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SELECTED MINERALS IN SKELETAL MUSCLES OF FALLOW DEER (*DAMA DAMA*) AND RED DEER (*CERVUS ELAPHUS*) FARMED IN THE ORGANIC SYSTEM – PRELIMINARY STUDY

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ABSTRACT

The aim of the present study was to identify and assess the determinants of the content of Ca, Mg, Zn, Fe, Cd, and Pb in *longissimus lumborum* (LL) and *semimembranosus* (SM) muscles of fallow deer and red deer reared in the organic system. The concentrations of 6 elements (Ca, Mg, Zn, Fe, Cd, Pb) in fallow deer and red deer meat produced in the organic system in Poland were analyzed with the use of inductively coupled plasma mass spectrometry. The animals, i.e. 12 ca. 2- and 3-year-old fallow deer (*Dama dama*) and 12 ca. 3- and 4-year-old red deer (*Cervus elaphus*), were culled during the autumn season. Both groups of animals comprised 6 males and 6 females. A significant effect of the species on the content of selected minerals in the meat was noted. It was found that the LL muscle from the fallow deer was a rich source of Ca, Mg, and Zn, and the meat from the red deer had high amounts of Zn and Fe. The age of the animals had a significant effect on the level of Mg in the red deer meat.

Key words: venison, meat, macroelements, microelements, potentially toxic element

INTRODUCTION

The increased interest in game consumption observed in recent years is associated with the rise in environmental pollution caused by conventional meat production and the growing public awareness of the low level of animal welfare [Ugarković et al. 2020]. However, the consumption of game meat in Europe is low, as it is consumed regularly by only approximately 4% of the population [Soriano and Sánchez-García 2021]. The European Union (EU) promotes game consumption in some countries through the program "European wild meat, nature in its purest form" [EC 2014]. Although Poland is one of the most important game producers in Europe, its average annual consumption per capita ranges from 50 g per person (2013) to 138 g per person (2016) [Kilar 2020]. In Europe, New Zealand, Australia, and North America, the game market offers meat from farmed fallow deer and red deer [Lorenzo et al. 2019]. In 2020, there were 785 such farms in Poland, where approximately 70 000 animals were reared [GIW 2020].

The close relationship between diet and human health confirmed in scientific research prompts consumers to search for organic food. Organic farms follow strictly defined meat production methods, which are controlled by independent professional certification organizations. This production system is the key determinant of the high nutritional value of game meat. The health benefits of the inclusion of organic food in the diet are associated with the presence of various biologically active substances in this food, e.g. minerals. Inadequate absorption of essential minerals leads to malnutrition, which is a worldwide problem [Woźniak et al. 2014, Skibsted 2016, Babicz et al. 2018], and serious chronic diseases (anemia, hypertension, osteoporosis, coronary artery disease) [Babicz and Kasprzyk 2019]. As reported in some publications [Kudrnáčová et al. 2018, Lorenzo et al. 2019, Soriano and Sánchez-García 2021], the nutrient content in meat may

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be influenced by many factors, e.g. animal species, sex, and age as well as environmental conditions. Moreover, the concentration of minerals varies between the type of muscles, the composition of muscle fibers, and physical activity of the animal [Holman et al. 2021, Nogalski et al. 2022].

The available literature does not provide studies of the mineral composition in the muscles of organically farmed fallow deer and red deer. Since the content of elements in food is important from the nutritional point of view, the aim of the present study was to identify and assess the determinants of the content of Ca, Mg, Zn, Fe, Cd, and Pb in *longissimus lumborum* (LL) and *semimembranosus* (SM) muscles of fallow deer and red deer reared in the organic system.

MATERIAL AND METHODS

The research material consisted of 12 samples of *longissimus lumborum* and 12 samples of *semimembranosus* muscles incised from the right half-carcasses of fallow deer and red deer. Both groups of animals comprised 6 males and 6 females, with an equal age and sex proportion. The fallow deer were approximately 2 and 3 years old, and the red deer were aged ca. 3 and 4 years. This is justified by the fact that in Poland, deer in such age ranges are most often hunted in farm farms. The commercial farms had an appropriate certificate of organic farming and reared the animals in accordance with the requirements of Regulation (EU) 2018/848 [Regulation EU 2018] of the European Parliament and of the Council of 30 May 2018, the Act on organic farming [Journal of Laws 2009] and the Act on farming and organic production [Journal of Laws 2022]. The staple food of the animals was natural pastures, with a density of 0.42 LU (large livestock units) per ha in the fallow deer and 0.20 LU per ha in the red deer. The pastures for the fallow deer were covered by 191 plant species, whereas 108 species were identified in the red deer feeding ground. Deer and bulls lived together in flocks. In winter, the animals received hay, haylage, straw, cereal grain, and root crops ad libitum. The animals were culled by shooting in the autumn season. After two days of cooling the carcasses at the temperature of 4°C, samples with the same size were collected from the LL and SM muscles from three places, packed in polyethylene bags, and transported to the laboratory in isothermal containers. The concentration of basic minerals (Ca, Mg, Zn, Fe,) was determined by means of atomic absorption spectrometry (AAS) with the use of a Varian SpectrAA 280 FS spectrometer. The samples of organs for determining minerals were subjected to wet mineralization in accordance with AOAC 986.15 standard [AOAC 2000]. To determine the concentration of Cd and Pb the solutions were analysed on an inductively coupled plasma mass spectrometer (ICP Mass Spectrometer Varian MS-820). Results were expressed as mg/kg of base wet weight.

The study results were statistically analyzed with one-way (differentiation of the levels of minerals in meat depending on the species) and three-way (differentiation of the levels of minerals depending on the muscle type, sex, and age) analysis of variance as well as the cluster analysis with the Ward agglomeration method, Fischer-Snedecor F test, and the NIR test. Differences were considered significant at $P \leq 0.05$. Before the statistical analysis, the assumptions of the normality of the distribution of the analyzed features in the groups were checked using the Shapiro-Wilk test. The calculations were made in the STATISTICA 13.1 program.

RESULTS AND DISCUSSION

Red meat provides highly bioavailable minerals required for proper development and health in humans [Babicz et al. 2018]. Magnesium is involved in over 600 enzymatic reactions and in the synthesis of proteins and ATP; it is also responsible for muscle relaxation [Ertl et al. 2016, van Dronkelaar et al. 2018]. Calcium and magnesium are essential for bone formation. In turn, iron is involved in the formation of hemoglobin and, as a component of the enzyme system, in detoxification and removal of foreign compounds from the organism. Together with Zn, it regulates the immune system [Wyness et al. 2011].

The fallow deer meat analyzed in the present study was characterized by significantly higher content of Mg, Ca and Fe and a significantly lower level of Zn ($P < 0.020$) in comparison with the red deer meat (Fig. 1). The differences in the content of macro- and microminerals between the deer species can be associated with their different diets. The effect of the muscle type on meat quality has been well documented [Holman et al. 2021, Nogalski et al. 2022].

Differences between LL and SM were observed in the present study as well. In the fallow deer group, LL was characterized by significantly higher content of Ca, Zn ($P < 0.000$), and Mg ($P < 0.004$) than that in SM. In the red deer, LL contained significantly higher amounts of Zn ($P < 0.009$) and Fe ($P < 0.013$) than SM (Table 1). In terms of practical application, the differences between the mineral composition of the red deer SM and LL indicate that the individual muscles can meet specific nutritional requirements or targets of different consumers. For instance, due to the higher (5.6 mg $\cdot$ kg^{-1}) iron content in LL, consumption of this muscle instead of SM can be recommended to consumers that intend to increase the dietary iron intake. The differences in the content of minerals between the types of muscles may be related to differences in their physical and metabolic activity, the composition of muscle fibers, and fat content [Hoffman et al. 2007, Lorenzo et al. 2019]. Lower content of Ca, Fe, and

Zn in wild red deer meat was reported by Lorenzo et al. [2019] and Soriano and Sánchez-García [2021]. In turn, Lorenzo et al. [2019] detected a higher Mg level. Lower levels of Ca, Mg, and Zn in the liver of wild deer were reported by Kudrnáčová et al. [2018].

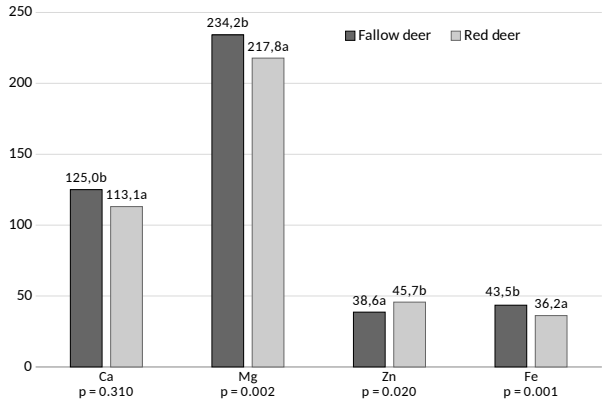

Fig. 1. Differences in the content of Ca, Mg, Zn, and Fe (mg · kg^{-1}) in the meat of fallow deer and red deer (average values)

The LL in the male fallow deer exhibited a significantly higher Fe concentration ($P < 0.002$) compared to female. It may have resulted from the higher activity and increased oxidative metabolism in males compared with females. Similarly, Ugarković et al. [2020] and Milczarek et al. [2021] found higher Fe content in male muscles than in female muscles. This finding is extremely important from the nutritional point of view, as iron is present in meat mainly in the form of easily digestible heme associated with myoglobin and hemoglobin. Its absorption from meat is by 20–30% higher than from plants [Buzała et al. 2016, Juárez et al. 2021]. A significant ($P < 0.000$) effect of age on the Mg content was found in the case of the red deer muscles. The muscles of the 4-year-old red deer had a higher level of this element than the meat from the 3-year-old animals. Furthermore, a study conducted by Ugarković et al. [2020] demonstrated higher Zn content in the muscles of older individuals compared to younger animals. The analysis of the fallow deer meat revealed interactions between the muscle type and sex in the case of the Mg and Fe content, muscle type and age for the Mg and Zn content, sex and age for the Ca, Mg, and Zn content, and between the muscle, sex, and age. In the red deer group, there were interactions between the muscle type and age and between the muscle, sex, and age in the case of the Mg content and interactions between the muscle type and sex, muscle and age, and sex and age in the case of Fe. The cluster analysis identified 4 segments in the fallow deer meat (Fig. 2, Table 2) and 5 segments in the deer meat (Fig. 3, Table 3) that differed significantly in the Ca, Mg, Zn, and Fe profiles. The data in Tables 3 and 4 provide an indication of the reasons for this variation.

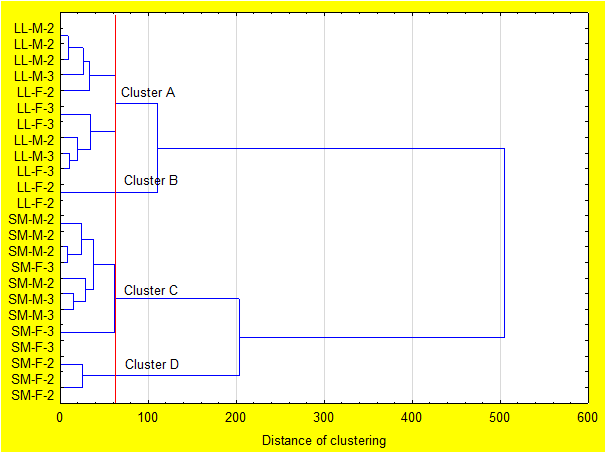

Fig. 2. Clustering dendrogram of Fallow deer (*Dama dama*) meat based on the profile of Ca, Mg, Zn and Fe

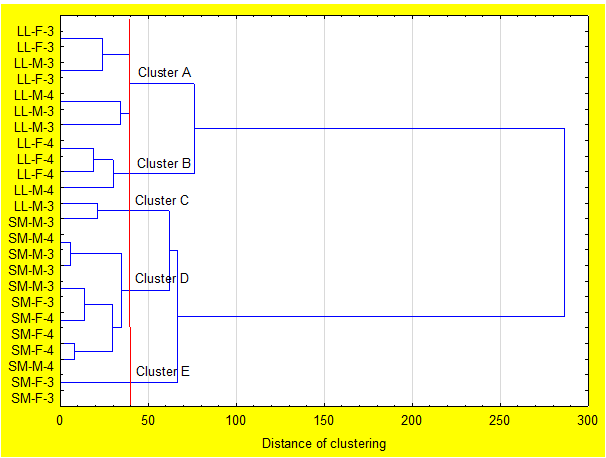

Fig. 3. Clustering dendrogram of Red deer (*Cervus elaphus*) meat based on the profile of Ca, Mg, Zn and Fe

Based on the results of the analysis of clusters of 4 segments of fallow deer meat (Table 2), it was found that cluster A exhibited a higher level of Ca, while cluster B were characterized by a significantly higher level of Ca, Mg and Zn and the lowest content of Fe. Moreover, cluster C exhibited a distinguished by low Ca content, high Mg content and the highest Fe content. In turn, cluster D is distinguished by a low Ca content, the lowest Mg and Zn content. The mean values included in Table 3 and the results of the NIR test indicate that, cluster A is distinguished by the lowest content of Ca and Mg and the highest content of Zn. Moreover, cluster B is characterized by low Ca content and the highest Mg content, while cluster C is distinguished by the highest Ca content and high Zn content and the lowest Mg content. In turn, cluster D is

Table 1. Differences in the content of Ca, Mg, Zn, and Fe (mg · kg^{-1}) in the meat of fallow deer (*Dama dama*) and red deer (*Cervus elaphus*) depending on the muscle type, age and age of the animals

Effects	Specification	Ca			Mg			Zn			Fe		
		x̄	SE	p	x̄	SE	p	x̄	SE	p	x̄	SE	p
Fallow deer (*Dama dama*)													
Muscle	LL (n = 12)	155.2	38.25	0.000	226.4	20.65	0.004	45.6	16.54	0.000	42.6	10.56	0.478
	SM (n = 12)	95.1	26.11		241.0	25.47		32.7	10.15		44.4	8.85	
Sex	M (n = 6)	124.0	29.06	0.486	235.1	25.66	0.758	38.9	15.21	0.307	48.1	10.09	0.002
	F (n = 6)	125.8	26.21		233.8	22.11		37.4	12.5		39.0	7.80	
Age	2 (n = 6)	125.3	25.08	0.765	233.5	23.84	0.199	39.1	14.66	0.085	43.9	12.65	0.449
	3 (n = 6)	123.9	29.44		236.1	20.96		38.0	10.23		42.8	14.03	
Muscle × Sex				0.602			0.000			0.189			0.010
Muscle × Age				0.379			0.001			0.000			0.385
Sex × Age				0.012			0.004			0.001			0.540
Muscle × Sex × Age				0.566			0.001			0.168			0.812
Red deer (*Cervus elaphus*)													
Muscle	LL (n = 12)	96.2	20.33	0.000	214.9	22.61	0.002	50.2	12.05	0.009	39.2	8.08	0.013
	SM (n = 12)	129.2	26.11		221.8	25.81		41.0	8.76		33.6	6.39	
Sex	M (n = 6)	114.4	25.01	0.839	213.7	21.65	0.225	46.7	10.22	0.558	36.1	7.88	0.794
	F (n = 6)	112.2	27.63		221.4	26.05		44.1	11.59		36.2	9.15	
Age	3 (n = 6)	114.6	20.16	0.903	213.1	18.87	0.000	45.8	12.74	0.872	38.0	10.33	0.245
	4 (n = 6)	110.8	19.44		223.6	21.04		45.6	10.60		34.7	8.49	
Muscle × Sex				0.963			0.128			0.489			0.049
Muscle × Age				0.915			0.003			0.915			0.042
Sex × Age				0.460			0.079			0.872			0.021
Muscle × Sex × Age				0.781			0.005			0.176			0.809

LL, *Longissimus lumborum*; SM, *Musculus semimembranosus*; M, Male; F, Female; 2, 2 years; 3, 3 years; 4, 4 years

Table 2. Mean content of Ca, Mg, Zn and Fe in Fallow deer (*Dama dama*) meat based on clustering

Clustering	Ca, mg · kg^{-1}	Mg, mg · kg^{-1}	Zn, mg · kg^{-1}	Fe, mg · kg^{-1}
A	155.1b	220.9b	43.4b	44.4b
B	153.0b	257.0c	58.0c	33.0a
C	96.0a	255.2c	32.1a	47.4b
D	93.1a	200.0a	29.3a	36.0a
ANOVA results				
F	31.95	8.31	6.51	18.52
p	0.000	0.000	0.003	0.026

a, b, c – significant between clusters in the NIR test (at the level of $a = 0.05$)

Table 3. Mean content of Ca, Mg, Zn and Fe in Red deer (*Cervus elaphus*) meat based on clustering

Clustering	Ca, mg · kg^{-1}	Mg, mg · kg^{-1}	Zn, mg · kg^{-1}	Fe, mg · kg^{-1}
A	91.1a	208.4a	51.6c	39.9b
B	95.0a	225.8b	46.0b	37.0b
C	150.0c	210.0a	51.0c	35.0b
D	128.0b	222.7b	43.2b	30.3a
E	122.0b	220.0b	30.0a	49.0c
ANOVA results				
F	31.95	8.31	6.51	18.52
p	0.000	0.000	0.002	0.000

a, b, c - significant between clusters in the NIR test (at the level of $a = 0.05$)

characterized by the lowest Fe content, and cluster E is distinguished by the lowest Zn content and the highest Fe content.

Trace elements, e.g. Pb and Cd, are considered toxic due to their adverse effects on humans and other mammals Song et al. 2021 [Song et al. 2021]. Hence, animals can be bioindicators of the degree of environmental contamination. In the present study, Cd was detected only in two samples of the fallow deer meat and in one sample of the red deer meat, but its level did not exceed 0.007 mg · kg^{-1}. In turn, Pb was detected only in three samples of the fallow deer meat and in two samples of the red deer meat, and its concentration did not exceed 0.026 mg · kg^{-1}. The concentrations of these toxic elements were below the established limits specified by FAO/WHO (2003) [Song et al. 2021] and the European Commission [Patel et al. 2020]. The levels of potentially toxic element defected in the present study do not pose a health risk to consumers.

CONCLUSIONS

In this study, the data on the content of Ca, Mg, Zn, and Fe in the organically produced meat of fallow deer and red deer were shown for the first time. A significant effect of the species on the content of selected minerals in the meat was noted. The analyses demonstrated an effect of the sex on the content of Fe in the fallow deer meat and age on the content of Mg in the red deer meat. In terms of practical application, the differences between the mineral composition of the deer SM and LL indicate that the individual muscles can meet specific nutritional requirements or targets of different consumers. Regardless of these differences, fallow deer and red deer meat is a valuable raw material containing suitable amounts of minerals for human nutrition.

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WYBRANE SKŁADNIKI MINERALNE MIĘŚNI SZKIELETOWYCH DANIELI (*DAMA DAMA*) I JELENI (*CERVUS ELAPHUS*) Z EKOLOGICZNEGO SYSTEMU CHOWU

STRESZCZENIE

Celem badań było określenie oraz ocena uwarunkowań zawartości Ca, Mg, Zn, Fe, Cd i Pb w mięśniach *longissimus lumborum* (LL) i *semimembranosus* (SM) danieli i jeleni z ekologicznego systemu chowu. Stężenia 6 pierwiastków (Ca, Mg, Zn, Fe, Cd, Pb) w ekologicznym mięsie danieli i jeleni z Polski analizowano za pomocą spektrometru masowego z plazmą sprzężoną indukcyjnie. Zwierzęta zostały odstrzelone w sezonie jesiennym, w tym 12 danieli (*Dama dama*) i 12 jeleni (*Cervus elaphus*) w wieku około 2 i 3 lat i w wieku około 3 i 4 lat. W obydwu grupach zwierząt było po 6 samców i 6 samic. Stwierdzono istotny wpływ gatunku na zawartość wybranych składników mineralnych w mięsie. Mięsień LL daniela, w porównaniu z SM, zawierał wyższą zawartość Ca i Mg oraz Zn. Z kolei mięsień LL jelenia szlachetnego charakteryzował się niskim poziomem Ca i Mg oraz wyższą zawartością Zn i Fe niż mięsień SM. Wykazano wpływ płci na zawartość Fe w mięsie daniela oraz wieku na zawartość Mg w mięsie jelenia. Stwierdzono, że mięso LL daniela jest bogatym źródłem Ca, Mg i Zn, a jelenia Zn i Fe. Wiek istotnie różnicował zawartość Mg w mięsie jeleni.

Słowa kluczowe: dziczyzna, mięso, makroelementy, mikroelementy, pierwiastki potencjalnie toksyczne

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