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Iodine deficiency as an environmental risk factor for thyroid gland diseases in animals

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Abstract

Among non-infectious diseases in humans and animals, iodine deficiency pathology is a significant problem worldwide due to its high prevalence and broad spectrum of clinical signs and consequences. Increasing anthropogenic pressure on the natural environment has led to an ecological crisis. The situation is complicated in the biogeochemical zones of Ukraine, where insufficient or excessive content of mobile forms of microelements in soils and water sources determines the biological reaction of local flora and fauna. In animals, this is manifested by endemic diseases, including hypothyroidism. Mineral elements, including iodine, are a structural material in the body of animals; they participate in the processes of digestion and absorption in the digestive tract, synthesis, splitting, and excretion of metabolic products, creating the necessary conditions for the normal functioning of enzymes, hormones, vitamins, stabilize acidic-alkaline balance and osmotic pressure. Of all the organs of the endocrine system, the thyroid gland is the most closely related to the environment since its structure and function largely depend on the supply of iodine from the outside. The authors describe in detail the role of synergists of iodine (selenium, iron, copper, zinc, cobalt) and antagonists, the imbalance of trace elements, the influence of ionizing radiation, and the nature of feeding. It is substantiated that the action of environmental elements and anthropogenic factors determines the appearance and risk of developing thyroid pathology in cows. The article presents materials from a complex study of the clinical course of iodine deficiency, as well as morphological and biochemical parameters of the blood of cows. The object of research is clinically healthy and sick animals – cattle. Diagnosis of thyroid pathology was carried out with the help of clinical and laboratory tests. The clinical examination of cows was carried out according to the generally accepted scheme, taking into account the results of the general condition and studies of individual organs and systems. The research was conducted in three districts of the Zhytomyr region (Korostenskyi, Narodytskyi, and Popilnianskyi). During the external examination of the animals, swelling in the intermaxillary space (Myxedema) was observed, which was found only in 5 out of 90 dairy cows (5.6 %), mainly from Narodytsky district (8.9 %), compared to 2.2 % in Korosten district. It was observed that goiter was established in only three cows out of 90 (3.35%); all were in Narodytsky district (6.7 %). Enophthalmos was detected in 24 out of 90 dairy cows (26.7 %), including 16 out of 45 cows (35.4 %) in the Narodytsky District, while this symptom was not detected in the Popilnya District dairy cows. It was established that the content of thyroxine in dairy cows of Narodytskyi and Korostensky districts ranged from 2.2 to 4.25 μg/100 ml (28.3–54.7 nmol/l), respectively, and was on average 3.4 ± 0.21 μg/100 ml (43.8 ± 2.70 nmol/l, in cows from the conditionally clean territory (Popelnyan district) – 5.3 ± 0.65 nmol/l.

Keywords: animal body; metabolism; biological indicators; clinical research; thyroid gland pathology; biochemical and morphological changes.

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1. Introduction

The intensification of modern industrial cattle breeding involves the development of new technologies and a constant increase in the productivity of animals, which ensures a stable growth in production and an increase in the quality of products (Borshch et al., 2020; Bashchenko et al., 2021; 2023). As it is known, this can be achieved only under the conditions of strengthening metabolic processes in the body of cattle. Studying the adaptive potential of animal organisms at an early age to maintain metabolic homeostasis and ensure average growth and development remains an urgent problem (Yaremko & Pelenio, 2016; Heine et al., 2021; Mylostyvyi et al., 2021; 2024). For each organism, its health is essential. The primary condition for maintaining proper condition is the metabolism in his body, and the state of this metabolism is reflected in the analysis of metabolites (Chala et al., 2021; Fedak et al., 2023). First of all, it concerns the

circulatory system, endocrine system, nervous system, humoral regulation, and other systems (Wang et al., 2021; Radzikhovskyi et al., 2022; Prylipko & Koval, 2022). Metabolism of substances and energy is a set of morphological, physical, physiological, and chemical processes of transformation of nutrients and energy in the body, on the one hand, and exchange of these substances and energy between the body and the environment, on the other. This continuous exchange is a fundamental feature of life (Buchko et al., 2019; Kulyaba et al., 2019; Grymak et al., 2020).

Mineral substances are important in physiological processes, the development of pathological conditions, and the formation of the adaptive response of the animal's body (Grushanska et al., 2018). In the environment and the organisms of people and animals, macro-microelements are in a specific ratio. Their value can be defined as the "synergy-antagonism" of biometals. This means some trace elements reduce the negative impact on the body, and some can increase it.

Humanity is forced to consume mineral resources that nature has accumulated for a billion years to meet its vital needs. As a result, there are local disturbances in the dynamic balance of biogeocenoses, and the biological diversity of flora and fauna is impoverished. All this determines the biological reaction of the local flora and fauna in the biogeochemical zones of Ukraine. Biological responses of animal organisms to the action of geochemical factors can be manifested by endemic diseases, particularly trace element diseases (Levchenko et al., 2001; Grushanska, 2018).

The geochemical features of Ukraine's natural regions are also characterized by a reduced content of iodine and an imbalance of microelements in environmental objects, an increased content of heavy metals and pesticides in the soil, and a significant release of toxic substances into the atmospheric air, seas, rivers, and soil, with the subsequent contamination of food products. Many regions of Ukraine are among the unfavorable ones in terms of the prevalence of iodine deficiency diseases (Slivinska & Shcherbaty, 2013; Tkachuk et al., 2021).

In recent years, a significant amount of research has been devoted to studying the influence of trace elements on metabolism and hormones (Tymoshenko et al., 2018). Mineral elements in the body of animals are a structural material; they participate in the processes of digestion and absorption in the digestive tract, synthesis, splitting, and excretion of metabolic products, are included in complexes with proteins, forming specific enzymes, and also serve as components of individual hormones, vitamins, stabilize acid-alkaline balance and osmotic pressure, which regulate metabolism and several other essential functions of the body (Vlizlo et al., 2006; Levchenko & Slivinska, 2010; Slivinska & Shcherbaty, 2013; Slivinska et al., 2020; 2023). The total iodine content in sheep's body is 0.3–0.7 mg per 1 kg of live weight (Klimešová et al., 2021). In addition, as already mentioned, its principal amount (about 60 %) is in the thyroid gland. The connection between iodine and the body's resistance to diseases has been discovered. The consequence of iodine deficiency is thyroid gland hyperplasia (Schlüter et al., 2018). With a constant iodine deficiency in animals, as in humans, an endemic goiter is formed, based on which there is a decrease in the activity of metabolic processes, increased deposition of fat and inhibition of protein synthesis, impaired reproductive capacity, a reduction in the genetic potential of productivity not only in the individual but also in the offspring (Lafta et al., 2023).

In Ukraine, the western Ukrainian regions (Lviv, Ivano-Frankivsk, Zakarpattia, Volyn, Rivne, Ternopil, Chernivtsi) were traditionally classified as iodine-deficient regions. Still, recently, the prevalence of iodine-deficiency diseases has been revealed in the northern regions (Zhytomyr, Kyiv, Sumy, and Chernihiv) and the central region (Vinnytsia, Poltava, Cherkasy, and Khmelnytskyi regions). Iodine deficiency is observed almost throughout Ukraine (Korzun et al., 2018; Kaminsky, 2022).

At the same time, the problem of metabolic disorders is one of the most acute in modern animal husbandry (Ovsiienko, 2019). For the optimal realization of animal productivity's genetic potential, preventing and treating diseases caused by a deficiency or excess of various mineral substances in diets is essential. These diseases decrease productivity and even kill animals. The most common of such diseases is endemic goiter or hypothyroidism, which is caused by iodine deficiency.

Elemental homeostasis is a particular form of the body's general homeostatic system, violations of which affect the body's ability to adapt to extreme conditions. The entire content of essential elements (iodine, cobalt, copper, zinc) is one of the most critical components in the body's normal functioning. Therefore, trace elements' critical role in the animal body's vital activity is beyond doubt.

The fundamental studies of biogeochemical zones and provinces of Ukraine, the study of the specifics of the clinical manifestation and course of trace element diseases in animals, in particular in cattle, and the development of methods of their diagnosis, therapy, and prevention were carried out by well-known Ukrainian scientists (Levchenko et al., 2001).

However, over the past thirty years, significant changes in the mineral composition of soils have occurred in the biogeochemical zones of Ukraine, which is caused by artificial and anthropogenic influences. This caused contamination of the territories with heavy metals, radionuclides, etc. The complicating effect of adverse technogenic factors of the environment, which cause changes in the biogeocenosis in interaction with the natural deficiency of essential (vital) nutrients, contributes to the emergence and spread of pathology of mineral metabolism in farm animals, particularly in lactating cows.

Hypothyroidism is widespread in many countries of the world, including Ukraine. The situation on the territory of Zhytomyr Oblast, where a large part of the soil and water bodies were radioactively contaminated as a result of the accident at the Chornobyl nuclear power plant, is becoming more complicated (Ligomina et al., 2013; Boyko et al., 2017). In-depth scientific research of biogeochemical zones and provinces of Ukraine, the study of the specifics of the clinical manifestation and course of trace element diseases in animals were carried out by well-known Ukrainian scientists (Slivinska et al., 2017).

Therefore, the work aimed to diagnose hypothyroid syndrome in cows, establish the causes and dynamics of endemic pathology in cows, identify patterns of occurrence, and characterize the factors contributing to the spread of the specified pathology.

2. Materials and methods

The research object is clinically healthy and diseased cows with a milk yield of 3.5 to 6.5 thousand kg per lacta-

tion. Clinical studies were conducted in clinically healthy and diseased animals with signs of mineral metabolism disorders according to the generally accepted scheme, with a parallel blood study and analysis of keeping and feeding animals.

Part of the work was performed in the Department of Normal and Pathological Morphology of Hygiene and Expertise. The research was carried out following the State initiative topic: "Biochemical and morphological changes in domestic animals due to metabolic and invasive pathologies – State registration number 0122U200482).

The research was conducted in three districts of the Zhytomyr region: Korostenskyi, Narodytskyi, and Popilnianskyi. It is located in two natural and climatic zones: its northern part is in the Polissya zone, and the southern part is within the Forest Steppe. The forests of the Zhytomyr Region, including the Narodnytskyi and Korostensky districts, belong to the northeastern biogeochemical zone with a low content of iodine, cobalt, copper, manganese, and zinc in soils and plants. The content of mobile forms of copper in the sandy soils of Polissia does not exceed 1.5 mg/kg of air-dry mass. All soils of the region are poor in zinc; 45 % contain less than 0.05 mg/kg of zinc and are classified as critically poor. The soils of experimental farms are critically zinc-poor. In the northern part of the Korosten district, the amount of cobalt in the soil is 1.13 mg/kg; in the soils of the Narodytsky district, cobalt contains 1.6 mg/kg, iodine, respectively, 3.3 and 3.7 mg/kg. The iodine content in water is 1.0–5.38 μg/l, much less than the optimal amount (16–20 μg/l).

The biogeochemical features of the territory of Zhytomyr Oblast have become significantly more complicated due to the introduction of a large amount of lime into the soil: 8–10 t/ha are applied in terms of 100 % calcium carbonate. It is known that calcium is an antagonist of the mobile forms of it, copper and zinc, which negatively affects their assimilation by plants. In addition, the presence of radioactive strontium and cesium in soils and fodder also negatively affects the migration and transformation processes of these elements.

Since the content of mobile forms of microelements in the soils of the Zhytomyr region is low, this contributes to a decrease in their quantity in feed. Thus, a little cobalt, copper, and iodine are contained in forage silage, hay, concentrated fodder, green mass of red clover, forage grass, iodine, and copper – in barley straw.

A clinical study of dairy cows in the districts of Zhytomyr region was conducted. Blood was studied from 90 cows (59, 16 and 15 heads, respectively).

The functional state of the thyroid gland was studied using the thyroxine content, which was determined by the ELISA method using the Triniti Biotech Cahtia T4 test system. Hemoglobin content was determined by the hemoglobin cyanide method, and the melange method determined the total number of erythrocytes. The hemoglobin content in one erythrocyte (HCE) was calculated based on these data. The acid resistance of erythrocytes with subsequent construction of erythrograms was studied according to I. I. Gitelzon and I. A. Terskov in the modification of V. P. Moskalenko.

It is worth noting that research (manipulation) on animals was carried out following the existing regulatory documents that regulate the organization of work using experimental animals and compliance with the principles of the "European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes" (Strasbourg, 1986), "General thematic principles of experiments on animals", approved by the First National Congress on Bioethics (Kyiv, 2001).

Statistical processing of the received digital data was performed using the Microsoft Excel program. Arithmetic mean values (M), mean squared error (m), and correlation coefficient (r) were determined. The probability of differences was assessed with Student's T-test (Horalskyi et al., 2019). The results of the obtained digital data of the investigated indicators were considered reliable at $P < 0.05–0.001$.

3. Results and discussion

A mosaic combination of biogeochemical localities with reduced iodine content in environmental objects and areas with anthropogenic and artificial pollution of the environment with heavy metal ions and substances with thyroid-disruptive and radioactive properties characterizes the territories of Ukraine. All these factors can affect various links of the hypothalamic-pituitary-thyroid axis, which can disrupt the synthesis, secretion, and transportation of thyroid hormones, distort their local effect on target cells, cause functional and organic changes in the gland with subsequent disorders of the entire organism (Tymoshenko et al., 2018; Hejna et al., 2018).

Monitoring the scientific literature allows us to conclude that animals can adapt to the deficiency of some mineral substances. However, if the mineral substances of the feed do not satisfy the minimum needs of the body and the diet does not correspond to the biological characteristics of the animals, then the animals may lose the ability to develop normally, the metabolism is disturbed, and their reproductive capacity decreases (Slivinska et al., 2017). Iodine is one of the main mineral substances necessary for regular animal activity (Tronko & Kravchenko, 2021). Iodine is the only trace element – an anion that determines its ability to influence metabolic processes, vital activity, and differentiation of cells and tissues of the animal body (Kaňa et al., 2015; Sumaiya et al., 2016). The main functions of iodine in the body are related to participation in the regulation of the speed of biochemical reactions, energy exchange, body temperature, induction of increased oxygen consumption by tissues, as well as involvement in the regulation of protein, fat, carbohydrate and water-electrolyte exchanges, regulation of tissue differentiation, growth processes, and development, in particular neuropsychological. In addition, iodine is involved in regulating the metabolism of some vitamins. Iodine deficiency occurs when iodine intake falls below recommended levels. This environmental phenomenon occurs in many parts of the world (Bogdanova et al., 2020; Tkachuk et al., 2021).

Some scientists think that iodine deficiency syndrome (Levchenko et al., 2001; Doletskiy et al., 2012) is manifested mostly by hypofunction of the thyroid gland (hypothyroidism, goiter). It is characterized by insufficient secretion of thyroid hormones by the thyroid gland or cessation of its function (Kononenko & Kravchenko, 2016; Shcherba & Korda, 2018; Lokes-Krupka et al., 2021).

In the northeastern biogeochemical region of Ukraine, the animal disease of iodine deficiency (hypothyroidism) attracts the special attention of scientists. The natural lack of iodine and other biogenic microelements (cobalt, copper, and zinc) changes the functional activity of the thyroid

gland, causes its morphological restructuring, and violates functional and metabolic processes in the animal body.

The thyroid gland (glandula thyreoidea) is one of the most important endocrine glands, the physiological activity of which is necessary for the normal functioning of the human and animal body. In many ways, the thyroid gland is a unique, specific endocrine organ that concentrates iodine and synthesizes thyroid hormones - triiodothyronine and thyroxine, which play a significant role in the regulation of metabolism and energy in the body of humans and animals, as well as in ensuring behavioral adaptive reactions. Lack of iodine, primarily in the biogeocenoses of northeastern Ukraine, is a stable natural factor that generally negatively affects the functional activity of the thyroid gland and contributes to the development of pathological processes. Thyroid pathology attracts the attention of biologists and specialists in veterinary and humane medicine due to its complexity and insufficiently studied pathogenesis, versatility, and significant violations of the functions of many organs and systems of the body. With iodine deficiency, the main pathomorphological changes are localized in the thyroid gland.

During the external examination of the animals, swelling in the intermaxillary space was detected – Myxedema, which was found in only 5 out of 90 dairy cows (5.6 %), mainly from Narodytskyi district (8.9 %), compared to 2.2 % – in Korostenskyi district Myxedema is a typical manifestation of iodine deficiency (Levchenko et al., 2001).

A typical sign of iodine deficiency is an increase in the size of the thyroid gland. A slight increase in it cannot be detected by inspection or palpation, as thick and rough skin makes such research difficult. Therefore, goiter was established only in 3 cows out of 90 (3.35 %); all of them were in Narodytsky district (6.7 %). The increase was bilateral, and the consistency of the gland was dense. Similar symptoms are described in the literature by eminent scientists who made a decisive contribution to studying trace element diseases (Doletskiy et al., 2012; Korzun et al., 2018; Ovsiienko, 2019).

Enophthalmos was detected in 24 out of 90 dairy cows (26.7 %), including 16 out of 45 cows (35.4 %) in the Narodytsky district, and this symptom was not detected in dairy cows in the Popilnya district.

During the cardiovascular system study, bradycardia and a tendency to its development were detected in 52 cows out of 90 (57.8 %). Bradycardia is caused by a relative increase in the tone of the vagus nerve (due to a decrease in sympathetic tone in hypothyroidism), as well as a reduction of the sensitivity of the myocardium to catecholamines (Levchenko et al., 2001). In addition to bradycardia, splitting of the first or second tone, and weakening of the first or both tones, sinus arrhythmia was observed in cows. Among the other symptoms, as a rule, in the zone of the biogeochemical province and radioactive contamination, typical signs of trace element deficiency were found: dryness and decreased elasticity of the skin, alopecia in various areas of the neck and lower back, growth of long coarse hair on the head between the horns and on the withers, the hair cover is dull, tousled. We noted such changes in 80 % of dairy cows from farms in Narodytskyi and Korostenskyi districts and only a third of cows in the Popilnya district. Changes in the hair cover are characteristic of polymicroelement (Iodine, Cobalt, Copper) deficiency.

In 84.4 % of cows of Korostenskyi and 95.5 % of Narodytskyi districts, anemia of the conjunctiva was established: its color was from pale pink to pale and even with a porcelain shade.

The number of erythrocytes in cows from the territory of radioactive contamination was, respectively, 4.6 ± 0.15 ($P < 0.001$) and 4.7 ± 0.14 T/L ($P < 0.001$), compared to 6.4 ± 0.17 T/L in cows of the control group. Oligocythemia was established in 75 % of cows in Korostenskyi and 80 % of Narodytskyi districts.

The average hemoglobin content in the cows of Narodytsky district was 94.8 ± 2.3 ($P < 0.001$), and in Korostensky – 98.7 ± 3.0 g/L ($P < 0.001$), compared to 113.3±1.8 – in Popilnyansk, among dairy cows, this indicator was reduced in – 41.7% of cows from both zones. For a more detailed analysis of the nature of these changes, we calculated the hemoglobin content in one erythrocyte (HCE).

HCE studies showed the development of hyperchromia in 62.5 % of cows in Korostenskyi and 60 % of Narodytskyi districts. In the remaining cows, erythrocytes were normochromic.

With anemia, there is a parallel decrease in the unit of blood volume of hemoglobin, erythrocytes, or both indicators. The analysis shows that anemia was detected in 17 out of 20 (85 %) cows in the Narodytskyi district. 64.7 % of cows have hyperchromic anemia, and 35.3 % have normochromic anemia. 9 out of 17 cows (52.9 %) have oligocythemia and oligochromemia. Anemia in 66.7 % of them is hyperchromic; in the rest, it is normochromic.

Hematopoiesis in sick cows is characterized by pronounced oligochromemia and hyperchromia; they simultaneously observed changes characteristic of endemic goiter and hyperchromic anemia.

From the point of view of bone marrow function, it was also interesting to study the age of erythrocytes. According to the obtained data, it can be seen that in the cows of the Narodytsky district, the share of “young” erythrocytes ranges from 42.5 % to 53.2 % and is, on average, 48.5 ± 1.2 %, while the share of old ones is, likely ($P < 0.05$) higher, compared to cows from other districts (14.8 ± 0.94 %).

Acid hemolysis of blood erythrocytes of cows located in the zone of polymicroelement deficiency and low-intensity radiation differed by more extended cell destruction, a lower and rightward-shifted central peak, compared to blood erythrocytes of cows from the clean zone, which were kept on a balanced diet. The output of the central peak of experimental cows began from the 4th minute, which is 0.5 min. later, its height was 10.8 % less than that of cows in the control group (17.2 % vs. 28.0 %). The erythrocytes of the experimental cows underwent maximum hemolysis in 5.5 minutes, while in the control cows – in 4.5 minutes. Destruction of erythrocytes was noted at the 9th and 7th minutes, respectively. Therefore, the curve of acid resistance (erythrogram) is characterized by a longer left part, which is an indicator of a more significant number of “old” erythrocytes in the blood, a stretched (longer) right part, which characterizes an increased number of more resistant to hemolysis “young” erythrocytes.

The soils and water sources of the northeastern biogeochemical zone of Ukraine are characterized by a natural lack of biogenic iodine and its synergists: cobalt, copper, and zinc (Korzun et al., 2018), which primarily causes the morphological restructuring of the thyroid gland and changes in its functional activity in humans and animals. It should be noted that even when animals are fed a balanced diet in terms of biogenic trace elements, the level of their biological

activity is primarily determined by the ecological state of the environment (Kovalenko et al., 2015).

At the same time, an essential factor in the development of goiter is iodine deficiency in soils and groundwater. According to this indicator, the northern regions of Zhytomyr Oblast belong to the areas where the probability of goiter endemicity is medium and, in some places – high. Thus, the development of this pathology is complicated by the low content of synergists (Cobalt, Copper, Zinc) and the increased content of iodine antagonists – ^{137}Cs, ^{90}Sr, Lead. The imbalance of mobile forms of trace elements in soils is one of the crucial factors in the occurrence and development of endemic hypofunction of the thyroid gland in animals.

Most of the symptoms of pathology in cows described by us are typical for hypothyroidism. It is essential to establish functional changes in the pathology of the thyroid gland, which are determined by the level of triiodothyronine (T_3) and thyroxine (T_4). A significant number of patients tend to develop hypothyroidism of the thyroid gland.

To confirm this diagnosis, we determined the amount of T_4 (thyroxine) in the blood serum of 10 cows from Narodytsky District and six from Korostensky District (Table 1).

Table 1
Thyroxine content in blood serum of cows of experimental and control farms

Region	Biometric indicator	T_4	
		μg/100 ml	nmol/l
Korostensky	Lim	4.1 – 8.0	52.8 – 103.0
	M ± m	5.3 ± 0.65	69.0 ± 8.4
Narodytsky	Lim	2.2 – 4.25	28.3 – 54.7
	M ± m	3.4 ± 0.21	43.8 ± 2.7
	t=	2.86	2.86
	P<	0.05	0.05

It was established that the content of thyroxine in dairy cows ranged from 2.2 to 4.25 μg/100 ml (28.3–54.7 nmol/l), respectively, and was, on average, 3.4 ± 0.21 μg/100 ml (43.8 ± 2.70 nmol/l, in cows from the Popelnyan district (conditionally clean territory) – 5.3 ± 0.65 nmol/l.

If the T4 content of cows from the Popilnya district was more significant than 4 μg/100 ml (>51.6 nmol/l), then among the cows of the Narodytsky district, only one cow (10 %) had thyroxine more than this amount, and cows with a lower thyroxine content 50 nmol/l were 9 (90 %). Therefore, the hypofunction of the thyroid gland was established in the cows of the experimental farm.

4. Conclusions

The cumulative effect of environmental factors, such as a deficiency of iodine synergists and an excess of antagonists, causes iodine deficiency in animals. This is accompanied by a decrease in the functional state of the thyroid gland and the development of hypothyroid syndrome. Clinical examination of cows revealed symptoms typical for iodine deficiency: dryness and hyperkeratosis of the skin, enophthalmos, anemic conjunctiva, bradycardia, enlargement of the thyroid gland, and Myxedema.

Deficiency of iodine synergists (Cobalt, Copper) causes a violation of hematopoiesis and the development of anemia in 85% of cows, which is expressed by oligocythemia and oligochromemia. Anemia is mainly macrocytic and hyperchromic, less often normochromic. Hypofunction of the thyroid gland was found in 90 % of cows: the content of thyroxine was in the range from 28.3 to 54.7 nmol/l and, on average, was 43.8 ± 2.7 nmol/l (3.4 ± 0.21 μg/100 ml).

Prospects for further research will aim at studying the migration of biogenic trace elements and determining their content in animals' bodies. These are the most optimal biological indicators of the mineral imbalance of biogeocenoses.

Prospects for further research. Further research will aim to study the migration of biogenic microelements and determine their content in animals' bodies, which are the most optimal biological indicators of the mineral imbalance of biogeocenoses.

Conflict of interest
The authors declare no conflict of interest.

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