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Concentrations of Selected Heavy Metals in Soil and Tomatoes (*Lycopersicon Esculenta Mill.)* Grown in Kirinyaga County, Kenya

Somo Q. Bilalo[1], Andrew A. Andayi[1], Eric C. Njagi[2]* and Brian M. Ptoton[3]

[1]Department of Physical and Biological Sciences, Murang'a University of Technology, P.O. Box 75-10200, Murang'a, Kenya

[2]Department of Physical Sciences, Chuka University, P.O. Box 109-60400, Chuka, Kenya

[3]Department of Physical and Biological Sciences, Murang'a University of Technology, P.O. Box 75-10200, Murang'a, Kenya

Abstract*:* The contamination of agricultural products by harmful heavy metals poses a significant global health concern, with potential links to severe public health issues such as cancer and neural impairment. Tomatoes (*Lycopersicon esculent Mill.)*, a dietary staple, can absorb and store both essential micronutrients and potentially harmful heavy metals, particularly in their consumable parts. This study investigated the concentration of cadmium, lead, copper, and chromium in tomatoes and corresponding soil samples from Kirinyaga County, Kenya. A total of 27 tomatoes and 27 soil samples were randomly collected from farms in three ecological zones of Kirinyaga County. Elemental analysis was performed using Microwave Plasma-Atomic Emission Spectroscopy (MP-AES). The mean concentrations of heavy metals in soil samples ranged from; cadmium: 0.0100±0.100 to 0.1133±0.0667, lead: 0.0570±0.0566 to 0.667±0.0367, copper: 0.8667±0.273 to 1.9±0.0577 and chromium 0.0670±0.0600 to 1.333±0.040 mg/kg. The mean concentrations of heavy metals in tomatoes ranged from; cadmium: 0.00367±0.003 to 0.00867±0.01, lead: 0.00133±0.003 to 0.00667±0.02, copper: 0.00667±0.02 to 0.0667±0.003 and chromium: below detection limit to 0.027±0.035 mg/kg. The concentrations of the heavy metals in soils and tomatoes were significantly lower than the maximum concentrations set by the WHO/FAO. The concentrations of the aforementioned heavy metals in soils were significantly lower than their global background concentrations in soils.

Keywords: Heavy metals, tomatoes, soil, bioaccumulation factor

1.0 INTRODUCTION

Tomato (*Lycopersicon esculentum mill*) is among the most produced and consumed vegetables in the world. Globally, the leading producers of tomatoes are China, USA, Turkey and India (Costa and Heuvelink, 2005). In Africa, Kenya is among the largest producers of tomatoes, and produced 973,304 tons in 2020 (AFA-HCD, 2020). In Kenya, Taita Taveta, Kirinyaga and Kajiado Counties are the leading producers of tomatoes (Sigei *et al*., 2014; AFA-HCD, 2020).

Tomatoes are widely consumed worldwide because of their nutritional, nutraceutical and flavoring properties. Tomatoes are a rich source of minerals, vitamins, amino acids, fatty acids, phytosterols, flavonoids and carotenoids (Beecher, 1998; Ali *et al*., 2021). Tomatoes contains several antioxidants including lycopene, β-carotene and quercetin (Beecher 1998). Antioxidants prevent or reduce oxidative damage of cells, proteins and DNA, and thus mitigate against diabetes, cardiovascular diseases, cancers and neurodegenerative diseases (Beecher, 1998; Nguetti *et al*., 2019; Ali *et al*., 2021). Tomatoes are consumed fresh, added to salads, cooked as a vegetable or processed to produce several products including tomato juice, paste, puree, powder and sauce, which are then consumed directly or used as ingredients for other foods (Beecher, 1998).

In 2020, Kirinyaga County produced 64,038 metric tons of tomatoes in valued at about 1.8B Kenya shillings (AFA-HCD, 2020). The bulk of the tomatoes are grown in open fields using the furrow irrigation (Waiganjo *et al*., 2006). Pesticides are extensively used to control diseases (e.g. fungal blights, bacterial and viral wilts) and insect pests such as the African bollworm, thrips and cutworms (Waiganjo *et al*., 2006). In addition, inorganic fertilizers such as diammonium phosphate (DAP), calcium ammonium nitrate (CAN) and nitrogen, phosphorus, and potassium (NPK) fertilizers are widely used (Waiganjo *et al*., 2006).

Tomatoes grown in Kirinyaga County are susceptible to heavy metal contamination because of extensive use of contaminated soils, pesticides, inorganic fertilizers and furrow irrigation using river water. Rivers can become contaminated with heavy metals via agricultural and urban run-offs, disposal of household wastes (Gatere *et al*., 2022). Consumption of food containing heavy metals can cause deleterious health effects including cancers, growth retardation and mental disorders (Rai *et al*., 2019). Cadmium can cause several adverse effects including kidney dysfunction, sexual disorders, lung and breast cancers and osteoporosis (Rai *et al*., 2019). Lead can have adverse effects on the central nervous system, cardiovascular diseases, cancers and mental disorders in children (Rai *et al*., 2019). Copper can affect renal and metabolic functions while chromium can cause renal dysfunction and respiratory diseases (Rai *et al*., 2019). The objective of this study was to determine the concentration cadmium, lead, copper and chromium in soils and tomatoes grown in Kirinyaga County.

2.0 RESEARCH METHODOLOGY

2.1. Study Area

Kirinyaga County is located in the central region of Kenya about 120 km from Nairobi. The county lies between 0.6591° S and 37.3827° E and covers an area of 1478.1 km^2 of which 801.7 km^2 is under agricultural production (KNBS, 2019). As shown in Figure 1, the county is divided into five sub-counties i.e. Kirinyaga Central, Kirinyaga East, Kirinyaga West, Mwea East and Mwea West (MoALFC, 2021). In 2019, the County has a population of 610411 persons with a projected annual growth of 1.5 % (KNBS, 2019).

Kirinyaga County has three ecological zones, namely, the lowland, the midland and the highland zones (Jaetzold *et al*., 2010). The lowland zone lies between 1158-2000 m above the sea level and covers most of Mwea East and Mwea West sub-counties (Jaetzold *et al*., 2010; MoALFC, 2021). The midland zone lies between 2000-3400 m above the sea level and covers the lower regions of Kirinyaga Central, Kirinyaga East, Kirinyaga West sub-counties (Jaetzold *et al*., 2010; MoALFC, 2021). The highland zone covers the upper regions of Kirinyaga Central, Kirinyaga East, Kirinyaga West sub-counties and the forested regions of Mount Kenya (MoALFC, 2021). Kirinyaga experiences bimodal annual rainfall with long rains falling between the months of March and May and short rains falling between the months of October and December (Jaetzold *et al*., 2010). Rainfall increases with altitude and ranges from 800-2200 mm per annum (Jaetzold *et al*., 2010). The annual average temperature in the study area ranges from 9.7-21.6°C (Waiganjo *et al*., 2006). The major rivers that support farming in the study area include Thiba, Nyamindi, Tana, Ragati, and Rwamuthambi rivers (Jaetzold *et al*., 2010).

The area consists primarily of the volcanic bedrock of Mt. Kenya with some isolated areas having rocks of the basement System (Baker, 1967; Jaetzold *et al*., 2010). Fertile volcanic soils are found in the midland and highland zones of the study area (Jaetzold *et al*., 2010). Dark grey to black cotton soils predominate in the lowland zone (Jaetzold *et al*., 2010). Major crops in the study area include tomatoes, beans, maize, bananas, coffee and tea (Jaetzold *et al*., 2010; MoALFC, 2021). In addition, rice and horticultural crops are grown under irrigation in the lowland zone (MoALFC, 2021).

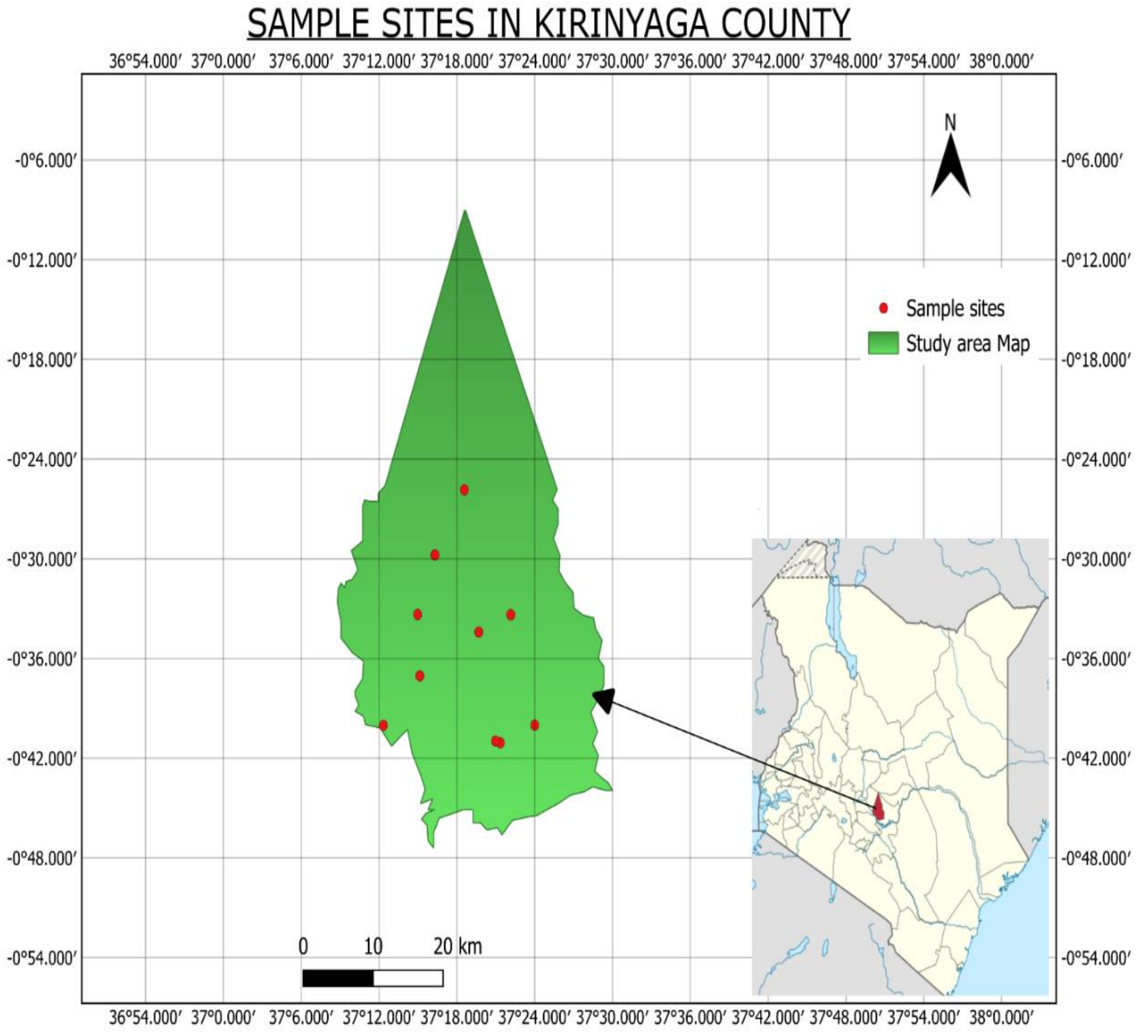

Figure1: Map of Kirinyaga County showing the sub-counties and ecological zones

2.2. Collection of Soil and Tomatoes Samples

Samples of soils and tomatoes were collected from twenty-seven farms in the three ecological zones of Kirinyaga County. As shown in Table 1, samples were collected at nine farms in the highland zone at Kimunye, Kerugoya and Baricho areas. In the midland zone samples were collected at nine farms at Sagana, Kagio and Mururi areas. In the lowland zone, samples were collected at nine farms at Wang'uru, Kiriiko and Thiba areas. Three of samples of tomatoes and three soil samples were collected at each sampling area.

Table 1. Sampling Sites, sample type and number of samples

Regions	Location	Type of samples	Number of samples
Highland zone	Kimunye	Tomatoes	3
		Soil	3
	Kerugoya	Tomatoes	3
		Soil	3
	Baricho	Tomatoes	3
		Soil	3
Midland zone	Sagana	Tomatoes	3
		Soil	3
	Kagio	Tomatoes	3
		Soil	3
	Mururi	Tomatoes	3
		Soil	3
Lowland zones	Wang'uru	Tomatoes	3
		Soil	3

	Kiriko	Tomatoes	3
		Soil	3
	Thiba	Tomatoes	3
		Soil	3
Total			54

Two kilograms of tomatoes were collected from at each sampling site. The tomatoes were randomly selected, wrapped in pre-cleaned aluminum foil, placed in polythene bags, and transported to the chemistry department laboratory at Murang'a University of Technology. Soil samples were simultaneously collected at a depth of 2.5 to 15 cm at each sampling point using a stainless steel soil auger. The soil samples were placed in pre-cleaned polyethylene bags and transported to the chemistry department laboratory at Murang'a University of Technology.

2.3. Digestion of Tomatoes and Soil Samples

Tomato samples were thoroughly washed with distilled water to remove any adhering dirt, sliced into small pieces using a stainless steel knife and air-dried for 24 h to remove moisture (Esther *et al.*, 2016). The dried samples were then placed in a Memmert oven oven for 24 h at 105°C, cooled and ground into powder using a mortar and pestle. The powder was then sieved using a 150-mesh sieve (Anugrahwati *et al*., 2020). Large particles and other detritus materials were removed from soil samples. The samples were then air-dried for 24 h, oven dried for 24 h at 105°C, ground into powder with a mortar and pestle and sieved using a 150-mesh sieve (Anugrahwa *et al.*, 2020).

The dry ashing method described in the literature by Anugrahwati and co-workers was used to digest tomatoes and soil samples (Anugrahwati *et al.*, 2020). 2.0 g of each powdered sample was placed in a beaker then 6.0 mL of H_2O and 4.0 mL of 35% HNO_3 were added to the beaker. The beaker was then heated on a hotplate at 100-120^{o}C to dryness. The resultant sample was heated in a muffle furnace for 1 h at 500^{o}C, cooled down and quantitatively transferred to a 100 mL volumetric flask. The volumetric flask was topped with a solution of 2% of HNO_3 and the mixture shaken thoroughly to homogenize and filtered using Whatman filter paper No. 42 and a 0.22-micron syringe filter.

2.4 Elemental Analysis

The concentrations of cadmium, lead, copper and chromium in the samples were determined using an Agilent 4210 Microwave Plasma Atomic Emission Spectrometer (MP-AES). The concentrations of the four elements was determined using a four-point calibration curve of a multi-element standard in emission mode. To evaluate the effectiveness of the MP-AES techniques and the experimental procedures, quality control tests were conducted.

A pre-digested samples was spiked with 5 mg/kg, prepared by serial dilution of a 1000 mg/kg stock standard solution, ensuring quality assurance (Yue *et al.*, 2022). The same digestion process was then simultaneously applied to both non-spiked and spiked samples. The levels of the heavy metals in each type of sample were determined by MP-AES, and the percentage recovery was calculated using the following equation.

$$Percentage\ recovery = \left(\frac{Concentration\ in\ spiked\ samples - Concentration\ in\ non{-}spiked\ samples}{Amount\ added}\right) x100$$

2.5. Bioconcentration Factor

The Bioconcentration Factor (BCF) was used to determine the ability of the tomato fruits to bioaccumulate the target metals from the soil. The BCF is defined as the ratio of the concentration of a metal in a plant tissue to the concentration of the metal in the media, both based on dry weight (Munir *et al*., 2021). The BCF was calculated using the following formula:

$$Bioconcetration\ Factor = \frac{[M]plant}{[M]soil}$$

Where, M_{plants} is the concentration of the heavy metal in a tomato sample and M_{soil} is the concentration of the heavy metal in the corresponding soil sample.

2.6. Statistical Analysis

A Microsoft Excel spreadsheet and IBM statistical software, version 25.1 of the Statistical Package for Social Sciences (SPSS), were used to conduct all of the statistical tests. Microsoft Excel was used to calculate the means, standard deviation, and relative standard deviation, among other descriptive statistics. Multivariate statistical analysis was used to examine the differences in heavy metal concentrations found in tomato and soil samples taken different zones. In order to ascertain the coherence and divergence of the data, the Pearson correlation analysis was used to examine the correlation between variables.

3.0 RESULTS AND DISCUSSION

3.1 Recovery of heavy metals from spiked samples

Matrix spiking was used to evaluate the performance of the MP-AES analytical method for analysis of the selected heavy metals in tomatoes. The percent recoveries of the metals from the spiked samples are shown in Table 2. The percent recoveries ranged from 99.4-100.1%. The obtained recoveries are within the acceptable range of 80-120% for metals (Harvey, 2000). Thus, matrix effects were minimal and the metals were quantified using the standard calibration method (Trancoso *et al*., 2003).

Table 2. Spike recoveries for selected metals in tomatoes samples

Heavy metals	*Conc. in nonspiked tomato sample (mg/kg)	Added amount (mg/kg)	**Conc. in spiked tomato sample (mg/kg)	Percentage recovery (%)a
Cd	0.0085	5.0	5.009	100.1
Pb	0.0141	5.0	5.011	99.4
Cu	0.039	5.0	5.02	99.6
Cr	0.011	5.0	5.01	99.9

*Average value; **mean ± SD of triplicate; % mean value ± SD of triplicate.

3.2 Concentrations of Heavy Metals in Soil Samples

The mean concentration of heavy metals in soil samples from each sampling area are shown in Table 3. The concentrations of cadmium in the highland zone (Kerugoya, Kimunye and Baricho areas) ranged from 0.0533-0.05700 mg/Kg. The mean concentrations of cadmium in the midland zone (Sagana, Kagio and Mururi areas) ranged from 0.09333-0.1133 mg/Kg. The mean concentrations of cadmium in the lowland zone (Wang'uru, Kiriko and Thiba areas) ranged from 0.0100-0.0800 mg/Kg. The mean concentrations of cadmium in all areas were below the 0.3 mg/Kg maximum tolerable limit for cadmium in soil established by WHO/FAO (2001). Cadmium is a non-essential heavy metal that is naturally present in all soils with background concentrations of 0.1-1.0 mg/Kg (Smolders and Mertens, 2013). Anthropogenic sources of cadmium in soils include phosphate fertilizers, sewage sludge and atmospheric deposition (Smolders and Mertens, 2013).

Table 3: The mean concentration of selected heavy metals in soil samples

Sampling Area	Mean concentration (mg/kg)			
	Cd	Pb	Cu	Cr
Kerugoya	0.05667±0.033	0.0570±0.0566	1.167±0.0667	0.9667±0.0881
Kimunye	0.05333±0.033	0.140±0.0416	1.5±0.115	1.2±0.0577
Baricho	0.05700±0.033	0.1533±0.0418	1.10±0.0577	0.7667±0.0801
Sagana	0.1133±0.0667	0.2100±0.0010	1.267±0.120	0.8333±0.115
Kagio	0.09333±0.145	0.1150±0.0122	0.8667±0.273	0.840±0.163
Mururi	0.100±0.100	0.3433±0.02962	1.667±0.176	1.333±0.040
Wang'uru	0.0567±0.0333	0.667±0.0367	1.833±0.0881	0.8±0.170
Kiriko	0.0100±0.100	0.29±0.04582	1.467±0.0333	0.0670±0.0600
Thiba	0.08±0.057	0.31±0.0568	1.9±0.0577	0.7833±0.060
Mean ± SE	0.06893±0.0667	0.206±0.0358	1.419±0.109	0.8433±0.092
RSD (%)	45.33	50.24	24.50	41.85

RSD, Relative standard deviation; SE, Standard Error.

The mean concentrations of lead in the highland, midland and lowland zones ranged from 0.0570-0.1530, 0.1150-0.3433 and 0.2900-0.6670 mg/Kg, respectively. The mean concentrations of lead in the three agro-ecological zones were below the 10 mg/Kg maximum tolerable limit for lead in soil established by WHO/FAO (2001). The global background concentrations of lead in soils is estimated to be 17 mg/Kg (Nriagu, 1978). The mean concentrations of lead in soils from the study area are therefore considerably lower than the mean concentrations in uncontaminated soils worldwide. This indicate that the amount of naturally occurring lead in the soils in very low. In addition, the soils in the study area are not contaminated with lead from anthropogenic sources such as sewage sludges, mining and smelting of lead, insecticides, lead-based paints, car batteries and leaded gasoline (Steinnes, 2013).

The mean concentrations of copper in the highland, midland and lowland zones ranged from 1.10-1.50, 0.8667-1.667 and 1.467-1.900 mg/Kg, respectively. The mean concentrations of copper in the three ecological zones were significantly lower than the 36 mg/Kg maximum tolerable limit for copper in soil established by WHO/FAO (2001). The mean concentrations of copper are also lower than the background concentrations of copper (2-50 mg/kg) in unpolluted soils (Oorts, 2013). This suggest that soils in the study area are generally not contaminated with copper from anthropogenic sources such as fertilisers, sewage sludges and pesticides (Oorts, 2013).

The mean concentrations of chromium in the highland, midland and lowland zones ranged from 0.7667-1.200, 0.8333-1.333 and 0.0670-0.8000 mg/Kg, respectively. The mean concentrations of chromium in the three ecological zones were significantly lower than the 65 mg/Kg maximum tolerable limit for chromium in soil established by WHO/FAO (2001). The concentrations of chromium in unpolluted soils are usually between 0.5 to 250 mg/kg with average values of between 40 and 70 mg/kg (Gonnelli and Renella. 2013). The concentrations of chromium in soils in the study area suggests that the soils are not polluted with chromium from anthropogenic sources. The differences in the concentrations of chromium in the study area can be attributed to geological variations. High concentrations of chromium are found in mafic and ultramafic rocks while low concentrations are found in sedimentary rocks (Gonnelli and Renella. 2013).

The spatial variations in the concentration of the heavy metals in soils can be attributed to the different types of soils in the study area. Soils in the highland and midland zones are the well-drained ando-humic nitisols, with humic andosols and humic nitisols, respectively (Jaetzold *et al*., 2010). Soils in the lowland zone are the pellic vertisols and verto-eutric nitisols, with mollic nitisols (Jaetzold *et al*., 2010).

3.3 Concentrations of Heavy Metals in Tomato Samples

The mean concentrations of cadmium, lead, copper and chromium in tomatoes obtained in the study area are shown in Table 4. The mean concentrations of cadmium in the highland zone ranged from 0.00533±0.008 to 0.00667±0.008 mg/Kg while concentrations in the midland zone ranged from 0.00367±0.003 to 0.00600±0.010 mg/Kg. The concentrations in the lowland zone ranged from 0.00400±0.005 to 0.00867±0.01 mg/Kg. The mean concentrations of cadmium in all areas were below the 0.05 mg/Kg maximum tolerable limit for cadmium in tomatoes established by WHO/FAO (2001). Although the concentrations of cadmium in tomatoes are significantly lower than the maximum allowable concentration, there is need for vigilance because cadmium is highly toxic, bioaccumulate in living organisms and has a long biological half-life (25–30 years) in living organisms (Sankhla & Kumar, 2019; Genchi *et al*., 2020). Thus, cadmium can have several chronic effects including testicular damage, renal and hepatic dysfunction, *osteomalacia*, cancers and damage to the adrenals and hemopoietic system (Genchi *et al*., 2020).

The mean concentrations of lead in the highland, midland and lowland zones ranged from 0.00133±0.003 to 0.00600±0.041, 0.00367±0.003 to 0.00633±0.01 and 0.00200±0.01 to 0.00667±0.02 mg/Kg, respectively. These concentrations are significantly lower than the 0.10 mg/Kg maximum tolerable limit for lead in tomatoes established by WHO/FAO (2001). Nevertheless, lead is highly toxic and bioaccumulate in tissues leading to adverse chronic effects including disorders of the central nervous system, neurological effects (e.g. developmental delays and nerve damage in adults) and cardiovascular diseases (Li *et al*., 2020).

The mean concentrations of copper in the highland, midland and lowland zones ranged from 0.0330±0.006 to 0.0467±0.003, 0.0367±0.003 to 0.0433±0.003 and 0.0533±0.003 to 0.0667±0.003 mg/Kg, respectively. These concentrations are significantly lower than the 5.0 mg/Kg maximum tolerable limit for copper in tomatoes established by WHO/FAO (2001). Copper is an essential micronutrient that is vital to the health of all living organisms. The metal is present in several enzymes and proteins that are crucial for maintaining a healthy central nervous system and prevention of neurological diseases such as aceruloplasminemia, amyotrophic lateral sclerosis, and Wilson disease (Desai and Kaler, 2008).

Table 4: Mean concentrations of heavy metals in tomato samples

Sampling Area	Metal concentration (mg/kg)			
	Cd	Pb	Cu	Cr
Kerugoya	0.00667±0.008	0.00153±0.003	0.0333±0.006	0.027±0.001
Kimunye	0.00600±0.020	0.00600±0.041	0.0467±0.003	0.0120±0.001
Baricho	0.00533±0.008	0.00133±0.003	0.033±0.006	0.027±0.035
Sagana	0.00600±0.010	0.00633±0.01	0.0367±0.003	0.0170±0.006
Kagio	0.00367±0.003	0.00400±0.005	0.0367±0.003	0.0110±0.006
Mururi	0.005±0.015	0.00367±0.003	0.0433±0.003	0.013±0.001
Wang'uru	0.00667±0.01	0.00667±0.02	0.0533±0.006	ND
Kiriko	0.00400±0.005	0.00200±0.01	0.0667±0.003	0.0140±0.000
Thiba	0.00867±0.01	0.00633±0.01	0.0533±0.003	0.0120±0.003
Mean ± SE	0.00578±0.0099	0.00420±0.011	0.0448±0.004	0.0186±0.006
RSD (%)	26.29	52.45	25.27	39.00

ND, Not detected; RSD, Relative standard deviation; SE, Standard Error.

The mean concentrations of chromium in the highland and midland zones ranged from 0.0120±0.001 to 0.027±0.035 and 0.0110±0.006 to 0.0170±0.006 mg/Kg, respectively. Chromium was not detected in samples obtained in Wang'uru area. The mean concentrations of chromium in samples obtained from Kiriko and Thiba areas were 0.0140±0.000 and 0.0120±0.003 mg/Kg, respectively. The concentrations of chromium are significantly lower than the maximum allowable limit of 2.3 mg/Kg set by the WHO/FAO (2001). Chromium exists in two oxidation states, the trivalent chromium (III) and the hexavalent chromium (VI), which is highly toxic (Genchi *et al*., 2021). Chromium (III) is essential for humans in trace amounts for metabolism of glucose, proteins and lipids (Genchi *et al*., 2021). However, in larger concentrations chromium have several adverse effects including cancers (Genchi *et al*., 2021).

3.4. Bioconcentration Factor

The results of this study show that BCF values differ significantly among the different sampling areas. The bioconcentration factors (BFCs) of the selected heavy metals are given in Table 5.0

Table 5.0 Bio concentration Factors (BCFs) of selected heavy metals

Tomato sampling Areas	Bioaccumulation Factor			
	Cd	Pb	Cu	Cr
Kerugoya	0.12	0.03	0.03	0.03
Kimunye	0.11	0.04	0.03	0.01
Baricho	0.09	0.009	0.03	0.03
Sagana	0.05	0.03	0.02	0.02
Kagio	0.04	0.03	0.04	0.01
Mururi	0.05	0.01	0.02	0.009
Wang'uru	0.12	0.009	0.03	*
Kiriko	0.4	0.007	0.05	0.2
Thiba	0.11	0.02	0.03	0.02

* Soil/Tomato ratio was not computed, one of the value is below the detection limit.

The bioaccumulation factor (BCF) for Cd was found to be highest at Kiriko (0.4 mg/Kg) and lowest in Sagana (0.04 mg/Kg). For Pb, the BCF was found to be maximum at Kimunye (0.04 mg/Kg) and minimum at Wanguru (0.007 mg/Kg). The highest BCF of Cu was noticed in Kiriko (0.05 mg/Kg) and the lowest at Sagana and Mururi (0.02 mg/Kg). The BCF value of Cr was observed to be highest at Kerugoya and Baricho (0.03 mg/Kg) and minimum at Mururi (0.009 mg/Kg). From the results, the bioaccumulation factor is lower than 1.0 in all the sampling areas, advocating for the lower accumulation of the selected heavy metals. Overall, variation in BCF values across the sampling areas was observed. This variation in the transfer factor of metals in different sampling areas is related to plants absorption capability, soil nutrient management and soil properties (Latif et al., 2018).

4.0 CONCLUSIONS

The concentrations of cadmium, lead, copper and chromium in soils and tomatoes obtained from the three ecological zones of Kirinyaga County were below the permissible limit set by WHO/FAO. In addition, the concentrations of the aforementioned heavy metals in soils were significantly lower than their global background concentrations in soils.

Availability of the Data

The data for the study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors assert no conflicts of interest.

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