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Effects of carcass weight and muscle on texture, structure, rheological properties and myofibre characteristics of deer

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Summary

Muscle fibre size and characteristic, perimysium thickness as well as texture and rhelogical properties of selected muscles (m. biceps femoris [BF], m. semimembranosus [SM], m. semitendinosus [ST], and m. quadriceps femoris [QF]) of deer of different carcass weight (50 ± 2 and 100 ± 3 kg SD) have been compared. Perimysium thickness, muscle fibre cross-section area and percentage of different fibre types: I (slow oxidative), IIA (fast oxidative-glycolytic) and IIB (fast glycolytic) per muscle fibre bundle were measured using a computer image analysis program. The texture was evaluated using the double penetration test and the force-deformation curve obtained served to calculate meat hardness, cohesiveness and chewiness. The relaxation test was used to determine rheological properties and the results were interpreted with a 5-element Maxwell body model. Of the all muscles tested, BF is characterized by fibers of higher cross sectional areas, thicker perimysium; it is also tougher, viscous and elastic and less chewy than the ST and SM or also than the QF, a muscle with a high content of white fibers while at the same time possessing low values of texture parameters and rheological properties. Higher toughness and lower values of rheological properties of muscles from deer of 100 kg carcass weight could also be connected with thicker perimysium, fibers of higher cross sectional area, and probably with a higher content of red fibers, compared with muscles from animals of smaller carcass weight.

Keywords: deer; carcass weight; texture; structure; muscle fibre type

Meat quality can be defined as „the total degree of satisfaction that meat gives the consumer" (9), and can be assessed by measuring biophysical and histochemical properties. Żochowska et al. (33, 34) observed correlation between fibre diameter, connective tissue thickness, fibre type composition, and meat texture parameters in wild boar meat. Some more studies suggest relationships between fiber type or size and texture or eating quality, especially tenderness in beef (5, 26, 33). However, the results are variable and sometimes contradictory. No correlation between muscle fibre traits and tenderness were found by Whipple et al., (31) however Klont et al., (12) suggest relationships exist between muscle fibre type and meat quality, particularly in pork. Muscle fibre size and composition, is on the one hand specific for different slaughter animal breeds or lines and, on the other, it could be affected by growth rate (20, 25). However, no data on muscle fibre characteristics in deer of different carcass weight and structure, textural and rheological properties of their muscles could be found simultaneously in the available literature.

The objectives in this study were to compare fibre type, structure, texture and rheological properties in muscles of deer and to study the effect of the carcass weight on the properties of four muscles (*biceps femoris*, *semimembranosus*, *semitendinosus*, and *quadriceps femoris*) in deer.

Material and methods

A total of eight carcasses from the female of deer, of two different ages (four carcasses in each group), shot during winter in an enclosed area in a forest of the Western Pomerania District were used. The carcass weights of the animals were 50 ± 2 and 100 ± 3 kg, while their ages were 0.5 and 4 years, respectively. Shortly after the animals were shot (30-45 min), 1 × 1 × 0.5 cm samples were taken from the mid-part of their following muscles: *biceps femoris* (BF), *semi-*

membranosus (SM), *semitendinosus* (ST), and *quadriceps femoris* (QF). The samples were frozen in liquid nitrogen and stored at –80°C for the analysis of muscle fibre characteristics. Half-carcasses of the experimental animals, kept at 4°C for 48 h from the moment of shooting were used to obtain the following muscles: BF, SM, ST, QF and L.

About 4 cm thick slices were cut perpendicularly to the fibres from each muscle. The slices were placed in thermo-resistant plastic bags, cooked in water at 85°C until the geometric centre reached 68°C, cooled and stored at 4°C for 12 h.

Myofibre characteristics were determined on liquid-nitrogen-frozen muscle samples. In order to classify the muscle fibres into type I, IIA and IIB groups, cross sections (10 μm) were cut at 26°C with a cryostat HM 505 EV. The sections were placed on glass slides, stained using the myosin ATPase method (8) with an alkaline preincubation solution (pH 10.4), and classified according to Brooke and Kaiser (3) into three groups: type I (slow oxidative), type IIA (fast oxidative-glycolitic), and type IIB (fast glycolytic). Stained sections were examined with the image analysis system using a computer program (Multi Scan Base v.13). Percentage of different fibre types (%) (type I, type IIA, and type IIB) per muscle fibre bundle were computed (more than 10 bundles were examined for each muscle sample). A magnification of 100 × was used.

Histological assays were made on frozen samples cut from the muscles of both groups of animals. The muscles were sectioned with a cryostat. The sections were placed on glass slides, contrast-stained with hematoxylin and eosin, and sealed with Canada balsam (4).

The Multi Scan Base v.13 computer image analysis software was used to evaluate the mean fibre cross-sectional area and perimysium thickness. The structural elements were measured in the area of fibre bundle, and more than 200 muscle fibre and perimysium thickness samples were analyzed.

Texture measurements were made on thermally treated samples of muscles brought to about 18°C. After removal of the plastic sheets, 20 ± 2 mm thick slices were cut out from each sample to determine their texture with an Instron 1140 apparatus interfaced with a computer. The texture was evaluated using the double penetration test. The test involved driving a 0.96 cm diameter shaft twice, parallel to the muscle fibre direction into a sample down to 80% of its height (16 mm), using the crosshead speed of 50 mm/min and a load cell of 50 N. The force-deformation curve obtained served to calculate meat hardness, cohesiveness and chewiness (1). The procedure was repeated 9-14 times on each sample.

Rheological properties were determined with the relaxation test run on the Instron 1140. A sample was compressed to 10% of its original height (2 mm) and left for 90 s. In order to calculate the elastic and viscous moduli, the general Maxwell's body model was used, the model involving a parallel coupling of a Hooke's body and two Maxwell's bodies. The following relaxation equation was applied:

$$\sigma = \varepsilon \cdot \left[E_0 + E_1 \cdot \exp\left(\frac{-E_1 \cdot t}{\mu_1}\right) + E_2 \cdot \exp\left(\frac{-E_2 \cdot t}{\mu_2}\right) \right]$$

where: σ – stress, ε – strain, E_0, E_1, E_2 – elasticity moduli of the Hooke's body and of the first and second Maxwell's bodies, respectively, μ_1, μ_2 – viscosity moduli of the first and second Maxwell's bodies, respectively, t – time.

Calculated values of the three elastic moduli are summarised in the figures as their sum; similarly, the values of the two viscous moduli are presented as their sum. The relaxation test was run 3 times on each muscle. During textural and rheological measurements, the muscle fibres were aligned in the direction of force.

Statistical analyses of the data involved the calculation of the mean values and standard deviations (SD) for each muscle and each group of deer. The differences in textural and histochemical properties between the muscles within a group of fallow deer as well as between the groups of animals of different carcass weight for each muscle were studied using the analysis of covariance. Treatment differences were tested for significance at the 1% level. All the calculations were performed with the Statistica® v. 5.0 PL software.

Results and discussion

As shown in table 1, the highest percentage of type I and lower percentage of types IIB and IIA fibres were found, regardless of the animal group, in the ST, whereas BF and QF were the muscles with a high percentage of type IIB fibres. Muscles from the deer of 100 kg carcass weight, compared to those from the animals of 50 kg carcass weight showed a higher percentage of type I and type IIA fibres. Results obtained in this study are in agreement with those found for wild boar muscles by many authors (25, 33, 34), and for cattle by Brandstetter et al. (2) who have shown that muscles of older animals compared to young ones contain a higher percentage of type I fibres. According to Wegner et al. (31) muscle fibres undergo a continual alteration throughout life and a „fibre type" merely reflects the constitution of a fibre at any particular time.

When the deer muscle structures were compared (tab. 1), BF was characterised by the highest mean fibre cross-sectional area and had the thickest perimysium. Lower values of these elements were found in SM and QF muscles, and ST was characterised by the most delicate histological structure i.e. the lowest fibre cross-sectional area and the thinnest connective tissue. Also Żochowska et al. (33) showed that the BF of wild boar is characterised by a less delicate structure than the other muscles tested. Numerous authors comparing different domestic animal species have reported higher cross-sectional areas or fibre diameters and thicker connective tissue in BF compared to SM or QF (19, 24).

A comparison of the values of the muscle structure elements in both groups of animals showed that the muscles from animals of 50 kg carcass weight consisted of fibres of lower (by about 33-63%) cross-sectional areas, and had thinner (by about 38-92%) perimysium than muscles from the deer of 100 kg carcass weight (tab. 1).The effect of age on meat structure has been the subject of research by Żochowska et al. (33, 34), who also found an increase in average muscle fibre diameter and connective tissue thickness with increasing carcass weight of wild boar. Also Nishimura et al. (23) found an increase in the thickness of the collagen fibres in the beef perimysium with an increase in cattle weight. According to Fang et al. (7)

Tab. 1. Mean fibre type percentage and structure elements of selected deer muscles

Muscle	Carcass weight (kg)									
	50					100				
	Fibre type			Structure elements		Fibre type			Structure elements	
	I (%)	IIA (%)	IIB (%)	fibre area (µm²)	perimysium thickness (µm)	I (%)	IIA (%)	IIB (%)	fibre area (µm²)	perimysium thickness (µm)
Biceps femoris	10.42^{a}_{A}	31.07^{a}_{A}	58.51^{c}_{A}	1597.1^{c}_{A}	14.98^{b}_{A}	22.48^{b}_{B}	35.10^{b}_{B}	42.42^{c}_{B}	2207.2^{b}_{B}	22.16^{b}_{2}
Semimembranosus	16.02^{b}_{A}	38.19^{b}_{A}	45.79^{b}_{A}	1505.4^{c}_{A}	14.62^{b}_{A}	16.41^{a}_{A}	42.83^{c}_{B}	40.76^{c}_{B}	2017.4^{a}_{B}	21.01^{ab}_{2}
Semitendinosus	48.39^{c}_{A}	32.26^{a}_{A}	19.35^{a}_{A}	1264.8^{a}_{A}	10.28^{a}_{A}	52.00^{d}_{B}	22.00^{a}_{B}	26.00^{b}_{B}	2060.9^{a}_{B}	18.75^{a}_{2}
Quadriceps femoris	11.36^{a}_{A}	31.06^{a}_{A}	57.58^{c}_{A}	1391.8^{b}_{A}	13.71^{b}_{A}	29.00^{c}_{B}	50.00^{d}_{B}	21.00^{a}_{B}	1998.1^{a}_{B}	19.95^{a}_{2}

Explanations: a – means with different superscripts differ significantly within an animal group at the 0.05; A – means with different subscripts differ significantly between animal groups at the 0.05

Tab. 2. Mean values of muscle texture parameters and rheological properties of deer

Muscle	Carcass weight (kg)									
	50					100				
	Texture parameters			Rheological properties		Texture parameters			Rheological properties	
	hardness (N)	cohesiveness (–)	chewiness (N × cm)	sum of viscous moduli (kPa)	sum of elastic moduli (kPa × s)	hardness (N)	cohesiveness (–)	chewiness (N × cm)	sum of viscous moduli (kPa)	sum of elastic moduli (kPa × s)
Biceps femoris	34.96^{b}_{A}	0.398^{a}_{A}	18.51^{a}_{A}	21813^{d}_{A}	257.26^{b}_{A}	39.26^{b}_{B}	0.430^{b}_{B}	21.62^{b}_{A}	19564^{b}_{B}	241.35^{b}_{B}
Semimembranosus	32.00^{ab}_{A}	0.414^{ab}_{A}	15.77^{a}_{A}	19072^{b}_{A}	229.01^{ab}_{A}	37.50^{ab}_{B}	0.367^{a}_{B}	15.97^{a}_{A}	19031^{b}_{A}	211.73^{a}_{A}
Semitendinosus	33.37^{ab}_{A}	0.433^{b}_{A}	18.09^{a}_{A}	18200^{a}_{A}	254.71^{b}_{A}	36.04^{a}_{A}	0.462^{b}_{B}	21.26^{b}_{A}	15949^{a}_{B}	237.40^{ab}_{B}
Quadriceps femoris	30.53^{a}_{A}	0.431^{b}_{A}	16.41^{a}_{A}	20164^{c}_{A}	211.69^{a}_{A}	34.28^{a}_{A}	0.395^{a}_{B}	16.86^{a}_{A}	19620^{b}_{B}	197.54^{a}_{A}

Explanations: as in tab. 1.

in pigs the perimysium thickens as a result of the increase in the number and thickness of perimysial sheets, which become thicker with growth.

Differences in muscle structure or different contents of red and white fibres in the deer muscles tested could be connected with the differences in the textural and rheological parameters observed in this study. Of all the muscles tested, the highest values of hardness, viscous and elastic moduli as well as the high chewiness were recorded in the BF muscle, while the lowest values of these parameters except viscous moduli and chewiness were observed in the QF muscle (tab. 2). The highest cohesiveness was observed in ST. No significant differences in the textural parameters and rheological properties were found between SM and QF muscles. No information about comparison of muscle texture and rheological properties in deer of different weight was found in the available literature. However, numerous authors comparing muscles of wild boars (19, 33, 34) or different species of farm animals (18, 27) have reported a similar order of hardness for muscles and showed BF to be tougher that either QF and SM. Higher values of the viscosity moduli of BF compared with other ham muscles tested was also reported by Żochowska et al. (34) for wild boars and by Lachowicz et al. (17) for pork.

A comparison between the textural parameters and rheological properties of the muscles from deer of different carcass weight showed that the muscles of animals of 100 kg carcass weight were characterised by higher hardness and chewiness than meet from smaller deer, whereas cohesiveness was not dependent on carcass weight (tab. 2). Meat obtained from deer of smaller carcass weight compared to those from animals of 100 kg carcass weight showed higher values of viscous and elasticity moduli (tab. 2). Results obtained in this study confirmed earlier findings obtained for wild boars by Żochowska et al. (33, 34) and for farm animals by Shorthose and Harris (28) and Kołczak et al. (15), who observed that muscles from older animals were tougher than those obtained from the younger ones.

The differences in muscle texture and rheological properties between deer of different carcass weight, demonstrated in this study, according to numerous authors may have resulted from differences in structural elements, and a higher hardness being related to a thicker connective tissue (7, 21, 33), or/and a higher mean fibre cross-sectional area (29, 33). The differences may have resulted also from different composition and properties of muscles proteins and lipids in particular muscle fibre types (32), or higher content of calpastatin in red fibres being the most important factors (6, 16). As shown by Karlsson et al. (11) type I fibres contained neutral lipids, whereas only about 26% of type IIA, and 1% of type IIB fibres contained neutral lipids, and at the same time had a higher triglyceride content which may be one factor of importance for meat quality, especially for meat tenderness. However, according to Kłosowska (13), red fibres are characterised by thicker connective tissue, so the higher hardness of deer muscles with a high percentage of type I fibres found in this study could be associated with a thicker endomysium. Also Karlsson et al. (10) and Kłosowska and Fiedler (14) reported that a higher percentage of white muscle fibres in muscles was inversely proportional to the shear forces.

To sum up, it can be concluded that BF was characterised by fibres of higher cross-sectional areas and thicker perimysium; it was also harder, viscous and elastic, less chewy than ST, SM and QF; the muscle had a high content of white fibres, and at the same time low values of texture parameters and rheological properties. Higher hardness and lower values of rheological properties of muscles from animals of 100 g carcass weight could also be associated with thicker perimysium, fibres of higher cross-sectional area and probably with a higher content of red fibres, compared with the muscles from the animals of smaller carcass weight.

Conclusions

The highest values of hardness, chewiness, viscous and elastic moduli, the highest mean cross-sectional area and the thickest perimysium were typical of BF, regardless of the animal group tested, lower values being recorded in QF and ST.

Compared with muscles from the animals of 100 kg carcass weight, those of small deer showed a lower mean fibre cross-sectional area, a thinner perimysium, and a higher percentage of type IIB fibres; they were also less hard, viscous, elastic and easier to chew.

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