

Potential of Sunflower (*Helianthus annuus* L.) for Phytoremediation of Soils Contaminated with Heavy Metals

Violina R. Angelova, Mariana N. Perifanova-Nemska, Galina P. Uzunova, Krasimir I. Ivanov, Huu Q. Lee

Abstract—A field study was conducted to evaluate the efficacy of the sunflower (*Helianthus annuus* L.) for phytoremediation of contaminated soils. The experiment was performed on an agricultural field contaminated by the Non-Ferrous-Metal Works near Plovdiv, Bulgaria. Field experiments with a randomized, complete block design with five treatments (control, compost amendments added at 20 and 40 t/daa, and vermicompost amendments added at 20 and 40 t/daa) were carried out. The accumulation of heavy metals in the sunflower plant and the quality of the sunflower oil (heavy metals and fatty acid composition) were determined. The tested organic amendments significantly influenced the uptake of Pb, Zn and Cd by the sunflower plant. The incorporation of 40 t/decare of compost and 20 t/decare of vermicompost to the soil led to an increase in the ability of the sunflower to take up and accumulate Cd, Pb and Zn. Sunflower can be subjected to the accumulators of Pb, Zn and Cd and can be successfully used for phytoremediation of contaminated soils with heavy metals. The 40 t/daa compost treatment led to a decrease in heavy metal content in sunflower oil to below the regulated limits. Oil content and fatty acids composition were affected by compost and vermicompost amendment treatments. Adding compost and vermicompost increased the oil content in the seeds. Adding organic amendments increased the content of stearic, palmitoleic and oleic acids, and reduced the content of palmitic and gadoleic acids in sunflower oil. The possibility of further industrial processing of seeds to oil and use of the obtained oil will make sunflowers economically interesting crops for farmers of phytoremediation technology.

Keywords—Heavy metals, organic amendments, phytoremediation, sunflower.

I. INTRODUCTION

HEAVY metal contamination of agricultural soils is a worldwide problem. A number of technologies have been employed for the removal of metals, such as fixation, soil excavation, leaching, and landfill of the top contaminated soil *ex situ*. However, many of these techniques have high maintenance costs and can result in secondary pollution [1] or adverse effect on biological activities, soil structure, and fertility [2]. Phytoremediation is an emerging technology, which should be considered for remediation of contaminated sites because of its cost effectiveness, aesthetic advantages and

long term applicability [3], [4]. This technology can be defined as the efficient use of plants to remove, detoxify or immobilize environmental contaminants in soils, waters or sediments through the natural, biological, chemical or physical activities and processes of the plants [5], [6]. It is most applicable in sites that have shallow contamination of organic, nutrient or metal pollutants [7], [8]. This plant-based technique is essentially an agronomic approach and its success depends ultimately on agronomic practices applied at the site. Addition of organic matter amendments, such as compost, fertilizers and wastes, is a common practice for immobilization of heavy metals and soil amelioration of contaminated soils [9]. Organic amendments have the ability to improve the physical, chemical and biological properties of soil by: (i) raising the pH; (ii) increasing the content of organic matter; (iii) adding nutrients that are essential for plant growth; (iv) increasing the capacity for holding water; and (v) modifying the bioavailability of heavy metals [10]–[12].

The use of crop plants for phytoremediation of contaminated soils has the advantages of their high biomass production and adaptive capacity to variable environments [13]. The ideal plant for phytoextraction of metals from contaminated soils must have certain characteristics, including: (i) tolerance to high concentrations of metals; (ii) short growing season and efficient accumulation of metals in the biomass; (iii) concentration of metals in above-ground parts of the plants; and (iv) easy to harvest [14], [15]. In addition to the removal of metals, phytoextraction will be economically more profitable if the plants can produce biomass with added value [16]. For example, energy crops such as oilseed plants, fiber plants and aromatic plants can be used to produce these valuable products [14]. There has been a growing interest in recent years [17]–[19] in the sunflower (*Helianthus annuus* L.) as a crop suitable for phytoremediation of organic compounds and heavy metals [20]. The sunflower's capacity to absorb heavy metals has been examined in field, container and hydroponic studies with various levels of pollution. It has been reported that sunflower accumulates large amounts of metals (Zn, Pb, Cu) [18], [21]–[24]. Results are often contradictory with regards to the capacity of the plant to move and accumulate metals. According to most authors, heavy metals are mainly accumulated in the roots of the sunflower, with little movement from the roots to the above-ground mass [18], [21]–[22]. Other authors have reported that some of the metals effectively move from the root to the above-ground parts [23], [25]. Most authors

V.R. Angelova is with the Agricultural University, Plovdiv Bulgaria (phone: 357 888 578126; fax: 357-32-633-157; e-mail: vileriz@abv.bg).

M. Perifanova-Nemska and G. Uzunova are with the University of Food Technology– Plovdiv Bulgaria (e-mail: maryiana.perifanova@abv.bg, gzheynova@yahoo.com).

K. I. Ivanov is with the Agricultural University, Plovdiv Bulgaria (e-mail: kivanov1@abv.bg).

H. Q. Lee is with the Center for Fertilizer Testing of Southern Regions, Hochiminh City, Viet Nam (e-mail: superquang@gmail.com).

observe that the accumulation of metals and their distribution in plants depends on the type of plant, plant organs, the phenological stage, the degree of contamination and the combination of metals in the soil [19], [21], [26]. According to [26], in the cultivation of sunflower on soils contaminated with cadmium (Cd) and on soils with combined pollution (Cd plus Zn and Cu), significant impacts are observed on plant growth and physiological response only in variants polluted with more metals, with significant accumulation of metals in the tissues and especially in the roots and in the old leaves.

Reference [19] evaluated the potential use of sunflower plants for phytoremediation and reported that sunflower can be used for the phytoextraction of metal-contaminated soils. In contrast, according to [21] the potential of sunflower for phytoextraction is very low. Cited results suggest that sunflower may be suitable for remediation of soils polluted with heavy metals and radionuclides. It is therefore necessary to conduct additional studies in growing sunflower on soils with high concentrations of metals, in order to determine its potential for remediation of contaminated soil.

The aim of this experiment was to compare the effect of organic soil amendments (compost and vermicompost) applied to the soil with regards to the accumulation of heavy metals by the sunflower (*Helianthus annuus* L.), as well as to assess the possibility of using the plant for phytoremediation of heavy metal contaminated soils.

II. MATERIAL AND METHODS

The experiment was conducted on an agricultural field exposed to contamination from the Non-Ferrous-Metal Works near Plovdiv, Bulgaria. The field experiment was a randomized, complete block design that consisted of five treatments and four replications (20 plots). The treatments were comprised of a control (without any organic amendments), compost amendments (added at 20 t/daa and 40 t/daa), and vermicompost amendments (added at 20 t/daa and 40 t/daa). The plot size was 24 m² (3 m x 8 m). The soil was excavated from each plot and combined and mixed with amendments 6 weeks before sunflower planting.

The characteristics of soils and organic amendments are shown in Table I. The soil is characterized by acid reaction (pH 5.8), loamy texture and a moderate content of organic carbon (2.2%). The total content of Zn, Pb and Cd is high (1430.7 mg/kg Zn, 876.5 mg/kg Pb and 31.4 mg/kg Cd, respectively) and exceeds the maximum permissible concentrations (200 mg/kg Zn, 70 mg/kg Pb, 1.5 mg/kg Cd).

The test plant was sunflower (*Helianthus annuus* L.). It was selected because it is known that sunflower is a fast-growing deep-rooted industrial oil crop [27]-[28] with high biomass production [29] that can remove heavy metals such as zinc or copper from contaminated environment [19].

Sunflower seeds were sown in rows in each plot, with the seeding holes in each row separated by a distance of 20 cm, and adjacent rows separated by a distance of 70 cm. Each hole was 7 cm deep, containing 3 seeds. After sunflower had grown for 15 days, the sunflower was thinned to one plant per hole. Upon reaching commercial ripeness, the sunflower plants

were gathered. Five plants per treatment (control, 20 t/daa compost, 40 t/daa compost, 20 t/daa vermicompost and 40 t/daa vermicompost) were chosen at random for analysis. Roots were excavated and separated from the adhering soil by washing. Shoots were divided into stems, leaves and sunflower heads. The samples were packed into plastic bags and immediately transported into the laboratory. At the laboratory they were washed with water, cut into pieces, and then oven-dried for 78 hours at 60 °C. The oil from the sunflower was derived under laboratory conditions through an extraction method with Soxhlet's apparatus. The contents of heavy metals (Pb, Zn and Cd) in the plant material (roots, stems, leaves and seeds) and in the oils of sunflower were determined by the method of the microwave mineralization.

TABLE I
CHARACTERIZATION OF THE SOIL AND THE ORGANIC AMENDMENTS USED IN THE EXPERIMENT

Parameter	Soil	Compost	Vermicompost
pH	5.8	6.9	7.5
EC, dS/m	0.2	0.2	2.2
Organic C, %	2.2	40.50	21.43
N Kjeldal, %	0.24	2.22	1.57
C/N	9.25	18.24	13.65
Pseudo-total P, mg/kg	642	12653.9	10210.8
Pseudo-total K, mg/kg	5517.5	6081.7	10495.1
Pseudo-total Pb, mg/kg	876.5	12.02	32.25
Pseudo-total Zn, mg/kg	1430.7	170.77	270.3
Pseudo-total Cd, mg/kg	31.4	0.192	0.686

MPC (pH <6.0) – Pb -60 mg/kg, Cd-1.5 mg/kg, Zn-200 mg/kg

The total content of heavy metals in the soils was determined in accordance with [30]. The mobile heavy metals contents were extracted by a solution of AB-DTPA (1 M NH₄HCO₃ and 0.005 M DTPA, pH 7.8) [31].

III. RESULTS AND DISCUSSION

A. Accumulation of Heavy Metals in Sunflower Plant

The accumulation and distribution of heavy metals in plants is specific for metals and depends on the concentration of the metal and their combination in the growth medium [32]. For the sunflower, reports on the accumulation of metals and distribution of the plant are mixed and are influenced by endogenous (e.g. genotype, phenological stages) [19], [21], [33] and exogenous [34] factors.

The distribution of heavy metals in the organs of the sunflower has a selective character that is specific for each individual element. The main part of Pb is accumulated in the leaves (59%) and a very small amount is contained in the seeds (1%). Similar results were obtained for Zn and Cd, whose main proportions are accumulated in the leaves (47 and 79%, respectively). Seeds contain only 2% of the total utilized Cd from sunflowers. The content of Zn is significantly higher in the seeds - 7% of the total absorbed Zn (Fig. 1). Similar results were obtained by Fassler et al. [13], suggesting that in the sunflower Cd, Zn, Mn, Cu and Fe move effectively in the above-ground parts and are preferentially accumulated in the leaves.

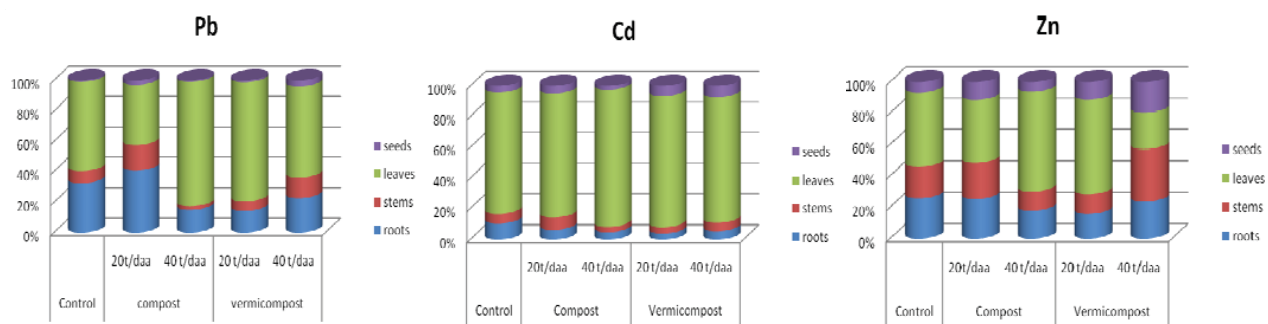


Fig. 1 Distribution of heavy metals in the organs of sunflower plant

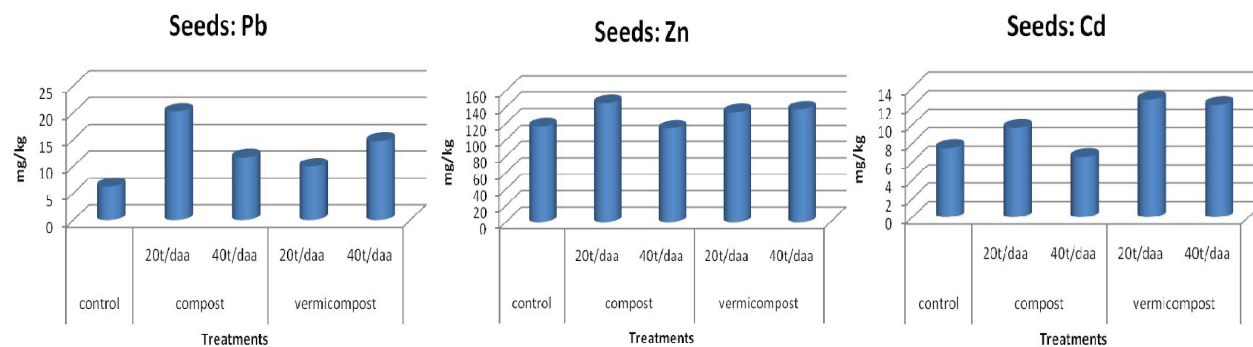


Fig. 2 Effect of organic amendments (compost and vermicompost) on the content of Pb, Cd and Zn (mg/kg) in the sunflower seeds

The distribution of Pb in the organs of the plants of all variants with the addition of compost and vermicompost follows the same relation that is observed in the control sample (Fig. 1). The highest content of Pb was found in the leaves, followed by the roots, stems and seeds. These results are contrary to the results obtained by [35], who found that in the above-ground parts of the plants the accumulation of heavy metals is lower as compared with the roots.

B. Content of Heavy Metals in Sunflower Seeds

The amount of heavy metals present in the seeds is significantly lower than that in the root system and the above-ground mass of the plants, indicating that their movement in the conduction system is severely limited. Our results do not support the findings by [36], which suggest that the highest content of Zn is in the seeds of the sunflower. Zn content in the seeds reaches up to 116.5 mg/kg (Fig. 2) and is much lower than the maximum amount that is toxic levels for animals (e.g. 1000 µg/kg for chickens, according to [4]. Similar results were obtained from [21], according to which the seeds of sunflower accumulate an average of 112 mg/kg of zinc.

The content of Cd in the seeds reaches 7.5 mg/kg and is significantly higher than the toxic levels for animals (500 µg/kg) [37] and reference values for food (1000 µg/kg) [38].

Our results are consistent with those obtained from [39] which found that the seeds of sunflower accumulate Cd. The results of [21] are not confirmed, as they found that the Cd content in sunflower seeds from contaminated areas is very low and ranges from 310 to 1340 µg/kg [40].

The content of Pb in the seeds of the sunflower reaches up to 6.3 mg/kg (only 1% of Pb absorbed by the sunflower) and is considerably lower than the maximum quantity that can have negative impacts on animals (30 mg/kg) [37], but exceeds the threshold value (3 mg/kg) accepted as safe for human consumption by more than double [38]. Given that only the seeds are part of the plant that is used for food, there is a risk of toxicity of Pb by the sunflower in its cultivation in contaminated soils.

Data published in literature on the heavy metal content in the seeds of the sunflower are often contradictory. [19] finds that sunflower accumulates relatively small quantities of heavy metals in the sunflower seeds. Similar results are obtained by [21], according to which the Pb content in sunflower seeds is low and reaches up to 219 µg/kg. According to [41], however, significant amounts of Cu, Zn, Pb and Cd are accumulated in the regenerative organs of the sunflower when it is cultivation on soils contaminated by heavy metals. Similar results were obtained from [36], suggesting that the highest is the content of Cu and Zn in the seeds of the sunflower when it is irrigated with wastewater.

The influence of organic amendments on the accumulation of Pb in the seeds essentially depends on their quantity. Increasing the content of heavy metals in the seeds compared to the control sample is strongly expressed, and in the variant with compost the Pb content increases from 6.3 mg/kg to 20.3 mg/kg when 20 t/decare of compost is incorporated, and up to 11.7 mg/kg when 40 t/decare of compost is incorporated. Similar results were obtained for Pb following the incorporation of vermicompost, where the content increased to

14.8 mg/kg after the incorporation of 40 t/decare of vermicompost (Fig. 2).

Increasing the Cd content in the seeds relative to the control sample is evident in the incorporation of vermicompost (up to 12.2 mg/kg - 12.8 mg/kg), as no significant influence is observed in the amount of incorporated amendments. The influence of compost on Cd content is not unidirectional. Reducing the Cd content in seeds relative to the control sample is observed only in the version with the incorporation of 40 t/decare of compost (up to 6.6 mg/kg).

The incorporation of vermicompost leads to an increase in Zn content in the seeds, up to 133.8 mg/kg - 137.5 mg/kg. A reduction of Zn content in the seeds relative to the control sample was observed only in the variant with the incorporation of 40 t/decare of compost (up to 113.9 mg/kg).

C. Phytoremediation Potential of Sunflower

Tables II-IV present the results for bioconcentration (BCF), translocation (TF) and enrichment (BAC, EF) factors, calculated for sunflowers from the control sample and the variants after the incorporation of the organic amendments. BCF values with respect to Pb are <1 indicating that the concentration of the element does not exceed its content in the soil. In Cd and Zn, these values are greater than 1. There are significant differences between the values obtained for the control sample and the variants treated with organic amendments. The incorporation of amendment leads to a significant decrease in the values of BCF (Table II). The values of TF show the amount of movement of the metals absorbed from the root system to the above-ground part of the plant. In general, TF does not exhibit the same pattern as BCF. The incorporation of compost and vermicompost leads to an increased translocation factor, which indicates an enhanced ability of plants to bioaccumulate heavy metals compared to the control sample (Table III).

TABLE II
BIOCONCENTRATION FACTOR (BCF)

Element	Control	Compost		Vermicompost	
		20 t/daa	40 t/daa	20 t/daa	40 t/daa
Pb	0.50	0.63	0.44	0.30	0.26
Cd	1.02	0.63	0.68	0.43	0.66
Zn	1.78	1.1	0.97	0.79	0.86

$$BCF = \frac{[Metal]_{\text{shoots}}}{[Available\ metal]_{\text{soil}}}$$

After the incorporation of vermicompost, the values of TF for Cd are increased from 8.5 in the control sample to 16.4 - 23.4. The incorporation of the compost also leads to an increase of TF, but this increase is significantly less (14.3-19.6). In terms of Pb in the incorporation of 40 t/decare of compost and 20 t/decare of vermicompost, the values of TF increase from 2.0 in the control sample, to 5.6 and 5.9, respectively. Similar results are observed for Zn. In the incorporation of compost, the values of TF for Zn increase from 2.6 to 4.2, while in the incorporation of 20 t/decare of vermicompost - the values of TF for Zn increase to 4.6.

In terms of Pb the enrichment factor (EF) for the control plants reaches up to 1.0, in Zn up to 4.6 and in Cd up to 8.6

(Table IV). The incorporation of 40 t/decare of compost and 20 t/decare of vermicompost leads to a substantial increase in these values.

TABLE III
TRANSLOCATION FACTOR (TF)

Element	Control	Compost		Vermicompost	
		20 t/daa	40 t/daa	20 t/daa	40 t/daa
Pb	2.04	1.38	5.55	5.86	3.21
Cd	8.47	14.3	19.7	23.40	16.35
Zn	2.61	2.50	4.21	4.58	2.41

$$TF = \frac{[Metal]_{\text{shoots}}}{[Metal]_{\text{roots}}}$$

The values obtained for EF and TF are the most important test that can be used to assess the potential of plants for phytoremediation. Our results show that in sunflowers from the control sample both EF and TF coefficients are larger than 1, and by this indicator it can also be classified as an accumulator in terms of Pb, Zn and Cd.

TABLE IV
ENRICHMENT FACTOR (BAC, EF)

Element	Control	Compost		Vermicompost	
		20 t/daa	40 t/daa	20 t/daa	40 t/daa
Pb	1.0	0.9	2.4	1.7	0.8
Cd	8.6	8.9	13.3	10.0	10.8
Zn	4.6	2.5	4.1	3.6	2.1

$$EF = \frac{[Metal]_{\text{shoots}}}{[Available\ metal]_{\text{soils}}}$$

Given the values of TF for the capacity of the sunflower to move contaminants from the soil and the value of BAC, it can definitely be argued that the incorporation of 40 t/decare of compost and 20 t/decare of vermicompost to the soil leads to an increased potential of the sunflower to move and accumulate Cd, Pb and Zn. Our results strongly suggest that the sunflower is a culture that is tolerant to heavy metals and can be grown on contaminated soil. It can be attributed to the accumulators of Pb, Zn and Cd and can successfully be used for phytoremediation of contaminated soils with heavy metals.

D. Quality of Sunflower Oil

The comparative analysis between our results and those published in literature show that in terms of lead and zinc there are significant differences in values, since the sunflowers in our experiment are grown on highly contaminated soil (Table V). However, our results for cadmium are lower in comparison to the data published for sunflower oil.

The Pb content in sunflower oil reaches up to 0.13 mg/kg (Table V). The maximum allowable concentrations (MAC) of Pb in oil that is of plant origin is 0.1 mg/kg. These results strongly suggest that the main part of Pb contained in the sunflower seeds does not pass into the oil that is obtained, its content in the oil is within the MAC and it can be used for food purposes.

The Cd content is below the limits of the quantification with the method used. Under the current standard, the Cd content should not exceed 0.05 mg/kg. Although the seeds contain Cd, it does not pass into the oil during their processing and it can hence be used for food purposes.

TABLE V
CONTENT OF HEAVY METALS (MG/KG) IN SUNFLOWER OIL

Element	Measured value		Reference			
	Control	Spain	China	Turkey	Italy	Iran
Pb	0.13	nd	0.006-0.015	0.05-0.11	0.05-0.16	0.0158
Cd	nd	nd	3.34-3.75	0.35-0.52	0.54-4.15	0.003
Zn	2.99	0.08-0.33	1.04-1.33	1.08-1.39	0.175-0.310	7.24

nd- not detected

MAC for Zn content in the vegetable oils is 10 mg/kg. In our studies Zn content in the obtained oil is lower than the MAC. In this case, contamination of seeds with Zn does not lead to contamination of the oil. These results strongly suggest that the main portion of Zn, contained in the sunflower seeds, does not pass into the oil obtained. This gives us reason to believe that the cultivation of sunflower on contaminated soils and the use of the oil for food purposes is possible.

Our results are consistent with those found by [42], according to which the contents of Cu, Fe and Pb in sunflower oil is low and does not contain Cd.

Incorporation of organic amendments lead to significant changes in the content of heavy metals in the oil. Their influence on the content of Pb and Zn in the oil is not

unidirectional and depends essentially on their quantity. The incorporation of compost leads to increased content of Pb, such increase is greater in the incorporation of 40 t/decare of compost (0.28 mg/kg) (Fig. 3). The incorporation of 40 t/decare of vermicompost leads to a decrease of Pb in the oil up to 0.106, that is within the MAC (0.1 mg/kg), while the incorporation of 20 t/decare has no significant influence. The incorporation of 40 t/decare of vermicompost is particularly effective in reducing Pb content in sunflower oil within the limit values (0.1 mg/kg of Pb), making it suitable for use for food purposes.

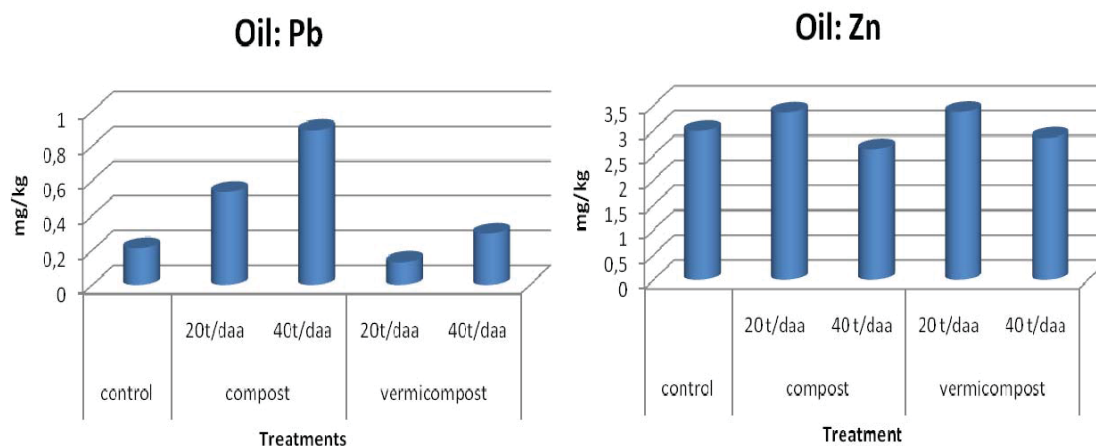


Fig. 3 Effect on the organic amendments (compost and vermicompost) on the content of Pb and Zn (mg/kg) in sunflower oil

The incorporation of 40 t/decare of compost and 40 t/decare of vermicompost reduces Zn content in the oil to 2.62 mg/kg and 2.85 mg/kg, respectively, while the incorporation of 20 t/decare of compost and vermicompost increases slightly (3.36 mg/kg-3.37 mg/kg). In all variants, however, Zn content in the oil is lower than the maximum permissible concentrations of oil of plant origin (10 mg/kg).

The Cd content in sunflower oil in all variants is below the limits of quantification with the method used both in the control sample and in the variants with incorporation of organic amendments. The incorporation of organic amendments has no significant influence on the Cd content in the oil and it can be used for food purposes.

The incorporation of organic amendments leads to an increase in the oil content of the seeds. The increase in the oil content of the seeds compared to the control sample is more

pronounced in the compost - increase is observed in both variants, as in the variant with 40 t/daa of compost it reaches 48.1%. The increase in oil content of the seeds compared to the control sample was found in variants with vermicompost (up to 46.0-46.4%), with no significant impact on the amount of incorporated vermicompost (Table VI). According to [43], the incorporation of vermicompost can increase the oil content of the seeds. It is believed that vermicompost not only increases the nitrogen content of the soil, but it contains different substances that stimulate growth, including idol acetic acid, gibberellin and vitamins B [44].

In the fatty acid composition of the tested oil, obtained from the extraction of sunflower seeds from the control sample, predominant are the unsaturated fatty acids, as their quantity respectively reaches up to 94.53%. In the composition of the oil of the control sample, oleic acid (C18:1, 90.3%) dominates,

followed by linoleic acid (C18:2, 3.97%), which attributes them to the oils of high oleic type in which the amount of oleic acid is in the range 75-90.7%, and the linoleic acid- 2.1-17.0% [45].

The data in Table VI show that the used organic amendments have a negligible impact on the amount of oleic acid in sunflower oil. Oleic acid is the predominant fatty acid which ranges from 89.01 to 91.91% of the total fatty acids in the different variants. The increase in the content of oleic acid compared to the control sample is weakly expressed, as in the variant with 20 t/decare of compost it reaches 91.91%, and in the variant of 40 t/decare of compost it reaches 91.64%. The addition of 20 t/decare and 40 t/decare of vermicompost leads to a slight decrease in the content of oleic acid, as significant impact is not observed on the amount of incorporated amendments (89.01 -89.15%). Our results do not confirm the findings of [46], according to which the addition of organic fertilizers leads to an increase in the content of oleic acid.

TABLE VI
THE FATTY ACID COMPOSITION OF SUNFLOWER OIL (EXPRESSED AS % OF TOTAL FATTY ACID COMPOSITION)

	Control	Compost		Vermicompost	
		20 t/daa	40 t/daa	20 t/daa	40 t/daa
Oil content	43.1	46.9	48.1	46.4	46.0
Saturated	5.47	6.99	7.40	9.40	8.45
C12:0	0.04	Nd	nd	Nd	nd
C16:0	4.16	3.67	3.75	4.00	3.95
C18:0	0.08	3.32	3.65	4.09	3.38
C20:0	0.36	Nd	nd	0.39	0.34
C22:0	0.83	Nd	nd	0.92	0.78
MUFA	90.56	91.91	91.64	89.28	89.45
C16:1	0.01	Nd	nd	0.09	0.10
C18:1	90.3	91.91	91.64	89.01	89.15
C20:1	0.25	Nd	nd	0.18	0.20
PUFA	3.97	1.10	0.96	1.32	2.10
C18:2	3.97	1.10	0.96	1.32	2.10
C18:3	nd	Nd	nd	nd	nd
Saturated/ Unsaturated	5.47: 94.53	6.99: 93.01	7.4: 92.6	9.4:90.6	8.45:91.55
Unsaturated/ Saturated	17.3	13.3	12.5	9.6	10.8

MUFA –monounsaturated, PUFA –polyunsaturated, nd- not detected

The organic amendments used influence the content of linoleic acid in sunflower oil. Reducing the content of linoleic acid compared to the control sample is pronounced as in the variant of 40 t/decare of compost it reaches 0.96%. Adding vermicompost also reduces the content of linoleic acid, this decrease is more pronounced with the incorporation of 20 t/decare of vermicompost - 1.32%

The organic amendments used influence the content of palmitoleic and gadoleic acid in sunflower oil. Increased content of palmitoleic acid and reduction of gadoleic acid is observed compared to the control sample.

The organic amendments used influence the composition of the saturated acids. Increasing the content of saturated acids is observed in all variants, as a significant increase compared to the control (5.47%) is observed in variants with the incorporation of vermicompost (9.4%).

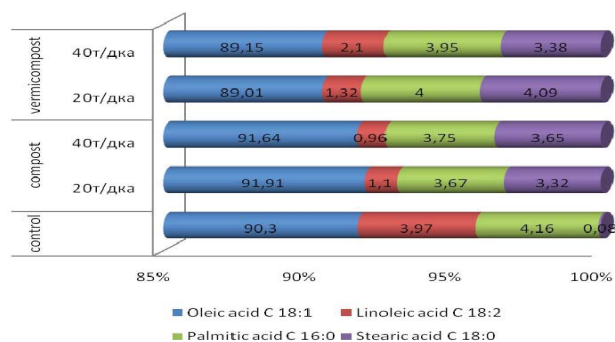


Fig. 4 Effect on the organic amendments (compost and vermicompost) on saturated and unsaturated acids

Palmitic acid is the main saturated fatty acid, followed by the stearic acid and these fatty acids together constitute about 6.99-8.09% of the total content of fatty acids of the oil in the incorporation of organic amendments. The content of palmitic acid decreases with the incorporation of organic amendment (Fig. 4). The amount of incorporated meliorant also has an influence. The lower content of palmitic fatty acid makes sunflower oil suitable for dietary purposes, while its higher content reduces its quality and increases the level of blood cholesterol. Consuming unsaturated fatty acids leads to the formation of the so-called “good” cholesterol, due to which vegetable oils are the basis for dietary nutrition.

Significant influence over the content of stearic acid in the oil is observed in the incorporation of organic amendments. The content of stearic acid in the control sample reaches 0.08%, while the incorporation of compost and vermicompost leads to its significant increase (3.32-4.09%). The amount paid amendments also has influence. By increasing the amount of compost the content of stearic acid in the oil increases. The incorporation of vermicompost also leads to the increase in the amount of stearic acid as this increase is more pronounced in the incorporation of 20 t/decare of vermicompost (4.09%).

Changes are also observed in the content of arachidonic, behenic and lauric acids in the oil. The introduction of compost and vermicompost leads to decreasing the content of lauric acid in the oil to 0% (i.e., it is not contained in the tested oils). In the variants with the incorporation of 20 t/decare of compost in the oil there are no arachidonic acid and behenic acid, while the incorporation of 40 t/decare has no influence on their content. The influence of vermicompost on the content of these acids is not unidirectional. The incorporation of 20 t/decare of vermicompost leads to slightly increased content of arachidonic acid and behenic acid, to 0.39 and 0.92%, respectively, while the incorporation of 40 t/decare leads to a reduction by 0.34 and 0.78%.

The ratio of saturated to unsaturated acids are influenced by the organic amendments that have been used. In the control sample, the ratio of unsaturated to saturated fatty acids (U/S) reached up to 17.3. The incorporation of compost and vermicompost leads to decrease in this ratio to 12.5 (40 t/decare of compost) and 9.6 (20 t/decare of vermicompost). According to [47], the increase in N in the soil leads to an

increase in the percentage of unsaturated fatty acids and decrease in the percentage of saturated fatty acids in linseed oil. Similar results were obtained by [48] who reported that the addition of nitrogen fertilizers affect the fat-acid composition of sunflower oil.

Vermicompost influence on the content of saturated fatty acids is not unidirectional. Adding vermicompost lowers the content of palmitic acid, leads to increase in the stearic acid and has no significant influence over the content of arachidonic and behenic acids. Similar are the results in respect of unsaturated acids. The incorporation of vermicompost leads to increased content of palmitoleic acid, leads to reduction in the content of oleic acid and has no significant impact on behenic acid compared to the control sample.

The addition of compost leads to lowering the content of palmitic acid and lauric acid, and at the same time leads to increased content of stearic acid. The incorporation of compost leads to increased oleic acid content and decreased linolenic and gadoleic acids compared to the control sample.

IV. CONCLUSION

The following conclusions can be made based on the results that have been obtained:

1. The distribution of the heavy metals in the organs of the sunflower has a selective character that in sunflower decreases in the following order: leaves > roots > stems > seeds.
2. The incorporation of 40 t/decare of compost and 20 t/decare of vermicompost to the soil leads to increased potential of sunflower to uptake and accumulate Cd, Pb and Zn.
3. The incorporation of compost and vermicompost leads to increase in the content of heavy metals in the sunflower seeds (except for cadmium in the incorporation of 40 t/decare of compost).
4. The main part of the heavy metals contained in the seeds, during their processing does not pass into the oil, so their content is within the concentration limits, and it can be used for food purposes.
5. The oil from the control sample, as well as the oils derived from processing of seeds of the variants with incorporation of compost and vermicompost do not contain Cd. The incorporation of compost leads to increased content of Pb in the oil. The incorporation of 40 t/decare vermicompost leads to a reduction of Pb to values within the maximum limits (0.1 mg/kg of Pb).
6. Organic soil amendments affect the oil content of seeds and fatty acid composition of sunflower oil. Changes are observed in the content of saturated and unsaturated fatty acids in the oil. Adding compost and vermicompost increases oil content in seeds. Adding organic amendments increases the content of stearic, palmitoleic and oleic acids and reduces the content of palmitic and gadoleic acids in sunflower oil.
7. Sunflower is a plant which is tolerant to heavy metals, can be attributed to the accumulators of Pb, Zn and Cd and

can be successfully used in the phytoremediation of heavy metal contaminated soils. The processing of seeds to oil and using the obtained oil for nutritional purposes will greatly reduce the cost of phytoremediation.

REFERENCES

- [1] N. Haque, J. R. Peralta-Videa, G. L. Jones, T. E. Gill, and J. L. Gardea Torresdey, "Screening the phytoremediation potential of desert broom (*Baccharis sarothroides* Gray) growing on mine tailings in Arizona, USA", *Environmental Pollution*, vol.153, pp.362–368, 2008.
- [2] I. D. Pulford and C. Watson, "Phytoremediation of heavy metal-contaminated land by trees-a review", *Environment International*, vol.29, pp.528–540, 2003.
- [3] A. P. G. C. Marques, R.S. Oliveira, A. O. S. S. Rangel, and P. M. L. Castro, "Application of manure and compost to contaminated soils and its effect on zinc accumulation by *Solanum nigrum* inoculated with arbuscular mycorrhizal fungi", *Environmental Pollution*, vol.151, pp.608–620, 2008.
- [4] R. L. Chaney, M. Malik, Y. M. Li, S. L. Brown, E. P. Brewer, J. S. Angle, and A. J. M Baker, "Phytoremediation of soil metals", *Current Opinion in Biotechnology*, vol.8, pp.279–284, 1997.
- [5] J. Ciura, M. Poniedzialek, A. Sekara and E. Jedrszezyk, "The possibility of using crops as metal phytoremediants", *Polish Journal of Environmental Studies*, vol.14, pp.17–22, 2005.
- [6] M. L. Lone, L. H. Zhen, J. S. Peter, and E. Y. Xiao, "Phytoremediation of heavy metal polluted soils and water: Progresses and perspectives", *Journal Zhejiang University Science Bulletin*, vol.9, pp.210–220, 2010.
- [7] J. L. Schnoor, "Phytoremediation", Groundwater Remediation Technologies Analysis Center Technology Evaluation Report TE-98-01, 37, 1997.
- [8] X. E. Yang, H.Y. Peng, and L.Y. Jiang, Phytoremediation of Copper from contaminated soil by *Elsholtzia splendens* as affected by EDTA, citric acid, and compost", *International Journal of Phytoremediation*, vol. 7, pp.69–83, 2005.
- [9] R. Clemente, D.J. Walker, and M. P. Bernal, "Uptake of heavy metals and As by *Brassica juncea* grown in a contaminated soil in Aznaco'llar (Spain)", The effect of soil amendments. *Environmental Pollution*, vol.138, pp.46–58, 2005.
- [10] D. J. Walker, R. Clemente, and M.P. Bernal, "The effects of soil amendments on heavy metal bioavailability in two contaminated Mediterranean soils", *Environmental Pollution*, vol. 122, pp.303–312 2003.
- [11] D. J. Walker, R. Clemente, and M.P. Bernal, "Contrasting effects of manure and compost on soil pH, heavy metal availability and growth of *Chenopodium album* L. in a soil contaminated by pyritic mine waste", *Chemosphere*, vol. 57, pp. 215–224, 2004.
- [12] V. R. Angelova, V. I. Akova, N. S. Artinova, and K. I. Ivanov, "The effect of organic amendments on soil chemical characteristics", *Bulgarian Journal of Agricultural Science*, vol. 19 (5), pp. 958–971, 2013.
- [13] A. Fässler, B.H. Robinson, S.K. Gupta, and R. Schulin, "Uptake and allocation of plant nutrients and Cd in maize, sunflower and tobacco growing on contaminated soil and the effect of soil conditioners under field conditions", *Nutrient Cycling in Agroecosystems*, vol.87, pp.339–352, 2010.
- [14] J.P. Schwitzguebel, D. Van Der Lelie, A. Baker, D.J. Glass, and J. Vangronsveld, "Phytoremediation: European and American trends, success, obstacles and needs", *J. Soils Sediments*, vol. 2, pp.91–99, 2002.
- [15] E. Nehnevajova, R. Herzig, G. Federer, K.H. Erismann, and J. P. Schwitzguebel, "Chemical Mutagenesis-A Promising Technique to Increase Metal Concentration and Extraction in Sunflowers", *Int. J. Phytoremediation*, vol. 9, pp.149–165, 2007.
- [16] A. Vassilev, J. P. Schwitzguebel, T. Thewys, D. van der Lelie, and J. Vangronsveld, "The use of plants for remediation of metal-contaminated soils", *Scientific World J.*, vol. 4, pp. 9–34, 2004.
- [17] D. Van der Lelie, J.P. Schwitzguebel, D. J. Glass, J. Vangronsveld, and A. Baker, "Assessing phytoremediation's progress in the United States and Europe", *Environ. Sci. Technol.*, vol.35, pp.447–452, 2001.
- [18] J. Lin, W. Jiang, and D. Liu, "Accumulation of copper by roots, hypocotyls, cotyledons and leaves of sunflower (*Helianthus annuus* L.)", *Biores. Technol.*, vol.86, pp.151–155, 2003.

- [19] E. Nehnevajova, R. Herzig, G. Federer, K. H. Erismann and J. P. Schwitzguebel, "Screening of sunflower cultivars for metal phytoextraction in a contaminated field prior to mutagenesis", *International Journal of Phytoremediation*, vol. 7, pp.337-349, 2005.
- [20] M. N. V. Prasad, "Sunflower (*Helianthus annuus* L.) - a potential crop for environmental industry", *Helia*, vol.30, pp.167-74, 2007.
- [21] P. Madejon, J. M. Murillo, T. Maranon, F. Cabrera, and M. A. Soriano, "Trace element and nutrient accumulation in sunflower plants two years after the Aznalcollar mine spill", *Sci. Total. Environ.*, vol. 307, pp.239-257, 2003.
- [22] L. Marchiol, G. Fellet, D. Perosa, and G. Zerbi, "Removal of trace metals by *Sorghum bicolor* and *Helianthus annuus* in a site polluted by industrial wastes: a field experience", *Plant Physiol. Biochem.*, vol. 45, pp.379-87, 2007.
- [23] J. K. Adesodun, M.O. Atayese, T. A. Agbaje, B. A. Osadiaye, O. F. Mafe, and A. A. Soretire, "Phytoremediation potentials of sunflowers (*Tithonia diversifolia* and *Helianthus annuus*) for metals in soils contaminated with zinc and lead nitrates", *Water Air Soil Pollut.*, vol. 207, pp.195-201, 2010.
- [24] T. Vamerali, L. Marchiol, M. Bandiera, G. Fellet, N. M. Dickinson, P. Lucchini, G. Mosca, and G. Zerbi, "Advances in agronomic management of phytoremediation: methods and results from a 10-year study of metal-polluted soils", *Ital. J. Agr.*, vol.7, pp.42, 2012.
- [25] E. M. Herrero, A. López-González, M. A. Ruiz, J. A. Lucas-García, and C. Barbas, "Uptake and Distribution of Zinc, Cadmium, Lead and Copper in *Brassica napus* var. *oleifera* and *Helianthus annuus* Grown in Contaminated Soils", *Int. J. Phytoremediation*, vol. 5, pp.153-167, 2003.
- [26] A. R. Rivelli, S. De Maria, M. Puschenreiter, and P. Gherbin, (2012): "Accumulation of cadmium, zinc and copper by *Helianthus annuus* L.: Impact on plant growth and uptake of nutritional elements", *International Journal of Phytoremediation*, vol.14, pp.320-334, 2012.
- [27] M. N. V. Prasad, "Phytoremediation of metals in the environment for sustainable development", *Proc. Indian Natl. Sci. Acad.*, vol. 70(1), pp.71-98, 2004.
- [28] N. Tahsin, and B. Yankov, "Research on accumulation of zinc (Zn) and cadmium (Cd) in sunflower oil", *Journal of Tekirdag Agricultural Faculty*, vol. 4(1), pp.109-112, 2007.
- [29] P. Zhuang, Z.H. Ye, C. Y. Lan, Z. W. Xie, and W. S. Shu, "Chemically assisted phytoextraction of heavy metals contaminated soils using three plant species", *Plant and Soil*, vol. 276(1-2), pp.153-162, 2005.
- [30] Soil quality - Extraction of trace elements soluble in aqua regia. ISO 11466, 1995.
- [31] P. N. Soltanpour, and A.P. Schwab, "A new soil test of macro- and micro-nutrients in alkaline soils", *Commun. Soil Sci. Plant Analysis*, vol. 8, pp.195-207, 1977.
- [32] S. De Maria, and A. R. Rivelli, "Trace element accumulation and distribution in sunflower plants at the stages of flower bud and maturity", *Italian Journal of Agronomy*, vol.8, pp. 65-72, 2013.
- [33] Y. M. Li, R. L. Chaney, A.A. Schneiter, J. F. Miller, E. M. Elias, and J. J. Hammond, "Screening for low grain cadmium phenotypes in sunflower, durum wheat and flax", *Euphytica*, vol. 94, pp.23-30, 1997.
- [34] M. C. January, T. J. Cutright, H. Van Keulen, and R. Wei, "Hydroponic phytoremediation of Cd, Cr, Ni, As, and Fe: can *Helianthus annuus* hyperaccumulate multiple heavy metals?", *Chemosphere*, vol.70, pp.531-537, 2008.
- [35] S. D. Lane, and E.S. Martin, "A histochemical investigation of lead uptake in *Raphanus satives*", *New Phytol.*, vol. 79, pp. 281-286, 1977.
- [36] H. Molahoseini, M. Feizi, and M. Seilsepour, "The concentration of some essential elements and cadmium in sunflower, turnip and forage corn under wastewater irrigation", in *Proc. The 1th International and The 4th National Congress on Recycling of Organic Waste in Agriculture*, Isfahan, Iran, 26 - 27 April 2012, pp.1-6.
- [37] R. L. Chaney, "Toxic element accumulation in soils and crops: protecting soil fertility and agricultural food-chains", in *Inorganic contaminants in the Vadose Zone*. B. Bar Yosef, N. J. Barrow, J. Goldshmid J, Eds.. Berlin: Springer-Verlag, 1989, 140-158, 1989.
- [38] H. J. Hapke, "Heavy metal transfer in the food chain to humans", in *Fertilizers and Environment*. C. Rodriguez-Barrueco, Ed. Dordrecht: Kluwer, 1996,431-436.
- [39] R. Chizzola, "Uptake and partitioning of cadmium in sunflowers, chamomile and St. John's wort. Zeitschrift für Arznei und Gewürzpflanzen", vol. 3, pp.91-95, 1988.
- [40] F. P. C. Blamey, R. K. Zollinger, and A. A. Schneiter, "Sunflower production and culture", in *Sunflower Science and Tehnology*. AA. Schneiter, Ed. American Society of Agronomy, Madison, 1997.
- [41] M. Korenovska, and O. Polacekova, "Trace elements content in virgin sunflower oil production", *Czech Journal of Food Sciences*, vol. 18, pp. 61-65, 2000.
- [42] Anonymous, *Metals in Cold Pressed Oils*, HMSO Publications Centre: London, UK, Food Surveillance Info. Sheet No. 138, 14, 1997.
- [43] V. Kumar, "Nitrogen economy in Indian mustard through use of *Azotobacter chroococcum*", *Crop Research*, vol. 8, pp. 449-452, 1994.
- [44] S. C. Wu, Z. H. Cao, Z. G. Li, and K. C. Cheung, "Effect of biofertilizer containing N-fixer, P and K solubilizers and AM fungi on maize growth: a greenhouse trial", *Geoderma*, vol.125, pp. 155-166, 2005.
- [45] E.A. Weiss, *Oilseed Crops* (second edition), Blackwell Science, Oxford, 2000.
- [46] P. Akbari, A. Ghalavand, A. M. Modarres Sanavy, and M. Agha Alikhani, "The effect of biofertilizers, nitrogen fertilizer and farmyard manure on grain yield and seed quality of sunflower (*Helianthus annuus* L.)", *Journal of Agricultural Technology*, vol.7(1), pp.173-184, 2011.
- [47] N. F. Kheir, E. Z. Harb, H. A. Moursi, and S. H. El-Gayar, "Effect of Salinity and Fertilization on Flax Plants (*Linum usitatissimum* L.). II. Chemical Composition", *Bull. Faculty Agriculture. (Univ. Cairo)*, vol. 42, pp.57-70, 1991.
- [48] B. T. Steer, and G. I. Seiler, "Changes in fatty acid composition of sunflower (*Helianthus annuus* L.) seeds in response to time of nitrogen application, supply rates and defoliation", *Journal of the Science of Food and Agriculture*, vol. 51, pp. 11-26, 1990.