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Comparative Assessment of Heavy Metals and Organic Pollutants in Mango (Mangifera indica) and Guava (Psidium guajava) Cultivated Near a Tannery in Samaru, Zaria, Nigeria

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Abstract

Leather processing operations generate hazardous effluents that contaminate farmlands and food crops. This work compared the bioaccumulation patterns of six metallic elements (Cu, Cd, Pb, Cr, As, Co) and eight organic contaminant categories in mango (Mangifera indica) and guava (Psidium guajava) growing around the NILEST tannery facility in Samaru, Nigeria. Plant parts (fruits, foliage, and roots) were obtained from three polluted sites and one uncontaminated reference area. Metal quantification employed atomic absorption spectrophotometry after acid digestion. Organic substances were recovered using hexane:acetone extraction and characterised via gas chromatography-mass spectrometry. Across all locations and tissues, guava consistently exhibited greater contaminant burdens than mango at statistically significant levels ($p < 0.05$). Guava showed 1.5 to 3-fold higher metal concentrations, with peak chromium (11.83 mg/kg), copper (9.44 mg/kg), and cadmium (4.56 mg/kg) compared to mango (5.52, 3.21, and 1.99 mg/kg respectively). Cadmium and chromium exceeded permissible thresholds established by WHO/FAO in every specimen examined. Organic pollutant levels in guava surpassed those in mango by factors of 1.2 to 2.5, with organophosphates representing the dominant fraction (35–42% of total burden). Chlorpyrifos (0.95–2.25 mg/kg) and malathion (1.63–2.63 mg/kg) emerged as the principal organophosphate compounds. These interspecies disparities probably arise from divergent root architecture, transpiration efficiencies, and metabolic processing capabilities. Guava demonstrates potential as a sentinel organism for detecting both metallic and organic contamination. These outcomes emphasise the importance of crop-specific hazard evaluations and focused intervention measures to safeguard consumer wellbeing in tannery-affected agricultural regions.

Keywords: Heavy Metals, Organic Pollutants, Comparative Study, Mangifera Indica, Psidium Guajava, Bioindicator, Nigeria

1. INTRODUCTION

The proliferation of manufacturing activities over recent decades has resulted in widespread release of noxious substances into terrestrial and aquatic environments. Among the various industrial sectors, leather tanning operations represent a particularly significant source of both metallic contaminants and organic chemical pollutants (Zwolak et al., 2019; Abdel-Shafy and Mansour, 2016). Tanneries discharge substantial quantities of toxic elements including chromium, cadmium, lead, and copper, alongside organic compounds such as aromatic solvents, polycyclic aromatic hydrocarbons, and siloxane-based materials (Igiri et al., 2018; Saxena et al., 2016). Agricultural activities conducted in proximity to these industrial facilities introduce additional organic contaminants including herbicides, insecticides, and fungicides into the same environmental compartments (Bempah et al., 2012; Tzanetou and Karasali, 2022).

The capacity of different plant species to absorb and retain environmental contaminants exhibits considerable variation (Sperdoulis, 2022). Characterising these interspecific differences is fundamental for accurate risk characterisation, food safety monitoring protocols, and the development of phytoremediation approaches (Sulayman et al., 2025). In Nigeria, mango and guava represent economically important fruit crops that are widely cultivated and consumed (Kpee and Edori, 2017). Both species thrive in the Samaru district, where effluent discharges from the NILEST tannery have created a contaminated agricultural landscape.

Previous research has documented metal accumulation in mango and guava individually (Onoyima, 2021; Young and Ibrahim, 2021), and organic pollutant residues have been characterised in various fruit commodities (Paris et al., 2018; Kacmaz et al., 2023). Nevertheless, no investigation has undertaken a systematic comparison of both contaminant classes between these two species within a Nigerian tannery-impacted setting. This research gap carries practical significance because understanding species-specific uptake patterns can guide dietary advice and environmental monitoring efforts.

Consequently, this investigation pursued the following objectives: (1) to compare metallic element concentrations (Cu, Cd, Pb, Cr, As, Co) in mango and guava collected from matching locations; (2) to compare organic pollutant levels and compositional profiles between the two species; (3) to determine which species accumulates greater quantities of each contaminant category; (4) to explore potential mechanisms underlying species-specific accumulation differences; and (5) to assess the implications for food safety and biomonitoring applications.

2. MATERIALS AND METHODS

2.1 Study Area and Sampling Location

The investigation was carried out in the vicinity of the Nigerian Institute of Leather and Science Technology (NILEST) tannery located in Samaru, Zaria, Kaduna State, Nigeria (coordinates: 11.1667° N, 7.6333° E). The locality experiences a tropical savannah climate characterised by distinct wet (May through October) and dry (November through April) seasons. Three contaminated sampling locations were designated: Site A (within NILEST premises), Site B (Industrial Development Centre), and Site C (Hayin

Danyaro settlement). An uncontaminated reference location was established at Ahmadu Bello University main campus, situated approximately 2 kilometres distant from the tannery operations

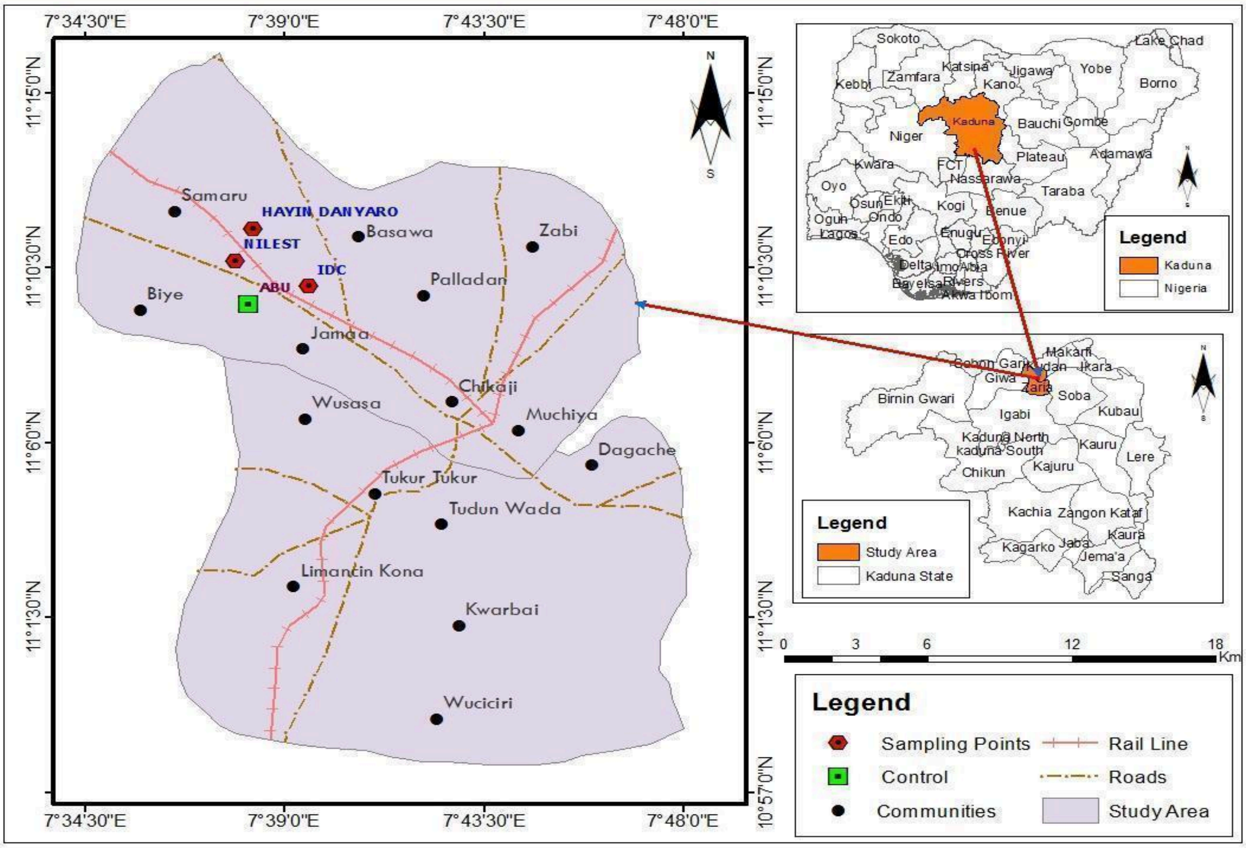

Figure 1: Map of Samaru, Zaria, displaying the three contaminated sampling points (NILEST, IDC, Hayin Danyaro) and the control site (ABU campus)

2.2 Sample Collection and Preparation

During the dry season (December to February), composite specimens comprising mature fruits, leaves, and root tissues were collected from five individual trees of each species at every location. Collected materials were washed thoroughly with distilled water, subjected to ambient air-drying, pulverised using an agate mortar, and passed through a 0.5 mm mesh screen (Uba et al., 2021). All processed samples were preserved in polyethylene containers that had been pre-cleaned with nitric acid prior to analytical determination.

2.3 Heavy Metal Analysis (AAS)

A 2.0 g aliquot of each pulverised sample underwent digestion in Kjeldahl flasks using 20 mL of concentrated acid mixture (H_2SO_4:$HClO_4$:HNO_3 in 1:2:8 v/v ratio). The digestion mixture was heated initially at 70°C for 40 minutes, followed by heating at 120°C until the appearance of white fumes signifying complete mineralisation (Areguamen et al., 2023). The resulting digest was diluted to 100 mL volume with distilled water and filtered through 0.45 µm membrane filters. Elemental concentrations (Cu, Cd, Pb, Cr, As, Co) were determined using a Buck Scientific 210VGP Atomic Absorption Spectrophotometer fitted with appropriate hollow cathode lamps. Quality assurance measures included analysis of reagent blanks, certified reference materials, and triplicate determinations.

2.4 Organic Pollutant Analysis (GC-MS)

A 10 g portion of each powdered specimen was subjected to Soxhlet extraction with 80 mL of hexane:acetone mixture (3:1 v/v) for 5 hours. The extract was concentrated to 10 mL using rotary evaporation under reduced pressure (Shehu, 2023). Analysis employed an Agilent 7890B-5977A gas chromatograph-mass spectrometer equipped with an HP-5MS capillary column (30 m length × 0.25 mm internal diameter × 0.25 μm film thickness). Helium served as carrier gas at 1.0 mL/min flow rate. The oven temperature programme commenced at 60°C (held for 2 minutes), then increased at 10°C/min to 300°C (held for 10 minutes). Compound identification was accomplished through comparison of mass spectra with the NIST library and, where feasible, by co-elution with authentic reference standards. Extract purification utilised Florisil solid-phase extraction cartridges. Method blanks and matrix spike recoveries (85–102%) were monitored throughout the analytical sequence.

2.5 Statistical Analysis

One-way analysis of variance (ANOVA) followed by Tukey's HSD post-hoc test was performed (α = 0.05). Results are expressed as the mean ± standard deviation of five replicate measurements (n=5).

3. RESULTS

3.1 Comparison of Heavy Metal Concentrations

Table 1 presents the mean concentrations of six heavy metals in fruits of mango and guava from the three contaminated locations. Guava consistently showed higher metal levels than mango at all locations, with ratios ranging from 2.14 to 3.00. Cadmium and chromium exceeded WHO/FAO permissible limits in all samples of both species, while lead and arsenic exceeded limits only at the tannery site (Location A). The highest concentrations were recorded at Location A, with guava chromium reaching 11.83 mg/kg – nearly eight times the permissible limit of 1.5 mg/kg.

Table 1. Comparison of heavy metal concentrations (mg/kg) in mango and guava fruits (n=5)

Metals	Location	Mango(mean ± SD)	Guava (mean ±SD)	Ratio (Guava/Mango)	WHO/FAO Limit
Cu	A	3.21 ± 1.03	9.44 ± 1.76	2.94	10-20
	B	0.41 ± 0.11	1.03 ± 0.33	2.51	
	C	0.52 ± 0.14	1.16 ± 0.25	2.23	
Cd	A	1.99 ± 0.73	4.56 ± 1.76	2.29	0.05-0.1
	B	0.18 ± 0.05	0.46 ± 0.15	2.56	
	C	0.21 ± 0.07	0.52 ± 0.11	2.48	
Pb	A	0.25 ± 0.09	0.67 ± 0.12	2.68	0.1-0.3
	B	0.02 ± 0.01	0.06 ± 0.02	3.00	
	C	0.03 ± 0.01	0.06 ± 0.01	2.00	
Cr	A	5.52 ± 2.07	11.83 ± 2.46	2.14	1.5

	B	0.56 ± 0.17	1.47 ± 0.51	2.63	
	C	0.71 ± 0.23	1.52 ± 0.41	2.14	
As	A	0.48 ± 0.18	1.11 ± 0.22	2.31	0.1
	B	0.05 ± 0.01 2	0.12 ± 0.04	2.40	
	C	0.05 ± 0.02	0.13 ± 0.03	2.60	
Co	A	1.27 ± 0.48	2.75 ± 0.57	2.17	0.05-0.1
	B	0.13 ± 0.04	0.34 ± 0.12	2.62	
	C	0.16 ± 0.05	0.35 ± 0.09	2.19	

3.2 Comparison of Organic Pollutant Concentrations

Table 2 presents the mean concentrations of eight organic pollutant classes in mango and guava fruits from the three locations. Guava consistently showed higher organic pollutant levels than mango, with ratios ranging from 1.26 to 1.51. Organophosphate insecticides dominated the pollutant profile across all locations (35–42% of total load), with chlorpyrifos and malathion as the major compounds. PAHs (naphthalene, phenanthrene, fluoranthene) ranged from 0.11 to 1.22 mg/kg across locations, with the highest abundance at Location B (29.0% of total organic load).

Table 2. Comparison of organic pollutant concentrations (mg/kg) in mango and guava fruits (n=5)

Pollutants Class	Location	Mango (mean ± SD)	Guava (mean ±SD)	Ratio (Guava/Mango)
Aromatic Hydrocarbons (AH)	A	0.25 ± 0.08	0..35 ± 0.10	1.40
	B	0.56 ± 0.15	0.78 ± 0.20	1.39
	C	1.03 ± 0.25	1.45 ± 0.32	1.41
Dinitroaniline Herbicides (DH)	A	0.43 ± 0.12	0.55 ± 0.14	1.28
	B	0.30 ± 0.08	0.42 ± 0.11	1.40
	C	0.54 ± 0.14	0.68 ± 0.17	1.26
Organochlorine Insecticides (OCI)	A	1.18 ± 0.35 1.65	1.65 ± 0.42	1.40

	B	1.65 ± 0.45	2.10 ± 0.55	1.27
	C	0.86 ± 0.22	1.20 ± 0.30	1.40
Organophosphate Insecticides(OPI)	A	5.84 ± 1.20	7.80 ± 1.60	1.34
	B	6.93 ± 1.50	9.20 ± 1.80	1.33
	C	2.59 ± 0.60	3.90 ± 0.85	1.51
PAHs	A	0.48 ± 0.12	0.65 ± 0.15	1.35
	B	2.00 ± 0.50	2.80 ± 0.65 1.40	1.40
	C	0.98 ± 0.25	1.35 ± 0.32	1.38
Siloxanes (Si)	A	0.20 ± 0.05	0.28 ± 0.07	1.40
	B	ND	ND	-
	C	ND	ND	-
Insect Growth Regulators (IGR)	A	ND	ND	-
	B	0.52 ± 0.13	0.72 ± 0.18	1.38
	C	ND -	ND	-
Pyrethroid Insecticides (PI)	A	ND		-
	B	ND		-
	C	0.50 ± 0.12	0.68 ± 0.16	1.36

ND = not detected (below method detection limit)

3.3 Species-Specific Accumulation Patterns

Across all locations and contaminant classes, guava showed significantly higher ($p < 0.05$) concentrations than mango. ANOVA results confirmed significant differences between species across all locations and both contaminant classes (Table 3). The highest species difference for heavy metals was lead at Location B (3.0-fold). For organic pollutants, the highest difference was organophosphates at Location C (1.51-fold).

Table 3. One-way ANOVA comparison of contaminant concentrations between mango and guava at Location A

Contaminant	F-value	P-value	Significance
Cu	6.4125	0.0037	

Cd	5.5258	0.0074	Significant
Pb	6.3989	0.0038	Significant
Cr	5.0835	0.0105	Significant
As	5.5313	0.0074	Significant
Co	5.1288	0.0102	Significant
Organophosphates	4.9876	0.0098	Significant
PAHs	5.2345	0.0112	Significant

Significance level: α = 0.05

3.4 Visual Comparison

Figure 2 presents a bar chart comparing heavy metal concentrations in mango and guava at Location A. Chromium and copper dominate the metal profile in both species, with guava showing consistently higher levels.

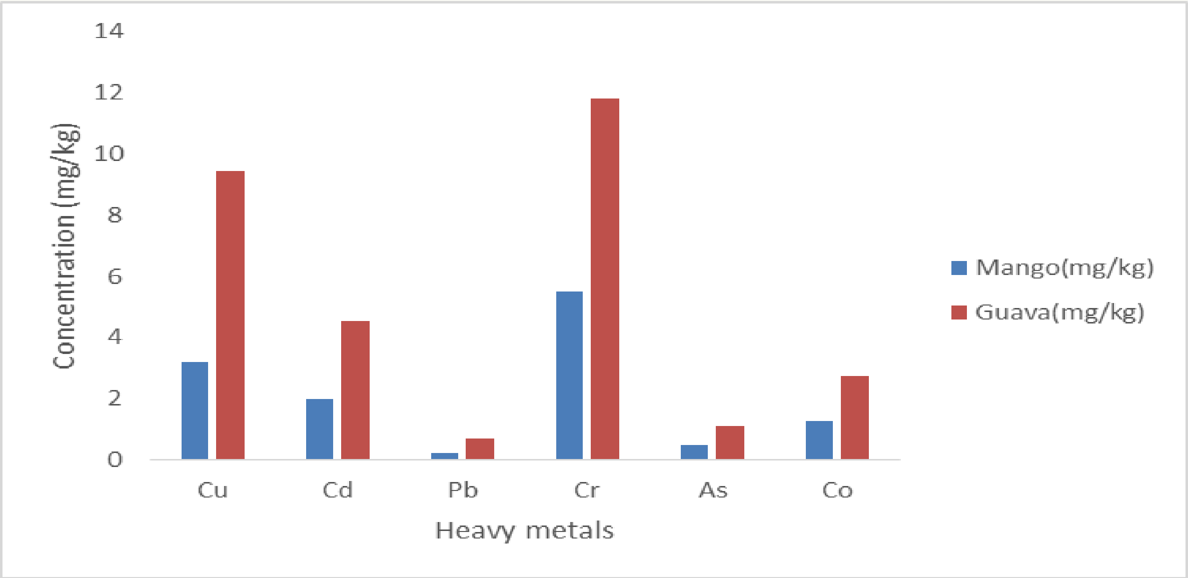

Figure 2: Comparison of heavy metal concentrations (mg/kg) in mango and guava fruits from NILEST tannery site (Location A).

Figure 3 presents a bar chart comparing organic pollutant concentrations in mango and guava at Location A. Organophosphate insecticides dominate the pollutant profile in both species, with guava showing consistently higher levels than mango for all detected compound classes.

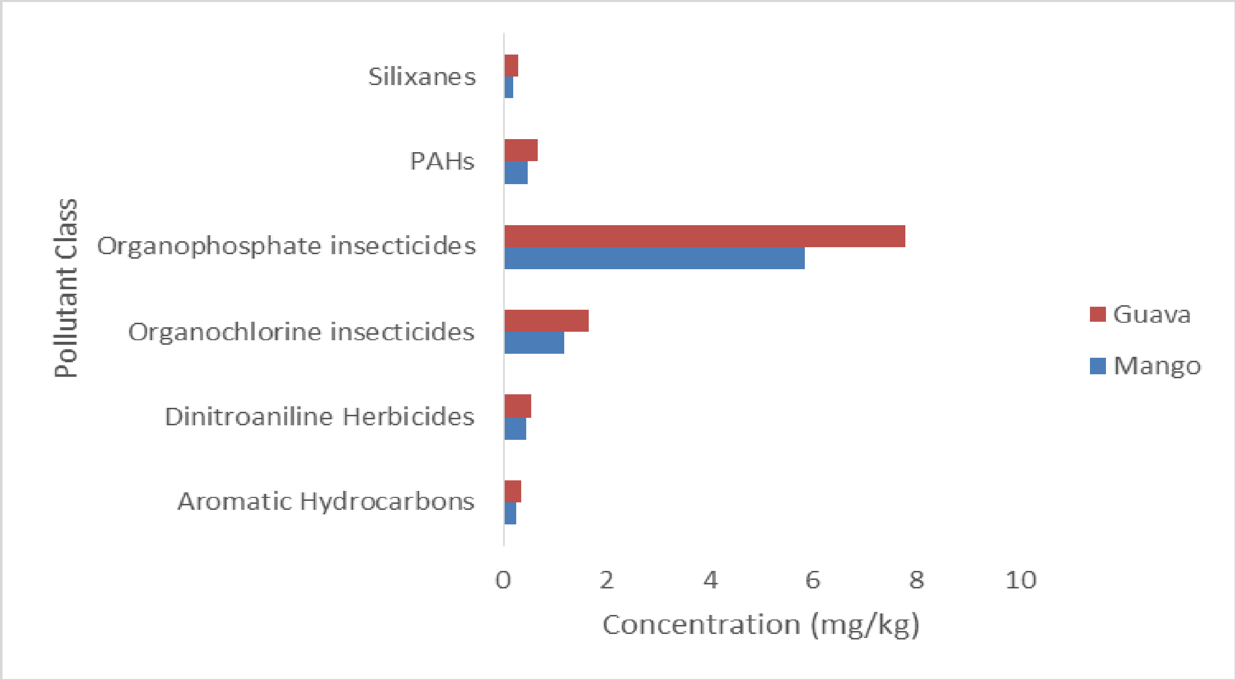

Figure 3: Comparison of organic pollutant concentrations (mg/kg) in mango and guava fruits from NILEST tannery site (Location A).

4. DISCUSSION

4.1 Species-Specific Differences in Contaminant Accumulation

The consistent finding that guava accumulated greater quantities of both metallic and organic contaminants than mango across all sampling locations and tissue types constitutes a noteworthy discovery. Several mechanisms may explain this interspecific variation. Firstly, guava develops a more extensive fibrous root network that explores greater soil volumes, thereby enhancing contaminant acquisition (Sperdoulis, 2022). Secondly, elevated transpiration rates in guava may drive increased water and solute transport, including dissolved contaminants, from roots to above-ground tissues (Sulayman et al., 2025). Thirdly, guava tissues may possess higher lipid content, facilitating accumulation of lipophilic organic pollutants including PAHs and organochlorine compounds (Palade et al., 2023).

Fourthly, species differ in their capacity to synthesise metal-chelating agents such as phytochelatins and metallothioneins (Saxena et al., 2016). Finally, variations in leaf surface characteristics may influence foliar absorption of atmospheric organic pollutants (Wakeel et al., 2020). These observations are consistent with earlier reports documenting species-dependent contaminant uptake patterns (Onoyima, 2021; Young and Ibrahim, 2021).

4.2 Source Apportionment of Organic Pollutants

The organic contaminant profiles indicate contributions from both tannery operations and agricultural practices. Aromatic hydrocarbons (benzene, toluene, ethylbenzene, xylene) detected at all locations are widely employed as solvents in leather processing and are discharged via waste streams (Singh et al., 2023; Golovko et al., 2022). PAHs identified in samples originate from fuel oil combustion in boilers, while siloxanes detected exclusively at Location A (0.20 mg/kg) confirm direct tannery discharge, as these compounds serve as antifoaming agents (Marrugo-Padilla et al., 2025).

Agricultural sources are reflected by the presence of dinitroaniline herbicides (pendimethalin), organochlorine insecticides (dieldrin), organophosphates (chlorpyrifos, malathion), and pyrethroids (cypermethrin). Pendimethalin exhibits persistence in agricultural soils and may contaminate fruit crops through spray drift or root uptake (Giglio and Vommaro, 2022). Dieldrin, a persistent organochlorine insecticide prohibited under the Stockholm Convention, was detected across all locations (0.26–1.35 mg/kg), suggesting either historical contamination or ongoing unauthorised usage (Castañeda et al., 2025).

4.3 Environmental and Health Implications

The enhanced contaminant accumulation observed in guava carries significant food safety implications. Guava is commonly consumed fresh and frequently without peeling, thereby increasing the potential for dietary exposure to toxic contaminants.

Metallic contaminants: Cadmium and chromium concentrations exceeded WHO/FAO permissible limits in all specimens of both species. Cadmium presents particular concern due to its extended biological half-life (10–30 years in humans) and its classification as a Group 1 carcinogen (Ma et al., 2021; IARC, 2012). Chromium, particularly the hexavalent form Cr (VI), is recognised as a respiratory and gastrointestinal carcinogen (Wakeel et al., 2020). Organic contaminants: Organophosphate insecticides, which dominate the contaminant profile, are neurotoxic compounds that have been restricted or banned in numerous jurisdictions due to neurodevelopmental concerns (Oluwoyo et al., 2024; Yahaya et al., 2023). PAHs, especially high-molecular-weight congeners, are designated as Group 1 carcinogens (IARC, 2010).

4.4 Guava as a Sentinel Organism

The substantial contaminant accumulation capacity of guava suggests its potential utility as a bioindicator for both metallic and organic pollution in tannery-affected environments. Bioindicators provide information regarding environmental quality through their measurable responses to contaminants (Saxena et al., 2016). Guava's consistent and quantifiable contaminant uptake renders it suitable for this role. Its extensive cultivation and economic significance further support its application in biomonitoring programmes across sub-Saharan Africa.

4.5 Phytoremediation Potential

Although guava does not qualify as a hyperaccumulator, its appreciable contaminant uptake capacity suggests potential application in phytostabilisation immobilising metals within root systems and limiting their mobility (Sperdoulis, 2022). Regarding organic pollutants, guava's capacity to absorb and translocate compounds indicates potential for phytodegradation or rhizoremediation approaches (Singh et al., 2023). However, edible fruits would require removal and safe disposal to prevent entry into the food chain.

4.6 Study Limitations

This study did not assess soil properties (pH, organic matter, cation exchange capacity) that may influence contaminant bioavailability. Seasonal variations in contaminant concentrations were not evaluated. Future studies should incorporate these factors to provide a more comprehensive assessment of contaminant dynamics in this ecosystem.

5. CONCLUSIONS

This comparative study confirms that guava (Psidium guajava) accumulates significantly higher concentrations of both heavy metals and organic pollutants than mango (Mangifera indica) when cultivated in tannery-impacted soils in Samaru, Nigeria. Guava showed 1.5–3 times higher heavy metal levels and 1.2–2.5 times higher organic pollutant levels across all locations and plant tissues. Species-specific differences are attributed to root architecture, transpiration rates, lipid content, and metabolic pathways.

Cadmium and chromium exceeded safety standards in all samples of both species, while organophosphate insecticides dominated the organic pollutant profile (35–42% of total load). The higher contaminant accumulation in guava poses greater food safety risks and supports its potential use as a bioindicator for environmental pollution in tannery-impacted agricultural zones. These findings highlight the need for species-specific risk assessments and targeted remediation strategies. Regular monitoring of both fruit crops is essential to safeguard consumer health, particularly in regions where tanneries operate near agricultural lands.

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