

ASSESSMENT OF CABBAGE POTENTIAL FOR HEAVY METAL PHYTOREMEDIATION ON FLY ASH LANDFILL SUBSTRATE

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Abstract: Coal combustion produces large amounts of ash, often deposited in open landfills without vegetation, posing environmental risks. Vegetation stabilizes ash, reduces erosion and pollutant mobility, and provides organic matter. Brassicaceae species, such as cabbage, can absorb heavy metals, making them suitable for phytoremediation. This study evaluated cabbage (“srpski melez”) growth and metal accumulation on a fly ash landfill in spring 2023. Substrate and plant samples were analyzed for pH, organic carbon, total nitrogen, N, P, K, Mn, Ni, Pb, and Zn. Germination and biomass were lower on ash, but metal concentrations in plants remained below phytotoxic thresholds. Cabbage grown on ash can phytostabilize zinc and phytoextract manganese and lead.

Keywords: fly ash landfill, phytoremediation, Brassicaceae, heavy metals

Introduction

Coal combustion in thermal power plants generates large amounts of ash, often deposited in open landfills without vegetation, posing environmental risks due to unfavorable physical and chemical properties and potential toxicity (Gajić et al., 2019). Vegetation can stabilize ash, reduce erosion and pollutant mobility, and contribute organic matter (Pandey et al., 2016). Brassicaceae species are particularly suitable for phytoremediation, as they can absorb and accumulate heavy metals in plant tissues (Radulescu et al., 2013; Sharma et al., 2008).

Since heavy metals cannot be degraded and may enter the food chain, phytoremediation provides an environmentally friendly approach to stabilize

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or remove pollutants (Raskin et al., 1994; Pilon-Smits, 2005). Successful phytoremediation requires selecting plant species capable of growing under adverse conditions (Suresh and Ravishankar, 2004).

This study aimed to evaluate cabbage growth and heavy metal accumulation on ash landfills compared to uncontaminated soil to assess its suitability for phytoremediation.

Materials and methods

The experiment was established at the end of May 2023 using cabbage seeds (“srpski melez”) at two sites: a fly ash landfill of the TENT B thermal power plant and a control agricultural field in Zminjak (Šabac, Serbia). Four 10 m² plots per site were cultivated under standard practices. Sampling was performed manually on 7 November 2023.

Three representative plants per plot were collected. Plant parts (roots, stalks, leaves) were washed, air-dried, and oven-dried at 65°C before grinding for analysis. Substrate samples from the rhizosphere were oven-dried at 95°C, ground, and sieved (0.5 mm).

Analyses included:

Substrate: pH (ISO 10390:1994), organic matter (Tyurin, 1965), total nitrogen (Kjeldahl), available phosphorus and potassium (Egner-Riehm, 1960), total and bioavailable Mn, Ni, Pb, Zn (atomic absorption).

Plant tissues: The concentrations of N (Kjeldahl), P (Gee et al., 1954), K (flame emission), Mn, Ni, Pb, Zn (atomic absorption).

Phytoremediation potential was assessed using bioconcentration (BCF), bioaccumulation (BAF), and translocation factors (TF) (Yoon et al., 2006). Results are presented as means ± standard deviation (n=4)

Results and discussion

Chemical properties of the substrate.

The basic chemical properties of the analyzed soil and ash are shown in Table 1.

Table 1. Fertility of the analyzed soil and ash

	Soil	Ash
pH _{H2O}	7.4	7.37
pH _{KCl}	6.48	6.09
Organic C (%)	1.84 ± 0.00	2.99 ± 0.23
Humus (%)	3.17 ± 0.01	-

Total N (%)	0.30 ± 0.01	0.08 ± 0.00
Easily available P ₂ O ₅ (mg P ₂ O ₅ /100 g soil)	87 ± 7.56	16.4 ± 1.27
Easily available K ₂ O (mg K ₂ O/100 g soil)	48 ± 2.89	26.34 ± 0.33

Soil and ash showed similar slightly acidic reactions (Džamić et al., 1996). Control soil had higher total N, available P and K, reflecting fertilization, while ash had higher organic C due to unburnt coal particles (Djurdjević et al., 2006) (Table 1).

Total concentrations of Mn, Ni, Pb, and Zn are shown in Table 2. In both substrates these concentrations were below the remediation values prescribed by Serbian legislation (Official Gazette of RS 30/18). Available forms of most analyzed elements were higher in the control soil, probably due to long-term agricultural management and fertilizer application (Alagić and Randelović, 2015).

Table 2. Concentration of total and available forms of the analyzed metals in the substrate (mg kg⁻¹)

	Total		Available	
	Soil	Ash	Soil	Ash
Mn	739 ± 3.6	630 ± 1.7	68.1 ± 3.2	2.7 ± 0.0
Ni	40.2 ± 0.1	67.1 ± 0.2	3.6 ± 0.0	3.8 ± 0.1
Pb	56.1 ± 1.6	38.7 ± 0.5	5.4 ± 0.2	bdl*
Zn	57 ± 0.2	42.5 ± 0.1	3.9 ± 0.1	1.3 ± 0.0

bdl – below the detection level

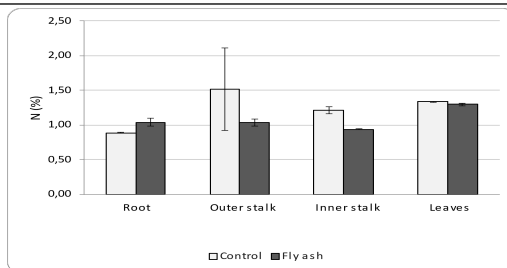
Plant growth and nutrient content

The percentage of plants reaching technological maturity was lower on the ash landfill (61%) than on the control soil (93%) (Table 3). Plants grown on ash developed smaller heads and exhibited lighter green coloration, most likely due to lower nutrient availability, particularly nitrogen. This is supported by the lower concentrations of nitrogen, phosphorus, and potassium detected in plants grown on ash, reflecting the reduced macronutrient content of the substrate (Červenski and Medić-Pap, 2018).

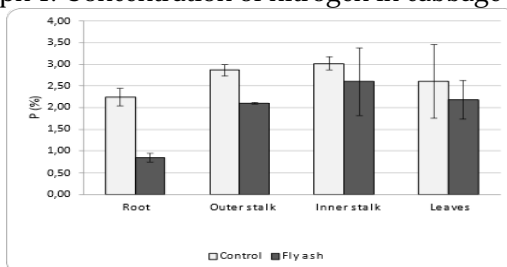
Table 3. Biomass of cabbage heads grown in soil and ash landfill

Substrate	Mass (kg)
Soil	2.16 ± 0.28
Ash	1.23 ± 0.21

The nitrogen concentrations were similar in the different organs (Graph 1). The absorbed nitrogen concentrations were within the typical average values found in plants (Topalović, 2021).



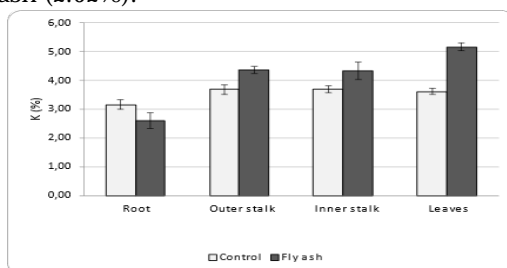
Graph 1. Concentration of nitrogen in cabbage parts



Graph 2. Concentration of phosphorus in cabbage parts

Phosphorus concentrations (Graph 2) were uniform in control plants, slightly lower in roots, while cabbage grown on ash accumulated P above typical ranges (0.05–1%; Topalović, 2021) and higher than reported for *Pisum sativum* ssp. *arvense*, *Brassica napus*, and *Medicago sativa* (Dželetović and Filipović, 1995).

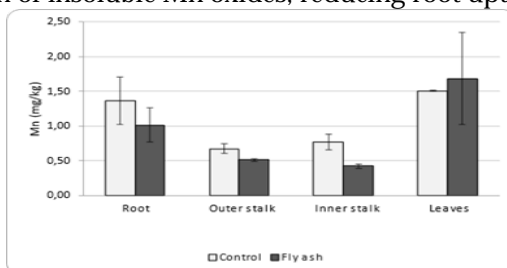
The highest potassium concentration was measured in the leaves of plants grown in control soil (3.62%), while the lowest value was recorded in the roots of plants grown on ash (2.62%).



Graph 3. Concentration of potassium in cabbage parts

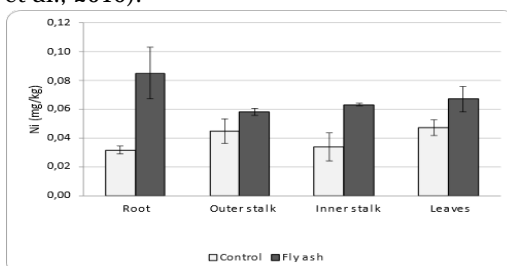
As shown in Graph 3 the absorbed concentrations of potassium in all plant parts at both sites were within the optimal ranges for plants, which, according to Stikić and Jovanović (2015), are 2–5%.

Manganese was highest in the leaves, but all concentrations remained well below phytotoxic levels (>500 mg/kg; Kabata-Pendias, 2011). The neutral pH of ash favors formation of insoluble Mn oxides, reducing root uptake (Graph 4).



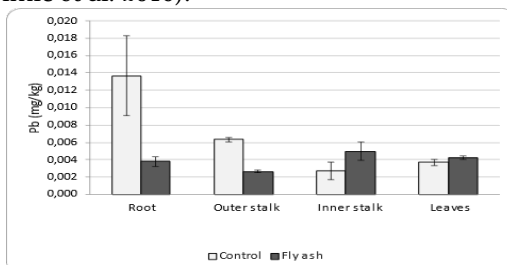
Graph 4. Concentration of manganese in cabbage parts

Nickel concentrations were higher in ash-grown plants (Graph 5), especially in roots, but remained far below phytotoxic levels (10–100 mg/kg; Kabata-Pendias, 2011) and were lower than in above-ground parts of perennial grasses and legumes (Simić et al., 2015).



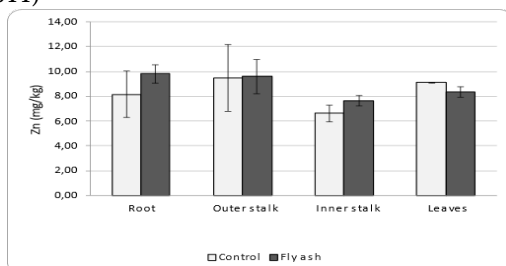
Graph 5. Concentration of nickel in cabbage parts

The highest lead concentration was found in the roots of the control plants (Graph 6). The Pb concentrations in the other plant parts from both substrates were uniform and well below the levels that cause phytotoxic effects in most plants (30-300 mg kg⁻¹; Ross 1994). Furthermore, the lead content in cabbage is significantly lower than that in other cultivated plants (Dželetović and Filipović 1995) and grasses (Simić et al. 2015).



Graph 6. Concentration of lead in cabbage

The Zn concentrations in the analyzed cabbage parts were uniform (Graph 7) and well below the levels toxic to most metal-sensitive plants (100-500 mg kg⁻¹; Kabata-Pendias 2011)



Graph 7. Concentration of zinc in cabbage parts

Metal uptake and translocation were assessed using BCF, BAF, and TF (Table 4). BCF values were <1 for all metals except Zn, which was efficiently accumulated in roots (BCF=7.555), indicating cabbage as a zinc accumulator (Usman et al., 2019).

Table 4. Bioconcentration (BCF), bioaccumulation (BAF), and translocation factor (TF) of plants grown on the ash landfill

	BCF	BAF	TF
Mn	0.367	0.610	1.660
Ni	0.022	0.018	0.789
Pb	-	-	1.106
Zn	7.555	6.413	0.849

According to Bhatti et al. (2018), BAF values greater than 1 indicate that cabbage can phytostabilize zinc, while TF values greater than 1 indicate that it can phytoextract manganese and lead.

The concentrations of Pb, Zn, and Ni determined in this study are well below the maximum tolerable values for animal feed (Table 5).

Table 5. Limit concentrations of potentially toxic elements in grasses (mg/kg)

	Pb	Zn	Ni
MTL	40	2000	50
CO	0.004 ± 0.0	8.32 ± 0.4	0.07 ± 0.01

MTL – Maximum tolerable level for animal feed (Adams 1975, NRC 2005); CO – Concentration of elements in cabbage leaves measured in this study

Conclusion

The results highlighted clear differences between control soil and ash substrate, with ash showing lower nutrient availability and reduced fertility,

negatively affecting cabbage growth. Despite this, cabbage adapted to ash conditions, accumulating essential nutrients within safe ranges. Mn, Ni, Pb, and Zn remained below phytotoxic levels. Phytoremediation assessment showed limited metal accumulation overall, but elevated BCF and BAF for Zn indicate effective uptake and stabilization, while $TF > 1$ for Mn and Pb suggests potential for phytoextraction. Thus, cabbage can grow on ash landfills and may be suitable for phytoremediation, particularly for zinc phytostabilization and manganese and lead phytoextraction

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