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Quality and Safety of Game Meat from the Biocenosis of the Beloosipovo Mercury Deposit (part 2)[1]

Alexander Yu. Prosekov*, **Olga G. Altshuler**, **Marina G. Kurbanova**

Kemerovo State University, Kemerovo, Russia

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**e-mail: aprosekov@rambler.ru*

Abstract.
Introduction. Mercury contamination is one of the most common environmental problems. The research objective was to study the qualitative composition and physicochemical properties of raw game meat obtained from the area near the Beloosipovo mercury deposit in order to define any possible contamination with xenobiotics.
Study objects and methods. The research featured rib eye muscle tissue and soft flesh of elks shot on the hunting farms of the Kemerovo Region aka Kuzbass.
Results and discussion. A complex set of experiments revealed the chemical composition of elk muscle tissue and flesh, as well as the mineral composition of elk muscle tissue. The samples were obtained from different parts of carcasses. The amino acid and fatty acid composition of elk muscle tissue made it possible to describe the biological value, mineral composition, and vitamin profile of elk meat. The physicochemical analysis included toughness, cooking losses, and moisture-retaining capacity, i.e. the properties that ensure juiciness. The research also featured the accumulation of xenobiotics in elk meat samples obtained from the biosinosis near the Beloosipovo mercury deposit.
Conclusion. The slaughter yield of elk meat was 51–53%, which exceeds the average yield of farm cattle meat by 4–6%. The moisture content was 73–78%, while the content of protein was between 20–24% and depended on the anatomical location of the muscle sample; the fat content reached 0.75–1.75%. The mercury accumulation at different storage temperature conditions ranged from 0.004 ± 0.001 to 0.009 ± 0.001 mg/kg, while the maximum allowable concentration of mercury is 0.03 mg/kg.

Keywords. Elk, mercury, biocenosis, meat, chemical composition, functional and technological properties, aging

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Исследование качества и безопасности мяса диких животных, полученного в условиях биоценоза Белоосиповского ртутного месторождения (часть 2)[1]

А. Ю. Просеков*, **О. Г. Альтшуллер**, **М. Г. Курбанова**

Кемеровский государственный университет, Кемерово, Россия

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**e-mail: aprosekov@rambler.ru*

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Аннотация.
Введение. Одна из самых распространенных экологических проблем связана с загрязнением окружающей среды соединениями ртути. Целью работы стало исследование качественного состава и физико-химических свойств нетрадиционного мясного сырья, а также изучение степени накопления ксенобиотиков в мясе диких животных, полученных в условиях биоценоза Белоосиповского ртутного месторождения.
Объекты и методы исследования. Мышечная ткань длиннейшей мышцы спины, а также мякоть мяса лосей, добытых ружейным способом егерями в охотничьих хозяйствах Кемеровской области – Кузбасса.
Результаты и их обсуждение. В ходе комплексных исследований был изучен химический состав мышечной ткани и мякоти мяса лося, а также минеральный состав мышечной ткани лося, полученной из разных анатомических частей туши животного. Биоологическую ценность мяса лося оценивали по результатам изучения аминокислотного и жирнокислотного состава мышечной ткани, а также минерального и витаминного состава. Были изучены физико-химические показатели мяса лося, характеризующие его жесткость, потери при тепловой обработке, способность связывать и удерживать влагу, что обеспечивает его сочность. Завершающий этап исследований связан с изучением накопления ксенобиотиков в опытных образцах нетрадиционного мясного сырья, полученного вблизи района Белоосиповского ртутного месторождения.
Выводы. Убойный выход составил 51–53 %, что превышает выход мяса крупного рогатого скота на 4–6 %. Содержание влаги в мясе лося составило 73–78 %, белка 20–24 %, в зависимости от анатомического расположения мышц, жира 0,75–1,75 %. Динамика накопления изменения ртути в мясе лося при разных температурных режимах его хранения составляла в пределах от 0,004 ± 0,001 до 0,009 ± 0,001 мг/кг (при ПДК 0,03 мг/кг).

Ключевые слова. Лось, ртуть, биоценоз, мясо, химический состав, функционально-технологические свойства, выдержка

Финансирование. С использованием (или на оборудовании) Центра коллективного пользования научным оборудованием Кемеровского государственного университета (КемГУ) ROR в рамках соглашения № 075-15-2021-694 от 05.08.2021, заключенного между Министерством науки и высшего образования Российской Федерации (Минобрнауки России) ROR и Кемеровским государственным университетом (уникальный идентификатор контракта RF----2296.61321X0032).

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Introduction

Environmental pollution has been the main concern of ecologists, doctors, and food manufacturers for the last several decades [1].

Heavy metals and mercury are one of the most widespread and dangerous environmental pollutants. Massive mercury poisoning occurred in the 1950s-1970s as a result of the consumption of fish from mercury-contaminated water sources. The massive character of this phenomenon also triggered extensive research on the effect of mercury on terrestrial ecosystems [2–4].

Short-chain alkyl mercury compounds cause the greatest ecotoxicological hazard. They form strong bonds with sulfur and weaker bonds with nitrogen, oxygen, and halogens. Strong mineral acids break the mercury-carbon bond to form inorganic compounds. Mercury has the highest ionization potential among other chalcophilic elements Due to this geochemical feature, mercury can be reduced to its atomic form and is highly resistant to oxygen and acids [5]. Mercury is scattered in the earth's crust: its deposits have a natural content of 0.02% [6–8]. In addition to the atomic state, mercury occurs in a bivalent and univalent state [9]. E.B. Swain *et al.* claim that the air usually contains up to 5000 tons of mercury vapor or aerosol, and elemental mercury vapors can remain in the atmosphere for 1–2 years [10]. Reactive ionic forms persist in the atmosphere from several hours to several days [11]. In low-polluted air, the concentration of mercury is 0.8–1.2 ng/m^3. However, near large mercury deposits it can be as high as 240 ng/m^3, and near gas deposits – 70 000 ng/m^3, while the average content of mercury is 0.5–2.0 ng/m^3 [12].

E.G. Pacyna *et al.* and R. Ebinghaus *et al.* proved that anthropogenic impact increases the man-induced component in the biogeochemical cycle, as well as the emigration and redistribution of natural mercury compounds [13, 14]. In nature, mercury compounds are highly volatile and rise in the air quite easily. In addition, mercury compounds are highly soluble in water. Mercury is one of the most toxic elements in the environment, with organic and inorganic mercury being the main forms found in food samples [15].

When dissolved in water, mercury forms strong soluble complex compounds with various organic substances. Methylmercury ($MeHg^+$) results from mercury ions Hg^{2+} and methyl radicals CH_3, which can be of different origins, including bacterial. In low salinity water, methylmercury ion $HgCH_3^+$ and hydroxymethylmercury CH_3HgOH are the most popular compounds of mercury. In natural water pools, humic and fulvic acids are the most widespread donors of methyl groups, while the content of humic acids in soil is also very high. Mercury methylation depends on the ionization of the abovementioned acids, the optimal pH values for these reactions being 6–8 [16–18].

The Kemerovo Region covers an area of about 95.5 thousand km^2. It is a large mining, processing, chemical, and agricultural center.

The Kemerovo State University conducted an expedition to the area of the Beloosipovo mercury deposit (Krapivinsky district). The team included scientists of the Institute of Biology, Ecology, and Natural Resources and was led by D.V. Sushchev, Candidate of Biological Sciences. The team established the patterns of mercury accumulation and distribution in various components of the terrestrial ecosystem. They determined the mercury content in soil, herbaceous plants, arthropods, and small mammals, which they harvested in various biotopes near the mercury deposit. A small plant evaporated mercury from ore in the Belaya Osipova river valley in 1969–1975 (https://www.krapivino.ru/node/15303).

Based on the e-catalog of geological documents (Russian Federal Geological Fund), specialists from the Kemerovo State University referred the Beloosipovo mercury deposit to the Kuznetsk fault zone. The mineralization here is uneven and scattered. The mercury deposit is estimated as 124 tons, cinnabar (HgS) being the main ore-bearing mineral. The deposit has a hydrothermal low-temperature origin and is located in the zone of deep and echelon faults. Mercury manifests itself here as occasional ore occurrences, points of mineralization, concentrate and geochemical aureoles, etc. Areas of high mercury concentration intersperse with barren ones. The area featured in the present research is part of the Pezas-Beloosipovo mercury ore zone and the Beloosipovo mercury ore deposit [19].

The highest concentration of mercury is 1.5 km north of the mine: soil – 0.72 and 0.96 mg/kg, plants – 0.064 mg/kg, insects – 0.063 mg/kg, rodents – 0.091 mg/kg, insectivores – 0.056 mg/kg. The maximum allowable concentration (MAC) of mercury in soil is 2.1 mg/kg. Therefore, the mercury concentration in the local soil was well within the norm (0.72 and 0.96 mg/kg).

Soil plays an important role in the global biogeochemical cycle of mercury. As it settles on the soil surface, its further route into aquatic ecosystems largely depends on terrestrial ecosystems [20, 21]. In addition to elemental mercury, soil contains inorganic and organic compounds [22]. Inorganic compounds exist in mobile (water- and acid-soluble), oxide, and sulfide forms.

Mercury concentration is known to be much lower in the soils of national parks with their minimal external anthropogenic impact than in the areas affected by human economic activities.

All forms of mercury in soils can be divided into four types:
1) water-soluble mercury is described as readily available to plants;
2) mercury soluble in an acetate-ammonium buffer solution (pH 4.8) is believed to be conditionally easily available to plants;
3) acid-soluble mercury is classified as potentially available to plants;
4) alkali-soluble forms of mercury are conditionally associated with mobile humic substances.

The content of mercury in one and the same type of soil can be different as it depends on the adjacent landscapes. For instance, its concentration is lower in separate eluvium than in conjugated transeluvial and super-aquatic soils, which is associated with migration-accumulative processes.

In continental biogeocenoses, mercury concentration increases in the following order: plants > insects > soil microorganisms > herbivorous mammals > carnivorous mammals > macromycetes [23].

In 2018–2021, water samples from the Belaya Osipova exceeded the MAC for mercury by 5–20%. Probably, the groundwater and surface floods are leaching mercury compounds from the deposit. However, the biological diversity proves that such concentrations have no pronounced impact on the local ecosystem. In fact, the concentration of mercury goes down as it moves up the food chains.

The Beloosipovo mercury deposit is surrounded by taiga with its typical flora and fauna, including game animals and birds. Professor A.Yu. Prosekov also commented on the diversity of Beloosipovo flora in his article *Migration of Mercury in the Food Chains of the Beloosipovo Biocenosis*. The local taiga is predominated by Siberian spruce (*Abies sibirica* Ledeb.), aspen (*Populus tremula* L.), birch (*Betula pubescens* Ehrh., *Betula pendula* Roth), and lush herbaceous vegetation up to three meters tall. The rich undergrowth is formed by such

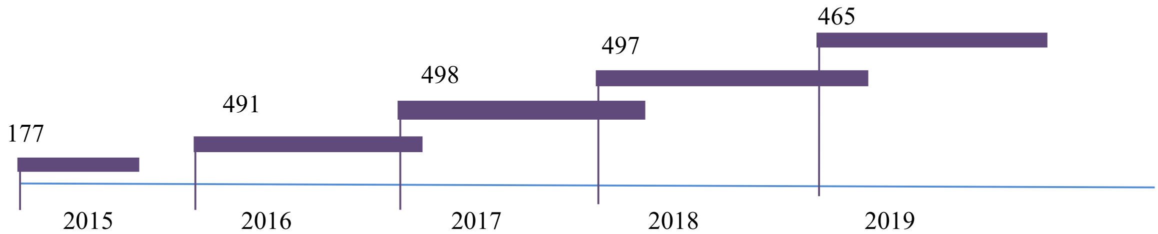


Figure 1. Elk population in the Krapivino district

shrubs as goat willow (*Salix caprea* L.), cranberry bush (*Viburnum opulus* L.), pea shrub (*Caragana arborescens Lam*.), Siberian mountain ash (*Sorbus sibirica* Hedl.), and bird cherry (*Padus avium* Mill.). Some undergrowth areas are represented by sparse shrubbery, which is known to attract wild animals, such as elk.

The list of herbaceous plants includes melancholy thistle (*Cirsium heterophyllum* (L.) Hill.), millet grass (*Milium effusum* L.), dissected hogweed (*Heracleum dissectum* Ledeb.), wild chervil (*Anthriscus sylvestris* (L.), cacalia (*Cacalia hastata* L.), Siberian hawk's beard (*Crepis sibirica* L.), northern wolfsbane (*Aconitum septentrionale* Koelle), meadowsweet (*Filipendula ulmaria* (L.) Maxim.), Siberian globeflower (*Trollius asiaticus* L.), and giant fescue (*Festuca gigantea* (L.) Vill.). All these plants serve as food base for taiga fauna.

Forest phytocenoses prevail in the research area, e.g. aspen-birch-fir forest with lush tall grass and occasional Siberian spruces. The growing anthropogenic load makes it necessary to study the patterns of its effect on the local wild animal population. Professor A.Yu. Prosekov described the changes in the elk population in his research *Effect of Forest Coverage on Elk Population in Kuzbass*. Figure 1 illustrates the pattern of elk population in the Krapivino district in 2015–2019 as reported by the Department of Wildlife Protection of the Kemerovo Region (Fig. 1) [24–26].

In 2017, the elk population reached its peak, while the total rise for 2015–2019 was 163%. The area of the hunting grounds in the Krapivino district is 8328 hectares, i.e. 805 hectares of forest per animal, which provides a fairly good forage base [25–27].

Elks (Alces a. Pfizenmayeri Zukowski) avoid dense forests. They prefer sparse forests and overgrown clearings, glades, and meadows that are rich in forage. The vast burnt-out areas with young plants are home to a large elk population. Elks spend all seasons in mixed and deciduous forests. In summer, they eat leaves, reaching as far as their considerable height allows them. They feed on tall grasses in burnt-out areas and logging spots. Late in summer, they eat all kinds of mushrooms, even fly agarics – for medicinal purposes. In September, elks start eating shoots and twigs, and by November they almost completely switch to browse forage. Their daily food intake varies from season to season. An adult elk consumes 35 kg of food per day in summer and 12–15 kg in winter, i.e. about seven tons of plant food per year. If elk population increases, they can damage forest nurseries and plantings. Elks use every opportunity to lick salt, sometimes even the salt mix that is used to melt snow on highways [28, 29].

The elk is a game animal, which makes its meat an object of research interest. Its quality and safety depends on the fact whether it accumulates such xenobiotics as mercury. Experimental studies and chance finds prove that 0.1–200 mg of mercury per 1 kg of wet weight can destroy the normal reproduction pattern and life of warm-blooded animals, depending on numerous factors [30].

Xenobiotic contamination of food raw materials and products usually corresponds with the degree of environmental pollution. Moving along the food chain, contaminants enter human body and cause serious health problems. Food chains are one of the main routes that harmful chemicals take to get into human body. Science knows more than nine million xenobiotics of various nature. According to the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), people consume 80–95% of contaminants with food and 4–7% with drinking water, while 1–2% enters human body from the air through the skin.

The research objective was to study the chemical composition, functional, technological, and physicochemical properties, and the accumulation of xenobiotics in the raw elk meat obtained from the biocenosis of the Beloosipovo mercury deposit.

The goal was to define:

– the anatomical and chemical composition of elk meat from the forests of the Krapivino region in the vicinity of the Beloosipovo mercury deposit;

– the amino acid, fatty acid, and mineral composition of elk meat, as well as its functional and technological properties;

– the degree of accumulation of mercury in meat samples in their native state during storage and after various methods of processing.

Study objects and methods

The research featured muscle tissue from the rib eye area and fat and muscle tissue from the hind legs of three elks (two males, one female) shot by the game wardens in the hunting farms of the Kemerovo Region. The sample description included the sex, body carcass weight, and approximate age of the animals. The selected samples were placed in a chemically neutral package, sealed, and stored at –20 ± 2°C. The sampling procedure and freshness test followed State Standard 7269-2015. Moisture content was determined according to State Standard 33319-2015; fat – by a Soxhlet extraction device according to State Standard 23042-2015; total protein – by the Kjeldahl method according to State Standard 25011-2017. All the biochemical studies involved modern analytical equipment from the laboratory of the Research Institute of Biotechnology, Kemerovo State University. The list of indicators to be defined included the content of fatty acids, vitamins, and macro- and microelements. The mineral composition of the elk meat was determined using an X-ray fluorescence spectrometer (Carl Zeiss Jena). The amino acid composition was tested with an automatic amino acid analyzer Aracus PMA GmbH, which was approved by directives 98/64/EU and 2000/45/EU. The method presupposed a cation-exchange separation of amino acids with a stepwise pH gradient and a post-column derivatization with ninhydrin. The fatty acid composition was determined by gas chromatography based on State Standard 55483-2013.

Hydrogen ions (pH) were studied by the potentiometric method, the moisture-binding and moisture-retaining capacity – by centrifugation and pressing. To define the mercury concentration, the muscle tissue samples were dried and subjected to dry ashing by the cold vapor method in a Julia 5K device.

Results and discussion

Three elks were shot in the Krapivinsky district during the hunting period (October – November) of 2017–2020 to assess the possible xenobiotic contamination of meat. Sample 1 weighed 270.0 ± 10.5 kg, sample 2 – 310.0 ± 13.5 kg, and sample 3 – 260.0 ± 10.0 kg. The carcasses weighed 143.40 ± 7.15 kg, 165.20 ± 8.26 kg, and 137.80 ± 6.89 kg, respectively. The slaughter yield was within 51–53%, which exceeded the meat yield from farm cattle (47–50%).

The elk is the largest representative of deer. The elk meat samples were dark red, with coarse fiber and almost no fat in the muscle tissue. Scarce fat stripes were observed on the neck and chest. The highest fat content was registered in the pelvic cavity and the lumbar area. The fat was white and hard and crumbled at room temperature. The melting point of fat from different parts of the carcass ranged from 47.1 to 48.5°C.

The lymph nodes were oval and varied in size. They were gray-white on the surface, while their peripheral areas were darker, which suggests that the animals were healthy.

The initial sensory analysis included boiling the samples in order to assess the quality of the broth. The broth was transparent and had a typical meaty smell, which indicated the good quality of the meat. The freshness test procedure for game meat included a complex of studies, which consisted of a sensory evaluation, bacterioscopy of deep layers, cooking test and ammonia reaction with Nessler's reagent. The complex analysis confirmed the freshness of the meat samples.

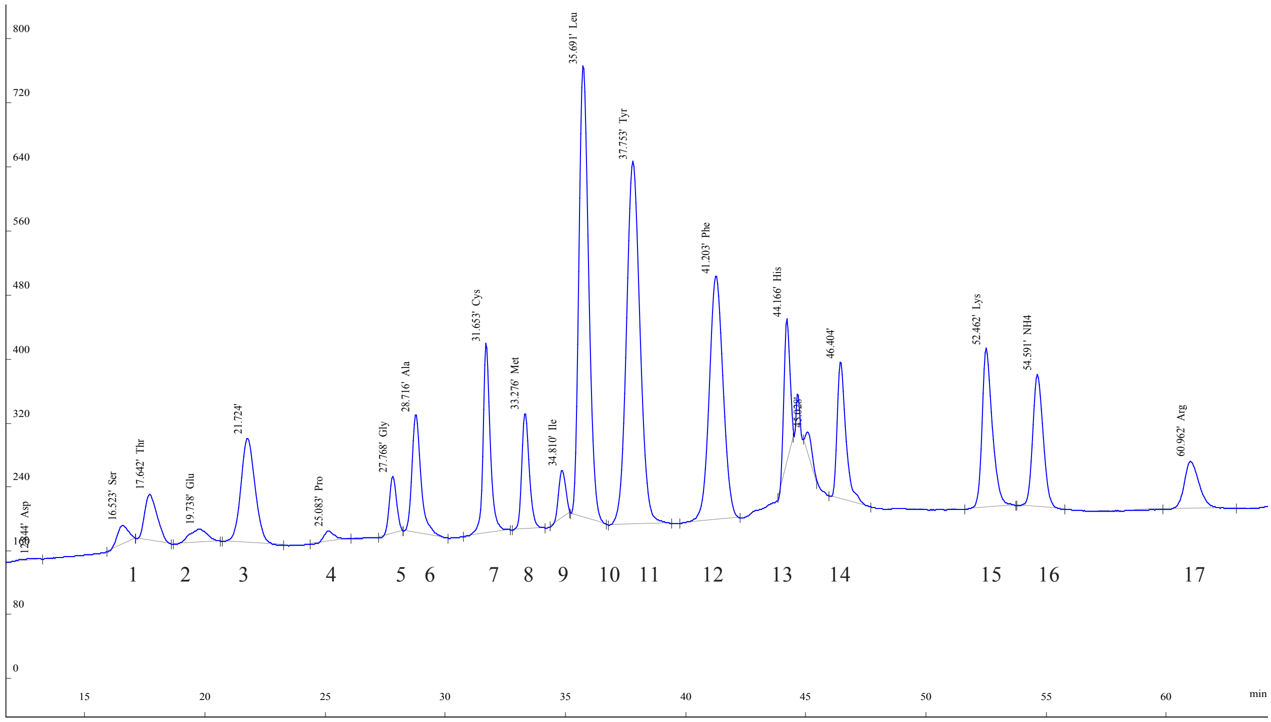
Table 1 shows the anatomical and chemical composition of the elk meat.

Table 1. Morphological and chemical composition of elk meat (n = 3)

Indicator	Sample 1	Sample 2	Sample 3	Mean value
Anatomical composition, kg				
Muscle tissue	105.39 ± 5.15	121.42 ± 6.08	101.28± 5.67	109.36 ± 5.46
Fat	0.86 ± 0.11	1.16 ± 0.09	0.84 ± 0.13	0.95 ± 0.11
Connective tissue	11.23 ± 1.75	13.05 ± 0.96	10.88± 1.18	11.72 ± 0.58
Bones and cartilage	25.81± 1.99	29.81 ± 1.69	24.82 ± 1.16	26.81 ± 1.60
Chemical composition of rib eye sample, g/100 g				
Moisture	77.85 ± 3.11	78.88 ± 2.94	77.61 ± 3.18	78.14 ± 3.90
Total protein	19.88 ± 0.79	21.56 ± 0.86	19.75 ± 0.78	20.39 ± 0.81
Fat	0.77 ± 0.03	0.82 ± 0.03	0.68 ± 0.02	0.75 ± 0.03
Ash	0.99 ± 0.04	1.23 ± 0.04	1.05 ± 0.04	1.09 ± 0.04
Chemical composition of the average sample of flesh, g/100 g				
Moisture	72.62 ± 2.27	74.14 ± 2.13	73.82 ± 2.04	73.52 ± 3.65
Total protein	23.32 ± 0.85	24.65 ± 1.05	22.91 ± 0.88	23.62 ± 1.18
Fat	1.70 ± 0.06	1.73 ± 0.07	1.80 ± 0.07	1.74 ± 0.08
Ash	1.21 ± 0.05	1.42 ± 0.04	1.34 ± 0.06	1.32 ± 0.06
Other substances	1.31 ± 0.05	1.48 ± 0.05	1.30 ± 0.04	1.36 ± 0.04

Table 2. Amino acid composition of elk meat (rib eye), g/100 g of protein (n = 3)

Amino acid	Content	Amino acid	Content
Essential		Nonessential	
Valine	2.55 ± 0.06	Methionine + Cysteine	2.87 ± 0.08
Isoleucine	3.83 ± 0.11	Hydroxyproline	0.55 ± 0.01
Leucine	3.58 ± 0.10	Glutamine	3.86 ± 0.11
Lysine	4.86 ± 0.24	Proline	0.98 ± 0.02
Methionine	1.75 ± 0.04	Serine	2.62 ± 0.07
Tryptophan	3.96 ± 0.02	Glycine	2.82 ± 0.08
Threonine	3.64 ± 0.10	Alanin	2.77 ± 0.08
Phenylalanine	1.73 ± 0.05	Arginine	3.66 ± 0.11
Total	25.90 ± 0.68	Total	20.13 ± 0.58



1 – tryptophan, 2 – threonine, 3 – isoleucine, 4 – hydroxyproline, 5 – serine, 6 – glycine, 7 – alanine, 8 – valine, 9 – methionine, 10 – cystine, 11 – leucine, 12 – glutamine, 13 – proline, 14 – phenylalanine, 15 – lysine, 16 – arginine, 17 – methionine + cysteine

Figure 2. Chromatographic profile of the amino acid composition of elk rib eye

The average morphological composition of elk carcasses was as follows (% of the carcass weight). Muscle tissue predominated, the yield being 73 ± 2%; the content of bones and cartilage was 18 ± 2%, connective tissue – 8 ± 1%, and fat – 0.7 ± 1%. Table 1 shows that the moisture content in the rib eye sample was 78.14 ± 3.90 g/100 g, which exceeded this indicator in the average flesh sample by 5.91%. The samples demonstrated a high protein content of 23.62%, which exceeded that of farm animal meat, e.g. in pork and beef, the mass fraction of protein is 14–15 and 16–17%, respectively. The protein:fat ratio was 1:0.07, while for farm cattle this ratio is 1:0.5. Unlike more traditional raw meat, elk meat has low fat content, which proves its dietary properties and a lower cholesterol profile.

The biological value of meat depends on the main nutrients, in particular, amino and fatty acids. Therefore, the next task was to determine these indicators for the rib eye samples (Tables 2 and 3, Fig. 2).

The total amount of essential amino acids in the elk rib eye samples exceeded the nonessential ones by 23%. The total amino acid level was 46.03 ± 1.38 g per 100 g of protein.

The list of the most abundant essential amino acids started with lysine (4.86 ± 0.24), tryptophan (3.96 ± 0.02), and isoleucine (3.83 ± 0.11). The nonessential amino acids were dominated by glutamine 3.86 ± 0.11 and arginine 3.66 ± 0.11 g/100 g of protein.

The ratio of the essential and nonessential amino acids was high in the rib eye samples: the protein quality index

Table 3. Fatty acid composition of elk rib eye, % (n = 3)

Acid	Content	Acid	Content
Saturated fatty acids		Unsaturated fatty acids	
Lauric	1.09 ± 0.03	Palmitooleic	6.54 ± 0.19
Myristic	0.75 ± 0.02	Oleic	44.02 ± 1.32
Palmitic	26.13 ± 0.74	Linoleic	1.10 ± 0.03
Stearic	5.26 ± 0.15	Linolenic	0.17 ± 0.01
Arachinic	0.09 ± 0.01	Total	51.83 ± 1.55
Total	33.32 ± 0.98		

Table 4. Mineral profile of elk meat, mg/100 g (n = 3)

Micronutrients	Sample 1	Sample 2	Sample 3	Mean value
Iron	2.91 ± 0.09	2.88 ± 0.08	2.93 ± 0.08	2.90 ± 0.08
Copper	5.48 ± 0.16	6.21 ± 0.18	6.33 ± 0.18	6.01 ± 0.18
Calcium	10.22 ± 0.30	10.31 ± 0.30	11.01 ± 0.35	10.51 ± 0.33
Magnesium	24.55 ± 0.49	24.41 ± 0.47	23.88 ± 0.45	24.28 ± 0.47
Sodium	77.41 ± 1.54	76.88 ± 1.53	77.32 ± 1.54	77.20 ± 1.54
Zink	125.66 ± 2.51	133.45 ± 2.66	129.75 ± 2.19	129.62 ± 2.28
Phosphor	194.43 ± 3.88	194.41 ± 3.88	196.22 ± 3.81	195.02 ± 3.85
Sulfur	195.54 ± 3.91	197.21 ± 3.94	196.51 ± 3.93	196.42 ± 3.95
Potassium	305.22 ± 6.10	307.33 ± 6.14	306.44 ± 6.11	306.33 ± 6.12

Table 5. Physicochemical, functional, and technological properties of elk muscle tissue (n = 3)

Indicator	Sample 1	Sample 2	Sample 3	Mean value
pH	5.80 ± 0.12	6.00 ± 0.14	6.2 ± 0.16	6.00 ± 0.14
Color intensity, E×1000	375.80 ± 11.10	376.91 ± 10.20	375.00 ± 10.50	375.90 ± 10.47
Moisture-binding capacity, %	74.66 ± 2.23	72.33 ± 2.16	73.11 ± 2.19	73.36 ± 3.50
Moisture-retaining capacity, %	58.62 ± 1.75	59.88 ± 1.79	60.21 ± 1.80	59.57 ± 1.78
Cooking loss, %	20.58 ± 1.21	18.99 ± 1.16	21.01 ± 1.23	20.19 ± 1.20
Rib eye area, cm^2 (at ribs 12–13)	31.21 ± 0.93	32.01 ± 0.96	31.80 ± 0.95	31.67 ± 0.95
Shearing strength, kg/cm^2	2.10 ± 0.06	2.59 ± 0.07	2.40 ± 0.07	2.36 ± 0.07

Table 6. Accumulation of mercury in elk muscle tissue during maturation (n = 3)

Exposure time	Mercury concentration, mg/kg of solids			Mean value
	Sample 1	Sample 2	Sample 3	
At 20 ± 2°C				
Control (fresh meat)	0.004 ± 0.001	0.003 ± 0.002	0.005 ± 0.001	0.004 ± 0.001
2 days	0.006 ± 0.002	0.005 ± 0.001	0.007 ± 0.001	0.006 ± 0.001
At –20 ± 2°C				
5 days	0.005 ± 0.001	0.004 ± 0.001	0.007 ± 0.001	0.005 ± 0.001
10 days	0.007 ± 0.001	0.006 ± 0.001	0.009 ± 0.001	0.007 ± 0.001
15 days	0.009 ± 0.001	0.008 ± 0.001	0.012 ± 0.001	0.009 ± 0.001

(PQI) was 7.2, with a rather high content of tryptophan and a low content of hydroxyproline. For beef, the PQI is 5.0–5.5.

Oleic acid proved to be the most abundant unsaturated fatty acid. It improves human metabolism and immune system; it is good against cholesterol and insulin resistance. Oleic acid occupied 85% of the total amount of unsaturated fatty acids. Palmitic acid topped the list of saturated fatty acids. The total amount of saturated fatty acids in the rib eye sample was 33.32 ± 0.98%, that of unsaturated – 51.83 ± 1.55%.

Minerals also increase the nutritional and biological value of meat. They are important for metabolism, growth, and development. Table 4 shows the mineral composition of the elk meat.

The samples proved to be rich in potassium (306.33 ± 6.12 mg/100 g), sulfur (196.42 ± 3.95 mg/100 g), and phosphorus (195.02 ± 3.85 mg/100 g). Unlike beef and pork, elk meat appeared to contain a lot of potassium, sodium, magnesium, iron, and phosphorus. For example, elk meat has more potassium than pork and beef by 7 and 10%, sodium – by 24 and 35%, and iron – by 17 and 30%, respectively. Iron with its 2.90 ± 0.08 mg/100 g was the predominant trace element.

The quality of the muscle tissue was tested according to its physicochemical parameters, cooking losses, and moisture-retaining properties, i.e. the properties that defined the juiciness of the meat. Another test measured the pH value, which depended on biochemical changes related to maturation processes and glycogen conversion (Table 5).

The analysis of the functional and technological properties involved moisture-binding capacity (73.36 ± 3.50%) and water-retaining capacity (59.57 ± 1.78%). The hydrogen index (pH) of meat varied from 5.8 to 6.2 units, which means that a small amount of lactic acid prevented the development of putrefactive microflora. The water-retaining capacity depends on the ability of proteins to bind water in various ways, both on the surface and inside. Therefore, it is responsible for juiciness, tenderness, market quality, cooking and freezing losses, etc.

The elk meat samples appeared to be quite tender: the shearing strength was 2.36 ± 0.07 kg/cm^2, and the cooking losses were only 20.19 ± 1.20%. The size of the rib eye characterizes the fleshing of carcass; this indicator was 31.67 ± 0.95 cm^2, which meant a relatively high meat production.

The final stage of the research featured the accumulation of xenobiotics, in particular, mercury.

The high toxicity of mercury depends on the type of compound. Various mercury compounds differ in the way they are absorbed, get involved into metabolic processes, and excreted from the body. Mercury is toxic because it interacts with sulfhydryl proteins. By blocking them, mercury changes their properties or inactivates a number of vital enzymes. As it enters the cell, mercury incorporates into the DNA, which can cause hereditary disorders [31].

The brain exhibits a special affinity for methylmercury: its ability to accumulate mercury is almost six times higher than that of other organs. Inorganic mercury compounds disrupt the metabolism of ascorbic acid, calcium, copper, zinc, and selenium. Organic mercury compounds affect the metabolism of proteins, cysteine, ascorbic acid, tocopherols, iron, copper, manganese, and selenium. It takes mercury compounds 70 days to leave human body. Zinc and especially selenium can protect human organism from mercury compounds. Selenium forms a non-toxic selenomercury complex as a result of demethylation of mercury. Ascorbic acid and copper can lower the toxicity of inorganic mercury compounds, while proteins, cysteine, and tocopherols help against organic mercury compounds. The acceptable weekly intake of mercury cannot exceed 0.3 mg. The acceptable daily intake of mercury is 0.0006 mg per 1 kg of body weight [31, 32].

The UN, WHO, and FAO developed the basic indicators of food hygiene based on toxicological criteria:

MAC is the maximum allowable concentration of contaminants in the air, water, and food from the point of view of safety for human health. Daily exposure to MAC for an arbitrarily long time does not trigger diseases or health problems that can be detected by modern research methods in the life of the present and subsequent generations.

ADI is acceptable daily intake that does not affect human health throughout life (mg/kg).

TDI is the tolerable daily intake calculated as ADI multiplied by the average body weight (60–70 kg) that a person can consume daily throughout life without risk to health [33].

The content of mercury in elk muscle samples was determined in fresh meat samples (control), after two days of storage at 20 ± 2 °C, and on storage days 5, 10, and 15 at –20 ± 2 °C (Table 6).

Mercury concentration in the muscle tissue increased with maturation, even at low temperatures. On storage day 15 at –20 ± 2 °C, it increased by approximately 2.25–2.6 times. At room temperature, the rate of mercury concentration in the muscle tissue doubled.

However, mercury concentrations at different temperatures did not exceed the MAC value of 0.03 mg/kg.

On storage day 15 at low temperatures, several samples were thawed and subjected to frying and boiling to determine the mercury content. Boiling decreased the mercury concentration by 22%. However, boiling does not affect the concentration of xenobiotics in mushrooms. In mushrooms, mercury is bound with amino groups of nitrogen-containing compounds, and in meat – with sulfur-containing amino acids. Frying decreased the mercury concentration by 25%: this value could be improved by subjecting the meat to preliminary grinding.

Conclusion

The present research revealed some useful data on the composition and properties of raw elk meat, such as mercury concentration and its patterns during storage.

The slaughter yield was 51–53%, which is significantly higher than for farm cattle (45–47%). The anatomical composition of elk carcass was as follows: muscle tissue – 73 ± 2%, bones and cartilage – 18 ± 2%, connective tissue – 8 ± 1%, fat tissue – 0.7 ± 1%. The moisture content in the rib eye muscle tissue was 78.14 ± 3.90 g/100 g, which exceeded the average flesh sample by 5.91%. The elk meat proved to have a high protein content of 20–24%, while the protein:fat ratio in the flesh sample was 1:0.07, which classifies the elk meat as a dietary product.

The total level of amino acids was 46.03 ± 1.38 g/100 g of protein, while the total amount of essential amino acids in the rib eye tissue exceeded that of nonessential acids by 23%. The total amount of saturated fatty acids in the rib eye sample was 33.32 ± 0.98%, that of unsaturated fatty acids – 51.83 ± 1.55%.

The mineral composition of elk meat was dominated by potassium (306.33 ± 6.12 mg/100 g), sulfur (196.42 ± 3.95 mg/100 g), and phosphorus (195.02 ± 3.85 mg/100 g).

The water-binding capacity was 73.36 ± 3.50%, while the water-retaining capacity was 59.57 ± 1.78%. The pH of the elk meat varied from 5.8 to 6.2 units; the shearing strength was 2.36 ± 0.07 kg/cm^2. The cooking losses were as low as 20.19 ± 1.20%.

The final set of experiments measured the level of xenobiotics in the elk meat obtained from the biocenosis of the Beloosipovo mercury deposit. The mercury content did not exceed the maximum allowable concentration of 0.03 mg/kg at different temperature conditions. At room temperature storage, the change in the mercury content in muscle tissue was twice as fast as in the frozen samples. Heat treatment decreased the concentration of mercury by 22–25%.

Contribution

All the authors contributed equally to the study and bear equal responsibility for information published in this article.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

References

1. Sergeeva IYu, Rainik VS, Markov AS, Vechtomova EA. Beverage composition for preventive nutrition: theoretical approach. Food Processing: Techniques and Technology. 2019;49(3):356–366. (In Russ.). https://doi.org/10.21603/2074-9414-2019-3-356-366.

2. Kocman D, Horvat M, Kotnik J. Mercury fractionation in contaminated soils from the Idrija mercury mine region. Journal of Environmental Monitoring. 2004;6(8):696–703. https://doi.org/10.1039/b403625e.

3. Zagury GJ, Neculita C-M, Bastien C, Deschênes L. Mercury fractionation, bioavailability, and ecotoxicity in highly contaminated soils from chlor-alkali plants. Environmental Toxicology and Chemistry. 2006;25(4):1138–1147. https://doi.org/10.1897/05-302R.1.

4. Wang D, Shi X, Wei S. Accumulation and transformation of atmospheric mercury in soil. Science of the Total Environment. 2003;304(1–3):209–214. https://doi.org/10.1016/S0048-9697(02)00569-7.

5. Vol′fson FI, Druzhinin AV. Glavneyshie tipy rudnykh mestorozhdeniy [The main types of ore deposits]. Moscow: Nedra; 1975. 391 p. (In Russ.).

6. Laperdina TG. Mercury determination in natural waters. Novosibirsk: Nauka; 2000. 222 p. (In Russ.).

7. Udodenko YuG, Devyatova TA, Gremyachih VA, Komov VT, Tregubov OV. The mercury maintenance in soils of different biotops of the Voronezh reserve. Regional Environmental Issues. 2011;(4):105–110. (In Russ.).

8. Udodenko YuG, Devyatova TA, Komov VT, Tregubov OV, Odintsov AN. Mercury concentration in soil and earthworm (*Oligochaeta, Lumbricidae*) of Voronezh state reserve. Proceedings of Voronezh State University. Series: Chemistry. Biology. Pharmacy. 2012;(2):209–214. (In Russ.).

9. Gladyshev VP, Levitskaya SA, Filippova LM. Analiticheskaya khimiya rtuti [Analytical chemistry of mercury]. Moscow: Nauka; 1974. 228 p. (In Russ.).

10. Swain EB, Jakus PM, Rice G, Lupi F, Maxson PA, Pacyna JM. Socioeconomic consequences of mercury use and pollution. Ambio. 2007;36(1):45–61. https://doi.org/10.1579/0044-7447(2007)36[45:SCOMUA]2.0.CO;2

11. Laperdina TG. Opredelenie form rtuti v ob″ektakh okruzhayushchey sredy [Determination of forms of mercury in environmental objects]. Rtut′. Problemy geokhimii, ehkologii, analitiki: sbornik nauchnykh trudov [Mercury: geochemistry, ecology, and analytics: collection of research papers]. Moscow: IMGREH; 2005. p. 62–97. (In Russ.).

12. Granovskiy EhI, Khasenova SK, Darishcheva AM. Zagryaznenie rtut′yu okruzhayushchey sredy i metody demerkurizatsii [Mercury Contamination and demerculization techniques]. Almaty: Kazgos INTI; 2001. 98 p. (In Russ.).

13. Pacyna EG, Pacyna JM, Steenhuisen F, Wilson S. Global anthropogenic mercury emission inventory for 2000. Atmospheric Environment. 2006;40(22):4048–4063. https://doi.org/10.1016/j.atmosenv.2006.03.041.

14. Ebinghaus R, Tripathi RM, Walischlager D, Lindberg SE. Natural and anthropogenic mercury sources and their impact on the air surface exchange of mercury on regional and global scales. In: Ebinghaus R, Turner RR, de Lacerda LD, Vasiliev O, Salomons W, editors. Mercury contaminated sites. Berlin, Heidelberg: Springer; 1999. pp. 3–50. https://doi.org/10.1007/978-3-662-03754-6_1.

15. Majlesi M, Malekzadeh J, Berizi E, Toori MA. Heavy metal content in farmed rainbow trout in relation to aquaculture area and feed pellets. Foods and Raw Materials. 2019;7(2):329–338. http://doi.org/10.21603/2308-4057-2019-2-329-338.

16. Yudovich YaE, Ketris MP. Mercury in coal as a serious environmental problem. Biosfera. 2009;1(2):237–247. (In Russ.).

17. Bloom N. Determination of picogram levels of methylmercury by aqueous phase methylation, followed by cryogenic gas chromatography with cold vapor atomic fluorescence detection. Canadian Journal of Fisheries and Aquatic Sciences. 1989;46(7):1131–1140. https://doi.org/10.1139/f89-147.

18. Burbacher TM, Rodier PM, Weiss B. Methylmercury developmental neurotoxicity: A comparison of effects in humans and animals. Neurotoxicology and Teratology. 1990;12(3):191–202. https://doi.org/10.1016/0892-0362(90)90091-P.

19. Prosekov AYu. Hydro power plant “Krapivinsky”: current state and possible risks. Bulletin of Kamchatka State Technical University. 2021;(56):54–63. (In Russ.). https://doi.org/10.17217/2079-0333-2021-56-54-63.

20. Stein ED, Cohen Y, Winer AM. Environmental distribution and transformation of mercury compounds. Critical Reviews in Environmental Science and Technology. 1996;26(1):1–43. https://doi.org/10.1080/10643389609388485.

21. Cristol DA, Brasso RL, Condon AM, Fovargue RE, Friedman SL, Hallinger KK, et al. The movement of aquatic mercury through terrestrial food webs. Science. 2008;320(5874):320–335. https://doi.org/10.1126/science.1154082.

22. Alekhina NN, Ponomareva EI, Zharkova IM, Grebenshchikov AV. Assessment of functional properties and safety indicators of amaranth flour grain bread. Food Processing: Techniques and Technology. 2021;51(2):323–332. (In Russ.). https://doi.org/10.21603/2074-9414-2021-2-323-332.

23. Ermakov VV. Biogennaya migratsiya i detoksikatsiya rtuti [Biogenic migration and detoxification of mercury]. Rtut′ v biosfere: ehkologo-geokhimicheskie aspekty: materialy mezhdunarodnogo simpoziuma [Mercury in the biosphere: ecological and geochemical aspects: Proceedings of the international symposium]. Moscow: GEOKHI RAN; 2010. p. 5–12. (In Russ.).

24. Prosekov AYu, Domracheva AI. Characteristics of the level of salinity and hunting resources in the Kemerovo region. AgroEcoInfo. 2021;43(1). (In Russ.). https://doi.org/10.51419/20211116.

25. Prosekov AYu. Effect of forest coverage on the dynamics of elk population in some areas of Kuzbass. Scientific Notes of V.I. Vernadsky Crimean Federal University. Biology. Chemistry. 2020;6(3):163–178. (In Russ.). https://doi.org/10.37279/2413-1725-2020-6-3-163-178.

26. Prosekov AYu, Boyko EV. Interrelation of forest biotopes and ungulates of Kuzbass. Use and Protection of Natural Resources of Russia. 2021;165(1):40–43. (In Russ.).

27. Skalon NV, Stepanov PG, Prosekov AYu. Number dynamics of the moose, wolf, and bear in the Kemerovo region from the second half of the 20th century to the beginning of the 21st century. Herald of Tver State University. Series: Biology and Ecology. 2020;57(1):128–138. (In Russ.). https://doi.org/10.26456/vtbio135.

28. Prosekov AYu, Kagan ES, Meshechkin VV. A predictive model of population dynamics of elk in Kemerovo region. The Herald of Game Management. 2020;17(2):100–106. (In Russ.).

29. Shabrov FA. On using data of state forest inventory while assessing productivity of forest hunting ground lands for nutrition of elk (*Alces alces* L.). Vestnik of Kostroma State University. 2014;20(7):79–81. (In Russ.).

30. Komov VT. Soderzhanie rtuti v organakh i tkanyakh ryb, ptits i mlekopitayushchikh evropeyskoy chasti Rossii [Mercury content in the organs and tissues of fish, birds, and mammals of European Russia]. Rtut′ v biosfere: ehkologo-geokhimicheskie aspekty: Materialy mezhdunarodnogo simpoziuma [Mercury in the biosphere: ecological and geochemical aspects: Proceedings of the international symposium]. Moscow: GEOKHI RAN; 2010. p. 14–18. (In Russ.).

31. Gorbunov AV, Lyapunov SM, Okina OI, Sheshukov VS. Intake assessment of small doses of mercury in the human body with food. Human Ecology. 2017;(10):16–20. (In Russ.). https://doi.org/10.33396/1728-0869-2017-10-16-20.

32. Antonenko VV. Otsenka kontaminatsii pishchevykh produktov, proizvedennykh i potreblyaemykh v Kurskoy oblasti [Assessment of contamination of foods produced and consumed in the Kursk region]. Molodezhnaya nauka i sovremennost′: materialy 85-oy Mezhdunarodnoy nauchnoy konferentsii studentov i molodykh uchenykh, posvyashchennoy 85-letiyu KGMU [Youth Science and Modernity: Proceedings of the 85th International research conference of students and young scientists dedicated to the 85th anniversary of Kursk State Medical University]; 2020; Kursk. Kursk: Kursk State Medical University; 2020. p. 309–312. (In Russ.).

33. Tutel′yan V.A. Novye riski i ugrozy v oblasti obespecheniya bezopasnosti pishchevoy produktsii [New risks and threats in the field of food safety]. Meat Technology. 2021;222(6):6–13. (In Russ.).