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The impact of available nickel on Metal Accumulation in Food Plants

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Abstract

The accumulation of nickel (Ni) in food plants is a growing concern due to its potential toxicity and ability to enter the food chain. Nickel can be taken up by plants and accumulate in various tissues, including edible parts, with concentrations influenced by factors such as soil characteristics, plant species, and environmental conditions. Elevated nickel levels in some soils in Albania, resulting from naturally nickel-rich (ultramafic) soils can increase the risk of plant uptake and subsequent human exposure.

This study evaluates the effect of available nickel in soil on its accumulation in food plants cultivated in the ultramafic zones of Poskë, Rajcë, and Prrenjas. The Mehlich-1 extraction method was used to determine available nickel concentrations in the soil, which were then analyzed using Atomic Absorption Spectrophotometry (AAS). To measure nickel concentrations in edible parts of plants, samples were digested and the resulting solutions were likewise analyzed using AAS. Results indicate a general trend where higher concentrations of extractable nickel in the soil correspond to increased nickel content in the edible parts of food plants. For instance, in Pojska, alfalfa grown in soil with 94.61 mg/kg of extractable nickel accumulated 75 mg/kg in its edible tissues, while oats in the same area showed similar uptake (95.28 mg/kg in soil and 76.8 mg/kg in plant tissue).

However, exceptions to this trend were observed. Some crops, such as onion from Rajcë and tomato from Rrajcë, showed low nickel accumulation relative to soil levels, suggesting that plant species have different capacities for nickel uptake and internal distribution. Leafy food plants such as salad, onion, and alfalfa generally exhibited higher nickel accumulation compared to fruiting plants like tomato and pepper. Additionally, crops such as tomato and corn appeared to limit nickel translocation to edible parts, possibly as a protective mechanism.

Overall, while a positive correlation exists between extractable soil nickel and nickel content in food plants, the degree of accumulation is clearly species-dependent. These findings highlight the importance of monitoring soil nickel levels, especially in areas affected by industrial activity or naturally high in nickel, to reduce potential risks to food safety and public health.

Keywords: Available Nickel; Ultramafic Soils; Food Plants; Edible Plant Parts; Nickel Accumulation in Plants.

1. Introduction

Heavy metals are naturally occurring elements with high density, some of which—like Ni, Cr, Pb, and Cd—are toxic even at low concentrations. They enter ecosystems from both natural sources, such as serpentine soils, and human activities like mining and agriculture (Hu et al., 2013).In Albania, serpentine soils cover over 11% of the land and are naturally enriched in heavy metals, especially Ni and Cr (Bani et al 2019; Bani et al 2024). Despite low fertility, these soils are used to grow vegetables, fruits, and cereals, which may accumulate harmful metal levels and pose health risks. This study aims to: (i) to assess the available forms of nickel in agricultural serpentine soil in south eastern Albania, to assess their ecotoxicity, (ii) evaluate the concentration of Ni in the edible parts of various vegetables, and (iii) compare the response of vegetables to available nickel in serpentine soils in southeast of Albania.

2. Materials and Methods

2.1. Study area

This study was conducted in 2024 on farmlands located in south east of Albania (Prrenjas, Rajce, Pojske).

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2.2. Sampling of Soil and Vegetables

Three subsamples were taken for each of the four vegetable species and one fruit species cultivated in the area. Both soil and edible plant parts were collected.
Soil samples were taken from the rhizosphere (root zone) of each plant type, with three repetitions per crop.

3.3. Soil and Plant sample preparation and analysis

Soil and plant analyses were performed at the Agricultural University of Tirana (AUT). Soil pH was measured using a 0.01 M $CaCl_2$ solution at a 1:2.5 soil-to-solution ratio.
The Mehlich-1 extractant was used to determine the available concentrations of nickel (Ni) in soil, which were then analyzed using atomic absorption spectrometry (AAS). For total concentrations of total nickel 0.5 g of soil was digested in aqua regia (a 1:3 mixture of 65% HNO_3 and 37% HCl) at 200°C for 40 minutes, followed by analysis via AAS. To determine Nickel concentrations in plant tissues, 0.2 g of dried plant material (edible parts and roots) was digested in a 4:1 mixture of 65% HNO_3 and 30% H_2O_2 using microwave digestion at 200°C for 25 minutes. Digest solutions were analyzed using Atomic Absorption Spectrophotometry (AAS) with the Analytik Jena AAS 400 instrument.

3. Results and Discussions

The extractable nickel (Ni) concentrations in soils cultivated with food crops varied widely, ranging from **11.2 mg/kg** (soil under salad in Prrenjas) to **95.28 mg/kg** (soil under oat in Pojska) (Figure 1). **Lowest Ni values** were observed in soils cultivated with salad at Prrenjas **(11.2 mg/kg)** and oat at Prrenjas (**21.4 mg/kg).** These results are in agreement with those reported by Bani et al., 2015). **Moderate values** appeared in soils under onion (Rajce: **22 mg/kg**; Hudenisht: **27.37 mg/kg**), salad (Hudenisht: **27.37 mg/kg),** tomato (Rrajce: **32 mg/kg**), and pepper (Rrajce: **32 mg/kg). Higher of concentration** were found in soils cultivated with corn (Rrajce: **53 mg/kg). Very high concentrations** occurred in soils cultivated with alfalfa **(94.61 mg/kg)** and oat **(95.28 mg/kg**) at Pojska. This is consistent with previous studies (Bani et al., 2019, 2024).

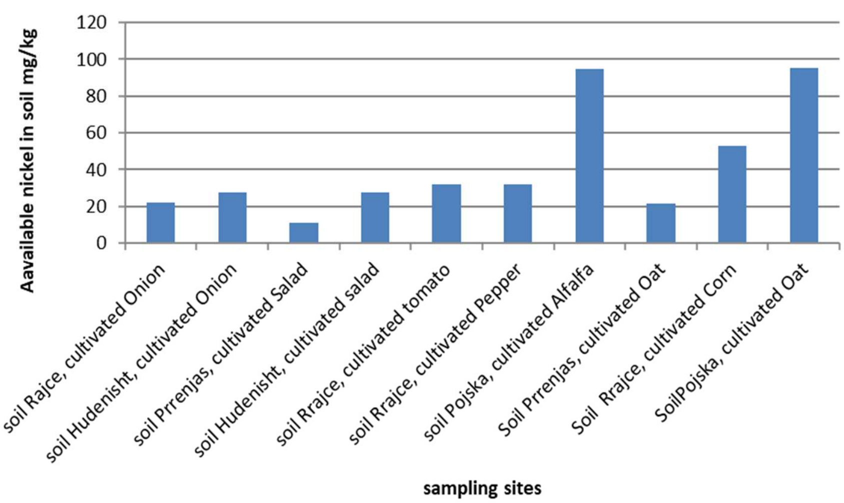

Figure 1. Soil available nickel (mean values, n=3) in agricultural and serpentine soil in South east of Albania

The nickel (Ni) concentrations in the edible parts of the analyzed food crops ranged from 10.6 mg/kg in tomato (Rrajce) to 81.4 mg/kg in onion (Rajce) (Figure 2). According to the WHO guideline of 10 mg/kg as the maximum permissible limit for Ni in food crops, nearly all samples exceeded the safe threshold. Only tomato (10.6 mg/kg) was close to the limit, but still slightly above it. Very high concentrations were found in onion (Rajce: 81.4 mg/kg; Hudenisht: 47 mg/kg), salad (Hudenisht: 61.4 mg/kg; Prrenjas: 28 mg/kg), alfalfa (Pojska: 75 mg/kg), and oat (Pojska: 76.8 mg/kg).

Moderately elevated concentrations were measured in pepper (Rrajce: 32 mg/kg), corn (Rrajce: 36 mg/kg), and oat (Prrenjas: 38 mg/kg). The lowest value was observed in tomato (Rrajce: 10.6 mg/kg), although this still exceeded the WHO guideline.

These results clearly demonstrate a serious food safety issue, since Ni concentrations in almost all tested crops were substantially higher than the recommended limit. This indicates a significant risk of dietary Ni exposure, which may lead to health problems such as dermatitis, respiratory complications, kidney damage, and even carcinogenic effects with chronic intake. Numerous studies have demonstrated that heavy metals can be absorbed by plant roots and transported to aerial parts, leading to accumulation in edible tissues, even when soil concentrations are relatively low (; Jolly et al., 2013; Sharma & Nagpal, 2018; Zwolak et al., 2019).

Variation in Ni accumulation was strongly influenced by crop type and location. Leafy crops such as salad, onion, alfalfa, and oat consistently showed the highest concentrations, which is consistent with their large surface area and strong tendency to accumulate metals from both soil and atmospheric deposition. In contrast, fruit crops such as tomato, pepper, and corn showed lower concentrations, although these still exceeded safe levels. Tomato was the closest to the WHO limit, suggesting that fruiting vegetables may accumulate less Ni than leafy or forage crops. Spatial differences were also evident, with crops grown in Pojska (alfalfa and oat) showing extremely high concentrations above 70 mg/kg, highlighting the strong influence of site-specific soil enrichment.

These findings are consistent with previous studies on serpentine soils in Albania (Bani et al., 2014), which reported high Ni uptake by plants due to the geochemistry of ultramafic parent materials. The present data confirm that the bioavailability of Ni in serpentine soils is readily translated into excessive accumulation in food crops.

From an agronomic perspective, the cultivation of vegetables and forages in such soils poses a serious challenge, as Ni concentrations surpass permissible limits by up to seven- to eight-fold. From a livestock feed perspective, crops like alfalfa and oat represent an additional concern, since excessive Ni can be transferred to the human food chain through milk and meat. These results emphasize the need for soil management strategies, such as crop selection favoring species with lower Ni uptake, soil amendments with organic matter, lime, or clay minerals to reduce Ni bioavailability.

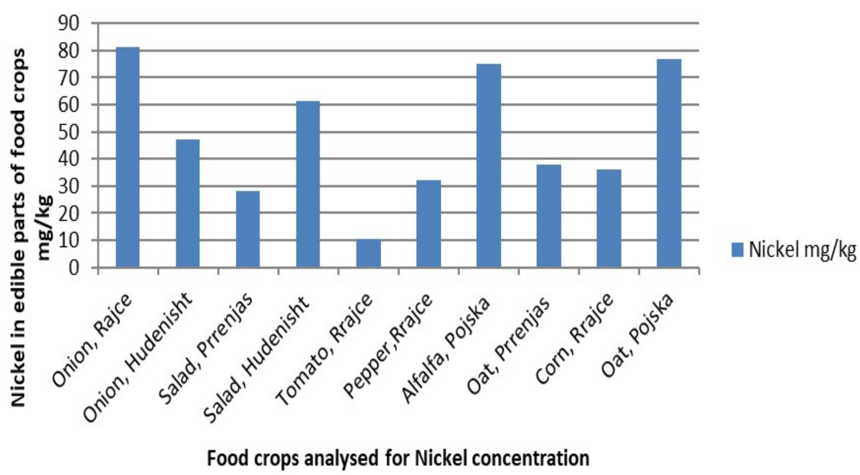

Figure 2. Nickel in edible parts of food crops cultivated in serpentine soil in southeast Albania (mean values). WHO limit for Ni in food crops = 10 mg/kg.

The scatter plot shows a low positive correlation (R = 0.265) between soil Ni availability and Ni concentration in edible plant tissues (Figure 3). This indicates that only about 26.5% of the variation in Ni concentrations in edible plant parts can be explained by soil Ni availability. The remaining ~73.5% of variation is attributable to other factors, including crop type and physiology (e.g., onion and salad are strong accumulators, whereas tomato is a weak accumulator), soil properties (pH, organic matter, clay content, competing ions), and environmental conditions (moisture, microbial activity, redox conditions).

The relatively low R^2 value (0.265) suggests that, although there is a general positive trend, soil Ni alone is not a strong predictor of plant Ni content. This emphasizes that plant-specific uptake mechanisms and interactions with soil chemistry play a dominant role in determining Ni accumulation.

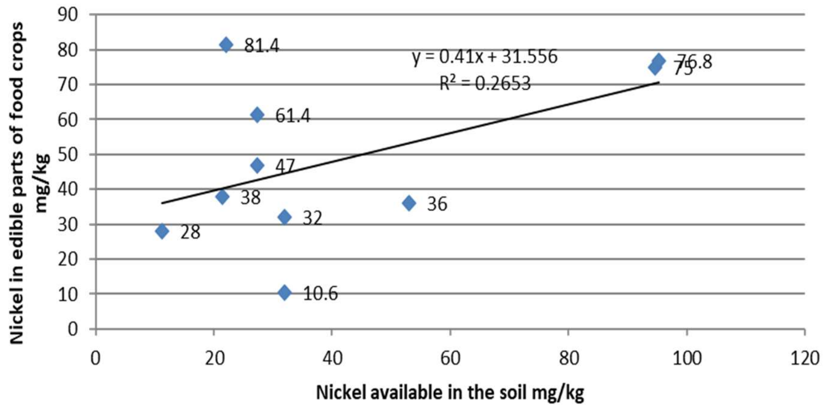

Figure 3: Relationships between available nickel in soil and nickel in edible parts of plants in soil of southeast of Albania.

4. Conclusions

The study indicates that Ni levels in nearly all analyzed food crops far exceed the WHO limit of 10 mg/kg, posing a significant risk to human and animal health. Leafy vegetables and forage crops are particularly affected, whereas fruiting vegetables tend to accumulate less Ni. Immediate interventions are necessary to ensure food safety in these Ni-rich serpentine soils.

The correlation between available soil Ni and Ni in edible crop parts is positive but weak ($R^2 = 0.265$). Soil Ni accounts for only about a quarter of the observed variation, while crop species, soil properties, and environmental factors explain the majority. These findings underscore the importance of careful crop selection and soil management in Ni-rich serpentine areas to reduce potential health risks.

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