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Batch-to-Batch Variation in Heavy Metal Concentrations in Commercial Sachet Tomato Paste Sold in Awka, Anambra State, Nigeria

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ABSTRACT

Heavy metals are major pollutants in many vegetables, and tomato and tomato products are not exempt. This study determined heavy metals in different batches of three tomato brands and compared concentrations across batches to identify the highest and lowest. Triplicate analyses of fourteen batches of three brands of sachet tomato pastes, sold in Awka, were analyzed for the following six heavy metals: Lead (Pb), Cadmium (Cd), Chromium (Cr), Copper (Cu), Zinc (Zn), and Manganese (Mn), using an Atomic Absorption Spectrophotometer (AAS). The mean and standard deviation (using Excel software), analysis of variance (ANOVA) with Tukey HSD, and principal component analysis (PCA) (using R software) were used to determine these heavy metals in the different batches of the tomato brands and the possible sources of this metal contamination. The results showed that the metals were present in these batches to varying degrees, likely due to contamination from soil chemistry, anthropogenic inputs, machinery/grinding equipment, and other factors. Sachet tomato batches from Brand A recorded the highest Mn concentration, while Cr generally showed the lowest concentration. Of the six elements evaluated, Mn consistently exhibited the highest absolute concentration across all batches (up to 5.298 ± 0.003 mg/kg). Crucially, the peak levels of toxic public health contaminants, Pb (0.089 ± 0.004 mg/kg) and Cd (0.067 ± 0.003 mg/kg), remained safely below the statutory maximum levels established by the joint FAO/WHO (Codex 193-1995), while Cr (0.072 ± 0.002 mg/kg) also remained safely below the permissible limit established by USDA (CH2025-0202). These findings confirm that while significant marketplace variations exist between individual product batches, the evaluated consumer brands are entirely non-toxic and safe for human consumption.

Keywords: Batches, Brands, Heavy metals, Principal component analysis, Sachet tomato paste

1.0. Introduction

The scientific name of Tomato is *Solanum lycopersicum* or lycopersicum *esculentum* (Khayat & Namvaran, 2013). World tomato production is approximately one hundred and thirty million tonnes (González et al., 2011). Most global tomato consumption is not as fresh tomatoes but rather in tomato paste form. This form is, in turn, the chief ingredient in other products like sauces, juices, and ketchups (Tornberg, 2017). Tomatoes, as well as tomato products, are rich in antioxidant compounds like carotenoids (especially lycopene), phenolic compounds, and ascorbic acid. Regular consumption of tomatoes and tomato products has been associated with reduced risk of contracting different kinds of cancer as well as cardiovascular diseases. The antioxidants in tomatoes are attributed with this positive influence (Borguini et al., 2009). More current hypotheses identify the benefits of tomatoes; hence, studies on the tomato product's role in health, as well as reduction in disease risk, go beyond the antioxidant role to comprise other mechanisms of protection such as anti-inflammatory and antithrombotic functions (Burton-Freeman & Reimers, 2011)

However, despite the many benefits of tomatoes and tomato products, heavy metal contamination in these foods has become a concern for tomato consumption. According to Okpaegbe et al. (2026), pollution of vegetables by heavy metals cannot be underrated, as they (the vegetables) are vital human dietary components (Okpaegbe et al., 2026). Several factors affect metal presence in vegetables, mainly crop species and their metabolism, initial soil pollutant concentration, organic matter availability, pH, and the presence of other molecules and ions (Romero-Estévez et al., 2020). These toxic heavy metals are considered problematic globally because they are non-biodegradable and can accumulate in the tissues of living organisms throughout the food chain (Ahmed et al., 2023). Poisoning by heavy metals results in attacks on the respiratory and gastrointestinal tracts, endocrine complications, and damage to the liver and kidneys, among others (Oladapo et al., 2023). For instance, Pb toxicity negatively affects brain development in children and causes reproductive issues in adults; Cd exposure can lead to lung and kidney damage; Cu exposure includes vomiting, abdominal pain, nausea, and liver damage (Tabassam et al., 2023), and so on.

In view of this, this work was carried out to analyze the presence and impact of heavy metals in different batches of 3 tomato brands sold in Awka and to compare which batches/brands are more contaminated by these heavy metals.

2.0. Materials and Methods

2.1. Study area, Sample collection, preparation and heavy metals analysis

Awka town is situated in the eastern part of Anambra State, in South-East Nigeria (Ezenwaji et al., 2017), and it's located between longitudes $7^0.04^1$E and $7^0.09^1$E and latitudes $6^0.11^1$ N and $6^0.15^1$N (Ezenwaji et al., 2017). We purchased 14 batches of 3 tomato paste brands in Awka city and took them to the lab for analysis. Brands A, B and C had 5, 4 and 5 batches respectively, with batch numbers as follows: 322A-2, 260B-5, 327A-2, 814A-2 and 212B (for brand A); 2025348-6, 2025349-3, 2025349-7 and 242-7 (for brand B); 231033, 2110B6, 1111B3, 1507B6 and 1211A6 (for brand C).

Heavy metal analysis of the individual batches was conducted using a GBC Xplora Atomic Absorption Spectrophotometer according to the APHA 1995 (American

Public Health Association) method. Tomato paste samples (2 g each) were weighed separately using a weighing balance and transferred into a 50 mL conical flask. Aqua regia (65 mL nitric acid, 5 mL sulphuric acid, and 2 mL perchloric acid) was prepared, 20 mL was added to each conical flask, and the mixture was boiled on a hot plate for 10 minutes to near dryness. In the conical flask, 10 mL of deionized water was added and boiled gently to dissolve the residue. The solution was cooled, filtered through No. 42 Whatman filter paper into a 50 mL volumetric flask, and made to mark with deionized water. The sample and the standard solutions were aspirated into the air-acetylene flame of a GBC Xplora Atomic Absorption Spectrometer (AAS) for analysis according to APHA (1995).

2.2. Calculation of Metal Concentration

The raw concentrations obtained from the Atomic Absorption Spectrometer (AAS) in mg/L were converted to final food concentrations on a wet weight basis (mg/kg wet weight) according to the recommended regulatory equation (1):

$$C_{sample}\left(\frac{mg}{kg}\right) wet\ weight = \frac{C_{AAS}\left(\frac{mg}{L}\right) \times V_{final}}{M_{sample}(kg)} \qquad 1$$

Where C_{AAS} is the raw concentration read by the instrument, V_{final} is the final volumetric flask dilution volume (50 mL = 0.050 L), and M_{sample} is the initial wet weight mass of the tomato paste (2 g = 0.002 kg). This yields an exact dilution factor of 25 (0.050 L/0.002 kg). The final concentrations presented in the results table reflect the fully calculated C_{sample} values expressed explicitly as mg/kg wet weight, interpreted mathematically as equivalent to parts-per-million (ppm) by mass.

2.3. Quality Assurance and Control

For quality assessment, the limits of detection (LOD) and limits of quantification (LOQ) for the metals were respectively determined (in ppm) as follows: (0.0003 and 0.0005) for Cr, (0.0001 and 0.0003) for Cd, (0.0001 and 0.0003) for Cu, (0.0002 and 0.0005) for Pb, (0.0001 and 0.0003) for Zn, (0.0001 and 0.0003) for Mn.

2.4. Statistical Analysis

We used the mean ± standard deviation (SD) of the tomato paste batches (in Microsoft Excel) to analyze the data. Inferential statistical modeling was conducted using RStudio (R version 4.3.0). To evaluate the distribution of heavy metals across tomato paste samples, we performed a One-Way Analysis of Variance (ANOVA) separately for each metal across all 14 independent batches. We ran triplicates (n = 3 per batch, totaling N = 42 observations per metal) to assess intra-batch vs. inter-batch variance. After a significant F-test, we used Tukey's Honest Significant Difference (HSD) post-hoc test to perform all pairwise comparisons between the 14 batches at $\alpha = 0.05$. To uncover multivariate patterns and sample groupings without a priori assumptions, we performed Principal Component Analysis (PCA) (in RStudio) on the data. We evaluated dimensionality reduction using eigenvalues and loading vectors to determine how the 14 batches cluster based on their collective multi-metal contamination profiles.

3.0. Results and Discussions

Table 1.0: Mean concentration (in mg/kg wet weight) of the heavy metals and Statistical Significance across Sachet Tomato Paste Batches with R software

Batch	Lead (Pb)	Chromium (Cr)	Cadmium (Cd)	Zinc (Zn)	Copper (Cu)	Manganese (Mn)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
A1	0.081 ± 0.003^{ab}	0.026 ± 0.004^{ab}	0.042 ± 0.003^{a}	0.063 ± 0.003^{ab}	0.026 ± 0.002^{ab}	4.153 ± 0.003^{a}
A2	0.046 ± 0.002^{c}	0.016 ± 0.002^{c}	0.018 ± 0.004^{b}	0.079 ± 0.002^{c}	0.037 ± 0.003^{c}	3.464 ± 0.003^{b}
A3	0.081 ± 0.003^{ab}	0.020 ± 0.004^{ac}	0.058 ± 0.003^{c}	0.058 ± 0.003^{bd}	0.076 ± 0.002^{d}	3.377 ± 0.002^{c}
A4	0.017 ± 0.002^{d}	0.016 ± 0.003^{c}	0.040 ± 0.003^{ad}	0.046 ± 0.004^{ef}	0.021 ± 0.002^{a}	2.851 ± 0.003^{d}
A5	0.022 ± 0.003^{de}	0.037 ± 0.004^{de}	0.020 ± 0.001^{b}	0.081 ± 0.003^{c}	0.029 ± 0.003^{be}	1.448 ± 0.004^{e}
B1	0.030 ± 0.003^{ef}	0.029 ± 0.003^{bef}	0.036 ± 0.003^{ae}	0.050 ± 0.002^{df}	0.038 ± 0.001^{c}	3.467 ± 0.003^{b}
B2	0.075 ± 0.004^{a}	0.072 ± 0.002^{g}	0.067 ± 0.003^{f}	0.072 ± 0.003^{ac}	0.029 ± 0.003^{be}	2.341 ± 0.060^{f}
B3	0.089 ± 0.004^{b}	0.035 ± 0.002^{be}	0.049 ± 0.002^{g}	0.070 ± 0.004^{bc}	0.024 ± 0.003^{ae}	5.298 ± 0.003^{g}
B4	0.022 ± 0.003^{de}	0.033 ± 0.002^{be}	0.027 ± 0.002^{hi}	0.066 ± 0.003^{ab}	0.033 ± 0.001^{bc}	5.267 ± 0.001^{gh}
C1	0.021 ± 0.003^{de}	0.024 ± 0.003^{acf}	0.024 ± 0.002^{bh}	0.034 ± 0.003^{g}	0.039 ± 0.003^{cf}	4.232 ± 0.003^{i}
C2	0.036 ± 0.002^{f}	0.064 ± 0.003^{g}	0.031 ± 0.003^{ei}	0.065 ± 0.004^{ab}	0.046 ± 0.003^{f}	5.223 ± 0.003^{h}
C3	0.049 ± 0.004^{c}	0.018 ± 0.002^{ac}	0.035 ± 0.002^{de}	0.050 ± 0.003^{df}	0.059 ± 0.003^{g}	1.462 ± 0.002^{e}
C4	0.035 ± 0.004^{f}	0.051 ± 0.004^{h}	0.029 ± 0.002^{eh}	0.041 ± 0.003^{fg}	0.028 ± 0.003^{be}	3.374 ± 0.003^{c}
C5	0.020 ± 0.003^{d}	0.044 ± 0.002^{dh}	0.034 ± 0.002^{dei}	0.036 ± 0.009^{eg}	0.085 ± 0.004^{h}	4.382 ± 0.003^{j}
WHO/FAO ML (mg/kg)	0.30	-	0.10	-	-	-
USDA/NHS (mg/kg)	-	0.5	-	-	-	-

ML: Maximum Limit. Values represent the mean ± Standard Deviation of triplicates (n=3). Superscript letters (a-j) within the same column indicate statistically significant differences between batches ($p < 0.05$) based on One-Way ANOVA followed by Tukey's HSD post-hoc test. Batches sharing a common letter are not significantly different ($p > 0.05$).

3.1.1. Heavy metal variation and significance level for non-essential metals of Pb, Cr and Cr across the batches of the tomato brands

Lead variation: From Table 1, brand A has similar but higher Pb concentrations in batches A1 and A3, which are far greater than in batches A4 and A5. The same trend appears in brand B, where batches B3 and B2, with Pb values of 0.089 mg/kg and 0.075 mg/kg, respectively, are much higher than in batches B1 and B4. Brand C showed relatively lower but undulating Pb metal concentrations across the 5 batches, with the highest values in batch C3 and the lowest in C5. Batches with very high, non-statistically significant Pb concentrations ($p>0.05$) were: (A2, A4), (A2, C3), (A4, C5), (B4, C1), and (C2, C4). Lead pollution in the paste could stem from contamination of the lot used to plant the tomatoes or from other anthropogenic activities during production. A study in Ecuadorian soil by Romero-Estévez (2020) also showed that high levels of cadmium and lead in Ecuadorian vegetables may be due to high metal levels in Ecuadorian soils (Romero-Estévez, 2020). Another study by Grochowska-Niedworok (2020) stated that vegetable contamination could result from farm location and during technological storage or processing. Pb values in all batches were well below the WHO/FAO (Codex CXS 193-1995) ML of 0.30 mg/kg, making the paste safe with respect to Pb.

Cadmium variation: In brand A, Cd concentration was highest in batch A3 (0.058) and lowest in batch A2 (0.018). For brand B, Cd was highest in batch B2 (0.067) and lowest in batch B4 (0.027). In brand C, it was highest in batch C3 (0.035) and lowest in batch C1 (0.024). Cadmium contamination could be traced to soil chemistry, the type of fertilizer used during tomato planting, or other related factors. Cd values in all batches were well below the WHO/FAO ML of 0.10 mg/kg, making the paste safe from Cd hazard. A study by Shavali-Gilani et al. (2025) from Tehran also showed that Cd fell below the permissible value, as seen in this study.

Chromium variation: Cr in brand A was highest in batch A5 (0.037) and lowest in batches A2 and A4 (0.016, respectively). In brand B, batch B2 (0.072) spiked much higher than the Cr concentrations in the other batches: B1 (0.029), B3 (0.035), and B4 (0.033). Brand C has the highest Cr concentration in C2 (0.064) and the lowest in C3 (0.018). Batches with very high, non-statistically significant Cr concentrations ($p>0.05$) were: (A1, A3), (A3, C3), (A4, C5), (B4, C1), and (C2, C4). Chromium was detected at trace levels across all batches (0.016 to 0.072 mg/kg). Specific statutory Maximum Levels for Chromium are not established in Codex CXS 193-1995 because it is monitored as a nutritional quality trace element rather than a public health threat. However, USDA (CH2025-0202) has a permissible limit of Cr as 0.5 mg/kg for Fresh vegetables. Cr values in all tomato batches in this study remained below this limit.

3.1.2. Heavy metal variation and significance level for essential metals of Zn, Cu and Mn across the batches of the tomato brands

Zinc variation: in brand A, Zn concentration was highest in batch A5 (0.081 mg/kg) and lowest in batch A4 (0.046 mg/kg). For brand B, the metal concentration was highest in batch B2 (0.072 mg/kg) and lowest in batch B1 (0.050 mg/kg). In brand C, the highest

concentration was in batch C2 (0.065 mg/kg), while the lowest was in batch C1 (0.034 mg/kg).

Copper variation: Cu in brand A had the highest concentration in batch A3 (0.076 mg/kg) and the lowest in batch A4 (0.021 mg/kg). In brand B, batch B1 (0.038 mg/kg) had the highest concentration value, while batch B3 (0.024 mg/kg) had the lowest Cu value. In brand C, Cu metal had the highest concentration value in batch C5 (0.085 mg/kg) and the lowest in batch C4 (0.028 mg/kg).

Manganese variation: Mn is unique, with values far higher than all other metals across batches in the three brands. In brand A, Mn concentration was highest in batch A1 (4.153 mg/kg) and lowest in batch A5 (1.448 mg/kg). For brand B, the metal concentration was highest in batch B3 (5.298 mg/kg) and lowest in batch B2 (2.341 mg/kg). In brand C, the highest concentration was in batch C2 (5.223 mg/kg), while the lowest was in batch C3 (1.462 mg/kg).

Zinc (Zn), Copper (Cu), and Manganese (Mn) were detected across all fourteen-sachet tomato paste batches, with peak concentrations reaching 0.081 ± 0.003 mg/kg for Zinc (Batch A5), 0.085 ± 0.004 mg/kg for Copper (Batch C5), and 5.298 ± 0.003 mg/kg for Manganese (Batch B3). Unlike Lead and Cadmium, specific statutory contaminant Maximum Levels (MLs) for Zn, Cu, and Mn are not established under the FAO/WHO Codex Alimentarius General Standard (CXS 193-1995). As Section 2.2 of the Codex standard explicitly states, elements that primarily have nutritional or food-quality significance rather than direct public-health toxicological threats are excluded from contaminant ceilings. Consequently, these elements represent safe, vital micronutrient contributions rather than toxic industrial pollution.

3.2. Principal component analysis (PCA)

Table 2.0: Principal Component Analysis (PCA) Eigen-Analysis and Total Variance Contribution

Metric	PC1	PC2	PC3	PC4	PC5	PC6
Standard Deviation	1.3925	1.1486	1.0533	0.9276	0.7816	0.4009
Percentage of Variance (%)	32.32%	21.99%	18.49%	14.34%	10.18%	2.68%
Cumulative Percentage (%)	32.32%	54.31%	72.80%	87.14%	97.32%	100.00%

Table 2.0 indicates the 6 PC Eigen-analysis and variance. Of the 6 PCs, PC1 to PC3 were more significant because they have values greater than 1, in compliance with Kaiser's criterion, which focuses on eigenvalues (or standard deviation) greater than 1 (as seen in PC1, PC2, and PC3). We used the combined variance of PC1 (32.32%) and PC2 (21.99% ≈ 22%), totaling 54.31%, for the biplot diagram in Figure 1; including PC3 (18.49%) increased the percentage to 72.80%.

Table 3.0: The Variable Loading Matrix (Eigenvectors) for the Extracted Principal Components (PC)

Metal Heavy Element	PC1	PC2	PC3	PC4	PC5	PC6
Lead (Pb)	**-0.6312** ✸	+0.1472	+0.1673	+0.3363	-0.0008	+0.6625

Chromium (Cr)	-0.2895	+0.0383	**-0.5935** ✸	-0.7034	+0.1346	+0.2228
Cadmium (Cd)	**-0.5757** ✸	+0.3840	+0.1331	-0.1136	-0.3436	-0.6103
Zinc (Zn)	-0.4060	**-0.5518** ✸	+0.0494	+0.1119	+0.6365	-0.3326
Copper (Cu)	+0.1466	**+0.6998** ✸	+0.1660	-0.0438	+0.6768	-0.0346
Manganese (Mn)	-0.0081	+0.1877	**-0.7563** ✸	+0.6040	+0.0238	-0.1650

Table 3.0 helps identify the metal load that defines each PC column under study. Each PC column is uniquely identified by a star sign. PC1 is strongly defined by negative loadings for Pb and Cd, alongside meaningful contributions from Zn and Cr. These metals are non-essential for humans, and their presence in the tomatoes could be a result of the fertilizer (phosphate fertilizer) used in the farmland during tomato cultivation. A study by Onwuka et al. (2019) found that Pb, Cr, and Ni in fresh tomato samples may result from farm soils containing the metals in which the tomatoes were planted. Chemical fertilizer use is also a source of heavy metal pollution (Kouame et al., 2023).

PC2 is primarily characterized by strong positive loadings of Cu and negative loadings of Zn. This pattern could reflect leaching of metal particles from equipment into the tomato during paste production or from other sources.

Finally, PC3 shows negative loadings for Cr and Mn. These metals in the tomato paste could have come from the soil type from which the tomatoes were obtained, equipment friction/wear and tear, or other related factors.

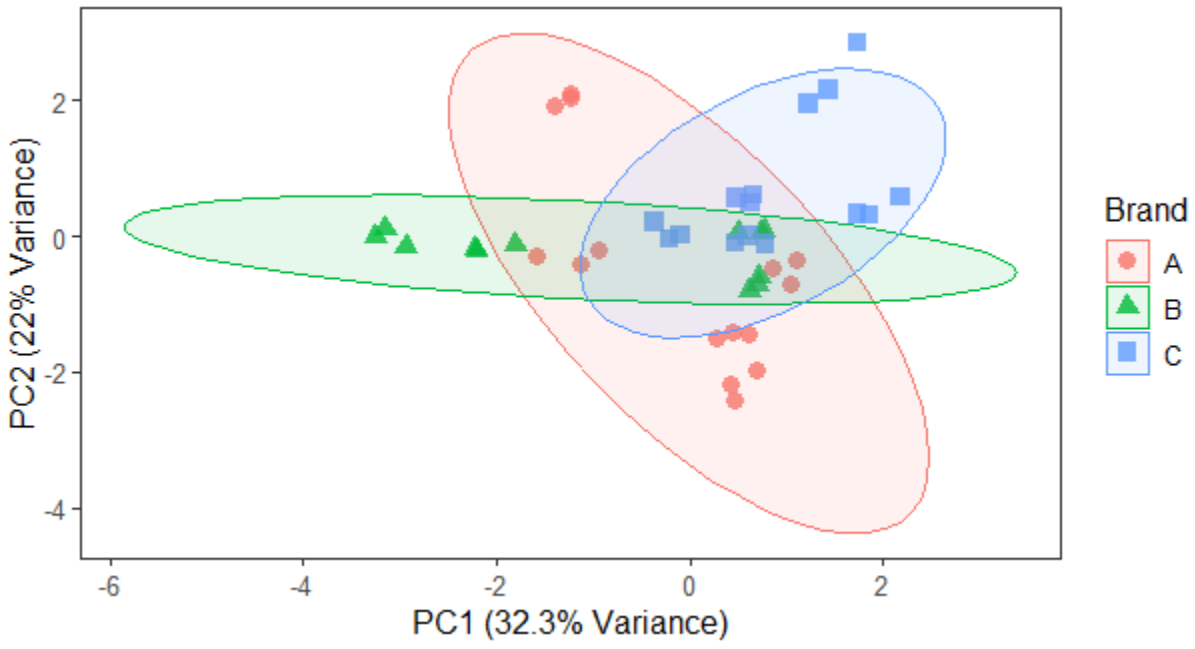

Figure 1.0: PCA brand biplot clustering based on heavy metal profiles

Figure 1.0 shows the heavy metal clustering patterns in the three-sachet tomato paste brands. Brand A, represented by a long, semi-vertical red ellipse, is shown along PC2. The 14 batches are scattered far along the ellipse. This dispersion pattern suggests high exploratory batch-to-batch variation and sample heterogeneity. That is, the batches from the brand may not have followed the same quality control procedure during production. In contrast, Batch C shows a smaller blue ellipse, with the 14 batches more tightly clustered than in Brand A. This batch clustering suggests a more uniform quality control procedure for this brand during batch-by-batch production.

Brand B is represented by a green horizontal ellipse stretched towards the negative PC1 axis. This indicates a completely different brand, with distinct chemical characteristics across batches. This may be due to different soil types where the tomatoes are sourced, or different machinery or industrial processes during paste production.

A work conducted by Gabriela S. Yánez-Jácome et al. (2025) on the "Assessment of metal-related health risks in processed tomato-based sauces from Quito, Ecuador: Evaluation and monitoring during and after a spice contamination event" showed that samples from some brands were close to one another, while other samples were dispersed from each other, signifying that processing technology, variability in the quality of ingredients, as well as machinery for packaging and materials impact the content of metals in final products. The three ellipses overlapped, with about 14 batches from the three brands in the intersection, as illustrated in Figure 1.0. This showed that, despite their differences, the three brands share some common mineral and trace element characteristics, which could point to exploratory pathways such as packaging materials or the type of manufacturing process.

4.0. Conclusion

The foregoing studies show significant variations in heavy metal concentrations across independent batches of the three commercial sachet tomato brands sold in Awka. These wide fluctuations indicate that while the individual values remain safely within public health guidelines, quality control measures and raw material sourcing pathways during batch-to-batch production lack consistent uniformity. Because processing variables and agricultural origins appear to introduce noticeable elemental variation between manufacturing cycles, we recommend that regulatory bodies enforce stricter, standardized quality-control monitoring procedures during commercial production of these sachet tomato pastes to ensure long-term batch uniformity and consumer safety.

References

Ahmed, D. A. E., Slima, D. F., Al-Yasi, H. M., Hassan, L. M., & Galal, T. M. (2023). Risk assessment of trace metals in Solanum lycopersicum L. (tomato) grown under wastewater irrigation conditions. *Environmental science and pollution research international*, *30*(14), 42255–42266. https://doi.org/10.1007/s11356-023-25157-8

American Public Health Association [1995] 3111B, Direct Air-Acetylene Flame Method, Standard Methods for the Examination of Water and Wastewater, 19th Edition, APHA, AWWA, WEF. https://www.standardmethods.org/ Accessed March 8, 2023

Borguini, R. G., & Ferraz Da Silva Torres, E. A. (2009). Tomatoes and Tomato Products as Dietary Sources of Antioxidants. *Food*

Reviews International, *25*(4), 313–325. https://doi.org/10.1080/87559120903155859

Burton-Freeman, B., & Reimers, K. (2011). Tomato Consumption and Health: Emerging Benefits. American Journal of Lifestyle Medicine. 5(2):182–191. https://10.1177/1559827610387488

Ezenwaji, E.E., Nzoiwu, C.P., & Chima, G.N. (2017). Analysis of Precipitation Concentration Index (PCI) for Awka Urban Area, Nigeria. Hydrol Current Res 8: 287. https://doi.org/10.4172/2157-7587.1000287

FAO/WHO Codex Alimentarius Commission. (1995). *General standard for contaminants and toxins in food and feed* (CXS 193-1995). Last amended in 2025. Food and Agriculture Organization; World Health Organization. https://openknowledge.fao.org/server/api/core/bitstreams/4d0e7245-8166-49ca-b822-ca80a1ff5cfe/content. Retrieved September 29, 2026

Featherstone, S. (2015). 2 - Food regulations, standards, and labelling, In Woodhead Publishing Series in Food Science, Technology and Nutrition, A Complete Course in Canning and Related Processes (Fourteenth Edition), Woodhead Publishing, Pages 21–61, ISBN 9780857096777, https://doi.org/10.1016/B978-0-85709-677-7.00002-5

Grochowska-Niedworok, E., Nieć, J., & Baranowska, R. (2020). Assessment of Cadmium and Lead Content in Tomatoes and Tomato Products. Rocz. Państw. Zakl. Hig., 71(3):313–319. https://doi.org/10.32394/rpzh.2020.0126

Khayat Nouri, M. H., & Namvaran Abbas Abad, A. (2013). Comparative study of tomato and tomato paste supplementation on the level of serum lipids and lipoproteins levels in rats fed with high cholesterol. *Iranian Red Crescent Medical Journal*, *15*(4), 287–291. https://doi.org/10.5812/ircmj.1007

Kouame, A.K., Nindjin, C., Konan, G.A., Bouatenin, M.J.P.K., & Koussemon, M. (2023). Chemical risk assessment of conventionally and organically grown tomatoes in Côte d'Ivoire. The North African Journal of Food and Nutrition Research, 7(16):130–135. https://doi.org/10.51745/najfnr.7.16.130-135

Tornberg, E. (2017). Chapter 8 - Influence of Fibers and Particle Size Distribution on Food Rheology, Editor(s): J. Ahmed, In Woodhead Publishing Series in Food Science, Technology and Nutrition, Advances in Food Rheology and Its Applications, Woodhead Publishing, Pages 177–208, ISBN 9780081004319, https://doi.org/10.1016/B978-0-08-100431-9.00008-5

Mónica González, M., Carmen Cid, M., & Gloria Lobo (2011). Chapter 133 - Usage of Tomato (Lycopersicum esculentum Mill.) Seeds in Health, Editor(s): Victor R. Preedy, Ronald Ross Watson, Vinood B. Patel, Nuts and Seeds in Health and Disease Prevention, Academic Press, Pages 1123–1132, ISBN 9780123756886, https://doi.org/10.1016/B978-0-12-375688-6.10133-1

Okpaegbe, U.C., Egah, G.O., & Ukpen, G. (2026). Determination of Heavy Metals Concentration in Tomatoes (Solanum Lycopersicum) Collected from Selected Farms in Wukari, Taraba State, Nigeria. Asian Journal of Applied Chemistry Research 17 (1):112–17. https://doi.org/10.9734/ajacr/2026/v17i1378.

Oladapoa, F.O., Awokoyab, J.O., & Egbedeyia, T.D. (2023). Comparative Risk Assessment of Some Toxic Elements' Contents in Domestic and Imported Tomato

Pastes and Ketchup in Nigerian Markets. J. Chem. Soc. Nigeria, 48(3):530 – 543.

Onwuka, K.E., Christopher, A.U., Igwe, J.C., & Achulonu, C.V. (2019). A Study on Heavy Metals Comparison in Processed Tomato Paste and Fresh Tomatoes Sold in a Market in Umuahia Metropolis of Abia State, Nigeria. Journal of Analytical Techniques and Research 1: 026–032. https://www.academia.edu/39979753/A_Study_on_Heavy_Metals_Comparison_in_Processed_Tomato_Paste_and_Fresh_Tomatoes_Sold_in_a_Market_in_Umuahia_Metropolis_of_Abia_State_Nigeria . Retrieved September 17, 2026.

Romero-Estévez, D., Yánez-Jácome, G.S., Simbaña-Farinango, K., Vélez-Terreros, P.Y., & Navarrete, H. (2020). Determination of cadmium and lead in tomato (*Solanum lycopersicum*) and lettuce (*Lactuca sativa*) consumed in Quito, Ecuador. Toxicology Reports, 7: 893-899. https://doi.org/10.1016/j.toxrep.2020.07.008

Shavali-Gilani, P., Abedini, A., Irshad, N., Maleknezhad, S., Yazdanfar, N., & Sadighara, P. (2025). Investigation of heavy metal levels in canned tomato paste, olives, and pickled. *Scientific reports*, *15*(1):1-7. https://doi.org/10.1038/s41598-025-06896-9

Tabassam, Q., Ahmad, M. S. A., Alvi, A. K., Awais, M., Kaushik, P., & El-Sheikh, M. A. (2023). Accumulation of Different Metals in Tomato (*Lycopersicon esculentum* L.) Fruits Irrigated with Wastewater. *Applied Sciences*, *13*(17): 1–17. https://doi.org/10.3390/app13179711

USDA/NHS (2025). Revised National Food Safety Standard on Maximum Levels of Contaminants in Foods Released. United States Department of Agriculture (Report number: CH2025-0202). https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Revised%20National%20Food%20Safety%20Standard%20on%20Maximum%20Levels%20of%20Contaminants%20in%20Foods%20Released_Beijing_China%20-%20People%27s%20Republic%20of_CH2025-0202.pdf. Retrieved September 30, 3026.

Yánez-Jácome, G.S., Vélez-Terreros, P.Y., De la Torre, A., Carvajal, W., & Navarrete, H. (2025). Assessment of metal-related health risks in processed tomato-based sauces from Quito, Ecuador: Evaluation and monitoring during and after a spice contamination event. Journal of Food Composition and Analysis, 148(108245):1–12. https://doi.org/10.1016/j.jfca.2025.108245