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Nutrient Variability and Heavy Metal Content in Vegetables: Insights for Nutrition and Safety

Yasser Jassim Dawood[1], Rusul Saad[2]* and Samara A. Madhloom[2]
[1]Iraqi National Cancer Research Center, University of Baghdad, Baghdad, Iraq
[2]Department of Science, College of Basic Education, Mustansiriyah University, Baghdad, Iraq
*Corresponding author (e-mail: rusul.s96@uomustansiriyah.edu.iq)

Vegetables provide the human body with essential bioavailable elements and metals, and a consistent source of these different elements is necessary and highly encouraged for everyday consumption. Heavy metals are of significant concern due to their potential toxicity and accumulation in the food chain. Because of their toxicity, these elements were the focus of this investigation. The purpose of this study was to use flame atomic absorption spectrophotometry (FAAS) to determine the amounts of certain elements and heavy metals in diverse vegetable samples.

We measured the concentrations of elements such as potassium (K), calcium (Ca), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd) in samples of the following vegetables: tomatoes, cucumbers, cauliflower, eggplant, okra, green pepper, potatoes, zucchini, carrot, and beetroot. These specimens were collected from regional marketplaces. in Baghdad, Iraq. All vegetables were analyzed by flame atomic absorption spectrophotometry.

The lowest and highest concentrations of all indicated components were measured in all tested vegetables and analyzed using descriptive statistics. The lowest amounts of the quantifiable elements were found in tomato, cucumber, green pepper, cauliflower, zucchini, and okra (Cr, Cd, Cu, Ni, Pb, and Co, respectively). In contrast, okra, tomato, potato, and cauliflower have the highest quantities of the elements (Ca, Fe, K, and Zn, respectively).

In the evaluation of heavy metals, certain species of vegetables, such as cauliflower and beetroot, have a greater concentration of Pb and Cd, respectively, than other vegetables. Other element concentrations varied amongst vegetables due to changes in element selectivity and uptake from soil solutions.

Keywords: Flame Atomic Absorption Spectrophotometry (FAAS), heavy metals, vegetables

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Vegetables are a staple of many individuals' diets worldwide because they provide essential nutrients, antioxidants, and metabolites. They also serve as buffers for acidic chemicals produced during the digestive process [1]. Vegetables are typically safe for dietary use, but the development of toxins in consumers' bodies over time is a big worry since it can lead to serious health issues. Several sources release significant volumes of garbage, effluents, chemicals, and energy into the environment [2].

As an important constituent of a stable diet, vegetables are the main basis of essential nutrients, vitamins, and minerals consumed by humans. However, options can also be developed for the use of heavy metals. When vegetables are grown in contaminated soil or irrigated with contaminated water, they can absorb heavy metals through the roots and accumulate in the roots. This accumulation poses a serious health risk, as heavy metals can be toxic even at low doses and are associated with various adverse health effects [3].

Chronic low-level heavy metal exposure harms humans and other animals since there is no effective mechanism for their removal. Mercury, cadmium, and lead are accumulative toxins. These metals generate environmental risks and are considered to be extremely poisonous. [4]. Vegetables absorb metals from contaminated soils and accumulate on sections of the vegetables exposed to air from polluted settings [5 ,6]. In general, most heavy metals are not biodegradable; they have long biological half-lives and have the potential for accumulation in various human organs, leading to unwanted side effects [7].

The customer nutrition guidelines strongly suggest vegetables as a part of a healthy and balanced diet, which is also supported by the “World Health

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Organization (WHO)" and "Food and Agriculture Organization (FAO)", and consumption of an average of 400 g of vegetables and fruits per day (excluding potatoes and other starchy tubers) to prevent some chronic diseases (heart disease, cancer, diabetes, and obesity), as well as to avoid micronutrient deficiencies is suggested [8]. Important components are essential for humans and normal physiological functioning, and many types of vegetables are a wonderful source of these nutrients [9]. Brassica vegetables are rich in Ca, K, Zn, Co, Cu, Fe, Ni, and Zn [10]. Leafy vegetables, roots, and tubers include substantial levels of Ca, Fe, K, Mg, and Mn [11]. However, a large decline in concentrations of nutritionally needed elements within a range of foods has been reported throughout time, which may have severe ramifications for the adequacy of mineral component dietary intake [12, 13].

The purpose of this study is to use flame atomic absorption spectrophotometry to evaluate the concentration levels of selected heavy metals in diverse vegetable samples, therefore offering useful insights into the possible contamination of vegetables and determining their safe ingestion.

EXPERIMENTAL

Chemicals and Materials

Vegetable samples were acquired from local markets in Baghdad, Iraq, including tomato, cucumber, cauliflower, eggplant, okra, green pepper, potatoes, zucchini, carrot, and beetroot. Every specimen was collected and stored in polythene bags by type before being brought to the laboratory for preparation and processing.

Characterization Methods

The samples were cleansed with deionized water and dried for roughly six hours in an oven at 80°C before being crushed to a fine powder with an agate mortar. 1.0 g of each sample was weighed with a sensitive balance (0.1 mg sensitive). Before the assessment, the samples were kept in a clean, dry, stoppered glass container.

Methods

Determination of Heavy Metals

Dry of the Vegetable Samples

The dry technique was utilized, followed by flame absorption spectrophotometric examination, as described in R. K. Sharma. [14]. Each result involved correctly measuring a 1.0 g. sample, which was subsequently digested using a closed digester system. The digestion is carried out by adding 2.0 mL of strong nitric acid. After one hour of cooling, dilute to 25.0 mL in a volumetric flask with deionized water.

The Flame Atomic Absorption Spectrophotometry Determination

The instrument was first calibrated with standard solutions of the target elements. The solution was aspirated into the instrument after all necessary setup and standardization procedures. All prepared sample solutions were analyzed by flame atomic absorption spectrophotometry FAAS method to determine the concentration of heavy metals used in this study. Blank solutions were also measured before the sample analysis using the same conditions.

Statistical Analysis

The analysis utilized version 25.0 of the IBM SPSS Statistics software (IBM Corporation, New York, United States). Descriptive statistics were employed for data analysis, and the results are presented as means ± standard deviation (SD).

Method Validation

To ensure the reliability and accuracy of the analytical results, method validation was performed. The detection limits (LOD) and quantification limits (LOQ) for each heavy metal were determined based on three and ten times the standard deviation of blank measurements, respectively. Recovery tests were conducted by spiking known concentrations of standard metal solutions into pre-analyzed vegetable samples and reanalyzing them under the same conditions. The recovery values ranged between 92% and 106%, indicating acceptable accuracy and efficiency of the analytical procedure. Precision was evaluated through triplicate measurements, with relative standard deviations (RSD) below 5%, confirming the method's repeatability and robustness.

RESULTS AND DISCUSSION

Table 1 presents the nutrient composition of different vegetables, including potassium (K), calcium (Ca), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd). The values represent the concentration of each nutrient (parts per million," ppm") in the specified vegetables.

These nutrient values are crucial for understanding the nutritional profile of these vegetables, which is important for dietary planning and ensuring adequate intake of essential nutrients. As demonstrated in Figure 1, the data reveal variability in nutrient content across the vegetables, with some vegetables exhibiting higher concentrations of certain nutrients compared to others. For example, Okra has the highest calcium (Ca) content at 73.3 ppm, while Tomato has the highest iron (Fe) content at 28 ppm. Additionally, Potatoes have the highest potassium (K) content at 12.1 ppm, and Beetroot has the highest manganese (Mn) content at 1.7 ppm.

Table 1. Nutrient composition of various vegetables measured in ppm* unit.

Vegetable	K	Ca	Cr	Mn	Fe	Co	Ni	Cu	Zn	Pb	Cd
Tomato	7	36.1	0.015	0.08	28	0.31	1.1	0.25	2.3	1.5	0.21
Cucumber	10.3	40.3	0.06	0.06	16	0.46	0.06	0.36	2.1	1.9	0.15
Cauliflower	8.9	45.7	0.06	0.53	14	0.57	0.04	0.7	4.2	2.7	0.35
Eggplant	7.1	62.5	0.1	0.15	2.5	0.29	0.08	0.61	3.2	1.7	0.26
Okra	6.5	73.3	0.05	0.09	4.1	0.17	0.09	0.51	1.6	2.2	0.65
Green pepper	3.4	45	0.03	1.6	3.6	0.37	1.2	0.01	0.8	0.6	0.45
Potatoes	12.1	7.98	0.07	0.47	10.1	0.29	0.05	0.86	4	0.43	0.57
Zucchini	11.9	69.05	0.05	0.67	1.9	0.27	0.07	0.45	3.2	0.15	0.37
Carrot	7.5	45.55	0.09	1.32	3	0.19	0.09	0.4	0.9	0.5	0.45
Beetroot	4.7	47.72	1.1	1.7	1.6	0.45	0.06	0.92	2.5	0.39	0.86

***ppm: parts per million**

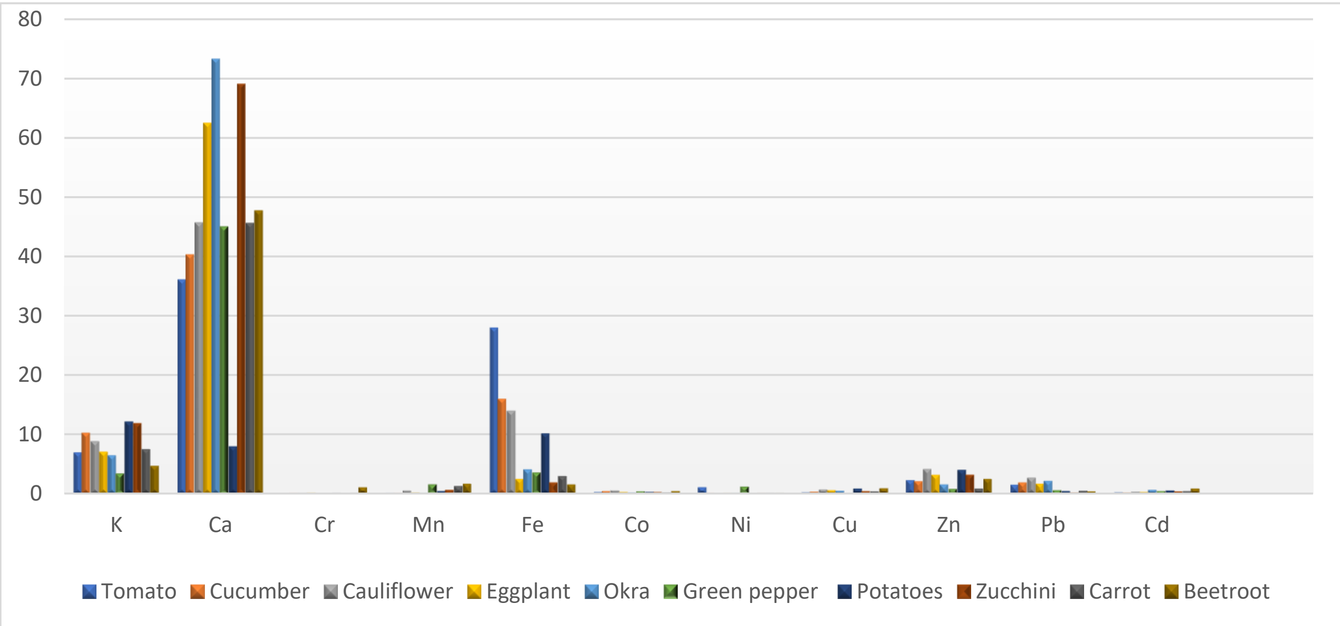

Figure 1. Nutrient content in studied vegetables.

Table 2. Descriptive statistics obtained from element content analysis in conventionally grown vegetables.

Elements	K	Ca	Cr	Mn	Fe	Co	Ni	Cu	Zn	Pb	Cd
Mean	7.94	47.32	0.16	0.66	8.48	0.33	0.28	0.50	2.48	1.20	0.43
Median	7.30	45.62	0.06	0.50	3.85	0.30	0.07	0.48	2.40	1.05	0.41
Minimum	3.40	7.98	0.01	0.06	1.60	0.17	0.04	0.01	0.80	0.15	0.15
Maximum	12.1	73.30	1.10	1.70	28	0.57	1.20	0.92	4.20	2.70	0.86
SD	2.87	18.59	0.33	0.64	8.62	0.12	0.45	0.27	1.18	0.89	0.21

Table 3. Descriptive statistics obtained from vegetable content analysis.

VEGT	Tomato	Cucumber	Cauliflower	Eggplant	Okra	Green pepper	Potatoes	Zucchini	Carrot	Beetroot
Mean	6.98	6.52	7.06	7.13	8.11	5.18	3.35	8.00	5.45	5.63
Median	1.10	0.46	0.70	0.61	0.65	0.80	0.57	0.45	0.50	1.10
Min	0.01	0.06	0.04	0.08	0.05	0.01	0.05	0.05	0.09	0.06
Max	36.10	40.3	45.7	62.50	73.3	45.00	12.1	69.05	45.55	47.72
SD	12.68	12.35	13.56	18.48	21.71	13.26	4.53	20.54	13.47	14.01

Tables 2 and 3 show ten types of vegetables, including tomato, cucumber, cauliflower, beetroot, carrot, potato, eggplant, okra, green pepper, and zucchini, collected from random markets. they were investigated for their elemental composition and nutritional value. Tables 2 and 3 summarize the descriptive statistics for multi-elemental analysis in the examined vegetable samples, expressed in ppm. The concentrations of all quantifiable components in the investigated vegetables are reported as mean, median, lowest, and maximum values, as well as spread factors like standard deviation. We concentrated on the key elements (K, Ca, Fe, and Zn) because of their importance in the human body.

As shown in Figure 2, the minimum and maximum amounts of components were measured in various varieties of vegetables. All of the components mentioned above had their minimum and maximum concentrations tested in all of the vegetables investigated. The lowest amounts of the quantifiable elements were found in tomato, cucumber, green pepper, cauliflower, zucchini, and okra (Cr, Cd, Cu, Ni, Pb, and Co, respectively). In contrast, okra, tomato, potato, and cauliflower have the highest quantities of the elements (Ca, Fe, K, and Zn). These differences in lowest and maximum values highlight the wide range of nutritional profiles seen in conventionally cultivated vegetables, as well as their potential influence on dietary consumption and health.

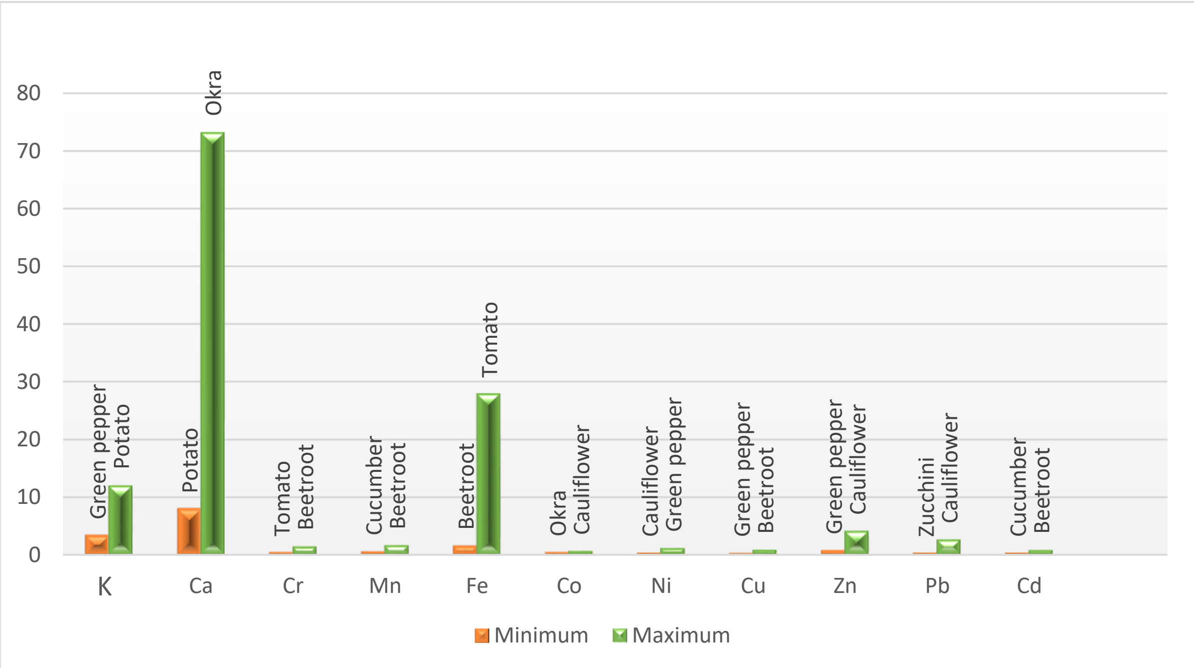

Figure 2. Minimum and maximum concentrations of quantified elements associated with vegetable-type.

Figure 3 shows that the distribution of lead (Pb) and cadmium (Cd) among the mentioned vegetables varies significantly. Lead concentrations range from 0.01 ppm to 73.3 ppm across vegetables, with higher levels found in Cauliflower, Okra, and Cucumber. Cadmium levels span from 0.06 ppm to 2.7 ppm, with Okra and Beetroot showing comparatively higher concentrations. But both elements have relatively low levels, with a mean of 1.207 ppm a median of 1.05 ppm, and an SD of 0.899 ppm for the lead, which indicates moderate dispersion around the mean for lead content. while for the cadmium, a mean of 0.432 ppm and a median of 0.41 ppm. The range from 0.15 ppm to 0.86 ppm shows minor variability. The SD of 0.215 ppm suggests relatively consistent levels of cadmium in the sampled vegetables.

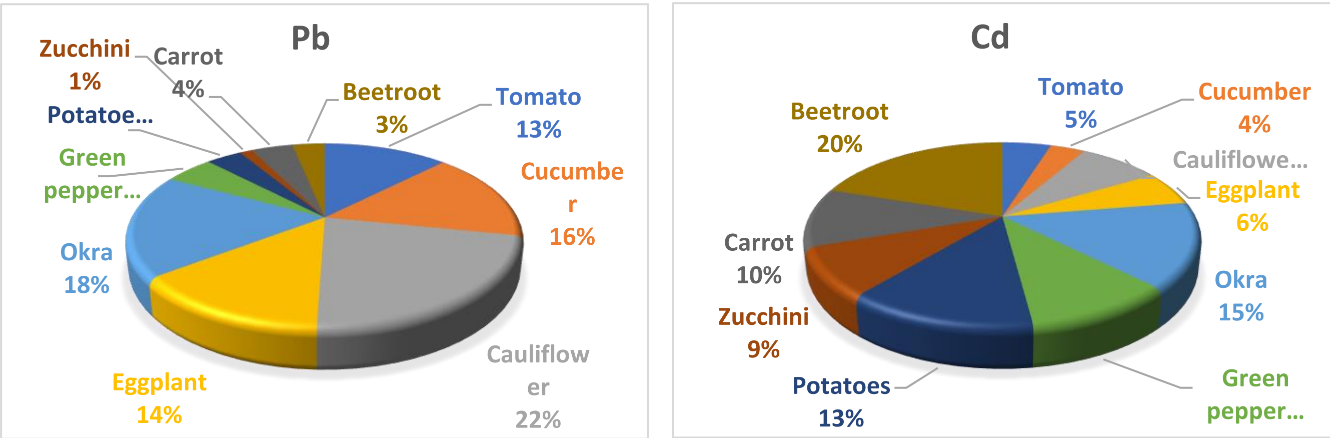

Figure 3. Lead and cadmium distribution among the studied vegetables.

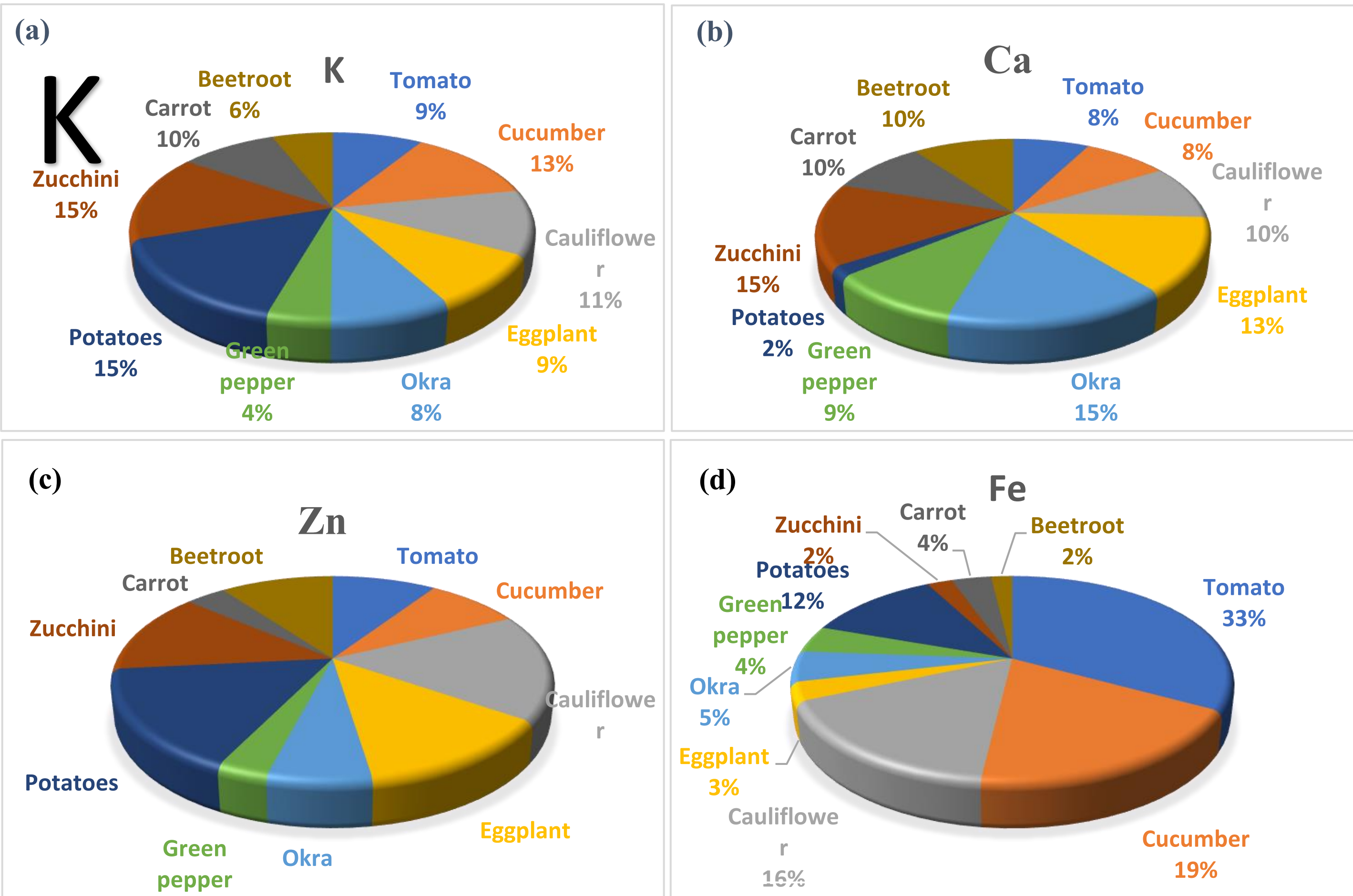

Figure 4. Major elements distribution among all studied vegetables.

Figure 4 explains Potassium (a): Potatoes ranked highest in potassium content (12.1 ppm), followed by Zucchini (11.9 ppm) and Cucumber (10.3 ppm). Potassium is essential for nerve and muscle function. Calcium (b): Okra had the highest calcium content (73.3 ppm), followed by Zucchini (69.05 ppm), and Cauliflower (45.7 ppm). This variability highlights the importance of calcium for bone health across different vegetables. Zinc (c): Cauliflower exhibited the highest zinc content (4.2 ppm), showcasing diversity in zinc levels across vegetables. Zinc plays a critical role in immune function and enzyme activity. Iron (d): Tomato showed the highest iron content (28 ppm), while Eggplant had the lowest (2.5 ppm). Iron is crucial for oxygen transport and metabolism in these vegetables.

When comparing the element concentrations in the studied vegetables with previous research, Mohamed et al. found that the concentration of K in vegetables was higher than in our study, showed in the following: Tomato, 17 ppm; in cucumber, 20 ppm; Cauliflower, 22ppm; Eggplant, 21 ppm; Okra, 7 ppm; Green pepper, 17.8 ppm; Potatoes,17 ppm; and Zucchini, 13 ppm, Carrot,19.8 ppm; and Beetroot, 5.7Ppm [15]. However, the Ca concentration was low in the study conducted by Sherif Tomato, 33 ppm; cucumber, 38 ppm; Cauliflower, 40 ppm; Eggplant, 50 ppm; Okra, 65 ppm; Green pepper, 42 ppm; Potatoes,6.5 ppm; and Zucchini, 55,3 ppm, Carrot,43.4 ppm; and Beetroot, 35.7 ppm [16].

Potassium and calcium play important roles in plant physiology, including water management, nutrient intake, and growth. In humans, potassium promotes fluid equilibrium, neuron function, and cardiovascular health, whereas calcium is required for bone strength, blood clotting, muscle function, and hormone secretion. Very high calcium and potassium levels in the soil can impede nutrient absorption and plant development [17].

Awadallah and Choudhury's investigation found an increased amount of chromium (Cr) in their investigated vegetables compared to our study, tomato, 0.03 ppm; cucumber, 0.08ppm; cauliflower, 0.07 ppm; eggplant, 0.2 ppm; Okra, 0.25; green pepper, 0.09 ppm; potatoes, 1.1 ppm; and zucchini, 0.08 ppm, Carrot, 1.4 ppm; and Beetroot,1.9 ppm [18, 19]. Individuals can become exposed to chromium by breathing, eating, or drinking, as well as through skin contact with chromium or chromium compounds. The concentration of chromium in air and water is usually low. Chromium (III) is a vital mineral found naturally in fruits and vegetables, meat, yeast, and grains, and a lack of it can lead to cardiac diseases, metabolic disturbances, and diabetes. However, excessive chromium consumption may result in skin rashes. Chromium VI poses a risk to human health, including stomach distress, kidney and liver damage, lung cancer, and, finally, death [20].

Anastácio's investigation also found a significant quantity of Mn, Tomato, 7.39 ppm; cucumber, 8.03 ppm; Cauliflower, 1.0 ppm; Eggplant, 21.6 ppm; Okra, 2.1 ppm; Green pepper, 5.73 ppm; Potatoes, 5.67 ppm; and Zucchini, 1.7 ppm, Carrot, 6.18 ppm; and Beetroot, 3.4 ppm [21]. Manganese (Mn) is an important trace mineral that the human body needs in minute amounts to operate properly. It plays a crucial role in several physiological processes, including enzyme activation, antioxidant defense, bone health, and carbohydrate metabolism. However, high manganese consumption can lead to toxicity, particularly if it originates from non-dietary sources such as Some plants, particularly leafy greens and legumes, can develop high manganese levels in their tissues. A variety of reasons, including manganese levels in the soil, the plant's capacity to absorb manganese, and weather circumstances. Vegetables may have higher levels of manganese in places with high manganese concentrations in the soil or areas prone to industrial contamination [22].

Hashmi and Sinha investigated the concentration of iron, which is one of the essential elements in some types of vegetables, and the following results were obtained: Tomato, 60.2 ppm; cucumber, 83.5 ppm; Cauliflower, 20 ppm; Eggplant, 43 ppm; Okra, 0.25 ppm; Green pepper, 49 ppm; Potatoes,48.2 ppm; and Zucchini, 3.1 ppm, Carrot, 29.4 ppm; and Beetroot, 2.3 ppm [23], [24]. The iron concentration in their studies was higher than in our current study. Iron is essential to human metabolism. It works as a catalyst and is found in larger quantities than trace elements. The highest iron content reported in spinach was 65.6 kg/g. The "National Research Council" recommends a dietary requirement of 10-12 mg of iron for males and 15 mg for females during pregnancy, with a maximum of 30 mg [25].

Chandana Janaka *et al*. reported that the concentration of cobalt in vegetables was higher than that in our research, Tomato, 1.29 ppm; cucumber, 0.93 ppm; Cauliflower, 0.63 ppm; Eggplant, 1.33 ppm; Okra, 6.7 Ppm; Green pepper, 1.24 ppm; Potatoes, 1.47ppm; and Zucchini, 0.34 ppm, Carrot, 1.41 ppm; and Beetroot,0.65 ppm [26]. Cobalt is a vital element for the human body, mostly found in vitamin B12. While excessive cobalt intake can be harmful, cobalt levels in vegetables are normally modest and do not pose a major risk of toxicity [27].

Koptsik, *et al*. indicated that the amount of Nickel in vegetables was higher than that in our study: Tomato, 14.46ppm; Cucumber, 10.88 ppm; Cauliflower, 0.67ppm; Eggplant, 11.87 ppm; Okra, 1.7 ppm; Green pepper, 12.92 ppm; Potatoes, 10.74 ppm; and Zucchini, 0.09 ppm, Carrot, 17.54 ppm; Beetroot, 0.69 ppm [28]. Tuzen, the study additionally revealed a significant amount of copper, and Tomato, 53 ppm; cucumber, 29 ppm; Cauliflower, 2.9 ppm; Eggplant, 65 ppm; Okra, 1.9 ppm; Green pepper, 53 ppm; Potatoes,10.3 ppm; and Zucchini, 7.9 ppm, Carrot, 11.5 ppm; and Beetroot, 5.5 ppm [29]. Han *et al*. found that the amount of zinc in vegetables was higher than in our research.

Tomato, 14.4 ppm; cucumber, 32.2 ppm; Cauliflower, 5.8 ppm; Eggplant, 50.7 ppm; Okra, 3.8 ppm; Green pepper, 8.51 ppm; Potatoes, 4.5 ppm; and Zucchini, 3.9 ppm, Carrot, 9.6 ppm; and Beetroot, 3.1 ppm [30]. Planting vegetables along the banks of rivers that flow through Tanzania, Dar es Salaam, has long been a widespread tradition. These rivers' waters are reported to be poisoned by heavy metals [31]. The heavy metals reported include Ni, Cu, and Zn. The primary sources of these heavy metals are industrial wastes and the indiscriminate discharge of residential or sewer drainage into rivers that are either untreated or poorly treated. It is expected that plants growing along the banks of the rivers Sinza and Msimbazi are not free of heavy metal contamination [32].

Tahvonen and Hršak reported the contents of Pb and Cd in food. concentration of Pb and Cd in vegetables was shown as follows the Pb contents in vegetables were high: Tomato, 2.5 ppm; cucumber, 4.2 ppm; Cauliflower, 1.4 ppm; Eggplant, 4.5 ppm; Okra, 5.9 ppm; Green pepper, 1.9 ppm; Potatoes, 2.8 ppm; and Zucchini, 0.5 ppm, Carrot, 7.9 ppm; and Beetroot, 1.1 ppm. On the other hand, the Cd content was high as well: Tomato, 0.77 ppm; cucumber, 0.59 ppm; Cauliflower, 0.6 ppm; Eggplant, 0.69 ppm; Okra, 0.95 ppm; Green pepper, 0.8 ppm; Potatoes, 0.84 ppm; and Zucchini, 0.45 ppm, Carrot, 0.81 ppm; and Beetroot, 1.0 ppm. [33], [34]. These results differ from our current results. The risky elements Pb and Cd are natural components of the earth's crust; they are taken up from the soil by plants and transported further down the food chain.[35]. Food is an important source of lead intake and the human body's burden [36]. Accumulation of lead in edible aquatic plants and animals has been reported [37]. Lead is harmful to the red blood cells, kidneys, neurological system, and reproductive organs. Excess cadmium has been documented to produce renal tubular failure, followed by osteoma Acia (bone softening) and other problems, which can lead to mortality [38]. Lead and cadmium poisoning has also been reported in Japan, where several people died and many more acquired physiological problems [39]. High amounts of zinc can cause harm to the pancreas, disturbance of protein metabolism, and arteriosclerosis, whereas elevated levels of copper have been linked to brain damage [40].

To evaluate the potential health risks associated with the consumption of vegetables analyzed in this study, the concentrations of heavy metals were compared with the permissible limits established by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO). According to WHO/FAO guidelines, the maximum allowable concentrations in vegetables are 0.3 ppm for Cd, 2.0 ppm for Pb, 40 ppm for Zn, and 10 ppm for Cu [41] In the current study, the mean concentrations of Cd (0.43 ppm) and Pb (1.20 ppm) in several vegetable samples exceeded or approached these limits, particularly in okra, cauliflower, and cucumber, indicating possible contamination and potential health concerns if consumed frequently. In contrast, the concentrations of Zn (2.48 ppm) and Cu (0.50 ppm) were well below the permissible limits, reflecting safe levels for human consumption. These variations suggest that while most essential elements (such as Zn, Cu, Fe, and Mn) were within acceptable nutritional ranges, the elevated values of toxic elements like Pb and Cd warrant regular monitoring of locally grown vegetables, especially those cultivated near industrial or high-traffic areas. Continuous evaluation and enforcement of agricultural and environmental safety standards are crucial to minimizing heavy metal exposure through dietary sources [42].

The variations observed between the current study and previous reports may be attributed to several factors. First, environmental conditions such as soil composition, irrigation water quality, and proximity to industrial or traffic-polluted areas can significantly influence the accumulation of heavy metals in vegetables. Second, agricultural practices, including conventional versus organic farming, and the use of fertilizers and pesticides, can result in varying levels of essential and toxic elements. Third, methodological differences in sample preparation, digestion techniques, and analytical instruments (e.g., FAAS calibration, detection limits) may also contribute to discrepancies in reported concentrations. Finally, geographical and varietal differences in the vegetables themselves may affect nutrient uptake and accumulation patterns. Collectively, these factors can explain the observed deviations between our findings and those reported in previous studies.

CONCLUSION

In conclusion, this study using flame atomic absorption spectrophotometry revealed the presence of heavy metals such as Pb and Cd in vegetables, indicating potential health risks and the importance of monitoring, regulation, and consumer awareness. The nutrient composition analysis of various vegetables reveals significant variability in the concentrations of essential elements such as potassium, calcium, iron, and zinc, highlighting the diverse nutritional profiles across different vegetables. Key findings include Okra having the highest calcium content, Tomato exhibiting the highest iron concentration, Potatoes being rich in potassium, and Cauliflower containing the most zinc. Additionally, variations in lead and cadmium levels were noted, with Cauliflower, Okra, and Cucumber showing higher lead concentrations and Okra and Beetroot having higher cadmium levels. These differences underscore the importance of selecting a variety of vegetables to ensure a balanced intake of essential nutrients and minimize exposure to harmful elements. The comparative analysis with previous studies indicates that environmental factors, agricultural practices, and regional differences significantly influence the nutrient content and safety of vegetables. Thus, regular monitoring and adherence to safety standards are essential to maximize the health benefits of vegetable consumption while minimizing potential health risks. Further, this study shows that vegetables, such as cauliflower and beetroot, have a greater concentration of Pb and Cd, respectively.

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