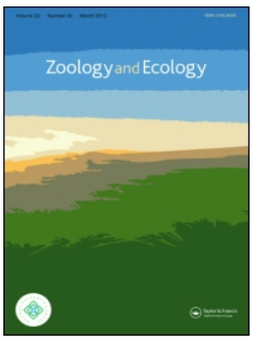

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Comparative evaluation of longissimus and semimembranosus muscle characteristics from free-living and farmed red deer (*Cervus elaphus*) in Lithuania

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ABSTRACT

The aim of the study was to compare characteristics of longissimus dorsi (LD) and semimembranosus (SM) muscles from free-living and farmed red deer (*Cervus elaphus*) in Lithuania. No significant differences were found either between LD and SM muscles of free-living and farmed red deer or within these muscles of red deer from different environments regarding meat pH and colour parameters. The assessment of meat toughness employing the Warner-Bratzler (WB) method showed the longissimus muscle of free-living deer to be tenderer than the semimembranosus muscle. The TPA (texture profile analysis) method, in contrast to the WB test, showed higher tenderness of the semimembranosus muscle in farmed red deer. The present study revealed only small differences in properties of free-living and farmed red deer meat, i.e. intramuscular fat in the longissimus muscle of free-living red deer had a lower and a more favourable n-6/n-3 PUFA ratio and the semimembranosus muscle a lower content of cholesterol than the respective muscles of farmed deer. Therefore, the meat of free-living red deer could be considered to be more acceptable in terms of healthy nutrition.

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Cholesterol; fatty acids; red deer; venison quality; meat tenderness

Introduction

Humans started to domesticate animals approximately 10 thousand years ago, and now they mostly use meat obtained from intensive animal production (De Castro Cardoso Pereira and Dos Reis Baltazar Vicente 2013). However, over the past 50 years, there have occurred changes in the way society and wildlife interact due to shifts in food preferences, growing health concerns, concerns about animal welfare and environment issues and, consequently, due to interests in alternative products, as well as in products produced by low input systems (Hoffman and Wiklund 2006; Macmillan and Phillip 2008). The evidence of civilization diseases and discussions in literature about human genetic adaptations to food from wild and domesticated animals have increased consumers' interest in game meat (Milton 2000; Hoffman and Wiklund 2006; De Castro Cardoso Pereira and Dos Reis Baltazar Vicente 2013). The recent archaeozoological analyses characterised a variety of faunal resources from the early Halocene. The Mesolithic red deer (*Cervus elaphus*) was found to be one of the most representative species on the southern slope of the Alps (Hohenstein et al. 2016). Other studies (Carden et al. 2012) indicate that the red deer was introduced into Ireland during the Neolithic period. On the territory of Lithuania, among terrestrial mammals the red deer has been known since the Late Neolithic (Stančikaitė et al. 2009). Currently, the red deer is one of the most widespread deer species found naturally with a fragmented distribution throughout Europe, Asia and North America (Hoffman and Wiklund 2006; Burbaitė and Csányi 2010; Quaresma et al. 2012; Skonhoft et al. 2013). Although red deer breeding in captivity dates back to ancient times, an increase in its role in modern agriculture has been observed only since the 1970s, when the rapid development of large-scale red deer farming began (Kuba, Landete-Castillejos, and Udała 2015). The low effort of red deer farming and higher prices for venison in the market compared with other types of meat suggest that the interest in red deer farming will continue to rise. Red deer meat displays different qualities which are due to the wide distribution and different origin of the animal (Druml et al. 2015). Despite various previously conducted studies, the information on the comparison of free-living red deer meat quality with that of farmed deer is still scarce.

The aim of the present study was to compare longissimus dorsi and semimembranosus muscle characteristics from free-living and farmed red deer (*Cervus elaphus*) in Lithuania.

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Materials and methods

Animals and meat samples

The free-living red deer used in this study were shot in accordance with the law No. IX–966 of 18th June, 2013 on hunting of the Republic of Lithuania. Fourteen free-living red deer (8 females and 6 males) used in the experiment were hunted in forests of the central-northern part of Lithuania in latitudes from 55°37′ to 56°14′ N and in longitudes from 23°33′ to 24°40′ E during the winter hunting season (November–January). The samples were excised from two muscles of different carcass sites: *m. longissimus dorsi* (LD), *m. semimembranosus* (SM) in a special area for hunted animals' dressing. All these 28 samples were provided by local hunters within 24 h after red deer shooting and were stored at +4° until analyses.

Fourteen (6 females and 8 males) farmed red deer raised in the northern part of Lithuania at the latitude of 56°14′ N and the longitude of 23°34′ E were shot during the same period (November–January) in a special yard and were transported to the local abattoir. Samples of LD and SM muscles were excised from the chilled carcass samples within a 24 h period after red deer shooting and stored at a temperature of +4° until analyses. The age of free-living and farmed deer varied between 1.5 and 3 years.

Chemical composition of muscles and hydroxyproline content

The dry matter content was determined by drying samples in an oven at a temperature of 105 °C until a constant weight was obtained (method No 950.46B; AOAC 1990). The crude protein content was determined by the Kjeldahl method using the Kjeltec system 1002 apparatus (Foss-Tecator AB). A conversion factor of 6.25 was used to convert total nitrogen to crude protein (method No 981.10; AOAC 1990). Intramuscular fat was determined by the Soxhlet extraction method (method No 960.39; AOAC 1990). Ash was determined by sample incineration in a muffle furnace at 550 °C for 24 h (method No 920.153; AOAC 1990). The content of protein, intramuscular fat and ash were expressed as g/100 g of muscle. The hydroxyproline content was determined using the NMKL-AOAC method (Kolar 1990).

Cholesterol content

The cholesterol content in meat was determined employing the extraction method described by Polak et al. (2008). The determination of cholesterol content was followed by HPLC separation and analysis. Collection and evaluation of the data were performed using the LC Solution (Shimadzu Corporation, Japan) operating system. The analytical column LiChrospher 100 RP-18e, 150 × 4.6 mm, 5 µm (Alltech Associates Inc., USA) with a guard column (LiChrospher 100 RP–18, 7.5 × 4.6 mm) was used. The cholesterol content was expressed as mg/100 g of fresh meat.

pH and colour measurements

Meat quality was assessed at 48 h post mortem. pH was measured using a digital portable pH-meter PT-380 (Boeco, Germany) equipped with a glass electrode (Witeg Laboratory Technik GMBH, Germany). Colour measurements were made on the freshly cut surface of samples after 30 min of blooming. Colour parameters were measured in the CIE L* a* b* and L* C h colour spaces (lightness, L*; redness, a*; yellowness, b*; chroma, C and hue, h) using a Chroma Meter CR-410 Konica Minolta (Japan) with a 50 mm aperture, a C illuminant and a 2° standard observer. The Chroma Meter was calibrated with a white standard ($Y = 85.3$, $x = 0.3173$, $y = 0.3251$) calibration plate before use.

Water holding capacity

Water holding capacity was measured in two ways: drip loss and cooking loss. Drip loss was assessed using the EZ-DripLoss method (Christensen 2003). To determine cooking losses, the frozen samples for TPA analysis were thawed at 4 °C for 24 h and weighed, and cooked in thin-walled plastic bags at 80 °C for 1 h by immersing in a water bath with automatic temperature control (Combes et al. 2003), and then cooled at room temperature (20 ± 2 °C) and weighed again. Cooking loss (%) is defined as the difference in weight of the sample (after wiping dry) before and after cooking and cooling, divided by the sample weight at the beginning and multiplied by 100.

Fatty acid profiles

The extraction of lipids for fatty acid analysis was performed with a mixture of chloroform/methanol as described by Folch, Less, and Sloane-Stanley (1957). Methylation of the samples was performed using sodium methoxide. The FAMEs were analysed using a gas liquid chromatograph (GC – 2010 SHIMADZU) fitted with a flame ionization detector. The separation of methyl esters of fatty acids was effected on the capillary column Rt 2560 (100 m × 0.25 mm × 0.2 µm; Restek, Bellefonte, PA, USA) by programming temperature from 140 to 240 °C. The column was operated at 140 °C for 5 min, then the temperature was increased to 240 °C at 4 °C/min and maintained for 20 min. The temperatures of the injector and detector were held, respectively, at 240 and 260 °C. The rate of flow of carrier gas (nitrogen) through the column was 1.06 ml/min. The peaks were identified by comparing the retention times of the standard fatty acids methyl esters '37 Component FAME Mix' and trans FAME MIX k 110 (Supelco, USA). The relative

Table 1. Chemical composition and cholesterol content in longissimus dorsi (LD) and semimembranosus (SM) muscles from free-living and farmed red deer.

										Significance		
	Free-living			Farmed			Gender			In muscles from different rearing systems		Interactions rearing system × gender
Variables	LD	SM	s.e.d.	LD	SM	s.e.d.	Females	Males	s.e.d.	LD	SM	
Dry matter, g/100 g	26.12	26.31	0.55	25.37	24.88	0.54	28.15	27.68	1.10	ns	*	ns
Protein, g/100 g	22.70	22.74	0.54	22.51	22.21	0.49	23.39	24.28	0.83	ns	ns	ns
Fat, g/100 g	1.55	1.66	0.28	1.22	1.11	0.17	1.53	1.42	0.28	ns	*	ns
Ash, g/100 g	1.19	1.42	0.13	1.18	1.13	0.05	1.47	1.37	0.15	ns	***	ns
Hydroxy-proline, mg/100 g	90.15	74.63	18.99	68.75	66.96	11.53	71.67	71.74	10.61	ns	ns	ns
Cholesterol, mg/100 g	49.09[a]	44.85[b]	2.04	47.80	51.17	2.06	46.73	47.32	1.84	ns	**	*

Notes: s.e.d. – standard error of difference; ns – not significant; [a–b] * $p < 05$; ** $p < 0.01$; *** $p < 0.001$.

proportion of each fatty acid was expressed as the relative percentage of the sum of the total fatty acids using the 'GC solution' software for Shimadzu gas chromatograph workstations.

Lipid quality indices

Lipid quality indices, i.e. the atherogenic index (AI) and the thrombogenic index (TI), were calculated according to Ulbricht and Southgate (1991). The hypocholesterolemic/hypercholesterolemic (h/H) ratio was calculated according to Fernández et al. (2007). The peroxidizability index (PI) was determined according to Du et al. (2003).

Instrumental evaluation of texture

The tenderness of longissimus and semimembranosus muscles was measured instrumentally by carrying out the Warner-Bratzler shear test (WB) and the texture profile analysis (TPA) using a Texture Analyser TA 1 (Measurement and Calibration Technologies Ametek Comp., Lloyd instruments, Largo, FL, USA) after cooking and cooling at room temperature (20 °C). Four samples were prepared from every muscle and subjected to WB and TPA tests. Samples for the WB test were obtained by cutting out 2 × 2 cm rectangles parallel to the muscle fibre direction. They were completely cut using a WB shear blade with a triangular slot cutting edge and two parameters were measured: work of shear and toughness according to the following testing procedures: pre-test speed: 3 mm/s, test speed: 1 mm/min, post-test speed: 3 mm/s. Samples for TPA were prepared and analysed by cutting 2 × 2 cm rectangles parallel to the muscle fibre direction and then compressing to 75%. In this test, a cylindrical 20 mm-diameter probe was used. The sample was placed under the probe that moved downwards at a constant speed of 3.0 mm/s (pre-test), 1.0 mm/min (test) and 1.0 mm/s (post-test). All WB and TPA parameters were measured and calculated in Newtons (N) using the Lloyd Instruments Ltd Nexygen/Ondio software together with the Production Test program Version V3.0.1.

Statistical analysis

The data were subjected to the analysis of variance in general linear (GLM Multivariate) procedure in SPSS 17 with LSD tests to determine the significance of differences of means between the groups. The models included the fixed effect of the rearing system (free-living vs. farmed), muscle type (LD vs. SM) and gender (female vs. male). The differences were regarded as significant when $p < 0.05$, but the differences when $0.05 \leq p < 0.10$ would have been considered as trends.

Results and discussion

The chemical composition analysis showed that only the SM muscle of free-living wild red deer had a higher percentage of dry matter, intramuscular fat ($p < 0.05$) and ash ($p < 0.001$) compared with the SM of farmed deer (Table 1). This study found a higher IMF content in SM and an insignificantly higher IMF content in LD muscles of free-living deer compared to farmed red deer, which is in agreement with the differences in LD fat between farm-raised and wild fallow deer (Daszkiewicz et al. 2015).

The cholesterol content ($p < 0.05$) in the LD muscle of free-living deer was found to be higher than in their SM (Table 1). Significant differences in cholesterol content between these muscle types have been reported for other animal species (Chizzolini et al. 1999; De Almeida et al. 2006). However, there is no information available concerning the comparison of cholesterol content in LD and SM muscles from free-living and farmed red deer. In the present study, the muscles of red deer were found to have lower cholesterol contents than those reported for semitendinosus and triceps brachii muscles of wild red deer (Polak et al. 2008) and for

Table 2. Meat quality properties of longissimus dorsi (LD) and semimembranosus (SM) muscles from free-living and farmed red deer.

										Significance		
	Free-living			Farmed			Gender			In muscles from different rearing systems		Interactions rearing system × gender
Variables	LD	SM	s.e.d.	LD	SM	s.e.d.	Females	Males	s.e.d.	LD	SM	
pH	5.42	5.39	0.08	5.37	5.44	0.07	5.44	5.40	0.07	ns	ns	ns
L*	35.67	36.38	1.20	35.43	36.09	1.27	34.58^{a}	36.76^{b}	0.96	ns	ns	*
a*	20.63	20.26	0.55	20.05	19.66	0.63	19.88	20.37	0.45	ns	ns	ns
b*	6.32	6.40	0.64	6.20	5.84	0.58	6.03	6.19	0.50	ns	ns	ns
C	21.61	21.27	0.67	21.01	20.53	0.73	20.80	21.31	0.55	ns	ns	ns
h	16.83	17.42	1.38	17.11	16.41	1.24	16.73	16.80	1.07	ns	ns	ns
Drip loss, %	1.80	2.04	0.77	3.42†	1.31†	1.15	1.75	2.21	0.72	ns	ns	ns
Cooking loss, %	36.24^{a}	38.44^{b}	1.22	35.92†	38.15†	1.24	37.33	37.16	0.85	ns	ns	ns

Notes: s.e.d. – standard error of difference; ns – not significant; $^{a–b}{}^{*}p < 0.05$; $^{\dagger}\ 0.05 \le p < 0.10$.

Table 3. Fatty acid (% of total FA) composition in intramuscular fat of longissimus dorsi (LD) and semimembranosus (SM) muscles from free-living and farmed red deer.

										Significance		
	Free-living			Farmed			Gender			In muscles from different rearing systems		Interactions rearing system × gender
Fatty acids	LD	SM	s.e.d.	LD	SM	s.e.d.	Females	Males	s.e.d.	LD	SM	
C12:0	0.12	0.16	0.04	0.29	0.21	0.08	0.07^{e}	0.25^{f}	0.04	†	ns	***
C14:0	3.25	3.27	0.41	4.83	3.66	0.94	2.48^{e}	4.15^{f}	0.47	ns	ns	***
C15:0	0.51	0.56	0.13	0.58	0.57	0.09	0.47	0.58	0.11	ns	ns	ns
C16:0	19.95	18.99	1.34	21.50	17.32	2.15	16.24^{c}	19.98^{d}	1.23	ns	†	***
C17:0	0.39	0.43	0.10	0.49	0.48	0.05	0.41	0.44	0.07	ns	ns	ns
C18:0	10.96	11.37	0.67	10.66^{a}	11.66^{b}	0.96	11.94	11.25	0.62	ns	ns	***
C20:0	0.05	0.06	0.02	0.03	0.02	0.03	0.52	0.04	0.02	ns	*	ns
C22:0	0.16	0.15	0.02	0.22	0.26	0.03	0.05	0.04	0.02	***	***	**
14:1n-7	0.71	0.77	0.23	1.21	1.11	0.22	0.69	0.97	0.18	ns	ns	**
16:1n-9 *trans*	0.38	0.43	0.06	0.43†	0.45†	0.04	0.43	0.42	0.05	ns	ns	ns
16:1n-9	0.40	0.42	0.09	0.66^{c}	0.78^{d}	0.04	0.56	0.57	0.07	***	***	ns
16:1n-7	5.50	5.58	0.95	5.18	4.82	0.68	4.65	4.85	0.66	ns	ns	***
17:1n-9	0.28	0.31	0.04	0.32	0.35	0.07	0.26	0.32	0.04	ns	ns	*
18:1 n-9 *trans*	1.08	1.32	0.19	1.01	1.18	0.16	1.21	1.17	0.16	ns	ns	ns
18:1n-9	12.71	14.21	1.08	12.43	12.71	0.99	11.75	13.02	0.83	ns	*	**
18:1n-7	3.33	3.06	0.31	2.78	2.60	0.22	2.97	2.69	0.22	†	ns	**
20:1n-9	0.10	0.14	0.03	0.10	0.07	0.03	0.08	0.10	0.03	ns	†	ns
22:1n-9	0.16	0.11	0.09	0.31	0.21	0.08	0.26	0.22	0.07	ns	***	*
18:2n-6 *trans*	0.48	0.48	0.09	0.21	0.22	0.04	0.36	0.32	0.06	***	***	ns
18:2n-6	13.52	13.20	1.17	11.82	12.94	1.46	0.16^{a}	0.12^{b}	1.00	ns	ns	*
18:3n-6	0.14	0.13	0.02	0.12	0.13	0.03	0.16†	0.12†	0.02	ns	ns	†
18:3n-3	4.17	4.06	0.35	2.73	3.37	0.51	4.19^{a}	3.49^{b}	0.33	**	ns	*
20:2n-6	0.12	0.12	0.02	0.09	0.10	0.03	0.12	0.10	0.02	ns	ns	ns
20:3n-6	0.67	0.65	0.07	0.74	0.75	0.09	0.83	0.72	0.06	ns	ns	ns
20:3n-3	0.33	0.34	0.10	0.12	0.11	0.03	0.18†	0.25†	0.07	**	***	†
20:4n-6	5.24	5.23	0.50	5.41	6.01	0.34	6.84^{c}	5.34^{d}	0.45	ns	*	**
20:5n-3	1.71	1.61	0.20	1.60	1.75	0.25	1.81	1.63	0.19	ns	ns	ns
22:2n-6	0.16	0.16	0.02	0.17	0.18	0.03	0.18	0.17	0.02	ns	ns	ns
22:4n-6	0.17	0.16	0.03	0.26	0.25	0.05	0.29^{e}	0.19^{f}	0.03	**	**	***
22:5n-3	2.27	2.17	0.17	2.28	2.51	0.26	2.54	2.31	0.17	ns	*	ns
22:6n-3	0.44	0.39	0.07	0.63†	0.79†	0.08	0.48^{a}	0.63^{b}	0.06	**	***	*
EPA+DHA	2.14	2.00	0.25	2.38	2.51	0.26	2.28	2.26	0.23	ns	*	ns
TFA	1.94	2.23	0.27	1.65	1.76	0.19	2.00	1.92	0.22	ns	†	ns
Undetected FA	10.18	9.62	0.71	11.31	11.92	1.11	11.93^{a}	10.45^{b}	0.58	ns	**	ns

Notes: s.e.d. – standard error of difference; ns – not significant; $^{a–b}{}^{*}p < 0.05$; $^{c–d}{}^{**}p < 0.01$; $^{e–f}{}^{***}p < 0.001$; $^{\dagger}\ 0.05 \le p < 0.10$. TFA = sum of *trans* fatty acid isomers.

other game and such domestic species as kudu, impala (Hoffman, Mostert, and Laubscher 2009), water buffalo, Brahman-influenced cattle (Giuffrida-Mendoza et al. 2015), and pigs (Hanczakowska, Świątkiewicz, and Grela 2015), but more similar to the values reported for cattle breeds (Brugiapaglia, Lussiana, and Destefanis 2014). Cholesterol contents in wild and farm-reared nutria were found to be different (Tulley et al. 2000). In the present study, only the SM of free-living red deer had a lower content of cholesterol $p < 0.01$) compared with the same muscle of farmed deer. The rearing system × sex interaction was observed only in the cholesterol content in meat ($p < 0.05$) and showed that farmed males had higher but free-living males lower cholesterol contents than females.

No significant differences were found in pH and colour parameters either between longissimus (LD) and semimembranosus (SM) muscles of free-living and those of

Table 4. Total saturated, monounsaturated and polyunsaturated fatty acids, fatty acid ratios and lipid quality indexes in the intramuscular fat of longissimus dorsi (LD) and semimembranosus (SM) muscles from free-living and farmed red deer.

										Significance		
	Free-living			Farmed			Gender			In muscles from different rearing systems		Interactions rearing system × sex
Variables	LD	SM	s.e.d.	LD	SM	s.e.d.	Females	Males	s.e.d.	LD	SM	
SFA	35.40	34.99	1.59	38.86	35.29	2.81	31.98^{c}	37.04^{d}	1.60	ns	ns	***
MUFA	25.03	26.69	1.62	24.42	24.28	1.57	23.01	24.54	1.11	ns	*	***
PUFA	29.40	28.70	2.16	26.16	29.11	3.23	33.09^{a}	27.97^{b}	1.91	ns	ns	***
PUFA/SFA	0.86	0.85	0.10	0.75	0.88	0.16	1.09^{c}	0.80^{d}	0.09	ns	ns	***
n-6/n-3	2.27	2.29	0.12	2.54	2.39	0.19	2.60†	2.35†	0.13	*	ns	**
AI	0.62	0.59	0.06	0.86†	0.65†	0.14	0.48^{c}	0.73^{d}	0.08	ns	ns	***
TI	0.71	0.69	0.06	0.91	0.72	0.12	0.62^{a}	0.78^{b}	0.07	ns	ns	**
h/H	2.09	2.21	0.23	1.94	2.29	0.43	2.92^{e}	2.00^{f}	0.19	ns	ns	***
PI	74.48	72.38	5.60	71.30	79.84	8.07	85.5^{a}	73.81^{b}	4.96	ns	*	***

Notes: s.e.d. – standard error of difference; ns – not significant; $^{a–b}{}^{*}p < 0.05$; $^{c–d}{}^{**}p < 0.01$; $^{e–f}{}^{***}p < 0.001$; SFA, MUFA, PUFA = sum of all detected saturated, monounsaturated and polyunsaturated fatty acids, respectively. PUFA/SFA = ratio of ΣPUFA to ΣSFA, n-6/n-3 = ratio of Σn-6 PUFA to Σn-3 PUFA, AI = atherogenic index, TI = thrombogenic index, h/H = hypocholesterolemic/hypercholesterolemic ratio, PI = peroxidizability index.

Table 5. Parameters of the texture profile analysis (TPA) and the Warner-Bratzler test (WB) of longissimus dorsi (LD) and semimembranosus (SM) muscles from free-living and farmed red deer.

										Significance		
	Free-living			Farmed			Gender			In muscles from different rearing systems		Interactions rearing system × gender
Variables	LD	SM	s.e.d.	LD	SM	s.e.d.	Females	Males	s.e.d.	LD	SM	
Cohesiveness	2.93	2.78	0.11	2.67	2.53	0.16	2.73	2.74	0.09	*	ns	ns
Guminess, N	15.51	16.57	2.03	16.68^{a}	11.33^{b}	2.29	15.70	15.12	1.72	ns	**	ns
Hardness, N	44.59	44.38	4.59	42.03^{c}	27.06^{d}	4.95	42.00	40.16	3.75	ns	***	ns
Springiness, N	0.81^{a}	0.82^{b}	0.01	0.81	0.82	0.01	0.81	0.82	0.01	ns	ns	ns
Chewiness, N	16.88	13.63	3.57	13.64^{a}	9.29^{b}	1.91	12.77	14.94	2.23	ns	**	ns
WB Toughness, N	56.72^{e}	83.32^{f}	7.52	75.26	79.64	6.43	78.89	98.74	26.20	*	ns	ns

Notes: s.e.d. – standard error of difference; ns – not significant; $^{a–b}{}^{*}p < 0.05$; $^{c–d}{}^{**}p < 0.01$; $^{e–f}{}^{***}p < 0.001$.

farmed red deer or within these muscles of red deer from different environments (Table 2), which contradicts the findings of Daszkiewicz et al. (2015), who reported pH and colour differences between longissimus lumborum (LL) muscles from free-living and farmed fallow deer. Despite various previously conducted red deer studies, the information concerning the quality and composition of these muscles from farmed and particularly from free-living red deer is scarce. The effect of the animal origin on reindeer muscle pH and colour parameters was investigated by Mielnik et al. (2011) in different Norway regions, but these authors did not find the effect of a muscle type and this is in agreement with our data. In the present study, the SM of free-living red deer had a higher ($p < 0.05$) cooking loss and the same muscle of farmed red deer tended to have a higher cooking loss than the LD muscle. However, no significant difference was found in the cooking loss between SM and LD muscles of red deer from different environments and this is in agreement with the findings of Daszkiewicz et al. (2015), who did not find the effect of the origin of fallow deer on cooking loss and drip loss. In the present study, males showed higher meat lightness (L* value) than females and this contradicts the findings of Purchas, Triumf, and Egelandsdal (2010) and Mielnik et al. (2011), who did not report significant gender-related differences in colour parameters of meat from red deer and reindeer. The rearing system × sex interaction was observed in L* values ($p < 0.05$) showing that meat from free-living and farmed males was lighter than that from females. No significant differences were found between males and females regarding pH and this contradicts the findings of Mielnik et al. (2011), who reported gender-related differences in reindeer meat pH.

A significant difference between the muscles was found only in individual stearic (C18:0; $p < 0.05$), palmitoleic (C16:1n-9; $p < 0.01$) and fatty acids, which were found to be higher in intramuscular fat of SM compared to LD of farmed deer (Table 3). Our previous study showed that the fatty acid composition in roe deer muscles varies according to the muscle type (Razmaitė et al. 2015), however these differences between LD and SM muscles were found to be the lowest. Although other authors (Polak et al. 2008) have reported on the fatty acid composition in other muscles of red deer than those analysed in the present study, they have also found negligible differences.

Farmed deer showed higher ($p < 0.001$) contents of individual saturated behenic (C22:0), monounsaturated palmitoleic (C16:1n-9) but lower ($p < 0.01$)

polyunsaturated alpha-linolenic (C18:3n-3), DHA (C22:6n-3), eicosatrienoic (C20:3n-3), docosatetraenoic (C22:4n-6) and linolelaidic (C18:2n-6 trans isomers; $p < 0.001$) fatty acids in LD compared with free-living red deer. These results are in discrepancy with the data reported by Daszkiewicz et al. (2015) for free-living and farmed fallow deer.

SM muscles from free-living deer had a higher content of total MUFA ($p < 0.05$; Table 4), including individual oleic (C18:1n-9) fatty acid, but a lower ($p < 0.001$) content of palmitoleic (C16:1n-9) fatty acid compared with farmed deer (Table 3). The lower content of palmitoleic fatty acid in SM muscles of free-living red deer detected in the present study is in agreement with the findings of Manley and Forss (1979), however, the higher content of oleic fatty acid contradicts the results obtained by Manley and Forss (1979). In the present study, free-living red deer were also shown to have higher contents of C20:3n-3 and C18:2n-6 trans isomers ($p < 0.01$) but lower contents of C20:4n-6 ($p < 0.05$), DHA (C22:6n-3; $p < 0.001$) and the sum of EPA and DHA ($p < 0.05$) in their SM muscles than farmed red deer.

The most obvious differences in the fatty acid composition were found between red deer genders. Males had higher contents of total saturated fatty acids (SFA; Table 4), including individual (Table 3) lauric (C12:0; $p < 0.001$), myristic (C14:0; $p < 0.001$), palmitic (C16:0; $p < 0.01$) and individual polyunsaturated eicosatrienoic (C20:3n-3; $0.05 \le p < 0.10$) and DHA (C22:6n-3; $p < 0.05$) fatty acids, and lower contents of total polyunsaturated (PUFA; Table 3), including linoleic (C18:2n-6; $p < 0.05$), gamma-linolenic (C18:3n-6; $0.05 \le p < 0.10$) and alpha-linolenic (C18:3n-3; $p < 0.05$), arachidonic (C20:4n-6; $p < 0.01$), adrenic (C22:4n-6; $p < 0.001$) and undetected fatty acids ($p < 0.05$). Triumf et al. (2012) have found a few significant gender-related effects. Their male group had a higher amount of SFA, MUFA and a lower amount of PUFA than the female group and this is in agreement with our data.

According to the recommendations of Bellagio's report on healthy agriculture, healthy nutrition and healthy people, the ratio (4:1) of n-6 PUFA to n-3 PUFA in the diet should be the goal (Simopoulos, Bourne, and Faergeman 2013). In the present study, a lower and a more favourable n-6/n-3 ratio ($p < 0.05$) was found in LD of free-living red deer compared with farmed deer, but in both studied muscles, both from free-living and from farmed red deer, n-6/n-3 PUFA ratios not only meet these requirements, but can also improve the total diet (Table 4). Atherogenic (AI), thrombogenic (TI) indexes and the hypocholesterolemic/hypercholesterolemic (h/H) ratio values in IMF of free-living deer showed a more favourable, although insignificantly, trend compared to farmed deer.

Males showed a lower PUFA/SFA ratio ($p < 0.05$), but the n-6/n-3 ratio in their IMF tended ($0.05 \le p < 0.10$) to be more favourable than that in females. Females exhibited more favourable AI ($p < 0.01$), TI ($p < 0.05$) indexes and h/H ($p < 0.001$) compared to males. Rearing system × gender interactions were observed for SFA, MUFA, PUFA, all indexes and ratios, and showed that IMF of farmed red deer males had more SFA, higher AI and TI indexes and a lower amount of PUFA, lower PUFA/SFA, n-6/n-3, h/H ratios than farmed females. In contrast to farmed red deer, free-living males had a lower amount of SFA, lower AI and TI indexes, and a higher amount of PUFA, higher PUFA/SFA, n-6/n-3, h/H ratios than free-living females. Farmed and free-living red deer males had lower contents of trans fatty acids compared with females.

The Warner-Bratzler (WB) test results indicating sensory hardness of meat, including venison (Purchas, Triumf, and Egelandsdal 2010; Hutchison et al. 2014) have received wider publication than those of the texture profile analysis (TPA). However, De Huidobro et al. (2005) have reported that data dispersion in TPA tests was lower and meat hardness was better predicted by TPA than by WB. These authors also noted that the WB method is more efficient when it is used in a test on cooked meat. In the present study, significant differences in TPA and WB parameters on cooked meat were also observed (Table 5). LD of free-living deer showed lower values for springiness, and WB toughness ($p < 0.001$) in comparison with SM. However, LD of farmed deer showed higher TPA values for gumminess and chewiness ($p < 0.05$), and hardness ($p < 0.01$) compared to SM. The comparison of the same muscles from different environments showed that cohesiveness of LD was higher ($p < 0.05$) in samples from free-living red deer but WB toughness was higher ($p < 0.05$) in those from farmed deer. The values of TPA gumminess ($p < 0.05$), hardness ($p < 0.001$) and chewiness ($p < 0.01$) were found to be higher in SM of farmed red deer. The data obtained by other authors are contradictory possibly due to differences in animal origin, animal slaughter methods, carcass chilling, meat cooking and the instrumental devices used. However, a similar trend in meat tenderness was observed in the WB test, where the LD muscle showed lower values compared to those of the SM muscle as determined in the present study and in the study by Hutchison et al. (2014) of the fallow deer suspended by pelvis post slaughter and Awassi ram lambs (Abdullah and Qudsieh 2009). There were no significant gender effects on TPA and WB parameters and no interactions revealed.

Conclusions

The present study revealed only small differences in properties of free-living and farmed red deer meat. No significant differences were found either between the LD and SM muscles of free-living and farmed red deer or within these muscles of red deer from different environments regarding meat pH and colour parameters, but the intramuscular fat in the longissimus muscle of

free-living red deer had a lower and a more favourable n-6/n-3 PUFA ratio and the semimembranosus muscle had a lower content of cholesterol than the respective muscles of farmed deer. Therefore, the meat of free-living red deer could be rated as more acceptable in terms of healthy nutrition. The WB method showed the longissimus muscle to be tenderer than the semimembranosus muscle from free-living deer. In contrast to the WB test, the TPA method showed higher tenderness of the semimembranosus muscle in farmed red deer. Further research is needed to specify prediction of meat texture parameters.

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