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INTENSITY OF HEAVY METALS ACCUMULATION BY VEGETABLE CULTURES FOR DIFFERENT DURATION OF THEIR VEGETATION

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It was analyzed that, in addition to pesticides and nitrates, heavy metals also belong to the substances that pollute soils, food and feed. Heavy metals such as Pb, Cd, Zn, Cu, Hg and others are recognized as the most dangerous pollutants. It was found that about 90% of heavy metals entering the environment are accumulated by soils, which then migrate into natural waters, are absorbed by plants and enter food chains. A certain amount of substances harmful to living organisms can be assimilated by cultivated plants and further along the food chain enter the human body. It was established that as a result of intensive farming, the amount of heavy metals in the soil is constantly increasing, which leads to a decrease in productivity and a deterioration in the quality of products, in particular, vegetable products. It is vegetable crops that provide the population with important food products, and industry with raw materials. Therefore, the study of the intensity of accumulation of heavy metals in vegetable products is relevant and necessary in modern conditions of production.

The intensity of soil pollution was investigated and it was established that the maximum permissible concentrations were not exceeded. The highest content of heavy metals in the soil was observed for Zn – 21.4 mg/kg, and the lowest – for Cd – 0.31 mg/kg. The hazard ratio of heavy metals in the soil of the studied area was the highest for Zn. In medium-ripe vegetables, there is an excess of the maximum permissible concentrations for Pb in Cucurbita pepo var. Giromontina L. and Phaseolus L., for Cd – in Cucumis sativus L. and Lycopersicon L., Cucurbita pepo var. Giromontina L. and Phaseolus L., for Zn – in Phaseolus L., for Cu – there is no excess of maximum permissible concentrations. In late-ripening vegetables, there is an excess of the maximum allowable concentrations for Pb in all vegetables, for Cd – in Allium sativum L., Allium cepa L., Daucus carota subsp. sativus L. and *Brassica oleracea L. var. capitata L. forma alba, for Zn – in Brassica oleracea L. var. capitata L. forma alba, for Cu – in all vegetables, except Brassica oleracea L. var. capitata L. forma alba. Cucurbita pepo var. Giromontina L. had the highest hazard ratio in medium-ripe vegetables for Cd, and the lowest hazard ratio for Phaseolus L. for Cu. Among late-ripening vegetables, the highest hazard ratio was for Allium sativum L. in terms of Pb, and the lowest in Brassica oleracea L. var. capitata L. forma alba for Cu. The highest coefficient of accumulation in mid-ripe vegetable samples was in Capsicum annuum L. for Cu, and the lowest for common Cucumis sativus L. for Pb. In late-ripening vegetable samples, the highest accumulation coefficient was in Allium sativum L. for Cu, and the lowest for Brassica oleracea L. var. capitata L. forma alba for Pb.*

Key words: *heavy metals, excess, intensity of accumulation, vegetables, maximum permissible concentration.*
Table 3. Fig. 5. Lit. 12.

Introduction. The population of Ukraine and the countries of the European Union need ecologically clean food products of plant origin. Recently, this issue has been caused by a significant excess of the content of toxic chemical elements in food products, which include heavy metals, in comparison with standard quality standards.

As a result of the intensive development of industrial production, an increase in the density of motor vehicles in the biosphere, a rapid process of heavy metal contamination of the soil layer, atmospheric air, water environment and plants is taking place. Pollution by heavy metals is one of the most widespread and strongest chemical pollutions [1].

Heavy metal pollution of the atmosphere, soil, and water reduces the productivity of agricultural and vegetable plants and disrupts naturally formed phytocenoses, causes under certain conditions the destruction of the assimilation potential of phytomass, leads to disruption of organogenesis processes in the form of specific changes that occur in plants, and worsens the quality of agricultural products [2].

The results of monitoring the safety of plant-based products in recent years showed that in 0.80–3.82% of the studied samples of food products in Ukraine, the excess of hygienic regulations on Pb was noted; 0.60–4.68% – by Hg; 1.09–1.75% – for Cd. Out of 10% of samples of vegetable products containing salts of heavy metals, half of them were found to exceed the maximum permissible concentrations [6].

Therefore, due to the dangerous impact of heavy metals on the human body, the content of Pb, Cd, Hg, Cu, Zn, Sn and As in vegetable raw materials is clearly regulated. According to their properties, heavy metals in various environments are able to accumulate or migrate to objects of living nature, depending on climatic conditions, physical and chemical properties and pH of the environment. Heavy metals take an active part in biological processes, are part of many enzymes, so they are compared with "trace elements". However, these concepts refer to the same elements, but are used in different meanings, characterizing first of all their concentration in the soil or plant products [11].

Attention was paid to this issue during the study of soil fertility, since such elements as Fe, Mn, Cu, Zn, Mo and Co are very important for the vital activity of plants, animals and people. Microelements can have a negative effect on plants if the concentration of their available forms exceeds a certain limit. Heavy metals such as Hg, Pb, and Cd are not vital for plants, animals, and humans, but on the contrary, even at low concentrations, they negatively affect the growth and development of biota and human health [2, 20]. Thus, the greatest attention is paid to toxic metals, which are widely used in production processes and accumulate in the environment, which pose a danger to all living things [3].

Today, the term heavy metals is most often studied not from a chemical, but from an ecological and toxicological point of view, in particular, how they affect the general condition of the human body, taking into account their distribution and pollution of the environment. From a toxicological point of view, the lower the maximum allowable concentration of a metal, the more poisonous it is [14, 16, 22].

It was found that heavy metals play a dual biological role in living organisms, in particular, in small concentrations they are part of enzymes that regulate metabolism, and in larger quantities they have a negative effect on living organisms. However, there is a group of metals for which only one negative concept of "heavy" in the sense of "toxic" has been fixed – Hg, Pb, Cd [4].

Heavy metals that have entered the human body are removed from it very slowly and accumulate mainly in the liver. In this regard, plant products grown even on slightly polluted soils can cause a cumulative effect, causing a gradual increase in the content of heavy metals in the body of animals and people. The permissible amount of heavy metals that a person can consume with food without risk of disease varies depending on the type of metal and is: for Pb – 3, Cd – 0.4-0.5, Hg – 0.3 mg per week [7].

The mechanisms of the toxic effect of heavy metals and their salts on plants, animals and humans have not been fully elucidated. According to the observations of chemists, toxicologists and ecologists, poisoning by salts of heavy metals is primarily due to the binding of cations of these compounds with sulfhydryl groups of SH (receptors) contained in protein molecules. Protein groups with As, Sb, Hg, and Bi ions are especially strongly combined [8].

As a result of the toxic effect of heavy metal compounds, the functioning of a number of vital body systems is disrupted and unwanted processes are initiated, in particular, metal ions stabilize and activate proteins that are part of enzymes, and during "metal poisoning" there is competition between necessary and toxic ions for possession binding sites in proteins and rich protein macromolecules are able to interact with the following heavy metals: Cd, Hg, Pb, etc. It has been established that metal cations bind to protein substances, amino acids, peptides and other vital substances in the body [9].

Toxic ions are distributed among many tissues and the greatest damage does not always correspond to the greatest metal concentration. So, for example, the majority of Pb (90%) is located in bones, but its toxicity is revealed due to the remaining 10% distributed in other tissues of the human body [10].

There are several mechanisms of heavy metals entering the human body: inhalation, oral, including alimentary and through the skin. Since plant products, in particular vegetables, are indispensable in the human diet, dangerous chemicals enter the human body along with them, where they remain forever. Reaching a certain concentration in the body, they create a negative impact, causing poisoning and gene mutations, affecting the central nervous system, kidneys, liver, skin, bones or teeth. Therefore, for the human body, heavy metals are carcinogenic or toxic even in small concentrations. In addition to the fact that they themselves poison the human body, they also clog it purely mechanically, since heavy metal ions settle on the walls of the most delicate systems of the body and clog the kidney and liver channels, thus reducing the filtration capacity of these organs. Accordingly, this leads to the accumulation of toxins and products of assimilation of living cells of the human body, that is, self-poisoning [5].

Hg, Pb and Cd are included in the list of the most dangerous environmental pollutants, agreed upon by the UN member states. Heavy metals have the ability to accumulate in various organs and are very slowly removed from the body. Thus, the period of biological half-life of Pb in the human body is several years. In this regard, the use of plant products, even those grown on lightly polluted soils, can cause a cumulative effect and lead to the deterioration of human health [7].

The study of mechanisms of protection against increased concentrations of heavy metals is at an early stage. Often in studies of metal toxicity, only the possible lethal effect (acute toxicity) is taken into account, but the sublethal (chronic) effect may be more important, both at the level of individual organisms and at the level of population groups [2].

Statement of the problem. Detection of heavy metals in vegetables has important theoretical and practical significance, especially for agriculture in areas with developed industry, where man-made soil pollution with various toxic elements and their compounds increases. It is important to know the MPC for the soil and the name of the polluting element or chemical compound. In recent years, the high toxicity of Be, As, Se, Sb, Tl, Ni, Sn, V, which are biologically active, has been discovered. According to state standards, toxic chemical elements are divided by hygienic safety classes [8, 9].

Pb, Hg, Cd, As and Zn are considered the main pollutants mainly because their man-made accumulation in the environment is at a particularly high rate. In agricultural production, this leads to a decrease in productivity and deterioration of product quality [10].

Assessment of the resistance of plants to pollution by heavy metals allows solving the problem of normalization of their content in soils and plants. Therefore, determining the transition of heavy metals from soil to plants is of great scientific and practical importance [5].

Research by V.B. Ilyin show that Cd, Pb, Zn, Ni, Cu are mobile only in an acidic environment, and their mobility sharply decreases in an alkaline environment [10]. That is, the factor of selective absorption of chemical elements by plants from the soil appears again, as in the case of their arrival from atmospheric air. Different types of soils are characterized by different self-cleaning abilities, that is, they have different buffering properties [6].

According to resistance to pollution, plants are divided into groups: the most resistant (cereals, sunflower); moderately resistant (beetroot, potato, carrot, tomato, pepper); weakly resistant (lettuce, annual herbs, perennial legumes, corn) [7].

The concentration of heavy metals largely depends on the part of the plant under consideration, their content in fruits and berries is lower than in leafy vegetables or root crops. Species differences among leafy vegetables were also observed. For example, for bioindication of pollution by heavy metals, you can use leafy cabbage, which accumulates Fe and Pb in its leaves [6, 10, 8].

The studies of many scientists prove that the number of elements decreases from roots to fruits and the difference is up to 500–600 times [5,7]. This is confirmed by the experiments of V.B. Ilyin, that the largest amount of heavy metals accumulates in the roots of the plant, and the smallest – in the fruits and organs of storage of assimilates [9]. Experimental data showed that with an excess supply of Cd in the plant, increased production of amino acids begins. Amino acids are necessary for the conversion of Cd into a non-toxic form or for the synthesis of the protein – metallothionein, which binds Cd. Mainly, these protective mechanisms are activated during internal root contamination. In addition, the content of heavy metals in fruits of different sizes is also different [10].

The translocation of metals in a plant largely depends on its age. A.A. Beus, P.I. Grabovska, P.V. Tikhonov proved that the most energetic absorption of mineral substances occurs in the young parts of the plant. The movement of metals inside the plant is determined by the chemical features of the element – for example, Cd, Zn, Pb are immobile, and Cu is extremely mobile [9, 11].

A number of preventive measures are taken to grow crops on contaminated soils. First of all, complex agrochemical cultivation is carried out, which consists in increasing the content of humus, neutralizing soil acidity. In the future, crops are placed on these fields, in which parts of plants that slowly accumulate heavy metals (tomatoes, melons, potatoes) are eaten [9].

If for some reasons it is impractical to comprehensively cultivate individual contaminated fields, technical crops should be placed on them: flax, hemp, castor oil, potatoes for processing into starch or alcohol, sugar beets for obtaining sugar, as well as essential oil plants, in particular garlic, for obtaining vegetable oils or raw materials for the perfume industry. In some cases, these areas can be set aside for seeds of vegetable or fodder crops [9, 11].

It is known that vegetables intended for processing into baby food products (cabbage, spinach, carrots, etc.) are not grown on contaminated soils [7].

In the conditions of irrigated agriculture, the intensity of heavy metal circulation in agrocenoses increases. Thus, with surface irrigation methods (sprinkling, furrows, checks), the accumulation of heavy metals in plants from the soil increases by an average of 1.2–1.7 times compared to rainy conditions [9, 10].

During the entry of heavy metals into plants through the root system, the soil absorption complex acts as a powerful sorption factor, and the root system is a selective barrier that excludes the entry of biologically inert elements into the above-ground phytomass. The mechanism of assimilation of heavy metals by the roots is similar to the absorption of the main nutrient macro- and microelements from the soil [5, 11].

The concentration of heavy metals in plants decreases under the influence of rain, fog, dew and other factors; reducing them content also occurs as a result of dilution of the growing phytomass in the process of plant growth and development and as a result of drying and falling of previously contaminated parts of plants, for example, leaves [1].

Accumulators of heavy metals among vegetable crops are green vegetables (lettuce, spinach, dill, parsley, celery), so it is not recommended to grow these crops on contaminated soil. According to the level of accumulation of chemical elements, vegetable crops are located mainly in the following descending order: spinach, salad, radish, tomato [2].

According to the calculation data of L.M. Kalachyan, A.O. Tadevosyan, N.N. Tsibulko and other scientists, the highest accumulation coefficients are characteristic for the intake of heavy metals in coriander, basil, parsley, lettuce and cauliflower. The highest level of accumulation of heavy metals is typical for coriander, basil, cucumber, eggplant, and melon [56]. The concentration of heavy metals in the edible parts of certain types of vegetables has clear differences. The observed ranges of concentrations of Pb, Cd, Cu, Zn and As in edible parts were 0.004–2.361 mg/kg, 0.002–2.918 mg/kg, 0.155–3.125 mg/kg, 1.151–54.65 mg/kg and 0.014–1.780 mg/kg, respectively, with an average concentration of 0.383, 0.161, 0.810, 10.16 and 0.207 mg/kg, respectively [3, 7].

Therefore, the question of the routes of entry and features of the accumulation of heavy metals in plant products still does not have clearly defined provisions and regularities.

The purpose of the article to investigate the intensity of accumulation of heavy metals by vegetable crops at different durations of their vegetation.

Research methodology. The research was carried out according to the research scheme, which included the selection of vegetables to study the concentration of heavy metals in them, grown on the territory of a private homestead of the village of Agronomichne, Vinnytsia district, Vinnytsia region. The area of the plot is 1200 m^2.

Soils were selected from the plots of the village of Agronomichne, Vinnytsia district, Vinnytsia region, using the envelope method from each plot separately, and the samples were sent to the laboratory for determination of heavy metals in them.

Were selected for the studyripe vegetable s of various types of mid- and late-ripening vegetables, namely: *Capsicum annuum L.*, *Cucumis sativus L.*, *Lycopersicon L.*, Cucurbita pepo var. Giromontina *L.*, *Phaseolus L.*, *Beta vulgaris L.*, *Allium sativum L.*, *Allium cepa L.*, *Daucus carota subsp. sativus L.* and *Brassica oleracea L. var. capitata L. forma alba*. Vegetable products were selected by the method of point samples from each plot, cleaned from the soil and sent to the laboratory for determination of Zn, Cu, Pb and Cd.

Laboratory studies to determine the content of heavy metals in vegetable products selected within the Vinnytsia district were conducted at the State Laboratory of Veterinary and Sanitary Examination on the basis of the Vinnytsia RSL of the State Production and Consumer Service.

Observations, records and measurements were carried out according to generally accepted methods:

– soil samples were taken from the 0–20 cm layer in accordance with DSTU ISO 10381–1:2004 [12];

- determination of the content of mobile forms of heavy metals (Pb, Cd, Zn, Cu) in soil and vegetables – after extraction with an acetate-ammonium buffer solution pH 4.8 by the method of atomic absorption spectrophotometry in accordance with DSTU 4770.

To assess the degree of danger of the pollutant element, we used the hazard ratio of the pollutant element – the ratio between the concentration of the pollutant in vegetables and their maximum permissible concentration. It is used to assess the degree of danger of a polluting element. Under normal conditions, the hazard ratio should be less than or equal to 1.

To assess the degree of accumulation of heavy metals, the accumulation factor of the pollutant element was used – the ratio of the concentration of the pollutant in vegetable products to its concentration in the soil. It is used to assess the possibility of transition of mobile forms of heavy metals from soil to vegetables.

Summary of research results. In the conditions of Vinnytsia district, when growing vegetable products, organic fertilizers are mainly used. The analysis of soil contamination by heavy metals (on the example of a private homestead plot) is shown in the table. 1 and shows that the concentration of Pb, Cd, Zn and Cu does not exceed the MPC.

Table 1

The content of heavy metals in the soils of the private homestead of the Vinnytsia district, mg/kg

Actual content				MPC				Hazard ratio			
Pb	Cd	Zn	Cu	Pb	Cd	Zn	Cu	Pb	Cd	Zn	Cu
5.44	0.31	21.4	1.2	6.0	0.7	23.0	3.0	0.9	0.44	0.93	0.4

Source: formed on the basis of own research

The results of the research, shown in the table. 1 show that exceeding the maximum allowable concentrations in the soil of the village of Agronomichne, Vinnytsia district (on the example of a private homestead) were not detected. The concentration of Pb, Cd, Zn, and Cu was 1.11, 2.21, 1.07, and 2.51 times lower than the MPC, respectively. The highest content of heavy metals in the soil was observed for Zn. It was higher than Pb, Cd, and Cu by 3.95, 69.07, and 17.84 times, respectively.

The hazard ratio of heavy metals in the homestead soil (Fig. 1) was the highest for Zn.

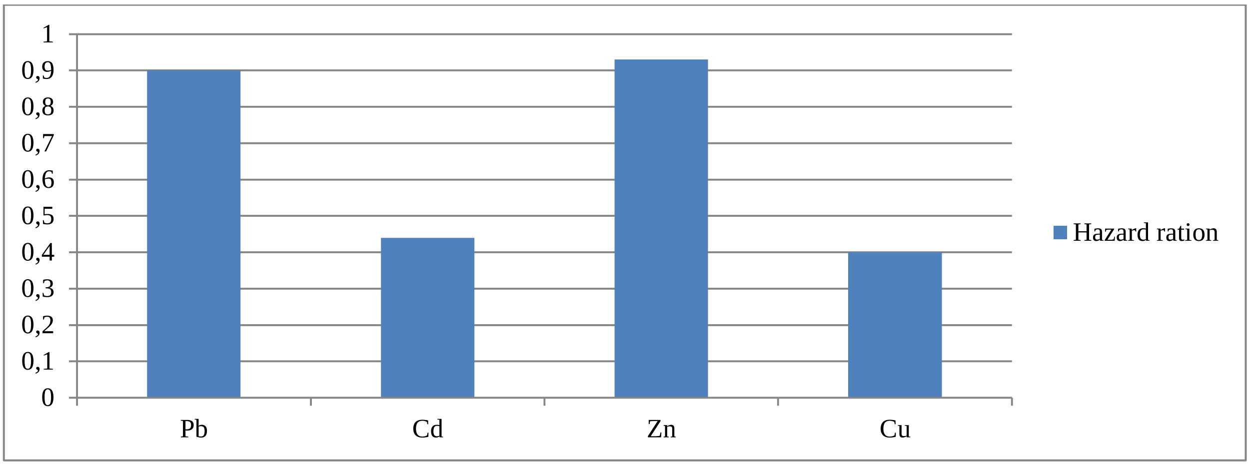

Fig. 1. The hazard ration of heavy metals in the soil of the private homestead of the Vinnytsia district

Source: formed on the basis of own research

Compared to Pb, Cd, and Cu, it was 1.03, 2.11, and 2.31 times higher, respectively.

Table 2 shows the ratio of the actual content of Pb, Cd, Zn and Cu in the investigated vegetable products of the mid-ripening period of their growing season to the MPC.

Table 2

The ratio of the actual content of Pb, Cd, Zn and Cu in samples of medium-ripe vegetables to MPC

Name of vegetables	Act. content Pb, mg/kg	MPC	MPC / act. cont.	Act. content Cd, mg/kg	MPC	MPC / act. cont.	Act. content Zn, mg/kg	MPC	MPC / act. cont.	Act. content Cu, mg/kg	MPC	MPC / act. cont.
Capsicum annuum L.	0.05	0.1	2.0	0.03	0.03	1.01	6.8	10	1.4	4.2	5.0	1.1
Cucumis sativus L.	0.04	0.1	2.5	0.04	0.03	0.75	2.1	10	4.7	3.8	5.0	1.3
Lycopersicon L.	0.09	0.1	1.1	0.07	0.03	0.42	3.9	10	2.5	2.4	5.0	2.0
Cucurbita pepo var . Giromontina *L.*	0.12	0.1	0.8	0.09	0.03	0.33	4.4	10	2.2	1.2	5.0	4.1
Phaseolus L.	0.16	0.1	0.6	0.08	0.03	0.37	12.4	10	0.8	0.7	5.0	7.1

Source: formed on the basis of own research

The obtained results of Table 2 show that exceeding the MPC for Pb is present in *Cucurbita pepo var. Giromontina L.* and *Phaseolus L.* in 1.21 and 1.61 times, respectively. In other types of vegetables, namely *Capsicum annuum L.*, *Cucumis sativus L.* and *Lycopersicon L.*, the Pb concentration was within the normal range and was lower than the MPC by 2.01, 2.53 and 1.15 times, respectively. At the same time, the highest concentration of Pb was observed in *Phaseolus L.* – 0.16 mg/kg. It was higher compared to *Capsicum annuum L.*, *Cucumis sativus L.*, *Lycopersicon L.* and *Cucurbita pepo var. Giromontina L.* in 3.24, 4.02, 1.75 and 1.31 times, respectively.

The concentration of Cd exceeded the MPC in almost all vegetables, except for *Capsicum annuum L.*. In *Capsicum annuum L.*, the concentration of Cd was equal to the maximum permissible concentration. In *Cucumis sativus L., Lycopersicon L., Cucurbita pepo var. Giromontina L.* and *Phaseolus L.,* the MPC concentration exceeded the maximum permissible by 1.31, 2.31, 3.03 and 2.65 times, respectively. The highest Cd content was in *Cucurbita pepo var. Giromontina L.* – 0.09 mg/kg. Compared with *Capsicum annuum L., Cucumis sativus L., Lycopersicon L.,* and *Phaseolus L.,* it was 3.04, 2.24, 1.23, and 1.18 times higher, respectively.

The concentration of Zn in the studied vegetables exceeded the maximum allowable limit only in *Phaseolus L.* by 1.25 times. Also in comparison *Capsicum annuum L., Cucumis sativus L., Lycopersicon L.* and *Cucurbita pepo var. Giromontina L.* it was 1.83, 5.90, 3.18 and 2.84 times higher, respectively. In *Capsicum annuum L., Cucumis sativus L., Lycopersicon L. and Cucurbita pepo var. Giromontina L.* concentration of Zn was lower than MPC by 1.45, 4.78, 2.52 and 2.21 times, respectively.

The concentration of Cu in all studied vegetables was within normal limits. In *Capsicum annuum L., Cucumis sativus L., Lycopersicon L., Cucurbita pepo var. Giromontina L.* and *Phaseolus L.* concentration of Cu was lower than the maximum permissible by 1.11, 1.33, 2.01, 4.45 and 7.16 times, respectively. The highest Cu content was in *Capsicum annuum L.*. It was higher compared to *Cucumis sativus L., Lycopersicon L., Cucurbita pepo var. Giromontina L.* and *Phaseolus L.* in 1.16, 1.76, 3.53 and 6.04 times, respectively.

Therefore, taking into account all the results, it can be concluded that in medium-ripe vegetables there is an excess of the MPC for Pb in *Cucurbita pepo var. Giromontina L.* and *Phaseolus L.*, according to Cd – in *Cucumis sativus L., Lycopersicon L., Cucurbita pepo var. Giromontina L.* and *Phaseolus L.*, for Zn – in *Phaseolus L.*, for Cu – there is no exceedance of the MPC.

Table 3 shows the ratio of the actual content of Pb, Cd, Zn and Cu in the investigated vegetable products of the late ripening period of their vegetation to the MPC.

Table 3

The ratio of the actual content of Pb, Cd, Zn and Cu in samples of late-ripening vegetables to MPC

Name of vegetables	Act. content Pb, mg/kg	MPC	MPC / act. cont.	Act. content Cd, mg/kg	MPC	MPC / act. cont.	Act. content Zn, mg/kg	MPC	MPC / act. cont.	Act. content Cu, mg/kg	MPC	MPC / act. cont.
Beta vulgaris L.	0.22	0.1	0.5	0.03	0.03	1.02	9.3	10	1.0	5.4	5.0	0.9
Allium sativum L.	0.21	0.1	0.4	0.08	0.03	0.34	6.4	10	1.5	7.2	5.0	0.6
Allium cepa L.	0.44	0.1	0.2	0.07	0.03	0.45	5.3	10	1.8	9.3	5.0	0.5
Daucus carota subsp. sativus L.	0.19	0.1	0.5	0.09	0.03	0.37	6.0	10	1.6	6.4	5.0	0.7
Brassica oleracea L. var. capitata L. forma alba	0.14	0.1	0.7	0.11	0.03	0.24	11.2	10	0.8	3.3	5.0	1.5

Source: formed on the basis of own research

The obtained results of Table 3 show that the content of Pb in all studied vegetables exceeded the maximum permissible concentrations. So, in *Beta vulgaris L., Allium sativum L., Allium cepa L., Daucus carota subsp. sativus L.* and *Brassica oleracea L. var. capitata L. forma alba*, the Pb content was 0.5, 0.4, 0.2, 0.5, and 0.7 times higher than the MPC, respectively. The highest content of Pb was in *Allium cepa L.* – 0.44 mg/kg, it was higher compared to *Beta vulgaris L., Allium sativum L., Daucus carota subsp. sativus L.* and *Brassica oleracea L. var. capitata L. forma alba* in 2.2, 2.0, 2.3 and 3.1 times, respectively.

The concentration of Cd exceeded the maximum permissible in all vegetables, except for *Beta vulgaris L.*, its content was equal to the MPC. In *Allium sativum L., Allium cepa L., Daucus carota subsp. sativus L.* and *Brassica oleracea L. var. capitata L. forma alba*, Cd concentration was 2.6, 2.3, 3.0, and 3.6 times higher than MPC, respectively. The highest Cd content was in *Brassica oleracea L. var. capitata L. forma alba* – 0.11 mg/kg, it was higher than *Beta vulgaris L., Allium sativum L.,* *Allium cepa L.* and *Daucus carota subsp. sativus L.* in 3.6, 1.3, 1.5, and 1.2 times, respectively.

The concentration of Zn exceeded the maximum permissible in *Brassica oleracea L. var. capitata L. forma alba* by 1.1 times. In all other vegetable samples, the concentration of Zn was lower than the MPC, in *Beta vulgaris L., Allium sativum L., Allium cepa L.* and *Daucus carota subsp. sativus L.* by 1.0, 1.5, 1.8 and 1.6 times, respectively. Zn content in *Brassica oleracea L. var. capitata L. forma alba* was higher compared to *Beta vulgaris L., Allium sativum L., Allium cepa L.* and *Daucus carota subsp. sativus L.* by 1.2, 1.7, 2.1 and 1.8 times, respectively.

The concentration of Cu exceeded the maximum permissible in *Allium sativum L., Allium cepa L.* and *Daucus carota subsp. sativus L.* by 1.4, 1.8 and 1.2 times, respectively. In *Beta vulgaris L.* and *Brassica oleracea L. var. capitata L. forma alba*, the Cu content did not exceed the MPC, it was 0.9 and 1.5 times lower than the MPC, respectively. The highest Cu content was found in *Allium cepa L.* – 9.3 mg/kg. It was higher compared to *Beta vulgaris L., Allium sativum L., Daucus carota subsp. sativus L.* and *Brassica oleracea L. var. capitata L. forma alba* by 1.7, 1.2, 1.4 and 2.8 times, respectively.

Therefore, in late-ripening vegetables, there is an excess of the MPC for Pb in all vegetables, for Cd – in *Allium sativum L., Allium cepa L., Daucus carota subsp. sativus L.* and *Brassica oleracea L. var. capitata L. forma alba*, by Zn – in *Brassica oleracea L. var. capitata L. forma alba*, according to Cu – in all vegetables, except for *Brassica oleracea L. var. capitata L. forma alba*.

To determine the general ecological condition of the studied territory, we calculated the indicator of the danger coefficient of heavy metals. So, Figure 2 shows

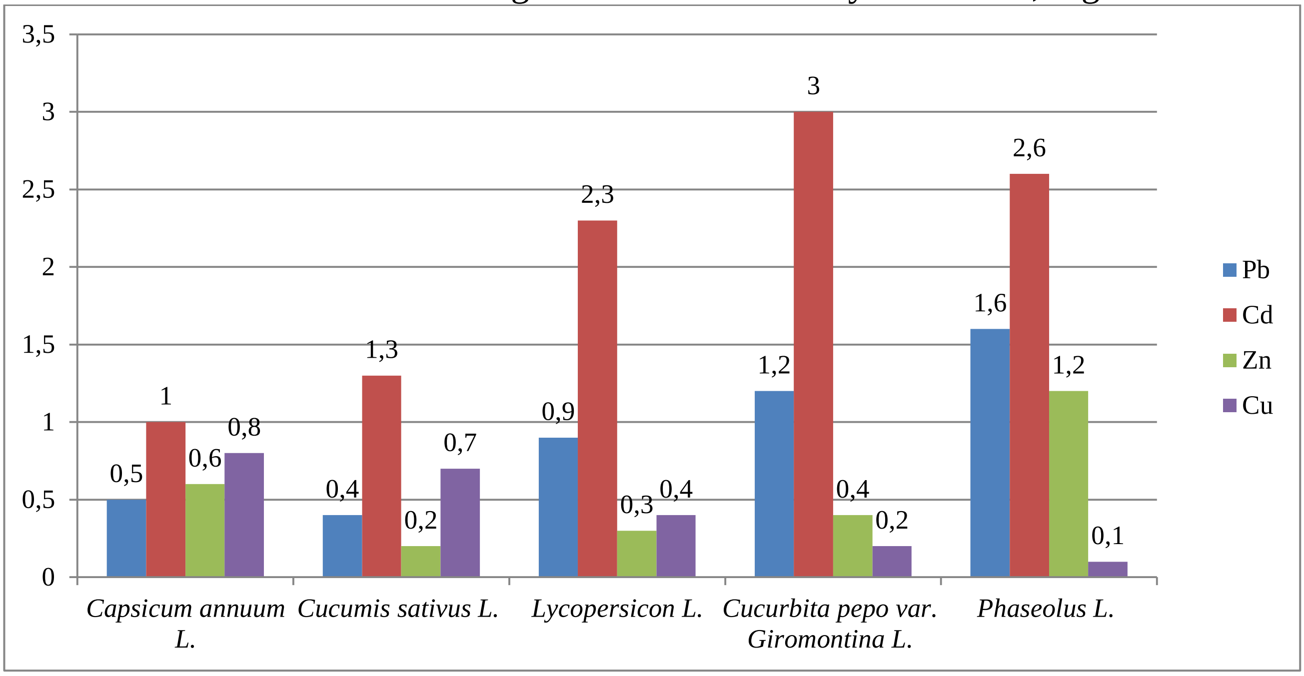

Fig. 2. The hazard ration of heavy metals for medium-ripe vegetables
Source: formed on the basis of own research

the hazard ratio of Pb, Cd, Zn, and Cu for vegetable products of the mid-season growing season.

From fig. 2. it can be seen that in *Capsicum annuum L.*, the highest indicator of the hazard ratio was the indicator for Cd. It was higher compared to Pb, Zn, and Cu by 2.0, 1.6, and 1.2 times, respectively. In *Cucumis sativus L.*, the hazard ratio was the highest also for Cd. Compared to Pb, Zn, and Cu, it was 3.2, 6.5, and 1.8 times higher, respectively. In *Lycopersicon L.*, the highest indicator of the hazard ratio was also the indicator for Cd. Compared with Pb, Zn, and Cu, it was 2.5, 7.6, and 5.7 times higher, respectively.

In *Cucurbita pepo var. Giromontina L.* the hazard ratio indicator was also the highest for Cd. Compared with Pb, Zn, and Cu, it was 2.5, 7.5, and 15.0 times higher, respectively. In *Phaseolus L.*, the highest indicator of the hazard ratio was the indicator for Cd. It was higher compared to Pb, Cd, and Cu by 1.6, 2.1, and 26.0 times, respectively.

In the private homestead we studied, all medium-ripe vegetables have a hazard ratio of Cd higher than 1, which indicates a dangerous level of its content. Also in *Cucurbita pepo var. Giromontina L.* and *Phaseolus L.* hazard ratio is higher than 1 for Pb, and for Zn only in *Phaseolus L.*. All other indicators are less than 1, which means that these vegetables are safe for consumption.

Figure 3 shows the hazard ratio of Pb, Cd, Zn, and Cu for vegetable products of the late growing season. From fig. 3 it can be seen that in *Beta vulgaris L.* the highest

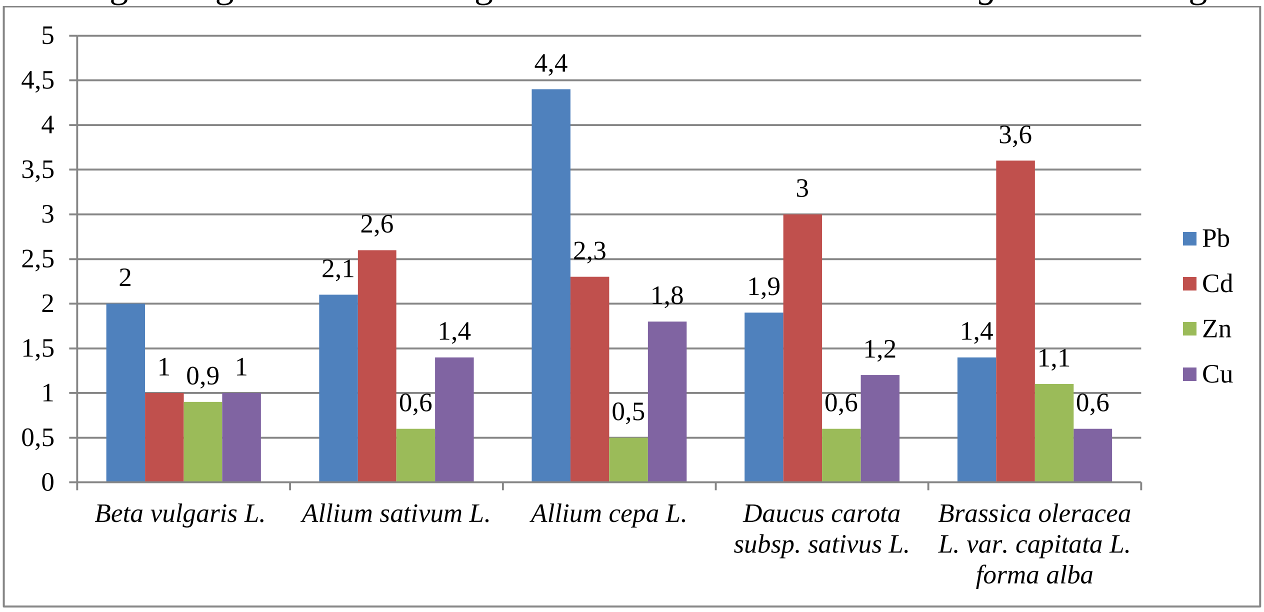

Fig. 3. The coefficient of danger of heavy metals for late-ripening vegetables

Source: formed on the basis of own research

indicator of the hazard ratio was the indicator of Pb, compared to Cd, Zn and Cu, it was higher by 2.0, 2.2 and 2.0 times, respectively. In *Allium sativum L.*, the highest indicator of the hazard ratio was observed for Cd. It was higher compared to Pb, Zn, and Cu by 1.2, 4.3, and 1.8 times, respectively. In *Allium cepa L.*, the highest hazard ratio was for Pb, compared to Cd, Zn, and Cu by 1.9, 8.8, and 2.4 times, respectively.

In *Daucus carota subsp. sativus L.* the highest indicator of the hazard ratio was for Cd. Compared to Pb, Zn, and Cu, it was 1.5, 5.0, and 2.5 times higher, respectively. In *Brassica oleracea L. var. capitata L. forma alba*, the hazard ratio indicator was the highest for Cd. Compared with Pb, Zn, and Cu, it was 2.5, 3.2, and 36.0 times higher, respectively. Therefore, the hazard ratio is higher than 1 for Pb, Cd in all studied late-ripening vegetables. According to Zn – only in *Brassica oleracea L. var. capitata L. forma alba*. According to Cu – in all studied vegetables, except for *Brassica oleracea L. var. capitata L. forma alba*.

We calculated the indicator of the accumulation coefficient, which is used to assess the possibility of the transfer of mobile forms of heavy metals from the soil to vegetables. Figure 4 shows the values of the accumulation coefficient in medium-ripe vegetables.

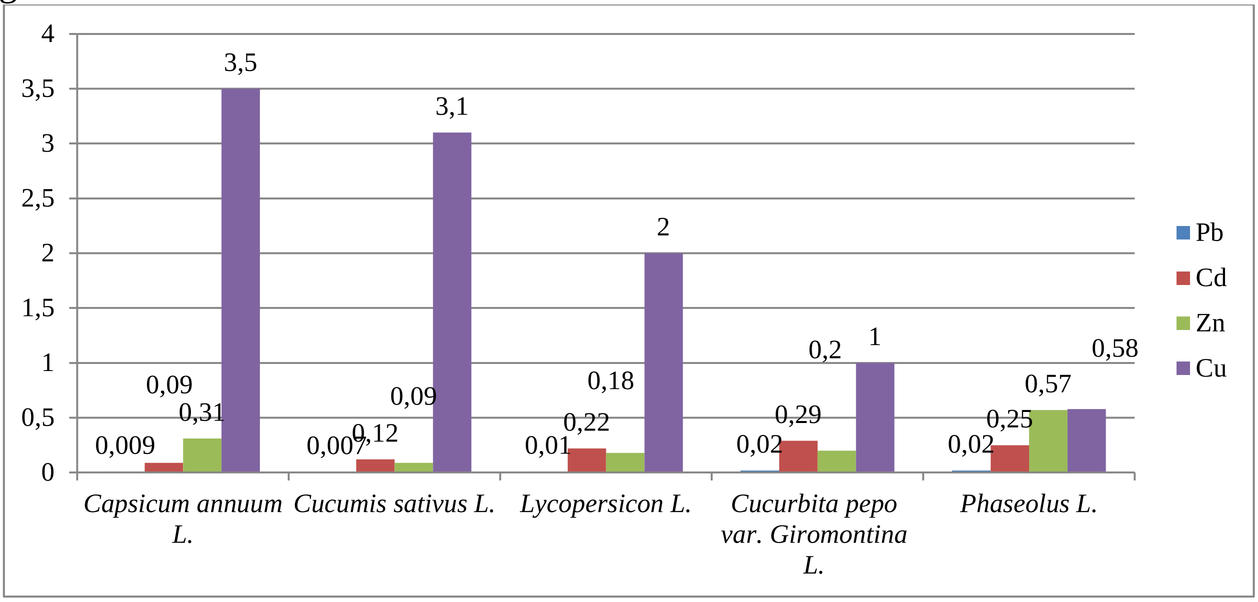

Fig. 4. Coefficient of accumulation of heavy metals for medium-ripe vegetables

Source: formed on the basis of own research

As can be seen from Figure 4, *Capsicum annuum L.* had the highest Cu accumulation coefficient. It was higher compared to Pb, Cd and Zn by 388.8, 38.8 and 11.2 times, respectively. In *Cucumis sativus L.*, the highest index of the accumulation coefficient was also that of Cu, which was higher than that of Pb, Cd, and Zn by 442.8, 25.8, and 34.4 times, respectively. In *Lycopersicon L.*, the highest index of the accumulation coefficient was also the index of Cu, it was higher compared to Pb, Cd, and Zn by 200.0, 9.0, and 11.1 times, respectively. In *Cucurbita pepo var. Giromontina L.* had the highest index for Cu, which was higher than Pb, Cd, and Zn by 50.0, 3.4, and 5.0 times, respectively. In *Phaseolus L.*, the Cu accumulation ratio was also the highest, compared to Pb, Cd, and Cu by 29.0, 2.3, and 1.0 times, respectively.

Figure 5 shows the values of the accumulation coefficient in late-ripening vegetables. Figure 5 shows that the accumulation ratio in *Beta vulgaris L.* was the highest for Cu, it was higher than Pb, Cd, and Zn by 150.0, 50.0, and 10.4 times, respectively. In *Allium sativum L.*, the highest index of the accumulation coefficient was also that of Cu, which was higher than that of Pb, Cd, and Zn by 200.0, 24.0, and 20.6 times, respectively.

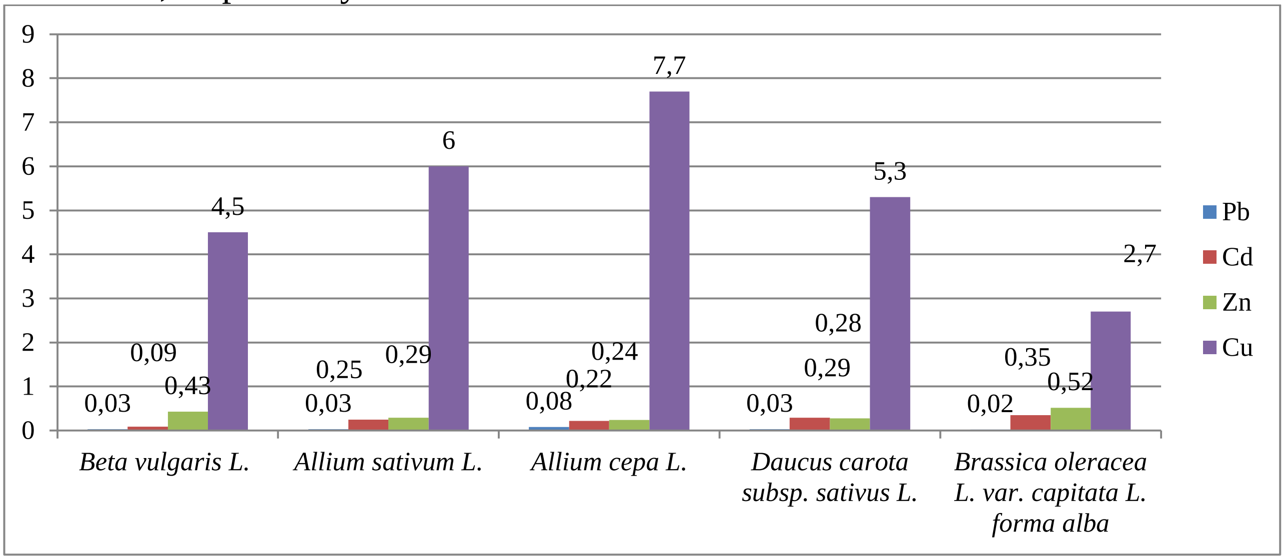

Fig. 5. Coefficient of accumulation of heavy metals for late-ripening vegetables

Source: formed on the basis of own research

In *Allium cepa L.*, the Cu accumulation coefficient was the highest, which in turn was 96.2, 35.0, and 32.0 times higher than Pb, Cd, and Zn, respectively. In *Daucus carota subsp. sativus L.*, the Cu index was 176.6, 18.2, and 18.9 times higher than Pb, Cd, and Zn, respectively. In *Brassica oleracea L. var. capitata L. forma alba*, the Cu accumulation coefficient was higher than Pb, Cd, and Zn by 135.0, 7.7, and 5.1 times, respectively.

So, it can be seen from Figures 4 and 5 that the transition of Cu from the soil to vegetable products is present in all studied samples, both mid-ripe and late-ripe vegetables.

Conclusions. As a result of the conducted research, it was established that the intensity of soil pollution in the private homestead of the village of Agronomichne, Vinnytsia District, Vinnytsia Region, did not exceed the MPC. The highest content was observed for Zn – 21.4 mg/kg, and the lowest – for Cd – 0.31 mg/kg. The hazard ratio of heavy metals in the soil of the studied area was the highest for Zn.

In medium-ripe vegetables, there is an excess of the MPC for Pb in *Cucurbita pepo var. Giromontina L.* and *Phaseolus L.*, according to Cd – in *Cucumis sativus L.*, *Lycopersicon L.*, *Cucurbita pepo var. Giromontina L.* and *Phaseolus L.*, for Zn – in *Phaseolus L.*, for Cu – there is no exceedance of the MPC. In late-ripening vegetables, there is an excess of MPC for Pb in all vegetables, for Cd – in *Allium sativum L.*, *Allium cepa L.*, *Daucus carota subsp. sativus L.* and *Brassica oleracea L. var. capitata L. forma alba*, by Zn – in *Brassica oleracea L. var. capitata L. forma alba*, according to Cu – in all vegetables, except for *Brassica oleracea L. var. capitata L. forma alba*.

The highest hazard ratio in mid-ripe vegetables was *Cucurbita pepo var. Giromontina L.* in Cd, and the lowest in *Phaseolus L.* in Cu. In late-ripening vegetables, *Allium cepa L.* had the highest hazard ratio for Pb, and *Brassica oleracea L. var. had the lowest. capitata L. forma alba* according to Cu.

The highest accumulation coefficient in mid-ripe vegetable samples was in *Capsicum annuum L.* for Cu, and the lowest in *Cucumis sativus L.* for Pb. In late-ripening vegetable samples, *Allium cepa L.* had the highest Cu accumulation coefficient, and *Brassica oleracea L. var. the lowest. capitata L. forma alba* according to Pb.

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АНОТАЦІЯ
ІНТЕНСИВНІСТЬ НАКОПИЧЕННЯ ВАЖКИХ МЕТАЛІВ ОВОЧЕВИМИ КУЛЬТУРАМИ ЗА РІЗНОЇ ТРИВАЛОСТІ ЇХ ВЕГЕТАЦІЇ

Проаналізовано, що до речовин, що забруднюють ґрунти, продукти харчування і корми належать, крім пестицидів і нітратів, також важкі метали. Важкі метали, як Pb, Cd, Zn, Cu, Hg та інші визнані найбільш небезпечними забруднюючими речовинами. Виявлено, що близько 90% важких металів, що поступають в навколишнє середовище, акумулюються ґрунтами, які потім мігрують в природні води, поглинаються рослинами і поступають в харчові ланцюги. Певна кількість шкідливих для живих організмів речовин може засвоюватися вирощуваними рослинами і далі по ланцюгах живлення надходити до організму людини. Встановлено, що внаслідок інтенсивного землеробства кількість важких металів у ґрунтах постійно зростає, що призводить до зниження продуктивності і погіршення якості продукції, зокрема, овочевої. Саме овочеві культури забезпечують населення важливими продуктами харчування, а промисловість – сировиною. Тому вивчення інтенсивності накопичення важких металів у овочевій продукції є актуальним і необхідним в сучасних умовах виробництва.

Досліджено інтенсивність забруднення ґрунтів і встановлено відсутність перевищення гранично допустимих концентрацій. Найвищий вміст важких металів у грунтах спостерігався по Zn – 21,4 мг/кг, а найнижчий – по Cd – 0,31 мг/кг. Коефіцієнт небезпеки важких металів у ґрунті досліджуваної ділянки був найвищим по Zn. У *середньостиглих овочів присутнє перевищення гранично допустимих концентрацій по Pb у кабачку-цукіні та квасолі звичайній, по Cd – у огірка та помідорі звичайній, кабачку-цукіні та квасолі звичайній, по Zn – у квасолі звичайній, по Cu – перевищення гранично допустимих концентрацій відсутнє. У пізньостиглих овочів присутнє перевищення гранично допустимих концентрацій по Pb у всіх овочах, по Cd – у часнику городньому, цибулі ріпчастій, моркві звичайній та капусті білокачанній, по Zn – у капусті білокачанній, по Cu – у всіх овочах, окрім капусти білокачанної. Найвищий коефіцієнт небезпеки у середньостиглих овочах був у кабачка-цукіні по Cd, а найнижчий – у квасолі звичайної по Cu. У пізньостиглих овочів найвищий коефіцієнт небезпеки був у цибулі ріпчастої по Pb, а найнижчий – у капусти білокачанної по Cu. Найвищий коефіцієнт накопичення у середньостиглих зразках овочів був у перцю салатного по Cu, а найнижчий – у огірка звичайного по Pb. У пізньостиглих зразках овочів найвищий коефіцієнт накопичення був у цибулі ріпчастої по Cu, а найнижчий – у капусти білокачанної по Pb.*

Ключові слова: *важкі метали, перевищення, інтенсивність накопичення, овочі, гранично допустима концентрація.*

Табл. 3. Рис. 5. Літ. 12.

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