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ORIGINAL ARTICLE / ÖZGÜN MAKALE

STUDY OF THE MINERAL ELEMENT CONTENT OF RED OAK (*QUERCUS RUBRA* L.) IN COMPARISON WITH SOIL

KIRMIZI MEŞENİN (QUERCUS RUBRA L.) MİNERAL ELEMENT İÇERİĞİNİN TOPRAK İLE KARŞILAŞTIRILMASI

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ABSTRACT

Objective: *The purpose of the present work was to to determine the content of mineral elements in annual shoots with leaves and in the fruits of wild individuals of red oak (Quercus rubra L.) from two different places of growth in comparison with their content in the soil under the plants.*
Material and Method: *The annual shoots with leaves of red oak with soil samples under plants were collected in August 2022 and fruits collected in September 2022 in Ukraine in the mixed forests near Tynne village (Rivne Oblast) and near Lisnyky village (Kyiv Oblast). The research was carried out by the X-ray fluorescence method on the "ElvaX-med" energy dispersive spectrometer.*
Result and Discussion: *As a result of the study, both types of raw materials of Quercus rubra (annual shoots with leaves and fruits) revealed the presence of 4 macro- (S, Cl, K, Ca), 8 micro- (Mn, Fe, Cu, Zn, Br, Rb, Sr, Pb) and 4 ultramicroelements (Cr, Co, Ni, Zr). It was determined that red oak plants are concentrators of potassium and sulfur from the soil (which is indicated by the high content of these macroelements both in the soil under the plants and in all studied raw materials). A high content of calcium in the raw material of red oak from both locations was noted, and this content is apparently characteristic of the plant itself, regardless of the soil on which it grows.*
Keywords: *Calcium, macroelements, microelements, potassium, red oak, sulfur, Quercus rubra, ultramicroelements, X-ray fluorescence method*

ÖZ

Amaç: *Bu çalışmanın amacı, kırmızı meşe (Quercus rubra L.) yabani bitkilerinin yıllık sürgünlerinde ve meyvelerinde mineral element içeriğini belirlemek ve bu içeriği bitkilerin altındaki toprakla karşılaştırmak olarak belirlenmiştir.*
Gereç ve Yöntem: *Kırmızı meşenin yıllık sürgünleri ile bitkilerin altındaki toprak örnekleri 2022 Ağustos'unda Ukrayna'da Tynne köyü (Rivne Oblast) ve Lisnyky köyü (Kyiv Oblast) yakınlarındaki karışık ormanlarda toplanmıştır. Araştırma, "ElvaX-med" enerji dispersif spektrometre üzerinde X-ışını floresans yöntemiyle gerçekleştirilmiştir.*
Sonuç ve Tartışma: *Çalışmanın sonucunda, Quercus rubra'nın (yıllık sürgünler ve meyveler) her iki tip ham maddesinde 4 makro- (S, Cl, K, Ca), 8 mikro- (Mn, Fe, Cu, Zn, Br, Rb, Sr, Pb) ve 4 ultramikroelementin (Cr, Co, Ni, Zr) varlığı ortaya çıkmıştır. Kırmızı meşe bitkilerinin topraktan*

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potasyum ve kükürtü yoğunlaştırdığı belirlenmiştir (bitkilerin altındaki toprakta ve incelenen tüm ham maddelerde bu makroelementlerin yüksek içeriği ile gösterilmektedir). Her iki bölgeden gelen kırmızı meşe ham maddesinde yüksek kalsiyum içeriği belirlenmiş ve bu içeriğin bitkinin kendine özgü olduğu, büyüdüğü topraktan bağımsız olduğu görülmüştür.
Anahtar Kelimeler: *Kalsiyum, makroelementler, mikroelementler, potasyum, kırmızı meşe, kükürt, Quercus rubra, ultramikroelementler, X-ışını floresans metodu*

INTRODUCTION

Mineral elements are compounds necessary for human metabolism. They are involved in the construction of organs, tissues, cells and their components, the maintenance of ionic balance in cells, the regulation of the activity of many enzymes and are part of hormones, vitamins, pigments and often determine their chemical and biological activity [1].

Medicinal plants, which are able to accumulate a significant amount of necessary mineral elements, can be used for the prevention and comprehensive treatment of many diseases that arise due to the imbalance of micro- and macroelements in the human body [2,3].

It should be noted that the content of mineral substances in plants can vary depending on the composition of the soil, climatic conditions and other factors [4], that's why it is advisable to study the elemental composition of medicinal plants in combination with the study of the elemental composition of the soil.

Red oak (*Quercus rubra* L., Fagaceae) is an invasive plant brought to Europe from North America [5], which has acclimatized well in the territory of Ukraine, is resistant to diseases and actively invades new territories, displacing the official medicinal species, common oak, from natural habitats, therefore, its raw material base is constantly growing. The raw material of red oak is used in traditional medicine for colds and viral diseases, to increase immunity and as an astringent, and is of scientific interest for pharmacognostic study with the aim of expanding the spectrum of use of *Quercus* L. species in official medicine, as well as the further development of new medicines based on it [6].

MATERIAL AND METHOD

Sample Collection

The annual shoots with leaves of red oak with soil samples under plants were collected in August 2022 and fruits of red oak collected in September 2022 in Ukraine in the mixed forests near Tynne village (Rivne Oblast) and near Lisnyky village (Kyiv Oblast).

Analytic Equipment

The study of the qualitative composition and quantitative content of mineral elements was carried out by the X-ray fluorescence method on the energy dispersive spectrometer "ElvaX-med" (Elvatech Ltd., Ukraine) in the Scientific and Technical centre "Viria Ltd." (Kyiv, Ukraine).

Method for the Assay of Mineral Elements

The method includes the following steps: to 50 mg of raw materials crushed to a powdery state, a binding organic compound without metal admixture was added. The mixture was dried, and a tablet with a diameter of 10 mm, a thickness of no more than 2 mm and a weight of 50 mg was made from this mass. The resulting tablet was analyzed on the device for 10 minutes. The fluorescence spectrum consists of a number of analytical lines. Each line corresponds to the energy of fluorescent radiation characteristic of the atoms of this element. Since the energy dispersive measurement method is used in the analyzer, the lines of all atomic elements in the sample are present in the resulting spectrum. The energy range is from 1 to 40 KeV. This corresponds to the range determination of elements from Na to U. The intensity of the spectral lines depends on the concentrations of the determined elements.

The composition of clean filter paper (State Standard GOST 12026-76) was previously measured and its spectrum was taken as background. The spectrum of the difference between the spectra of the working sample and the background spectrum was used for the calculation.

The mass fraction of the element was calculated according to the calibration characteristics of the analyzer. Calibration of the analyzer for determiniung the mass fraction of an individual element was carried out using standard solutions of metal ions according to State Standard Samples of Solutions of Ukraine (1.0 mg/dm^3; State Standard Samples of Ukraine DSZU 022.86-98), which are used for calibration, attestation and verification of analytical devices: photocolorimeters, spectrophotometers, atomic absorption spectrophotometers, etc.

The sensitivity threshold of the method, when evaporating 50 ml of water, for most elements is 0.01 µg/l (10-5 ppm) [7].

The result was taken as the average arithmetic value of five consecutive measurements, the statistical processing of the obtained results was carried out using the Student's test to determine the standard deviation at the significance level of 95% according to the monograph of the State Pharmacopoeia of Ukraine (SPhU) "5.3.N.1. Statistical analysis of the results of a chemical experiment".

RESULT AND DISCUSSION

According to the results of the investigation in samples of red oak raw materials collected in a mixed forest near the village of Lisnyky village (Kyiv Oblast) 10 mineral elements in fruits and 11 mineral elements in annual shoots with leaves were identified. 20 mineral elements were found in the soil under the plant. In samples of *Q. rubra* raw materials collected in a mixed forest near Tynne village (Rivne Oblast) 16 mineral elements were identified in fruits and 11 mineral elements in annual shoots with leaves. 20 mineral elements were found in the soil samples collected under investigated plants from two locations.

Spectrograms of the content of mineral elements are presented in Figure 1–6 and the results are in Table 1-2 and Figure 7.

Table 1. The content of mineral elements in the raw material of *Q. rubra* in comparison with the soil (Lisnyky, Kyiv Oblast), µg/g

Element (Tested sample)			Fruits	Annual shoots with leaves	Soil under the plant
Mineral substances	Macro	S	1187.41±39.18 * 3.3**	1691.32±67.65 z3.9	4846.20±193.84 2.8
		Cl	-	-	444.91±19.57 4.3
		K	3174.00±136.48 4.2	2320.66±95.14 4.0	3678.74±172.90 4.6
		Ca	788.32±30.74 3.8	2155.11±103.44 4.7	795.78±29.44 3.6
	Micro (trace)	Mn	8.21±0.40 4.8	315.15±13.55 4.2	919.44±28.50 3.0
		Fe	25.62±1.02 3.9	71.46±2.35 3.2	6139.06±251.70 4.0
		Cu	2.51±0.11 4.3	-	6.12±0.24 3.9
		Zn	4.95±0.14 2.8	15.94± 0.62 3.8	24.23±1.13 4.6
		Br	-	-	4.87±0.18 3.6
		Rb	16.16±0.64 3.9	2.81±0.08 2.8	18.91±0.92 4.8
		Sr	1.87±0.09 4.8	5.42±0.22 4.0	14.40±0.56 3.8
		Pb	-	-	13.21±0.64 4,8

Table 1 (*continue*). The content of mineral elements in the raw material of *Q. rubra* in comparison with the soil (Lisnyky, Kyiv Oblast), µg/g

Element \ Tested sample			Fruits	Annual shoots with leaves	Soil under the plant
	Ultramicro	Ti	-	-	1488.40±43.16 2,8
	Ultramicro	Cr	-	2.85±0.11 3.8	28.95± 0.89 3.0
	Ultramicro	Co	-	4.56±0.20 4.3	290.34±8.71 2.9
	Ultramicro	Ni	4.49±0.20 4.4	3.09±0.10 3.2	30.93±1.54 4.9
	Ultramicro	Zr	-	-	158.44±4.75 2.9
	Ultramicro	Sn	-	-	214.82±7.30 3.4
	Ultramicro	W	-	-	29.11±1.07 3.6
	Ultramicro	Ba	-	-	865.05±40.65 4.6

Note: "-" – chemical element wasn't detected;

The obtained results are presented in the form: $\frac{\overline{X} \pm \sigma\overline{X}}{cv}$,where:

* $\overline{X}$ – arithmetic mean; $\sigma\overline{X}$ (MSE) – the mean squared error;

** cv – coefficient of variation;

$p < 0.05$

Table 2. The content of mineral elements in the raw material of *Q. rubra* in comparison with the soil under investigated plants (Tynne, Rivne Oblast), µg/g

Element \ Tested sample			Fruits	Annual shoots with leaves	Soil under the plant
Mineral substances	Macro	S	1390.89±69.54 * 4.9**	4132.47± 198,35 4.7	5709.82±235.15 4.1
Mineral substances	Macro	Cl	76.27±2.36 3.1	-	1056.94±52.85 5.0
Mineral substances	Macro	K	3475.87±142.51 4.1	2498.99±97.46 3.8	5724.41±234.70 4.0
Mineral substances	Macro	Ca	590.50±27.75 4.6	3063.76± 107.23 3.4	6088.35±280.06 4.5
Mineral substances	Micro (trace)	Mn	3.38±0.14 4.1	41.88± 2.09 4.9	326.92±11.44 3.4
Mineral substances	Micro (trace)	Fe	13.87±0.44 3.1	40.80± 1.67 4.0	5632.21±259.08 4.6
Mineral substances	Micro (trace)	Cu	2.67±0.10 3.7	1.46± 0.04 2.7	10.20±0.38 3.7
Mineral substances	Micro (trace)	Zn	6.50±0.2 3.0	12.04± 0.38 3.1	37.09±1.07 2.8
Mineral substances	Micro (trace)	Br	0.36±0.016 4.4	-	6.07± 0.22 3.6
Mineral substances	Micro (trace)	Rb	24.01±1.05 4.3	5.69± 0.21 3.6	8.61± 0.35 4.0
Mineral substances	Micro (trace)	Sr	2.28±0.10 4.3	6.90± 0.31 4.4	15.57±0.45 2.8
Mineral substances	Micro (trace)	Pb	0.13±0.004 3.0	-	14.58±0.65 4.4

Table 2 (*continue*). The content of mineral elements in the raw material of *Q. rubra* in comparison with the soil under investigated plants (Tynne, Rivne Oblast), µg/g

Element \ Tested sample			Fruits	Annual shoots with leaves	Soil under the plant
	Ultramicro	**Ti**	-	-	1228.09± 40.52 3.2
		Cr	0.97±0.036 3.7	1.65± 0.04 2.4	43.49± 1.91 4.39
		Co	0.38±0.015 3.9	-	221.88±7.98 3.5
		Ni	0.29±0.009 3.1	1.92± 0.07 3.6	49.08±1.57 3.1
		Zr	0.10±0.002 2.0	-	64.28±1.99 3.0
		Sn	-	-	223.35±10.05 4.4
		Y	-	-	7.22±0.34 4.7
		Ba	-	-	1220.81±40.28 3.2

Note: The explanations of symbols in Table 1

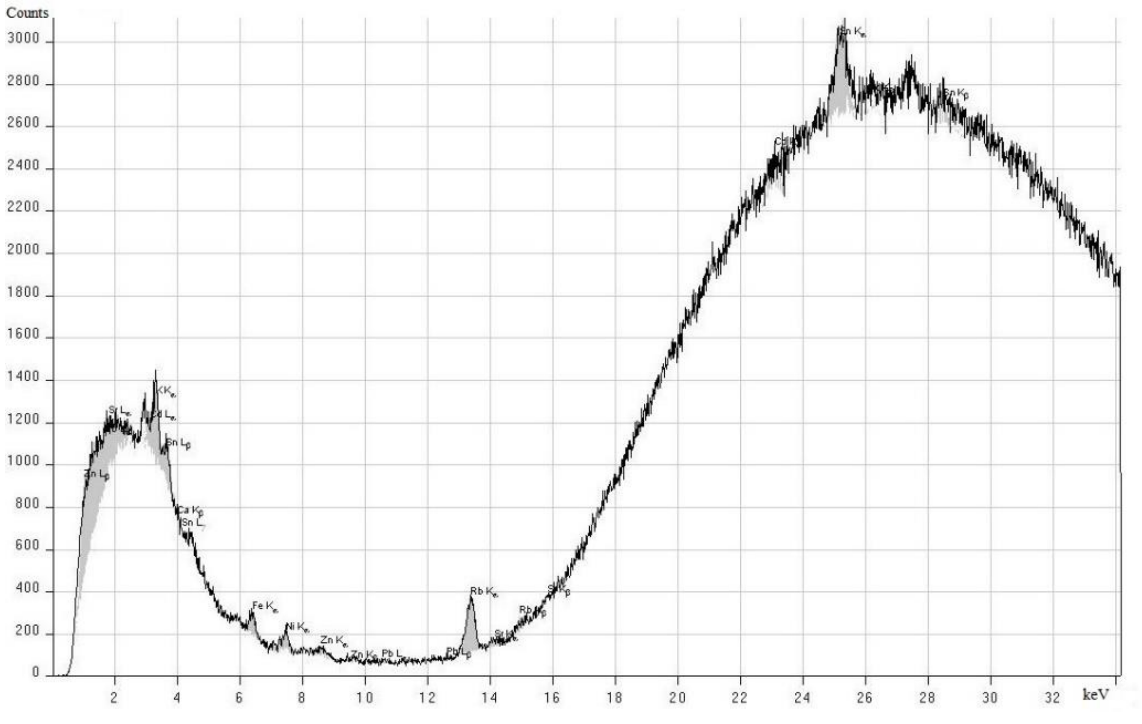

Figure 1. Spectrogram of the content of mineral elements in *Q. rubra* fruits (Lisnyky, Kyiv Oblast)

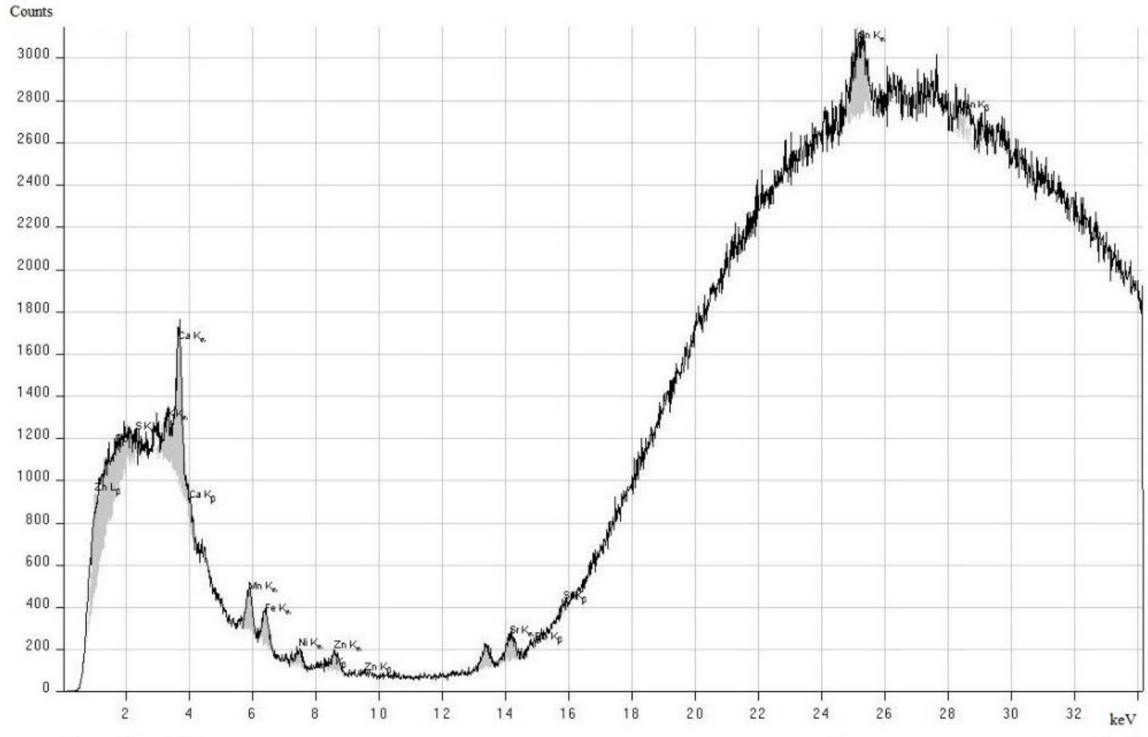

Figure 2. Spectrogram of the content of mineral elements in *Q. rubra* annual shoots with leaves (Lisnyky, Kyiv Oblast)

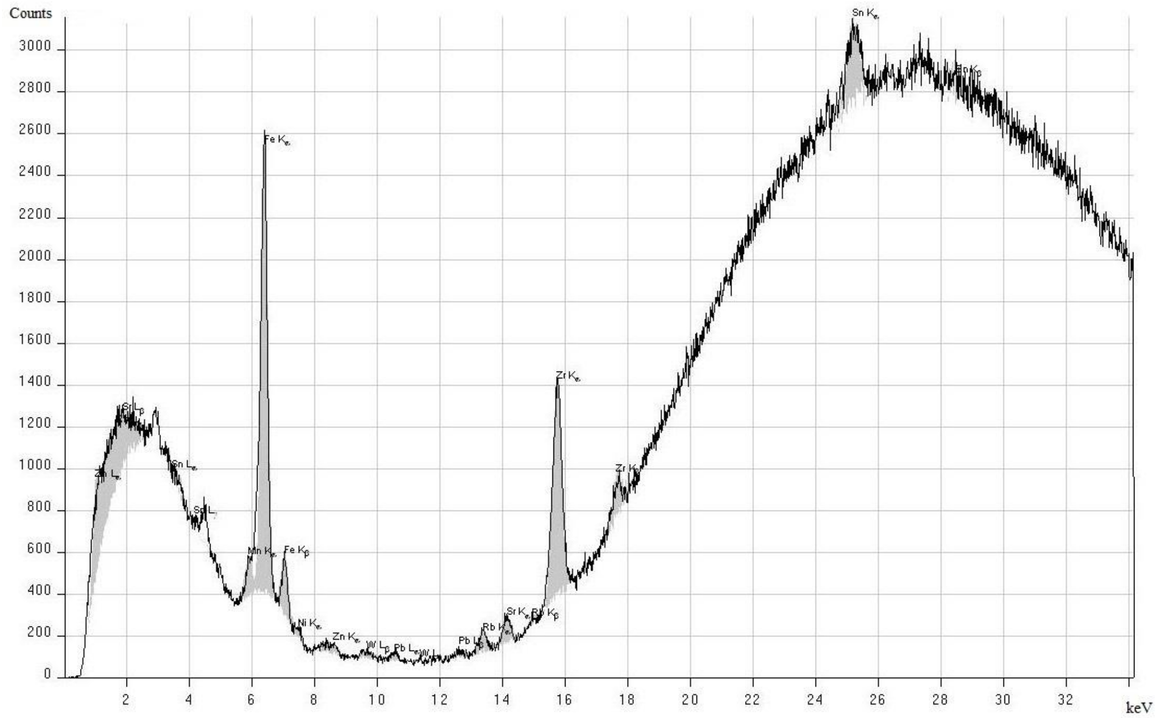

Figure 3. Spectrogram of the content of mineral elements in the soil under *Q. rubra* plants (Lisnyky, Kyiv Oblast)

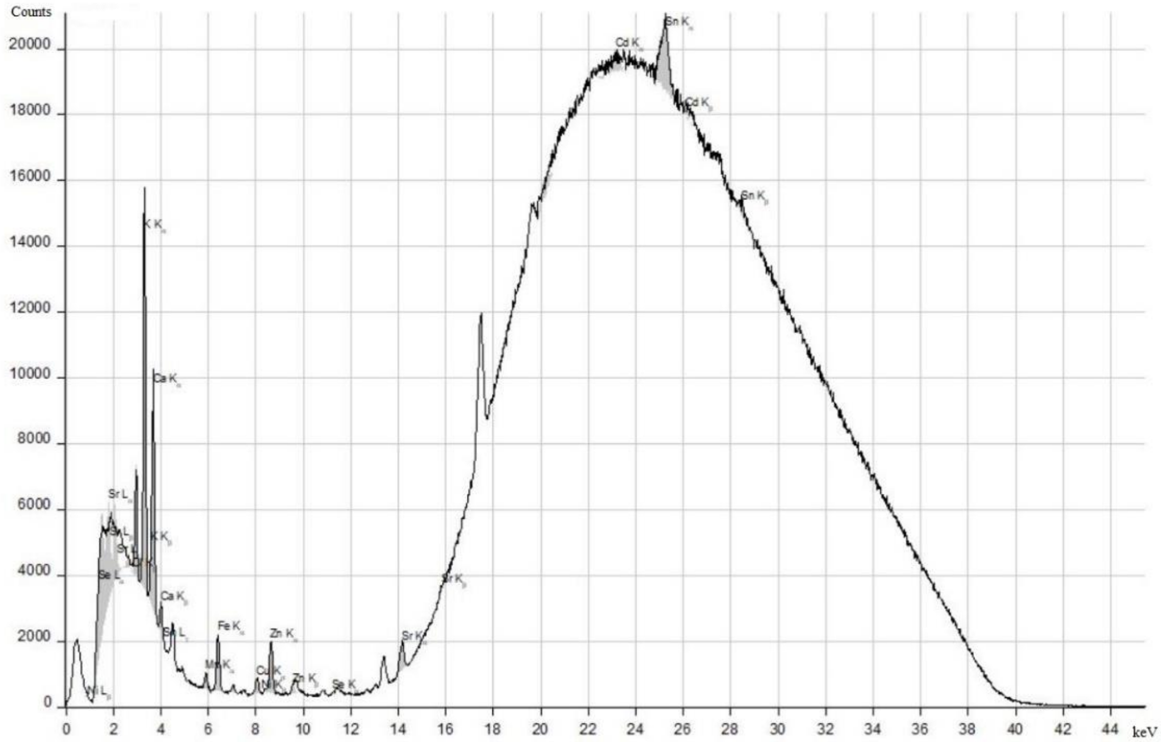

Figure 4. Spectrogram of the content of mineral elements in *Q. rubra* fruits (Tynne, Rivne Oblast)

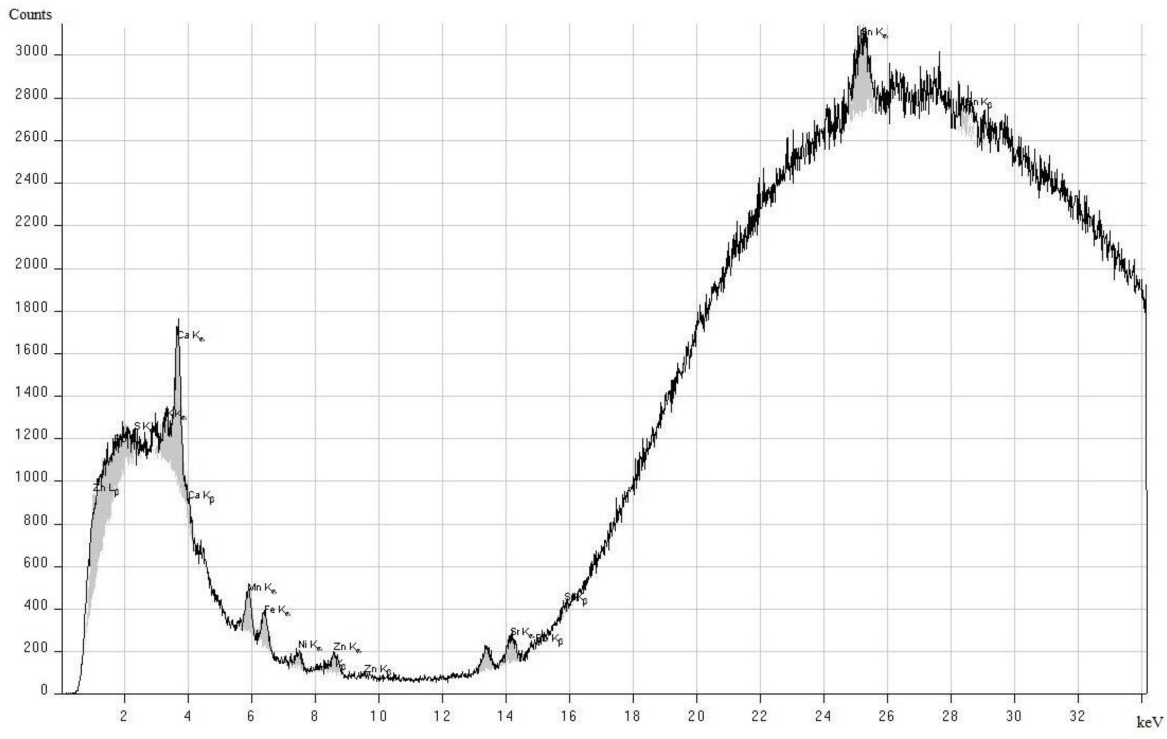

Figure 5. Spectrogram of the content of mineral elements in *Q. rubra* annual shoots with leaves (Tynne, Rivne Oblast)

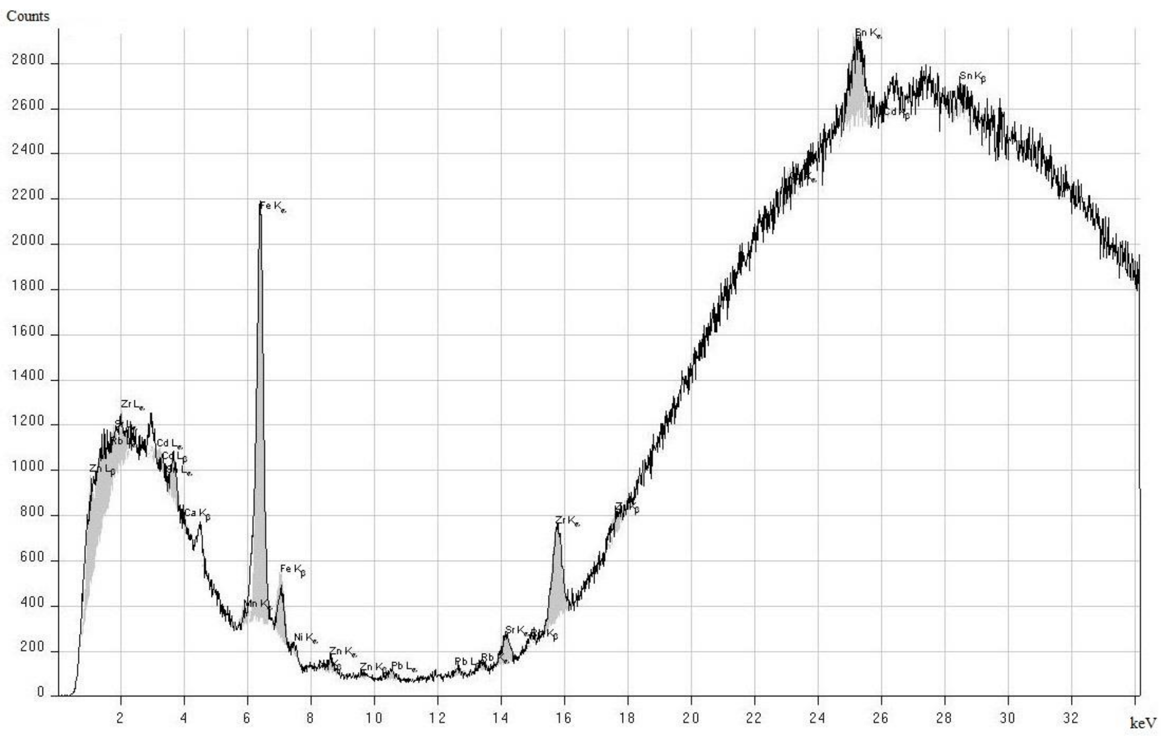

Figure 6. Spectrogram of the content of mineral elements in the soil under *Q. rubra* plants (Tynne, Rivne Oblast)

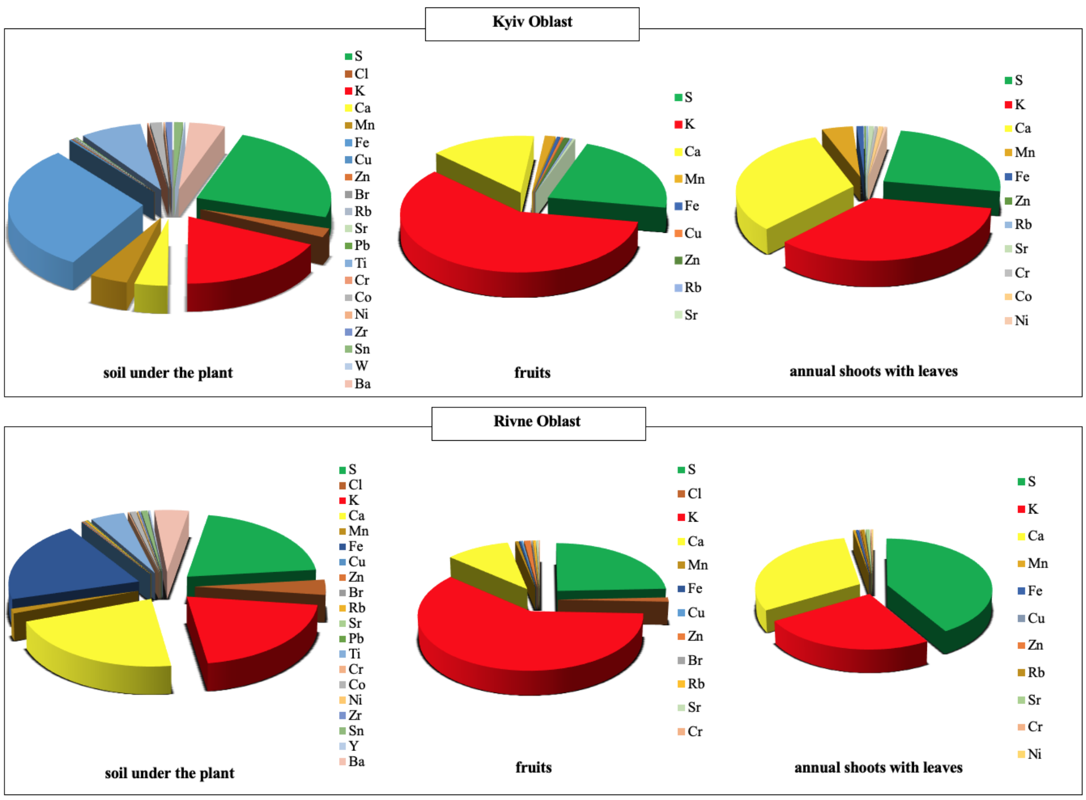

Figure 7. Comparative diagrams of the content of mineral elements in the soil under the plants and in the raw materials of *Q. rubra* collected in Kyiv and Rivne Oblasts

Among the macronutrients in the raw material of annual shoots with leaves, potassium and calcium dominate, the content of sulfur is somewhat lower; the macroelement composition is dominated by manganese, the content of ferrum is significantly lower (by 4.4 times) and zinc is even lower (by 19.7 times), strontium and rubidium are present in small amounts; cobalt, nickel and chromium were found among ultramicroelements.

Potassium dominates among macronutrients in fruits, the content of which is 4 times greater than calcium, and 2.6 times greater than sulfur; the microelement composition is dominated by ferrum, the content of rubidium is somewhat lower, and manganese, zinc, copper, and strontium are present in small amounts; nickel was found among the ultramicroelements.

The high content of potassium in the soil (3678.74 μg/g) correlates with the high content in fruits (3174.00 μg/g) and annual shoots with leaves (2320.66 μg/g); the same regularity can be noted for sulfur. At the same time, the significant content of calcium in annual shoots with leaves is apparently characteristic of the plant itself, determined genetically, since the calcium content in the soil under the red oak plants growing in Kyiv Oblast is not high enough.

The fact that a fairly high content of iron in the soil does not lead to a significant accumulation of this trace element in the raw material of red oak is noteworthy. The same applies to titanium, barium, and stanium, which are not detected at all in red oak raw materials, despite their significant content in the soil.

At the same time, the low content of some macroelements in the soil (Cu, Br) can be associated with the insignificant content or the complete absence of these elements in the raw materials.

In general, the total content of mineral elements (μg/g) was the highest in annual shoots with leaves – 6588.37, of which: 6167.09 – macroelements, 410.78 – microelements, and 10.5 – ultramicroelements; it is somewhat smaller in fruits – 5213.54, of which: 5149.73 – macroelements, 59.32 – microelements and 4.49 – ultramicroelements.

For all research objects, the following series of element accumulation can be identified according to the decrease in their content: for fruits – macroelements: K > S > Ca; macroelements: Fe > Rb > Mn > Zn > Cu > Sr; for annual shoots with leaves – macroelements: K > Ca > S, microelements: Mn > Fe > Zn > Sr.

In the mineral composition of red oak annua shoots with leaves collected in Kyiv Oblast, potassium is 35%, sulfur – 26%, calcium –33%, manganese – 5%, and 1% of the total amount is ferrum, the content of other mineral elements is lower than 1% (Figure 7).

In the mineral composition of fruits collected in Kyiv Oblast, the content of potassium is 61%, sulfur – 23%, calcium – 15%, and the content of other mineral elements is less than 1% (Figure 7).

As can be seen from the data in Table 2, the raw material of *Q. rubra* collected in Rivne Oblast is characterized by a high content of sulfur, potassium and calcium. Among microelements, annual shoots with leaves are dominated by manganese and ferrum, and in fruits – rubidium, the content of which is 1.4 times higher than in raw materials collected in Kyiv Oblast. Chromium, cobalt, nickel, and zirconium are among the ultramicroelements in the fruits (chromium and nickel are also present in annual shoots with leaves).

Among the macronutrients in the fruits, potassium dominates, the content of sulfur is less (by 2.5 times) and calcium is much less (by 5.8 times); among microelements, rubidium significantly predominates, the content of ferrum is somewhat lower, other microelements are present in red oak fruits in small quantities; the content of ultramicroelements (Cr, Co, Ni, Zr) in fruits is less than one μg/g.

Among the macroelements in the raw material of annual shoots with leaves, a high content of sulfur and calcium is observed, the content of potassium is slightly lower; the microelement composition is characterized by a high content of manganese and iron, the content of which is 3 times greater than the content of other trace elements present in this raw material; the ultra-microelement composition is represented by chromium and nickel.

The high content of sulfur in the soil (5709.82 μg/g) correlates with the high content in annual shoots with leaves (4132.47 μg/g). Among the macronutrients in fruits, potassium prevails (3475.87 μg/g), the content of which in the soil is also significant (5724.41 μg/g). The content of ultramicroelements in the soil significantly exceeds their content in raw materials. Titanium and barium, which are present in significant quantities in the soil, are completely absent in the red oak raw materials collected in Rivne Oblast.

The total content of mineral elements (μg/g) in the raw material of red oak collected in Rivne Oblast was the highest in annual shoots with leaves – 9807.56, of which: 9695.22 – the content of macroelements, 108.77 – microelements, and 3.57 – ultramicroelements; it is somewhat smaller in fruits – 5588.47, of which 5533.53 – the content of macroelements, 53.2 – microelements, and 1.74 – ultramicroelements.

Based on the results of the analysis, a series of accumulation of elements was identified for all objects according to the decrease in their content: for fruits – macroelements: K > S > Ca > Cl; microelements: Rb > Fe> Zn > Mn > Cu > Sr > Br > Pb; for annual shoots with leaves – macroelements: S > Ca > K, microelements: Mn > Fe > Zn > Sr > Rb > Cu.

According to the results of the study of the content of mineral elements in the fruits and annual shoots with leaves of *Q. rubra* wild plants collected from different places of growth in comparison with their content in the soil under investigated plants (Tables 1–2), different regularities of the accumulation of mineral elements in raw materials of red oak in Kyiv and Rivne Oblasts.

The raw material collected in Rivne and Kyiv Oblasts is characterized by a high content of K, S, Ca, Mn, and Fe. In general, the composition of mineral elements in the studied raw material of red oak from the both investigated locations is similar, some differences (for example, the presence of bromine, cobalt and zirconium in the fruits of red oak growing in Rivne Oblast) are obviously related to the peculiarities of the mineral composition of the soil where studied plants grow.

The composition of the soil under investigated plants in both Rivne and Kyiv Oblast is slightly different, in particular, the total quantitative content of mineral elements in the soil in Kyiv Oblast is 9765.63 μg/g, and the soil under the plant in Rivne Oblast – 18579.52 μg/g, which also affects the mineral composition of red oak plants growing on this soil. In particular, based on the obtained results, it can be assumed that red oak plants are concentrators of potassium and sulfur from the soil (this is indicated by the high content of these macroelements both in the soil under the plants and in all studied raw materials).

A high content of calcium in the raw material of red oak from both locations was noted, and this content is apparently characteristic of the plant itself, regardless of the soil on which it grows. This is supported by the significant quantitative content of calcium in annual shoots with leaves – 2155.11 μg/g in red oak plants from Kyiv Oblast, which grew on soil with a relatively low Ca content – 795.78 μg/g.

The content of heavy metals was within the limits of the requirements put forward by the SPhU for plant raw materials [8].

The identified differences in the accumulation of macro- and microelements by various organs of the studied plant can be explained by the unequal degree of assimilation of certain elements, as well as the ecological conditions of the place of growth [9], to confirm the influence of the soil on the accumulation of mineral elements, additional studies of raw materials collected from places of growth with different soil composition are required.

It should be noted that the mineral elements present in all samples of the studied raw materials have a significant physiological role for the human body [10]. Deficiency of one of the minerals can cause a violation of the metabolism of the human body. For example, Zn and Cu stimulate immune activation, participate in the processes of hematopoiesis and wound healing [11,12], Se is an irreplaceable microelement with antioxidant properties, necessary for the optimal functioning of the immune system and the thyroid gland [13], Ca participates in formation of bone tissue, is a part of cellular structures, it is a mandatory component of the system of maintaining the acid-alkaline balance of the body’s internal environment [14]. Sulfur has an anti-allergic effect, participates in the production of collagen, is necessary for the brain, blood vessels and liver, is able to reduce pain in muscles and joints [15], is part of the active centers of the molecules of a number of enzymes in the form of SH functional groups, which participate in many enzymatic reactions, in particular, in the creation and stabilization of the native three-dimensional structure of proteins, and in some cases they act directly as catalytic centers of enzymes, they are part of various coenzymes, including coenzyme A [16]. The fruits of plants collected in both investigated places of growth contain a significant amount of potassium, which is necessary for the normal functioning of the cardiovascular system, stabilization of the water-salt balance, and maintenance of normal blood pressure [17].

In our previous work devoted to the study of polyphenolic compounds in raw materials of red oak [18], it was identified that the leaves and annual shoots of *Q. rubra* are distinguished by the content of rutin, chlorogenic and sinapic acids.

A high content of such mineral elements as sulfur, potassium, calcium is determined. They take part in various metabolic processes related to the transport of electrons (sulfur in the electron transport chain takes one of the unpaired oxygen electrons into a free orbital, participates in fixing and transporting methyl groups) with the formation of the transmembrane potential and the spread of the potential change across the cell membrane by exchange with sodium ions along the concentration gradient (biological role of potassium), with the functioning of cell membranes, the work of the nuclear apparatus of the cell (calcium inhibits the release of histamine, thus reducing the manifestations of allergic reactions, pain syndrome and inflammatory processes, is a blood coagulation factor, participates in the formation of the immune response, etc.) [19], may make an additional contribution to the revealing of potential types of pharmacological action characteristic of the polyphenols found in the raw material: P-vitamin, anti-inflammatory, analgesic, anti-allergic, antibacterial, as well as help lower blood pressure and improve heart function [20].

According to literature data the raw materials (bark, fruits, leaves) of a number of species of the genus *Quercus* contain a significant amount of mineral elements. In particular, in the species *Q. brantii* Lindl., *Q. infectoria* Oliv., *Q. cerris* L., *Q. coccifera* L., *Q. libani* Oliv. and *Q. suber* L., among the macroelements there are Ca, P, Mg, K and Na, and the microelement composition is represented by Fe, Zn, Cu and Mn [21,22].

In the most studied raw material of the official medicinal species of the genus *Quercus* – the bark of the common oak (Q. *robur* L.) – the mineral composition is represented by such macroelements as K, Ca, Mn and Fe; microelements – Mg, Cu, Zn, Sr, Pb and B [23].

Our results of determining the quantitative content of mineral elements in the raw material of red oak generally agree with the data of other authors regarding the mineral composition of some species of the oak genus [21,22,24].

Thus, according to the results of Ozkan et al. [25], obtained for a number of *Quercus* species growing in Turkey, the majority macronutrient for all the studied species (Q. *brantii, Q. infectoria, Q.cerris, Q. coccifera, Q. libani* and *Q. suber*) is potassium, the content of which significantly exceeds the corresponding content of other mineral elements. At the same time, the quantitative content of potassium in the species studied by the author varies from 10930 to 11910 μg/g; the calcium content is somewhat lower (from 8320 to 8670 μg/g). The microelement composition of the species of the oak genus studied by Kalamac et al. [22] in terms of composition and quantitative content is also similar to *Q. rubra* (in particular, a high content of manganese and ferrum is noted).

In general, the content of mineral elements in other studied species of the oak genus collected from places of growth in Turkey was 3.4-4.7 times higher than the corresponding content we identified for the raw material of red oak growing in Kyiv and Rivne Oblasts of Ukraine. This may be related both to the peculiarities of the species *Q. rubra* itself, and to the mineral composition of soils in Turkey, which, unfortunately, were not investigated in the relevant works of Turkish authors on the study of the mineral composition of species of the oak genus [22].

Basically, comparing the data available in the literature on the mineral composition of different species of the oak genus with the results of our research, we can conclude that the mineral composition of the species of the genus *Quercus* is quite similar, although certain differences are noted, in particular, for red oak is characterized by a high content of sulfur in the raw material, which is not found in other species of the oak genus.

Conclusion

Quantitative content of macro-, micro- and ultramicroelements of two types of raw materials (annual shoots with leaves and fruits) of *Q. rubra* from two different places of growth (Kyiv region, Rivne region) was determined in comparison with their content in the soil collected under the plants.

The presence of 16 mineral elements was found in the raw material of wild red oak from natural habitats in Rivne Oblast: in the fruits – 4 macro- (S, Cl, K, Ca), 8 – micro- (Mn, Fe, Cu, Zn, Br, Rb, Sr, Pb) and 4 – ultramicroelements (Cr, Co, Ni, Zr); in annual shoots with leaves: 3 – macro- (S, K, Ca), 6

– micro- (Mn, Fe, Cu, Zn, Rb, Sr) and 2 – ultramicroelements (Cr, Ni). The presence of 12 mineral elements was found in the raw material of wild red oak from natural habitats in Kyiv Oblast: in the fruits – 3 macro- (S, K, Ca), 6 – micro- (Mn, Fe, Cu, Zn, Rb, Sr) and 1 – ultramicroelement (Ni); in annual shoots with leaves: 3 – macro- (S, K, Ca), 5 – micro- (Mn, Fe, Zn, Rb, Sr) and 3 – ultramicroelements (Cr, Co, Ni).

The raw material collected in both locations in Ukraine is characterized by a high content of K, S, Ca, Mn and Fe. In general, the composition of mineral elements in the studied raw material of red oak is similar, some differences (for example, the presence of bromine, cobalt and zirconium in the fruits of red oak growing in Rivne Oblast) are obviously related to the peculiarities of the mineral composition of the soil the studied plants grow.

Based on the obtained results, it can be assumed that red oak plants are concentrators of potassium and sulfur from the soil (this is indicated by the high content of these macroelements both in the soil under the plants and in all the studied raw materials). A high content of calcium in the raw material of red oak from both locations was noted, and this content is apparently characteristic of the plant itself, regardless of the soil on which it grows. The obtained results show that the raw material of red oak is rich in vital mineral elements.

Thus, the results of the study of the mineral composition of different types of *Q. rubra* raw materials followed by a conclusion about the prospects of using annual shoots with leaves and fruits of red oak for the development of medicines with different directions of action (anti-inflammatory, analgesic, anti-allergic, antioxidant, etc.) and dietary supplements.

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AUTHOR CONTRIBUTIONS

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CONFLICT OF INTEREST

The authors declare that there is no real, potential, or perceived conflict of interest for this article.

ETHICS COMMITTEE APPROVAL

The authors declare that the ethics committee approval is not required for this study.

REFERENCES

1. Horobets, A.O. (2019). Vitamins and trace elements as specific regulators of physiological and metabolic processes in the body of children and adolescents. Ukrainian Journal of Perinatology and Pediatrics, 4(80), 75-92. [CrossRef]
2. Anash, F. (2016). PhD Thesis. Experimental substantiation of the use of aspen bark extract tablets in ulcerative diseases of the intestines. National Pharmaceutical University, Kharkiv, Ukraine.
3. Radha, K.M., Puri, S. (2021). Evaluation of nutritional, phytochemical, and mineral composition of selected medicinal plants for therapeutic uses from cold desert of Western Himalaya. Plants, 10(7), 1429. [CrossRef]
4. Jabborova, D., Sayyed, R.Z., Azimov, A., Jabbarov, Z., Matchanov, A., Enakiev, Y., Baazeem, A., El Sabagh, A., Danish, S., Datta, R. (2021). Impact of mineral fertilizers on mineral nutrients in the ginger rhizome and on soil enzymes activities and soil properties. Saudi Journal of Biological Sciences, 28(9), 5268-5274. [CrossRef]
5. Stanek, M., Stefanowicz, A.M. (2019). Invasive *Quercus rubra* negatively affected soil microbial communities relative to native *Quercus robur* in a semi-natural forest. Science of The Total Environment, 696, 133977. [CrossRef]

6. Debrynyuk, M.Y., Prydka, P.P. (2013). Red oak (*Quercus rubra* L.) in forest plantations of Stradch TPFC: distribution and silvicultural taxation specification. Scientific bulletin of the Ukrainian National Forestry University, 23(17), 9-14.
7. Konovalova, O.Y., Hurtovenko, I.O., Gergel, E.M., Gergel, O.V., Shuraeva, T.K., Kuz, K.O. (2016). Research on the mineral composition of Agastache fennel and Agastache Nettle grass. In: S.Yu. Danylchenko, N.A. Tretyakova, I.O. Surikova, A.V. Myhal (Eds.), Pharmacy of the 21st century: trends and perspectives, 1, (p. 96). Kharkiv: National Pharmaceutical University.
8. State Pharmacopoeia of Ukraine (2015). (2nd ed). Kharkiv, Ukrainian Scientific Pharmacopoeial Center for Quality of Medicines, p.1130.
9. Korablova, O.A., Rakhmetov, D.B., Shanaida, M.I., Vergun, O.M., Bagatska T.S., Svydenko, L.V., Ivashchenko, I.V. (2021). The content of macro- and microelements in plants of the genus *Artemisia* under conditions of introduction in the M.M. Gryshko National Botanical Garden of the NAS of Ukraine. Plant Varieties Studying and Protection, 17(3), 199-209. [CrossRef]
10. Baloch, S. (2021). Essential and non-essential elements in medicinal plants: A review. Biomedical Journal of Scientific & Technical Research, 33(4), 26098-26100. [CrossRef]
11. Rahman, M.T., Karim, M.M. (2018). Metallothionein: A potential link in the regulation of zinc in nutritional immunity. Biological Trace Element Research, 182, 1-13. [CrossRef]
12. Jarosz, M., Olbert, M., Wyszogrodzka, G., Młyniec, K., Librowski, T. (2017). Antioxidant and anti-inflammatory effects of zinc. Zinc-dependent NF-κB signaling. Inflammopharmacology, 25, 11-24. [CrossRef]
13. Ojeda, M.L., Nogales, F. (2022). Dietary selenium and its antioxidant properties related to growth, lipid and energy metabolism. Antioxidants, 11, 1402. [CrossRef]
14. Cormick, G., Belizán, J.M. (2019). Calcium intake and health. Nutrients, 11(7), 1606. [CrossRef]
15. Miller, C.G., Schmidt, E.E. (2020). Sulfur metabolism under stress. Antioxidants & Redox Signaling, 33(16), 1158-1173. [CrossRef]
16. Konovalova, O.Y., Mitchenko, F.A., Shuraeva, T.K., Dzhan, T.V. (2012). Mineral elements of medicinal plants and their role in human life. Kyiv, Publishing and printing center "Kyiv University", p. 192.
17. Petrushyna, G.O. (2023). Inorganic chemistry: "Biogenic elements". Directory. Dnipro, Thresholds, p.65.
18. Konovalova, O., Omelkovets, T., Sydora, N., Hurtovenko, I., Kalista, M., Shcherbakova, O. (2023). Investigation of the polyphenol composition of red oak (*Quercus rubra* L.) raw materials. ScienceRise: Pharmaceutical Science, 2(42), 75-81. [CrossRef]
19. Kalibabchuk, V.O. (2019). Medicinal chemistry. (4nd ed). Kyiv, Medicine, p.335.
20. Kolasani, A., Xu, H., Millikan, M. (2011). Evaluation of mineral content of Chinese medicinal herbs used to improve kidney function with chemometrics. Food Chemistry, 127, 1465-1471. [CrossRef]
21. Mohammadzadeh, A., Samadi-Maybodi, A., Khodadoust, S. (2013). Determination of trace elements in soilб leaves and fruits of *Quercus brantii* grown in Iouthwestern Iran by atomic spectroscopy. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 113, 423-426. [CrossRef]
22. Kalamac, A., Özkan, Ç.Ö., Yilmaz, K. (2022). Effect of species on macro and micro mineral composition of some shrub leaves with respect to sheep requirements. Black Sea Journal of Agriculture, 5(2), 87-90. [CrossRef]
23. Kotov, A.G., Kotova, E.E., Khokhlenkova, N.V., Yarnykh, T.G., Buryak, M.V., Vovk, O.H. (2010). Comparative analysis of regulatory documentation for raw oak bark. Pharmacom, 3, 57-61.
24. Stanek, M., Piechnik, Ł., Stefanowicz, A.M. (2020). Invasive red oak (*Quercus rubra* L.) modifies soil physicochemical properties and forest understory vegetation. Forest Ecology and Management, 472, 118253. [CrossRef]
25. Ozkan C.O., Atalay A I., Kurt O., Kamalak A. (2016). Effect of species on macro and micro mineral composition of oak leaves with respect to sheep requirements. Livestock Research for Rural Development. 28(6), 107.