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SNUDY OF THE NUTRIENT COMPOSITION OF AMELANCHIER ALNIFOLIA FRUTTS

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Abstract. Based on literature data, the nutrient composition and biological activity of alder-leaved serviceberry (Amelanchier alnifolia) fruits were studied. Experimental research was conducted to investigate the patterns of accumulation of essential and toxic trace elements from the soil at the plant's growing site. The content of microelements in the plant material and soil was determined using atomic absorption spectrophotometry. Three berry samples collected from different regions of Lviv Oblast (Davydiv village, Solonka village, and the city of Dublyany), as well as soil samples from the respective growing sites, were analyzed. It was found that alder-leaved serviceberry fruits are characterized by a high fiber content, a broad amino acid profile including essential amino acids, and contain essential microelements and vitamins. Among the fats present in the seeds, a significant proportion consists of monounsaturated and cis-polyunsaturated fatty acids, and the seed oil contains phytosterols. Bioactive components identified in the fruits, such as anthocyanins, phenolic acids, and polymeric proanthocyanidins, may indicate the antioxidant activity of the plant. Based on the results of microelement accumulation studies, it was shown that alder-leaved serviceberry berries are capable of accumulating copper and cadmium even at minimal concentrations of these elements in the soil, with copper accumulation being particularly high. The content of cobalt, nickel, and chromium in the soil correlates with their levels in the berries. No ability of the plant to accumulate manganese and lead in the fruits was confirmed–despite significant concentrations in the soil, these metals were not detected in the berries. The identified characteristics of the nutrient composition and biological activity of alder-leaved serviceberry berries indicate their promising potential for enriching the human diet. When cultivating the plant for this purpose, it is important to consider the patterns of accumulation of essential and toxic trace elements from the soil at the site of growth.

Keywords: Amelanchier alnifolia, nutritional and biological value, soil, microelement accumulation.

Introduction. Formulation of the problem

Manufacturing of food products using innovative technologies based on non-traditional plant raw materials, including wild plants, is becoming increasingly relevant due to the high content of nutritional and biologically active substances in these plants. This allows improving the qualitative adequacy of food rations, ensuring that their chemical composition meets the physiological needs of human body, as well as improving the taste, aroma, and other properties of products [1]. Thus, today, special attention is paid to food products that do not contain synthetic antioxidants, such as butylhydroxytoluene. However, in the food industry, there can still be traced the need for using antioxidants to extend the shelf life of products. To meet the modern requirements of global consumers and food producers, it is necessary to study and offer raw materials and their components that have high nutritional value and have a positive effect on human health [2]. Fruits and vegetables constitute valuable sources not only of carbohydrates, proteins, minerals, pectins, and organic acids, but also of bioactive secondary metabolites such as natural antioxidants. Wild Amelanchier alnifolia is no exception here.

Analysis of recent research and publications

Amelanchier alnifolia is a deciduous shrub originating from the northern prairies and plains of North America. Its berries constitute an excellent source of nutrients such as fiber, minerals (manganese, calcium, potassium, magnesium, iron), and vitamins (tocopherol, pyridoxine, riboflavin, ascorbic acid, thiamine, pantothenic acid) [3]. In Ukraine, members of the Amelanchier genus are considered non-traditional for cultivation. However, interest in Amelanchier alnifolia and other promising, but currently undervalued plants is growing with the increase in the wellbeing of the population. It is often compared to species such as sea buckthorn (Hippophae L.), honeysuckle (Lonicera L.), mountain ash (Sorbus L.), and viburnum (Viburnum L.), which are becoming popular due to their decorative, taste, and medicinal properties. Amelanchier alnifolia is a very plastic and unpretentious plant that grows as a large bush or tree. It can be used as an ornamental, nectar-producing, phyto-remediation, and medicinal plant. It is valued for its rapid growth, early fruiting and perenniality, as well as for its resistance to adverse conditions. Amelanchier can withstand temperatures down to –(40-50) °C, and its flowers – down to –(5-7) °C. It grows successfully on soils of different composition and acidity, thrives on moist light soils, sometimes even marshy ones, tolerates drought well, and can grow on rocky and sandy areas. However, it does not tolerate poorly drained clay soils with a low content of humus. In the flora of Ukraine, the Amelanchier genus is represented by three species: A. ovalis, A. Canadensis, and A. spicata. A. ovalis is a native species, while A. canadensis and A. spicata have been introduced and naturalized. Other species, such as A. rotundifolia, A. integrifolia, A. oligocarpa, A. laevis, A. alnifolia, A. florida, A. utahensis, and A. asiatica, are grown mainly as ornamental plants in private collections, botanical gardens, and arboreta. They are considered promising for introduction, but for A. canadensis and A. spicata. Until recently, only two species were represented in the collection of the National Dendrological Park "Sofiyivka" (the town of Uman): A. ovalis and A. canadensis. However, over the past decade, the following species have been added to the collection: A. alnifolia, A. asiatica, A. florida, A. laevis, A. spicata, A. stolonifera, A. utahensis, and A. pumila. Some of these plants were delivered to Sofiiyvka in the 1950s and 1960s, but were identified only in 2004–2014. The reintroduction of species contributed to the clarification of the species composition of existing plants. Currently, the collection of the National Dendrological Park "Sofiyivka" includes 14 species of the Amelanchier genus [4].

It is known that the antioxidant potential of a plant largely depends on the content of bioactive components, especially polyphenols. Polyphenolic compounds available in Amelanchier alnifolia, such as anthocyanins, phenolic acids, and polymeric proanthocyanidins, deserve special attention due to their positive correlation with the antioxidant activity of the plant. Not only do these compounds affect the sensory properties of food, but have anticarcinogenic, antiulcer, cardioprotective, and antidiabetic effects, and inhibit bacterial growth and development [5]. Phenolic acids which are the main class of polyphenols can protect the body from damage caused by free radicals. These biologically active substances have higher antiradical activity than antioxidant vitamins. They also have better bioavailability and water solubility compared to flavonoids. Phenolic acids are absorbed in the stomach, while most flavonoids are degraded under the effect of pH, digestive enzymes, and intestinal microorganisms.

Recently, the problem of technogenic and anthropogenic pollution of the environment with metals, in particular, toxic ones, has become relevant. Metals are usually concentrated in the upper humus layer (0–20 cm), where they are available in the form of ions (mobile form) or a fixed, immobile form. It is metals in a mobile form that are capable of accumulating in plant phytomass and fruits and causing a negative effect on biota and humans, and absorption by different plants occurs differently and depends on the physiological needs of the plant [6-8]. At the same time, a correlation has been proven between the content of some metals in the soil and the degree of their accumulation in the overground vegetative and reproductive organs of plants [9], which fact must be taken into account when non-traditional plant raw materials are used in human diets.

Goal of the paper: analysis of the nutrient composition and biologically active compounds in alder-leaved serviceberry (Amelanchier alnifolia) berries, as well as the ability to accumulate essential and toxic trace elements from the soil at the site of plant germination.

Research materials and methods

Theoretical studies included a review and generalization of literature data characterizing the nutritional value of Amelanchier alnifolia. The content of metals in plant raw materials and soil was determined by atomic absorption spectrophotometry with sample spraying in an air-acetylene flame.

Before analysis, Amelanchier alnifolia was dried and prepared following DSTU (State Standard of Ukraine) 7670:2014 using the dry mineralization method, which is based on the complete decomposition of organic substances through sample burning in an electric furnace. At the same time, the raw material samples in the crucibles were treated with ethyl alcohol, kept for 24 hours, then placed on an electric hotplate and carefully carbonized until the smoke stopped. The samples carbonized in the crucibles were placed in an electric furnace, and carbonization continued at a temperature of (250 ± 25) °C, while the temperature was gradually increased to (450 ± 25) °C until gray ash was obtained. Then the cooled ash was moistened with a minimum amount of nitric acid and kept in an electric furnace at (300 ± 25) °C for 0.5 h. This cycle was repeated several times until white or slightly colored ash was obtained. Then the ash was treated with nitric acid solution (1:1 in volume) and evaporated to wet salts. The resulting residue was dissolved in (15-20) cm^3 of nitric acid solution with a mass fraction of 1%, quantitatively transferred to a volumetric flask, and analyzed under DSTU EN 14082:2019.

Preparation of soil samples for analysis included the stage of drying in the air, sieving through a sieve with a 1 mm mesh size, extraction of elements in the acetate-ammonium buffer (pH 4.8) and analysis under DSTU 4770.1:2007 (determination of the content of mobile manganese compounds), DSTU 4770.2:2007 (determination of the content of mobile zinc compounds), DSTU 4770.3:2007 (determination of the content of mobile cadmium compounds), DSTU 4770.5:2007 (determination of the content of mobile cobalt compounds), DSTU 4770.6:2007 (determination of the content of mobile copper compounds), DSTU 4770.7:2007 (determination of the content of mobile nickel compounds), DSTU 4770.8:2007 (determination of the content of mobile chromium compounds), and DSTU 4770.9:2007 (determination of the content of mobile lead compounds). Blank solutions for the analysis of Amelanchier alnifolia and soil were prepared by way of treating the reagents simultaneously and similarly to the samples. The mass concentration of elements was calculated according to the calibration characteristics of the dependence of the optical density on the amount of substance in the calibration solutions.

Three samples of berries collected in different areas of Lviv region (the village of Davydiv, the village of Solonka, the town of Dubliany) were analyzed. Measurement data was presented as an average value, and the total expanded uncertainty of the result in absolute units was indicated (coverage factor equal to 2).

Results of the research and their discussion

Analysis of the nutrient composition of alder-leaved serviceberry (Amelanchier alnifolia) berries revealed the presence of a spectrum of essential and non-essential amino acids. In fruits of the Saskatoon berry from Canada, 16 proteinogenic amino acids were identified, including nine essential and seven non-essential ones. Several free amino acids, such as O-phosphoethanolamine, 3-methyl-L-histidine, asparagine, L-ornithine, L-citrulline, and hydroxy-L-proline, were detected for the first time in these fruits.

The average content of free amino acids in the analyzed genotypes was 46.58 mg/100 g dry weight, ranging from 34.71 mg/100 g dry weight. In Amelanchier fruits collected in Skierniewice (Poland), 23 amino acids were identified, including 11 essential and 12 non-essential free amino acids.

Among the non-essential amino acids, the predominant ones were: Arginine (~44.4%), Phenylalanine (~27.2%), Histidine (~10.1%), Tryptophan (~6.3%), O-phosphoethanolamine (~3.9%), Lysine (~2.8%), Leucine (~2.1%), Valine (~1.5%), 3-methyl-L-histidine (~1.1%), Methionine, threonine, and urea (<1.0%). Among the essential amino acids, the major ones included: Asparagine (~40.2%), Aspartic acid (~28.0%), Glutamic acid (~13.1%), Serine (~10.2%), Proline (~4.8%), L-ornithine (~1.5%), Tyrosine (~1.4%), Alanine, L-citrulline, hydroxy-L-proline, and glycine (<1.0%) [10].

The content of saturated fats in serviceberry (Amelanchier) seed oil is 9.8 g/100 g , 31 g/100 g of monounsaturated fats, and 58 g/100 g of cis-polyunsaturated fats. It also includes around 10 g/kg of phytosterols, primarily β-sitosterol, Δ5-avenasterol, campesterol, and stigmasterol.

The content of cyanogenic compounds, namely amygdalin and prunasin, ranges from 42–118 mg/kg and 5–17 mg/kg of fresh weight, respectively. These compounds are localized in the seeds, which significantly slows their absorption during berry consumption.

Serviceberry fruits are rich in anthocyanins (cyanidin-3-galactoside, cyanidin-3-glucoside, cyanidin-3-arabinoside, and cyanidin-3-xyloside), flavonols (quercetin-3-galactoside, quercetin-3-glucoside, quercetin-3-arabinosylglucoside, quercetin-3-arabinoside, quercetin-3-rutinoside, and quercetin-3-xyloside), proanthocyanidins (A- and B-type procyanidins with varying degrees of polymerization), phenolic carboxylic acids, and volatile compounds [11].

It should be noted that the content of polyphenols in the fruits of the studied berry and their parts significantly depended on the fraction of the fruit that was analyzed, i.e. peel, pulp, and seeds, as well as on the variety/genotype. The peel of the fruit is rich in polyphenolic compounds and demonstrates the highest antioxidant activity, which strongly correlated with the content of polyphenols. The seeds are rich in the total content of essential and non-essential free amino acids, the content of which correlated well with the inhibitory activity against α-amylase and α-glucosidase. A high content of the total free amino acids (hydroxy-L-proline, O-phosphoethanolamine, L-citrulline) was found in the pulp of the fruit. A positive correlation was found between the antioxidant capacity and the content of polyphenolic compounds. The total average polyphenol content was 1.79 g GAE/100 g DM in the fruits of the Saskatoon berries studied and 0.98 g GAE/100 g DM in fruit components. The highest average polyphenol content was obtained in the fruit peel (2.00 g GAE/100 g DM) and the lowest in the seeds (0.32 g GAE/100 g DM) [12].

In the food industry, the fruits of Amelanchier alnifolia are used to make drinks, syrups, wine, jams, and jellies. They are also added to pies and cakes. The berries can be mixed with other fruits, especially sour ones. Syrup made from Amelanchier fruits is used in the production of functional drinks due to its stability, antioxidant properties, taste, and color. Due to the high content of anthocyanins, Amelanchier fruits are used as natural food dyes. The berry pomace after juice production can serve as a natural source of antioxidants, extending the shelf life of products and improving their quality, taste, color, aroma, consistency, and appearances. The use of Amelanchier in craft brewing allows expanding the assortment and improving the quality of fruit beer. Adding ozonized fruits of this plant can also extend the shelf life of products [13]. Adding freeze-dried Amelanchier alnifolia berries to wheat flour during the production of cookies enriches it with nutrients. Replacing (10-15)% of wheat flour with Amelanchier berry powder improves the sensory properties of cookies, in particular the appearances and taste, compared to the control sample [14]. It has also been found that enrichment of rye bread with free and microencapsulated Amelanchier powders improves its nutritional value. The content of polyphenolic compounds and antioxidant capacity shows a strong positive correlation with the amount of the functional additive. Higher phenolic content and antioxidant activity were found in products enriched with microencapsulated maltodextrin powder. Microencapsulation, at the same time, helps to improve the relative bioavailability of antioxidant compounds [15]. It is proposed to use wild Amelanchier berries for the production of purees and preserves, keeping their beneficial properties. This allows them to be considered as a valuable ingredient for the creation of innovative food products [16]. An experiment was conducted on the preservation of Amelanchier berries by vacuum-microwave drying to assess their suitability for obtaining microbiologically stable dried fruits with high nutritional value. The use of this method allows for the production of a stable, high-quality canned product with moderate shrinkage and good preservation of bioactive substances. The optimized vacuum-microwave drying method applied to frozen fruits allows for the preservation of 70% of cyanidin glycosides available in the raw material [17].

The identified content of mobile forms of metals (hereinafter referred to as metals) in the soils where Amelanchier alnifolia germinated, except for the nickel content in the soil sampled in the village of Davydiv and in the town of Dubliany, does not exceed the maximum permissible concentration (MPC), which, given the correlation between the content of metals in the soil and in the plants, may tetify to a low risk of their accumulation in the fruits (Table 1) [9, 18].

The soils studied were characterized by low, compared to the MPC value, content of zinc, copper, manganese, cobalt, chromium - metals that can be considered essential in the composition of plants. However, the content of elements that are characterized by a toxic effect on the body, such as lead, cadmium and especially nickel, in the soil is more significant.

The results of identifying the content of metals in the berries of Amelanchier alnifolia show that the levels of accumulation of the same elements in the plants collected in different areas are somewhat different (Table 2), however, the content of cadmium is at almost the same level, while manganese and lead were not detected in the berries.

As shown in Fig. 1, there is no correlation between the zinc content in the soil in the area of Amelanchier alnifolia germination and in the berries of the plant.

Fig. 2-3 demonstrates that with a minimum content of copper and cadmium in the soil, the levels of accumulation of these metals in the berries of the plant are maximum, and a more pronounced accumulation is observed in the case of copper, which confirms the data on the ability of plants to accumulate metals even when their content in the soil does not exceed the maximum permissible concentrations [19-21]. A somewhat different nature of bioaccumulation in the berries of Amelanchier alnifolia is characteristic of such metals as cobalt, nickel, and chromium. Fig. 4-6 show that the content of these elements in the soil correlates with their content in the berries, viz. with an increase in the content of cobalt, nickel, and chromium in the soil, their content in the plant increases proportionally.

Table 1. **Metal content in the soil at the place of Amelanchier alnifolia germination**

Indicator name	MPC, mg/kg[1]	Identified content and measurement result uncertainty (U), mg/kg		
		village of Davydiv	village of Solonka	town of Dubliany
Zinc	23.0	15.212 (2.744)	12.098 (2.178)	4.182 (0.753)
Copper	3.0	0.046 (0.008)	0.035 (0.006)	0.013 (0.002)
Manganese	140.0	33.812 (6.086)	21.543 (3.878)	30.631 (5.514)
Cobalt	5.0	< 0.10[2]	< 0.10[2]	0.20 (0.04)
Lead	6.0	0.913 (0.164)	0.867 (0.156)	1.162 (0.209)
Cadmium	0.7	0.199 (0.036)	0.103 (0.019)	0.070 (0.013)
Nickel	4.0	6.947 (1.250)	2.012 (0.362)	5.360 (0.965)
Chrome	6.0	0.15 (0.03)	0.044 (0.008)	0.56 (0.10)

Note 1. MPC – maximum permissible concentration in the soil
Note 2. Below the limit of quantification (LOQ) of the methodology

Table 2. Metal content in the fruits of Amelanchier alnifolia

Indicator name	Identified content and measurement result uncertainty (U), mg/kg		
	village of Davydov	village of Solonka	city of Dublyany
Zinc	0.270 (0.005)	0.442 (0.088)	0.893 (0.179)
Copper	< 0.05[1]	0.094 (0.019)	0.108 (0.022)
Manganese	< 0.03[1]	< 0.03[1]	< 0.03[1]
Cobalt	< 0.03[1]	0.091 (0.018)	0.14 (0.025)
Lead	< 0.02[1]	< 0.02[1]	< 0.02[1]
Cadmium	0.031 (0.006)	0.028 (0.006)	0.036 (0.007)
Nickel	2.582 (0.516)	1.067 (0.213)	2.960 (0.592)
Chrome	0.34 (0.068)	0.115 (0.023)	0.49 (0.098)

Note 1. MPC – maximum permissible concentration in soil

Note 2. Below the limit of quantification (LOQ) of the methodology

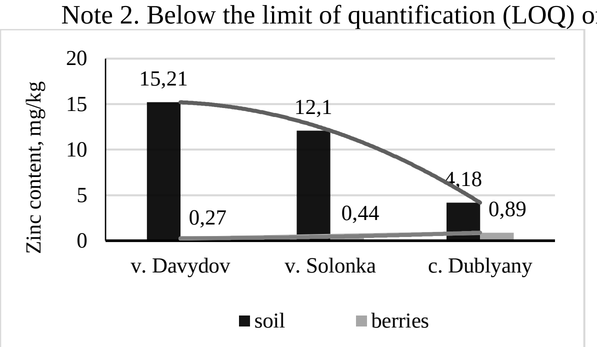

Fig.1. Zinc content in the soil in the area of Amelanchier alnifolia germination and in the berries of the plant

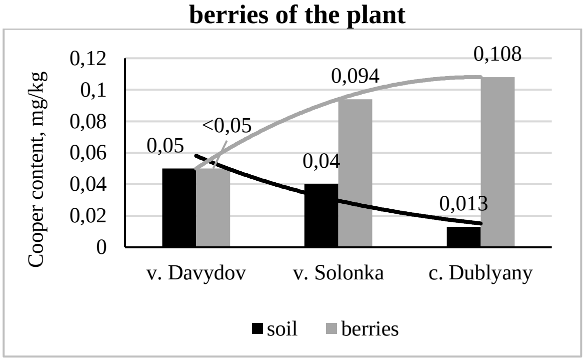

Fig. 2. Copper content in the soil in the area of Amelanchier alnifolia germination and in the berries of the plant

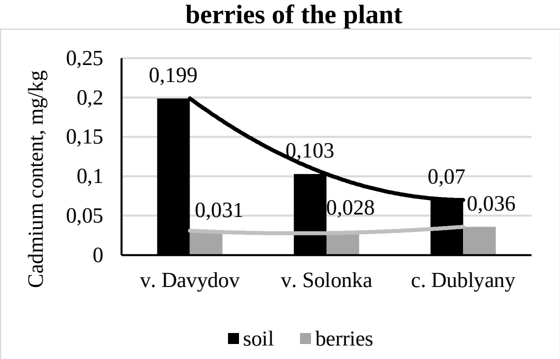

Fig. 3. Cadmium content in the soil in the area of Amelanchier alnifolia germination and in the berries of the plant

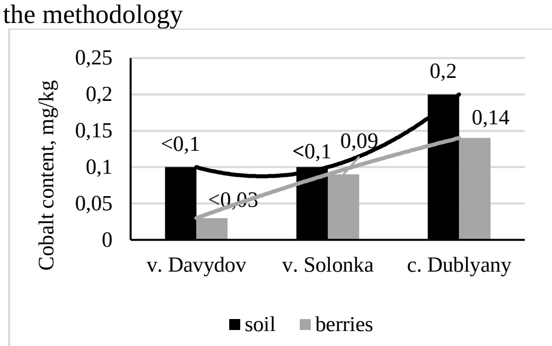

Fig. 4. Cobalt content in the soil in the area of Amelanchier alnifolia germination and in the berries of the plant

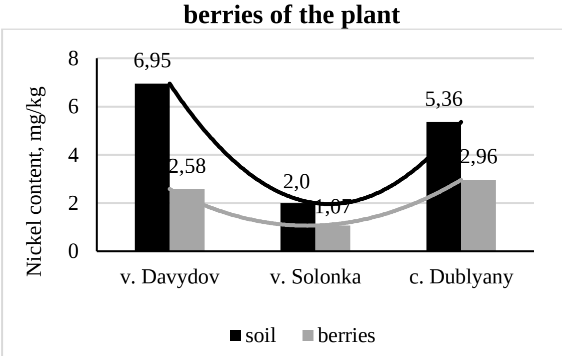

Fig.5. Nickel content in the soil in the area of Amelanchier alnifolia germination and in the berries of the plant

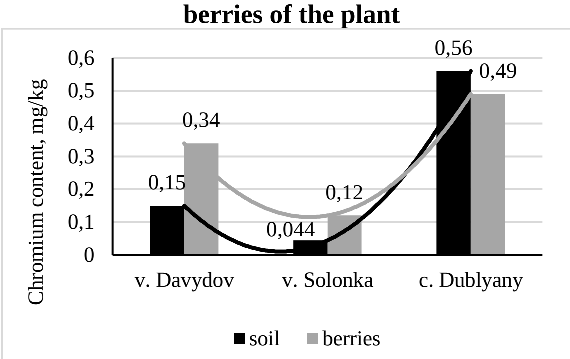

Fig.6. Chromium content in the soil in the area of Amelanchier alnifolia germination and in the berries of the plant

There is no correlation between the content of manganese and lead in the soil in the area of Amelanchier alnifolia germination and in the berries of the plant, and at the same time, when the level of presence of these metals in the soil was fairly significant, these elements were still not detected in the berries (Fig. 7, 8).

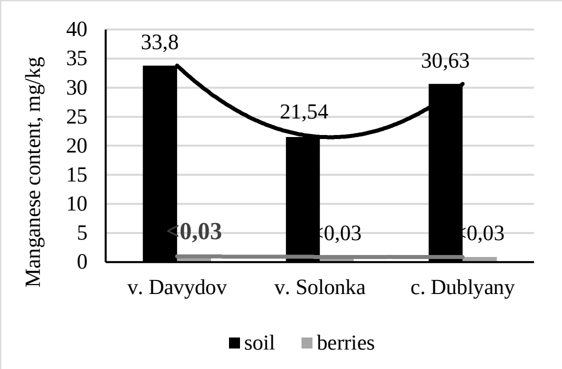

Fig.7. Manganese content in the soil in the area of Amelanchier alnifolia germination and in the berries of the plant

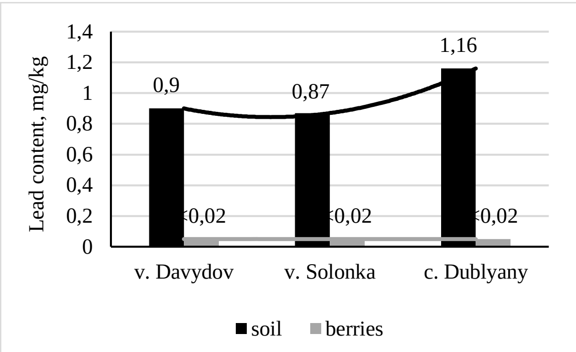

Fig. 8. Lead content in the soil in the area of Amelanchier alnifolia germination and in the berries of the plant

Summarizing the obtained data on the nature of metal accumulation in the berries of Amelanchier alnifolia from soils, such factors should be taken into account as the composition of the soil, its acid reaction, humidity, and the presence of microorganisms, which are factors that affect not only the degree of bioavailability of essential and toxic elements, but also the ability to synthesize nutrients and biologically active compounds [22, 23].

Conclusion

It has been established that alder-leaved serviceberry (Amelanchier alnifolia) fruits are characterized by a high fiber content, a broad spectrum of amino acids including essential ones, and contain essential microelements and vitamins. Among the fats present in the seeds, a significant proportion consists of monounsaturated and cis-polyunsaturated fatty acids, and the seed oil contains phytosterols.

The antioxidant activity of alder-leaved serviceberry fruits is supported by the presence of biologically active compounds such as anthocyanins, phenolic acids, and polymeric proanthocyanidins.

It has been shown that alder-leaved serviceberry berries are capable of accumulating copper and the toxic element cadmium even at minimal concentrations of these elements in the soil at the plant's growing site. At the same time, the level of copper accumulation is high. The content of cobalt, nickel, and chromium in the soil correlates with their levels in the berries. No ability of the plant to accumulate manganese and lead in the fruits has been confirmed – despite significant concentrations of these metals in the soil, they were not detected in the berries.

The identified characteristics of the nutrient composition and biological activity of alder-leaved serviceberry berries indicate their potential for enriching the human diet. When cultivating the plant for this purpose, it is important to consider the patterns of accumulation of essential and toxic trace elements from the soil at the site of growth.

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ВИВЧЕННЯ ОСОБЛИВОСТЕЙ НУТРІЄНТНОГО СКЛАДУ ПЛОДІВ ІРГИ ВІЛЬХОЛИСТОЇ

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Анотація. На основі даних літератури вивчено нутрієнтний склад та характер біологічної активності плодів ірги вільхолистої. Експериментально досліджено закономірності накопичення есенціальних та токсичних мікроелементів з ґрунту на місці її проростання. Вміст мікроелементів у рослинній сировині та грунті визначали методом атомно-абсорбційна спектрофотометрії. Було проаналізовано три зразки ягід, які зібрані у різних регіонах Львівщини (с. Давидів, с. Солонка, м. Дубляни) та зразки грунтів, де проростала рослина. Встановлено, що плоди ірги вільхолистої характеризуються високим вмістом клітковини, широким спектром амінокислотного складу, включно з незамінними амінокислотами; містять есенціальні мікроелементи та вітаміни. Серед жирів, що є в насінні рослини, значна частка належить мононенасиченим та цис-поліненасиченим жирам. Олія з насіння ірги містить фітостероли. Такі біоактивні компоненти, знайдені у складі плодів ірги, як антоціани, фенольні кислоти та полімерні проантоціанідини, можуть свідчити про антиоксидантну активність рослини. За результатами вивчення закономірностей накопичення мікроелементів з грунтів показано, що ягоди ірги вільхолистої здатні до накопичення міді та кадмію за мінімального вмісту цих елементів у грунтах, водночас рівень накопичення міді є високим. Вміст кобальту, нікелю та хрому в грунтах корелює з їх вмістом у ягодах рослини. Не підтверджено здатності ірги вільхолистої до накопичення в плодах мангану та свинцю – попри значущий вміст у грунтах, у ягодах цих металів не було виявлено. Встановлені характеристики нутрієнтного складу та біологічної активності ягід ірги вільхолистої вказують на перспективність їх використання для збагачення харчового раціону людини. При культивуванні рослини для цих цілей повинні бути враховані закономірності накопичення есенціальних та токсичних мікроелементів з ґрунту на місці її проростання.

Ключові слова: ірга вільхолиста, харчова та біологічна цінність**,** грунт, накопичення мікроелементів.