres was reduced by 30% compared to strength on the 5th day after slaughter.

The age of the calves only significantly affected the lightness (L*) and redness (a*) of the meat (Table 7). A lower L* value was measured in meat of older calves, and a significant ($P \leq 0.01$) difference was confirmed between calves aged 6 months and those aged 7 and 8 months. The opposite trend ($P \leq 0.05$) was observed in the case of the a* parameter. It has been shown that with the increasing age of calves their meat contained a higher proportion of the red colour. Regardless of calf age, with ageing time (5 vs. 12 d) the MLL showed significantly higher values of lightness, redness, yellowness and hue angle.

Discussion

The indices of slaughter value established in the present investigation are similar to those reported in other studies of the Limousin breed (Aldai et al., 2012; Golze, 2001; Simčič et al., 2006). However, a lower dressing percentage (56.3–58.0%) after chilling of Limousin crossbreds was reported by Terler et al. (2014). It is worth mentioning that the observed variation in the slaughter value among the results of the cited authors may result from different feeding (Cerdeńo et al., 2006) or diverse growth rates of the animals (Przysucha and Grodzki, 2007). Supplementary results of slaughter values of Limousin calves involved in the present study were presented previously (Litwińczuk et al., 2013).

In general, the proximate composition of MLL from Limousin suckler beef of the different age groups was similar to that reported in the literature. Aldai et al. (2012) observed the following distribution of basic chemical components in *m. longissimus lumborum* of Limousin calves (aged 7 months) naturally suckled by their mothers in mountain areas and that received *ad libitum* access to concentrate up to a maximum of 3 kg/day/head: 75.86% water, 22.19% total protein, 1.44% crude fat and 1.29% ash. In contrast, a lower intramuscular fat content than that reported here was previously reported by Golze (2001) in *m. longissimus dorsi* of Limousin calves (IMF = 0.5%) of a similar age (214 d) and by Terler et al. (2014) in *m. longissimus lumborum* of older (320 d) crossbred Simmental × Limousin suckler male calves (IMF = 0.6%). However, Furfaro et al. (2005) analysed the meat quality of older Limousin × × Rossa Siciliana hybrids and found no significant effect of age (10–12 vs. 14–16 vs. 18–22 months) on the chemical composition of *longissimus thoracis et lumborum* muscle. The average content of protein and fat amounted to 23.10% and 1.75%, respectively. The results of Furfaro et al. (2005) are consistent with those (i.e., no effect of animal age on intramuscular fat content) of the presented study.

The content of total CLA (sum of different isomers) reported by Aldai et al. (2012) in the *longissimus thoracis et lumborum* muscle of Limousin male calves slaughtered at an average age of 7 months averaged 1.41% (as % of total fatty acid methyl esters), and the rumenic acid (18:2 c9t11) accounted for more than 75%. These results are consistent with our findings. However, the total PUFA content was higher (13.09%) than that obtained in the present study for Limousin calves aged from 6 to 8 months. The fat content in the meat and the amount of fat cover on the carcass are factors affecting the fatty acid profile. A much higher content of total PUFA (30.80%), and less MUFA and SFA (32.68 and 36.53%, respectively) were reported by Ripoll et al. (2013) in the *longissimus thoracis* muscle (with 0.43% of IMF) of grazing suckler male calves (aged 226 days and 227 kg at slaughter) from the Parda de Montaña breed. The level of PUFA (particularly long-chain fatty acids) decreased as fat content in the meat increased, which was also observed in the present study. This is mainly due to an increase in the proportion of neutral lipids (triacylglycerols) in the intramuscular adipose tissue, which are rich in SFA, accompanied by a decrease in phospholipids, with which PUFA are mainly associated (De Smet et al., 2004; Warren et al., 2008). According to Scollan et al. (2006), the PUFA/SFA ratio in beef is relatively low, ranging on average from 0.05 to 0.11. A low PUFA/SFA ratio in beef with respect to the recommended value (over 0.4) is a natural phenomenon associated with hydrogenation in the rumen of the cattle of unsaturated fatty acids originating in commercial feeding.

The correlations presented in our study between an increase of Mg, Zn and Fe contents with calf age (Table 4) could be explained by the fact that polyvalent metals such as iron, zinc and magnesium accumulate with age and are among the major cross-linking agents in living organisms. An increase of iron content with age in steer muscles was observed by Kotula and Lusby (1982). In addition, Schönfeldt et al. (2010) reported an increase in the concentration of iron and magnesium with beef age, however, the copper content decreased. The concentrations of K and Fe reported for MLL of calves aged 7 months in this study were similar to those found by Giuffrida-Mendoza et al. (2007) in the *longissimus dorsi thoracis* muscle of Buffalo weaners of the same age. However, the Na, Zn and Cu content levels found by Giuffrida-Mendoza et al. (2007) were twice as high as those found in the present investigation. In general, the inconsistent effect of cattle age (7, 17, 19 and 24 months of age) on mineral content was confounded by environmental conditions (Giuffrida-Mendoza et al., 2007). Mineral concentrations in the muscle are usually dependent on their own internal metabolism in situations of an adequate mineral status. Moreover, the distribution pattern could be related to metal interactions or antagonisms to maintain a correct mineral balance (García-Vaquero et al., 2011).

The pH value of all calf meat was within the desired range, indicating the proper process of postmortem glycolysis and, indirectly, the proper handling of the animals prior to their slaughter (Ferguson and Warner, 2008). Significantly greater EC values ($P \leq 0.01$) measured from 2 d up to 12 d after slaughter, concomitant with greater drip loss indicated a weakening of cellular membranes in the muscle tissue after slaughter and maintenance of water by myofilaments that make the fluids translocate within the intra- and intercellular space.

Our data indicated the highest cooking loss from the meat of calves aged 8 months compared with that of younger animals. However, Revilla and Vivar-Quintana (2006) reported a reduction of cooking loss depending on the duration of postmortem ageing (3, 5 and 7 d) for the *longissimus dorsi* muscle of Limousin hybrids. In the case of young bulls of 8 months, cooking loss decreased from 21.2 (3 d) to 12.5% (7 d).

Aldai et al. (2012) reported a comparable shear force (averaged 5.10 kg) to that obtained in the present study after 12 d postmortem for the *longissimus lumborum* muscle of Limousin calves (aged 7 months) after 11 d of ageing. Similar results were reported by Revilla and Vivar-Quintana (2006) after 7 d of ageing of the *longissimus dorsi* muscle of 8-month-old Limousin crossbred bulls (5.05 kg). Consistent with the results of Berry (1993) and Belew et al. (2003), a consumer is sure of getting loin steaks of suitable tenderness if the Warner-Bratzler (W-B) shear force does not exceed a 3.9 kg value (38.2 N). However, Shackelford et al. (1991) and Destefanis et al. (2008) claim that the W-B threshold value for commercial beef is, respectively, 45.1 N and 42.9 N. Boleman et al. (1997) suggested the following categories for beef steaks on the grounds of the W-B force: tender from 2.27 up to 3.58 kg (22.3–35.1 N), moderate 4.08–5.40 kg (40.0–53.0 N), and tough 5.90–7.21 kg (57.9–70.7 N). According to this division, the ultimate MLL tenderness shown in the present studies implies that it belongs to the moderate (calves aged 7 and 8 months) or tough (calves aged 6 months) categories.

The maintenance of red colour is mainly due to the myoglobin reducing activity (MRA) of the meat, which is influenced by several factors. The darker colour of muscles of older animals could be consequently associated with a higher intake of pasture and more exercise related to their age (and myoglobin concentration) (Mancini and Hunt, 2005). Beef obtained from animals fed on pasture for a longer period of life results in a natural richness in "red" oxidative muscle fibres and high concentrations of natural antioxidants (Insani et al., 2008).

The results of the colour parameters of calves meat packaged in vacuum packaging, showed a significant increase in all values in subsequent measurements during the storage period. The postmortem protein degradation (directly dependent on the final pH), contributes to the increase of scattering of light on the meat surface, which contributes to an increase of the L*, a* and b* values (Abril et al., 2001). The higher value of hue angle measured after exposure to air during the storage indicate a faster browning of stored beef, and must be considered as it represents a critical factor assessed by consumers (Stella et al., 2013). Vacuum packaging represents a protective factor, as it removes oxygen from the environment and favours the growth of lactic acid bacteria, which positively influence the MRA of meat by the production of lactate, which is known as a "colour stabilizer" (Kim et al., 2006). Revilla and Vivar-Quintana (2006) assessed the impact of ageing (3, 5 or 7 d) on the colour of the *longissimus dorsi* muscle of Limousin hybrids and showed a reduction in 8-month-old bulls in both the lightness (L* value from 44.20 to 40.83) and the yellowness (b* value from 15.91 to 13.79), while the balance of the redness (a*) was maintained.

Conclusions

This study showed a positive correlation between the age of calves and the protein and calorie contents in meat. However, the hydration of muscle proteins (water:protein proportion) significantly decreased with increasing calf age. The calf age significantly influenced the increase in Mg, Zn and Fe concentrations and decrease in Cu concentration. In addition, a higher Ca content and lower Mn content were observed with increasing age. The fatty acid composition was similar irrespective of calf age, with the exception of the CLA content, which decreased in older animals. The meat of the youngest calves (aged 6 months) was significantly ($P \leq 0.05$) lighter and less red compared to the muscles of older animals (aged 7 and 8 months). Moreover, the meat of 6-month-old calves showed the most significant drip loss. There was no effect of calf age on the meat shear force. However, postmortem ageing under vacuum correlated with a significant increase in meat tenderness. The lack of significant differences, especially with regard to the meat pH, tenderness (shear force), and with concomitant significantly higher protein content in relation to the slaughter age, indicates the validity of increasing the duration of fattening of the Limousin calves reared with their mothers on the pasture until the age of 8 months, which is a maximum in this category. This suggests that the best strategy to improve meat quality from calves of different ages is to allow them to suckle until slaughter.

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