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Assessment of Trace Metal Contaminants and Consumer Preference in Tomato Varieties Produced in Two Mining Communities of Nigeria



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ABSTRACT

Tomato varieties (*Solanum lycopersicum* L.) produced in areas prominent for mining activities contribute more deposits of metal contaminants. In turn, affects the quality and value of the products. Highlighting the level of metal contaminant in consumer's most preferred tomato variety is also necessary for health and well-being. This study specifically aimed to investigate, i) the variability between six metal contaminants in UTC, Yowlings, and Derica tomatoes; ii) we also explored the relationship between the metal contaminants and tomato quality, and lastly, we ascertained which socioeconomic factor specifically determined preference for a particular variety of the tomatoes. The metal contaminants examined and found present using ICP-OES were nickel (Ni), chromium (Cr), lead (Pb), arsenic (As), cadmium (Cd), and mercury (Hg). We found a good agreement between most of the analyte and the National Institute of Standards and Technology (NIST) Certified Reference Material 1573a (CRM 1573a) values. Although this study's recovery for the analyte was between 83.22% and 111.00%, we also found contrary to our prediction that Cr, Ni, and Cd concentrations were higher in Derica, UTC, and the Yowlings varieties during the rainy season. A two-way ANOVA between tomatoes and planting seasons was not statistically significant ($P > 0.05$) in contrast to the mixed model (GLMMs) analysis that indicated a significant ($P < 0.05$) relationship between lycopene concentration, size of tomatoes, and concentration of metals screened. We also found using a principle component analysis (PCA) and correlation matrix that the concentration of Pb in the tomato varieties was significantly related to the As level. Despite As and Cr concentrations being higher in the Derica tomato variety, most consumers preferred it. Derica tomato contained metal contaminants that could be harmful to human health. Therefore, there is need to monitor the production procedures involved prior to supply of the tomato product.

Tomato varieties (*Solanum lycopersicum* L.) produced in areas prominent for mining activities contribute more deposits of metal contaminants. In turn, it affects the quality and value of the product. Therefore, highlighting the level of metal contaminant in consumer's preferred tomato variety is also necessary for health and well-being. In many countries, there could be different varieties of vegetables or fruits (such as tomatoes) considered nutritious over another. The preference for a particular tomato product over another is usually strengthened and determined by its availability, taste, texture, shape, color, freshness, size, variety, and income (Adeoye et al., 2015; Ceylan & Alidou, 2021). Also, these mentioned factors could influence consumer purchasing behavior (Adeoye et al., 2015; Ceylan & Alidou, 2021).

Conversely, the choice of cultivar, storage, handling procedures, harvest time, and methods used in cultivation usually influence farmers' choice of a particular tomato fruit (Mulat et al., 2019).

Vegetables and fruits such as tomatoes are among the components of a healthy diet consumed in cooked or raw forms (Liang et al., 2019). Despite being a beneficial component of healthy diets, vegetables, and fruits could also get contaminated by metals (Mawari et al., 2022). Metals occur through natural or anthropogenic processes (Ali et al., 2019; Yan et al., 2020). They can accumulate in the environment as airborne, soil, and water pollutants (Ledin, 2000; Nişu et al., 2019; Rehman et al., 2021). As metals persist and bioaccumulate in the environment (Ali et al., 2019), they easily enter fruits and plant tissues by

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solubilizing through root exudates (Arif et al., 2016; Yan et al., 2020). Metals also make their way into plant tissues by getting absorbed through direct atmospheric deposition of metals on plant surfaces (Zhuang et al., 2009).

Another mechanism that contributes to the accumulation of metals is anthropogenic activities. For instance, the process whereby farmers use contaminated water or misuse chemicals, e.g., pesticides to control pests during tomato production (Ngowi et al., 2007; Mdegela et al., 2013; Ahmed et al., 2023). Another contributor to the accumulation of metals is the fertilizer used by farmers. Fertilizers are capable of improving the quality of fruits, but reports indicate that fertilizers containing urea (mostly used to enhance plant growth) could also bring about the accumulation of metals in soils and crops as well (Gimeno-García et al., 1996; Benson et al., 2014). As such, there should be concerns that a retailer and/or market buyers may not be aware that a succulent and edible tomato sold at the market could also be contaminated with higher levels of metals.

Thus, to disseminate information about the level of metals in preferred tomato fruits, and to also aid producers and researchers to employ methods that ensure the reduction of metals and to improve food safety during production (Mulat et al., 2019), this study became necessary. This study's objective was i) to investigate the variability between six metals in UTC, Yowlings, and Derica tomatoes; ii) to investigate if the relationship between metals and tomato quality is significant ii) and to investigate which socioeconomic factor determines the preference for a particular variety of tomato.

Features used to measure tomato quality were lycopene, weight (mass), volume, beta-carotene, and ascorbic acid levels. Although mass/volume were used as a measure for tomato size (assuming that heavier tomatoes should have more volume), demand, cost of production, storage, and disease resistance were used to measure farmers' motive for preference to cultivate a variety of tomatoes over another. Conversely, demand, cost, taste, size, availability, storage, and disease resistance were used as features to measure both retailers' and market buyers' motives for preference of tomatoes they usually sell/consume.

In Nigeria, the planting seasons for tomatoes usually occur between August and September of the rainy season. However, when irrigation is used for production, the best time for planting is during the dry season (Ugonna et al., 2015) of October to January (Daily Trust, 2022). Some of the planting sites for tomato production involve areas that were linked to mining in Nigeria, e.g., Tin deposits in Jos-Plateau, while Coal deposits in Enugu (Fatoye & Gideon, 2013; Azgaku & Osuala, 2015). The metals screened from tomatoes produced from these areas were mercury (Hg), lead (Pb), arsenic (As), nickel (Ni), cadmium (Cd), and chromium (Cr). These metals could be harmful to most living tissues (Chen et al., 2019; Rai et al., 2019; Heshmati et al., 2020) and could affect the morphology and size of tomato fruits produced (Jaramillo & Sánchez, 2013; Iqbal et al., 2018).

We expected that i) tomato fruits produced during the dry season should contain more concentration of metals due to less water content in them when compared with the ones produced during the rainy season, assuming that during the rainy season, most farms get watered by rain to dilute the metals (Shabalala et al., 2013). ii) We expected a negative relationship between nutritional quality and metals (Anagaw et al., 2019), assuming that ascorbic acid in tomato fruits usually gets reduced due to the accumulation of metals contaminants (such as Cd, Co, Ni, and Pb) (Hashem et al., 2017). Furthermore, we expected that most respondents would prefer fresh and larger-sized tomatoes regardless of price value, assuming fresh and large-sized tomatoes have higher market value, are attractive, healthier, and safely produced for consumption (Niño et al., 2019).

Material and methods

Study area. Jos-Plateau and Nsukka-Enugu communities were purposively selected for this study because these areas are active in the production and marketing of tomato fruits (Iwuchukwu et al., 2017; Onuwa & Folorunsho, 2022). The sites (communities) visited within Jos-Plateau for data collection were Kuru (9°44'N8°50'E), Lamingo (9°52'N8°54'E), and Rayfield (9°50'N8°54'E), while within Nsukka-Enugu, Edem (6°51'N7°20'E), Okpuje (7°1'N5°53'E), and Ibagwa-Ani (6°54'N7°20'E), respectively. Owing to the favorable climatic condition experienced in Jos-Plateau, crops grown include tomatoes like mainly the UTC and Derica varieties (Adegboye, 2012). Unlike the varieties of tomatoes produced in Jos-Plateau, the main tomato fruit produced in Nsukka-Enugu is Yowlings. Thus, we collected data from farmers, retailers, and market buyers. Data from farmers were collected on their farms (on-site) during the planting season in Jos and Nsukka, whereas data from retailers and market buyers were collected on-sight at Ogige market in Nsukka-Enugu using questionnaires. Ogige market is usually very active from the morning to evening hours of Tuesday down to the weekends; therefore, the three tomato varieties are usually found during these periods.

Sample size and administration of the questionnaires. We used Slovin's formula $n = N/(1 + Ne^2)$ to estimate the study sample size. Where N = Total population was ascertained from the Nigerian Population Commission (NPC, 2006), and e = Error tolerance or precision level was set at 5% (Henry-Unaeze & Ugwu, 2022). Thus, we calculated and found that Jos-Plateau and Nsukka-Enugu's sample size summed up to 399 and 400, respectively. Data collection involved two main approaches; first was a presurvey of tomato production sites (for 2 weeks) to familiarize with farmers on-site, and second was the collection of main data for analyses. Data about farming procedures adopted by each farmer were collected using a semistructured questionnaire. Fresh tomato fruits used to screen for the presence/level of metals were purchased from the farms of the interviewed farmers in Jos and Nsukka. On the other hand, data from retailers and market buyers were collected on-sight at Ogige-Market in Nsukka. The period used to collect data from participants commenced from August to early October (rainy season of the year 2022) and November to January of the subsequent year (dry season). All data from tomato farmers, retailers, and market buyers were collected weekly from 7 am to 2 pm when the respondents were active.

Data collection. The following study produced a total of 2000 questionnaires, respondents were interviewed orally through a simple random sampling method. However, most learned respondents preferred to fill in the required information themselves. Some general information needed on the questionnaire included respondents' age, marital status, gender, location, occupation, and level of education. Meanwhile, farmers, retailers, and consumers' responses to other questions on the questionnaire are found in Table 7 and the supplementary file of this study.

Morphological assessment of tomato fruits. Samples of Derica ($n = 80$), Yowling ($n = 80$), and UTC ($n = 80$) were purchased for this study, for a total of 240 tomatoes. Equal amounts of each tomato variety were selected to avoid introducing bias. The purchased tomatoes were weighed, and their volume was assessed one after the other at the field to determine the fruit mass and size (Mutschler et al., 1986). Weight was assessed using an AND® weighing balance (after correcting to zero). To assess the volume of the tomatoes, the values obtained for diameter and height measurement (using a NEOTECK® digital Vernier caliper) were used. Thus, the tomato volume was calculated by the formula enumerated by Mutschler et al. (1986) below.

$$\text{Volume} = (1/6) \times (\text{height}) \times (\text{diameter})^2$$

Reagents, solutions, and samples. All laboratory wares were rinsed with 10% (v/v) HNO₃ solution and then washed with high-purity water to remove metal contaminants. Afterward, the materials were dried under ambient temperature. The purchased solvents and reagents supplied from JOECHEM® chemical stores, Nsukka-Enugu, were of commercially available purity standard. The GZ Industrial Supplies® in Nigeria- Ikeja were employed to supply the deionized water which had a resistivity of 18 MΩ cm. More so, GZ Industrial Supplies® was contracted to prepare all standard and sample solutions used for this study. The Suprapur® high purity acid for trace analyses used for this study's sample dissolution had the following grades and brand company: 65% (m/m) HNO₃ and 30% (m/m) H₂O₂ (Merck, Germany). The mono-elemental high-purity solution grade 1 g L⁻¹ stock solutions for the six metals screened elements: nickel (Ni), chromium (Cr), lead (Pb), arsenic (As), cadmium (Cd), and mercury (Hg) were supplied by Merck (Darmstadt, Germany). The plasma torch argon was of greater purity at 99.99% (Iqbal et al., 2018).

Instrumentation. Acid digestion of tomatoes was conducted with a DK 6 series semiautomatic digestion unit (VELP Scientific®) fitted with an aluminum heating block that ensures high thermal homogeneity heating up to 2450 Hz, with an energy output of 900 W. The temperature level of the block is usually regulated by a microprocessor that is extremely stable, homogeneous, and precise at a ± 0.5°C of all selectable thermal condition that guarantee high precision and repeatability and allows digestion of up to six samples with 240 mL test tubes.

The dry ashing of this study was conducted on a muffle furnace (Bionics® Scientific) that heats samples up to 800°C to 1800° and has a ramp/dwell control. Afterward, a Varian Vista Pro with a charge-coupled device (CCD) simultaneous ICP-OES optical emission spectrometer. The Sturman-Masters Spray Chamber, Water-Cooled (Jacketed), for Varian 700-ES Series and the MEINHARD® V-Groove OneTouch Nebulizer were used (Santos et al., 2017). The metal concentration was measured under the manufacturers' recommendation that suggest a power maintained at 1.3 kW, plasma gas flow = 15.0 L min⁻¹, auxiliary gas flow = 1.5 L min⁻¹, and nebulizer gas flow = 0.7 L min⁻¹. For the ICP OES analysis, the emission lines were chosen in line with previous interference studies (Santos et al., 2017). The following emission lines were used: Cd^I 228.802, Cr^{II} 267.716, Ni^{II} 227.021, Pb^I 217.000, As^I 197.000, Hg^{II} 254.960.

Digestion procedure. The tomatoes were transported to the herbarium unit of the Department of Plant Science and Biotechnology, the University of Nigeria-Nsukka for identification by Mr. Felix Nwafor. The tomatoes were rinsed in distilled water, cut into smaller pieces, and then washed again before drying at 65°C for 3 days using a laboratory oven (Gallenkamp®) at 45°C (Bressy et al., 2013; Li et al., 2017). Afterward, about 300 mg from each dried tomato were microwaved with 1 mL of 30% (mm⁻¹) hydrogen peroxide and 7.0 mL of nitric acid added to each sample microwaved in a closed system (Sineo®). Subsequently, we cooled the samples and further diluted the sample with water to reach a final volume of 15.0 mL. Then, the sample blanks were prepared for each sample batch, and the experiment was conducted in triplicate using the ICP-OES (Bressy et al., 2013; Gebeyehu & Bayissa, 2020). Digestion of the beta-carotene involved washing the sample with 2 mL of a methanol/dichloromethane mixture (45:55 v/v). Then, evaporated to dryness, the residue was then redissolved in a mixture of acetonitrile/dichloromethane (50:50 v/v) (Baranska et al., 2006). Finally, the separation was conducted using a Biobase® HPLC (Model: 1100), while the concentrations of Hg, Ni, As, Cd, Pb, and Cr contained in the digested tomato fruits were determined after calibrating the instrument by the blank. The calibration involved evaluating based on corresponding correlation coefficients (r²) of the calibration curves under the HORIBA® ICP-OES spectrometer and the metal values reported in dry weight of µg g⁻¹.

Determination of the acidity and residual carbon of the digests: Acid-base titrations of the digests were also conducted to investigate the final acidity of the samples. Titration was conducted with the standard solution of sodium hydroxide (0.0997 mol/L) and phenolphthalein (1.0% m/v in ethanol). More so, standard solutions for the calibration curves were fully prepared at the same level of acid concentration for each digestion procedure. In determining the residual carbon content to finally quantify it using ICP-OES at the value of 193.027 nm, the digested solutions were sonicated using a Fisher Scientific® ultrasonic bath, this is usually done to remove any volatile carbon compound that may have been existing (Bressy et al., 2013). The standard solutions for the calibration curves of the residual carbon were then prepared using citric acid (Gouveia et al., 2001).

Validating the study: The limits of detection (LOD) and accuracy for this study were conducted using the National Institute of Standards and Technology (NIST). Specifically, the tomato leaf Certified Reference Material 1573a (CRM 1573a) from NIST of the United States of America was used. Therefore, our precision was measured in terms of the percentage of the variation coefficient. The limits of detection (LOD) and quantification (LOQ) of each of the analyte were calculated as the analyte concentration levels which corresponded to three and ten times, while the standard deviation of ten independent measurements of the blank, were divided by the slope of the calibration curve, after the measurements of emission intensities by ICP-OES were conducted (Bressy et al., 2013; Santos et al., 2017).

Analyses of lycopene. Lycopene is a carotenoid compound that signifies the red pigment of tomatoes (Dorais et al., 2001), although there are several methods used in extracting this pigment (e.g., Ravelo-Pérez et al., 2008; Fish, 2012; Hashem et al., 2018). The current study adopted a fast and simple method (i.e., high-performance liquid chromatography (HPLC)) outlined by Craft (2001) and Cucu et al. (2012) using a Biobase® HPLC (Model: 1100). The system was fitted with a photodiode array detector (PDA). Separation was conducted on a 3 m 250 mm × 4.6 mm C₃₀ column (Sykam® S 3355) at 25 °C before the carotenoids were absorbed by using the using a ternary gradient elution on a C₃₀ reversed-phase column (Lee et al., 2001). The concentration of stock lycopene solution was finally calculated in hexane at 472 nm (Craft, 2001).

Analyses of beta-carotene. Beta-carotene (pro-vitamin A carotene) was quantified using the method of AOAC (1990). Five grams of the already digested tomato solution (stated above) was measured into a conical flask, before mixing with 12.5 mL of 0.5 N ethanolic KOH. The mixture was refluxed using an ESCO® orbital shaker before the addition of 37.5 mL of ether solution. The solution was filtered using a HAVER® EML 200 digital plus gradation machine. The filtrate was then added to sodium sulfate and evaporated to dryness using a Bionics® electric hot plate. The sample was then recovered using 10 mL of chloroform, and the absorbance of the resulting solution was read at 520 nm and calculated under an ultraviolet-visible spectrophotometer (Youngsworth®) using the formula below (Adebisi et al., 2014).

$$\text{Beta-carotene } (\mu\text{g}/100 \text{ g}) = \frac{\text{Absorbance of sample} \times \text{Dilution Factor}}{\text{Weight of sample (g)}}$$

Analyses of ascorbic acid. Ascorbic acid was assessed using the method of Riemschneider et al. (1976). This involved adding 5 g of the digested tomato mixture into a conical flask, followed by adding 45 mL of distilled water, then mixing (using an orbital shaker). The resultant solution was filtered and mixed with 2 mL of indophenols, stirred before transferring the mixtures into a burette, then titrated against the indophenols solution. The expected color change from a deep blue to deep brown-light yellow indicates the endpoint (Adebisi et al., 2014). Finally, the concentrations of ascorbic acid were measured using the formula below: C₁V₁ = C₂V₂.

$$C_1 = \text{concentration of indophenols}$$

V_1 = volume of indophenols = 2 mL

C_2 = concentration of Ascorbic acid

V_2 = volume of standard ascorbic acid titrated against 2 mL of indophenols

Statistical design and data analyses. Data were analyzed in R version 3.2.5 (R Development Core Team 2018). A descriptive statistical analysis was used to sum up the mean, minimum and maximum values of the metals of UTC, Derica and Yowlings tomato fruits. To investigate the variability between six metals in UTC, Yowlings, and Derica tomatoes, a two-way analysis of variance (using the Tukey test) was used to explore a model consisting of the metal concentration set as the dependent variable, while the explanatory axis consisted of seasons and tomato varieties. In addition to the models were the interactions that consisted of the tomato varieties and seasons. Season added as a covariate was to explore if the concentration of the metals found in the tomatoes was influenced by the period of planting (assuming the concentration of metals would vary by season due to the use of polluted water for irrigation during the dry season). Significant factors were then subjected to a multiple-pairwise comparison of means of the metals screened from the tomato varieties using the Tukey test.

Secondly, to explore the relationship between metals and tomato quality, Pearson's correlation coefficient matrix and principal component analysis (PCA) were conducted to explore how the metals correlate with each other in the different varieties of tomatoes. Third, to test if the concentration of metals relates to the quality of tomato fruits, lycopene, beta-carotene, and ascorbic acid, the values measured for the mass and volume (i.e., mass/volume) of the tomatoes were used as the dependent variables. The used values of mass over volume became necessary because heavier tomatoes should occupy more volume and size. On the other hand, the concentration of metals was set on the explanatory axis throughout. Still, on the explanatory axis, there were random effects that consisted of metals and tomato IDs hierarchically set in a nested form (i.e., 1|metals ID/Tomatoes ID). The relationship between tomato quality and metals was explored in *lmer* to enable the fitting of linear mixed-effects models (*lmer*) with Gaussian identity function fixed into the package *lme4*. In mixed effect models (MEM), the summary table was used to deduce the level of significance ($P < 0.05$).

Results

Level of detection and metals concentration. This study found that the concentration of metals from Derica occurred in the following ascending order: Pb > As > Hg > Ni > Cd > Cr. From Yowlings, the concentration of metals occurred in the following order: Hg > As > Pb > Ni > Cr > Cd. For UTC, the order is Pb > As > Hg > Ni > Cr > Cd, respectively. The results also indicated that the LODs values for the metals screened in $\mu\text{g g}^{-1}$ were as follows: Cd (0.009), Cr (0.064), Hg (0.128), Ni (0.025), As (0.03), Pb (0.13). The precision and accuracies of the determinations were assessed by the analysis of tomato leaf Certified Reference Material (CRM 1573a). This study also found a good agreement between most of the metals and the National Institute of Standards and Technology (NIST) Certified Reference Material 1573a (CRM 1573a) values

Table 1

Analysis of tomato leaf Certified Reference Material (CRM 1573a) by and ICP OES ($\mu\text{g g}^{-1}$ at 95% of confidence level)

Metal	Reference value	Determined	% Recovery
Hg	0.034 ± 0.02	0.033 ± 0.03	83.22
Ni	1.59 ± 0.07	1.61 ± 0.01	111.00
Cd	1.52 ± 0.04	1.49 ± 0.02	91.02
Cr	1.99 ± 0.06	1.92 ± 0.40	104.07
Pb	0.67 ± 0.01	0.74 ± 0.02	92.10
As	0.27 ± 0.05	0.25 ± 0.10	88.14

(Table 1). Basically, the determined and reference values for Hg were (0.033 ± 0.03 and 0.034 ± 0.02), Ni (1.61 ± 0.01 and 1.59 ± 0.07), Cd (1.49 ± 0.02 and 1.52 ± 0.04), Cr (1.92 ± 0.40 and 1.99 ± 0.06), As (0.25 ± 0.10 and 0.27 ± 0.05), and the determined value for Pb was (0.74 ± 0.02), while the recovery values for the analyte were between 83.22% and 111.00%. (Table 1).

Variation in metal concentration. Seasonality in concentration levels of metals was not statistically different between tomato varieties ($P > 0.05$) and did not vary by lycopene and vitamins concentration levels. Although the mean concentration levels of the tomato varieties were not statistically correlated, there were still some mean differences. For instance, UTC variety of tomatoes had a higher concentration of Ni during the rainy season, while Hg was the least. During the dry season, Ni was still the highest in concentration in contrast to Pb which was the least (Table 2). However, Cr concentration level in Derica was much during the rainy season, while Pb was the least. During the dry season, As had the highest concentration level in Derica, while Cd had the least. Yowlings had Cd as the highest occurring metal during the rainy season, while As was the least. During the dry season, Cr occurred as the highest and Hg the least. Based on nutritional content, more beta-carotene and lycopene were observed in Yowlings variety of tomato, while UTC had more beta-carotene. Also, the mean size of the tomato (mass/volume) was higher in Derica when compared to UTC and Yowlings (Table 2).

Factorial analyses for metal concentration and tomato varieties. The two-way ANOVA between tomato varieties and planting seasons was not statistically significant ($P > 0.05$) (Table 3). Thus, the pairwise-comparison of the concentration means of metals of the tomatoes using Tukey contrast was not conducted.

Correlation coefficient matrix for metal concentration. The correlation coefficient matrix of the metals of the tomato fruits to ascertain the level of metal relatedness indicated that Pb and As were the only metals that were significantly ($P < 0.05$) related (Table 4).

Table 2

Descriptive analysis for the concentration of nutrients and analyte screened from UTC, Derica, Yowlings tomatoes during the rainy season and dry season ($n = 240$, dry season = 120, rainy season = 120)

Variety	Metal	Rain ($\mu\text{g g}^{-1}$)	Dry ($\mu\text{g g}^{-1}$)
UTC	Hg	0.06 ± 0.10	0.93 ± 0.03
	Pb	0.12 ± 0.00	0.18 ± 0.11
	As	0.18 ± 0.50	0.21 ± 0.13
	Ni	10.54 ± 0.01	5.32 ± 0.05
	Cd	5.89 ± 0.03	2.96 ± 0.02
	Cr	0.10 ± 0.00	2.68 ± 0.02
	Beta-carotene	956.1 ± 0.10	935.9 ± 0.00
	Ascorbic acid	16.58 ± 0.40	16.96 ± 0.10
	Lycopene	12.25 ± 0.11	13.13 ± 0.20
	Mass/volume	0.46 ± 0.50	0.43 ± 0.03
Derica	Hg	1.63 ± 0.50	3.74 ± 0.11
	Pb	0.15 ± 0.01	0.17 ± 0.05
	As	0.19 ± 0.01	7.42 ± 0.14
	Ni	4.87 ± 0.03	0.23 ± 0.09
	Cd	2.30 ± 0.06	0.06 ± 0.00
	Cr	7.33 ± 0.00	3.94 ± 0.50
	Beta-carotene	898.8 ± 0.10	976.8 ± 0.20
	Ascorbic acid	15.48 ± 0.04	14.85 ± 0.11
	Lycopene	12.73 ± 0.30	12.07 ± 0.30
	Mass/volume	3.15 ± 0.40	0.52 ± 0.07
Yowlings	Hg	0.32 ± 0.00	0.12 ± 0.01
	Pb	0.28 ± 0.01	0.46 ± 0.16
	As	0.23 ± 0.05	0.53 ± 0.04
	Ni	3.61 ± 0.03	0.21 ± 0.15
	Cd	17.46 ± 0.01	0.10 ± 0.00
	Cr	7.14 ± 0.12	6.79 ± 0.00
	Beta-carotene	973.01 ± 0.00	977.40 ± 0.01
	Ascorbic acid	15.38 ± 0.12	15.11 ± 0.09
	Lycopene	12.80 ± 0.40	13.24 ± 0.11
	Mass/volume	0.78 ± 0.00	0.48 ± 0.02

Table 3Two-way ANOVA between the concentration of analyte in relation to the tomato varieties and planting seasons ($n = 240$; Yowlings = 80, Derica = 80, UTC = 80)

	Df	Sum Sq	Mean Sq	F	P
Seasons	1	164.00	164.22	2.39	0.12
Tomato variety	2	39.00	19.25	0.280	0.75
Seasons $\times$ Tomato variety	2	98.00	49.04	0.713	0.49

Also, the results from the PCA analyses indicated that both Pb (0.95) and As (0.94) contributed more to the level of metals in the first PC at 0.30% variance, while the second PC indicated that only Cd contributed (0.81) at 0.30% variance (Table 5).

Mixed model analyses for tomato size, vitamins, and concentration of metals. The mixed model analyses indicated that the vitamins measured (beta-carotene and ascorbic acid) did not relate to the concentration level of the metals ($P > 0.05$). However, the reciprocal index of weight and volume (size) of the tomatoes related positively to the concentration of the metals (0.10), unlike the concentration of lycopene which related negatively (-0.04) (Table 6).

Responses from respondents. Of the 2000 questionnaires, 615 (33%) respondents were farmer's, 473(25%) retailers', 788(44%) market buyers, while 125 were the left over. The data from the questionnaires indicated that Derica was the farmers (35%), retailers (46%), and market buyers' (40%) choice of tomato. Most farmers cited the main preference for Derica tomato was its market cost value (37%), and high demand (33%) for the tomato variety. Retailers cited demand (21%), storage, and disease resistance (37%). Meanwhile, the size of the tomato (33%), storage, and disease resistance (28%) were cited by market buyers (Table 7). Most of the farmers produced tomatoes through the conventional mode of farming (72%), preferred ponds and dams (48%) as their water resource point. Most farmers cited the use of agro-chemicals often (56%). In using agro-chemicals, most farmers do not have knowledge about the presence of metals in them (72%). However, most farmers came to admit having knowledge about the health implications of metals (55%) on child birth (39%). This knowledge was acquired not in school but in organized workshops (76%). Despite the knowledge acquired, farmers do not have much information about procedures aimed at safer production of tomato fruits (67%), but those farmers with the knowledge suggested that contaminated soils (41%) and industrialized areas (38%) should be avoided during tomato production to prevent metal contamination (Table 7). On the other hand, most retailers do not have knowledge about metals (67%) when compared with most market buyers (65%). Retailers with knowledge about metals also acquired it from organized workshops (71%), in contrast, market buyers acquired the knowledge from schools (39%) (Table 7).

Discussion

Despite that tomato has a high nutritional value that makes it rank among the most consumed vegetables (Trebolazabala et al., 2017), tomato could also get contaminated by metals arising from contaminated soils from contaminated sites. The risk of metal contamination

Table 4

Correlation coefficient matrix of analyte in the tomato fruit

Metals	As	Cd	Cr	Hg	Ni	Pb
As		0.85	0.74	0.94	0.74	0.001
Cd	0.85		0.24	0.49	0.39	0.39
Cr	0.74	0.24		0.53	0.40	0.68
Hg	0.94	0.49	0.53		0.58	0.59
Ni	0.74	0.39	0.40	0.58		0.78
Pb	0.001	0.50	0.68	0.59	0.78	

Pearson correlation at $p < 0.05$.**Table 5**

Loadings of PCA for analyte screened from the three variety of tomato fruits

	P1	P2
As	0.94	0.03
Cd	- 0.04	0.81
Cr	- 0.11	- 0.72
Hg	- 0.09	- 0.04
Ni	- 0.08	- 0.05
Pb	0.95	- 0.08
%Variance	0.30	0.20

Pearson correlation was used to compute between original variables and principle components.

Table 6

Concentration of metals in relation to beta-carotene and ascorbic acid, lycopene and mass/volume of tomatoes screened

Variable	Estimate	SE	t	P
Intercept	0.00	0.00	0.00	0.00
Mass/volume	0.10	0.05	2.09	0.04
Beta-carotene	3.33	2.05	1.63	0.11
Ascorbic acid	0.03	0.03	1.02	0.31
Lycopene	-0.04	0.02	-2.60	0.01

of the environment is rising rapidly, accumulating in not only soils but also in plant uptake (Tóth et al., 2016).

This study found a good agreement between most of the analyte and the reference values of the National Institute of Standards and Technology (NIST) Certified Reference Material 1573a (CRM 1573a) values (Table 1). However, contrary to the prediction that the overall mean metal concentration level in the three varieties of tomatoes screened should be low during the rainy season (due to the high dilution effect), we found that some metals such as Cr, Ni, and Cd concentration level were higher in Derica, UTC, and Yowlings during the rainy season (Table 2). Normally, metals are unique and possess features (e.g., physical and chemical properties) that give them specific toxicological mechanisms of action (Tchounwou et al., 2012). A metal such as Cd is a nonessential metal element for plants, and it is usually present in soils (Panos et al., 2013). Cadmium accumulation has been linked to nutrient transporters (Huang et al., 2020) that are prominent in most edible parts of plants or seeds of crops (Touceda-González et al., 2015). Chromium is known to accumulate less in tomatoes, but its toxicity depended on the valence state and carriers of other essential ions (e.g., sulfate or iron) in plants (Karthika et al., 2017).

Table 7

Information about farmers, retailers and market buyers' choice for the varieties of tomatoes screened for metals

	Farmers	Retailers	Market buyers
Variable	<i>n</i> = 615 (33%)	<i>n</i> = 473 (25%)	<i>n</i> = 788 (42%)
Farmers choice (i.e. most cultivated) and retailers (i.e. preferred to sell)/market buyers (preferred to purchase) choice			
UTC	202(33)	99(21)	279(35)
Derica	214(35)	219(46)	316(40)
Yowlings	199(32)	155(33)	193(24)
Farmers reason for cultivating the preferred tomato variant (most preferred is UTC)			
Demand	206(33)		
Maturity	129(21)		
Cost	229(37)		
Storage and disease resistance	51(8)		
Retailers reason for preferred variant (most preferred Derica)			
Demand		101(21)	
Taste		64(13)	
Cost		79(17)	
Storage and disease resistance		174(37)	
Availability		55(12)	
Market buyers reason for preferred (most preferred Derica)			
Taste			135(17)
Cost			14(2)
Size			262(33)
Availability			155(20)
Storage and disease resistance			222(28)
Farmers method of tomato production			
Organic	173(28)		
Conventional	442(72)		
Farmers source of water			
Ponds and dams	296(48)		
Wells and boreholes	109(18)		
Rain	201(33)		
Pipe	9(1)		
Number of times farmers make use agro-chemicals			
Yes, often	344(56)		
Yes, rarely	204(33)		
No	67(11)		
Farmers knowledge about toxic metals in agro-chemicals			
Yes	171(23)		
No	444(72)		
Knowledge about the health implication of toxic metals			
Yes	340(55)	181(38)	511(65)
No	275(45)	292(62)	277(45)
Choose one major health implication of potentially toxic metals			
Cancer	32(12)	19(10)	89(17)
Birth defect	104(39)	33(18)	92(18)
Poisoning	44(16)	15(8)	241(47)
None	92(33)	114(63)	89(17)
Knowledge about toxic metals			
Yes	393(64)	158(33)	512(65)
No	222(36)	315(67)	276(35)
Where was the knowledge about toxic metals acquired?			
School	10(3)	2(1)	202(39)
Books	33(8)	0(0)	108(21)
Television	7(2)	17(11)	33(6)
Workshops	298(76)	112(71)	79(15)
Others	45(11)	27(17)	90(18)
Farmers knowledge about procedures to ensure safe production of tomato fruit against toxic metals?			
Yes	201(33)		
No	414(67)		
Farmers' suggestion for reducing accumulation of toxic metals in tomatoes			
Avoiding contaminated water	41(20)		
Contaminated soil	83(41)		
Industrialized areas	77(38)		

A high level of Cr also interferes with several metabolic processes, obstructing seed germination or early seedling growth (Nath et al., 2005). The presence of Ni may be because vegetables represent a major source of Ni exposure (Roccotiello et al., 2022), and Ni in vegetables increased as a function of the concentration of the metal in the soil (Correia et al., 2018). As such, the mobility of Ni makes it convenient to be redistributed through phloem and fruits of the vegetables (Page & Feller, 2005).

We found that As had a stronger significant relationship with Pb (increase with increasing concentration of the other) (Tables 4 and 5; Fig. 1). Arsenic has the ability to be slowly leached through soils (Hood, 2006), and its uptake is often high enough to cause phytotoxicity in sensitive plants (Ross & Crowe, 1976). The uptake and accumulation of As in tomato fruits are usually enhanced by changes in pH, and as such, a high concentration of As usually leads to a reduction in plant pigments. Polluted plants appear to be in a poorer state, mak-

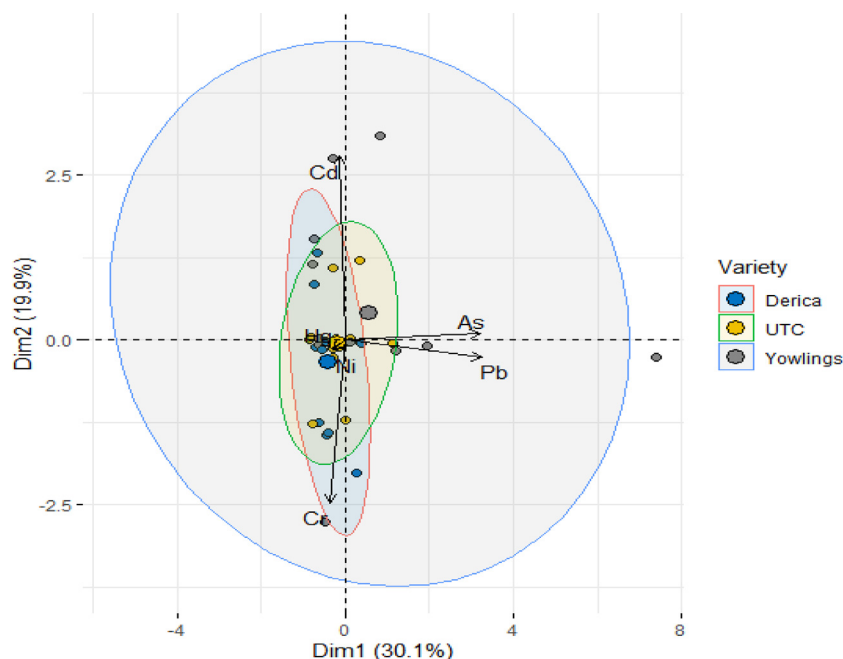


Figure 1. Principal component analyses (PCAs) indicating the score plot for the first and second components. The large oval grey shape indicates the distribution of metals in 'Yowlings'; the small yellow and blue oval shapes are distributions of the metals in 'UTC' and 'Derica'. Usually, the arrow length on a PCA indicates the approximation of variance of the variables, while angles approximate the correlations. The points that are closer to each other indicate they have similar scores on the PCA components. Although Yowlings variety of tomatoes overlapped with the other varieties, the biplot indicates that As and Pb are strongly, positively, correlated to each other when compared with Cr, Cd, Ni, Hg. ($n = 240$).

ing them unable to adapt or adjust to high As concentrations (Miteva, 2002). Arsenic leads to impairment of cellular respiration by interfering with oxidative phosphorylation that results from the inhibition of various mitochondrial enzymes (Hong et al., 2014). The correlation between As and Pb could be that these two metals are historically used in plant pest control (as calcium arsenate, lead arsenate, copper arsenate) (McBride, 2013) and could suggest that their concentration is influenced by their interactions.

The variety of tomatoes also determines the nutrient concentration and size of the tomato product. Although this study found more concentration of lycopene and beta-carotene in Yowlings tomatoes, while ascorbic acid in UTC; the relationship between lycopene and the metals was negative (Table 6). A previous study has suggested metals can reduce ascorbic acid and lycopene levels in tomatoes (Hashem et al., 2017). Lycopene is a pigment primarily responsible for deep-red coloration of tomato fruits and their products. It is significant due to its biological and physicochemical properties that make it a natural antioxidant. We also suggest that the ability of Yowlings to accumulate more of lycopene and vitamins could be due to the variety of the tomato, the cultivation techniques, the locality and probably the sampling period (Hernandez-Suarez et al., 2007).

This study also found that most farmers, retailers, and market buyers preferred the Derica tomato (Table 7). The farmers majorly cited the tomato market cost value and high demand for Derica variety as reasons for their preference. The preference for Derica due to high demand as a result of scarcity is usually associated with a rise in the price (Van Herpen et al., 2014), thus, that could have a substantial effect on consumer food choices, nutrition, and health (Andreyeva et al., 2010). Also, farmers would want to produce the Derica variety for profit gain, which might also lead to poorer methods of preventing higher concentration levels of metals. For instance, some farmers could use excessive fertilizers to promote maturity.

The retailers cited demand, storage, and disease resistance, while the size of Derica tomato, storage, and also disease resistance were cited as the reason for the market buyers preferring Derica. In line with

a previous study, the demand for a particular tomato variety was among the attributes that usually determined consumer preference (Adegbola et al., 2018). This study specifically aimed to investigate the variability between six metals in UTC, Yowlings, Derica tomatoes; to investigate if the relationship between metals and tomato quality is significant and to investigate which socioeconomic factor determines the preference for a particular variety of tomatoes. We found that the six metals were positive in the three tomato fruits, and the mean concentration of Cd was the overall highest among the six metals screened. The high concentration level of Cd was observed more in Yowlings, As and Cr in Derica, while Ni in the UTC variety.

The high concentration of metals and their significant relationship (e.g., Pb and As) witnessed in this study could be the result that the responding farmers usually make use of the conventional mode of farming tomatoes and besides, most farmers cited ponds and dams as their water resource points. This study found that most farmers cited the use of agro-chemicals often and do not have much basic knowledge about the presence of metals in chemicals. Despite this, most farmers came to admit having knowledge about the health implication of metals to child birth. This knowledge was acquired by the farmers through organized workshops. But in spite of this knowledge acquired, farmers do not have much information about procedures aimed at safely producing tomato fruits; however, most farmers with the knowledge suggested that contaminated soils and industrialized areas should be avoided during tomato production to prevent metal contamination. On the other hand, most market buyers cited their knowledge of metals acquired from schools.

Previously, it was suggested by the report of food and drug administration on total diet, that As, Pb, or Hg in tomatoes were not found in detectable amount (USFDA, 2020). However, the present study confirmed their presence. The presence of these metals in these tomato varieties might be due to the mode of farming and the use of chemicals. Or the areas or regions where the tomato fruits were produced could have naturally contributed to the rise in levels of the metals. For instance, Jos-Plateau produces Derica and UTC tomatoes, how-

ever, the state is known as the center for tin mining in Nigeria. More so, some studies indicated that Pb, As, and Hg found in tomatoes from mining site of Jos were higher than the Food and Agriculture Organization/World Health Organization (FAO/WHO) permissible limits (Joseph et al., 2016; Kolawole et al., 2022). Enugu, on the other hand, is known for coal mining in Nigeria (Omotehinse & Ako, 2019). As such, the metals found in Yowlings might have come from the mining activities because Nsukka is located in Enugu. Nevertheless, to assure a safely and conscious exploitation of the three varieties of tomatoes, we recommend continuity through monitoring studies. Future studies could compare whether these metals might be found in other areas where mining activities are less observed.

Contributor

The study was conceived and designed by DCU, FAA, AVE; the study was performed by DCU, FAA, AVE, CCA, CBO, ANA; the laboratory analyses by MPO, FAA, DCU, AVE, ANA; statistical design and data analyses by FAA; writing, editing and approval of manuscript for publication DCU, FAA, AVE, CCA, CBO, MPO, ANA.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jfp.2023.100166>.

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