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THE EFFECT OF DIFFERENT METHODS OF HEAT TREATMENT OF GREEN VEGETABLES ON THE MINERAL CONTENT. A STUDY OF FIVE GREEN VEGETABLES FROM KOSOVO

S u m m a r y

Background. It is widely accepted that green vegetables are a rich source of nutrients, especially among populations that consume plant-based diets. A diet based on green vegetables can help to prevent cognitive decline, as well as other health problems. In this study, five green vegetables commonly consumed in Kosovo were subjected to an analysis of the influence of heat treatment methods such as boiling, frying and microwave cooking on the mineral content, as well as the reduction of toxic metals in their composition.

Results and conclusions. In general, cooked vegetables lose a lot of their nutrients such as potassium (K), sodium (Na), phosphorus (P), magnesium (Mg), zinc (Zn), copper (Cu) and manganese (Mn) compared to raw vegetables. Conversely, all cooked vegetables had increased levels of calcium (Ca), which ranged from 5 to 16 %, and iron (Fe) from 6 to 12 %, while the concentration of Cu, Pb and Ni was lower in all the vegetables examined. The concentration of Cr was higher in all green vegetables (uncooked); the sample of spinach had higher levels of Zn, Fe, Mn and Cd than the maximum allowed limit suggested by FAO/WHO. This study showed that microwave cooking was the most effective method for preserving the nutritional values (minerals) and reducing the toxic elements of vegetables, while boiling had an effect on reducing nutritional minerals. On the other hand, the frying of the vegetables examined had an effect on increasing the mineral composition and moderate reduction of toxic elements. Therefore, the food processing method in general has a pronounced effect on the composition of nutritional minerals, while a minimal effect on the reduction of toxic metals content in the green vegetables analyzed.

Keywords: green vegetables, boiling, frying, microwave cooking, minerals, toxic metals

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Introduction

The vegetable crop sector is generally considered one of the main branches of the agricultural economy in Kosovo [24]. Green vegetables refer to a group of vegetables that are rich in dietary fiber, vitamins, minerals, carotene and essential amino acids [33]. These vegetables are an integral part of the daily diet of people, because they are rich in important nutritional components, especially with mineral elements such as potassium, calcium, phosphorus, sodium, magnesium, copper, iron and zinc [19]. They are known for maintaining health and preventing diseases because of their valuable nutritional nutrients needed to build the human body [40]. The examples of green vegetables include spinach, broccoli, green pepper, green cabbage, kale, etc., and they usually have dark colors. The consumption of green vegetables rich in vitamin C has been reported to protect against coronary heart disease [5]. Green vegetables also improve the immune system and alleviate illnesses including bronchitis, cataracts, asthma and other respiratory syndromes [21]. In addition, they also help in brain health due to neuroprotective actions of lutein, folate, carotene, vitamin K and other bioactive compounds [29].

Although green vegetables are a good source of minerals, vitamins and phytochemicals, they are susceptible to contamination with various toxic elements if these vegetables are grown in areas that are polluted, for example with poisonous metals such as Cd, Pb, Ni, Zn, etc., which accumulate in the edible parts of plants [4]. Toxic metal pollution of the food chain has recently become a serious problem because of its considerable accumulation in biosystems through contaminated water, soil and air [31]. Eating contaminated vegetables is considered one of the main routes for human exposure to hazardous elements [26]. The negative effects of various pollutants, including heavy metals as toxic elements, affect food safety and human health in general. For sustainable global growth, food security is one of the most important issues worldwide [32, 41].

In terms of consumption, people usually use green vegetables as fresh (raw), however, in most cases they can be processed as well. The most common cooking methods of these vegetables are boiling, stir-frying, and more recently, microwaving [25]. To preserve their nutritious and health-promoting qualities, vegetables are frequently prepared at home at one’s convenience, according to tradition or to one’s personal taste [27]. Recent studies suggest that thermal treatment impacts the mineral and bioactive composition of vegetables, with both positive and negative consequences reported [6]. There have been studies reporting on how cooking methods affect the loss and preservation of various food vitamins, minerals, heavy metals and phenolic components [28, 20, 34].

In general, food engineers and scientists define boiling as the cooking process in water. When water is heated to a boiling point of 100 °C, huge bubbles form at the bottom of the pan, rising quickly and shattering the liquid's surface. Broccoli loses $5 \div 10$ % of its total minerals when it is cooked, however, boiling also helps break down the vegetable's cell walls and releases more nutrients [16].

During boiling, green vegetables reduce nutrients and phytochemicals [3]. On the other hand, the amount of proteins and minerals in fried food is largely unaffected during processing. Moreover, frying results in a smaller loss of heat-sensitive vitamins than other cooking methods because of its high temperature and quick transit time [11]. In order to achieve the optimal quality of fried vegetables, the term "frying" refers to the process of frying vegetables into small pieces and transferring heat from cooking materials called pans to vegetables [16]. Microwave heating is a relatively new culinary method, and there is little research on its effects on the mineral nutrients and harmful components of green vegetables [13]. Due to a number of factors, including energy efficiency and a shorter cooking time than for frying or boiling, microwave cooking helps preserve essential nutrients in vegetables. Heat-sensitive nutrients are less likely to degrade in microwaves because of their lower temperatures compared to boiling or frying [13].

In contrast to frying or boiling, which normally require higher temperatures (e.g., frying oil is often around 160 °C to 180 °C), microwaves usually cook food at a lower temperature (commonly between 100 °C and 120 °C). The microwave's more accurate temperature control lowers the possibility of overcooking, which can destroy water-soluble vitamins like vitamin C and several B vitamins, as well as heat-sensitive minerals, for instance potassium [25]. Water-soluble minerals are less likely to leach when there is little or no water present in the microwave. Essentially, heating vegetables in the microwave at controlled temperatures and with minimal amounts of water or oil leads to better mineral retention, especially compared to such methods as frying or boiling that can result in significant nutrient loss due to high heat and rinsing [13].

The purpose of this study was to analyze the effect of various cooking processes on mineral and hazardous metal content in selected green vegetables often consumed in Kosovo (Figure 1). Considering the potential toxicity of green vegetables that are occasionally grown in areas contaminated with toxic elements such as near industrial facilities (thermal power plants, coal mines, highways or solid waste landfills), their common use among the people in Kosovo, and the necessity of food security, more research is required on these vegetables in this region. As a result, the study is focused on the determination of hazardous metals in green vegetables, as well as the effect of cooking methods on mineral and toxic metal content in order to make recommendations about their consumption.

Figure 1. Raw green vegetables
Rycina 1. Surowe zielone warzywa

Materials and methods

Materials

A total of 50 samples (10 samples for each type) of fresh, cultivated and commonly consumed green vegetables in Kosovo including Spinach (*Spinacia oleracea* L.), Green pepper (*Capsicum annuum* L.), Parsley (*Petroselinum crispum*), Green Cabbage (Brassica oleracea var. capitata) and Broccoli (*Brassica oleracea* var. *italica*) (Table 1) were purchased from the local market in Pristina (Kosovo) in the period of May-June 2024. All the collected samples were packed separately in polyethylene bags and brought to the laboratory for preliminary treatment and analysis.

Table 1. Raw green vegetables used in this study
Tabela 1. Surowe zielone warzywa użyte w tym badaniu

No	Common name / Nazwa powszechna	Scientific name / Nazwa naukowa
1	Spinach / Szpinak	*Spinacia oleracea* L.
2	Green pepper / Zielona papryka	*Capsicum annuum L.*
3	Parsley / Pietruszka	*Petroselinum crispum*
4	Green Cabbage /Zielona kapusta	*Brassica oleracea var. capitate*
5	Broccoli / Brokuły	*Brassica oleracea var. italica*

Cooking methods

All samples that were used to test the effect of cooking were analyzed within 15 hours of their preparation. The treatment time, the amount of added water and the sample amount are given in Table 2. After each treatment, the samples were drained of water and dried at room temperature. All chemicals used in this study were of analytical grade and purchased from Sigma-Aldrich Chemical Co. (St. Louis, MO, SHBA).

Table 2. Treatment time, amount of water and sample mass
Tabela 2. Czas obróbki, ilość użytej wody i masa próbki

Treatment / Rodzaj obróbki	Time / Czas [min]	Water / Woda [cm^3]	Sample mass / Masa próbki [g]
Raw (Fresh) / Surowe (Świeże)	-	-	200
Boiled / Gotowane	10	150	50
Stir-fried / Smażone	6	-	50
Microwave / Mikrofalowane	2	5	50

Determination of nutritional minerals and toxic metals in green vegetables

The preparation of samples: Green vegetable samples were thoroughly cleaned under running water, then with distilled water and spread on dry filter papers to remove surface moisture. Then the green vegetables were cut into equal pieces (the sample size: 2 cm x 2 cm) and divided into four equal parts, out of which one-part (raw) served as control and the other three parts were subjected to three different cooking methods (i) boiling (ii) stir-frying and (iii) microwave cooking.

The preparation of Standard Solutions: A 1,000 mg/dm^3 standard stock solution of the elements K, Na, P, Ca, Mg, Fe, Ni, Mn, Zn, Cr, Cu, Cd and Pb in 5 % HNO_3 was used to create the working standard solutions for each element. Using the stock standard solution, 100 cm^3 volumetric flasks were filled with intermediate standard solutions containing 10 mg/dm^3. Four new working standards for each element were obtained by diluting the intermediate standards with deionized water. The identical analytical procedures were used to produce blank solutions, and each element was the subject of three duplicate measurements.

The levels of nutritional minerals and toxic metals in raw and cooked green vegetable samples by three different methods, such as boiling, stir-frying and microwave treatment, were measured using the Microwave Plasma Atomic Emission Spectroscopy (MP-AES 4200) apparatus using the methodology previously employed by Shemnsa et al. [39]. The measurement of metals in the dissolved blank solution was also carried out concurrently with the samples, maintaining constant parameters and following the same process.

Statistical analysis

The results were analyzed using OriginPro 9.0 software (OriginLab Corporation) and reported as the mean ± standard deviation (SD). To validate and compare the average values of the elements across various sampling sites, a one-way ANOVA and Tukey's test were used to compare the mean values ($p < 0.05$) among samples.

Results and discussion

Content of nutritional minerals and toxic elements in some green vegetables

The content of nutritional minerals and toxic elements between green vegetable samples is presented in Table 3. The most abundant element among nutritional minerals as macronutrients was K, followed by Ca, P, Mg and Na. The fact that the minerals such as nitrogen, phosphorus, potassium and magnesium are highly mobile in plant tissues and migrate from older plant tissues to younger ones is the primary cause of the high potassium concentration found in green vegetables [30]. Higher concentrations of K, Ca, P and Mg can also be attributed to the roles of these elements in the plant growth and development. Elevated Ca levels are also the result of the quantity of calcium-containing minerals in soil and water, which are often abundant and easily absorbed by plants [42].

On the other hand, green vegetables had the highest concentration of Fe out of all the micronutrients examined, followed by Zn, Mn, Cr, Ni and Cu. In general, having considered the levels of all elements analyzed in green vegetables, it can be concluded that the concentrations of macro- and micronutrients in these vegetables had a similar trend. Our study is in a good agreement with previous similar studies by Razzak et al. [35], Żurawik et al. [44] and Yue et al. [43].

Overall, K > Ca > P > Mg > Na > Fe > Mn > Zn > Cu > Cr > Ni was the order in which the relative quantity of mineral nutrients was found in the observed green vegetables. The toxic elements Cd and Pb were below the allowed values according to the FAO/WHO (Cd 0.05 ÷ 0.20 mg/kg and Pb 0.05 ÷ 0.30 mg/kg), except green pepper, where higher values were recorded (Table 9). These findings demonstrate that the sampling sites are free of harmful industrial waste pollution. Moreover, the low concentration of harmful substances implies that the plantations where these vegetables are cultivated probably do not utilize commercial herbicides or fertilizers [1]. Furthermore, Pb and Cd provide no nutritional benefit to humans; as well as their minimum concentrations are sensitive [36].

The finding that lead (Pb) and cadmium (Cd) concentrations are below permissible limits in most green vegetables is important because Pb and Cd are toxic heavy metals that can accumulate in the human body and cause a variety of health problems, including damage to the kidneys, liver and the nervous system, as well as can have carcinogenic effects. On the other hand, this indicates that the risk of exposure to these harmful substances through the consumption of green vegetables is low and helps to ensure that the food supply is safe for consumers [36].

Table 3. Minerals content and toxic elements of tested raw green vegetables
Tabela 3. Zawartość składników mineralnych i toksycznych w badanych surowych zielonych warzywach

Minerals / Składnik mineralny	Raw green vegetables / Surowe zielone warzywa				
	Spinach / Szipnak (*Spinacia oleracea* L.)	Green pepper / Zielona papryka (*Capsicum annuum* L.)	Parsley / Pietruszka (*Petroselinum crispum)*	Green Cabbage / Zielona kapusta (*Brassica oleracea var. capitate*)	Broccoli / Brokuły (*Brassica oleracea var. italica*)
	Mineral nutrients / Składnik mineralny [mg/kg]				
K	4,800[d] ± 50.21	4,750[c] ± 41.22	3,640[c] ± 35.44	4,680[c] ± 48.11	5,120[d] ± 51.24
Na	770[c] ± 26.11	40.0[a] ± 8.11	912.0[b] ± 18.43	260.0[d] ± 50.11	280.0[b] ± 21.22
Ca	2,876[b] ± 21.22	2,453[b] ± 21.23	2,351[b] ± 21.23	2,980[c] ± 45.23	3,122[d] ± 51.23
P	2,900[b] ± 21.23	2,098[c] ± 41.22	186[b] ± 10.0	1,234[b] ± 15.22	3,012[b] ± 21.23
Mg	689[b] ± 20.11	522[c] ± 45.33	511[b] ± 10.11	7,232[d] ± 51.22	943.22[d] ± 50.11
Fe	39.66[a] ± 1.45	34.22[b] ± 10.11	41.22[a] ± 1.20	65.80[b] ± 1.77	45.50[a] ± 1.40
Zn	8.32[a] ± 0.10	6.30[a] ± 0.11	10.70[a] ± 0.12	3.40[a] ± 0.12	10.50[a] ± 0.11
Cu	2.40[a] ± 0.10	2.66[a] ± 0.10	1.49[a] ± 0.10	5.52[a] ± 0.10	2.68[a] ± 0.03
Mn	8.79[a] ± 0.30	1.22[a] ± 0.10	1.60[a] ± 0.10	4.10[a] ± 0.10	9.80[a] ± 0.55
	Toxic elements / Element toksyczny (mg/kg)				
Cr	14.10[a] ± 0.12	13.60[a] ± 0.12	14.13[a] ± 0.11	12.90[a] ± 0.12	12.91[a] ± 0.12
Cd	0.12[a] ± 0.01	0.21[a] ± 0.01	0.11[a] ± 0.01	0.12[a] ± 0.01	0.13[a] ± 0.01
Pb	0.21[a] ± 0.01	0.17[a] ± 0.01	0.18[a] ± 0.01	0.21[a] ± 0.01	0.18[a] ± 0.01
Ni	12.20[a] ± 0.12	10.23[a] ± 0.11	11.21[a] ± 0.12	11.10[a] ± 0.12	10.56[a] ± 0.11

Explanatory notes / Objaśnienia:
Data are presented as average value ± standard deviation of three replicates / Dane przedstawiono jako wartość średnią ± odchylenie standardowe z trzech powtórzeń

The effect of different cooking methods on mineral nutrients and toxic elements content

Modifications may improve or decrease the quality of cooked vegetables, depending on the type/caliber of raw vegetables, as well as the conditions of the particular cooking method. The vegetable preparation techniques that are most frequently used include boiling, steaming, stir-frying, pressure cooking, baking and microwaving. Cooking food that preserves most nutrients and offers the greatest benefits for consumers requires an understanding of how different cooking methods alter nutrients and bioactive compounds in vegetables [22]. The relationship between the type of vegetables and the effectiveness of the cooking method in preserving nutrients varies depending on water and fiber content [25]. Vegetables with higher water content tend to lose more nutrients when cooked, while steaming is generally better for preserving water-soluble and fat-soluble vitamins. High-fiber vegetables often benefit from cooking methods like roasting or steaming that preserve their nutrients while softening their fiber for easier digestion [14]. Spinach has a high-water content, hence steaming is the best method to retain nutrients such as vitamin C and folate, as it avoids the nutrients leaching into the water, while broccoli has a high fiber and water content, therefore steaming helps preserve glucosinolates and vitamin C, as boiling can leach them into the water [10].

Nutrient minerals such as potassium, sodium, phosphorus, calcium, magnesium, iron, zinc, copper and chromium of raw and cooked green vegetables are shown in Tables 3 ÷ 8. The nutritional mineral content of green vegetables showed different trends, which can be attributed to their existence in different forms in plant tissues, such as K in free form and Fe as bound to proteins or other compounds having high molecular weight [23]. The high potassium (K) content in green vegetables can be attributed to several factors related to a plant’s biology, a growing environment and nutritional needs. The high potassium content in green vegetables is a result of their biological and physiological needs. Potassium plays a central role in supporting plant growth, photosynthesis and nutrient transport, all of which are especially important in green leafy vegetables [37]. Additionally, factors such as the level of potassium in the soil, a plant's ability to absorb and store potassium, and the high transpiration rates of leafy vegetables contribute to their enrichment with potassium. These elements, combined with the large surface area of a plant's leaves, make green vegetables particularly rich in potassium [8].

The nutritional mineral level of Broccoli (Brassica oleracea var. italica) was much higher than that of other green vegetables. However, the content of Zn, Fe and Mn of broccoli was above the maximum allowable level recommended by FAO/WHO [15], although the accumulation of Cu content was below the maximum level in all analyzed green vegetables. The tables (3 ÷ 8) demonstrate that boiled green vegetables had a significant loss of minerals such as K, Mg, Zn, Cu, Mn compared to fresh vegetables. The loss of minerals in green vegetables during the cooking process can be attributed to the leaching effect [2].

However, the calcium and iron contents of all cooked vegetables increase and range from 5 to 16 % and 6 to 12 %, respectively. Calcium (Ca) is often found at higher concentrations in green vegetables for several reasons related to the biological processes of a plant, the role of calcium in a plant’s growth, and the influence of soil and water compositions. The high concentration of calcium in green vegetables results from a plant's biological needs for strong cell walls, membrane integrity and stress management, all of which are facilitated by calcium. In addition, soil and water compositions play a critical role in calcium availability. Calcium-rich soils with a suitable pH, along with the use of calcium-rich water and fertilizers, contribute to a higher calcium content in vegetables. Green vegetables are particularly efficient at accumulating calcium in their leaves, making them an important dietary source of this essential nutrient [7].

Although leaching during cooking is typically expected to result in a loss in a mineral content, a particular rise in calcium and iron reported in this study may have been caused by a decrease in oxalic acid. Our findings concur with those of earlier research reported by previous studies [18] which also found similar increases in calcium and iron, as well as decreases in the content of potassium, magnesium, zinc, copper and manganese. The concentrations of toxic elements such as cadmium, lead, nickel and chromium in the analyzed vegetables are also presented in Tables 3 ÷ 8. It was found that the concentration of Cd was higher in the green pepper 0.21 ± 0.01 mg/kg; the concentration of Pb was also higher in the green pepper 0.17 ± 0.01 mg/kg, and Ni was found to be higher in spinach and parsley, for which the following values were reported: 12.20 ± 0.2 mg/kg and 11.21 ± 0.12 mg/kg, respectively. Boiling, as a cooking method, showed a reduction of these elements, ranging from 19 to 38 %, 14 ÷ 38 %, 7 ÷ 22 % in cadmium, nickel and chromium, respectively, in the analyzed green vegetables (Tables 3 ÷ 8).

In addition, the decrease in these elements can be attributed to the release of hazardous metals from the cooked plant tissue as free salts or in combination with soluble amino acids and uncoagulated proteins, or to the dissolution and volatilization of toxic metals during the cooking process [18]. Our findings were in agreement with those reported by Razzak et al. [35], who found a reducing trend in the content of toxic metals in vegetables. On the other hand, cooking in a microwave was the most effective method for preserving nutritional values (minerals) and reducing toxic metals of green vegetables, while stir-frying had an effect on increasing the nutritional mineral composition, with a moderate impact on reducing toxic elements. Our study is consistent with previous studies carried out by Lee et al. [25], Fratianni et al. [17].

Green vegetables are a good source of elements such as calcium, magnesium, sodium, potassium, calcium, phosphorus and trace elements such as iron, zinc, manganese and copper, which are essential for human nutrition [12]. The nutrient mineral composition and the presence of toxic metals in green and cooked vegetables vary depending on the conditions of their growth, the time of their harvest, the nutrients of the soil in which they are grown, the methods of cooking, cooking time, and the analytical conditions of measuring these elements [38]. The level of ripeness and storage method before cooking play an important role in determining the concentration of toxic and nutritional minerals in green vegetables [35]. These factors can affect the bioavailability, retention and distribution of minerals, including essential nutrients (such as calcium, magnesium, potassium) and potentially harmful elements (such as toxic metals or oxalates). As vegetables ripen, their mineral content (both nutritional and potentially toxic) can increase [23].

Table 4. Mineral and toxic elements content in Spinach (*Spinacia oleracea* L.) cooked using different methods
Tabela 4. Zawartość składników mineralnych i toksycznych w szpinaku (*Spinacia oleracea* L.) gotowanym różnymi metodami

Mineral nutrients / Składnik mineralny [mg/kg]									
Treatment / Obróbka	K [mg/kg]	Na [mg/kg]	Ca [mg/kg]	P [mg/kg]	Mg [mg/kg]	Fe [mg/kg]	Zn [mg/kg]	Cu [mg/kg]	Mn [mg/kg]
Control (Fresh) / Kontrola (Świeże)	4,800[d] ± 50.21	770[c] ± 26.11	2,876[b] ± 21.22	2,900[a] ± 21.23	689.34[a] ± 20.11	39.66[b] ± 1.05	8.32[a] ± 0.10	2.40[a] ± 0.10	8.79[a] ± 0.30
Conventional boiling / Tradycyjnie gotowane	2,600[c] ± 40.21	412[b] ± 16.11	3,502[b] ± 20.21	3,970[a] ± 21.00	523.21[b] ± 20.11	23.76[a] ± 1.02	7.64[a] ± 0.10	2.31[a] ± 0.10	8.21[a] ± 0.01
Stir-fried / Smażone	4,300[d] ± 50.21	570[b] ± 22.11	3,076[b] ± 21.22	3,100[a] ± 21.00	719.34[a] ± 20.11	36.42[b] ± 1.05	7.92[a] ± 0.10	2.21[a] ± 0.10	8.72[a] ± 0.30
Microwave heating / Ogrzewane mikrofalowo	5,300[d] ± 50.21	886[b] ± 25.11	3,845[b] ± 21.22	3,450[a] ± 21.00	794.31[a] ± 20.11	37.14[b] ± 1.05	8.21[a] ± 0.10	2.31[a] ± 0.10	8.65[a] ± 0.30

Toxic elements / Składnik toksyczny (mg/kg)				
Treatment / Obróbka	Cr [mg/kg]	Cd [mg/kg]	Pb [mg/kg]	Ni [mg/kg]
Control (Fresh) / Kontrola (Świeże)	14.10[a] ± 0.12	0.12[a] ± 0.01	0.21[a] ± 0.01	12.20[a] ± 0.12
Conventional boiling / Tradycyjnie gotowane	12.11[a] ± 0.12	0.11[a] ± 0.01	0.15[a] ± 0.01	10.00[a] ± 0.12
Stir-fried / Smażone	12.54[a] ± 0.12	0.13[a] ± 0.01	0.13[a] ± 0.01	10.67[a] ± 0.12
Microwave heating / Ogrzewane mikrofalowo	13.18[a] ± 0.12	0.12[a] ± 0.01	0.14[a] ± 0.01	11.40[a] ± 0.12

Explanatory notes / Objaśnienia:
Data are presented as average value ± standard deviation of three replicates / Dane przedstawiono jako wartość średnią ± odchylenie standardowe z trzech powtórzeń

Table 5. Mineral and toxic elements content in green pepper (*Capsicum annuum* L.) cooked using different methods
Tabela 5. Zawartość składników mineralnych i toksycznych w papryce zielonej (*Capsicum annuum* L.) gotowanej różnymi metodami

Mineral nutrients / Składnik mineralny [mg/kg]									
Treatment / Obróbka	K [mg/kg]	Na [mg/kg]	Ca [mg/kg]	P [mg/kg]	Mg [mg/kg]	Fe [mg/kg]	Zn [mg/kg]	Cu [mg/kg]	Mn [mg/kg]
Control (Fresh) / Kontrola (Świeże)	4,750^{d} ± 41.22	40.0^{c} ± 8.11	2,453^{c} ± 21.23	2,098^{c} ± 41.22	522.0^{c} ± 45.33	34.22^{c} ± 1.11	6.30^{b} ± 0.11	2.66^{a} ± 0.01	1.22^{a} ± 0.01
Conventional boiling / Tradycyjnie gotowane	2,710^{c} ± 40.21	23.0^{b} ± 8.11	2,958^{c} ± 21.23	2,943^{c} ± 41.22	482.0^{b} ± 45.33	18.32^{b} ± 1.11	5.64^{a} ± 0.11	2.46^{a} ± 0.01	1.13^{a} ± 0.01
Stir-fried / Smażone	4,100^{d} ± 50.21	29.0^{b} ± 8.11	2,651^{c} ± 21.23	2,256^{c} ± 41.22	602.0^{d} ± 45.33	30.65^{c} ± 1.11	5.87^{a} ± 0.11	2.42^{a} ± 0.01	1.16^{a} ± 0.01
Microwave heating / Ogrzewane mikrofalowo	5,200^{c} ± 50.21	51.0^{d} ± 8.11	3,348^{d} ± 21.23	2,558^{c} ± 41.22	691.0^{d} ± 45.33	31.41^{c} ± 1.11	6.12^{b} ± 0.11	2.54^{a} ± 0.01	1.20^{a} ± 0.01

Toxic elements / Składnik toksyczny (mg/kg)				
Treatment / Obróbka	Cr [mg/kg]	Cd [mg/kg]	Pb [mg/kg]	Ni [mg/kg]
Control (Fresh) / Kontrola (Świeże)	13.60^{a} ± 0.12	0.21^{a} ± 0.01	0.17^{a} ± 0.01	10.23^{a} ± 0.11
Conventional boiling / Tradycyjnie gotowane	11.62^{a} ± 0.12	0.19^{a} ± 0.01	0.14^{a} ± 0.01	8.63^{a} ± 0.11
Stir-fried / Smażone	11.83^{a} ± 0.12	0.20^{a} ± 0.01	0.16^{a} ± 0.01	9.03^{a} ± 0.11
Microwave heating / Ogrzewane mikrofalowo	12.23^{a} ± 0.12	0.21^{a} ± 0.01	0.17^{a} ± 0.01	10.13^{a} ± 0.11

Explanatory notes / Objaśnienia:

Data are presented as average value ± standard deviation of three replicates / Dane przedstawiono jako wartość średnią ± odchylenie standardowe z trzech powtórzeń

Table 6. Mineral and toxic elements content in Parsley (*Petroselinum crispum*) cooked using different methods

Tabela 6. Zawartość składników mineralnych i toksycznych w pietruszce (*Petroselinum crispum*) gotowanej różnymi metodami

Mineral nutrients / Składnik mineralny [mg/kg]

Treatment / Obróbka	K [mg/kg]	Na [mg/kg]	Ca [mg/kg]	P [mg/kg]	Mg [mg/kg]	Fe [mg/kg]	Zn [mg/kg]	Cu [mg/kg]	Mn [mg/kg]
Control (Fresh) / Kontrola (Świeże)	3,640^{c} ± 35.44	912.0^{c} ± 18.43	2,351^{c} ± 21.23	187.55^{b} ± 10.0	511.0^{c} ± 10.11	41.22^{d} ± 1.20	10.70^{b} ± 0.11	1.49^{a} ± 0.01	1.60^{a} ± 0.01
Conventional boiling / Tradycyjnie gotowane	1,982^{b} ± 35.44	847.0^{c} ± 18.43	2,862^{c} ± 21.23	273.55^{c} ± 10.0	471.1^{b} ± 10.11	25.32^{b} ± 1.20	10.05^{b} ± 0.11	1.43^{a} ± 0.01	1.51^{a} ± 0.01
Stir-fried /Smażone	3,124^{c} ± 35.44	876.0^{c} ± 18.43	2,582^{c} ± 21.23	213.51^{c} ± 10.0	595.0^{c} ± 10.11	36.18^{c} ± 1.20	10.27^{b} ± 0.11	1.46^{a} ± 0.01	1.53^{a} ± 0.01
Microwave heating / Ogrzewane mikrofalowo	4,122^{d} ± 35.44	1,056^{d} ± 18.43	3,449^{d} ± 21.23	234.50^{c} ± 10.0	637.0^{d} ± 10.11	38.43^{c} ± 1.20	10.51^{b} ± 0.11	1.47^{a} ± 0.01	1.57^{a} ± 0.01

Toxic elements / Składnik toksyczny (mg/kg)				
Treatment / Obróbka	Cr [mg/kg]	Cd [mg/kg]	Pb [mg/kg]	Ni [mg/kg]
Control (Fresh) / Kontrola (Świeże)	14.13^{a} ± 0.11	0.11^{a} ± 0.01	0.18^{a} ± 0.01	11.21^{a} ± 0.12
Conventional boiling / Tradycyjnie gotowane	12.14^{a} ± 0.11	0.10^{a} ± 0.01	0.15^{a} ± 0.01	9.24^{a} ± 0.12
Stir-fried /Smażone	12.57^{a} ± 0.11	0.11^{a} ± 0.01	0.17^{a} ± 0.01	10.11^{a} ± 0.12
Microwave heating / Ogrzewane mikrofalowo	13.23^{a} ± 0.11	0.11^{a} ± 0.01	0.18^{a} ± 0.01	11.10^{a} ± 0.12

Explanatory notes / Objaśnienia:
Data are presented as average value ± standard deviation of three replicates / Dane przedstawiono jako wartość średnią ± odchylenie standardowe z trzech powtórzeń

Table 7. Mineral and toxic elements content in Green Cabbage (*Brassica oleracea var. capitate*) cooked using different methods
Tabela 7. Zawartość składników mineralnych i toksycznych w kapuście zielonej (*Brassica oleracea var. capitate*) gotowanej różnymi metodami

Mineral nutrients / Składnik mineralny [mg/kg]									
Treatment / Obróbka	K [mg/kg]	Na [mg/kg]	Ca [mg/kg]	P [mg/kg]	Mg [mg/kg]	Fe [mg/kg]	Zn [mg/kg]	Cu [mg/kg]	Mn [mg/kg]
Control (Fresh) /	4,680^{c} ± 48.11	260.0^{a} ± 50.11	2,980^{b} ± 45.23	1,234^{a} ± 15.22	7,232^{c} ± 51.22	65.80^{d} ± 1.02	3.40^{a} ± 0.02	5.52^{a} ± 0.02	4.10^{a} ± 0.01

Kontrola (Świeże)									
Conventional boiling / Tradycyjnie gotowane	2,340^{b} ± 48.11	210.1^{a} ± 50.11	2,485^{b} ± 45.23	2,131^{b} ± 15.22	6,782^{b} ± 51.22	50.48^{c} ± 1.02	2.74^{a} ± 0.02	5.32^{a} ± 0.02	4.0^{a} ± 0.01
Stir-fried / Smażone	4,131^{c} ± 48.11	223.4^{a} ± 50.11	2,165^{b} ± 45.23	1,526^{a} ± 15.22	7,843^{c} ± 51.22	62.23^{d} ± 1.02	2.97^{a} ± 0.02	5.41^{a} ± 0.02	4.03^{a} ± 0.01
Microwave heating / Ogrzewane mikrofalowo	4,983^{c} ± 48.11	354.0^{b} ± 50.11	4,053^{c} ± 45.23	1,714^{a} ± 15.22	8,335^{d} ± 51.22	62.99^{d} ± 1.02	3.28^{a} ± 0.02	5.48^{a} ± 0.02^{a}	4.08^{a} ± 0.01

Toxic elements / Składnik toksyczny (mg/kg)				
Treatment / Obróbka	Cr [mg/kg]	Cd [mg/kg]	Pb [mg/kg]	Ni [mg/kg]
Control (Fresh) / Kontrola (Świeże)	12.90^{a} ± 0.12	0.12^{a} ± 0.01	0.21^{a} ± 0.01	11.10^{c} ± 0.12
Conventional boiling / Tradycyjnie gotowane	10.06^{a} ± 0.12	0.11^{a} ± 0.01	0.20^{a} ± 0.01	9.14^{b} ± 0.12
Stir-fried / Smażone	11.14^{a} ± 0.12	0.12^{a} ± 0.01	0.21^{a} ± 0.01	9.78^{b} ± 0.12
Microwave heating / Ogrzewane mikrofalowo	12.00^{a} ± 0.12	0.12^{a} ± 0.01	0.21^{a} ± 0.01	10.82^{c} ± 0.12

Explanatory notes / Objaśnienia:

Data are presented as average value ± standard deviation of three replicates / Dane przedstawiono jako wartość średnią ± odchylenie standardowe z trzech powtórzeń

Table 8. Mineral and toxic elements content in Broccoli (*Brassica oleracea var. italica*) cooked using different methods

Tabela 8. Zawartość składników mineralnych i toksycznych w brokułach (*Brassica oleracea var. italica*) gotowanych różnymi metodami

Mineral nutrients / Składnik mineralny [mg/kg]									
Treatment / Obróbka	K [mg/kg]	Na [mg/kg]	Ca [mg/kg]	P [mg/kg]	Mg [mg/kg]	Fe [mg/kg]	Zn [mg/kg]	Cu [mg/kg]	Mn [mg/kg]
Control (Fresh) / Kontrola (Świeże)	5,120^{c} ± 51.24	280.0^{a} ± 21.22	3,122^{b} ± 51.23	3,012^{b} ± 21.23	943.22^{d} ± 50.11	45.50^{b} ± 1.10	10.50^{a} ± 0.11	2.68^{a} ± 0.01	9.80^{a} ± 0.02
Conventional boiling / Tradycyjnie gotowane	2,421^{a} ± 51.24	231^{a} ± 21.22	2,631^{a} ± 51.23	4,121^{c} ± 21.23	845.23^{c} ± 50.11	30.18^{a} ± 1.10	9.84^{a} ± 0.11	2.47^{a} ± 0.01	9.71^{a} ± 0.02

Stir-fried / Smażone	4,621[b] ± 51.24	248.0[a] ± 21.22	2,241[a] ± 51.23	3,291[b] ± 21.23	982.21[d] ± 50.11	41.93[b] ± 1.10	10.07[a] ± 0.11	2.53[a] ± 0.01	9.73[a] ± 0.02
Microwave heating / Ogrzewane mikrofalowo	5,352[c] ± 51.24	371.0[b] ± 21.22	4,322[c] ± 51.23	3,563[b] ± 21.23	1,065[c,d] ± 50.11	42.69[b] ± 1.10	10.42[a] ± 0.11	2.65[a] ± 0.01	9.78[a] ± 0.02

Toxic elements / Składnik toksyczny (mg/kg)				
Treatment / Obróbka	Cr [mg/kg]	Cd [mg/kg]	Pb [mg/kg]	Ni [mg/kg]
Control (Fresh) / Kontrola (Świeże)	12.91[a] ± 0.12	0.13[a] ± 0.01	0.18[a] ± 0.01	10.56[a] ± 0.11
Conventional boiling / Tradycyjnie gotowane	10.84[a] ± 0.12	0.12[a] ± 0.01	0.17[a] ± 0.01	9.63[a] ± 0.11
Stir-fried / Smażone	11.71[a] ± 0.12	0.12[a] ± 0.01	0.18[a] ± 0.01	10.02[a] ± 0.11
Microwave heating / Ogrzewane mikrofalowo	12.01[a] ± 0.12	0.13[a] ± 0.01	0.18[a] ± 0.01	10.86[a] ± 0.11

Explanatory notes / Objaśnienia:

Data are presented as average value ± standard deviation of three replicates / Dane przedstawiono jako wartość średnią ± odchylenie standardowe z trzech powtórzeń

Table 9. FAO/WHO maximum permissible values of toxic metals in vegetables (FAO/WHO—*Codex Alimentarius Commission* 2011; 2022) [9]

Tabela 9. Maksymalne dopuszczalne wartości metali toksycznych w warzywach według FAO/WHO (FAO/WHO – Komisja Kodeksu Żywnościowego 2011; 2022) [9]

Element	FAO/WHO maximum permissible values [mg/kg]
Cd	0.05 ÷ 0.20
Pb	0.05 ÷ 0.30
Ni	67.9
Fe	425.5
Cu	73.3
Zn	99.4

Proper storage methods, such as refrigeration or freezing, can help preserve minerals and prevent nutrient degradation. Conversely, improper storage conditions (heat, light or exposure to pollutants) can reduce the concentration of beneficial minerals and increase the concentration of harmful ones. Given that cooking by boiling has a detrimental effect on nutritional mineral composition, it can be concluded that microwave cooking is a better way to maintain a nutritional balance of mineral composition. Microwave cooking is considered more effective in preserving beneficial minerals because it has shorter cooking times, as well as uses minimal water and gentler heat, which helps minimize mineral losses. In contrast, methods like boiling and stir-frying expose food to prolonged heat or large amounts of water, leading to a greater loss of nutrients.

Conclusions

1. Raw (fresh) green vegetables are a natural source of nutritional minerals and other bioactive compounds that the human body needs for normal functioning. Ones of the most consumed green vegetables in the dietary pattern in Kosovo are presented in this study, spinach, broccoli, parsley, green peppers, cabbage.
2. Depending on the cooking methods applied to green vegetables explored in this study, they lost about 40 ÷ 50 % of nutritional minerals such as potassium, sodium and phosphorus during the treatment compared to the initial unprocessed green vegetables. However, there were also cases of increased mineral compositions depending on the processing method.
3. Boiling generally exerted a detrimental effect on the content of nutritional minerals, while having a positive effect on the reduction of toxic metals. Stir-frying had a moderate effect on these elements.

4. Microwave cooking, on the other hand, retained the majority of nutritious minerals and increased their amount, while having minimal influence on the reduction of toxic metals.
5. Therefore, there were no discernible variations in the results of the content of toxic elements in raw and cooked green vegetables ($p < 0.05$). Additional research is required to determine the toxicity and bio accessibility of trace elements from green vegetables, as well as new dietary protocols during dietary intake in the region.

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WPŁYW RÓŻNYCH METOD OBRÓBKI TERMICZNEJ ZIELONYCH WARZYW NA ZAWARTOŚĆ SKŁADNIKOW MINERALNYCH. BADANIE PIĘCIU ZIELONYCH WARZYW Z KOSOWA

S t r e s z c z e n i e

Wprowadzenie. Powszechnie przyjmuje się, że zielone warzywa są bogatym źródłem składników odżywczych, zwłaszcza wśród populacji spożywających diety roślinne. Dieta oparta na zielonych warzywach może pomóc zapobiegać pogorszeniu funkcji poznawczych, a także innym problemom zdrowotnym. W tym badaniu pięć zielonych warzyw powszechnie spożywanych w Kosowie zostało poddanych analizie wpływu metod obróbki termicznej, takich jak gotowanie, smażenie i gotowanie w kuchence mikrofalowej, na zawartość składników mineralnych, a także redukcję toksycznych metali w ich składzie.

Wyniki i wnioski. Ogólnie rzecz biorąc, gotowane warzywa tracą wiele składników odżywczych, takich jak potas (K), sód (Na), fosfor (P), magnez (Mg), cynk (Zn), miedź (Cu) i mangan (Mn) w porównaniu z surowymi warzywami. Z drugiej strony, wszystkie gotowane warzywa miały zwiększony poziom wapnia (Ca), który wahał się od 5 do 16 % i żelaza (Fe) od 6 do 12 %, podczas gdy, stężenie Cu, Pb i Ni było niższe we wszystkich badanych warzywach. Stężenie Cr było wyższe we wszystkich zielonych warzywach (niegotowanych). Próbka szpinaku miała wyższe poziomy Zn, Fe, Mn i Cd niż maksymalny dopuszczalny limit sugerowany przez FAO/WHO. Badanie to wykazało, że gotowanie w kuchence mikrofalowej było najskuteczniejszą metodą zachowania wartości odżywczych (minerałów) i redukcji toksycznych elementów warzyw, podczas gdy gotowanie miało wpływ na redukcję odżywczych składników mineralnych. Z drugiej strony, smażenie badanych warzyw miało wpływ na zwiększenie składu mineralnego i umiarkowaną redukcję pierwiastków toksycznych. Dlatego też sposób przetwarzania żywności ogólnie ma wyraźny wpływ na skład minerałów odżywczych, podczas gdy minimalny wpływ na redukcję zawartości metali toksycznych w analizowanych zielonych warzywach.

Słowa kluczowe: zielone warzywa, gotowanie, smażenie, gotowanie w kuchence mikrofalowej, minerały, metale toksyczne