

Scifood

vol. 20, 2026, p. 486-501

<https://doi.org/10.5219/scifood.124>

ISSN: 2989-4034 online

<https://scifood.eu>

© 2026 Authors, License: CC BY-NC-ND 4.0

Received: 20.2.2026

Revised: 28.4.2026

Accepted: 2.5.2026

Published: 11.5.2026



Lipid quality, oxidative stability and elemental composition of *musculus biceps femoris* of red deer (*Cervus elaphus*): effects of wild and farmed production systems

Adriana Pavelková, Matúš Rajský, Ondřej Bučko, Peter Haščík

ABSTRACT

This study evaluated the effect of production system on the chemical composition, fatty acid profile, lipid quality indices, oxidative stability, and elemental composition of *musculus biceps femoris* of red deer (*Cervus elaphus*). The study was conducted as a comparative observational assessment of animals originating from hunting areas and farm breeding systems. Proximate composition was similar between groups, with protein content ranging from 23.07 to 23.44 g/100 g and intramuscular fat remaining low (0.65–0.78 g/100 g), confirming the lean character of venison. In contrast, differences were observed in lipid composition, as meat from farmed animals contained higher levels of polyunsaturated fatty acids (18.48 vs. 15.85%) and n-6 fatty acids (14.75 vs. 12.85%). These differences were reflected in lipid quality indices, particularly in a lower thrombogenic index in farmed animals. Lipid oxidation increased progressively during storage, with malondialdehyde values rising from approximately 0.16–0.19 mg/kg after 1 month to 0.72–0.86 mg/kg after 12 months. After prolonged storage, meat from wild animals showed higher levels of oxidation. Mineral composition was generally stable, with differences detected only for magnesium (0.236 vs. 0.209 g/kg) and copper (2.295 vs. 1.647 mg/kg). Heavy metal concentrations were very low and remained below established safety limits. Overall, the production system had little effect on basic composition but influenced lipid profile and oxidative stability. These findings confirm the nutritional value of venison and highlight the importance of feeding conditions and storage in determining its quality.

Keywords: red deer, venison, fatty acid profile, lipid oxidation, mineral composition, production system

INTRODUCTION

The growing demand for high-quality, nutritionally valuable meat has led to increased interest in alternative protein sources, including game meat. Among these, red deer (*Cervus elaphus*) (Figure 1) is one of the most important wild ungulates in Europe, both for wildlife management and for its potential as a source of premium meat. Compared with conventional livestock production, the characteristics of venison are strongly influenced by the production system, particularly whether animals originate from free-ranging hunting areas or controlled farm environments. These differences may affect not only the nutritional composition of the meat but also its safety and technological properties.

From a nutritional perspective, venison is widely recognised for its high protein content and low intramuscular fat, which contribute to its favourable dietary profile. Studies on cervid meat have consistently shown that it contains high-quality protein and a beneficial fatty acid composition, often characterised by relatively high proportions of polyunsaturated fatty acids (PUFA) [1], [2]. In addition, venison is considered a valuable source of essential minerals, particularly iron, zinc, and selenium, which play important roles in human metabolism and

health [3], [4]. The intake of these micronutrients from game meat may contribute significantly to meeting dietary requirements, especially in populations with limited access to diverse food sources.



Figure 1 Red deer (*Cervus elaphus*).

The lipid fraction of venison is another key determinant of its nutritional value. The fatty acid composition of deer meat is influenced by several factors, including feeding regime, environmental conditions, and the physiological status of the animals. Free-ranging animals typically consume natural vegetation, which may result in a higher proportion of unsaturated fatty acids, whereas farmed animals are often exposed to more controlled diets that can alter lipid composition [5], [6]. While a higher PUFA content is considered beneficial from a nutritional standpoint, it is also associated with increased susceptibility to lipid oxidation, which can negatively affect meat quality during storage.

Lipid oxidation represents one of the main factors limiting the shelf life and sensory quality of meat. The formation of secondary oxidation products, such as malondialdehyde, is influenced by multiple factors, including fatty acid composition, antioxidant content, and the presence of pro-oxidative elements such as iron [7], [3]. As game meat is typically rich in heme iron, it may be more prone to oxidative changes under certain conditions, particularly during prolonged storage.

In addition to nutritional quality, venison safety is closely linked to the presence of toxic elements. Wild animals are directly exposed to environmental contaminants, including heavy metals such as cadmium and lead, which can enter the food chain through soil, water, and vegetation [8], [9]. These elements tend to accumulate in animal tissues, with higher concentrations typically observed in organs compared to muscle [3]. However, muscle tissue—the primary edible portion—generally contains lower levels of contaminants and is considered safe for human consumption when sourced from non-polluted environments [10], [11].

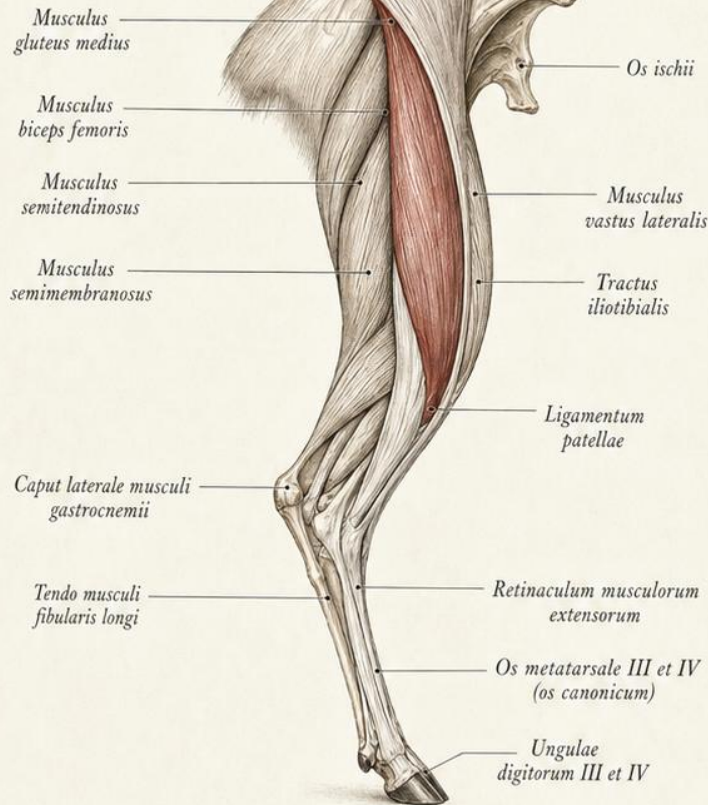
Food safety authorities have established maximum limits for certain toxic elements in meat to protect consumer health. According to the European Food Safety Authority [12], [13] and the World Health Organization [14], the levels of cadmium and lead in muscle meat are typically low and do not pose a significant risk under normal consumption patterns. Nevertheless, environmental conditions and hunting practices, particularly the use of lead-based ammunition, may influence contamination levels in game meat and should be considered when assessing its safety.

Cervus elaphus

Extremitas pelvina — musculi et structurae

Vista lateralis

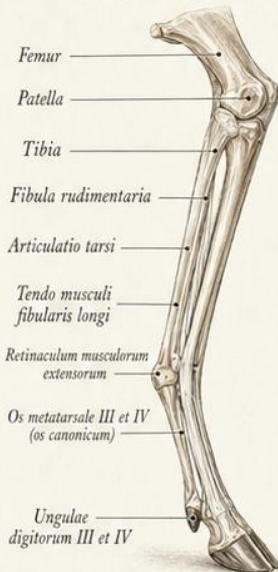
Musculatura superficialis



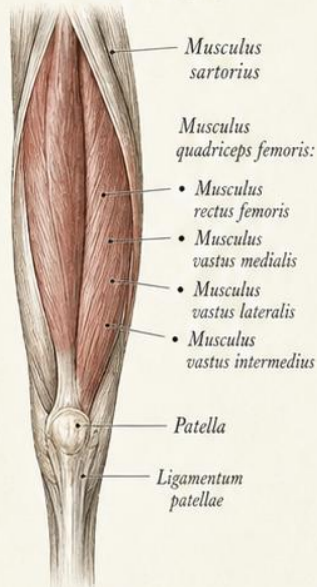
Principalia excisionis carnis (termini commerciales)



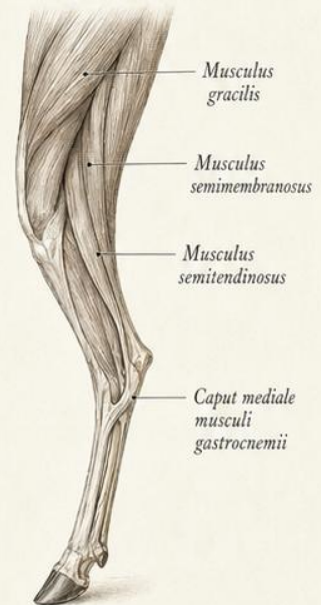
Vista lateralis Ossa et tendines



Vista cranialis Musculi femoris



Vista medialis



Nomina anatomica veterinaria — schema didacticum

Figure 2 Cervus elaphus, Extremitas pelvina – musculi et structurae, schema didacticum.

Although numerous studies have investigated individual aspects of venison quality, such as fatty acid composition, mineral content, or contamination with heavy metals, comprehensive evaluations integrating these parameters in relation to production system remain limited. In particular, direct comparisons between meat from wild-hunting areas and from farm breeding systems within a single experimental framework remain relatively scarce.

Therefore, the aim of the present study was to provide an integrated assessment of red deer (*Cervus elaphus*) meat (Figure 2) originating from hunting areas and farm breeding systems by analysing its chemical composition, fatty acid profile, lipid quality indices, oxidative stability, and mineral and heavy metal content. This approach allows for a more comprehensive understanding of the relationships between production system, meat quality, and potential implications for human nutrition and food safety.

Scientific Hypothesis

It was hypothesised that differences in production system (wild hunting area vs. farm breeding) significantly influence the lipid composition, oxidative stability, and elemental profile of red deer (*Cervus elaphus*) meat. Specifically, it was expected that meat from wild animals would exhibit a higher proportion of polyunsaturated fatty acids, which may increase susceptibility to lipid oxidation compared to farmed animals. In addition, it was hypothesised that selected trace elements, influenced by environmental conditions and feeding regimes, may modulate oxidative processes through their pro-oxidant or antioxidant activity.

Objectives

The main objective of this study was to evaluate the quality of red deer (*Cervus elaphus*) meat in relation to production system (wild vs. farm), with a focus on lipid composition, oxidative stability, and elemental profile.

The specific objectives were:

1. To determine and compare the fatty acid composition and lipid quality indices of red deer meat from wild and farmed animals.
2. To assess and compare oxidative stability between production systems using selected lipid oxidation parameters.
3. To quantify and compare the concentrations of selected essential and toxic elements in both groups.
4. To evaluate the relationships between lipid composition, oxidative stability, and elemental content within and between production systems.

MATERIAL AND METHODS

Samples

Samples description: The biological material consisted of red deer (*Cervus elaphus*) meat obtained from animals originating from two production systems: wild populations (hunting grounds) and farm breeding. A total of 70 animals were included in the study, comprising 40 individuals from hunting grounds and 30 from farm breeding systems.

Animals included in the study were of comparable physiological maturity, with an estimated age of 2–4 years, representing the most common slaughter or harvest category for red deer. No differentiation based on sex was applied, and animals were included regardless of sex; however, efforts were made to ensure a balanced representation between groups to minimise potential bias.

Samples collection: Wild animals were harvested during the official hunting season for red deer in the Slovak Republic, in accordance with national legislation governing wildlife management (Act No. 274/2009 Coll. and related implementing regulations). Hunting was conducted in selected hunting areas located in the western region of Slovakia, representing typical habitats of red deer populations.

Farmed animals originated from a commercial deer farm located in western Slovakia, where animals were raised under controlled conditions and slaughtered in accordance with standard commercial practices.

Immediately after harvesting or slaughter, carcass weight was recorded using a digital scale (WTC 2000, RADWAG, Poland). Carcasses were subsequently transported under refrigerated conditions (approximately 4 °C) to the laboratory.

Feeding conditions

Wild animals fed exclusively on natural vegetation, including grasses, herbs, shrubs, and forest biomass, reflecting seasonal dietary variability typical for free-ranging populations.

Farmed animals were fed a mixed feeding regime consisting of pasture grazing supplemented with conserved forages (hay or silage) and concentrate feed based on cereals (e.g. barley, oats) and protein supplements. This feeding strategy reflects common practices in commercial red deer farming systems and ensures adequate nutrient intake for growth and maintenance.

Samples preparation: Carcasses were stored at 4 °C for 4–5 days *post-mortem* to allow standard ageing and tenderisation processes. After maturation, samples of the *musculus biceps femoris* were excised, trimmed of visible connective tissue and external fat, and homogenised prior to analysis.

Number of samples analysed: A total of 70 muscle samples (one per animal) were analysed. All analytical determinations were performed in triplicate for each sample, and mean values were used for subsequent statistical evaluation.

Chemicals

All chemicals used were of analytical grade. Petroleum ether used for lipid extraction was obtained from Merck (Darmstadt, Germany). Fatty acid methyl ester standards (Supelco 37 Component FAME Mix) were purchased from Sigma-Aldrich (Steinheim, Germany). Reagents used for TBARS analysis, including 2-thiobarbituric acid (TBA), trichloroacetic acid (TCA), and butylated hydroxytoluene (BHT), were also supplied by Sigma-Aldrich (Germany).

Animals, Plants and Biological Materials

The analysed material consisted exclusively of red deer (*Cervus elaphus*). Feeding conditions differed between production systems: wild animals consumed natural vegetation, whereas farmed animals were fed a combination of pasture, conserved forages (hay or silage), and cereal-based concentrate feed.

Instruments

Basic chemical composition was determined using an INFRATEC 1265 analyser (FOSS, Hillerød, Denmark). Fatty acid composition was analysed by gas chromatography (GC-FID) equipped with a capillary column suitable for fatty acid methyl ester separation (e.g. CP-Sil 88 or equivalent). Oxidative stability was determined using a T80 UV/VIS spectrophotometer (PG Instruments Ltd., United Kingdom), with absorbance measured at 532 nm. Elemental composition was determined using inductively coupled plasma optical emission spectrometry (ICP-OES), while mercury (Hg) content was analysed using a mercury analyser (MA-3 Solo, Nippon Instruments Corporation, Japan).

Laboratory Methods

Chemical composition: The basic chemical composition (moisture, crude protein, intramuscular fat, and cholesterol) was determined using near-infrared spectroscopy (INFRATEC 1265, FOSS, Hillerød, Denmark). The instrument was calibrated using manufacturer-provided calibration models previously validated against standard reference methods (e.g. AOAC procedures). Measurements were performed according to the manufacturer's instructions.

Fatty acid composition: Total lipids were extracted using Soxhlet extraction according to ISO 1443. Fatty acid methyl esters (FAME) were prepared in accordance with ISO 12966-2. FAME were analysed using gas chromatography (GC-FID) equipped with a capillary column CP-Sil 88 (100 m × 0.25 mm × 0.20 µm; Agilent Technologies, USA) or equivalent. Helium was used as the carrier gas at a constant flow rate of 1.0 mL·min⁻¹. The injector and detector temperatures were set at 250 °C and 260 °C, respectively. The oven temperature program was as follows: initial temperature 120 °C (held for 5 min), increased to 200 °C at 4 °C·min⁻¹, and then to 220 °C at 2 °C·min⁻¹ with a final hold of 10 min. Individual fatty acids were identified by comparison with standard mixtures (Supelco 37 Component FAME Mix, Sigma-Aldrich, Germany) and expressed as a percentage of total identified fatty acids.

Lipid nutritional indices: Lipid quality indices were calculated based on fatty acid composition using established equations (Ulbricht & Southgate, 1991): Atherogenic index (AI), Thrombogenic index (TI), Hypocholesterolaemic/Hypercholesterolaemic ratio (h/H), PUFA/SFA ratio, n-6/n-3 ratio.

Oxidative stability: Lipid oxidation was determined by measuring malondialdehyde (MDA) content using the thiobarbituric acid reactive substances (TBARS) method. Briefly, homogenised samples were reacted with thiobarbituric acid (TBA) in the presence of trichloroacetic acid (TCA), and the mixture was heated under controlled conditions. After cooling, absorbance was measured at 532 nm using a UV/VIS spectrophotometer. Quantification was performed using a calibration curve prepared with 1,1,3,3-tetraethoxypropane (TEP) as a standard, and results were expressed as mg malondialdehyde (MDA) per kg of sample.

Determination of trace elements and heavy metals: Samples were subjected to microwave-assisted digestion using nitric acid and hydrogen peroxide. Samples were subjected to microwave-assisted digestion using concentrated nitric acid (HNO₃, 65%) and hydrogen peroxide (H₂O₂, 30%). Digestion was performed under controlled temperature and pressure conditions according to the manufacturer's protocol. Elemental concentrations (Ca, P, Mg, Na, K, Fe, Zn, Cu, As, Cr, Cd, Pb) were determined using inductively coupled plasma optical emission spectrometry (ICP-OES; e.g. iCAP 7000 Series, Thermo Scientific, USA or equivalent). Mercury (Hg) content was analysed using a direct mercury analyser (MA-3 Solo, Nippon Instruments Corporation, Japan). Method accuracy was verified using certified reference material (CRM-ERM CE278K). Limits of detection

(LOD) and quantification (LOQ) were established based on signal-to-noise ratios (3:1 and 10:1, respectively) and were within acceptable ranges for all analysed elements.

Description of the Experiment

Study flow: The experiment was designed as a comparative study evaluating red deer (*Cervus elaphus*) meat from two production systems (wild vs. farmed). The experimental workflow consisted of several sequential phases. First, carcass characteristics were recorded. Subsequently, muscle samples (*musculus biceps femoris*) were collected and prepared for analysis. Chemical composition, fatty acid profile, lipid quality indices, oxidative stability, and elemental composition were determined using the analytical methods described above. Finally, all data were statistically evaluated to assess the effect of production system.

Quality Assurance

Number of repeated analyses: All laboratory analyses were performed in triplicate (analytical replicates), and mean values were used for statistical evaluation.

Number of experiment replication: The experimental unit was the individual animal ($n = 70$), representing biological replicates. Each animal was analysed independently.

Reference materials: Standard mixtures of fatty acid methyl esters (Supelco 37 Component FAME Mix) and certified reference materials (CRM–ERM CE278K) were used to verify analytical accuracy and method performance.

Calibration: All instruments were calibrated prior to analysis and routinely checked using calibration standards in accordance with manufacturer recommendations and internal laboratory quality control procedures.

Laboratory accreditation: Analyses were performed in research laboratories of the Slovak University of Agriculture in Nitra under established internal quality assurance procedures.

Data Access

The datasets generated and analysed during this study are available from the corresponding author upon reasonable request.

Statistical Analysis

Statistical analysis was performed using XLSTAT® software (version 2018.5, Addinsoft, New York, USA). The experimental unit was the individual animal. For each animal, laboratory determinations were carried out in triplicate, and mean values were used for statistical evaluation. Prior to hypothesis testing, data were assessed for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene’s test. Differences between the two production systems (hunting area vs. farm breeding) were evaluated using an independent samples t-test (two-tailed). In cases where the assumption of homogeneity of variances was violated, Welch’s t-test was applied. When data did not meet the assumptions of normality, the non-parametric Mann–Whitney U test was used. Results are presented as mean \pm standard deviation (*SD*), and statistical significance was set at $p < 0.05$. In addition to statistical significance, the biological relevance of observed differences was considered based on the magnitude and consistency of variation between groups.

Reporting and transparency statement

This study represents a comparative analytical design based on samples obtained from two production systems (wild hunting area vs. farm breeding). Randomisation and blinding were not applicable due to the nature of sample collection. All samples were included in the analysis, and no data were excluded. The sample size was determined based on the availability of animals during the hunting season and farm production.

RESULTS AND DISCUSSION

Chemical composition

The chemical composition of *musculus biceps femoris* of red deer (*Cervus elaphus*) is presented in Table 1. No statistically significant differences were observed between animals from hunting areas and those from farm breeding systems for any of the analysed parameters ($p > 0.05$). Protein content ranged from 23.07 to 23.44 g/100 g, intramuscular fat from 0.65 to 0.78 g/100 g, water content from 72.86 to 73.39 g/100 g, and cholesterol from 0.39 to 0.41 g/100 g. These findings indicate a high degree of stability in proximate composition irrespective of production system.

The protein content observed in the present study is consistent with values typically reported for cervid meat. Previous studies have shown that venison generally contains high levels of protein, commonly ranging between approximately 20 and 24 g/100 g, depending on species, muscle type, and physiological factors [1], [15]. Similar values have also been reported in comparative studies of wild ungulates, confirming that protein concentration in deer muscle is relatively stable and primarily determined by intrinsic biological factors rather than production system [2]. In addition, the relatively stable protein and moisture content observed in cervid meat may also reflect

the limited influence of short-term dietary variation on structural muscle components, which are primarily determined by physiological and metabolic factors [16].

Intramuscular fat content was low in both groups, confirming the lean nature of red deer meat. Low fat levels are a characteristic feature of game meat and are often attributed to higher physical activity and natural feeding conditions. Studies on red deer and other cervid species consistently report intramuscular fat levels below 2%, with limited variation between wild and farmed animals when age and physiological status are comparable [1], [17]. The results obtained in the present study fall at the lower end of this range, highlighting the particularly lean character of the analysed samples.

Table 1 Chemical composition of *musculus biceps femoris* of red deer (*Cervus elaphus*) (g/100 g fresh matter).

Parameter	Wild (hunting area)	Farm breeding	p-value
Protein	23.07 ± 0.75	23.44 ± 0.25	0.256
Fat	0.78 ± 0.36	0.65 ± 0.18	0.434
Water	72.86 ± 1.81	73.39 ± 0.83	0.501
Cholesterol	0.41 ± 0.05	0.39 ± 0.04	0.438

Note: Values are expressed as mean ± standard deviation (SD). Differences between wild and farmed animals were evaluated using the statistical procedure described in the Statistical Analysis section. No significant differences were detected at $p < 0.05$.

Water content (72.86–73.39 g/100 g) remained within the expected range for venison and showed minimal variability between groups. Moisture content in cervid meat is typically inversely related to fat content, and therefore tends to be relatively stable in lean meat systems [20]. This relationship is evident in the present results, where consistently low fat levels correspond to relatively uniform water content across both production systems. From a comparative perspective, venison is generally characterised by a combination of high protein content and low fat levels, distinguishing it from conventional livestock meat. These attributes contribute to its classification as a nutritionally valuable food with favourable dietary properties [2], [5]. In addition, the relatively low lipid content may influence technological properties, including water-holding capacity and susceptibility to oxidative changes.

Importantly, the absence of significant differences between wild and farmed animals suggests that the production system has only a limited impact on basic chemical composition. This observation is consistent with previous findings indicating that proximate composition in cervid meat is relatively stable, whereas more pronounced differences between production systems are typically observed in lipid composition rather than in protein, fat, or moisture content [6].

Overall, the results presented in Table 1 confirm that red deer meat from both hunting areas and farm breeding systems is a lean and nutritionally valuable product. At the same time, the lack of significant differences between groups indicates that proximate composition alone is not sufficient to distinguish between production systems. More pronounced differences are therefore expected in lipid-related parameters and other quality characteristics.

Fatty acids composition

The fatty acid composition of *musculus biceps femoris* of red deer (*Cervus elaphus*) is presented in Table 2. The results indicate that the production system influenced the lipid profile selectively, with significant differences observed mainly in the polyunsaturated fatty acid (PUFA) fraction, whereas saturated (SFA) and monounsaturated fatty acids (MUFA) remained largely unaffected.

Total SFA content was comparable between wild and farmed animals (34.85 vs. 34.70%; $p > 0.05$), with palmitic (C16:0) and stearic acid (C18:0) as dominant components. Similarly, MUFA levels did not differ significantly (47.30 vs. 46.84%; $p > 0.05$), with oleic acid (C18:1 n-9) representing the major fatty acid in both groups. These findings are in line with previous studies reporting that SFA and MUFA fractions in cervid meat are relatively stable and less sensitive to differences in feeding conditions or production system [2], [5]. The stability of these lipid fractions is generally attributed to endogenous lipid metabolism in ruminants, which tends to regulate the deposition of saturated and monounsaturated fatty acids.

In contrast, total PUFA content was significantly higher in farmed animals (18.48 vs. 15.85%; $p < 0.05$), primarily due to an increase in n-6 fatty acids (14.75 vs. 12.85%; $p < 0.05$). This difference was largely driven by linoleic acid (C18:2 n-6), which was significantly higher in farmed animals. Similar patterns have been reported in cervid species, where feeding regime is a key determinant of fatty acid composition, particularly affecting the PUFA fraction [6], [17]. Controlled feeding systems may result in higher intake of concentrates or specific feed components, which can increase the proportion of n-6 fatty acids in muscle tissue. The deposition and modification of fatty acids in ruminant muscle are influenced by complex metabolic processes, including ruminal

biohydrogenation and enzymatic activity, which regulate the final lipid composition to some extent, independent of dietary intake [18].

Table 2 Fatty acid composition (% of total fatty acids) of red deer (*Cervus elaphus*) meat from wild and farmed systems.

Parameter	Wild	Farm	p-value
ΣSFA	34.85 ± 1.34	34.70 ± 1.57	0.958
C12:0 (Lauric)	0.10 ± 0.01	0.10 ± 0.01	0.842
C14:0 (Myristic)	1.36 ± 0.04	1.34 ± 0.05	0.311
C16:0 (Palmitic)	24.35 ± 0.29	24.32 ± 0.18	0.745
C17:0 (Heptadecanoic)	0.31 ± 0.04	0.34 ± 0.03	0.062
C18:0 (Stearic)	10.78 ± 0.38	10.66 ± 0.28	0.412
ΣMUFA	47.30 ± 1.42	46.84 ± 1.60	0.363
C16:1	0.32 ± 0.05	0.34 ± 0.04	0.214
C18:1 (9c, oleic)	29.90 ± 4.10	31.48 ± 2.40	0.221
C18:1 (11c/15t, vaccenic)	4.82 ± 0.12	4.84 ± 0.15	0.648
C20:1 (Eicosenoic)	0.42 ± 0.08	0.50 ± 0.09	0.041
ΣPUFA	15.85 ± 2.95	18.48 ± 1.52	0.031
Σn-3 PUFA	0.55 ± 0.08	0.60 ± 0.09	0.128
Σn-6 PUFA	12.85 ± 2.10	14.75 ± 1.10	0.027
C18:2 (n-6, linoleic)	10.20 ± 2.80	12.00 ± 1.60	0.034
C20:4 (n-6, arachidonic)	1.95 ± 0.35	1.85 ± 0.20	0.402
CLA (9c,11t-18:2)	0.13 ± 0.02	0.13 ± 0.02	0.917
C18:3 (n-3, linolenic)	0.22 ± 0.04	0.25 ± 0.05	0.091
C20:5 (n-3, EPA)	0.10 ± 0.02	0.11 ± 0.02	0.274
C22:5 (n-3, DPA)	0.14 ± 0.02	0.15 ± 0.02	0.198
C22:6 (n-3, DHA)	0.04 ± 0.01	0.04 ± 0.01	0.633

Note: Values are expressed as mean ± standard deviation (SD). SFA – saturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids; n-3 – omega-3 fatty acids; n-6 – omega-6 fatty acids; CLA – conjugated linoleic acid; EPA – eicosapentaenoic acid; DPA – docosapentaenoic acid; DHA – docosahexaenoic acid. Differences between wild and farmed animals were evaluated using the statistical procedures described in the Statistical Analysis section. Significant differences are indicated in bold ($p < 0.05$).

The n-3 PUFA fraction did not differ significantly between groups ($p > 0.05$), although slightly higher values were observed in farmed animals. Individual n-3 fatty acids, including α -linolenic acid (C18:3), EPA (C20:5), DPA (C22:5), and DHA (C22:6), remained at relatively low levels in both groups. This observation is consistent with findings in ruminant species, in which extensive rumen biohydrogenation limits the incorporation of long-chain n-3 fatty acids into muscle tissue [5]. The relatively low levels of long-chain n-3 fatty acids may also be associated with limited endogenous synthesis and conversion efficiency, which has been described as a characteristic feature of ruminant metabolism [19].

Among individual fatty acids, a statistically significant difference was observed only for eicosenoic acid (C20:1), which was higher in farmed animals ($p < 0.05$). However, given its relatively small proportion, this difference is unlikely to have a major impact on overall nutritional quality. Other fatty acids, including conjugated linoleic acid (CLA) and arachidonic acid, did not differ significantly between groups, indicating a relatively stable fatty acid pattern across production systems.

From a nutritional perspective, the higher PUFA content observed in farmed animals may be considered favourable; however, this increase was primarily associated with n-6 fatty acids rather than n-3 fatty acids. Previous studies have highlighted that the nutritional value of meat lipids depends not only on total PUFA content but also on the balance between n-6 and n-3 fatty acids [1], [15]. In this context, the relatively high n-6/n-3 ratio observed in both groups indicates that improvements in total PUFA content are not necessarily accompanied by an optimal fatty acid balance.

Comparative studies across cervid species have demonstrated that fatty acid composition is influenced more strongly by diet and environmental conditions than by species-specific factors [2], [21]. This is consistent with the present findings, where differences between wild and farmed animals are primarily reflected in the PUFA fraction, suggesting a dietary rather than physiological origin.

Overall, the results presented in Table 2 demonstrate that the production system influenced fatty acid composition mainly through changes in PUFA, particularly n-6 fatty acids, while SFA and MUFA remained

relatively stable. These findings confirm that differences between wild and farmed red deer are expressed primarily in lipid composition rather than in total fat content, highlighting the importance of feeding conditions in shaping the nutritional quality of venison.

Lipid quality indices

Lipid quality indices of musculus biceps femoris of red deer (*Cervus elaphus*) are presented in Table 3. Only limited differences between wild and farmed animals were observed, with statistically significant variation detected exclusively for the thrombogenic index (TI).

Table 3 Lipid quality indices of red deer (*Cervus elaphus*) meat.

Parameter	Wild	Farm	p-value
Atherogenic index (AI)	0.473 ± 0.021	0.460 ± 0.015	0.087
Thrombogenic index (TI)	1.093 ± 0.046	1.061 ± 0.032	0.043
Hypocholesterolemic/ Hypercholesterolemic ratio(h/H)	0.403 ± 0.120	0.472 ± 0.076	0.070
PUFA/SFA	0.467 ± 0.082	0.522 ± 0.060	0.064
n-6/n-3	23.019 ± 2.349	24.119 ± 1.581	0.147

Note: Values are expressed as mean ± standard deviation (SD). Differences between wild and farmed animals were evaluated using the statistical procedures described in the Statistical Analysis section. Significant differences were considered at $p < 0.05$.

The atherogenic index (AI) ranged from 0.460 to 0.473 and did not differ significantly between groups ($p > 0.05$). Similarly, the hypocholesterolaemic/hypercholesterolaemic ratio (h/H) and PUFA/SFA ratio showed no significant differences, although slightly more favourable values were observed in farmed animals. In contrast, TI was significantly lower in farmed animals (1.061 vs. 1.093; $p < 0.05$), indicating a modest improvement in lipid quality.

These indices reflect the balance between saturated and unsaturated fatty acids and are widely used to assess the potential impact of dietary lipids on cardiovascular health [22]. Lower values of AI and TI, together with higher PUFA/SFA and h/H ratios, are generally considered favourable, as they indicate a higher proportion of beneficial unsaturated fatty acids relative to atherogenic saturated fatty acids.

The observed values are consistent with previously reported data for cervid meat, which is typically characterised by a relatively favourable lipid profile compared with conventional red meats [2], [5]. Studies on deer and other wild ungulates have shown that their meat often exhibits lower atherogenic and thrombogenic potential, largely due to higher proportions of unsaturated fatty acids, particularly PUFA.

The lower TI observed in farmed animals corresponds to the higher PUFA content identified in this group, suggesting that even moderate changes in fatty acid composition can influence lipid quality indices. This relationship has been demonstrated in cervid species, where variations in feeding regime are reflected not only in fatty acid profiles but also in derived nutritional indices [4]. Diet-related changes, particularly in the PUFA fraction, appear to be the primary driver of differences in these indices.

Although the PUFA/SFA ratio exceeded the recommended threshold of 0.4 in both groups, the n-6/n-3 ratio remained high (23.0–24.1) and did not differ significantly between production systems. Similar patterns have been reported in studies of cervid meat, where an increase in total PUFA is not necessarily accompanied by an optimal balance between n-6 and n-3 fatty acids [1], [15]. This highlights the importance of considering multiple indices simultaneously when evaluating the nutritional quality of meat lipids.

From a broader perspective, lipid quality indices in venison are influenced more strongly by diet and environmental conditions than by species-specific factors, as demonstrated in comparative studies of wild ungulates [2], [21]. The present findings support this concept, indicating that the observed differences between wild and farmed animals are primarily attributable to feeding conditions rather than to intrinsic biological variability. The nutritional relevance of fatty acid balance is well established, as excessive n-6 fatty acid intake relative to n-3 has been associated with adverse health effects, including pro-inflammatory responses [24].

Overall, the results demonstrate that the production system had only a limited effect on lipid quality indices, with significant differences observed only for TI. These findings confirm that a comprehensive evaluation of lipid quality requires the combined interpretation of multiple indices, rather than reliance on a single parameter, and that dietary factors play a central role in shaping the nutritional profile of venison.

Oxidative stability

The oxidative stability of musculus biceps femoris of red deer (*Cervus elaphus*) during storage is presented in Table 4. Lipid oxidation, expressed as malondialdehyde (MDA; mg/kg), increased progressively over time in both production systems, confirming that storage duration is the primary factor influencing oxidative deterioration.

Table 4 Oxidative stability (mg MDA/kg meat) of *musculus biceps femoris* of red deer (*Cervus elaphus*) during storage.

Storage time	Hunting area	Farm breeding	p-value
1 month	0.186 ± 0.077	0.163 ± 0.072	0.342
2 months	0.298 ± 0.076	0.269 ± 0.047	0.194
3 months	0.381 ± 0.069	0.377 ± 0.057	0.820
12 months	0.864 ± 0.128 ^a	0.716 ± 0.176 ^b	0.023

Note: Values are expressed as mean ± standard deviation (SD). Lipid oxidation is expressed as mg malondialdehyde (MDA)/kg meat. Different superscripts (a, b) indicate statistically significant differences ($p < 0.05$). Statistical differences were evaluated using one-way ANOVA

At early storage stages (1–3 months), no significant differences between wild and farmed animals were observed ($p > 0.05$), with MDA values ranging from 0.163 to 0.381 mg/kg. However, after prolonged storage (12 months), a significant difference was detected ($p = 0.023$), with higher MDA values in meat from the hunting area compared to farmed animals (0.864 vs. 0.716 mg/kg), indicating lower oxidative stability in wild animals during long-term storage.

The MDA values observed in the present study (0.16–0.86 mg/kg) are consistent with ranges reported for cervid meat during storage. Similar levels of lipid oxidation have been described in deer meat under refrigerated and frozen conditions, where oxidation progresses gradually but remains relatively low under controlled storage environments [7]. These findings confirm that lipid oxidation in venison typically develops slowly, particularly in lean meat systems with low fat content.

Despite the higher PUFA content observed in farmed animals, their meat exhibited lower MDA values after prolonged storage. This indicates that oxidative stability is not determined solely by fatty acid composition but rather reflects a complex interplay among lipid profile, antioxidant capacity, and pro-oxidative factors. Previous studies have demonstrated that endogenous antioxidants, such as lipid-soluble compounds present in muscle tissue, play an important role in limiting oxidative processes in cervid meat [5].

In addition to antioxidant protection, lipid oxidation is influenced by pro-oxidative components, particularly heme iron. Game meat is characterised by relatively high iron content, which can catalyse oxidative reactions and accelerate lipid degradation [3]. This may partially explain the higher MDA values observed in wild animals during extended storage, as differences in mineral composition and environmental exposure can affect the pro-oxidative potential of muscle tissue. In addition to iron, other trace elements may also influence oxidative processes by acting as catalysts or inhibitors of lipid oxidation, depending on their chemical form and concentration in muscle tissue [23].

From a comparative perspective, similar oxidative behaviour has been reported in studies of cervid species, where lipid oxidation increases progressively during storage while generally remaining within acceptable limits for meat quality [2]. This pattern reflects the combined effects of low intramuscular fat content and the presence of both pro- and antioxidant factors in venison.

Despite the increase in MDA values over time, the levels recorded in the present study remained relatively low and are not expected to cause significant deterioration in sensory quality. Studies evaluating lipid oxidation in game meat indicate that moderate increases in MDA during storage are typical and do not necessarily lead to unacceptable changes in flavour or overall quality under appropriate storage conditions [7].

Overall, the results demonstrate that oxidative stability of red deer meat is primarily driven by storage duration, while differences between wild and farmed animals become evident mainly during long-term storage. The findings also highlight that oxidative behaviour reflects a multifactorial process involving fatty acid composition, antioxidant capacity, and pro-oxidative elements, rather than a single determining factor.

Mineral elements

The mineral composition of musculus biceps femoris of red deer (*Cervus elaphus*) is presented in Table 5. Overall, macroelements showed only minor variation between wild and farmed animals, whereas statistically significant differences were observed for magnesium (Mg) and copper (Cu).

Table 5 Mineral composition of *musculus biceps femoris* of red deer (*Cervus elaphus*).

Parameter	Hunting area	Farm breeding	p-value
Ca (g/kg)	0.085 ± 0.02	0.099 ± 0.02	0.075
P (g/kg)	1.936 ± 0.10	1.941 ± 0.13	0.904
Mg (g/kg)	0.209 ± 0.01 ^b	0.236 ± 0.01 ^a	0.001
Na (g/kg)	0.602 ± 0.11	0.605 ± 0.06	0.932
K (g/kg)	3.037 ± 0.20	3.148 ± 0.21	0.177
Fe (mg/kg)	25.292 ± 6.11	27.422 ± 5.00	0.389
Zn (mg/kg)	32.908 ± 12.49	30.845 ± 7.62	0.676
Cu (mg/kg)	2.295 ± 0.88 ^a	1.647 ± 0.23 ^b	0.041

Note: Values are presented as mean ± standard deviation (SD). Different superscripts (a, b) indicate statistically significant differences between wild and farmed animals ($p < 0.05$).

Calcium (Ca), phosphorus (P), sodium (Na), and potassium (K) did not differ significantly between groups ($p > 0.05$), with values of 0.085–0.099 g/kg, 1.936–1.941 g/kg, 0.602–0.605 g/kg, and 3.037–3.148 g/kg, respectively. These results are consistent with previous findings indicating that macroelement composition in venison is relatively stable and largely regulated by physiological processes rather than production system [3]. Similar stability of major minerals has been reported in studies of cervid species, where variation in macroelements is generally limited compared with trace elements. The physiological roles of macroelements, including calcium, magnesium, and phosphorus, are closely linked to metabolic regulation and muscle function, which contributes to their relatively stable concentrations in muscle tissue [16], [23].

Magnesium content was significantly higher in farmed animals (0.236 vs. 0.209 g/kg; $p = 0.001$), which may be attributed to more consistent dietary intake under controlled feeding conditions. The influence of feeding regime on mineral composition has been documented in deer and other ruminants, where Mg levels reflect dietary supply and feed composition [8]. Controlled diets in farmed systems can lead to more uniform mineral intake compared with the variable forage available in natural habitats.

Iron (Fe) and zinc (Zn) did not differ significantly between groups, with values of 25.29–27.42 mg/kg and 30.85–32.91 mg/kg, respectively. These concentrations are consistent with values reported for cervid meat, confirming venison as a rich source of bioavailable micronutrients [4], [3]. In particular, the relatively high iron content of game meat contributes to its nutritional value, as iron is an essential element involved in oxygen transport and enzymatic processes.

Copper (Cu) content was significantly higher in wild animals (2.295 vs. 1.647 mg/kg; $p = 0.041$), likely reflecting environmental exposure and natural feeding conditions. Trace element concentrations in wild ungulates are known to be influenced by soil composition, vegetation, and local environmental conditions, leading to variability between populations [8], [25]. Higher Cu levels in wild animals may therefore be associated with habitat-specific mineral availability rather than intrinsic physiological differences.

From a nutritional perspective, venison is considered a valuable source of essential minerals. Comparative studies have shown that deer meat can contain higher levels of certain micronutrients, such as iron and zinc, than conventional livestock meat while maintaining low levels of toxic elements [4]. This combination of beneficial mineral composition and low contamination contributes to the favourable nutritional profile of venison.

In addition to nutritional aspects, mineral composition may also influence technological and oxidative properties of meat. Elements such as iron can act as pro-oxidants, promoting lipid oxidation processes, whereas other components may contribute indirectly to oxidative stability [3]. This highlights the importance of considering mineral composition alongside lipid oxidation when evaluating meat quality. Selenium and other trace elements present in venison also play an important role in antioxidant defence mechanisms, contributing to overall nutritional value [19].

The results indicate that the production system had a limited effect on mineral composition, with significant differences detected only for Mg and Cu. These findings suggest that mineral content in venison is primarily governed by physiological regulation, while dietary and environmental factors contribute to variability in selected elements.

Heavy metals

The concentrations of selected heavy metals in *musculus biceps femoris* of red deer (*Cervus elaphus*) are presented in Table 6. All analysed elements were detected at very low levels, frequently below the limit of quantification (LOQ), and no clear differences between wild and farmed animals were observed.

Table 6 Heavy metal content of *musculus biceps femoris* of red deer (*Cervus elaphus*) (mg/kg fresh weight).

Parameter	Hunting area	Farm breeding	EU maximum level
As	< 0.030	< 0.030	Not established
Cr	< 0.050	< 0.050	Not established
Cd	< 0.0040	< 0.0040	0.05
Pb	< 0.010	< 0.018	0.10
Hg	< 0.0020	< 0.0020	Not established

Note: Values are expressed as mg/kg fresh weight. Results are presented as values below the limit of quantification (LOQ). EU maximum levels according to current European food safety regulations. “Not established” indicates that no maximum limit is defined for muscle meat.

Cadmium (Cd) and lead (Pb), which are of primary concern in food safety assessment, were present at concentrations well below the maximum levels established for meat. In both groups, Cd concentrations were below 0.004 mg/kg, while Pb levels did not exceed 0.018 mg/kg. These values are substantially lower than the limits set by the European Food Safety Authority [12], [13] and are consistent with international assessments indicating that exposure to these elements through muscle meat is generally low [14].

Arsenic (As), chromium (Cr), and mercury (Hg) were also detected at very low levels (<0.030, <0.050, and <0.002 mg/kg, respectively), and no maximum limits are currently established for these elements in muscle tissue. The consistently low concentrations suggest minimal environmental contamination and confirm the high hygienic quality of the analysed samples.

The present findings are consistent with previous studies on cervid species, which have shown that muscle tissue generally accumulates only low levels of toxic elements [3], [11]. This is largely explained by the physiological distribution of heavy metals in the organism, where higher concentrations are typically found in metabolically active organs such as liver and kidney, while skeletal muscle contains comparatively lower levels [8], [10].

Environmental exposure remains a key factor influencing heavy metal content in wild animals. Variability in soil composition, vegetation, and anthropogenic inputs may affect the uptake and accumulation of elements such as Cd and Pb in the food chain [9], [25]. In addition, hunting practices may contribute to contamination, particularly in the case of lead, which can originate from the use of lead-based ammunition [26]. However, the absence of elevated concentrations in the present study suggests that both the hunting areas and farm environments were characterised by relatively low levels of contamination. The transfer of heavy metals through the food chain, from soil to plants and subsequently to animals, has been widely documented as a major pathway of contamination in terrestrial ecosystems [27], [28].

From a comparative perspective, similar low concentrations of heavy metals in muscle tissue have been reported in other studies of wild ungulates. For example, investigations of red deer and roe deer have shown that Cd and Pb levels in muscle generally remain below regulatory thresholds, even in environments with moderate contamination [29], [25]. These findings support the view that muscle meat from wild animals does not represent a significant source of heavy metal intake under normal conditions.

Despite the low concentrations observed, the presence of toxic elements in game meat remains an important consideration in food safety assessment. Risk evaluation studies indicate that, although heavy metals can accumulate in wildlife, the contribution of muscle meat to total dietary exposure is typically limited, particularly when consumption patterns are moderate [30], [4]. This highlights the importance of considering both concentration levels and consumption frequency when assessing potential health risks. Environmental and anthropogenic factors, including agricultural practices and industrial emissions, may further contribute to spatial variability in contamination levels observed in wild animal populations [31].

The results demonstrate that the content of heavy metals in red deer meat is very low and does not pose a risk to consumer health. Compliance with EFSA limits, together with consistency with WHO risk assessments and previously published data, confirms the safety and suitability of both wild and farmed venison for human consumption.

Limitations

Despite the comprehensive evaluation of lipid composition, oxidative stability, and mineral content of red deer (*Cervus elaphus*) meat, several limitations of the present study should be considered.

Although the sample size was adequate to detect major differences between production systems, it may not have been sufficient to reveal more subtle variations, particularly for parameters showing non-significant trends, such as the PUFA/SFA ratio, AI, and n-6/n-3 ratio.

Another limitation is the focus on a single muscle (*m. biceps femoris*), which may not fully reflect the variability in chemical composition and lipid characteristics across the carcass. Since muscle type can influence both lipid profile and oxidative behaviour, the results should be interpreted with caution when extrapolating to other muscles.

Information on individual dietary intake was not available, especially for animals from hunting areas. As a result, differences in fatty acid and mineral composition can only be interpreted indirectly, based on expected feeding patterns rather than controlled dietary data.

Oxidative stability was assessed using the TBARS method (MDA), which primarily reflects secondary oxidation products. While this approach is widely used, it does not fully capture the complexity of oxidative processes. The inclusion of additional indicators, such as primary oxidation products or measures of antioxidant capacity, would allow for a more comprehensive evaluation.

Finally, heavy metal analysis was limited to muscle tissue. Given that toxic elements tend to accumulate in organs such as liver and kidney, the present findings provide only a partial assessment of total exposure. Despite these limitations, the study offers an integrated evaluation of key meat quality parameters in red deer, combining lipid composition, oxidative stability, and mineral content within a single experimental framework. Future research incorporating multiple muscles, controlled feeding conditions, and a broader range of oxidative and contaminant indicators would further improve understanding of venison quality across different production systems.

CONCLUSION

This study evaluated the effect of production system on the chemical composition, lipid profile, oxidative stability, and elemental composition of *musculus biceps femoris* of red deer (*Cervus elaphus*). Proximate composition was not significantly affected, with protein content ranging from 23.07 to 23.44 g/100 g and intramuscular fat remaining low (0.65–0.78 g/100 g), confirming the lean nature of venison. In contrast, lipid composition was influenced by production system, as farmed animals showed higher PUFA (18.48 vs. 15.85%) and n-6 fatty acids (14.75 vs. 12.85%), resulting in a lower thrombogenic index (1.061 vs. 1.093). However, the n-6/n-3 ratio remained high in both groups (23.0–24.1). Oxidative stability decreased during storage, with MDA values increasing from approximately 0.16–0.19 mg/kg at 1 month to 0.72–0.86 mg/kg after 12 months. Meat from wild animals showed significantly higher oxidation after prolonged storage. Mineral composition was largely stable, with differences observed only for Mg (0.236 vs. 0.209 g/kg) and Cu (2.295 vs. 1.647 mg/kg). Heavy metal concentrations remained very low (Cd < 0.004 mg/kg; Pb < 0.018 mg/kg), confirming compliance with food safety standards. Overall, production system had a limited effect on basic composition but influenced lipid quality and oxidative behaviour. These findings confirm venison as a nutritionally valuable meat, while highlighting the importance of feeding strategies and storage conditions for optimizing its quality.

REFERENCES

- Polak, T., Rajar, A., Gašperlin, L., & Žlender, B. (2008). Cholesterol concentration and fatty acid profile of red deer meat. *Meat Science*, 80(3), 864–869. <https://doi.org/10.1016/j.meatsci.2008.04.005>
- Daszkiewicz, T., & Mesinger, D. (2018). Fatty acid profile of meat from female roe deer and red deer. *International Journal of Food Properties*, 21(1), 2276–2282. <https://doi.org/10.1080/10942912.2018.1508160>
- Jarzyńska, G., & Falandysz, J. (2011). Selenium and 17 other largely essential and toxic metals in muscle and organ meats of red deer (*Cervus elaphus*)—Consequences to human health. *Environment International*, 37(5), 882–888. <https://doi.org/10.1016/j.envint.2011.02.017>
- Sevillano-Morales, J., Sevillano-Caño, J., Amaro-López, M. A., & Cámara-Martos, F. (2023). Probabilistic assessment of the intake of trace elements by consumption of red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*) meat. *Applied Sciences*, 13(24), 13263. <https://doi.org/10.3390/app132413263>
- Kilar, J., & Kasprzyk, A. (2021). Fatty acids and nutraceutical properties of lipids in fallow deer meat. *Foods*, 10(10), 2290. <https://doi.org/10.3390/foods10102290>
- Kasprzyk, A., Kilar, J., Walenia, A., & Kusz, B. (2022). Comparison of Lipid Properties and Cadmium and Lead Content in Red Deer (*Cervus elaphus*) Meat from Three Feeding Grounds. *Animals*, 12(20), 2859. <https://doi.org/10.3390/ani12202859>
- Reitznerová, A., Semjon, B., Bartkovský, M., Šuleková, M., Nagy, J., Klemková, T., & Marciničák, S. (2023). Comparison of lipid profile and oxidative stability of deer meat during storage. *Applied Sciences*, 13(6), 4059. <https://doi.org/10.3390/app13064059>

8. Cygan-Szczegielniak, D. (2021). The levels of mineral elements and toxic metals in the longissimus lumborum muscle, hair and selected organs of red deer (*Cervus elaphus* L.) in Poland. *Animals*, 11(5), 1231. <https://doi.org/10.3390/ani11051231>
9. Ali, H., Khan, E., & Ilahi, I. (2019). Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation. *Journal of Chemistry*, 1–14. <https://doi.org/10.1155/2019/6730305>
10. Lehel, J., Laczay, P., Gyurcsó, A., Jánoska, F., Majoros, S., Lányi, K., & Marosán, M. (2015). Toxic heavy metals in the muscle of roe deer (*Capreolus capreolus*)—food toxicological significance. *Environmental Science and Pollution Research*, 23(5), 4465–4472. <https://doi.org/10.1007/s11356-015-5658-1>
11. Srebočan, E., Prevendar Crnić, A., Ekert-Kabalin, A. M., Lazarus, M., Jurasović, J., Tomljanović, K., Andreić, D., Strunjak Perović, I., & Čož-Rakovac, R. (2011). Cadmium, lead, and mercury concentrations in tissues of roe deer (*Capreolus capreolus* L.) and wild boar (*Sus scrofa* L.) from Lowland Croatia. *Czech Journal of Food Sciences*, 29(6), 624–633. <https://doi.org/10.17221/249/2010-cjfs>
12. EFSA. (2009). Scientific opinion on cadmium in food. *EFSA Journal*, 7(3), 980. <https://doi.org/10.2903/j.efsa.2009.980>
13. EFSA. (2010). Scientific opinion on lead in food. *EFSA Journal*, 8(4), 1570. <https://doi.org/10.2903/j.efsa.2010.1570>
14. World Health Organization (WHO). (2011). Evaluation of certain food additives and contaminants (WHO Food Additives Series No. 64).
15. Strazdiņa, V., Jemeljanovs, A., Šterna, V., & Antone, U. (2010). Evaluation of fatty acid composition of deer meat. *Animal Husbandry. Scientific Articles*, 37–34. ISSN 1392-6144.
16. Anderson R. A. (1981). Nutritional role of chromium. *The Science of the total environment*, 17(1), 13–29. [https://doi.org/10.1016/0048-9697\(81\)90104-2](https://doi.org/10.1016/0048-9697(81)90104-2)
17. Razmaitė, V., Pileckas, V., Šiukščius, A., & Juškienė, V. (2020). Fatty acid composition of meat and edible offal from free-living red deer. *Foods*, 9(7), 923. <https://doi.org/10.3390/foods9070923>
18. Dumont, E., Vanhaecke, F., & Cornelis, R. (2006). Selenium speciation from food source to metabolites: a critical review. *Analytical and Bioanalytical Chemistry*, 385(7), 1304–1323. <https://doi.org/10.1007/s00216-006-0529-8>
19. Hatfield, D. L., Berry, M. J., Gladyshev, V. N. (2012). Selenium: Its Molecular Biology and Role in Human Health. <https://doi.org/10.1007/978-1-4614-1025-6>, ISBN: 978-1-4614-1024-9
20. Klupsaite, D., Buckiuniene, V., Sidlauskienė, S., Lele, V., Sakiene, V., Zavistanaviciute, P., Klementaviciute, J., Viskontaite, E., & Bartkiene, E. (2020). Comparison studies of the chemical, physical, technological, and microbiological characteristics of the European roe deer, boar, red deer, and beaver hunted wild game meat. *Animal Science Journal*, 91(1). Portico. <https://doi.org/10.1111/asj.13346>
21. Starčević, M., Glamočlija, N., Baltić, B., Glišić, M., Laudanović, M., Krstić, M., & Bošković Cabrol, M. (2025). Nutritional Value of Wild-Harvested Game Meat of Fallow Deer (*Dama dama*), Red Deer (*Cervus elaphus*), and Roe Deer (*Capreolus capreolus*). *Acta Veterinaria*, 75(1), 63–81. <https://doi.org/10.2478/acve-2025-0006>
22. Ulbricht, T. L. V., & Southgate, D. A. T. (1991). Coronary heart disease: Seven dietary factors. *The Lancet*, 338(8773), 985–992. [https://doi.org/10.1016/0140-6736\(91\)91846-M](https://doi.org/10.1016/0140-6736(91)91846-M)
23. Elin R. J. (1988). Magnesium metabolism in health and disease. *Disease-a-month : DM*, 34(4), 161–218. [https://doi.org/10.1016/0011-5029\(88\)90013-2](https://doi.org/10.1016/0011-5029(88)90013-2)
24. Rayman, M. P. (2008). Food-chain selenium and human health: emphasis on intake. *British Journal of Nutrition*, 100(2), 254–268. <https://doi.org/10.1017/s0007114508939830>
25. Ciobanu, M. M., Boișteanu, P. C., Munteanu, M., Târziu, D., Rațu, R. N., & Postolache, A. N. (2021). Bioavailability of heavy metals (Pb and Cd) in wild roe deer meat. *Scientific Papers. Series D. Animal Science*, 64(2), 227–232.
26. Gerofke, A., Martin, A., Schlichting, D., Gremse, C., & Müller-Graf, C. (2019). Heavy metals in game meat. *Chemical Hazards in Foods of Animal Origin*, 585–609. https://doi.org/10.3920/978-90-8686-877-3_24
27. Gall, J. E., Boyd, R. S., & Rajakaruna, N. (2015). Transfer of heavy metals through terrestrial food webs: a review. *Environmental monitoring and assessment*, 187(4), 201. <https://doi.org/10.1007/s10661-015-4436-3>
28. Olaoye, J. (2024). Bioaccumulation and Toxicological Effects of Heavy Metals in Wildlife: Implications for Ecosystem Health and Human Exposure. *International Journal of Science, Architecture, Technology and Environment*, 294–303. <https://doi.org/10.63680/ijate0325035.07>
29. Kuiters, A. T. (1996). Accumulation of cadmium and lead in red deer and wild boar. *Veterinary Quarterly*, 18(3), 134–135. <https://doi.org/10.1080/01652176.1996.9694715>

30. Mesinger, D., & Ociecek, A. (2021). Risk assessment of wild game meat intake in the context of the prospective development of the venison market in Poland. *Polish Journal of Environmental Studies*, 30(2), 1307–1315. <https://doi.org/10.15244/pjoes/124744>
31. Shetty, B. R., Jagadeesha, P. B., & Salmataj, S. A. (2025). Heavy metal contamination and its impact on the food chain: exposure, bioaccumulation, and risk assessment. *CyTA - Journal of Food*, 23(1). <https://doi.org/10.1080/19476337.2024.2438726>

Funds:

This work was supported by [APVV] under grant [no. 23-0077].

Acknowledgments:

-

Competing Interests:

The authors declare no conflict of interest.

Ethical Statement:

All experimental procedures involving animals were conducted in accordance with the applicable legislation and guidelines for the care and use of animals in research. The animals used in this study were handled under standard commercial farming conditions, and no additional experimental interventions causing pain, suffering, or distress were applied beyond routine husbandry and slaughter practices.

Slaughter procedures were carried out in a licensed slaughterhouse in compliance with European Union regulations on the protection of animals at the time of killing (Council Regulation (EC) No 1099/2009). Muscle samples were collected *post mortem*, and therefore no live animal experimentation was performed.

According to national and institutional guidelines, ethical approval was not required for this type of study, as it involved the use of samples obtained from animals slaughtered for commercial purposes.

AI Statement:

AI tools, such as Grammarly and DeepL, were used for performing English grammar proofreading. Chat GPT 5.4 was used for the creation of the composition of Figure 2.

Contact Address:

Adriana Pavelková

Affiliation: Slovak University of Agriculture in Nitra, Faculty of Biotechnology and Food Sciences, Institute of Food Sciences, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia

Tel.: +421376414313

E-mail: pavelkova.adriana@uniag.sk

ORCID: <https://orcid.org/0000-0002-8275-8557>

Author contribution: conceptualisation, methodology, project administration, validation, investigation, resources, writing – original draft, writing – review & editing, visualisation.

Matúš Rajský

Affiliation: Institute of Nutrition, Research Institute for Animal Production Nitra, National Agricultural and Food Centre, Hlohovecká 2, 951 41 Lužianky, Slovakia

Tel.: +421376546557

E-mail: matus.rajsky@gmail.com

ORCID: <https://orcid.org/0000-0002-7446-6917>

Author contribution: conceptualisation, methodology, formal analysis, investigation, resources, data curation.

Ondrej Bučko

Affiliation: Slovak University of Agriculture in Nitra, Faculty of Agrobiological and Food Resources, Institute of Animal Husbandry, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia

Tel.: +421376414802

E-mail: ondrej.bucko@uniag.sk

ORCID: <https://orcid.org/0000-0001-6942-511X>

Author contribution: validation, formal analysis, investigation, resources, data curation, writing – original draft, writing – review & editing, visualisation, software.

Peter Haščík

Affiliation: Slovak University of Agriculture in Nitra, Faculty of Biotechnology and Food Sciences, Institute of Food Sciences, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia

Tel.: +421376414708

E-mail: peter.hascik@uniag.sk

ORCID: <https://orcid.org/0000-0002-3402-5658>

Author contribution: methodology, formal analysis, resources, writing – original draft, writing – review & editing, project administration, funding acquisition.

Corresponding author: **Peter Haščík**

Copyright notice:

© 2026 The Author(s). Published by HACCP Consulting, Slovakia, European Union, on *Scifood* (<https://scifood.eu>), the official website of the journal. *Scifood* is owned and operated by HACCP Consulting s.r.o. (<https://www.haccp.sk>). This article is published as **Open Access** under the **Creative Commons Attribution–NonCommercial–NoDerivatives 4.0 International License** <https://creativecommons.org/licenses/by-nc-nd/4.0/> (CC BY-NC-ND 4.0). This license permits non-commercial use, sharing, distribution, and reproduction in any medium or format, provided that appropriate credit is given to the author(s) and the original publication, a link to the license is provided, and the work is not modified, adapted, or transformed.