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## Accumulation of Heavy Metals in Agricultural Crops and Ecological Series of Crops Placement

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### Abstract:

The accumulation of toxic elements in vegetables and melons grown in agriculture, *Brassica rapa* - turnip, *Solanum lycopersicum* - tomato, *Citrullus lanatus* - watermelon, *Capsicum annuum* - bell pepper, *Daucus carota* - carrots, *Cucurbita pepo* - pumpkin, *Cucumis melo* - melon, and also *Prunus armeniaca* - apricot from fruit trees were analyzed. The excess of maximum allowable concentrations in agricultural crops of the element As by 1.65-1.75, Cd - 1.6-2.3, Cr - 1.2-2.35, Cu - 1.6-3.3, Ni - 1.16-3.53, Pb - 1.54-3.08, Al - 1.36-3.5, Sb - 2.0-33, Se - 1.1-3.3 times was established. The maximum allowable concentration of mercury in vegetables and melons was equal to 0.02 mg/kg, and in the chosen plants this indicator was close to the maximum allowable concentration (MAC). An ecological series of vegetable and melon crops (tomatoes → pumpkin → turnips → bell peppers → melons → watermelons → carrots) has been developed for their placement on fields contaminated with heavy metals Se, As, Pb, Cd, Zn, included in the first class in terms of the degree of danger to human health, while Ni, Cu, Cr metals were from the second class, and metal Mn from the third class. Agricultural crops in the ecological series are placed in inverse proportion to the regularities of the hyper accumulation of heavy metals in them.

**Keywords:** accumulation of heavy metals, agricultural crops soil, ecological series of vegetable and melon crops, ecological monitoring, heavy metals, toxic elements.

### Introduction:

An increase in the production of agricultural crops leads to soil pollution with their residues and emissions from the environment, accumulation in large quantities of various chemical compounds and has a negative effect on the ecological state of the soil cover. The priority tasks for providing the population with ecologically clean products are soil cleansing, as well as increasing crop yields and improving the quality of agricultural products<sup>1</sup>.

Ecological monitoring is the observation, assessment and forecasting of future changes in environmental pollution as a result of anthropogenic impact. Ecological monitoring is a priority when assessing the contamination of selected soils and agricultural products with heavy metals. This is due

to the fact that for several decades the use of mineral fertilizers in agriculture, as well as the release of waste from various areas of anthropogenic impact, led to their accumulation in the soil cover<sup>2</sup>.

Essential elements such as Cu, Zn, Ni, Co, Mn and others that enter the body are largely absorbed due to their participation in the structure of many enzyme systems and proteins with protective, transport and regulatory function. High levels of micronutrients also lead to intoxication<sup>3</sup>. Manganese in plants predominantly activates the action of various enzymes (or is a part of them), which are of great importance in oxidation - reduction processes, photosynthesis, respiration, etc. Various agricultural crops take out from 100

(barley) to 600 g/ha (sugar beet) manganese with a harvest. Despite the significant content of manganese in soils (100-4000 mg/kg), most of it is in the form of poorly soluble compounds<sup>4</sup>.

The heavy metals which have been studied extensively the last decades are: Cd, Hg, Zn, Cu, Ni, Cr, Pb, and Fe. Some metals that have received more attention are Hg, Cd, and Pb, because of their highly toxic properties and their effects on the environment and the living organisms<sup>5</sup>.

Ecological assessment is a determination of the degree of suitability (favorableness) of the natural and landscape conditions of the territory for human habitation and any type of economic activity. Comprehensive ecological assessment includes landscape differentiation of the territory and analysis of the stability of landscapes to anthropogenic impact, determination of anthropogenic load, assessment of environmental pollution, and determination of the severity of the ecological situation<sup>6</sup>.

Among them, the soil cover plays a special role. Such pollutants accumulate in the atmosphere in the form of heavy metals and enter the soil. As a result of the impact of anthropogenic factors, we create two types of cases, consciously and unconsciously, the composition of the soil is ecologically unsuitable and polluted<sup>7</sup>. The distribution of heavy metals over the organs of plants is determined mainly by the properties of metals and the specific characteristics of plants but in most cases does not depend on seasonal and edaphic conditions. According to some authors, the distribution of metals in a plant is determined by the peculiarities of the genotype to a greater extent than the process of accumulation of elements. In this regard, plant species and even their varieties can differ significantly in the distribution of heavy metals between organs. In general, the distribution of metals in plants takes place as follows: root > stem > leaf > fruits (seeds). On average, above-ground organs contain 10-15, and according to some sources, 20 times less heavy metals than plant roots. The ability of the roots to retain heavy metals limits their further transport to the aboveground organs. At the same time, many studies show that with an increase in the content of heavy metals in the environment, their accumulation increases both in the roots and in the aerial part - stems, leaves and generative organs<sup>7</sup>.

According to many scientists, plants are the main key in the ecological chain relating all objects of the biosphere. The absorption of various kinds of toxic elements by plants, including heavy metals, is the most dangerous.

The eating of plants collected in contaminated areas can threaten the health of the population, negatively affecting the work of internal organs and the physiological processes taking place in them. From plant raw materials, heavy metals pass into food, and then enter the human body. Therefore, the study of ecological cleanliness of plant materials and extracts based on them is relevant<sup>8</sup>.

Composting is very cheap and reliable techniques for the solid waste containing organic matter. If the compost contains contaminants such as heavy metal (HM) then it will be harm to the environment. Heavy metals are toxic to soil, plants, aquatic life and human health if their concentration is high in the compost. HMs exhibit toxic effects towards soil biota by affecting key microbial processes and decrease the number and activity of soil microorganisms. Even low concentration of HMs may inhibit the physiological metabolism of plant. Uptake of HMs by plants and subsequent accumulation along the food chain is a potential threat to animal and human health. Contaminants in aquatic systems, including HMs, stimulate the production of reactive oxygen species (ROS) that can damage fishes and other aquatic organisms. Hence the compost has to be used for agriculture it should be free from HMs. Therefore, the present study evaluated the effects of HMs containing compost on soil, plants, human health and aquatic life<sup>9</sup>. In urban lands, the presence of heavy metals (HMs) mainly originated from industrial emissions and traffic, whereas in rural lands the HMs pollution came from warfare activities, sewage sludge, mining, drilling, electroplating, tannery, fertilizers and pesticides. The use of HMs polluted lands for crops cultivation primarily causes reduction in the total yield and results in edible parts contamination, which harmfully disturb human health. There are important health risks associated to wastewater use for agriculture, which is a probable source of HMs such as Fe, Cu, Mn, Zn, Cd, Ni, Cr, and Pb<sup>10</sup>. Human can get "his share" of HMs not only directly from the inhaled air and soil dust, but also through food produced on contaminated agricultural lands<sup>11</sup>.

Monitoring studies for 1996-2006 in the city of Yerevan, the accumulation of certain elements (Pb, Ni, Cu) in vegetables in concentrations exceeding many times the maximum allowable concentrations was revealed. Thus, the lead content was the most high in basil and exceeded the maximum allowable concentration (0.5 mg/kg) by more than 10 times, in pepper - 3 times, and in tomato - 4.4 times<sup>12</sup>.

The highest measured chromium content exceeded the median value by almost 10 times. The content of arsenic in the soil exceeded the limit value of 25

mg/kg in both years. The average values of arsenic were 25.83 mg/kg in 2019 and 27.17 mg/kg in 2020. The toxic effects of Cd and As are potentially greater than those of other heavy metals<sup>13</sup>.

Analysis of the results of the 2007 study showed, that in plant products nickel and lead have been accumulating most of all. The average concentrations of these elements exceeded the MAC in vegetables: Ni - by 4.6-12.0 and Pb - by 2.7-10.6 times. The main purpose was the assessment of the safety of vegetable food for the prevention of potential risks for the population health. The accumulation of nickel and lead in vegetables in concentrations exceeding maximum permissible limits was found out. The high concentrations of lead and mercury were identified in mulberry fruits<sup>14</sup>.

According to the estimates of the World Health Organization, the average intake of aluminum in the human body from all possible sources (water, food, packaging, air) ranges from 11 to 136 mg per person per week. For European countries, this index is 11 - 91 mg per person per week. According to the EFSA estimate, depending on the scenario taken into account, the consumption of five aluminum-containing food additives (aluminum-ammonium sulfate (E523)); acidic sodium aluminophosphate (E 541); sodium aluminum silicate (E 554); calcium aluminosilicate (E 556); aluminosilicate (kaolin) (E 559)) by the population of different age groups (children of primary and school age, adolescents, adults, the elderly) ranges from 2.3 to 76.9 mg/kg of body weight per week on average and from 7, 4 to 145.9 mg/kg body weight per week for 95% of the population<sup>15,16</sup>. Aluminum is one of the most abundant metals on our planet. It is widely used in industry, it is also found in the air as an oxide. And aluminum is also found in food, dishes, drugs and does not pose a particular threat. This metal penetrates into the body along with food, in the form of food additives or during cooking in aluminum dishes, using foil for baking, using packaging boxes, vegetables and fruits canned in cans. Its effect on the body is expressed in the formation of phospholipids, which slow down the activity of enzymes, which can cause poor memory and Alzheimer's disease<sup>17</sup>.

For vegetable and melons gourds, there is a unit for the maximum allowable concentration of heavy metals (MAC), which is defined as 30 mg of aluminum per kilogram of product<sup>18</sup>.

Arsenic is a highly toxic substance, a well-recognized poison that is used as a drug to fight anemia, to improve appetite. Arsenic enters the body with vegetables and fruits, which have

absorbed it from the ground in which it has accumulated. Usually this poisonous substance strikes the liver, skin, hair, nails. May cause cancer of the larynx, eyes and leukemia<sup>17</sup>. Cadmium is one of the toxic elements (similar to mercury), capable of actively accumulating in the body in large quantities. Cadmium can cause muscle pain and fragility of bones, kidneys and lungs. It accumulates in the kidneys, lungs and adrenal glands and can cause cancer, kidney failure, infertility and bone deformities<sup>17</sup>.

According to the data obtained by Ramankova A.A. and Batlutskaya I.V, the maximum concentrations of cadmium (Cd) accumulate in the leaves and roots, the maximum concentration of lead (plumbum) - in the inflorescences and leaves of the analyzed plants<sup>19</sup>.

The average content of the copper in the soil is 15-20 mg/kg. The total world reserves of copper in ores are estimated at 465 million tons. The total content of copper in the phytomass of the continents is 25 million tons, the mass fraction of copper in plants is  $2 \cdot 10^{-4}\%$ . Soil solutes contain copper at a concentration of 0.001-0.06 mg/l. The maximum allowable concentration of copper in vegetable and melon crops is 10 mg/kg<sup>17</sup>.

Mercury is highly toxic to all types of life. Mercury vapor is phytotoxic and manifests itself in slowing down the growth of branches and roots of plants and accelerating the aging of plants. This is one of the trace elements that is always present in the human body. In the absence of contact with mercury, about 1 mg% mercury was found in the kidneys in 67% of the cases studied and about 1 mg% mercury in the liver in 33%. In industrial settings, the ingestion of mercury through the respiratory tract into the body in the form of vapor or dust is of paramount importance<sup>17</sup>.

Nickel is the main route for food to enter the body. These include cocoa and tea, chocolate, milk and milk products, legumes, nuts, seeds, whole grains, buckwheat, oatmeal, fish, seafood, meat, intestines, eggs, mushrooms, apricots, currants, cherries, onions and dill, sorrel, salads, carrots and some other vegetables. One person receives up to 0.6 mg of nickel per day; but, according to scientists, a person needs from 100 to 300 mcg. If a little nickel gets into the body, then the blood sugar level may rise slightly, but the hemoglobin level will decrease; the growth of children has slowed down. When nickel enters the body with food, it can cause the development of tumors and mutations that pass through the cell<sup>20</sup>. Lead is one of the most toxic mineral elements. It is believed that up to 85% of lead in the human body comes from food. Although under natural conditions it is present in all plant

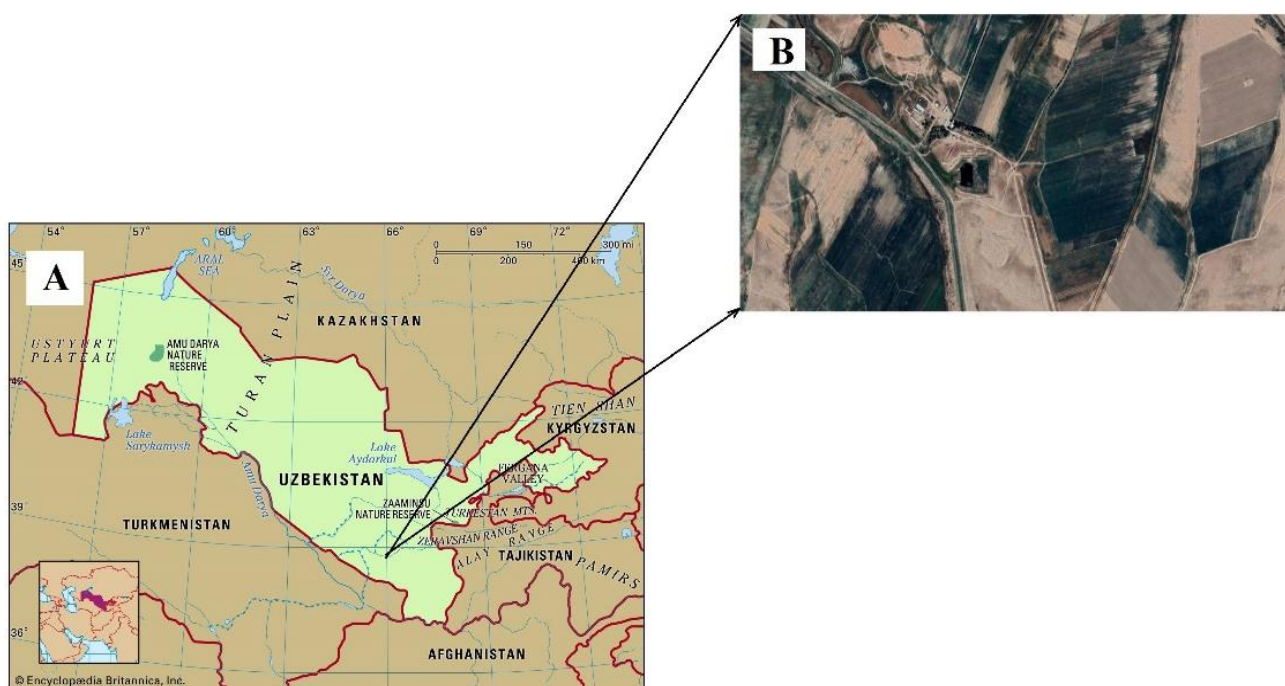
species, the role of this element in metabolism has not yet been identified. The normal concentration of lead in plants is in the range of 0.5-10 mg/kg, toxic - 30-300 mg/kg<sup>21</sup>.

This work was performed via (i) analysis of the amount of toxic heavy metals in vegetable and melon crops, (ii) determination of the state of contamination with heavy metals, (iii) based on the state of accumulation of heavy metals in vegetable and melon crops, the development of an ecological series of vegetable and melon crops, which determines their placement on agricultural land according to the degree of their ability to accumulate heavy metals, that is, on fields heavily contaminated with heavy metals, place crops that weakly accumulate heavy metals. Such placement of crops reduces the accumulation of toxic heavy metals in them.

### Materials and Methods:

The present work has used materials of local agro-ecological monitoring, held in the Guzar

district of the Kashkadarya region. The climate of the studied area, Guzar district, located in the southeast of the Kashkadarya region of the Republic of Uzbekistan, is continental. The average annual temperature is 16°C. The average temperature in January is 1.9°C, the lowest temperature is -23°C. The average temperature in July is 26.6°C, the highest temperature is 46°C. The average annual rainfall is 285 mm. Most of the precipitation falls in spring and winter. The growing season is 272 days. The soils are light and typical gray soils. The irrigated area of the Burkhan farm, where crops were studied, is 47.4 ha, and the area of the Guzar White Horse farm is 180 ha, the fields are located at an altitude of 415-430 meters above sea level (Fig. 1).



**Figure 1. Geographical overview of the study area (Image source: Google Earth scene from September 2019).**

The concentration of toxic elements in crop products was measured in accordance with SanPiN No. 0366-19<sup>22</sup>. The content of heavy metals in crop products was determined according to the generally accepted method<sup>16</sup>. Analysis of results was performed on the basis of a computer program of statistical analysis, which was carried out on 24 elements of the periodic table. Physicochemical

analyses were carried out on the consumable parts of all plants selected for the content of heavy metals according to the method of <sup>23</sup>. Analyzed As, Cd, Cr, Cu, Hg, Ni, Pb, Al, Fe, Sb, Se and Zn, are the maximum allowable concentration of accumulated elements in plants<sup>22, 24</sup>.

The exchange of lead in the human and animal body has been studied very little. Its biological role is

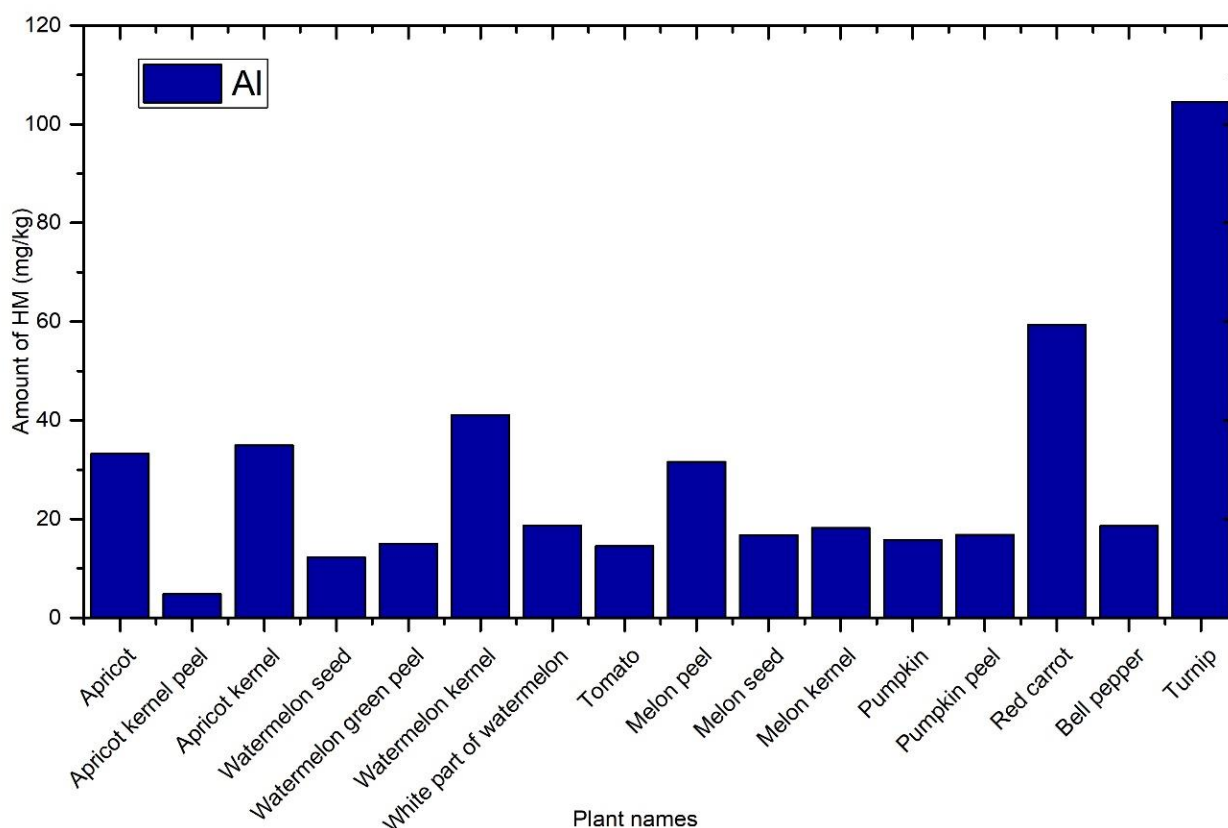
also not completely clear. It is known that lead enters the body with food (0.22 mg), water (0.1 mg) and dust (0.08 mg). Usually, the lead content in the body of men is about 30 mcg %, and in women it is about 25.5 mcg %. From a physiological point of view, lead and almost all of its compounds are toxic to humans and animals. Lead, even in very small doses, accumulates in the human body, and its toxic effect gradually intensifies<sup>25</sup>.

**Results:**

To analyze the elements, the accumulation of which is observed in vegetable and melon crops grown in agriculture, *Brassica rapa* - turnip, *Solanum lycopersicum* - tomato, *Citrullus lanatus* - watermelon, *Capsicum annuum* - bell pepper, *Daucus carota* - carrot, *Cucurbita pepo* - pumpkin, *Cucumis melo* – melon were selected, *Prunus armeniaca* - apricot was selected from fruit trees.

The turnip is a root vegetable, its root vegetable contains the element Al (aluminum) in the amount of 104.6 mg/kg, that is, 3.5 times higher than the MAC. In addition, among the selected

crops, the content of 59.4 mg/kg was found in carrots, which is 1.98 times higher than the MAC. In a separate study of pieces of watermelon, the following results were obtained. The highest indicator was found in the core of watermelon - 41 mg/kg, in the seed part of the watermelon - 12.3 mg/kg, in the green peel of the watermelon - 15.0 mg/kg, in the white part - 18.7 mg/kg. The average content of the aluminum element in watermelon, 21.81 mg/kg, may not exceed the maximum allowable concentration, but in the part of watermelon consumed by humans, this element turned out to be 1.37 times higher than the MAC. It was found to be 18.2 mg/kg in the central part of the melon kernel, 17.2 mg/kg in the seed part and 31.6 mg/kg in the peel part of the melon. In vegetables and melons gourds, as well as in apricots, high concentrations of the Al element were found, exceeding the MAC. The highest concentration of the Al element was found in the turnip plant, which poses a danger to human health (Fig. 2. and Table 1).



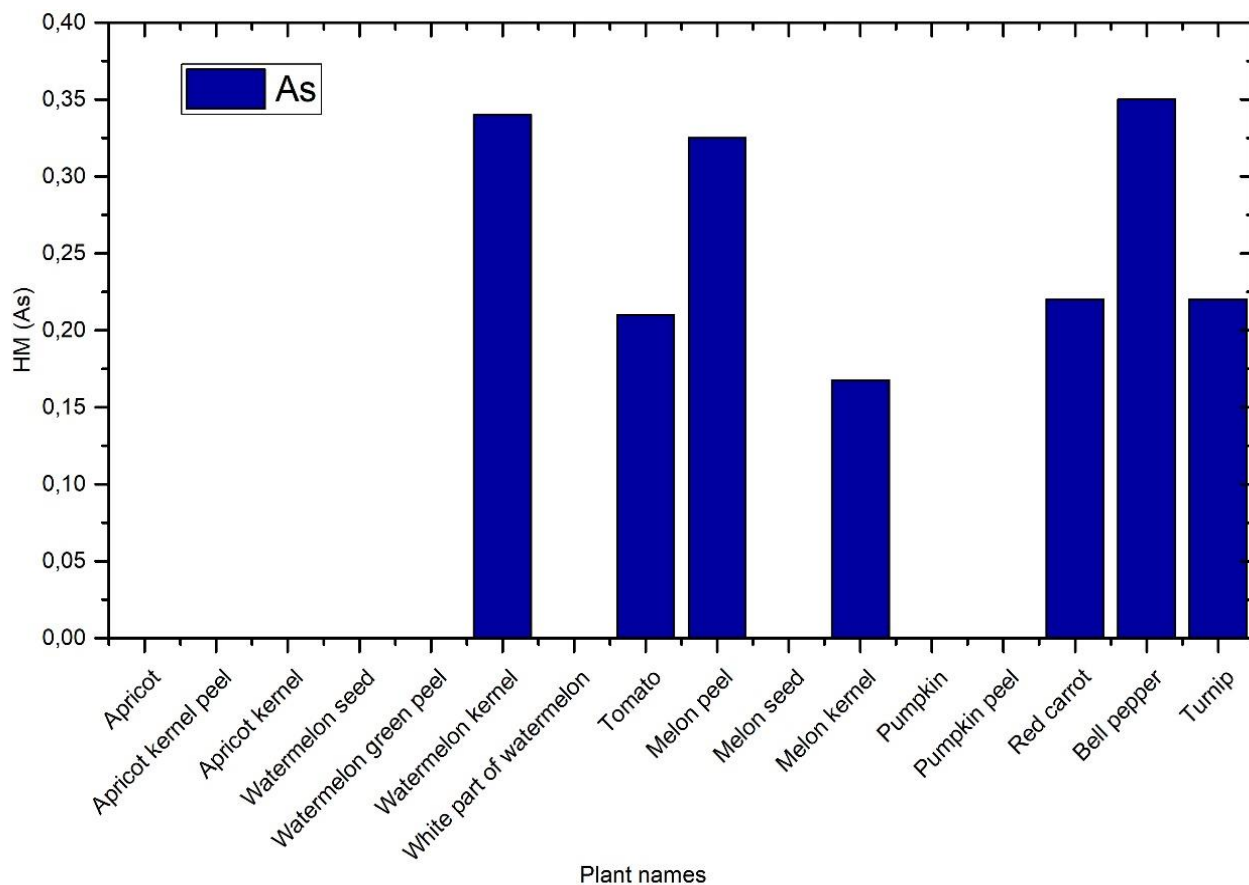
**Figure 2. Accumulation of the Al element in agricultural crops.**

Considering that the maximum allowable concentration of As (arsenic) for vegetable and melon crops is 0.2 mg/kg, based on the above-mentioned analyzes of agricultural products, we can

say that the arsenic content in tomatoes, in the hearts of melons and watermelons, in red carrots and bell peppers is slightly higher than the MAC. Melon kernels turned out to be within the MAC, but

in the melon peels 1.65 times more, watermelon kernels, red carrots and tomatos - 1,1 times, and bell pepper - 1.75 times the MAC. No arsenic

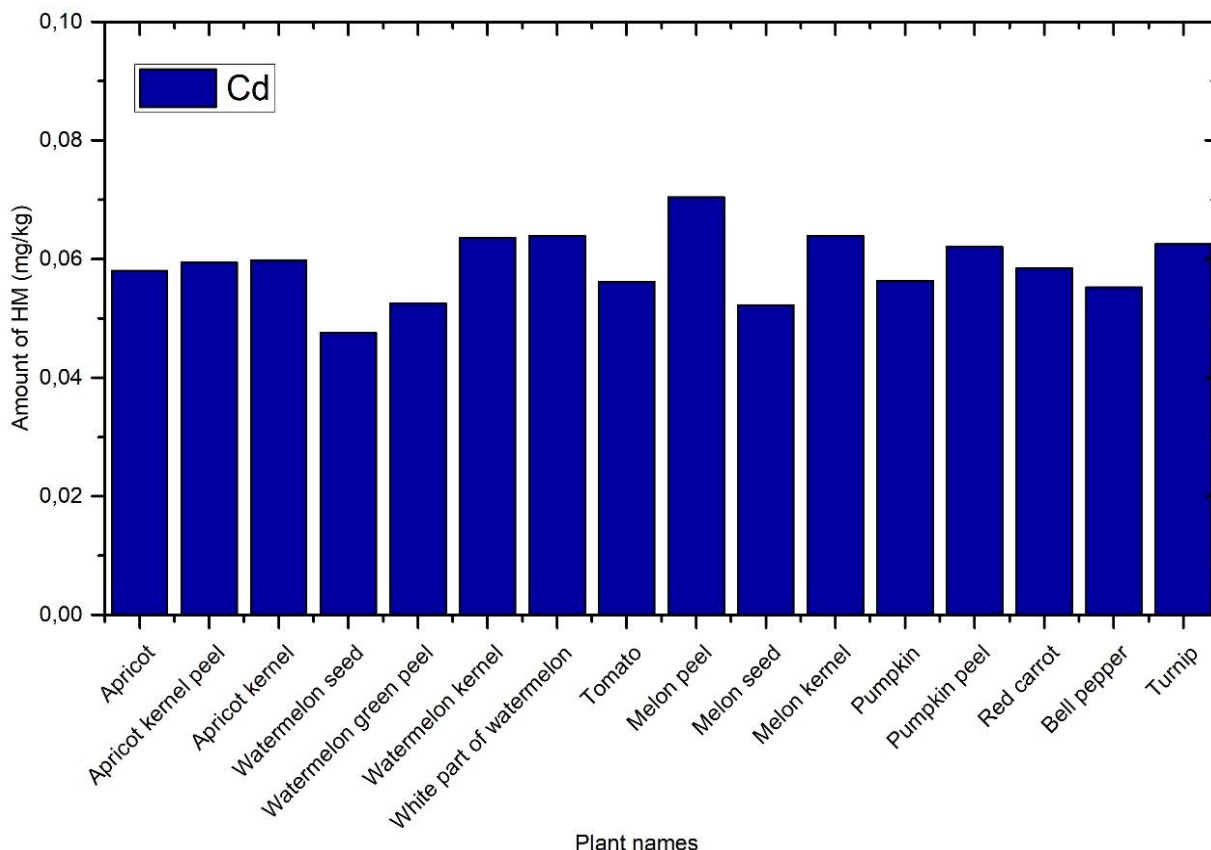
accumulation was observed in the fruit tree plant (Fig. 3. and Table 1).



**Figure 3. Accumulation of the As element in agricultural crops.**

The maximum allowable concentration amount of Cd (cadmium) for vegetable and melon crops is 0.03 mg/kg, at the same time, it was found that in all monitored plants, the content of the element

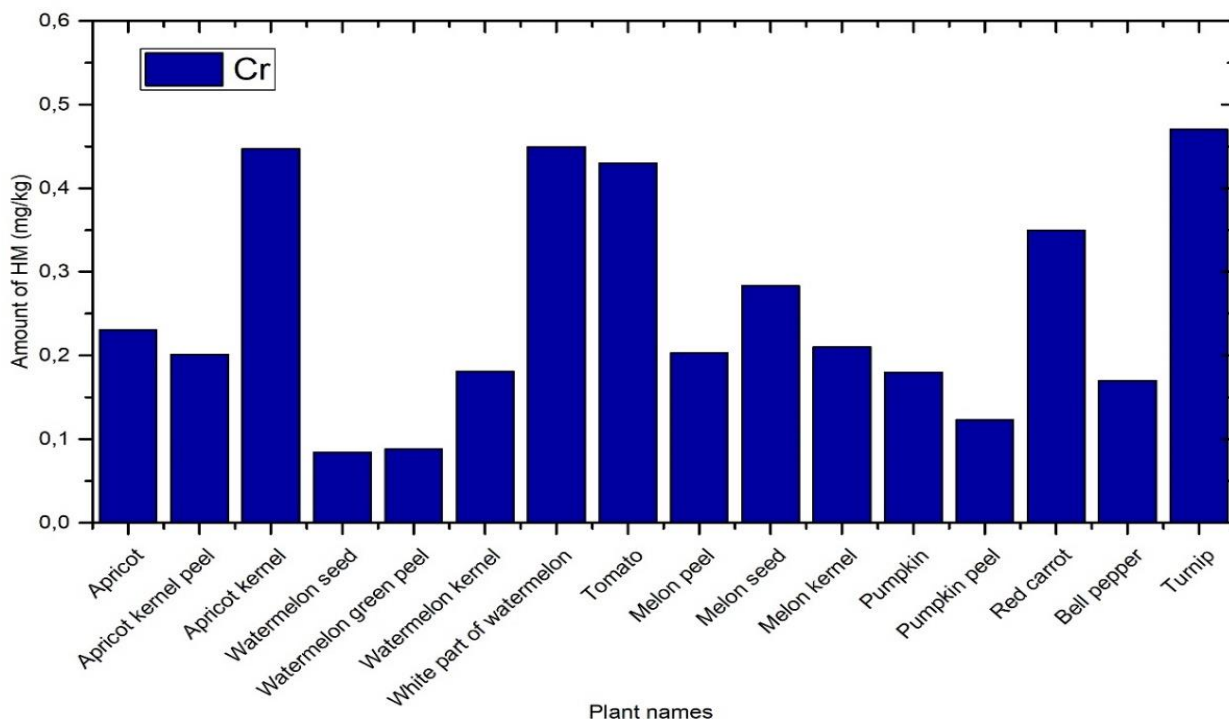
exceeds the maximum allowable concentration (MAC). The highest indicator was found in melon peel, namely 0.07 mg/kg, which is 2.3 times higher than the MAC (Fig.4. and Table 1).



**Figure 4. Accumulation of the Cd element in agricultural crops.**

The maximum allowable concentration for Cr (chromium) in melons and vegetables is 0.2 mg/kg, and the highest accumulation is found in the turnip root crop, and this indicator is 2.35 times higher than the MAC, and in tomatoes this indicator is 2.15

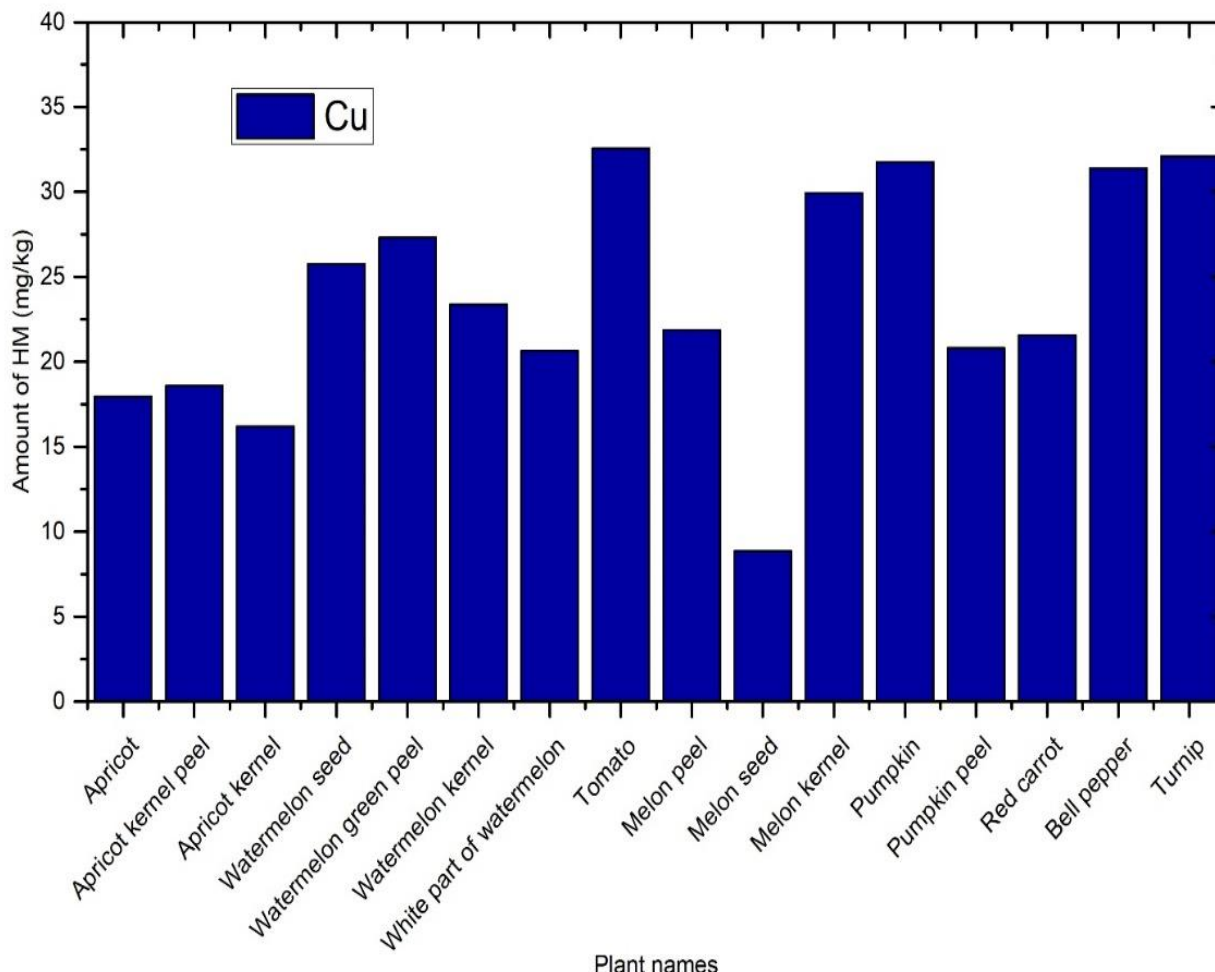
times higher than the MAC. It was found that peels and kernels of bell pepper and pumpkin do not exceed the MAC, but in the watermelon kernel 0.18 mg/kg, and in the white part - 2.25 times more than the MAC (Fig.5. and Table 1).



**Figure 5. Accumulation of the Cr element in agricultural crops.**

The accumulation of the element Cu (copper) in the tomato plant is 3.3 times higher than the MAC, in the melon kernel - by 7.0 mg/kg more than in the watermelon kernel. The element copper accumulates in greater quantities than in fruit trees,

and differs twice as much. The content of the element copper in vegetables and melon crops forms the following descending series: tomato → turnip → pumpkin → bell pepper → watermelon → carrot → melon (Fig.6. and Table 1).

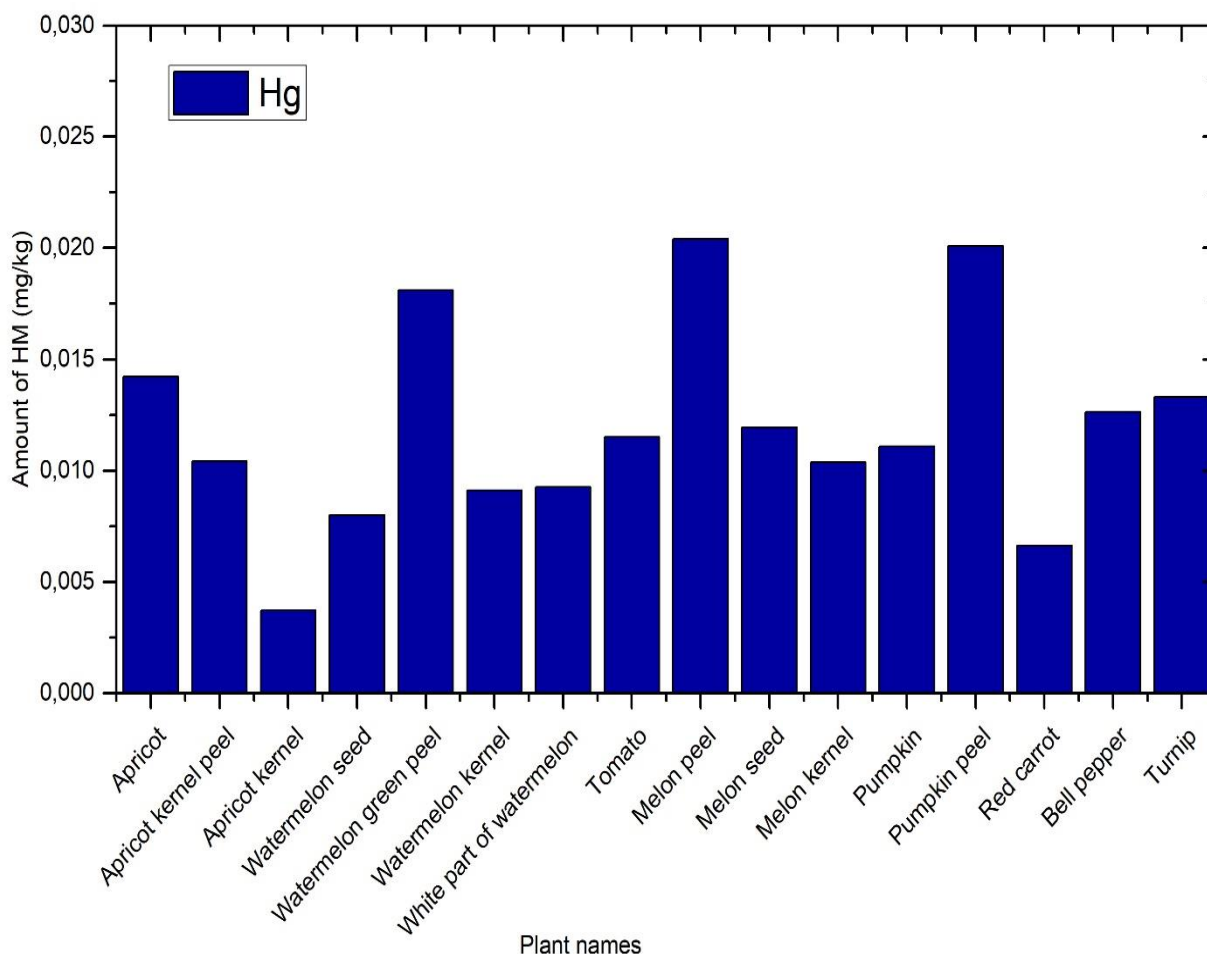


**Figure 6. Accumulation of the Cu element in agricultural crops.**

The maximum allowable concentration for vegetables and melon crops for the element of Hg (mercury) is 0.02 mg/kg, and it can be seen that in individual plants these values are close to the allowable concentration. Element mercury observed in the peels of melon and pumpkin in the range of 0.0204-0.0201 mg/kg. In the green peel of the watermelon, 0.181 mg/kg was noted. In

ecologically suitable parts for consumption, the mercury content is about 0.0037-0.0142 mg/kg. From an ecological point of view, it can be said that the mercury element in the soil is less than the MAC, and it was found that some plants have an accumulation process in the bark layer (Fig.7. and Table 1).





**Figure 7. Accumulation of the Hg element in agricultural crops.**

The MAC for the mobile form of Ni (nickel) in the soil is 4 mg/kg, and the MAC for vegetables and melon crops is 0.5 mg/kg. When assessing the ecological value of crops grown in the study area, one should pay attention to the toxic elements in the plant. The nickel content in tomatoes and pumpkins is 1.608-1.761 mg/kg, which, respectively, is 3.22-3.52 times higher than the MAC. The amount of nickel in the pumpkin peel is also 0.389 mg/kg. When studying a watermelon by dividing it into

parts, the green peel, white peel, core and seeds, only in the white part of the watermelon the element is 1.37 times more than the MAC. However, it has been proven, that edible kernels to be harmless to the environment. The element nickel is 1.2 times higher than the allowable concentration in seeds and kernels of melons, 1.26-1.25 mg/kg in red carrots and turnips, 0.866 mg/kg in bell peppers, which is 1.2-3.5 times higher the MAC in vegetables and melon crops (Fig.8. and Table 1).

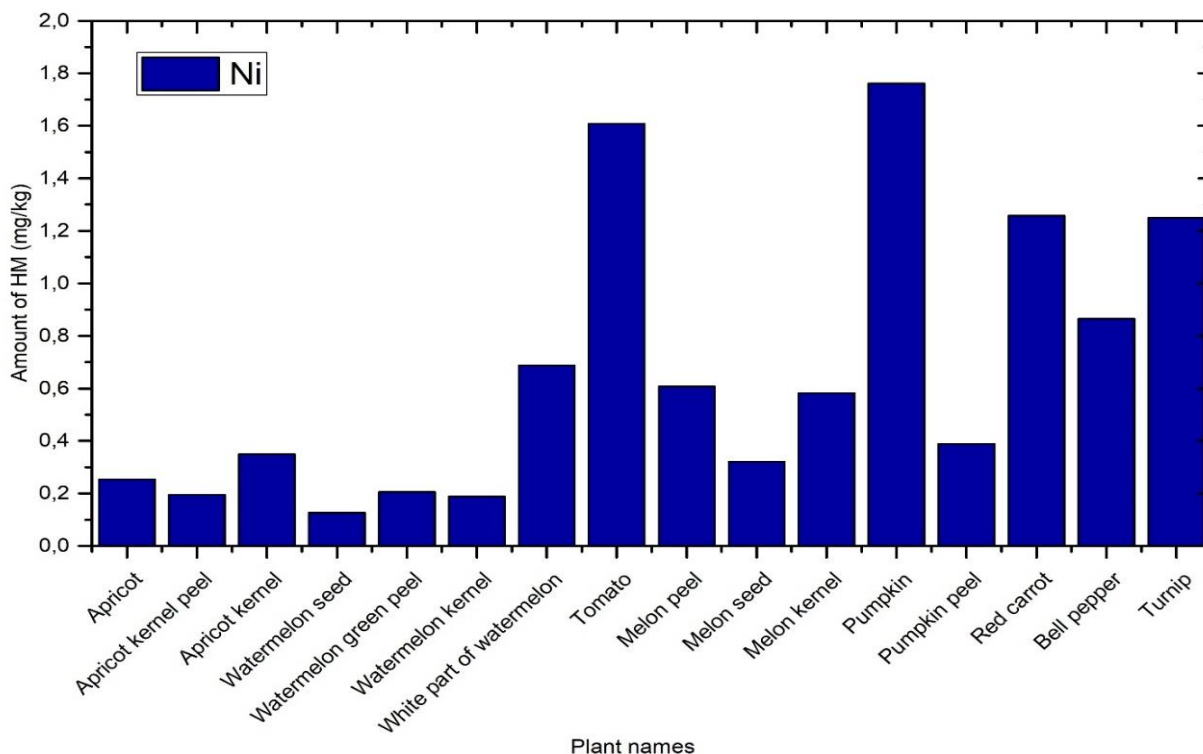


Figure 8. Accumulation of the Ni element in agricultural crops.

The maximum allowable concentration for vegetables and melon crops for the element of Pb (lead) is 0.5 mg/kg. In different parts of the watermelon, the element of lead is contained in different amounts, the highest lead content in the kernel of the watermelon is 1.1 mg/kg, which is 2.2 times more than the MAC, in the white part the

accumulation is 0.52 mg/kg. In the melon kernel, the lead content is 0.783 mg/kg, which is 1.56 times more than the MAC, and 1.542-1.49 mg/kg is accumulated in tomatoes and bell peppers, on average 3.08 times more, than MAC (Fig.9. and Table 1).

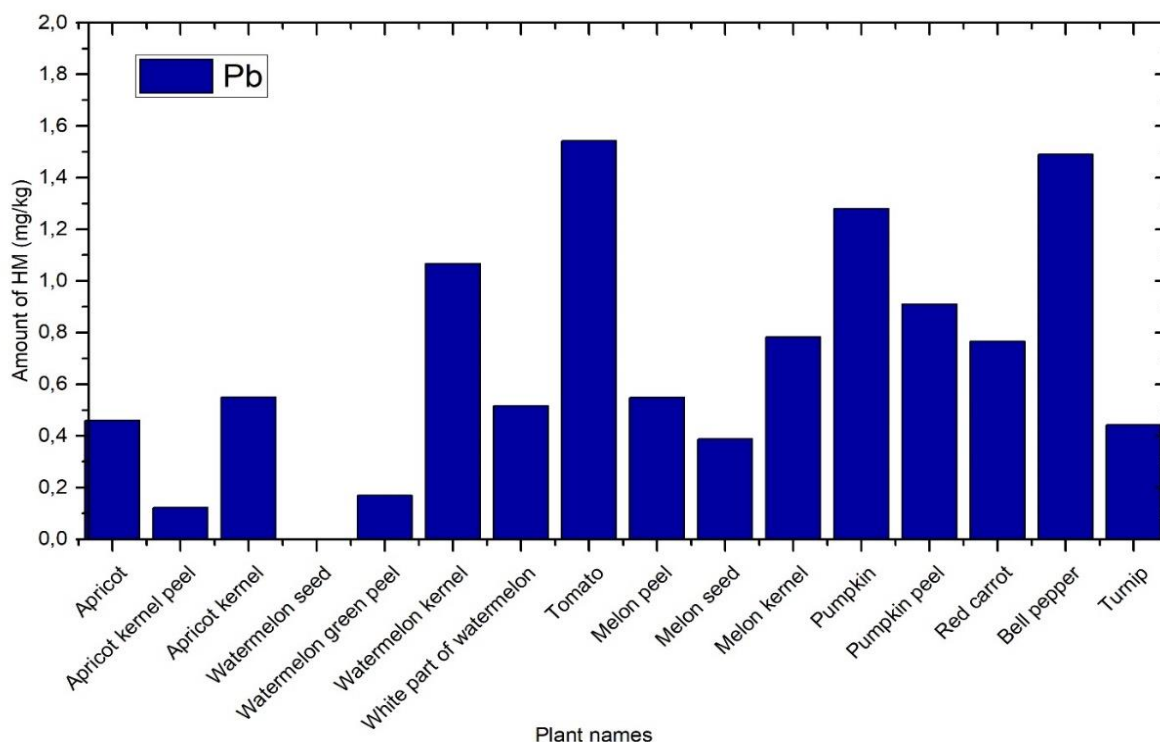


Figure 9. Accumulation of the Pb element in agricultural crops.

Only in turnip plants, the Zn (zinc) element is 1.7 times higher than the MAC, and the Fe (iron) element in the white part of watermelon and tomatoes is 1.3-1.4 times higher than the MAC.

**Table 1. The accumulation of heavy metals in plants and their parts as (mg/kg plant matter).**

Plant parts	Cr	Co	Cd	Be	As
Apricot	0.23±0.03	5.80±0.61	0.058±0.01	0.52±0.04	ND
Apricot kernel peel	0.20±0.02	6.45±0.09	0.059±0.02	0.52±0.032	ND
Apricot kernel	0.45±0.03	7.25±0.05	0.06±0.02	0.54±0.046	ND
Watermelon seed	0.08±0.03	11.50±0.05	0.048±0.016	0.53±0.035	ND
Watermelon green peel	0.09±0.01	12.94±0.08	0.053±0.01	0.67±0.063	ND
Watermelon kernel	0.18±0.02	4.51±0.21	0.064±0.008	0.59±0.07	0.34±0.12
White part of watermelon	0.45±0.03	3.0±0.06	0.064±0.01	0.50±0.03	ND
Tomato	0.43±0.10	5.0±0.24	0.056±0.014	0.64±0.028	0.21±0.066
Melon peel	0.20±0.03	0.03±0.012	0.07±0.012	0.58±0.030	0.33±0.18
Melon seed	0.28±0.02	0.01±0.002	0.052±0.009	0.52±0.034	ND
Melon kernel	0.21±0.05	2.11±0.25	0.064±0.011	0.54±0.031	0.17±0.037
Pumpkin	0.18±0.02	2.66±0.11	0.056±0.01	0.51±0.031	ND
Pumpkin peel	0.12±0.02	5.43±0.03	0.062±0.012	0.41±0.030	ND
Red carrot	0.35±0.03	4.50±0.66	0.058±0.091	0.50±0.051	0.22±0.06
Bell pepper	0.17±0.04	3.75±0.15	0.055±0.0081	0.43±0.038	0.35±0.075
Turnip	0.47±0.05	0.73±0.04	0.063±0.011	0.69±0.044	0.22±0.076

Cr - chromium, Co - cobalt, Cd - cadmium, Be - beryllium, As - arsenic, ND-not detected.

**Table 1. (cont.) The accumulation of heavy metals in plants and their parts as (mg/kg plant matter).**

Plant parts	Al	Fe	Hg	Ni	Pb
Apricot	33.24±8.06	43.84±1.09	0.0142±0.002	0.25±0.02	0.46±0.031
Apricot kernel peel	4.83±0.34	4.18±0.28	0.0104±0.001	0.19±0.0014	0.122±0.56
Apricot kernel	34.94±0.31	9.43±0.37	0.0037±0.002	0.35±0.04	0.55±0.044
Watermelon seed	12.25±0.11	3.50±1.107	0.008±0.002	0.126±0.041	ND
Watermelon green peel	15.0±0.35	0.437±0.005	0.0181±0.0015	0.206±0.018	0.169±0.006
Watermelon kernel	41.03±10.67	33.94±0.05	0.0091±0.0015	0.188±0.024	1.10±0.052
White part of watermelon	18.65±0.35	61.75±0.116	0.0093±0.0013	0.688±0.046	0.52±0.0057
Tomato	14.51±3.79	69.35±0.147	0.0115±0.0042	1.608±0.056	1.542±0.135

Melon peel	31.63±0.27	10.47±0.008	0.0204±0.0016	0.607±0.19	0.55±0.012
Melon seed	16.76±1.88	6.05±0.0072	0.012±0.0013	0.321±0.10	0.39±0.018
Melon kernel	18.16±3.80	41.06±2.25	0.0104±0.0013	0.58±0.01	0.783±0.011
Pumpkin	15.72±0.69	32.51±5.50	0.011±0.0015	1.761±0.22	1.28±0.29
Pumpkin peel	16.80±0.54	2.93±1.02	0.0201±0.0011	0.389±0.087	0.91±0.051
Red carrot	59.39±24.17	8.03±0.68	0.0066±0.0027	1.26±0.011	0.77±0.079
Bell pepper	18.60±7.35	34.10±3.32	0.0126±0.003	0.866±0.008	1.49±0.040
Turnip	104.58±28.38	17.28±1.63	0.0133±0.0013	1.25±0.36	0.44±0.014

Al - aluminum, Fe - iron, Hg - mercury, Ni - nickel, Pb - lead, ND-not detected.

**Table 1.(cont.) The accumulation of heavy metals in plants and their parts as (mg/kg plant matter).**

Plant parts	B	Ba	Cu	Li	Mn
Apricot	129.3±7.50	36±4.99	17.94±0.90	19.87±1.48	23.28±1.62
Apricot kernel peel	25.88±3.82	33±2.41	18.59±0.16	15.13±1.36	14.23±0.73
Apricot kernel	126.3±6.33	34±2.37	16.19±0.06	44.9±3.39	28.5±2.10
Watermelon seed	57.44±4.11	33±2.17	26±1.59	39.4±2.48	32.8±3.08
Watermelon green peel	158.13±14.3	39±2.20	27±1.61	56±3.21	12.9±1.23
Watermelon kernel	57.30±4.02	28±1.27	23.4±1.73	22.41±2.85	21.56±2.43
White part of watermelon	65.13±3.50	41±4.93	20.7±1.18	10.76±1.47	48.25±4.12
Tomato	24.24±1.61	36±2.47	33±2.61	15.3±2.46	34.75±2.69
Melon peel	47.88±1.54	48±2.91	21.86±1.72	8.63±1.23	50.38±4.44
Melon seed	64.38±3.47	40±2.30	8.86±1.45	13.41±1.19	136.8±12.4
Melon kernel	139±11.02	43±3.61	30±2.47	16.8±1.48	31.4±2.21
Pumpkin	74.08±3.03	37±2.86	32±3.41	6±1.128	21.5±2.06
Pumpkin peel	34.25±1.60	36±2.27	21±2.22	7.75±1.17	19.6±1.70
Red carrot	69.11±3.85	60±5.12	21.54±1.44	10±1.46	55.3±4.13
Bell pepper	37.43±2.04	34.83±2.45	31.38±2.37	10.77±1.56	38±2.68
Turnip	99.3±3.31	54.08±4.49	32.08±1.47	ND	122.75±3.5

B - boron, Ba - barium, Cu - copper, Li - lithium, Mn - manganese, ND-not detected.

**Table 1.(cont.) The accumulation of heavy metals in plants and their parts as (mg/kg plant matter).**

Plant parts	Mo	Sb	Se	Sr	Tl
Apricot	9.14±0.89	3.5±0.65	0.74±0.041	47.55±3.91	44.60±2.04
Apricot kernel peel	10.92±1.29	ND	0.53±0.009	23.08±1.21	18.1±0.45
Apricot kernel	18.58±1.38	5±0.97	0.42±0.012	44.8±3.35	66±5.18
Watermelon seed	9.38±0.81	10±1.21	0.99±0.022	10.08±0.78	74.8±4.34
Watermelon green peel	13.06±1.27	4±0.72	1.45±1.15	164.5±4.8	49.4±2.13
Watermelon kernel	10.99±1.65	5±1.02	1.41±1.22	44.35±2.73	26.48±1.21
White part of watermelon	15.95±1.32	0.6±0.08	1.07±0.024	191.88±2.30	20.52±1.14
Tomato	9.3±0.62	2±0.62	1.63±1.34	41.9±1.22	37.57±1.54
Melon peel	11.23±1.23	ND	1.56±1.30	223.1±2.11	46.4±2.21

Melon seed	15.23±1.28	5±0.99	0.88±0.019	56.3±3.16	12.08±1.03
Melon kernel	11.56±1.22	7±0.98	0.59±0.014	125.3±3.97	53.05±4.26
Pumpkin	8.28±0.52	4±0.65	0.57±0.016	152.7±5.14	49.13±2.085
Pumpkin peel	13.48±1.16	ND	1.62±1.31	91.5±2.18	23.2±2.076
Red carrot	10.05±0.53	5±0.79	0.82±0.021	137.60±3.89	48.73±2.76
Bell pepper	12.23±1.26	4±0.58	0.90±0.022	29.93±3.12	19.06±1.46
Turnip	18.23±2.17	5±0.63	1.65±1.34	745.8±6.22	24.78±1.78

Mo - molybdenum, Sb - antimony, Se - Selenium, Sr - Strontium, Tl - Thallium, ND-not detected.

**Table 1.(cont.) The accumulation of heavy metals in plants and their parts as (mg/kg plant matter).**

Plant parts	U	V	W	Zn
Apricot	0.9±0.02	4.3±0.42	2±0.97	2±0.8
Apricot kernel peel	0.6±0.03	3.2±0.2	ND	1.6±0.4
Apricot kernel	0.7±0.04	3.1±0.24	5±1.13	1.3±0.45
Watermelon seed	0.54±0.02	3.1±0.39	2±0.86	3.8±1.51
Watermelon green peel	0.9±0.05	3.3±0.41	7±2.75	1.7±0.6
Watermelon kernel	1.0±0.11	3.7±0.36	7±3.17	5.8±1.65
White part of watermelon	0.6±0.04	3.5±0.42	7±3.49	6.6±2.89
Tomato	1.0±0.09	3.6±0.39	4±1.69	5.2±1.17
Melon peel	1.0±0.12	4±0.64	17±3.035	5.2±2.13
Melon seed	1.1±0.08	2.38±0.37	11±1.035	4±1.81
Melon kernel	0.6±0.03	3.2±0.67	12±1.67	2.8±3.11
Pumpkin	0.9±0.04	3.5±0.56	8±3.86	7.5±4.12
Pumpkin peel	0.4±0.03	3.4±0.65	4±1.05	4.4±0.98
Red carrot	0.5±0.07	4.3±0.89	8±2.069	5.1±1.21
Bell pepper	0.6±0.08	3.1±0.36	5±1.16	5.8±2.18
Turnip	0.4±0.03	4.5±0.86	23±1.17	17.1±3.22

U - uranium, V - vanadium, W - wolfram, Zn - zinc, ND-not detected.

The recommended concentration levels of the analyzed heavy metals by FAO/WHO in vegetables is shown in Table 2<sup>26</sup>.

**Table 2. FAO/WHO maximum permissible values of heavy metals in vegetables**

Element	FAO/WHO maximum permissible values (mg/kg)
Cd	0.2
Pb	0.3
Ni	67.9
Fe	425.5
Cu	73.3
Zn	99.4

### Discussion:

This state of vegetable and melon crops is ecologically dangerous for consumption and can be the cause of various diseases of the human body. Based on the accumulation of heavy metals in vegetables and melons grown in agriculture, it is recommended to compose a series of plants with a decreasing accumulation of heavy metals in them, to place plants according to ecological state of territories contaminated with toxic elements. Likewise, the turnip had the lowest lead accumulation in the - 0.44 mg/kg, which turned out to be less than the MAC<sup>24</sup>.

On the basis of the analyzes presented in Table 1, an ecological series of the agricultural crops with MAC of heavy metals was developed for the plant composition. As already mentioned at the

end of the introduction, the ecological series of agricultural crops was developed based on the degree of their ability to accumulate toxic heavy metals in themselves. Therefore, in areas contaminated with Al metals (MAC 30 mg/kg), in addition to turnips and carrots, it is recommended to plant melons → watermelons → bell pepper → pumpkin → tomato. This is due to the fact that it was found that the accumulation of the element aluminum in these plant organs is small. It was found that all types of crops grown on soils contaminated with ions of the element arsenic contain a large amount of the element, and based on the data, it is not recommended to collect vegetables and melon cultures. It is not recommended to grow vegetables and melons, as all products grown on soils contaminated with cadmium and chromium ions contain a large amount of the elements Cd, Cr and Cu. This is due to the fact that an excess of allowable elements in the composition of the soil leads to the accumulation of large amounts in all types of vegetables and melon cultures<sup>27</sup>.

The accumulation of heavy metals in the above-mentioned plants is less concentrated only in the organs of watermelon plants and exceeds the allowable norm in all other plant organs. In soils contaminated with the element nickel, it is recommended to plant watermelon and melons from melons.

HM concentrations in *Solanum lycopersicum* and *Solanum melongena* have been found to be higher than permissible limits of FAO. Both plants also have shown elevated bioconcentration factors values for most of measured heavy metals. For *S. lycopersicum* the bioconcentration factor values of Fe, Cd, Cu, Pb, Cr, Mn, Ni, and Zn have been found to be 42.150, 27.250, 1.023, ND, 5.926, 4.649, 29.409, and 0.459 respectively. While for *S. melongena*, they have been 2.360, 21.333, ND, 0.170, ND, 3.113, 50.318, and 0.623, respectively<sup>10</sup>.

The concentrations of Cd, Co, Ni, Zn, and Cu (mg/ kg DW) by tomato and eggplant have been reached to 57.03, 40.44, 326.70, 255.78, and 476.38, respectively for *S. lycopersicum* fruits; and 73.00, 40.47, 319.18, 250.64, and 61.62, respectively for *S. melongena* fruits. These values of metals in tomato and eggplant far exceed the permissible levels of European Union and FAO<sup>27</sup>.

On the basis of a statistical analysis of the features of agricultural crops to accumulate toxic heavy metals in themselves, the following ecological series of agricultural crops were compiled to reduce the degree of accumulation of this heavy metal in them:

1. Al (MAC 30 mg/kg) - turnips → carrots → watermelon → bell pepper → melon → pumpkin → tomato;

2. As (MAC 0.2 mg/kg) - bell pepper → watermelon → turnips → carrots → tomato → melon → pumpkin;

3. Cd (MAC 0.03 mg/kg) - watermelon → melon → turnip → carrot → tomato → pumpkin → bell pepper;

4. Cr (MAC 0.2 mg/kg) - turnip → tomato → carrot → melon → watermelon → pumpkin → bell pepper;

5. Cu (MAC 10 mg/kg) - tomato → turnip → pumpkin → bell pepper → melon → watermelon → carrot;

6. Fe (MAC 50 mg/kg) - tomato → melon → bell pepper → watermelon → pumpkin → turnip → carrot;

7. Hg (MAC 0.02 mg/kg) - turnip → bell pepper → tomato → pumpkin → melon → watermelon → carrot;

8. Ni (MAC 0.5 mg/kg) - pumpkin → tomato → carrot → turnip → bell pepper → melon → watermelon;

9. Pb (MAC 0.5 mg/kg) - tomato → bell pepper → pumpkin → watermelon → melon → carrot → turnip;

10. Sb (MAC 0.3 mg/kg) - melon → watermelon → turnip → carrot → pumpkin → bell pepper → tomato;

11. Se (MAC 0.5 mg/kg) - turnip → tomato → watermelon → bell pepper → carrot → melon → pumpkin;

12. Zn (MAC 10 mg/kg) - turnip → pumpkin → bell pepper → tomato → carrot → watermelon → melon.

### Conclusion:

It is recommended to plant technical crops when the content of lead ions in the soil is higher than the MAC, but it is not recommended to grow vegetables and melon cultures.

Taking into account the accumulation of heavy metals when studying the state of pollution by toxicants of agricultural crops, it is not recommended to plant plants 1, 2, 3 in a series. This is due to the fact that the absorption of toxic heavy metals by plants is dangerous to human health.

All the obtained results of analyzes showed that, from an ecological point of view, the accumulation of toxicants in plant organs occurs as a result of direct and indirect impacts of anthropogenic factors, which ultimately have a negative impact on people themselves through the ecosystem.

In conclusion, it should be noted that all elements with a toxic effect, such as heavy metals in irrigated soils, have a negative impact on the environment, on agricultural products, and also accelerate the process of migration through them.

### Authors' declaration:

- There is no conflict of interests on the article.
- The article does not contain figures, drawings or tables that do not belong to us, the authors of the manuscript.
- Figures, drawings and tables prepared by other authors are not included in the article.
- Ethical Clearance: The project was approved by the local ethics committees of the Karshi State University, the Research Institute of Soil Science and Agrochemistry, the Karshi branch of the Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, the Karshi Engineering and Economic Institute, Uzbekistan

### Authors' contributions statement:

Z.Z.U participated in the development and doing research, laboratory work, presented the analysis, discussed the results and wrote the manuscript.

Kh. N. K presented the idea of research, analyzed it, participated in their development and implementation, discussed the results, participated in the study of literature and contributed to the preparation of the manuscript.

Z.U.U worked on the logic of the presentation of the results, checked the analytical methods, discussed the results, edited the text of the manuscript, participated in the literature review and contributed to the final version of the manuscript.

R.A. E participated in the preparation of figures and diagrams, discussed the results, edited the text of the manuscript and contributed to the final version of the manuscript.

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## تراكم المعادن الثقيلة في المحاصيل الزراعية والسلسلة البيئية لوضع المحاصيل

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### الخلاصة:

الهدف من الدراسة هو تحليل تراكم المعادن الثقيلة في المحاصيل الزراعية، لتطوير سلسلة بيئية لوضع محاصيل الخضار والبطيخ في الحقول الزراعية الملوثة بالعناصر السامة. تم تقدير كمية المعادن الثقيلة في محاصيل الخضر والبطيخ بطريقة الامتصاص الذري. تم تحليل العناصر السامة التي لوحظ تراكمها في الخضار والبطيخ المزروع في المزارع: اللفت، الطماطم، الرقي، الفلفل الحلو، الجزر، اليقطين، البطيخ، أيضا تم تحليل المشمش من أشجار الفاكهة. زيادة التركيزات القصوى المسموح بها في المحاصيل الزراعية للعناصر: الزرنيخ (As) بمقدار 1.75-1.65، Cd - 1.6-2.3، Cr 1.2-2.35، Cu - 1.6-3.3، Ni - 1.16-3.53، Pb - 1.54-3.08، Al - 1.36-3.5، Se - 1.1-3.3، Sb - 2.0-3.3، مرة تم إنشاؤها. كان الحد الأقصى المسموح به لتركيز الزئبق في الخضار والبطيخ يساوي 0.02 مجم / كجم، وكان هذا المؤشر في النباتات المختارة قريبا من الحد الأقصى المسموح به للتركيز (MAC). تم تطوير سلسلة بيئية من محاصيل الخضار والبطيخ (الطماطم ← اليقطين ← اللفت ← الفلفل الحلو ← البطيخ ← الرقي ← الجزر) لوضعها في الحقول الملوثة بالمعادن الثقيلة Se، As، Pb، Cd، Zn، المدرجة في الأول صنف من حيث درجة الخطورة على صحة الإنسان، في حين جاءت معادن النيكل والنحاس والكروم من الدرجة الثانية، ومعدن المنغنيز من الدرجة الثالثة. يتم وضع المحاصيل الزراعية في السلسلة البيئية في تناسب عكسي مع انتظام التراكم المفرط للمعادن الثقيلة فيها. الكلمات المفتاحية: التربة، المحاصيل الزراعية، المعادن الثقيلة، العناصر السامة، تراكم المعادن الثقيلة، السلسلة البيئية لمحاصيل الخضر والبطيخ، الرصد البيئي.

الكلمات المفتاحية: التربة، والمحاصيل الزراعية، والمعادن الثقيلة، والعناصر السامة، وتراكم المعادن الثقيلة، والسلسلة البيئية لمحاصيل الخضار والبطيخ، والرصد البيئي