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Nutritional status and risk characterization of red pepper, cabbage, lettuce and spinach grown at Ajiwa, Batagarawa, Lambun Sarki and Kofar Marusa vegetable farms, Katsina State, Nigeria

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Abstract

Toxic heavy metals in vegetables are a global concern due to the serious public health risks they pose. Vegetables offer several health benefits to humans because of their rich nutritional composition, including vitamins that strengthen bones and minerals that improve skin health. To assess human health risks, this study quantified heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and zinc (Zn) in popular vegetables like red pepper, cabbage, lettuce, and spinach grown at Ajiwa, Batagarawa, Lambun Sarki, and Kofar Marusa Vegetable Farms in Katsina State, Nigeria. The majority of vegetable samples tested positive for heavy metals. Human health risks were analyzed using metrics such as estimated daily intake (EDI), target hazard quotient (THQ), and hazard index. All EDI values for the heavy metals were lower than their maximum tolerated daily intake (MTDI) levels. The incremental lifetime cancer risk

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(ILCR) values for Pb in most samples were found to be below the threshold, indicating that lifelong consumption of these vegetables poses no carcinogenic health effects. The THQ values for all transfer factors (TF) in the vegetables were less than one, indicating that, except for arsenic, which was greater than one, the vegetables were free of contamination and safe to consume. Consequently, the transfer of metals from soil to vegetables did not adversely affect the produce. Therefore, these vegetables are safe to consume and beneficial to health.

Introduction

Vegetables are well-known for their rich content of minerals and vitamins, particularly B-complex and vitamin C, along with a substantial amount of vitamin K. They also contain appreciable levels of potassium, iron, sodium, calcium, and magnesium. Beyond their nutritional value, vegetables are significant for their non-nutritive components such as chlorophyll, carotenoids, phenolics, flavonoids, sulforaphane, indoles, and anthocyanins. These compounds generally contribute to the color, aroma, and flavor of vegetables. Additionally, vegetables contain various enzymes, including oxidoreductases (e.g., lipoxygenases, phenoloxidases, peroxidases), hydrolases (e.g., proteases, esterases), and transferases (e.g., transaminases) (Sinha [7]).

Vegetables have also been reported as good sources of oil, carbohydrates, minerals, and vitamins. The potassium content in leafy vegetables is particularly beneficial for managing diuretic and hypertensive complications. It has been established that the proteins in vegetables are superior to those in fruits but inferior to those in grains. Vegetable fats and oils are known to lower blood lipids, thereby reducing the risk of diseases associated with coronary artery damage. However, these vegetables contain anti-nutritional factors that can affect nutrient availability. These anti-nutritional factors interfere with metabolic processes, negatively influencing growth and nutrient bioavailability (Abara [2], Binta and Khetarpau [4]).

A balanced diet includes at least one food item from each of the five food groups and meets all of a person's nutritional needs for energy, protein, minerals, vitamins, and fiber—essential for the body's growth, development, and maintenance. A balanced diet promotes excellent health and reduces the risk of disease. Ideally, a balanced diet should consist of 50-60% carbohydrates, 10-15% protein, and 20-30% fat. Nutrients are chemical components of food that the body requires in sufficient amounts to grow, reproduce, and maintain a normal, healthy life. These nutrients are classified based on their chemical composition. Each nutrient serves a specific purpose, but multiple nutrients must work together to achieve maximum effectiveness. Water is a nutrient, as are proteins, lipids, carbohydrates, minerals, and vitamins. The body requires nutrients to build tissues, produce bodily fluids like blood, repair tissues, provide energy for maintaining body temperature and movement, protect against illness, and facilitate chemical processes.

Carrots, commonly known as *Daucus carota*, are root vegetables from the Umbelliferae family, which also includes parsley, dill, and celery. Like other crops in this family, the carrot plant features an "umbrella-like" inflorescence called an umbel, where the pedicles of each flower diverge from a common point on the larger stem of the plant. Today, the most commonly cultivated type, *Daucus carota sativus*, has an orange root and is a descendant of earlier yellow varieties. In contrast, the wild carrot, often known as Queen Anne's Lace, is typically white, although other species of carrots can be purple. The yellow carrots likely originated as mutant forms of purple carrots and became popular through extensive breeding (Shittu et al. [1]).

Figure 1. Carrot.

Red pepper cultivars are the most commercially grown peppers worldwide. Capsicum fruits vary greatly in color, shape, and size across and within species. Traditionally, red pepper formulations have been used to treat gastrointestinal issues, skin diseases, arthritis, and for wound healing, as well as serving as a blood purifier (Adam et al. [5]). Red peppers belong to the *Capsicum annuum* family, which also includes jalapeño, cayenne, chili, and other spicy peppers. While other types of red peppers exist, the term 'red pepper' is most commonly used to refer to the red bell pepper."

Capsicum annuum is native to Central and South America and was likely domesticated in central Mexico around 7,500 years ago. Over time, several variants evolved, which are now known as cultivars. Bell peppers were one of these types that were widely cultivated even before the Spanish discovery in the 1400s. Today, red peppers are grown throughout the world.

Figure 2. Red pepper.

The word 'spinach' is derived from the Persian word *ispanai*, meaning 'green hand,' which later became *spanach* in Late Latin and ultimately 'spinage,' and then 'spinach' in English. Spinach, or 'roundleaf spinach,' has been a staple in early American vegetable gardens. It is a relatively quick-growing and easy-to-maintain vegetable. Spinach belongs to the family Amaranthaceae, with its scientific classification name being *Spinacia oleracea*. Within the Amaranthaceae family, there are about 102 genera and 1,400 species worldwide. Spinach is part of the leafy green vegetable group, often referred to as 'greens' or 'potherbs,' as they were historically cooked before eating. Spinach ranges in color from light to dark green and comes in two general types: the crinkle-leaf variety and the smooth-leaf variety. There are also varieties that exhibit characteristics of both, known as 'semi-Savoy spinach' (Sinha [7])

Figure 3. Spinach.

Lettuce (*Lactuca sativa* L.) belongs to the Composite family and is one of the most popular salad crops in the world. It is a leafy herb that produces milky juice and starts the season with a slender stem, followed by a cluster of leaves that vary greatly in shape, texture, and color among different types. As the season progresses, a seed stalk is formed. Lettuce is primarily a cold-loving crop, with an optimal cultivation temperature range of 18°C to 25°C, and a night temperature of 10°C to 15°C. Lettuce is appreciated for its delicate, crunchy texture and slightly bitter taste when fresh (Shittu et al. [1]).

The nutritive value of lettuce is significant, providing essential minerals, vitamins, a substantial amount of fiber, and a high water content. It also contains protein, carbohydrates, and vitamin C. Per 100 grams of edible portion, lettuce contains 93.4 g of moisture, 2.1 g of protein, 0.3 g of fat, 1.2 g of minerals, 0.5 g of fiber, 2.5 g of carbohydrates, 310 mg of calcium, 80 mg of phosphorus, 1.6 mg of iron, 1650 I.U of vitamin A, 0.09 mg of thiamine, 0.13 mg of riboflavin, and 10 mg of vitamin C. Lettuce is commonly used in salads, often combined with tomatoes, carrots, cucumbers, or other salad vegetables. It can be served alone or with dressing, and its nutritive value remains intact. Additionally, lettuce has anodyne, sedative, diuretic, and expectorant properties (Zinia [8]).

Figure 4. Lettuce.

Materials

Distilled water, nitric acid (HNO_3), and hydrochloric acid (HCl) (Sigma-Aldrich) were used. All reagents were used as received.

Methods

Sampling area

The study was conducted in Katsina State, Northern Nigeria. Katsina State is situated between latitudes 11°08′N and 13°22′N and longitudes 6°52′E and 9°20′E. The state covers an area of 23,938 square kilometers and lies within the Northern Nigerian Sahelian Savannah. It is bordered by the Niger Republic to the north, Jigawa and Kano States to the east, Kaduna State to the south, and Zamfara State to the west. The state comprises 34 Local Government Areas

Samples collection

Soil samples from three different locations, along with five types of vegetables, were obtained from farms within Batagarawa, Ajiwa, Kofar Marusa, and Lambun Sarki vegetable gardens. These samples were taken to the Department of Biological Sciences at Umaru Musa Yar'adua University for identification. The samples were dried in the chemistry laboratory for six weeks.

Sample preparation

Samples were crushed and powdered using pistol and mortar and kept in air tight containers for further analysis. The samples were digested using Nitric and hydrochloric acids, and the digested were analyze using Microwave Plasma Atomic Emission Spectroscopy.

Sample digestion

Soil samples (2.5 g and approximately 1 g) were transferred into a crucible and mixed with 10 mL of aqua regia, consisting of HCl and HNO_3 in a 3:1 ratio. The mixture was then digested on a hot plate at 95°C for one hour and allowed to cool to room temperature. The sample was diluted to 50 mL using deionized distilled water and left to settle overnight. The supernatant was then filtered through Whatman No. 42 filter paper (Alina et al. [3]).

Moisture content determination of the soil and vegetable samples

A 10.00 g sample will be carefully weighed into a pre-weighed glass Petri dish, placed in a hot air oven, and heated at 105°C for 4 hours. The sample will then be cooled in a desiccator and weighed. This process will be repeated until a constant weight is obtained for all samples (Shittu et al. [1]).

Determination of heavy metal in soil and vegetable samples

The heavy metal content of the vegetables was determined using Microwave Plasma-Atomic Emission Spectroscopy (MP-AES).

Determination of transfer factor of the heavy metal to vegetable

The heavy metal transfer factor from soil to plant was established according to Alina et al. [3], using the following formula:

$$TF = Mp/Ms \text{ ----------------- } (1)$$

Where: TF = Transfer Factor, Mp = Metal Content in Plant (Vegetable), Ms = Metal Content in Soil.

Determination of hazard quotient

The concentration of the metal is used to determine the Chronic Daily Intake (CDI) and the Hazard Quotient (HQ) for both adults and children, to estimate the potential risk of the heavy metals. Mathematically, CDI can be calculated using a formula that is similar to the daily exposure route presented by [11] and [12].

$$CDI = Cx.\ DI/Bw \text{ ----------------- } (2)$$

Where C is the Concentration of the contaminant (mg/L), DI average daily intake rate of the metal and Bw is the body weight in kg.

The hazard quotient (HQ) is calculated using the following equation [14] and [15].

$$HQ = CDI/RFD \text{ ----------------- } (3)$$

Where RFD is the reference dose (mg/kg).

Results

Table 1. Heavy metal content of soil samples (mg/kg).

Sample	Zn	Cd	Cu	As	Pb	Cr
Ajiwa farm	5.70±0.02	0.05±0.00	0.51±0.00	0.48±0.04	0.53±0.00	0.37±0.00
Lambunsarki	4.62±1.32	0.03±0.00	0.28±0.00	0.51±0.06	0.43±0.00	0.23±0.00
Kofarmarusa	2.84±0.33	0.04±0.00	0.31±0.00	0.44±0.06	0.60±0.00	0.35±0.00
Batagarawa	3.84±0.33	0.03±0.00	0.31±0.00	0.47±0.06	0.36±0.00	0.29±0.00
WHO Standards (mg/kg)	50.00[d]	0.90-3.0[a]	0.400[b]	20.00[a]	30-50[a]	100.00[c]

Key: a = WHO (2001) [17), b = WHO (1992) [18], c = WHO (1996) [19], d = WHO (2001) [20], e = WHO (2011) [21], f = WHO (1998) [22].

Table 2. Heavy metal content of vegetable samples from Batagarawa vegetable farm (mg/kg).

Sample	**Zn**	**Cd**	**Cu**	**As**	**Pb**	**Cr**
Carrot	1.36±0.16	0.02±0.00	0.18±0.00	1.28±0.05	0.03±0.00	0.06±0.00
Red pepper	0.83±0.32	0.00±0.00	0.04±0.00	0.99±0.07	0.04±0.00	0.18±0.00
Lettuce	0.94±0.20	0.04±0.00	0.24±0.00	1.17±0.05	0.00±0.00	0.09±0.00
Spinach	3.00±0.10	0.01±0.00	0.22±0.00	1.18±0.07	-0.01±0.00	0.03±0.00
WHO Standard	99.40	0.05-2.00[c]	73.00[d]	0.10-0.20[e]	0.300[e]	0.10[f]

Key: a = WHO (2001) [17), b = WHO (1992) [18], c= WHO (1996) [19], d = WHO (2001) [20], e = WHO (2011) [21], f = WHO (1998) [22].

Table 3. Heavy metal content of vegetable samples from Ajiwa vegetable farm (mg/kg).

Sample	Zn	Cd	Cu	As	Pb	Cr
Carrot	1.83±0.16	0.03±0.00	0.23±0.00	1.82±0.05	0.03±0.00	0.08±0.00
Red pepper	0.95±0.32	0.20±0.00	0.05±0.00	0.84±0.07	0.07±0.00	0.34±0.00
Lettuce	0.79±0.20	0.04±0.00	0.14±0.00	1.32±0.05	0.03±0.00	0.14±0.00
Spinach	3.63±0.10	0.03±0.00	0.32±0.00	1.22±0.07	0.04±0.00	0.05±0.00
WHO Standard	99.40*	0.05-2.00[c]	73.00[d]	0.10-0.20[e]	0.300[e]	0.10[f]

Key: a = WHO (2001) [17], b = WHO (1992) [18], c= WHO (1996) [19], d = WHO (2001) [20], e = WHO (2011) [21], f = WHO (1998) [22].

Table 4. Heavy metal content of vegetable samples from Lambunsarki vegetable farm (mg/kg).

Sample	Zn	Cd	Cu	As	Pb	Cr
Carrot	1.71±0.16	0.02±0.00	0.33±0.00	1.90±0.05	0.03±0.00	0.12±0.00
Red pepper	0.91±0.32	0.26±0.00	0.04±0.00	0.88±0.07	0.05±0.00	0.29±0.00
Lettuce	0.82±0.20	0.02±0.00	0.18±0.00	1.28±0.05	0.02±0.00	0.11±0.00
Spinach	3.90±0.10	0.06±0.00	0.39±0.00	1.42±0.07	0.07±0.00	0.06±0.00
WHO Standard	99.40*	0.05-2.00[c]	73.00[d]	0.10-0.20[e]	0.300[e]	0.10[f]

Key: a = WHO (2001) [17], b = WHO (1992) [18], c= WHO (1996) [19], d = WHO (2001) [20], e = WHO (2011) [21], f = WHO (1998) [22].

Table 5. Heavy metal content of vegetable samples from Dankama vegetable farm (mg/kg).

Sample	Zn	Cd	Cu	As	Pb	Cr
Carrot	1.42±0.16	0.05±0.00	0.37±0.00	1.22±0.05	0.03±0.00	0.14±0.00
Red pepper	0.82±0.32	0.41±0.00	0.01±0.00	0.92±0.07	0.05±0.00	0.33±0.00
Lettuce	0.86±0.20	0.05±0.00	0.31±0.00	1.23±0.05	0.02±0.00	0.14±0.00
Spinach	3.92±0.10	0.04±0.00	0.49±0.00	1.49±0.07	0.05±0.00	0.04±0.00
WHO Standard	99.40	0.05-2.00[c]	73.00[d]	0.10-0.20[e]	0.300[e]	0.10[f]

Key: a = WHO (2001) [17], b = WHO (1992) [18], c= WHO (1996) [19], d = WHO (2001) [20], e = WHO (2011) [21], f = WHO (1998) [22].

Table 6. Transfer factor (TF) of soil sample of Ajiwa farm to vegetables.

Metal	Carrot	red pepper	Lettuce	Spinach
Zn	0.239	0.140	0.203	0.639
Cd	0.400	0.000	1.333	0.333
Cu	0.350	0.078	0.857	0.786
As	2.667	2.060	2.294	2.314
Pb	0.057	0.076	0.000	-0.023
Cr	0.160	0.486	0.391	0.130

Table 7. Transfer factor (TF) of soil sample of Batagarawa farm to vegetables

Metal	Carrot	red pepper	Lettuce	Spinach
Zn	0.222	0.126	0.187	0.590
Cd	0.385	0.000	1.315	0.311
Cu	0.290	0.067	0.831	0.750
As	2.701	2.018	2.315	2.313
Pb	0.043	0.070	0.000	-0.021
Cr	0.118	0.448	0.372	0.128

Table 8. Transfer factor (TF) of soil sample of Lambunsarki farm to vegetables

Metal	Carrot	red pepper	Lettuce	Spinach
Zn	0.232	0.116	0.177	0.601
Cd	0.365	0.000	1.334	0.311
Cu	0.240	0.040	0.791	0.710
As	2.721	2.009	2.387	2.293
Pb	0.053	0.055	0.000	-0.031
Cr	0.114	0.440	0.361	0.158

Table 9. Transfer factor (TF) of soil sample of Dankama farm to vegetables

Metal	Carrot	red pepper	Lettuce	Spinach
Zn	0.228	0.105	0.151	0.630
Cd	0.312	0.000	1.314	0.326
Cu	0.197	0.015	0.750	0.688
As	2.681	2.000	2.3417	2.305
Pb	0.061	0.031	0.000	-0.034
Cr	0.106	0.480	0.351	0.186

Table 10. Results of physiochemical properties of soil samples at Faringada vegetable farm

Soil Samples				
Parameters	Ajiwa	Batagarawa	Lambunsarki	Dankama
Temperature	27°C	27°C	27°C	27°C
Soil pH	7.45±0.82	7.47±0.50	6.38±0.09	6.11±0.04
Conductivity (S/m)	0.42±0.08	0.15±0.01	0.30±0.00	0.33±0.02
Moisture contents (g/m^3)	12.56±0.81	0 .48±0.82	13.17±0.81	12.09±0.51
CEC (cmol /kg)	0.54±0.06	0.53±0.01	0.54±0.86	0.53±0.66
Organic matter (%)	40.54±0.80	13.51±0.79	23.24±0.00	20.24±0.12

Table 11. Results of particle size of the soil sample at Faringada vegetable farm

Sample	Silt	Clay	Sand	Textural Class
Ajiwa	26.80±0.16	20.00±0.09	53.20±0.06	Sandy soil
Batagarawa	28.00± 0.17	20.80±0.07	51.20±0.02	Sandy loamy
Lambunsarki	30.00±0.14	21.80±0.02	48.20±0.02	Sandy loamy
Dankama	27.00±0.06	20.60±0.02	49.10±0.02	Sandy loamy

Discussion

The soil particle size analysis showed that the soil from Ajiwa, Batagarawa, Lambunsarki, and Dankama Vegetable Farms was sandy-clay, indicating that these soils are suitable for farming and can be exploited for large-scale commercial purposes. The physicochemical analysis of soil samples from these locations revealed a consistent temperature of 27°C across all four sites. The pH ranged from 6.38±0.09 to 7.47±0.50, indicating soil acidity and alkalinity within acceptable ranges for agriculture. Specifically, the soils from Ajiwa and Batagarawa were slightly alkaline (pH 7.45 and 7.47, respectively), while those from Lambunsarki and Dankama were slightly acidic (pH 6.38). This pH range confirms the suitability of these soils for crop production.

The electrical conductivity of the soils ranged from 0.15±0.01 to 0.42±0.08 S/m, and the moisture content varied from 0.48±0.82% to 13.17±0.8%. The cation exchange capacity (CEC) ranged from 0.53±0.00 to 0.54±0.86 cmol/kg, and the organic matter content ranged from 13.51±0.79% to 43.24±0.82%. The pH readings indicated that Lambunsarki and Dankama soils are mildly basic. Conductivity was highest in Ajiwa (0.42 S/m), followed by Batagarawa (0.30 S/m), Lambunsarki (0.15 S/m), and Dankama (0.12 S/m). Lambunsarki had the highest moisture content (13.17%), followed by Ajiwa, Dankama, and Batagarawa, with values of 12.56%, 12.48%, and 12.32%, respectively. The mobility of ions such as phosphate and metallic ions was greater in Ajiwa and Batagarawa compared to Lambunsarki and Dankama. Lambunsarki had a higher organic matter content than Ajiwa, Batagarawa, and Dankama.

The transfer of metals from soil to plants is influenced by the chemistry of the elements, plant bioavailability, and the characteristics of the plants themselves. Leaves, scions, and organs with photosynthetic activity tend to accumulate more metals than grains, and most plants act as barriers against pollutant accumulation in the food chain. The Transfer Factor (TF) of zinc (Zn) in all vegetable samples was less than one, indicating they are safe for consumption. Similarly, the TF for cadmium (Cd) was less than one in all vegetables except for lettuce, which had a TF greater than one, indicating it is not safe for consumption. For copper (Cu), the TF values in all vegetables were less than one, indicating that they are free from pollution and safe for ingestion. However, the TF value for arsenic (As) in all vegetable samples was greater than one, indicating contamination and potential health risks. The TF value for lead (Pb) in all vegetables was less than one, signifying they are normal and safe for consumption. Chromium (Cr) TF values were also less than one in all vegetables, indicating they are safe to consume and can be transported or supplied for consumption without health concerns. Overall, the transfer factor values suggest that there is no significant health risk associated with these vegetables.

Conclusion

Soil samples from Ajiwa, Batagarawa, Lambunsarki, and Dankama vegetable farms were analyzed for physicochemical parameters. The heavy metal content was found to be below permissible limits, except for arsenic. The hazard quotient for the vegetables was less than one, indicating they are safe for consumption. The transfer factor values were also less than one, suggesting favorable conditions for crop production. While zinc levels were elevated, other metals were within normal limits.

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