Impact of Manganese, Nickel and Zinc Distribution from Lignite Fuels on Cultivated and Non- Cultivated Plants

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Abstract: Manganese, nickel and zinc were determined in soils and 4 plants (2 cultivated: *Brassica oleracea, Zea mays* and 2 non cultivated: *Rumex acetosa, Verbascum phlomoides*) around the Coal Power Plant (CPP) - Agios Dimitrios, the largest CPP in Greece. In general, roots showed a higher metal content compared to the other over ground parts. This is more prominent in *Brassica oleracea* for all studied metals except zinc, where the highest zinc concentration is found in the sclerechyma (central vein) of the internal leaf. Thus, *Brassica oleracea* meets the objectives of phytoremediartion of lands contaminated by heavy metals. Periodically planting of *Brassica oleracea* could reduce the level of heavy metals in the area in order to clean up and prepare soils for other cultivations. The most contaminated leaves revealed a variation in epidermis roughness. In *Verbascum phlomoides* the multicellular, multilevel hairs on the leaf surface fixed a considerable number of air particles effectively. In contrast, the waxy cuticle of *Rumex acetosa*, enabled the fast rinsing of the air particles by rainwater and wind. The aim of the present study is also to highlight the differences in the ability of various plant organs or tissues to accumulate heavy metals, using cultivated (crops) and non-cultivated (native) plans found around the coal power plant. Pollution monitoring, especially by crops, may provide useful information for the design of monitoring networks that can facilitate the determination and intercomparison of metals around CPPs internationally.

Keywords: Heavy metals, Lignite, Coals, Monitoring, Manganese, Nickel, Zinc, native plants, cultivated plants, leaf surfaces.

1. INTRODUCTION

Lignite is used in coal power plants (CPP) for electricity production and it has remained a primary source of energy for generating electricity in many countries till today. During the coal formation process an enrichment of trace metals in the coal structure occurs through biochemical process in geochemical transformation [1, 2]. Lignite coal contains relatively high quantities of heavy metals in comparison with other geological fuels [3]. Coal burning is one of the major sources of heavy metal atmospheric releases around the coal power plants.

When coal is burned, releases impurities causing environmental and social problems as well as environmental imbalances since smaller particles can be transported in longer distances [2]. In this respect, the flying ash escapes with fuel gases constitutes a source of pollutants for drinking-water contamination and bioaccumulation in plants or animals. Thus, the lignite coal is an important source of heavy metals during the combustion procedure, to generate energy in a CPP, into the nearby environment [1, 4]. Atmospheric deposition is an important mechanism determining the fate of airborne particles from their origin to the plant leaves, the first available surface as they are transferred by the wind. The leaves, through their stomata, are the first interceptors of air pollutants and their interception capacity depends on leaf shape, phyllotaxy, waxy cuticle and trichomes [5].

The evaluation of heavy metal concentrations near CPP area is of great importance due to their serious effects on plant organisms and human health [6]. Deposition of fly ash on plant organs and surface soil may influence chemical composition and plant metabolism by influx of trace metals. There are a great number of studies regarding the absorption and bioaccumulation of metals by plants and their biological or toxicological effects [7-9]. Although the uptake and accumulation of airborne emissions have been extensively analyzed, only a few studies have been performed in the field using plant material as passive sampler in biomonitoring [10-13]. The use of plant samples has the advantage of high spatial resolution, due to their great availability and low sampling costs.

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In an analogous study in this area, high Cr concentrations in soil were found near the CPP, whereas for Cu and Pb no correlation with the distance has been noted [14]. The aim of the present study is to investigate the differences in the ability of various plant organs or tissues to accumulate Mn, Ni and Zn, using cultivated plants (*Zea mays* L. and *Brassica oleracea* var. capitate L.) and non-cultivated (*Rumex acetosa* L. and *Verbascum phlomoides* L.) growing in the vicinity of Agios Dimitrios, the largest coal power plant in north-western Greece. The suitability of these species for biomonitoring of soil pollution was also studied. These species were chosen because they are common in the both cultivated and non-cultivated fields and can be sampled systematically using standardized sampling and analytical methods for inter-comparison monitoring in areas with industrial pollution. Another goal of this study is to investigate their suitability for phytoremediation since they absorb and bioaccumulate metals present in the environment.

2. MATERIALS AND METHODS

2.1. Study Area and Sample Collection

Ptolemais area, which is located in north-western Greece, has four large CPP-stations, due to the presence of the largest deposit of lignite in Greece. The operation of CPP-stations produce more than 60% of the total electric energy that is consumed in Greece per year. The largest among them is CPP-Agios Dimitrios produces 1220 MW. Five sampling areas were established in CPP- Agios Dimitrios region in SE direction, taking into account the geomorphological and meteorological data (Figure **1**).

Five sampling sites were chosen of approximately 500 m^2, in a distance of 2.5 km. At each site, samples of cultivated and native plants were uniformly collected (about 10 subsamples of each plant species). In addition to the sampling scheduled, samples from the same species from a relatively clean area (Grevena), about 60 km SW of CPP-Agios Dimitrios, were also collected, in order to use them as control specimens.

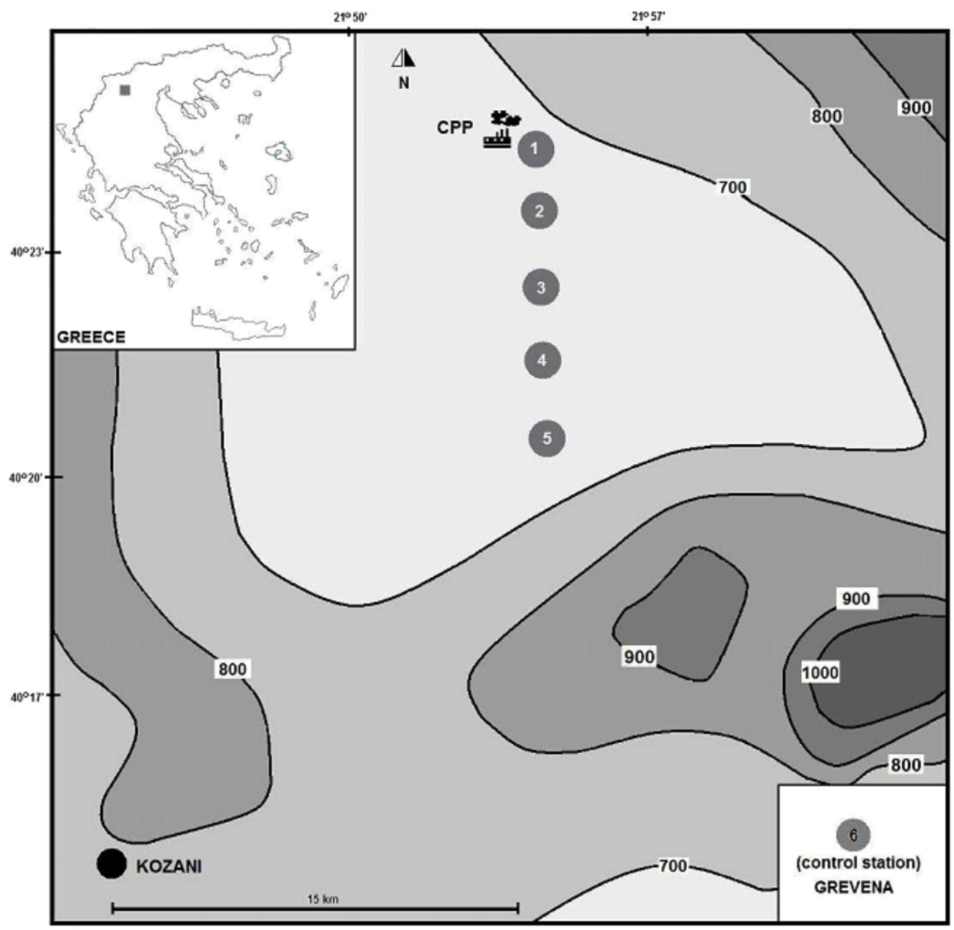

Figure 1: Map of Ptolemais basin (N. Greece) indicating the sampling areas (1-5) at the south-east side of Agios Dimitrios Power Plant. The distance between the sampling areas is approximately 2.5 Km.

The aim of the sampling was to cover a wide spectrum of plant species (monocotyledons – dicotyledons), leaf type (broad - narrow, smooth - pubescent), root type (tap - fibrous, fleshy – thin) or of economic importance (crops - native).

The collected plant species were: *Zea mays* (Poaceae) (maize), *Brassica oleracea* var. capitata L. Fam. Brassicaceae (cabbage), *Rumex acetosa* L. Fam. Polygonaceae (sorrel) and *Verbascum phlomoides* L. Fam. Scrophulariaceae (mullein). The plant organs of each (seeds, flowers, leaves, stems, roots and rhizomes) were analyzed separately, in order to study the amount of accumulation of metals in various plant organs or tissues. To avoid cross-contamination only plastic tools (knives, scissors etc.) were used. Apart of plant material, surface soil at a maximum depth of 5 cm was sampled from an area of about 2 m^2 using a plastic shovel.

Sample Treatment

Samples were put initially in plastic bags and then oven dried at 70°C to constant weight (about 10 hours). The dried samples were pulverized in a Moulinex mill and after homogenization were placed in polyethylene bags stored in a desiccator. 0,3 g dry weight (DW) of each plant subsample was accurately weighed in an open PTFE baker, 20 ml of concentrated HNO_3 (Merck, p.a.) were added and it was left at room temperature overnight. Then it was heated to fully evaporate and 20 ml of diluted HNO_3 (1:1) were added. Finally it was heated at 160°C for 30 minutes. For soil samples, a portion of 0.2 g DW was accurately weighed in an open PTFE baker, 1 ml $HClO_4$ and 20 ml of concentrated HF (Merck, p.a.) were added and heated to fully evaporate HF as well as $HClO_4$. Then 20 ml 6M of HCl were added and heated for 30 minutes. The final solutions were diluted to 200 ml volume with distilled - deionized water. These final solutions were analyzed for heavy metal content.

2.2. Determination of Metals

The metal contents were determined using the atomic absorption spectrometry (AAS). Zinc and Mn were determined by flame, while Ni by graphite furnace, in a Perkin Elmer AAnalyst 800 AAS. The detection limit of the spectrometer for Zn is 5 μg/g for plant material and 15 μg/g for soil and for Mn, 8 μg/g for plant material and 20 μg/g for soil. For Ni the detection limits are 0,3 μg/g for plant material and 1 μg/g for soil. In order to check the validity of methods employed standard reference material (CRM 281) was used from the CBR (Community Bureau of Reference). The concentrations are given as μg/g DW, and the results are the mean values from triplicate analyses of each sample.

2.3. Scanning Electron Microscopy (SEM)

Selected plant leaves cut in pieces and fixed in 2.5% glutaraldehyde in 0.05 M buffered in cacodylate. After dehydration in ethanol series their adaxiar or abaxial surface were studied using a 20kV JEOL JMS-840A scanning electron microscope. The microscope was equipped with an energy - dispersive X-ray (EDXR) Oxford ISIS 300 micro-analytical system and the necessary software for point microanalysis, linear microanalysis and chemical mapping of the surface under examination. Operating conditions were: accelerating voltage 20kV, probe current 45nA and counting time 60s, with ZAF correction being provided on-line. The samples were coated with carbon, using a Jeol JEE-4X vacuum evaporator. Surface and in depth examinations of the compositional variation were performed using Scanning Electron Microscopy with associated Energy Dispersive Spectroscopy.

2.4. Statistical Data Evaluation

Statistical analysis was performed by using SPSS 16.0 (IBM) statistical package. From the results of the chemical analysis mean values and relative standard deviation (mean±SE) for each species at each site were calculated. To ascertain the significance of difference in metal distribution between different stations in different species, the mean values were further statistically evaluated with one- way analysis of variance (one- way ANOVA), followed by Duncan's multiple range test, at a p = 0,05 significance level.

3. RESULTS

Heavy Metals in Plants and Soil

3.1. Manganese

Manganese content in plants ranged from the detection limit (DL=8 μg/g) to 414±0.34 μg/g. Metal concentration between soil specimens and plant material showed that content levels were significantly higher in the soil (710±133 μg/g) than in the corresponding plants (64±6 μg/g). At the control station manganese content in soil material is lower (642±22 μg/g) than that of the studied area but with no significant difference. Plant material in the control station showed higher metal concentration (MeanValue 76±22 μg/g) than that of the studied area (64±6 μg/g). Among plants *Verbascum phlomoides* (140±47 μg/g) collected from the control station and *Zea mays*

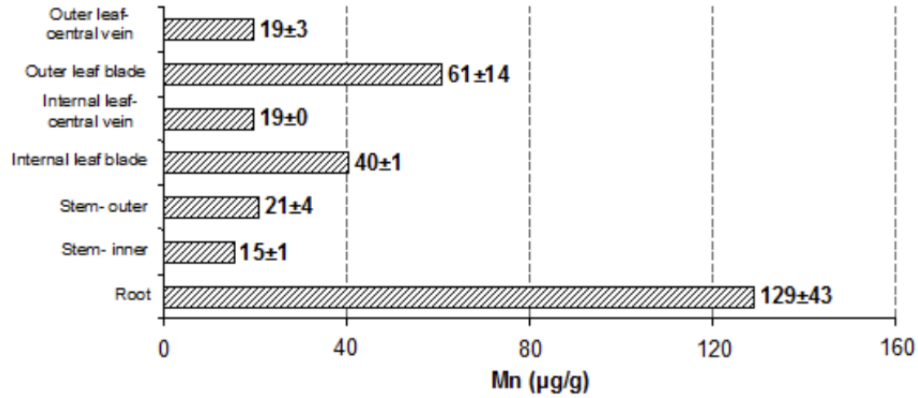

Figure 2: Manganese content on the various organs and tissues of *Brassica oleracea* var. capitata.

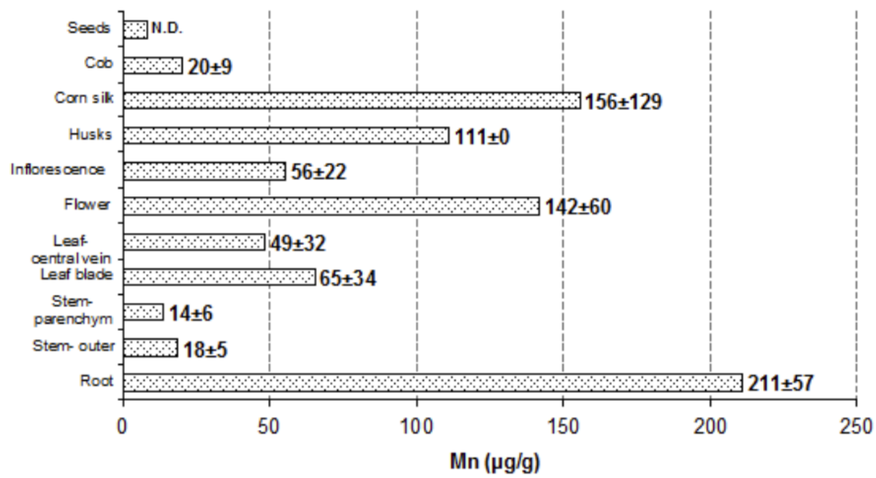

Figure 3: Manganese content on the various organs and tissues of *Zea mays*.

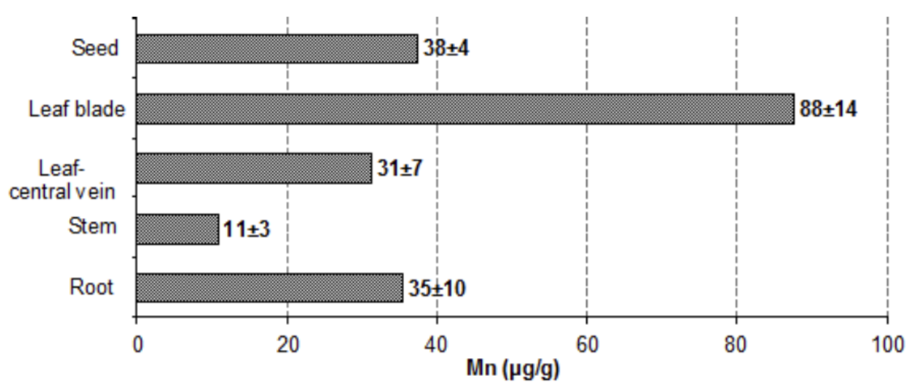

Figure 4: Manganese content on the various organs and tissues of *Rumex acetosa*.

(116±55 μg/g) from station 3 of the studied area, were the most contaminated.

In *Brassica oleracea* roots were significantly contaminated (129±43 μg/g) (p=0.00), followed by the outer leaf blade (61±14 μg/g) with no significant difference from that of the internal leaf (40±1 μg/g). In the other parts no significant differences were observed (Figure **2**). In the case of *Zea mays* the highest content was absorbed by the root (211±57 μg/g). In corn silk and male flowers the concentrations were also, yet not significantly high (156±129 and 142±60 μg/g respectively) (Figure **3**). In *Rumex acetosa* the most polluted plant organ was the leaf (88±14 μg/g) (p=0.00), followed by the seed (38±4 μg/g) and the tap root (35±10 μg/g). Leaf central vein and stem, both sclerenhymatous parts, were the least contaminated

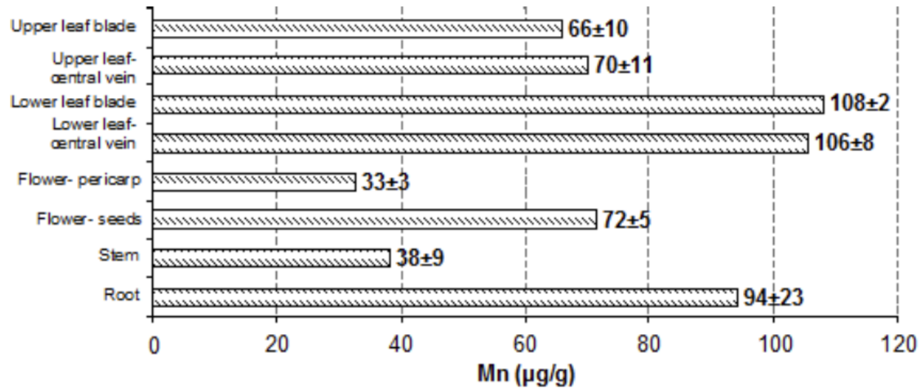

Figure 5: Manganese content on the various organs and tissues of *Verbascum phlomoides*.

(31±7 µg/g and 11±2 µg/g respectively) (p=0.00) (Figure **4**). In *Verbascum phlomoides* the lower (older) pubescent leaf blade and central vein were the most polluted organs (108±2 µg/g, 106±8 respectively) with no significant difference from the root (94±23 µg/g) (Figure **5**).

3.2. Nickel

Nickel content in plants ranged from 1±0 µg/g to 218±1.2 µg/g, whereas soil concentrations ranged from 110±0.03 µg/g to 403±0.1 µg/g. Nickel content levels were significantly higher in the soil specimens (M. V. 126±10 µg/g) than in the corresponding plants (M. V. 35±4 µg/g). Among plants *Verbascum phlomoides* was the most contaminated (46±1.8 µg/g) followed by *Rumex acetosa* (32±2.1 µg/g) whereas the least contaminated was *Brassica oleracea* (15±1.5 µg/g).

In *Brassica oleracea* the root was the most contaminated part (54±6 µg/g) (p=0.00) followed by the sclerenhymatous outer part of the stem (cortex) (27±22 µg/g), whereas the parenchymatous inner part of the stem (medulla) was the least contaminated (3.6±0.5 µg/g) (Figure **6**). In the case of *Zea mays* the highest metal content was absorbed by husks (83±0 µg/g). Seeds (1.6±0.2 µg/g) and sclerenchymatous parts such as the cob (2.5±1 µg/g), the outer sclerenchymatic part of stem (3±1 µg/g) were the least contaminated (Figure **7**). In *Rumex acetosa* the most polluted was the tap root (58±16 µg/g) followed by seeds (54±15 µg/g). The sclerenchymatous leaf central vein or stem (5.3±0.8 µg/g and 8.1±2 µg/g respectively) were the least polluted plant parts (Figure **8**). In *Verbascum phlomoides,* the most polluted plant organ was the root (64±13 µg/g) and the sclerenchymatous central vein of upper leaves (64±9 µg/g) with significant difference from both upper and basal leaf blade (32±9 µg/g and 36±7 µg/g respectively). The other parts did not show any significant differences (Figure **9**).

3.3. Zinc

Zinc content in plants ranged from the detection limit (D.L.=5 µg/g) to 953±0.3 µg/g, whereas the soil concentrations ranged from 100±0 µg/g to 144±0 µg/g. Metal content between soil and plants showed that metal content levels were significantly higher in the soil

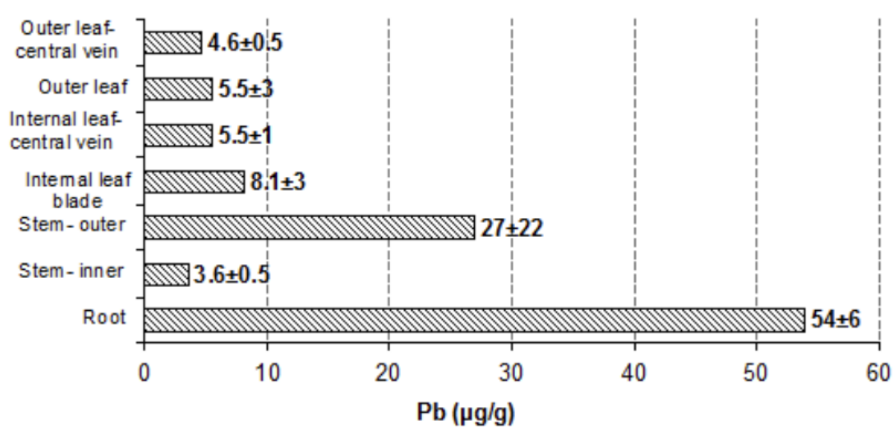

Figure 6: Nickel content on the various organs and tissues of *Brassica oleracea* var. capitata.

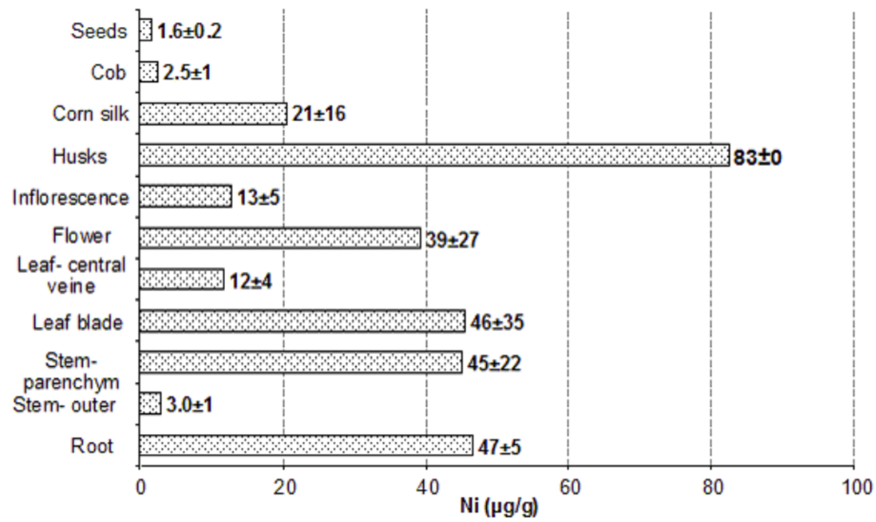

Figure 7: Nickel content on the various organs and tissues of *Zea mays*.

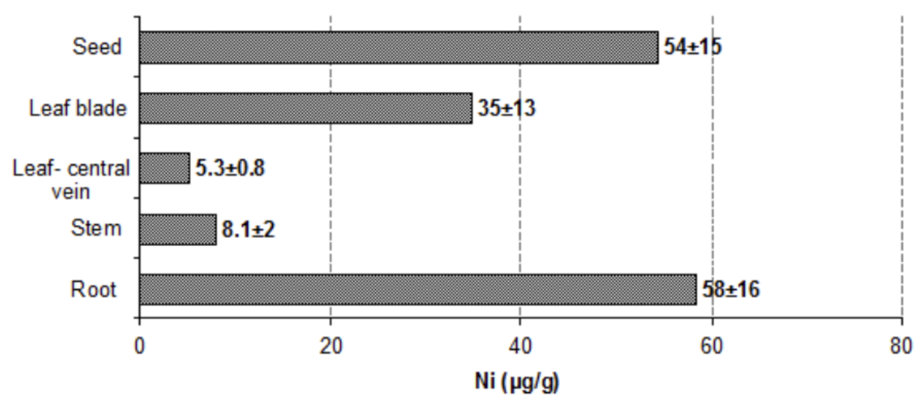

Figure 8: Nickel content on the various organs and tissues of *Rumex acetosa*.

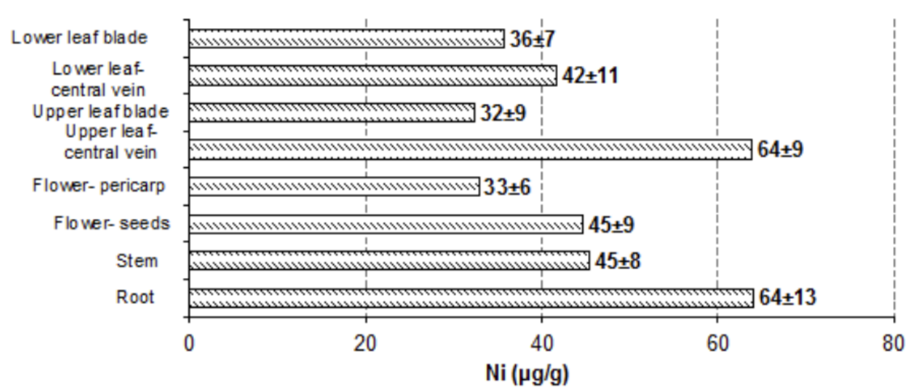

Figure 9: Nickel content on the various organs and tissues of *Verbascum phlomoides*.

near the CPP (M. V. 118±11 μg/g) than in the corresponding plants (M. V. 49±7 μg/g). Among plants, *Brassica oleracea* was the most polluted (80±51 μg/g) followed by *Verbascum phlomoides* (48±4.4 μg/g) whereas the least contaminated was *Rumex acetosa* (29±0.9 μg/g).

In *Brassica oleracea* zinc accumulation was located mainly in the inner leaves and especially more in the central vein (250±233 μg/g) than in the rest leaf blade (155±122 μg/g) (p=0.00) (Figure **10**). In *Zea mays* the highest quantity of metal was found in the male flower (100±0 μg/g). The statistical analysis showed significant differences from the rest of the plant parts.

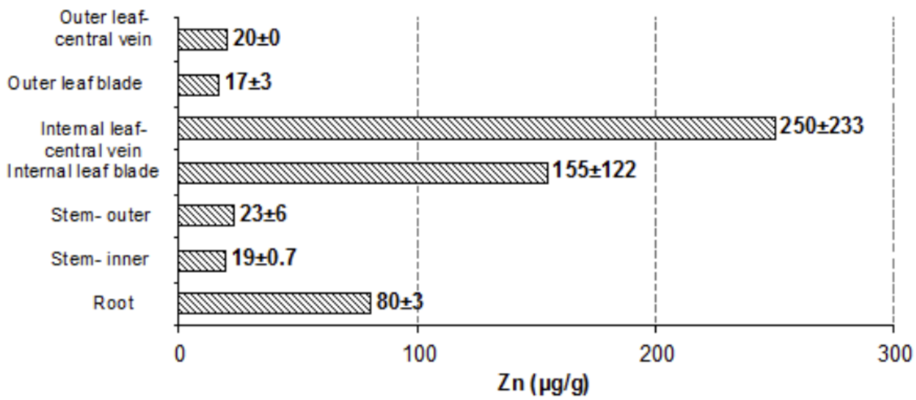

Figure 10: Zinc content on the various organs and tissues of *Brassica oleracea* var. capitata.

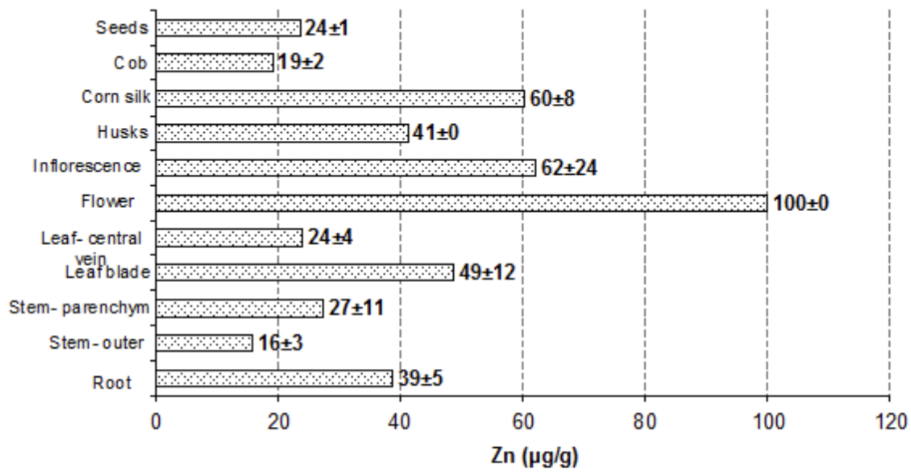

Figure 11: Zinc content on the various organs and tissues of *Zea mays*.

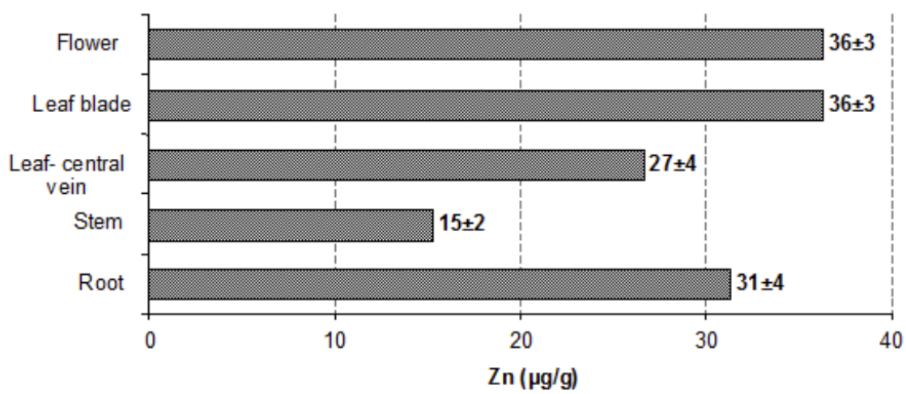

Figure 12: Zinc content on the various organs and tissues of *Rumex acetosa*.

In comparison to other metals, the root was the least contaminated plant organ (39±5 μg/g); however, seeds were not (24±1 μg/g) (Figure **11**). In *Rumex acetosa* significant differences were found between the stem (15±2 μg/g) and the other parts where concentrations varied between 27±4 and 36±3 μg/g (Figure **12**). In *Verbascum phlomoides* the statistical analysis showed higher Zn content in the blade (76±26 μg/g) and the central vein (73±33 μg/g) of basal leaves. Seeds were also contaminated (66±5 μg/g), with the other parts not showing any significant differences (Figure **13**).

Fly Ash Particle Deposition

SEM images proved agglomeration of spherical fly ash particles containing mainly inorganic amorphous or crystalline material. These particles have a variable morphology and chemical composition. The presence of branched, multilevel hairs on both leaf epidermis of

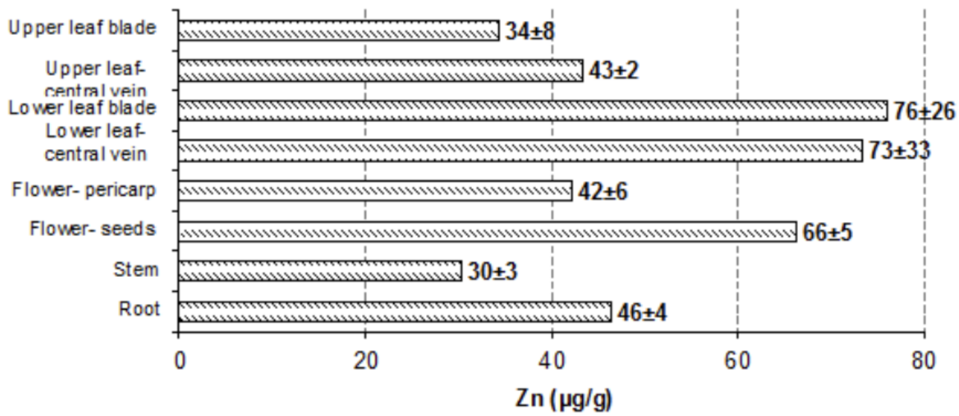

Figure 13: Zinc content on the various organs and tissues of *Verbascum phlomoides*.

Verbascum phlomoides enabled the fixing of bigger size spherical particles (Figures **14**, **15**). Similarly, the non-glandular, single celled trichomes of *Zea mays* leaves (Figure **16**) or husk ears (Figure **17**) enable the trapping of fly ash particles. The smooth leaf surfaces of *Brassica oleracea* or *Rumex acetosa* covered by epicuticular wax, which forms a dense sheet over the epidermis cells adhering weak the fly ash particles (Figures **18**, **19**). Numerous small particles were observed along the silk trichomes of *Zea mays*, which are styles of the female part of the flower (Figure **20**). Fly ash particles reaching the receptive area of silks are captured easily by the sticky trichome cell walls (Figure **21**).

Larger fly ash particles (20-40 μm) were generally found on the adaxial surface (Figure **14**, **18**), while those with shorter diameter (1-20 μm) were concentrated on the adaxial surface (Figure **19**). EDS analyses in fly ash spherical particles showed amounts of Ca, Si, Al, K, Mg and some potential toxic heavy metals. The SEM-EDS elemental analysis of fly ash particles on both epidermis of plant leaves are given in Table **1**. A typical spectrum from fly ash particles of Figure **14** is given in Figure **22**.

4. DISCUSSION

4.1. Root Uptake

There is significant difference in the effectivity to bio-accumulate heavy metals among various plant organs or tissues [15, 16]. Root system usually reveal the highest metal quantities than the other above ground parts since it is the main organ associated with it [17]. This general rule is typically observed in *Brassica oleracea* and *Zea mays* for manganese and *Brassica oleracea*, *Rumex acetosa* and *Verbascum*

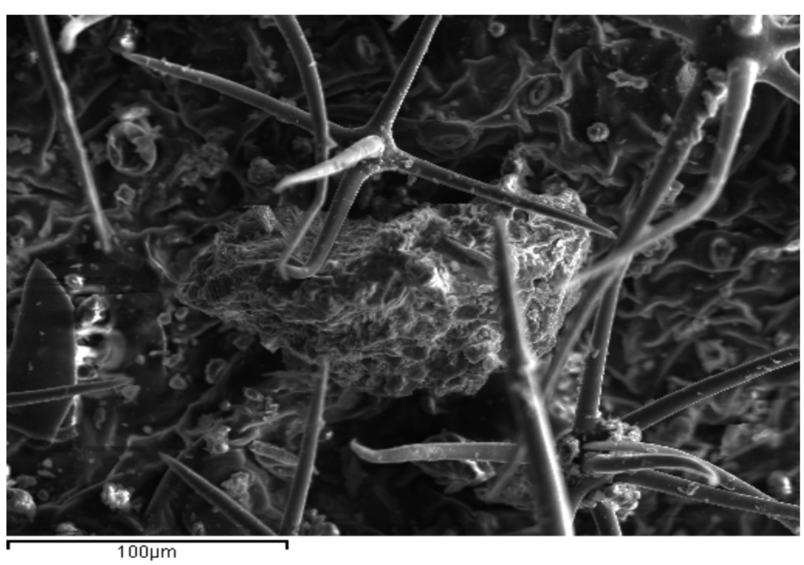

Figure 14: Particles trapped within trichomes on the upper leaf epidermis *of Verbascum phlomoides.*

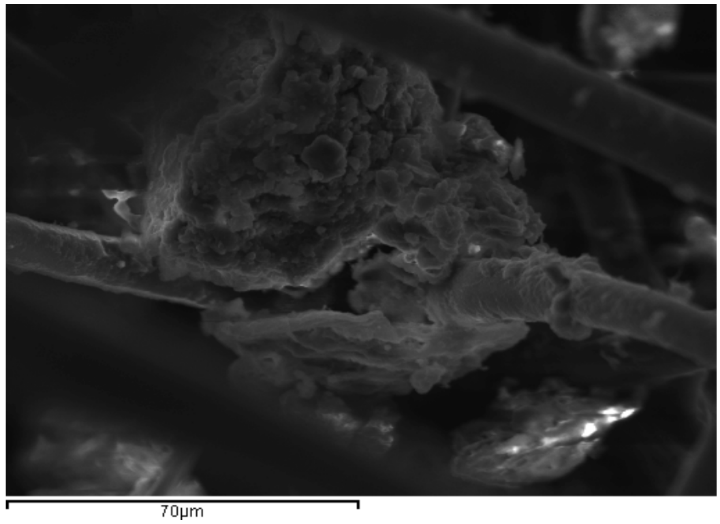

Figure 15: Particles well connected, within trichomes on the lower leaf epidermis *of Verbascum phlomoides.*

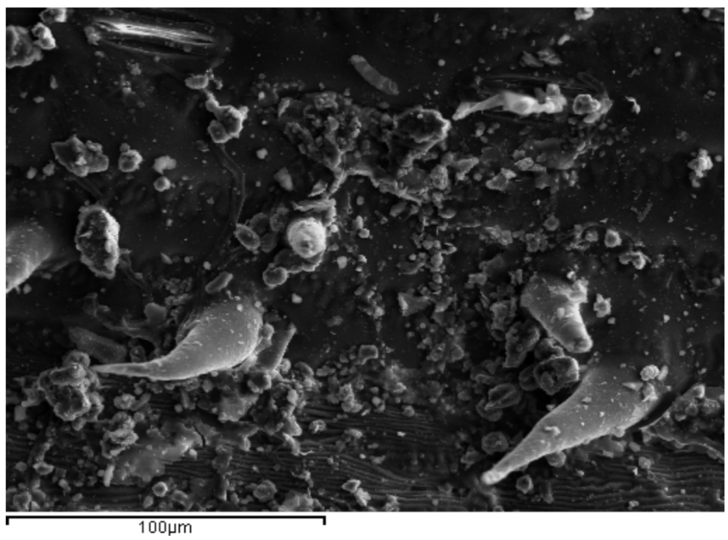

Figure 16: Particles trapped within non-glandular hairs on the upper leaf epidermis of *Zea mays.*

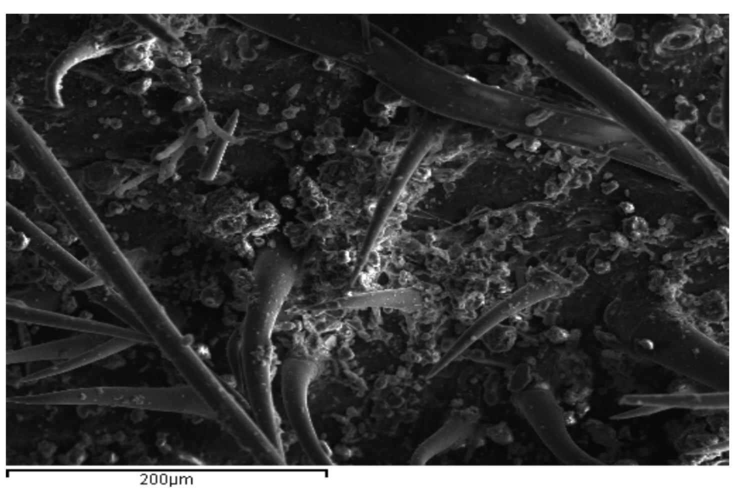

Figure 17: Particles trapped within non-glandular hairs on the outer ear surface of *Zea mays* husks.

phlomoides for Ni. Zn has not shown significant root accumulation in any of the studied plant species.

In general, if we look over the deposition on foliar surface or uptake by stomata and insist on the root

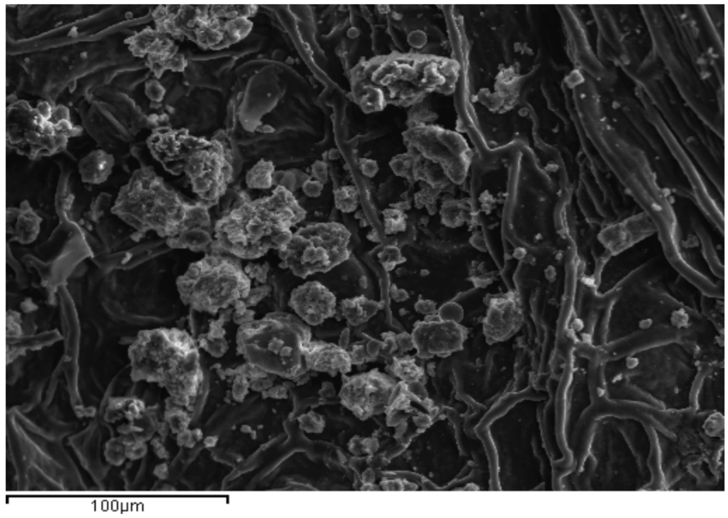

Figure 18: Particles deposited in aggregate on the upperl leaf epidermis *of Rumex acetosa.*

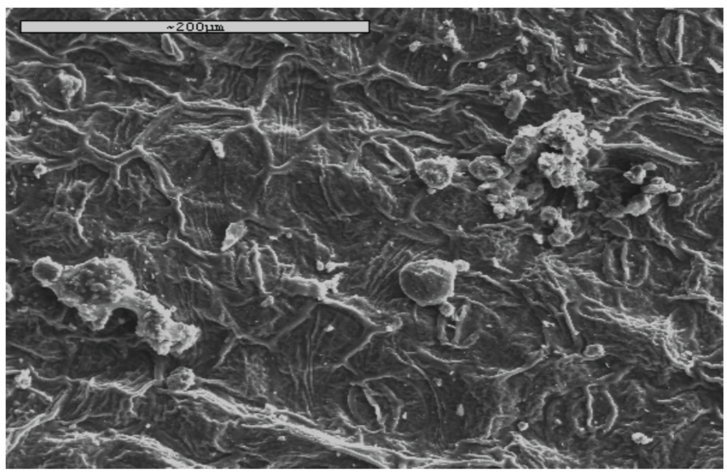

Figure 19: Relatively few particles deposited on the lower leaf epidermis *of Rumex acetosa.*

uptake, we shall see that roots reveal a higher heavy metal level among the other plant organs or tissues. This evident mainly in *Brassica oleracea* for all studied metals except Zn, where the highest Zn concentration was found in the central vein of the internal leaf where vascular bundles are present. Zn is also bound to vascular tissue in roots, stems and leaves absorbed from the xylem [18]. High Zn concentrations were also found in the same tissue (vascular bundle) in leaves of *Verbascum phlomoides.* Additionally, high Mn and Ni concentrations were observed in the central leaf vein as well, rich in vascular bundles, in *Verbascum phlomoides* leaves.

Zn is very mobile within plant organs and tissues. Under adequate supply, the Zn absorbed by roots is rapidly transported to the above ground parts of the plant [19]. *Brassica oleracea* is effective to accumulate significant concentrations of heavy metals in a high degree [20-22]. The Brassicaceae family has the highest number taxa that are established for hyperaccumulation of metals [23]. The obtained results show that *Brassica oleracea* possesses high potential for phytoremediation technologies to remove, detoxify or stabilize pollutants from the contaminated soils. Many species have been identified to be root accumulators, useful for phytoremediation of soils contaminated by heavy metals [24-26].

4.2. Foliar Deposition

Fly-ash particles landing on the leaf surface create a shading effect, lessening light penetration and block opening/closing of stomata. If we overlook the transport via root system and concentrate on foliar uptake, it is clear that the most polluted leaves reveal a variation in foliar roughness. In *Verbascum phlomoides* (mullein) and *Zea mays* (maize) the non-glandular, multilevel hairs on the leaf or ear epidermis enable trapping a great number of particles. Additionaly, the netted form

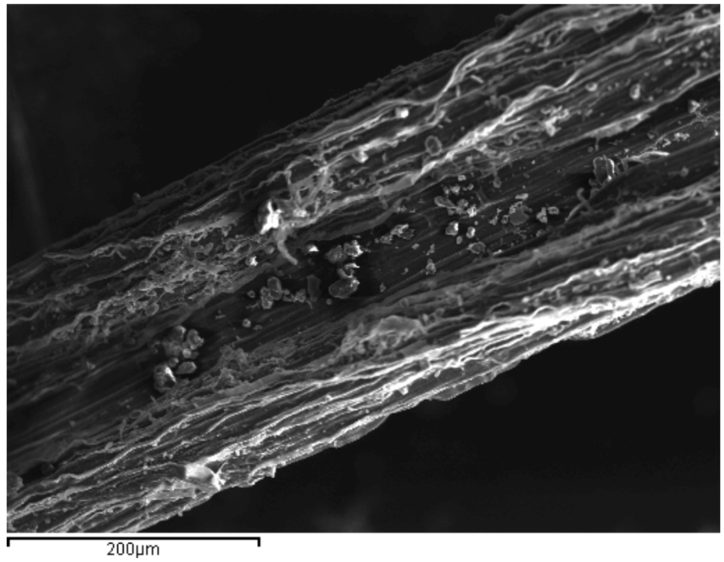

Figure 20: Fly ash particles were along the silk trichomes of *Zea mays.*

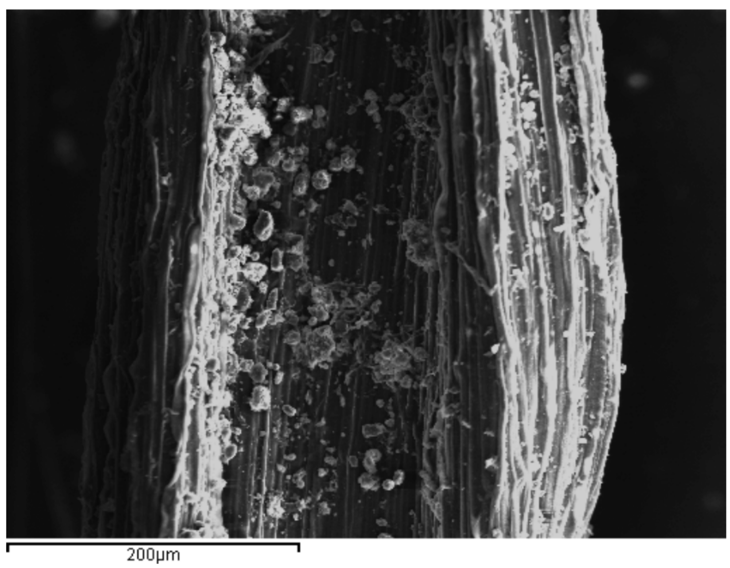

Figure 21: Fly ash particles on the receptive area of silks captured by the sticky cell walls.

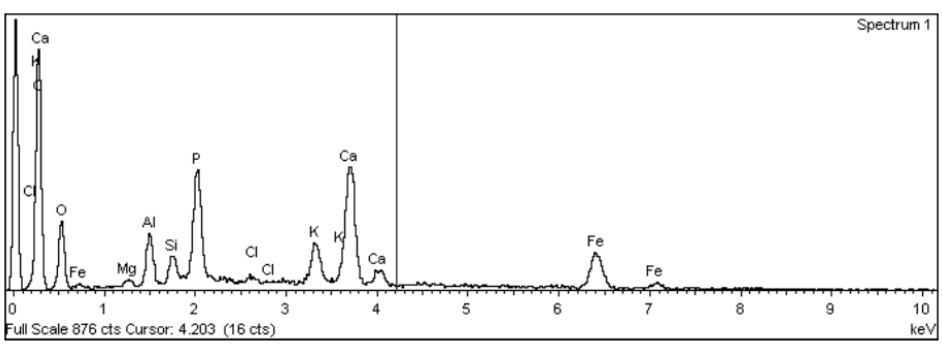

Figure 22: A typical spectrum of fly ash particles of Fig. 14 on the adaxial leaf surface.

of vascular bundles in leaves, increase the surface roughness and thus the air particle retaining capacity. The air moisture entangled between the trichomes is retained, so that it is not readily diffused into the dry surrounding environment. This is obvious in the case of Mn and Zn uptake by leaves of *Verbascum phlomoides.*

Table 1: SEM-EDS Elemental Analysis of Fly Ash Spherical Particles on Plant Leaf Surfaces

Element	Weight %			
	Fig. 14/22	**Fig. 15/23**	**Fig. 16/24**	**Fig. 17/25**
Mg	4.27	10.61	8.37	3.14
Al	20.82	17.26	11.59	10.54
Si	51.65	41.84	17.41	33.69
P	0.53	0.50	4.83	0.19
Cl	0.46	0.35	1.64	0.46
K	14.07	12.30	9.05	5.87
Ca	3.03	2.08	37.05	33.09
Cr	0.00	0.19	0.41	0.00
Mn	0.26	0.16	0.00	0.40
Fe	4.10	12.51	4.95	10.58
Ni	0.16	0.19	0.23	0.38
Cu	0.65	0.76	1.25	1.21
Zn	0.00	0.39	0.00	0.29
Pb	0.00	0.85	3.22	0.17
Totals	100.00	100.00	100.00	100.00

The waxy cuticle of *Brassica oleracea* leaves form a non-cellular layer over the epidermal cells, which enables the fast removal of the particles by rainwater or wind. Fly ash particles, containing trace metals [27] adhere weak the smooth foliar epidermis. The waxy cuticle, which covers the epidermal cells, acts as limiting barrier for metal absorption by the underlying tissues [28, 29]. This may be an explanation for those leaves with a smooth surface to be ‘‘smoke proof’’ as far as Ni and Zn are concerned. In general, basal leaves are more loaded than the upper ones, since they are exposed to air pollution for much longer time. This is also obvious for manganese in *Brassica oleracea* leaves.

Zea mays appeared as a flower accumulator for zinc, because high levels of metal were found in the male flower, followed by inflorescence stalk, corn silk and seeds. This indicates an efficient translocation of Zn to the remote aerial part and a high mobility within plant tissues [30]. Another explanation could be the fact that, the male flowers (tassel) of *Zea mays* growing in cluster with numerous florets give rise to a large exposed surface for efficiently trapping of air particles. For the same reason the moist and sticky corn silk, which is a part of the female flower, with short trichomes increasing the total exposed surface, showed high zinc concentration (60±8 μg/g) as well. Silks are the pollen receptive organs of *Zea mays* female florets, facilitating pollen capture and germination [31]. This parameter has a significant biological and environmental importance favoring fly ash particle adhesion competing pollen capture. In *Brassica oleracea* internal leaves, especially the rich in vascular tissue central vein, which are better protected from direct foliar deposition of air particles showed elevated Zn concentrations (155±122 μg/g) than the outer exposed leaves (17±3 μg/g).

4.3. Seeds

The heavy metal content mainly in maize have been extensively measured since this plant has been used for human nutrition by the food industries [32-34]. *Zea mays* seeds fortunately accumulate at lower concentrations all three metals studied. These metals are relatively immobile within plant tissues and thus the translocation from leaves or roots to the other plant organs (e. g. seeds) occurred in very low concentrations [35]. It is quite possible that the seed coat also plays a role in protecting the internal tissues, limiting the entry of metallic ions. In contrast, zinc, which is an essential micronutrient and is very mobile within plants [36], shows some accumulation capacity in *Zea mays* seeds.

Seeds are not suitable as storage organs for metal deposition than roots or leaves. This could be explained due to their short life period as well as their small surface area to biomass ratio and the fact that only the phloem and not the xylem is available to enter the grain [37]. Thus, essential micronutrients destined for the developing seed via a transpiration stream have to leave the xylem in order to be actively loaded into the phloem. On the other hand, the seed correspondence to heavy metals makes them useful symptomatic indicators. This is prominent in seeds of *Verbascum phlomoides*, which revealed high amounts of all metals studied. This plant showed relatively high metal content in reproductive organs (*e.g*. seeds), in comparison to the vegetative ones (*e.g*. leaves, shoot).

The mobility of metals is noteworthy for the uptake and distribution within plant tissues. Mn has intermediate mobility, whereas Zn and Ni are easy to mobilize, highly bio-available and therefore present rapid uptake and translocation rates. Zinc has notable translocation within plant [38]. Nevertheless, this study has shown that only very small amounts of Zn are transferred from roots to other parts of the plant, such as seeds. Biofortification strategies demand that inorganic trace elements leave the root and be targeted to the edible plant organs, such as leaves or seeds especially in crops. Thus, it is significant concern to ensure that toxic heavy metals remain trapped in the root [39].

CONCLUSIONS

This research work has revealed that there is no serious heavy metal contamination in the area of the coal power plant. In some cases the control region is more polluted with heavy metals than the studied area. Concerning the various plant organs, leaves with rough surface, *e.g*. *Verbascum phlomoides,* are the most overloaded organs of the plants. Some metals such as Zn have the ability to translocate easily in the plant body while others do not have such ability. Some cultivated plant species such as *Brassica oleracea* or *Zea mays* that accumulate great metal concentrations in the non-edible organs (root), could be easily used for the remediation, by periodically planting of these plants in order to clean up soils for other cultivations. After harvesting the edible parts (leaves or seeds) from the plants, the roots loaded by heavy metals, can be removed from the contaminated soil which becomes cleaner than before. The plant species used in this work have practical and commercial value because they are consumed by human and animals. In addition, since they can be easily found and cultivated globally, they could be used in comparative studies of international level.

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