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Estimated Dietary Intake of Essential Trace Elements from Selected fruits and Vegetables in Minna Town, Nigeria

Hauwa Idris Muhammad, Yahaya Ahmed Iyaka, Chiemela Chinma and Rasaq Bolakale Salau

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Abstract: *This study quantitatively evaluates the concentrations, dietary intake, and potential health risks of essential trace elements (Ni, Co, Se, and Mo) in selected fruits and vegetables using experimental and statistical analyses. Elemental concentrations were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), revealing higher levels of Ni (0.624 µg/g) in lettuce, Co (0.131 µg/g) in baobab leaf, Se (0.029 µg/g) in cucumber, and Mo (0.170 µg/g) in cucumber. Estimated daily intake (EDI) calculations indicated that vegetable consumption contributed significantly to dietary exposure, with mean values of Ni (0.3626 µg/kg.bw/day), Co (0.0182 µg/kg.bw/day), Se (0.0134 µg/kg.bw/day), and Mo (0.0614 µg/kg.bw/day). One-way ANOVA revealed significant differences ($p < 0.05$) in elemental concentrations across different food groups. Pearson correlation analysis showed strong positive relationships between elemental concentration and HI ($r > 0.80$, $p < 0.05$) for Co and Mo, while Spearman correlation confirmed similar trends in non-normally distributed data. findings emphasize the need for continuous monitoring of trace elements in food sources and dietary moderation to minimize potential toxicological effects.*

Keywords: *Essential trace elements, dietary intake, fruits, vegetables*

Hauwa Idris Muhammad
Department of Chemistry, Federal University of Technology, Minna, Niger state, Nigeria.
Department of Chemistry, Ibrahim Badamasi Babangida University Lapai Niger state.
Email: hauwalarai2010@gmail.com
Orcid id: 0000-0002-0426-7269

Yahaya Ahmed Iyaka
Department of Chemistry, Federal University of Technology, Minna, Niger state, Nigeria.
Email: iyaka.yahaya@futminna.edu.ng

Rasaq Bolakale Salau
Department of Chemistry, Federal University of Technology Minna, Niger state, Nigeria.
Email: rasaqsalau@futminna.edu.ng

Chiemela Chinma
Department of Food Science and Technology, Federal University of Technology Minna, Niger state, Nigeria.
Email: chinmachiemela@futminna.edu.ng

1.0 Introduction

The assessment of dietary intake of essential trace elements is crucial for understanding their contribution to human health and nutrition. Trace elements such as Cr, Mn, Ni, Co, Cu, Zn Se, and Mo are vital for various metabolic and physiological processes in the human body (Kele *et al*., 2020; Maret, 2016; Ogoko *et al*., 2022). These elements play essential roles in enzymatic functions, immune responses, and antioxidant activities, among other biological processes (Watanabe *et al*., 2020). However, deficiencies or excessive intake of these elements can lead to severe health consequences, including metabolic disorders and toxicity (Prashanth *et al*., 2015). Therefore, monitoring the levels of these elements in food sources is necessary to ensure nutritional adequacy and prevent health risks.

Fruits and vegetables are significant sources of essential nutrients and trace elements in human diets. They contribute to overall nutritional balance and provide bioavailable forms of these micronutrients (FAO, 2017). However, the elemental composition of fruits and vegetables varies depending on soil quality, agricultural practices, and environmental contamination (Alloway, 2013). In Nigeria, previous studies have reported the presence of trace elements in various food items, particularly in cooked meals, cereals, and tubers (Onianwa *et al*., 2001; Shokunbi *et al*., 2019). However, limited studies have focused on raw fruits and vegetables, which are often consumed directly and thus may pose a different risk of dietary exposure.

Several studies have investigated the trace element content of foods across different regions of Nigeria. Onianwa *et al*. (2001) assessed heavy metal contamination in food crops and reported variations in trace element concentrations due to soil contamination and agricultural practices. Shokunbi *et al*. (2019) analyzed the essential trace element content in Nigerian foodstuffs, focusing on cooked foods and their health implications. Similarly, Davidson and Ene-Obong (2019) examined the nutritional composition of traditional Nigerian diets and found that variations in trace elements were influenced by food preparation methods. However, these studies primarily focused on processed or cooked foods, leaving a gap in the assessment of trace element content in fresh, raw fruits and vegetables. Additionally, previous research did not specifically estimate dietary intake levels of essential trace elements from fresh produce and their potential health risks to consumers.

To address this knowledge gap, the present study aims to evaluate the levels of essential trace elements (Ni, Co, Se, and Mo) in selected fruits and vegetables sold in major markets in Minna, Niger State, Nigeria. Minna, a rapidly growing urban center, has a diverse population that relies heavily on locally sourced fruits and vegetables for daily nutrition. Given the region's agricultural activities and potential environmental contaminants, it is important to assess the dietary intake of these trace elements and determine whether their consumption poses any health risks.

This study will employ Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to analyze trace element concentrations in the selected food items. ICP-MS is a highly sensitive and accurate analytical technique widely used for detecting trace elements in food and environmental samples (Beauchemin, 2018). The study will also estimate the daily dietary intake of these elements among the local population and compare the results with internationally recommended limits, such as the provisional tolerable daily intakes (PTDI) established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (WHO, 2006). Furthermore, the study will evaluate the Target Hazard Quotient (THQ) to assess potential health risks associated with trace element consumption (USEPA, 2012).

2.0 Materials and Methods

2.1 Study Location

The study was conducted in Minna, Niger State, Nigeria, across three major markets: Tunga, Gwari and Kure. These markets were selected due to their high patronage and diverse supply of fruits and vegetables, which are widely consumed by residents of Minna and surrounding areas. Minna is geographically located between 8°00′ to 11°30′N latitude and 3°30′ to 7°40′E longitude at an elevation of 243 meters above sea level in north-central Nigeria. All chemical reagents used in this study were of analytical grade, and deionized water of high purity was obtained from a Milli-Q purification system (Millipore, MA, USA) to prevent contamination during sample preparation and analysis.

2.2 Sample Collection and Preparation

A total of ten (10) different types of fruits and vegetables commonly consumed in Minna were sampled from the three selected markets. To ensure representativeness, samples were obtained from three different vendors per market, forming a composite sample for each type of fruit and vegetable. Thus, a total of 30 individual samples were collected, which were then pooled into 10 composite samples for analysis (Table 2.1).

Upon collection, samples were transported to the laboratory under controlled conditions. Each sample was thoroughly washed with deionized water to remove surface contaminants. They were then oven-dried at 80°C until a constant weight was achieved. The dried samples were pulverized using an Excella VTCL 750-watt blender and stored in sterilized, trace element-free plastic containers to prevent contamination.

2.3 Sample Digestion

Dried and homogenized samples were digested using a microwave digestion system to ensure efficient breakdown of organic matter. Precisely 6 mL of ultra-pure HNO_3 and 1 mL of H_2O_2 were added to each sample within a Teflon digestion vessel and processed using a MARS microwave digester. The digestion process was carried out under controlled temperature and pressure conditions.

After digestion, the resultant white ash was dissolved in deionized water, quantitatively transferred into new trace element-free plastic bottles with screw caps, and made up to 20 mL with deionized water. The prepared solutions were immediately subjected to elemental analysis to prevent degradation or contamination.

2.4 Analytical Instruments for Elemental Analyses

The concentrations of four essential trace elements were determined using an Agilent 7900 Inductively Coupled Plasma-Mass Spectrometer (ICP-MS). The instrument was calibrated before analysis to ensure accuracy. The operating conditions of the ICP-MS were as follows:

- **RF Power:** 1600 W
- **Carrier Gas (Argon):** 0.83 L/min
- **Sample Depth:** 10 mm
- **Make-up Gas:** 0.15 L/min
- **Helium Flow:** 5 mL/min
- **Hydrogen Flow:** 6 mL/min
- **Nebulizer Flow Rate:** 0.4 mL/min (Micro Mist)

The ICP-MS was routinely calibrated using certified standard solutions, and quality control measures, including blank and duplicate sample analysis, were implemented to ensure data reliability.

2.5 Data Reporting and Statistical Analyses

Results obtained from the ICP-MS analysis were expressed as mean ± standard deviation, along with the minimum and maximum concentrations for each trace element. Statistical analyses were performed using IBM SPSS Statistics 20.0 to evaluate the significance of differences in trace element concentrations across different markets and among fruit and vegetable samples.

Inferential statistical tests, including one-way ANOVA and Tukey's post hoc test, were used to determine significant differences between groups at $p < 0.05$. Pearson correlation analysis was also conducted to assess relationships between elemental concentrations in different sample types.

3.0 Results and Discussion

3.1 Essential Trace Elements in Fruits and Vegetables

The results presented in Table 1 reveal significant variations in the concentrations of essential trace elements—Nickel (Ni), Cobalt (Co), Selenium (Se), and Molybdenum (Mo)—across different fruits and vegetables. These variations can be attributed to factors such as soil composition, agricultural practices, environmental exposure, and the natural ability of plants to accumulate these elements.

Table 1: Concentration of Essential Trace Elements in Fruits and Vegetables (mg/kg)

Food Group	**Sample**	**Ni**	**Co**	**Se**	**Mo**
Fruits	Banana	1.76 (1.08-3.05)	0.01 (0.00-0.02)	0.02 (0.01-0.03)	0.22 (0.18-0.28)
	Coconut	3.02 (2.52-3.90)	0.03 (0.01-0.04)	0.20 (0.09-0.27)	0. (0.13-0.20)
	Orange	2.29 (0.47-5.48)	0.001 (0.00-0.01)	0.04 (0.02-0.06)	0.07 (0.04-0.10)
	Pawpaw	1.90 (0.78-3.52)	0.07 (0.04-0.11)	0.13 (0.00-0.24)	0.32 (0.23-0.42)
	Watermelon	4.22 (2.40-5.88)	0.18 (0.04-0.41)	0.10 (0.02-0.20)	0.10 (0.06-0.11)
Vegetables	Baobab leaf	1.62 (1.23-2.21)	0.21 (0.11-0.36)	0.05 (0.04-0.05)	0.26 (0.23-0.28)
	Cabbage	14.97 (1.43-33.49)	0.19 (0.14-0.29)	0.06 (0.01-0.16)	1.17 (0.87-1.45)
	Carrot	5.34 (1.12-13.57)	0.07 (0.04-0.11)	0.02 (0.00-0.02)	0.68 (0.16-1.35)
	Cucumber	5.66 (1.70-12.70)	0.20 (0.10-0.34)	0.51 (0.00-0.85)	0.56 (0.45-0.63)
	Lettuce	6.53 (1.27-10.11)	0.17 (0.14-0.22)	0.04 (0.01-0.07)	0.48 (0.18-0.83)

The concentrations (mg/kg dry weight) of Ni, Co, Se, and Mo in the analyzed fruits and vegetables from the present study are shown in Table 2.1 as mean ± standard deviation (SD) of triplicate analyses of the samples.

Nickel plays an essential role in plant metabolism and is a crucial component of some enzymes. Among the fruits analyzed, watermelon exhibited the highest concentration of Ni (4.22 mg/kg), while bananas had the lowest (1.76 mg/kg). The Ni levels observed in this study align with similar mean values (1.316 and 1.5 mg/kg) reported in previous studies on fruits consumed in Misurata, Libya, and Al-Karak city, Jordan (Elbagermi *et al.*, 2012; Altarawneh, 2019). However, lower Ni values (0.6, 0.037, 0.04, and 0.05 mg/kg) have been recorded for fruits from Pakistan, Bangladesh, and Nigeria (Ismail *et al.*, 2011; Shaheen *et al.*, 2016; Rahman and Islam, 2019; Oyasowo *et al.*, 2021). In vegetables, cabbage showed a markedly higher Ni concentration (14.97 mg/kg), compared to baobab leaves (1.62 mg/kg), which suggests a strong tendency of cabbage to accumulate Ni. Ni levels of 0.21 and 1.0 mg/kg were recorded for vegetables consumed in Quetta City and Bangladesh, respectively (Nisa *et al.*, 2020; Rahman and Islam, 2019). The high Ni content in cabbage raises concerns about potential toxicity, as excessive Ni intake has been associated with allergic reactions, respiratory issues, and potential carcinogenic effects.

Cobalt is an essential trace element required for vitamin B12 synthesis and plays a role in nitrogen fixation in plants. In the present study, Co values ranged from 0.001 mg/kg in oranges to 0.18 mg/kg in watermelon. Studies on fruits from Southern Italy and Romania reported similar Co levels ranging from 0.01 to 0.04 mg/kg and 0.001 to 0.03 mg/kg, respectively (Heghedus-Mindrus *et al.*, 2014; Esposito *et al.*, 2019). However, higher cobalt levels in fruits have been reported in other studies

(Adetoy *et al*., 2009). Vegetables analyzed in the present study contained minute quantities of cobalt, with baobab leaves exhibiting the highest concentration (0.21 mg/kg). This is in agreement with studies indicating that leafy vegetables are rich in Co (Ekholm, 2007; Nisa *et al*., 2020). Higher Co values of 0.62 mg/kg were reported for cucumber in Libya (Elbagermi *et al*., 2012), while 0.54 mg/kg and 1.54 mg/kg were recorded for carrots in Libya and Ethiopia, respectively (Elbagermi *et al*., 2012; Marga, 2016).

Selenium is an important antioxidant that supports immune function and prevents oxidative stress. The levels of Se in the analyzed samples varied, with fruits showing values between 0.02 mg/kg in banana and 0.20 mg/kg in coconut. Previous studies have reported that fruits generally contain low levels of Se, as selenium-rich foods are primarily cereals, meats, and seafood (Ullah *et al*., 2018). A lower mean Se content of 0.024 mg/kg was recorded for oranges bought from supermarkets in Poland (Czech *et al*., 2020). Among vegetables, cucumber had the highest Se concentration (0.51 mg/kg), suggesting that cucumbers grown in Minna may be a good dietary source of selenium. A lower Se content of 0.004 mg/kg was reported for cabbage consumed in India (Singh and Garg, 2006).

Molybdenum is vital for enzyme activity in both plants and animals. The Mo content in fruits ranged between 0.07 mg/kg in oranges and 0.32 mg/kg in pawpaw. The Mo levels in vegetables varied from 0.26 mg/kg in baobab leaves to 1.17 mg/kg in cabbage. Lower Mo concentrations (0.0074 mg/kg) have been reported for cabbage consumed in Korea (Choi *et al*., 2009). Mo concentrations in vegetables depend largely on soil composition, as soil is the primary source of this element in plants (Lewis *et al*., 2016). Foods are the main source of molybdenum, and vegetables such as lettuce, spinach, cauliflower, and kale are rich in this element (Gaya and Ikechukwu).

The variations observed in elemental concentrations could be attributed to several factors. The natural abundance of trace elements in soil significantly influences plant uptake, with soil pH, organic matter content, and mineral composition playing key roles in determining bioavailability. Agricultural practices, including the use of fertilizers, pesticides, and irrigation water quality, can introduce or influence trace element accumulation in crops. Environmental factors such as proximity to industrial or mining activities may contribute to elevated trace element levels in certain crops. Additionally, different plant species exhibit varying abilities to absorb and accumulate specific trace elements based on their metabolic needs and physiological adaptations.

The findings further indicate that while these food sources contribute essential trace elements to the diet, certain vegetables, such as cabbage and cucumber, contain notably high concentrations of Ni and Se, respectively. Regular monitoring of trace elements in food crops, alongside soil quality assessments, is essential to ensure dietary safety and public health. Future studies should focus on assessing the bioavailability of these trace elements in human diets, potential health risks associated with long-term consumption, and the impact of soil amendments and agricultural practices on elemental composition in crops.

3.2 Estimated Daily Intake (EDI)

Table 2 presents the Estimated Daily Intake (EDI) of Nickel (Ni), Cobalt (Co), Selenium (Se), and Molybdenum (Mo) from selected fruits and vegetables commonly consumed in Minna, Nigeria. The EDI values are expressed in micrograms per kilogram of body weight per day (µg/kg.bw/day) and provide insights into the potential dietary exposure to these essential trace elements. Understanding these intake levels is crucial for assessing both the nutritional benefits and potential health risks associated with excessive consumption.

Table 2: Estimated Daily Intake (EDI) (µg/kg.bw/day) of Essential Trace Elements in Fruits and Vegetables

Food Group	Sample	Ni (µg/kg.bw/day)	Co (µg/kg.bw/day)	Se (µg/kg.bw/day)	Mo (µg/kg.bw/day)
Fruits	Banana	0.386	0.004	0.004	0.049
	Coconut	0.508	0.004	0.033	0.026
	Orange	0.369	0.002	0.006	0.011
	Pawpaw	0.072	0.003	0.007	0.012
	Watermelon	0.445	0.019	0.010	0.010
	Mean	0.356	0.0064	0.012	0.022
Vegetables	Baobab leaf	0.300	0.039	0.009	0.048
	Cabbage	0.236	0.008	0.021	0.023
	Carrot	0.260	0.005	0.004	0.020
	Cucumber	0.393	0.023	0.029	0.170
	Lettuce	0.624	0.016	0.004	0.046
	Mean	0.3626	0.0182	0.0134	0.0614

The estimated daily intake (EDI) values highlight variations in trace element consumption from different fruits and vegetables, with vegetables generally contributing higher levels of cobalt (Co) and molybdenum (Mo) than fruits. These estimations were derived from consumption patterns obtained via a Food Frequency Questionnaire completed digitally by 161 adult individuals residing in Minna town and its environs. The values were converted from dry weights to wet weight basis using moisture content data from Nigerian cooked foods (Sokumbi *et al*., 2019).

The mean daily intake of nickel (Ni) from vegetables (0.3626 µg/kg.bw/day) is slightly higher than from fruits (0.356 µg/kg.bw/day). Among vegetables, lettuce exhibited the highest Ni intake (0.624 µg/kg.bw/day), while pawpaw had the lowest (0.072 µg/kg.bw/day). Considering that high Ni intake can trigger allergic reactions and pose potential health risks, regular monitoring is necessary, especially for individuals sensitive to Ni exposure (EFSA, 2020).

Vegetables had a notably higher mean Co intake (0.0182 µg/kg.bw/day) compared to fruits (0.0064 µg/kg.bw/day), with baobab leaves (0.039 µg/kg.bw/day) containing the highest amount. Fruits, particularly oranges (0.002 µg/kg.bw/day), had relatively lower Co intake values. Since Co is essential for vitamin B12 synthesis, moderate intake from vegetables can contribute to meeting dietary requirements (EFSA, 2014).

The mean Se intake from vegetables (0.0134 µg/kg.bw/day) was slightly higher than from fruits (0.012 µg/kg.bw/day), with cucumber (0.029 µg/kg.bw/day) and coconut (0.033 µg/kg.bw/day) emerging as the richest sources. Selenium is a crucial antioxidant that supports immune function (EFSA, 2015), and these findings suggest that cucumber and coconut may help meet dietary Se requirements. However, the estimated daily Mo intake was significantly higher in vegetables (0.0614 µg/kg.bw/day) than in fruits (0.022 µg/kg.bw/day), with cucumber (0.170 µg/kg.bw/day) showing the highest intake. Since Mo is essential for enzyme function, particularly in nitrogen metabolism, vegetables such as cucumber and baobab leaves appear to be valuable dietary sources (EFSA, 2014).

A comparison of the data from Table 1, which presents the elemental concentrations (mg/kg) of Ni, Co, Se, and Mo, and Table 2, which shows the EDI (µg/kg.bw/day) of these elements, provides insights into the relationship between elemental content in food and potential dietary exposure.

In Table 1, the highest Ni concentration was recorded in watermelon (4.22 mg/kg) among fruits and in cabbage (14.97 mg/kg) among vegetables. However, in Table 2, lettuce exhibited the highest estimated Ni intake (0.624 µg/kg.bw/day), despite its lower Ni concentration compared to cabbage. This suggests that differences in average consumption rates of these foods influence actual dietary exposure. The concentration of Co (Table 1) showed the highest levels in baobab leaves (0.21 mg/kg) and cucumber (0.20 mg/kg). This trend is reflected in Table 2, where baobab leaves had the highest EDI of Co (0.039 µg/kg.bw/day), confirming that vegetables contribute more to dietary Co intake than fruits. The lower EDI of Co from fruits in Table 2 aligns with the lower Co concentrations observed in Table 1, indicating that fruits are not significant sources of dietary cobalt.

Selenium (Table 1) showed the highest concentration in cucumber (0.51 mg/kg), followed by coconut (0.20 mg/kg). A similar trend is observed in Table 2, where cucumber had the highest EDI of Se (0.029 µg/kg.bw/day), confirming its role as a key dietary source of selenium. The correlation between high Se concentration in food and its corresponding high estimated daily intake suggests that selenium bioavailability is influenced by its initial content in the food source. However, the highest concentration of Mo was found in cabbage (1.17 mg/kg) and carrot (0.68 mg/kg). Despite this, in Table 2, cucumber showed the highest EDI of Mo (0.170 µg/kg.bw/day), despite having a lower concentration compared to cabbage and carrot. This discrepancy indicates that dietary intake is not solely dependent on elemental concentration but also on the frequency and quantity of food consumption.

Given the lack of Provisional Tolerable Daily Intake (PTDI) values for Ni, Co, Se, and Mo, risk assessment was performed using the Recommended Daily Intake (RDI) and other guidelines: 25-35 µg/day for Ni (EFSA, 2020), an upper limit of 1.6 µg/day for Co (EFSA, 2014), an RDA of 31.0–65.6 µg/day for Se (EFSA, 2015), and an RDA of 45 µg/day for Mo (EFSA, 2014). These findings underscore the nutritional importance of fruits and vegetables in providing essential trace elements. However, the higher estimated intake of Ni from certain vegetables, particularly lettuce, suggests the need for further investigation into potential health risks associated with prolonged exposure. Regular dietary assessments and soil quality monitoring are recommended to ensure safe consumption levels and minimize potential toxic effects.

The above results further align with the following observation

(i) Dietary intake is influenced by food consumption rates – While some foods have high elemental concentrations, their estimated daily intake may be lower if they are consumed in smaller quantities. This is evident in cabbage, which had the highest Ni and Mo concentrations in Table 1, but lower EDI values in Table 2 compared to more frequently consumed vegetables like cucumber and lettuce.

(ii) Fruits contribute less to trace element intake than vegetables – The mean EDI values for all elements were higher in vegetables than in fruits, aligning with the trend of higher elemental concentrations observed in vegetables in Table 1.

(iii) Nickel intake requires monitoring – The high Ni concentration in cabbage and high Ni EDI from lettuce suggest a potential risk for excessive Ni exposure, particularly for individuals consuming large quantities of these vegetables.

(iv) Cucumber is a key dietary source of Se and Mo – The high Se and Mo intake from cucumber highlights its nutritional significance, reinforcing its potential role in addressing selenium deficiency.

The comparison between elemental concentrations and estimated daily intake values emphasizes the need to consider both food composition and consumption patterns when evaluating dietary exposure to essential trace elements. While elemental concentrations provide baseline data on nutrient content, EDI values offer a more practical perspective on actual dietary intake and potential health implications. Regular dietary assessments and monitoring of trace element bioavailability in food sources are crucial for ensuring balanced nutrient intake and preventing excessive exposure to potentially toxic elements.

3.3 Target Hazard Quotient (THQ) and Hazard Index (HI) of Study Samples

To assess the potential health risks associated with the consumption of fruits and vegetables containing trace elements, Table 3 presents the Target Hazard Quotient (THQ) for Nickel (Ni), Cobalt (Co), Selenium (Se), and Molybdenum (Mo), as well as the Hazard Index (HI) for each food item. The THQ is a risk assessment tool that evaluates non-carcinogenic health risks by comparing estimated daily intake (EDI) with reference oral doses. A THQ value greater than 1 suggests potential health risks, while an HI (sum of THQs for all elements in a given food item) exceeding 1 indicates a cumulative health risk from multiple elements.

Table 3: Target Hazard Quotient (THQ) and Hazard Index (HI) of Study Samples

Food Group	Ni (THQ)	Co (THQ)	Se (THQ)	Mo (THQ)	HI
Fruits					
Banana	1.93E-02	1.49E-02	1.68E-03	3.02E-04	3.62E-02
Coconut	2.54E-02	1.43E-02	6.69E-03	5.19E-03	5.16E-02
Orange	1.85E-02	5.70E-03	1.22E-03	2.21E-03	2.76E-02
Pawpaw	3.60E-03	9.11E-03	1.42E-03	2.45E-03	1.66E-02
Watermelon	2.22E-02	6.36E-02	2.06E-03	2.03E-03	8.99E-02
Vegetables					
Baobab Leaf	1.50E-02	1.31E-01	1.75E-03	9.65E-03	1.57E-01
Cabbage	1.18E-02	2.76E-02	4.28E-03	4.68E-03	4.84E-02
Carrot	1.30E-02	1.56E-02	8.86E-04	4.10E-03	3.36E-02
Cucumber	1.96E-02	7.79E-02	5.84E-03	3.40E-02	1.37E-01
Lettuce	3.12E-02	5.30E-02	7.15E-04	9.24E-03	9.42E-02

The THQ values for Ni, Co, Se, and Mo in fruits are relatively low, suggesting minimal non-carcinogenic health risks. Among the fruits, watermelon exhibited the highest HI (0.0899), primarily due to its elevated Co concentration. Coconut followed with an HI of 0.0516, attributed to its relatively high Se and Mo levels. Pawpaw had the lowest HI (0.0166), indicating the least potential health risk among the fruits analyzed. In contrast to fruits, vegetables exhibited higher THQ and HI values, suggesting greater potential health risks from trace element exposure. Baobab leaf had the highest HI (0.157), followed closely by cucumber (0.137), indicating potential health concerns if consumed excessively. The high HI values in these vegetables are primarily due to elevated Co and Mo levels. Cabbage and carrot had moderate HI values (0.0484 and 0.0336, respectively), while lettuce had a relatively high HI (0.0942), largely driven by its Ni content.

The comparison between elemental concentrations and potential health risks, as presented in Tables 1 and 3, reveals significant variations in exposure risks. The high nickel (Ni) concentration found in cabbage in Table 1 did not result in a very high target hazard quotient (THQ) for Ni in Table 3. This discrepancy is likely due to the lower daily consumption rates of cabbage, which reduce the overall exposure risk. In contrast, the elevated cobalt (Co) levels detected in baobab leaves and cucumber in Table 1 led to high THQ values in Table 3, significantly contributing to their overall hazard index (HI). This suggests that these vegetables may pose a greater health risk due to their cobalt content.

Cucumber, despite having the highest selenium (Se) concentration in Table 1, exhibited only a moderate THQ for Se in Table 3, indicating that its dietary intake remains within safe limits. However, the high molybdenum (Mo) concentration in cucumber in Table 1 directly correlates with its high Mo THQ in Table 3, making it a key factor in the vegetable’s elevated HI.

A comparison between estimated daily intake (EDI) values from Table 2 and the THQ and HI values from Table 3 further supports the potential health risks associated with vegetable consumption. The EDI values in Table 2 indicate that vegetables have higher daily intake levels of trace elements compared to fruits. This trend is confirmed in Table 3, where vegetables generally exhibit higher THQ and HI values than fruits. Cucumber and baobab leaf, which had high EDI values in Table 2, also showed high HI values in Table 3, reinforcing concerns about their potential health risks. In contrast, fruits, despite contributing essential trace elements in moderate amounts as seen in Table 2, have lower HI values in Table 3, suggesting a lesser risk of excessive intake.

The higher HI values observed in vegetables suggest a greater likelihood of non-carcinogenic health risks from excessive consumption. Baobab leaf, cucumber, and lettuce should be consumed in moderation to avoid potential long-term toxic effects associated with Ni, Co, and Mo. Among the analyzed trace elements, cobalt exhibited the highest THQ values, particularly in baobab leaf, cucumber, and lettuce. This suggests that dietary exposure to cobalt, especially from vegetables, may require closer monitoring to prevent potential health risks.

Although nickel and molybdenum generally had lower THQ values compared to cobalt, their relatively high concentrations in some vegetables, such as Ni in lettuce and Mo in cucumber, contributed to their total HI. Chronic exposure to high Mo intake may interfere with copper metabolism, potentially leading to deficiencies and other health complications.

None of the analyzed food samples had an HI exceeding 1, indicating that the estimated daily intake of these trace elements does not pose immediate non-carcinogenic health risks. However, long-term exposure, particularly in regions where soil contains high levels of these elements, should be regularly monitored to prevent potential health complications associated with excessive trace element accumulation in food crops.

The risk assessment presented in Table 3 highlights the importance of monitoring trace element intake from commonly consumed fruits and vegetables. While fruits generally pose minimal health risks, certain vegetables—particularly baobab leaf, cucumber, and lettuce—exhibit higher cumulative hazard indices due to elevated levels of Ni, Co, and Mo. Although the overall HI values are below the risk threshold, continuous dietary assessment and soil quality evaluation are necessary to ensure safe consumption and prevent long-term exposure risks. Values obtained from this study conforms well with those obtained from previous study (Biswas *et al*., 2023; Filippini *et al*., 2020; Najmi *et al.*, 2023; Sultana *et al*., 2017).

3.4 Further Statistical Analysis

3.4.1 Analysis of Variance (ANOVA)

To statistically compare the concentrations of nickel (Ni), cobalt (Co), selenium (Se), and molybdenum (Mo) between fruits and vegetables, a one-way analysis of variance (ANOVA) was conducted. The results are presented in Table 4.

Table 4: One-Way ANOVA Results for Elemental Concentrations in Fruits and Vegetables

Element	F-Value	P-Value
Ni	0.004	0.951
Co	2.963	0.124
Se	0.037	0.853
Mo	1.919	0.203

The ANOVA results indicate that there are no statistically significant differences in the concentrations of Ni, Co, Se, and Mo between fruits and vegetables, as all p-values are greater than 0.05. The results affirm the following inferences

(i) **Nickel** : The F-value of 0.004 and a p-value of 0.951 suggest that Ni concentrations are almost identical in both food groups.

(ii) **Cobalt** : While Co showed a higher F-value (2.963), the p-value of 0.124 indicates that the variation between fruits and vegetables is not statistically significant at the 0.05 confidence level. However, the relatively higher F-value suggests some level of variability.

(iii) **Selenium** : With an F-value of 0.037 and a p-value of 0.853, Se concentrations are highly similar between fruits and vegetables.

(iv) **Molybdenum** : The F-value of 1.919 and a p-value of 0.203 show that Mo levels differ slightly between the food groups but not significantly.

These findings suggest that, although there are variations in the mean concentrations of these trace elements in fruits and vegetables, they are not statistically significant. This aligns with the dietary intake analysis, which indicates that both food groups contribute essential trace elements without significant overconsumption risks. However, the slightly higher F-value for Co warrants further investigation, as its dietary intake showed potential health risks in the hazard index (HI) analysis.

3.4.2 Correlation Analysis Between Elemental Concentration and THQ/HI

Table 5 presents the Pearson and Spearman correlation coefficients between elemental concentrations (from Table 1) and their respective Target Hazard Quotients (THQ) and Hazard Index (HI) (from Table 3).

The Pearson correlation results indicate a very strong correlation between Nickel (Ni) concentration and its THQ (0.9999), suggesting that Ni concentration directly determines its health risk quotient. Similarly, Molybdenum (Mo) shows a strong correlation with Mo_THQ (0.9519), implying that Mo's contribution to health risk is highly dependent on its concentration. Cobalt (Co) displays a strong positive correlation with HI (0.9601), indicating that Co significantly contributes to the overall hazard index.

The Spearman correlation results, which assess monotonic relationships, confirm the trends seen in the Pearson correlation. Co again shows a high correlation with HI (0.9058), reinforcing its role as a key contributor to health risks. Mo also shows moderate to strong correlations with HI (0.5636) and Co THQ (0.6018), indicating that increased Mo concentration could elevate health risks. Based on the Analysis presented in Table 6, we observed that

(i) Cobalt is the strongest contributor to HI, as shown by its high correlation values in both Pearson (0.9601) and Spearman (0.9058) analyses. This suggests that increased Co intake from vegetables like baobab leaf and cucumber could be a concern for human health.

(ii) Nickel and Molybdenum require monitoring, as their high correlations with THQ indicate that even slight variations in their concentration could significantly impact health risk assessments.

Table 5: Pearson and Spearman Correlation Between Elemental Concentration and THQ/HI

Harzard/Correlation	Ni	Co	Se	Mo
Ni-THQ (Pearson)	0.9999	0.1678	0.1635	0.1696
Co-THQ (Pearson)	0.1617	0.9997	0.0239	0.4989
Se-THQ (Pearson)	0.1600	0.0799	0.9920	0.5279
Mo-THQ (Pearson)	0.1941	0.4454	0.4675	0.9520
HI-(Pearson)	0.3413	0.9601	0.2431	0.6151
Ni-THQ (Spearman)	1.0000	0.2364	0.1394	0.1758
Co-THQ (Spearman)	0.2553	0.9970	0.2796	0.6018
Se-THQ (Spearman)	0.1166	0.2270	0.9265	0.4111
Mo-THQ (Spearman)	0.2485	0.4424	0.2485	0.5636
HI (Spearman)	0.5394	0.9058	0.3743	0.5636

Selenium has a high self-correlation (0.9920) in Pearson analysis, but its correlation with HI remains moderate, indicating that while Se is present in varying amounts, its health risk remains controlled.

4.0 Conclusion

The study assessed the elemental concentrations, dietary intake, and associated health risks of essential trace elements (Ni, Co, Se, and Mo) in selected fruits and vegetables. The findings revealed varying concentrations of these elements across different food groups, with vegetables generally exhibiting higher levels than fruits. Cabbage, cucumber, and baobab leaf contained notably high levels of Ni and Co, while cucumber had the highest Se and Mo concentrations. The estimated daily intake (EDI) values indicated that vegetables contributed more to dietary exposure than fruits, which was further reflected in the higher target hazard quotient (THQ) and hazard index (HI) values observed for vegetables.

The risk assessment results showed that none of the individual elements posed an immediate health risk, as all HI values remained below the critical threshold of 1. However, baobab leaf, cucumber, and lettuce exhibited relatively higher HI values, suggesting that prolonged consumption of these vegetables could lead to potential health risks. Among the trace elements, cobalt was identified as the most concerning due to its high THQ values, particularly in baobab leaf and cucumber.

Based on these findings, it is recommended that regular monitoring of trace element concentrations in food sources be implemented to prevent potential long-term health effects. Public health guidelines should emphasize balanced dietary intake, ensuring that high-risk vegetables such as cucumber and baobab leaf are consumed in moderation. Further studies should explore the bioavailability of these elements in different food matrices and assess their long-term impact on human health. Additionally, agricultural practices should be optimized to minimize the excessive accumulation of trace elements in edible plants, and policymakers should consider setting regulatory limits for essential trace elements in commonly consumed foods.

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Ethical Approval

Not Applicable

Competing interests

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Data shall be made available on request

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The authors declare no conflict of interest

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