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Breed-specific features of mineral element content in the wool of ewe lambs depending on different natural and climatic zones of their keeping

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The aim of the study was to determine the content of macro- and microelements (Calcium, Magnesium, Iron, Zinc, Copper, Cobalt, Manganese, Cadmium, and Lead) in the wool of ewe lambs of different breeds, grown during the spring–summer–autumn periods and kept in various natural and climatic zones of Ukraine. Wool samples were collected from the area behind the scapula. Mineral elements were determined using an atomic absorption spectrophotometer C-115 PK (Ukraine). No clearly expressed differences indicating breed-specific features of calcium content in the wool of ewe lambs were found. Regarding magnesium, although the amplitude of its content variations among different breeds was quite high (7.3-fold), certain breed-specific traits were observed. Specifically, the highest values were recorded in coarse wool, lower in semi-fine, and the lowest in fine wool. In wool, among all the studied microelements, zinc was found in the highest concentration, though its content showed considerable variability. While no breed-specific features were identified for zinc, zonal differences were observed: the lowest zinc content was found in fine-wool sheep from the Southern Steppe zone, and the highest — in those from the Polissia zone. Among all studied elements, iron proved to be the least variable (a difference of only 2.2-fold). No significant interbreed or zonal differences in its content were identified, which may indicate a sufficient supply of this element in soil and feed. The amount of copper in the wool varied. The highest levels were recorded in wool from OLIBS sheep, and the lowest — in Askanian fine-wool sheep. The average manganese content in wool was 2.95 mg/kg; however, in Karakul sheep (Bukovynian type) it was several times higher, while in Askanian fine-wool sheep it was the lowest. The average lead content was 2.91 mg/kg, with the highest values observed in the wool of Karakul sheep — 4.60 and 3.94 mg/kg, respectively, in the Bukovynian and Askanian prolific types. Cadmium was the least abundant element in sheep wool among all those studied, with an average content of only 0.18 mg/kg. The highest values were found in Karakul sheep (Bukovynian type) — 0.41 mg/kg, and the lowest — in OLIBS sheep — 0.06 mg/kg.

Keywords: sheep, ewe lambs, breed, wool, macroelements, microelements, natural and climatic zones

Introduction

The mineral composition of sheep wool, similar to the hair of other animal species, can be used in research for assessing environmental contamination, evaluating the level and nature of nutrition, and determining the general health status of animals. Hair is a metabolically inert biological material, and the mineral elements incorporated into its structure during the proliferative activity of the hair follicle are firmly bound to protein matrices [3]. Existing data indicate that the mineral content of hair reflects the elemental concentrations within the organism and the state of metabolism, whereas their levels in blood may vary only briefly or not at all [22, 25]. Hair growth occurs continuously during the anagen phase, thus the hair shaft accumulates and retains the full mineral content present during this period. Therefore, some researchers recommend analyzing wool not as an entire staple, but rather for specific growth periods corresponding to consistent dietary intake [25].

Hair is an ideal substrate for biological research, as it is easy to collect from any animal, it does not require special preservation, and can be stored long-term. Compared to blood, urine, or milk, hair is a more effective bioindicator of environmental, soil, and water contamination [13]. As early as 1989, Enne et al. [6] reported high concentrations of toxic metals (Cd, Cu, Pb, Zn) in sheep wool from industrial regions of Italy. Other researchers [11] found significantly elevated levels of Al, Ba, Cd, Co, Fe, Mn, Mo, Pb, S, Ti, and Zn in the wool of sheep raised in areas near copper industries compared to those from ecologically clean regions.

Numerous factors influence wool growth and consequently the accumulation of mineral elements. However, the mineral content of wool primarily depends on the elemental composition of the soil and, therefore, of the feed [20]. The mineral composition of feeds is highly variable and influenced by several factors, including the natural-geographical zones of crop cultivation, soil quality and composition, use of mineral fertilizers, precipitation, vegetation period, genetic traits, and species or varietal characteristics.

According to soil types and climatic features, Ukraine is divided into seven natural zones: Polissia, Forest-Steppe, Northern and Central Steppe, Southern Steppe, Mountainous Crimea, and the Mountainous, Foothill, and Lowland zones of the Carpathians [9]. These zones differ in the mineral composition of soil, water, and feeds. In the western zone (especially mountainous areas), there is a notable deficiency of iodine, while its content in feed is sufficient in the southern and central parts of the country. Southern regions are typically deficient in calcium, zinc, copper, and in some cases selenium. The Forest-Steppe zone is characterized by a lack of cobalt, copper, zinc, and sometimes manganese. Notably, many scientific studies report mineral deficiencies in both soil and feed resources [1, 18].

It is important to note that mineral absorption in sheep depends on numerous factors: feed quality and composition, age, physiological state, sex, and particularly productivity level — especially wool production — as the normal course of wool fiber formation requires not only sufficient energy and structural substrates but also a broad spectrum of mineral elements, which are found in wool in considerable quantities [21, 22].

In a study on the mineral composition of wool, K. H. Burns et al. [4] reported that 1 kg of dry wool matter contains 4.2 g of ash, including: Ca — 2300 mg, Na — 305 mg, Mg — 185 mg, P — 137 mg, Zn — 115 mg, Fe — 60 mg, K — 45 mg, Mn — 25 mg, and Cu — 25 mg. A total of 24 elements have been identified in purified wool samples [10].

Numerous scientific and reference sources indicate that even within individual natural and climatic zones, certain areas exhibit specific mineral characteristics of feeds — so-called biogeochemical provinces. Almost all feed resources in Ukraine are deficient in sulfur, zinc, copper, and manganese, while in the western region, iodine deficiency is also observed [5, 19].

Materials and Methods

The study was conducted on wool samples grown during the pasture season from yearling ewes of various breeds reared in different regions of Ukraine. These included animals from the following natural and climatic zones:

— Southern Steppe: Askanian fine-wool breed, Askanian meat-wool breed (black-headed type), and the Askanian prolific type of Karakul sheep;

— Central Steppe: OLIBS type and Prydniprovska meat breed;

— Forest-Steppe: Kharkiv intrabreed type of the Précoce breed and Sokilska lambskin breed;

— Polissia: French Lacaune and Merinolandschaf breeds;

— Pre-Carpathian (Foothill) zone: Bukovynian type of the Askanian Karakul breed;

— Mountainous zone: Ukrainian Mountain Carpathian breed.

Wool samples were collected by clipping with curved scissors from the skin area behind the shoulder blade. To remove suint, mechanical debris, and feed contaminants, the wool was first washed in a neutral detergent, thoroughly rinsed under running warm water, and then in distilled water. The samples were then air-dried at room temperature, and all remaining impurities were manually removed by fluffing the wool. Organic contaminants were eliminated by rinsing the wool with 96 % ethanol. The prepared samples were dried to constant weight and stored in a desiccator.

Approximately 2 g of wool were mineralized by dry ashing in a muffle furnace at 450 °C. The ash residue was dissolved in a small volume of 3N hydrochloric acid and diluted to 10 ml.

Mineral elements — cobalt (Co), manganese (Mn), copper (Cu), zinc (Zn), iron (Fe), magnesium (Mg), calcium (Ca), cadmium (Cd), and lead (Pb) — were determined using an atomic absorption spectrophotometer C-115 PC (Ukraine).

Experimental data were processed using *Microsoft Excel*. Statistical analysis of the results was performed using arithmetic mean and standard error (M±m), and the confidence interval was assessed for significance (P) using Student's *t*-test. Differences were considered statistically significant at P<0.05 [14].

Results and Discussion

Table 1 presents the maximum and minimum values of mineral element content in the wool of ewe lambs, as well as the range of variation between them. These data complement the interpretation of the observed changes. In particular, the results show that the greatest difference (15.4-fold) pertains to cobalt content. This may indicate uneven cobalt levels in feed across different regions, as well as breed-specific features of its accumulation and potential antagonistic or synergistic interactions. Wide variations were also found for copper, magnesium, cadmium, zinc, and manganese, whereas the smallest differences were observed for iron, lead, and calcium.

An analysis of the data revealed that the average calcium content (table 1) in the wool of ewe lambs of different breeds was 3.31 g/kg.

Table 1. Average, maximum, and minimum concentrations of mineral elements in the wool of ewe lambs of different breeds (M±m, n=4)

Element	Average	Maximum (M±m)	Minimum (M±m)	Difference
Calcium, g/kg	3.31	5.44±0.58	1.69±0.17	3.2
Magnesium, g/kg	0.64	1.61±0.11	0.21±0.01	7.6
Cobalt, mg/kg	1.67	3.24±0.60	0.21±0.01	15.4
Copper, mg/kg	2.68	5.45±0.64	0.85±0.10	6.4
Zinc, mg/kg	70.57	138.6±10.06	20.80±4.42	6.6
Iron, mg/kg	38.77	50.99±1.73	24.73±4.33	2.0
Manganese, mg/kg	2.95	4.00±0.37	0.66±0.03	6.0
Cadmium, mg/kg	0.18	0.41±0.09	0.06±0.002	6.8
Lead, mg/kg	2.91	4.60±0.49	1.75±0.21	2.6

The lowest values were found in the Askanian fine-fleeced breed (1.69 g/kg) and the Précoce breed (1.86 g/kg), while the highest were in the French Lacaune breed (5.44 g/kg) and the Askanian meat-wool breed (black-headed type) (5.00 g/kg).

Therefore, the results suggest no clear pattern that would indicate consistent breed- or region-specific features in calcium content in the wool of ewe lambs, as the lowest and highest values were found in breeds with different types of wool productivity (fine, semi-fine, and coarse wool). This is also supported by the average data grouped by wool type: the highest calcium levels were found in semi-fine wool breeds (4.41 g/kg), while nearly equal levels were observed in fine and coarse wool breeds — 3.14 and 3.10 g/kg, respectively (fig. 2).

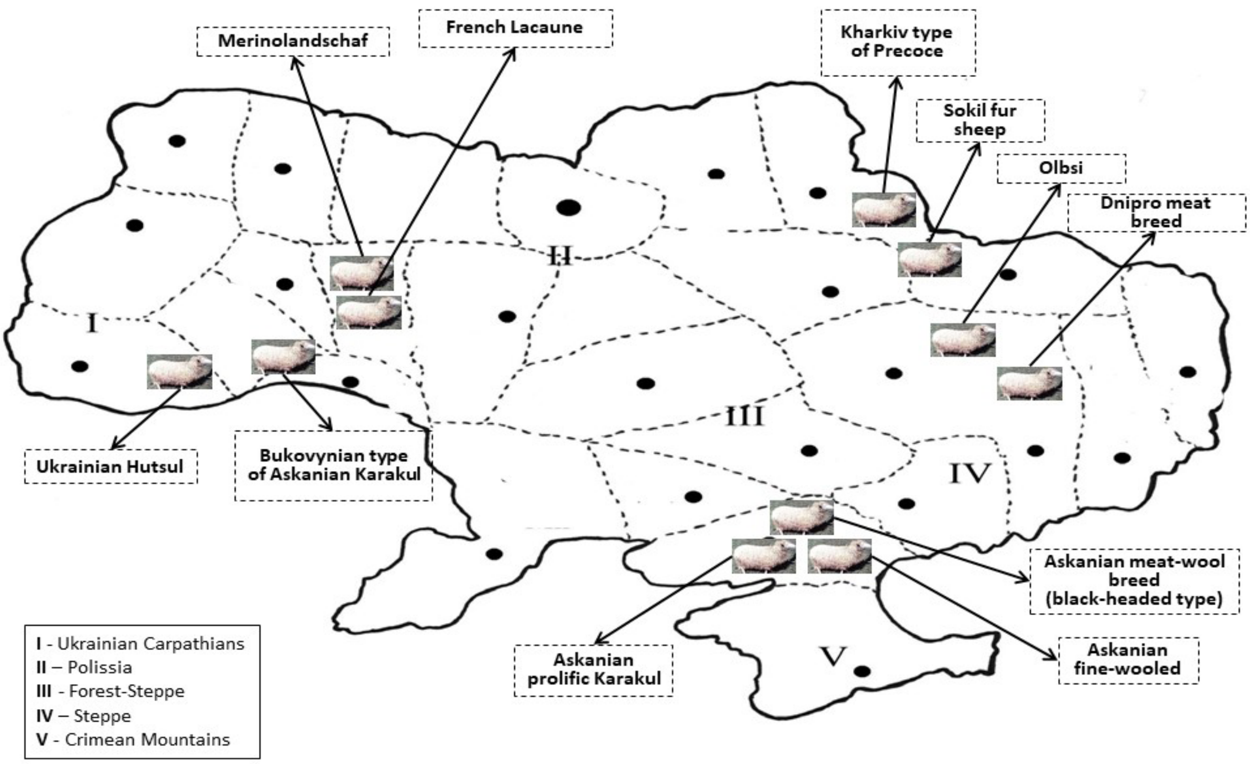

Figure. **Biogeochemical zones of Ukraine**

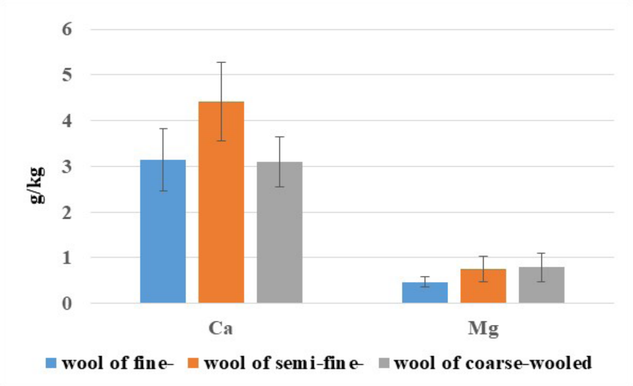

Fig. 2. Average content of Ca and Mg in the wool of fine-, semi-fine-, and coarse-wooled sheep breeds

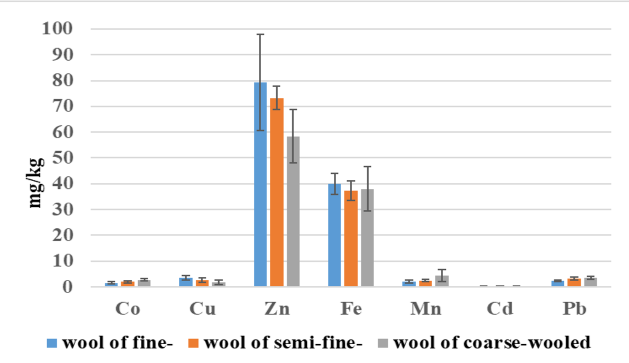

Fig. 3. Average content of trace elements in the wool of fine-wooled, semi-fine-wooled, and coarse-wooled sheep breeds

We believe that the observed differences are primarily related to the nutritional supply of this element, which could vary depending on the natural zone in which the animals were grazed during the pasture season.

Regarding magnesium, its highest concentration was detected in the wool of Karakul sheep (Bukovynian type) — 1.61 g/kg, and the lowest — in the wool of Précoce sheep (0.21 g/kg) (table 2). Despite the relatively large variation in Mg content in the wool of different breeds (7.3-fold), the highest average values were observed in coarse-wooled breeds (0.79 g/kg), and the lowest — in fine-wooled breeds (0.47 g/kg). Thus, in this case, certain breed-specific features in the magnesium content of wool can be noted (fig. 2).

Among the group of studied microelements, except for cadmium and lead, zinc showed the highest concentrations in wool, and cobalt — the lowest. Specifically, the average Zn content was 70.57 mg/kg, while that of Co was only 1.67 mg/kg (table 1). The highest Co content was found in the wool of Karakul sheep (Bukovynian type) — 3.54 mg/kg, and the lowest — in Précoce sheep (0.21 mg/kg). Wool from fine-wooled sheep breeds had the lowest Co levels (1.38 mg/kg), while semi-fine-wooled breeds had the highest (2.66 mg/kg) (tables 2, 3, 4).

Despite this, it is difficult to identify clear breed- or region-specific patterns, as significant differences in the content of this element were found between French Lacaune and Merinolandschaf sheep (0.49 mg/kg vs. 2.41 mg/kg, respectively), which were kept in the same natural and climatic zone. Similar differences were observed between Askanian fine-wooled sheep and OLIBS sheep. Notably, among all the studied macro- and microelements, cobalt showed the greatest variability. The difference between the maximum and minimum levels exceeded 15-fold (table 1).

The zinc content (table 3) in the wool of ewe lambs of the studied breeds varied, with the highest concentration observed in the wool of Précoce sheep (138.6 mg/kg). In contrast, the wool of another fine-wooled breed, the Askanian sheep, had the lowest zinc concentration — 20.9 mg/kg. Low Zn levels were also recorded in the wool of prolific Karakul sheep (27.8 mg/kg) (table 2). It should be noted that these two breeds (Askanian fine-wooled and prolific Karakul) were kept in the same natural and climatic zone of the Southern Steppe, as was the Askanian meat-wool (black-headed type). However, the latter had a considerably higher Zn level (68.70 mg/kg), nearly reaching the average value (70.57 mg/kg) (table 4). The highest Zn concentrations were found in the Polissia and Central Steppe zones, where French Lacaune, Merinolandschaf, OLIBS, and Dnipro meat sheep were raised.

The wool of sheep was also found to contain a relatively high concentration of iron, with an average value of 38.77 mg/kg. The highest Fe levels were observed in the wool of OLIBS sheep (50.99 mg/kg), and the lowest in that of prolific Karakul sheep (24.73 mg/kg) (table 1). Overall, we did not identify any pronounced breed- or region-specific differences in Fe content in wool, which may indicate an optimal iron content in Ukrainian soils, and, consequently, sufficient supply of this element to animals. Data from the same table also show that iron demonstrated the smallest variation between its maximum and minimum values among all the studied mineral elements.

The average copper content in wool was relatively low (2.68 mg/kg), but varied across breeds. The highest Cu levels were recorded in the wool of OLIBS, French Lacaune, and Ukrainian Hutsul sheep-breeds with different productivity types raised in different natural and climatic zones. The lowest concentrations of this element were found in the wool of sheep raised in the Southern Steppe zone (Askanian fine-wooled and prolific Karakul) and the Lowland zone of the Carpathians (Bukovynian type of Askanian Karakul). These findings clearly indicate regional differences in soil copper content and also suggest the potential role of antagonistic or synergistic interactions between elements (tables 2, 3, 4).

Analysis of the manganese content in wool showed that its average level was 2.95 mg/kg. However, this value appears to be elevated due to the extremely high Mn concentration in the wool of Karakul sheep (Bukovynian type) — 11.66 mg/kg, which is not consistent with the values recorded in other breeds. For instance, among the remaining breeds, the highest Mn level was detected in Merinolandschaf sheep (4.00 mg/kg), while the lowest

Table 2. Content of mineral elements in the wool of ewe lambs of coarse-wool breeds from different zones (M±m, n=4)

Element	Askanian prolific Karakul (Southern Steppe)	Bukovynian type of Askanian Karakul (Lowland Carpathians)	Ukrainian Hutsul (Mountain Carpathians)	Sokilska lambskin sheep (Forest-Steppe)
Calcium, g/kg	2.05±0.34	4.20±0.34**	2.24±0.12	3.89±0.53*
Magnesium, g/kg	0.24±0.08	1.61±0.11**	0.37±0.03	0.93±0.02**
Cobalt, mg/kg	2.54±0.23	3.24±0.60	1.84±0.11	1.04±0.24**
Copper, mg/kg	0.85±0.10	0.90±0.08	4.07±0.05**	1.18±0.41
Zinc, mg/kg	27.8±4.42	66.5±3.72**	74.7±2.18**	64.7±2.73**
Iron, mg/kg	24.73±4.33	48.89±1.78*	40.88±7.24	37.42±4.45
Manganese, mg/kg	0.80±0.19	11.66±1.14**	2.49±0.65	2.53±0.59
Cadmium, mg/kg	0.17±0.04	0.41±0.09*	0.17±0.02	0.17±0.04
Lead, mg/kg	3.94±0.73	4.60±0.49	2.60±0.10	2.79±0.31

Note. In this and the next table, P — comparison to the Askanian prolific Karakul type: * — P<0.05; ** — P<0.01; *** — P<0.001.

Table 3. Content of mineral elements in the wool of yearling ewes of fine-wooled breeds from different zones (M±m, n=4)

Element	Askanian fine-wooled (Southern Steppe)	OLIBS (Central Steppe)	Kharkiv type of Précoce (Northern Forest-Steppe)	French Lacaune (Polissia)	Merinolandschaf (Polissia)
Calcium, g/kg	1.69±0.17	2.83±0.27	1.86±0.32	5.44±0.88**	3.89±0.21**
Magnesium, g/kg	0.25±0.03	0.39±0.02	0.21±0.01	0.88±0.08**	0.66±0.13**
Cobalt, mg/kg	2.39±0.13	0.37±0.04**	0.21±0.01**	0.49±0.05**	2.41±0.13
Copper, mg/kg	0.81±0.09	5.45±0.64**	3.87±0.47**	4.33±0.36**	2.95±0.75**
Zinc, mg/kg	20.8±4.42	81.85±4.24**	138.6±10.06**	84.4±7.98**	70.3±2.64**
Iron, mg/kg	26.44±2.68	50.99±1.73**	36.34±4.18	44.75±9.86	41.45±4.15
Manganese, mg/kg	0.66±0.03	2.08±0.07**	1.07±0.11	2.23±0.61**	4.00±0.37**
Cadmium, mg/kg	0.10±0.01	0.06±0.002	0.13±0.03	0.17±0.01*	0.20±0.01**
Lead, mg/kg	2.81±0.23	1.75±0.21	2.24±0.47	2.54±0.20	2.38±0.61

values were recorded in the wool of Askanian fine-wooled sheep (0.66 mg/kg) and prolific Karakul sheep (0.80 mg/kg). Thus, in this case, regional differences in manganese accumulation may be suggested. However, another breed raised in the same zone — Askanian meat-wool sheep (black-headed type) — does not align with this trend, showing a moderate Mn level of 2.83 mg/kg.

When comparing wool types, the highest mean manganese concentration was observed in coarse-wooled breeds (4.37 mg/kg), followed by semi-fine-wooled (2.47 mg/kg) and fine-wooled breeds (2.00 mg/kg). These results may indicate breed-specific characteristics, likely associated with fiber structure (tables 2, 3, 4).

The average lead (Pb) content in the wool of yearling ewes during the grazing period was 2.91 mg/kg. The highest concentrations were recorded in Karakul sheep — 4.60 and 3.94 mg/kg, in the Askanian and Bukovynian types, respectively — as well as in Askanian meat-wool sheep (black-headed type) — 3.68 mg/kg. The lowest Pb content was found in the wool of OLIBS sheep (1.75 mg/kg). These results also suggest breed-specific patterns, as the highest Pb content was observed in coarse-wooled breeds and the lowest in fine-wooled breeds (tables 2, 3, 4; fig. 2).

Among all the studied elements, cadmium (Cd) exhibited the lowest concentration, averaging 0.18 mg/kg. Similar to Pb, the highest Cd levels were found in Karakul ewes (Bukovynian type) (0.41 mg/kg) and Askanian meat-wool sheep (black-headed type) (0.27 mg/kg), which may reflect breed-related metabolic traits for this

Table 4. Content of mineral elements in the wool of yearling ewes of semi-fine-wooled breeds from different zones (M±m, n=4)

Element	Askanian meat-wool breed, black-headed type (Southern Steppe)	Dnipro meat breed (Central Steppe)
Calcium, g/kg	5.00±0.42	3.29±0.49*
Magnesium, g/kg	1.05±0.14	0.50±0.04**
Cobalt, mg/kg	2.41±0.21	1.54±0.12**
Copper, mg/kg	1.71±0.34	3.36±0.86
Zinc, mg/kg	68.7±2.82	77.80±2.62
Iron, mg/kg	41.10±5.23	33.57±0.57
Manganese, mg/kg	2.83±0.74	2.11±0.72
Cadmium, mg/kg	0.27±0.04	0.13±0.02*
Lead, mg/kg	3.68±0.09	2.71±0.22*

Note. * — P<0.05; ** — P<0.01; *** — P<0.001 compared to Askanian meat-wool (black-headed type).

heavy metal. Conversely, low Cd levels were found in Askanian fine-wooled sheep (0.10 mg/kg), with the lowest overall value in OLIBS sheep (0.06 mg/kg). On average, coarse-wooled breeds showed the highest Cd concentrations (0.23 mg/kg).

The results of our study revealed a number of factors that significantly influence the content of macro- and microelements in sheep wool. However, analyzing these factors remains challenging, as there are currently no reliable data on the optimal concentrations of specific mineral elements in sheep wool. Thus, knowing the content of each element may provide insight into the mineral status of the animal's body — whether it is adequate, excessive, or deficient. Nevertheless, interpretation of such results can be problematic and should take into account the biological characteristics of mineral metabolism, as these elements interact not only with each other but also with the organic components of the diet and metabolic processes.

At optimal dietary levels of manganese and iodine, no antagonistic effect between them is observed. However, when manganese intake is high and iodine is low, the accumulation of the latter in the thyroid gland decreases. Iodine increases the content of Mn, Zn, Cu, Ni, and Fe in the body. Antagonists of iodine include calcium, manganese, cobalt, and lead; sulfur acts as an antagonist of silicon, while iodine inhibits fluorine. Interactions between mineral elements may also be disrupted by deficiencies or excesses of vitamins, protein, or fat in the diet [15]. Therefore, it is necessary to consider the specific interactions of nutrients in the feed, taking into account the physiological state, productivity level, and feeding regime of the animals.

We did not observe any clear breed-specific differences in calcium content in the wool of ewe lambs. The differences found likely reflect the variability in dietary calcium intake during the grazing period. This view is supported by other researchers. For instance, Szigeti et al. [25] indicate that calcium content in wool can reflect dietary intake. Other authors have noted a negative correlation between dietary calcium and the phosphorus and zinc content in sheep wool. Concerning calcium, the literature offers contradictory findings, which may be attributed to its role in bone tissue formation. Its direct involvement in wool production is unclear. However, calcium may be involved in the keratinization process during the final stages of keratin synthesis in wool fibers, similar to calcification or mineralization in bones. Accordingly, it has been suggested that the elasticity of wool fibers may depend on their calcium content, with higher calcium levels potentially reducing fiber elasticity [15].

Our research revealed a wide range in magnesium concentrations in the wool of ewe lambs from different breeds, along with certain breed-specific characteristics — particularly lower levels in fine-wooled breeds. Regional differences related to dietary intake were also evident. It is known that spring pasture grasses contain particularly low levels of magnesium, while leguminous plants have much higher concentrations. Thus, magnesium levels in wool may increase several-fold when animals graze on legumes [7]. Therefore, assessing the magnesium status of animals through wool analysis must account for such factors.

Copper is known to be potentially toxic to sheep even when dietary levels are within the normal range (10–11 mg/kg), especially under conditions of molybdenum deficiency [16, 24]. According to Suttle and McMurray [23], a copper concentration of 4.14 mg/kg in wool suggests adequate intake, while values below 2.5 mg/kg indicate deficiency. Based on our data, most regions of Ukraine appear to provide sufficient copper, particularly the Forest-Steppe, Polissia, and the Carpathian Mountain zones. The lowest concentrations of copper in wool were found in sheep kept in the Southern Steppe region — specifically the Askanian fine-wooled and prolific Karakul breeds. A wide range of copper levels in sheep wool has been reported by other authors [2, 13]. Copper directly affects wool growth, keratinization, and fiber pigmentation [8]. Deficiency also leads to disrupted fiber crimp. Copper absorption in the gastrointestinal tract is influenced by Ag, Cd, Zn, Mo, and especially sulfur, all of which reduce its bioavailability. Symptoms of copper deficiency in animals often result from interactions with S, Mo, Ag, and Cd. According to Suttle [23], copper content in wool is a reliable indicator of the animal's copper status, as it reflects the combined effects of all factors influencing its availability.

Some authors [12] report that the normal zinc content in wool ranges between 115–120 mg/kg. Similar values were obtained in our earlier study [8], which investigated the wool of Précoce ewes and their offspring (138–158 mg/kg), where the diet was balanced in terms of this element. Thus, the analysis of our current data shows that zinc levels in the wool of ewe lambs of various breeds, kept in different regions, ranged from 20.9 to 93.4 mg/kg. This indicates a deficiency of this element in the soils of Ukraine, a conclusion consistent with other authors' findings. Particularly low Zn levels (20.9–27.8 mg/kg) were observed in the wool of sheep kept in the Southern Steppe zone — specifically, Askanian fine-wooled sheep and the Askanian prolific Karakul type. However, the wool of Askanian meat-wool crossbred sheep contained several times more zinc (93.4 mg/kg), which may suggest breed-specific differences in Zn absorption. This may also explain the optimal zinc level (138.7 mg/kg) found in the wool of Précoce sheep (Kharkiv intrabreed type), which were kept in the Forest-Steppe zone.

Analyzing the obtained data on the content of individual mineral elements in the wool of sheep of different breeds, kept in various regions, we conclude that the data are ambiguous, as they are influenced by many factors. Nevertheless, some clear patterns can be identified. For example, in the Southern Steppe zone, zinc and copper concentrations are low, whereas cobalt levels are sufficient — an important microelement with a wide range of biological effects. Notably, rumen microorganisms use cobalt to synthesize vitamin B□□, and the requirement for cobalt in ruminants is about 0.1 mg/kg of dry matter. However, we recorded quite low concentrations of this element in the wool of ewe lambs from the Northern Forest-Steppe zone — Précoce (Kharkiv intrabreed type) at 0.21 mg/kg, Sokilska lambskin at 1.04 mg/kg, and OLIBS sheep at 0.34 mg/kg — while several times higher levels were found in the wool of Dnipro meat-type sheep (1.54 mg/kg). It should be noted that OLIBS and Dnipro meat sheep were both kept in the Central Steppe zone.

It is also difficult to interpret the significant differences in cobalt content between the wool of French Lacaune (0.49 mg/kg) and Merinolandschaf sheep (2.41 mg/kg), even though they were kept in the same climatic zone. This may be related to the different productivity types of these breeds: Lacaune being dairy and Merinolandschaf dual-purpose (meat and wool). Other authors have also reported wide variations in cobalt content in wool [13, 24].

Numerous authors have documented a broad range of iron concentrations in wool, which depend on its content in soil and feed [2, 17]. Our study recorded the smallest variation in the wool Fe content compared to other macro- and microelements. From this, we concluded that feeds in the studied regions provide sufficient iron. It is worth noting that iron supplementation in the diet significantly reduces copper availability for sheep.

Regarding manganese, there are limited data in the literature about its wool concentration and role in wool production. It is widely recognized that manganese is a component of many enzymes and that deficiency in sheep leads to disrupted metabolic processes — particularly of carbohydrates, proteins, and minerals — as well as impaired synthesis of certain vitamins, growth retardation, and delayed sexual development in young animals. Our findings revealed a sixfold difference in Mn concentration in wool, with no consistent breed- or region-specific patterns. Therefore, we suggest that there may be different mechanisms of Mn absorption in sheep, influenced not only by dietary content but also by interactions with other elements and overall metabolism.

Cadmium and lead are considered "conditionally essential" elements that occur in trace amounts yet are consistently present in the animal body, including wool. The analyzed data suggest some breed-specific characteristics. For example, the highest lead concentrations were found in the wool of Karakul sheep, which have pigmented fleece. As for Pb, the variation between maximum and minimum values was relatively small (a 2.6-fold difference), whereas for Cd, the difference was wider: the maximum concentration reached 0.429 mg/kg, and the minimum 0.059 mg/kg. Various authors report inconsistent results regarding these heavy metals. For instance, B. Patkowska-Sokoła et al. recorded minimal fluctuations in Pb (2.32–2.59 mg/kg), while others noted a much broader range (0.015–6.94 mg/kg) [13, 24]. Similarly wide variations have been observed for Cd [2, 24]. These results are therefore difficult to interpret unequivocally.

The presented data show that the vast majority of differences are statistically significant ($P<0.05$), indicating that studies of this type must consider both breed characteristics and feeding patterns, which are dependent on the regional conditions of sheep management.

It was established that the wool of ewe lambs of different breeds contains varying amounts of macro- and microelements (Ca, Mg, Co, Cu, Zn, Fe, Mn, Cd, Pb), which is determined by a combination of factors, including breed-specific characteristics related to the production type, as well as the environmental and climatic zones in which the animals are kept—zones that differ in the content of these elements in soil, feed, and water.

Sheep wool is a rather informative biological matrix for assessing the intake of mineral elements into the organism. However, it is important to consider that variations in the content of these elements are influenced by multiple factors, such as breed-related characteristics tied to the type of productivity and the environmental conditions of sheep husbandry. In addition, biological traits of the animals and various interactions between elements — not only among themselves but also with the organic components of the diet and metabolic processes — have a significant impact on the mineral composition of wool fibers.

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Породні особливості вмісту мінеральних елементів у вовні ярок залежно від різних природньо-кліматичних зон їх утримання

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Метою роботи було встановити вміст макро- і мікроелементів (Кальцій, Магній, Ферум, Цинк, Купрум, Кобальт, Манган, Кадмій, Плюмбум) у вовні ярок різних порід, яка виросла у весняно-літньо-осінній періоди за їх утримання в різних природньо-кліматичних зонах України. Зразки вовни відбирали з ділянок шкіри за лопаткою. Мінеральні елементи визначали за допомогою атомно-абсорбційного спектрофотометра С–115 ПК (Україна). Не встановлено чітко виражених різниць, які б вказували на породні особливості вмісту Ca у вовні ярок. Стосовно Mg, то, хоча амплітуда коливань його вмісту у вовні різних порід є досить високою (7,3 рази), однак простежуються породні особливості. Зокрема, найвищі показники притаманні грубій вовні, нижчі – напівтонкій, а найнижчі – тонкій. Серед усіх досліджуваних мікроелементів найбільше у вовни є Zn, проте спостерігаються значні коливання його вмісту. Хоча не виявлено особливостей породного характеру, натомість є зональні особливості. Зокрема, найменше Zn є у вовні тонкорунних овець із зони Південного Степу, а найбільше – із зони Полісся. Серед усіх досліджуваних елементів найменш лабільним виявився Ферум (різниця усього у 2,2 раза). Не встановлено його суттєвих міжпородних чи зональних особливостей, що може свідчити про достатній вміст цього елемента у ґрунті та кормах. У вовні є різна кількість Cu. Найбільше його зафіксовано у олібсів, а найменше – у вовні овець асканійської тонкорунної породи. Середній вміст Mn у вовні становить 2,95 мг/кг, проте у каракульських овець (буковинский тип) його показники вищі у декілька разів, а у асканійських тонкорунних овець – найнижчі. Середній вміст Плюмбуму становить 2,91 мг/кг: найвищі показники характерні для вовни каракульських овець 4,60 та 3,94 мг/кг, відповідно, буковниський і асканійський багатоплідний типи. У вовні овець є найменша кількість Cd, у порівнянні з іншими досліджуваними елементами: його середній вміст всього 0,18 мг/кг. Максимальні показники характерні для каракульських овець (буковинский тип) – 0,41 мг/кг, а мінімальні – для олібсів – 0,06 мг/кг).

Ключові слова: вівці, ярки, порода, вовна, макро- і мікроелементи, природньо-кліматичні зони