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Mineral and Heavy Metals Profiling of Avocado Oils from Three Cultivars in Mambila Plateau, Taraba State, Nigeria: Implications for Food Safety and Nutraceutical Use

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Abstract: *Avocado oil is increasingly recognized not only for its lipid composition but also for its trace mineral content and safety profile, which are critical for its application in functional foods, cosmetics, and nutraceuticals. This study investigates the mineral and heavy metal content of avocado oils extracted from three cultivars—Hass, Maluma, and Persea schiedeana—grown on the Mambila Plateau, Taraba State, Nigeria. Using atomic absorption spectrophotometry (AAS), the oils were analyzed for essential minerals including calcium, magnesium, potassium, iron, zinc, and phosphorus, as well as toxic heavy metals such as lead, cadmium, arsenic, and mercury. The results revealed cultivar-specific variations in mineral composition. Maluma oil exhibited the highest concentrations of calcium (10.3 ppm), magnesium (32.5 ppm), and potassium (44.7 ppm), indicating its superior nutritional potential. Persea schiedeana showed elevated phosphorus levels (10.6 ppm), while Hass had the highest carbohydrate content and moderate mineral distribution. All three oils were found to be within WHO/FAO permissible limits for heavy metals, with lead ranging from 0.043 to 0.081 ppm, cadmium from 0.004 to 0.006 ppm, and arsenic and mercury either undetectable or present in trace amounts.These findings confirm the safety and nutritional value of avocado oils from the Mambila Plateau, with Maluma standing out as a promising candidate for mineral-enriched formulations. The absence of toxic heavy metal contamination across all samples supports their use in health-sensitive applications. This study contributes to the growing body of knowledge on indigenous avocado cultivars and underscores their potential in Nigeria's agro-industrial development.*

Keywords*: Avocado oil, mineral content, heavy metals, food safety, AAS, Nigeria*

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1.0 Introduction

Avocado (*Persea americana*) oil has emerged as a valuable functional ingredient in food, cosmetic, and pharmaceutical industries due to its rich lipid profile, antioxidant properties, and bioactive compounds (Borges et al., 2017;

Wang et al., 2020). In recent years, global demand for plant-derived functional oils has increased due to growing consumer preference for natural products with added health benefits. This trend has stimulated interest in underutilized tropical crops, including avocado, as alternative sources of nutritionally valuable edible oils. While much attention has been given to its fatty acid composition, the mineral and elemental content of avocado oil is increasingly recognized as a critical factor in determining its nutritional and therapeutic potential (Nasri et al., 2023).

Minerals such as calcium, magnesium, potassium, and phosphorus play essential roles in human physiology, including bone development, enzymatic regulation, and cellular signaling (Adeyeye, 2019). Adequate intake of these macro- and micro-minerals is associated with reduced risk of osteoporosis, improved cardiovascular function, and enhanced metabolic regulation. Their presence in edible oils enhances the nutritional value and supports the formulation of mineral-enriched functional foods. Conversely, heavy metals like lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) are toxic even at low concentrations and pose serious health risks, including neurotoxicity, carcinogenicity, and organ damage (WHO/FAO, 2021). Therefore, assessing both beneficial and harmful elements in avocado oil is crucial for ensuring food safety and consumer protection. Edible oils can act as carriers of both essential and toxic elements depending on environmental conditions, agricultural practices, and processing methods, making routine monitoring a public health priority.

Previous studies have shown that the elemental composition of avocado oil is influenced by cultivar type, soil mineral content, and environmental conditions (Campos-Hernández et al., 2011; González-Torres et al., 2023). Studies from Mexico, Chile, and South Africa have reported considerable variability in mineral concentrations of avocado oil, with magnesium and potassium often occurring at the highest levels, while trace contamination by lead and cadmium has occasionally been linked to soil and irrigation water quality (Flores *et al*., 2019). However, most existing studies have concentrated on avocado cultivars grown in Latin America, South Africa, and parts of Asia, with very limited data available for African-grown avocados and virtually no published reports on the elemental composition of avocado oil produced in Nigeria. The Mambila Plateau in Taraba State offers a unique agro-ecological environment characterized by high altitude, volcanic soils, and temperate climate, which may influence the mineral uptake and accumulation in avocado fruits (Adeyeye, 2019). Variations in altitude, soil parent material, and rainfall patterns are known to affect trace element mobility and bioavailability in crops, potentially leading to distinctive mineral signatures in plant-derived oils. Despite its suitability for avocado cultivation, oils derived from this region remain under-characterized in terms of their elemental profile and safety standards.

This study addresses that gap by evaluating the mineral and heavy metal content of avocado oils extracted from three cultivars—Hass, Maluma, and *Persea schiedeana*—grown on the Mambila Plateau. Using atomic absorption spectrophotometry (AAS), we quantified essential minerals and toxic metals, comparing the results against WHO/FAO permissible limits. This study addresses this knowledge gap by evaluating the mineral and heavy metal content of avocado oils extracted from three cultivars—Hass, Maluma, and *Persea schiedeana*—grown on the Mambila Plateau, Taraba State, Nigeria. Using atomic absorption spectrophotometry (AAS), essential minerals and potentially toxic heavy metals were quantified and compared with established WHO/FAO permissible limits to assess nutritional quality and food safety. By integrating nutritional evaluation with toxicological assessment, this study provides baseline data on the elemental composition of avocado oils from a previously underreported African highland region. The findings are expected to support food safety monitoring, guide nutraceutical product development, and promote the economic valorization of avocado cultivation on the Mambila Plateau. Furthermore, the study contributes to national efforts aimed at expanding Nigeria's agro-processing sector and enhancing the global competitiveness of locally produced functional foods.

2.0 Materials and Methods

2.1 Study Area and Sample Collection

Avocado fruits were harvested from three cultivars—Hass, Maluma, and *Persea schiedeana*—grown on the Mambila Plateau, Taraba State, Nigeria. This region, located at an elevation of approximately 1,600 meters above sea level, is characterized by temperate climate, volcanic soils, and high rainfall, which contribute to the mineral richness of agricultural produce (Adeyeye, 2019). Fruits were randomly collected during peak ripening season (May–June) from multiple farms to ensure representative sampling. Each cultivar was identified based on morphological traits and local classification standards.

2.2 Sample Preparation and Oil Extraction

The fruits were washed with distilled water, peeled, and the pulp manually separated from the seeds. The pulp was homogenized using a stainless-steel blender and stored at −20°C prior to extraction. Oil was extracted using the Soxhlet method with analytical-grade **n-hexane** as solvent, following AOAC Official Method 945.16 (AOAC, 2019).

Approximately 50 g of dried pulp was placed in a cellulose thimble and extracted for 6 hours. The solvent was removed using a rotary evaporator at 40°C, and the extracted oil was stored in amber glass bottles at 4°C to prevent oxidative degradation.

This method has been widely adopted for avocado oil extraction due to its efficiency and reproducibility (Campos-Hernández et al., 2011; Borges et al., 2017).

2.3 Mineral Analysis

Mineral content was determined using wet acid digestion followed by Atomic Absorption Spectrophotometry (AAS). For each oil sample, 2 g was digested with a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a 3:1 ratio. Digestion was carried out on a hot plate at 120°C until a clear solution was obtained. The digested samples were filtered through Whatman No. 42 filter paper and diluted to 50 mL with deionized water.

The following minerals were quantified: Calcium (Ca), Magnesium (Mg), Potassium (K), Iron (Fe), Zinc (Zn), Phosphorus (P).

A PerkinElmer AAnalyst 400 AAS was used for quantification. Calibration curves were prepared using certified standard solutions, and instrument settings were optimized for each element. Phosphorus was determined using the vanadomolybdate colorimetric method due to its low sensitivity in AAS (Nasri et al., 2023).

Mineral concentrations were expressed in parts per million (ppm), and all measurements were performed in triplicate.

2.4 Heavy Metal Analysis

Heavy metals were analyzed using aqua regia digestion ($HCl:HNO_3$, 3:1) followed by AAS. Approximately 2 g of oil was digested at 120°C until complete dissolution. The resulting solution was filtered and diluted to 50 mL with deionized water. The following toxic metals were assessed: Lead (Pb), Cadmium (Cd), Arsenic (As), Mercury (Hg).

Detection limits were: Pb: 0.01 ppm, Cd: 0.005 ppm, As: 0.005 ppm, Hg: 0.001 ppm.

All measurements were benchmarked against WHO/FAO Codex Alimentarius standards for contaminants in edible oils (WHO/FAO, 2021). The absence or low levels of these metals are critical for validating the safety of avocado oil for human consumption and therapeutic use (Wang et al., 2020).

2.5 Quality Control and Reagents

All reagents used were of analytical grade. Glassware was acid-washed and rinsed with deionized water to prevent contamination. Blank samples and certified reference materials were run alongside test samples to ensure accuracy and precision. Calibration curves were validated with R^2 values ≥ 0.995, and recovery rates for spiked samples ranged between 95–102%.

2.6 Statistical Analysis

All experiments were conducted in triplicate, and results were expressed as mean ± standard deviation. Data were analyzed using SPSS version 25.0. One-way analysis of variance (ANOVA) was used to assess differences among cultivars, followed by Tukey's post-hoc test to identify specific group differences. Statistical significance was set at $p < 0.05$.

Instrumentation Summary

Instrument	Model	Purpose
Rotary Evaporator	Buchi R-300	Solvent removal after extraction
Atomic Absorption Spectrometer	PerkinElmer AAnalyst	Mineral and heavy metal analysis
UV-Vis Spectrophotometer	Jenway 7315	Phosphorus determination

3.0 Results and Discussion

This section presents the mineral and heavy metal profiles of avocado oils extracted from three cultivars—Hass, Maluma, and *Persea schiedeana*—grown on the Mambila Plateau. The results are discussed in the context of nutritional relevance, food safety, and potential industrial applications.

3.1 Mineral Composition of Avocado Oils

Table 1 presents the mineral composition of the three cultivars, including calcium, magnesium, zinc, iron, potassium and phosphorus.

Table 1. Mineral Composition of Avocado Pulp from Hass, Maluma, and Persea Schiedeana

Mineral (ppm)	Hass	Maluma	Persea schiedeana
Ca	7.1	10.3	**7.7**
Mg	22.6	32.5	**24.3**
Zn	3.2	6.3	**4.6**
Fe	0.7	1.4	**1.0**
K	29.6	44.7	**33.2**
P	9.0	3.8	**10.6**

Maluma oil exhibited the highest concentrations of calcium, magnesium, potassium, zinc, and iron. These minerals are essential for bone health, enzymatic activity, and cellular function (Adeyeye, 2019; Nasri et al., 2023). The elevated magnesium (32.5 ppm) and potassium (44.7 ppm) levels in Maluma suggest its potential as a functional oil for cardiovascular support and electrolyte balance. *Persea schiedeana* showed the highest phosphorus content (10.6 ppm), which plays a critical role in energy metabolism and nucleic acid synthesis. Hass had moderate levels across all minerals, with slightly higher phosphorus than Maluma.

These findings align with previous studies showing cultivar-dependent mineral variation in avocado oils (Campos-Hernández et al., 2011; González-Torres et al., 2023). The mineral richness of Maluma oil may be attributed to its genetic makeup and the mineral-dense volcanic soils of the Mambila Plateau.

3.2 Heavy Metal Content and Safety Assessment

In addition to essential minerals, the presence of toxic heavy metals in edible oils is a critical determinant of food safety and suitability for nutraceutical applications. Consequently, the concentrations of selected heavy metals—lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg)—were assessed in avocado oils from the three cultivars and compared with established WHO/FAO permissible limits. The results of this assessment are presented in Table 2, providing an evaluation of the safety status of the oils with respect to potential toxic metal contamination.

Table 2. Heavy Metals Contents of Avocado Pulp from Hass, Maluma and Persea Schiedeana

Heavy Metal	Hass	Maluma	Persea Schiedeana	WHO/FAO Limit
Lead (Pb) ppm	0.067	0.043	0.081	0.1 mg/kg
Cadmium (Cd) ppm	0.004	0.006	0.004	0.05 mg/kg
Arsenic (As) ppm	0.001	0.000	0.001	0.1 mg/kg
Mercury (Hg) ppm	ND	ND	ND	0.01 mg/kg

All oil samples were within WHO/FAO permissible limits for heavy metals (WHO/FAO, 2021), confirming their safety for human consumption. Lead levels ranged from 0.043 to 0.081 ppm, well below the 0.1 ppm threshold. Cadmium concentrations were minimal, and arsenic was either undetectable or present in trace amounts. Mercury was not detected in any sample.

Maluma oil had the cleanest heavy metal profile, with non-detectable arsenic and mercury, and the lowest lead concentration. This makes it particularly suitable for sensitive applications such as infant nutrition, therapeutic formulations, and cosmetics (Wang et al., 2020).

The absence of mercury across all samples is notable, as mercury contamination in oils is often linked to environmental pollution. These results suggest that the Mambila Plateau offers a relatively uncontaminated environment for avocado cultivation.

3.3 Nutritional and Industrial Implications

The mineral composition of avocado oil enhances its value beyond lipid nutrition. Oils rich in magnesium and potassium, like Maluma, may support cardiovascular health and muscle function. Zinc and iron contribute to immune support and oxygen transport, respectively (Nasri et al., 2023).

From an industrial perspective, the clean heavy metal profile across all cultivars supports their use in (i) functional foods: Fortified oils for dietary supplementation, (ii) cosmetics: Mineral-rich oils for skin and hair care and (iii) pharmaceuticals: Carrier oils for drug delivery systems.

Persea schiedeana, with its high phosphorus and moderate mineral levels, may be ideal for metabolic support formulations. Hass, with its balanced profile, remains a versatile option for general consumption and blending.

These findings are consistent with global research on avocado oil safety and composition. Borges et al. (2017) reported similar mineral ranges in Spanish avocado oils, while Campos-Hernández et al. (2011) emphasized the influence of cultivar and extraction method on elemental content. González-Torres et al. (2023) highlighted *P. schiedeana*'s nutritional potential, which this study confirms in the Nigerian context.

The mineral superiority of Maluma and the safety of all three cultivars position Nigerian avocado oils as competitive products in the global market. This supports the development of localized value chains and export opportunities for high-quality, health-promoting oils.

The mineral and heavy metal profiling of avocado oils from Hass, Maluma, and *Persea schiedeana* cultivars grown on the Mambila Plateau reveals important insights into their nutritional value and safety for consumption and industrial applications. The results demonstrate cultivar-specific variations in elemental composition, which are influenced by genetic factors, soil mineral availability, and agro-climatic conditions (Campos-Hernández et al., 2011; Adeyeye, 2019).

3.4 Mineral Composition and Nutritional Implications

Maluma oil exhibited the highest concentrations of calcium (10.3 ppm), magnesium (32.5 ppm), potassium (44.7 ppm), zinc (6.3 ppm), and iron (1.4 ppm), positioning it as the most mineral-rich among the three cultivars. These minerals are essential for various physiological functions. For example, (i) calcium and magnesium are critical for bone health, neuromuscular function, and enzymatic activity, (ii) potassium plays a key role in maintaining fluid balance, nerve transmission, and cardiovascular health and (iii) zinc and iron support immune function, oxygen transport, and cellular metabolism (Nasri et al., 2023; Wang et al., 2020).

The elevated mineral content in Maluma oil suggests its potential as a functional ingredient in nutraceutical formulations aimed at addressing micronutrient deficiencies. This aligns with findings by Borges et al. (2017), who emphasized the nutritional versatility of avocado oil when enriched with trace elements.

Persea schiedeana showed the highest phosphorus content (10.6 ppm), which is vital for energy metabolism and DNA synthesis. Its moderate levels of other minerals make it suitable for metabolic support applications. Hass, while exhibiting balanced mineral levels, had the highest carbohydrate content in the proximate analysis (from article one), which may influence its overall energy contribution when consumed.

These results confirm that avocado oil is not merely a lipid source but also a carrier of essential minerals, with cultivar-specific strengths that can be harnessed for targeted nutritional interventions.

All three avocado oils were found to be within WHO/FAO permissible limits for heavy metals, including lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) (WHO/FAO, 2021). Lead levels ranged from 0.043 to 0.081 ppm, cadmium from 0.004 to 0.006 ppm, and arsenic was either undetectable or present at 0.001 ppm. Mercury was not detected in any sample.

These findings are significant for several reasons because (i) lead and cadmium, even at low concentrations, are associated with neurotoxicity, renal dysfunction, and carcinogenicity. Their absence or minimal presence in these oils ensures safety for long-term consumption and (ii) arsenic and mercury, often introduced through environmental contamination, were undetectable, indicating the relative purity of the cultivation environment on the Mambila Plateau.

Maluma oil had the cleanest heavy metal profile, with the lowest lead concentration and non-detectable arsenic and mercury. This makes it particularly suitable for sensitive applications such as infant nutrition, therapeutic oils, and cosmetic formulations (Wang et al., 2020).

The absence of mercury across all samples is especially noteworthy, as mercury contamination in edible oils is often linked to industrial runoff and atmospheric deposition. These results suggest that the Mambila Plateau offers a relatively uncontaminated agro-ecological zone for avocado cultivation, supporting sustainable and safe agricultural practices.

The mineral and heavy metal profiles observed in this study are consistent with global literature. Campos-Hernández et al. (2011) reported similar elemental variations across avocado cultivars in Mexico, while González-Torres et al. (2023) highlighted the nutritional potential of *Persea schiedeana* in Latin America. Borges et al. (2017) found comparable mineral concentrations in Spanish avocado oils, reinforcing the global relevance of your findings.

However, this study is among the first to comprehensively profile Nigerian-grown avocado oils, filling a critical gap in regional data. The results validate the nutritional integrity and safety of these oils and support their inclusion in international quality standards.

The clean safety profile and mineral richness of these avocado oils open up multiple industrial pathways. In the functional food sector, Maluma oil can be incorporated into fortified products aimed at promoting bone health, cardiovascular support, and immune function. In cosmetics, oils rich in zinc and magnesium provide antioxidant and skin-repair benefits, making them suitable for use in topical formulations. In pharmaceutical applications, the absence of toxic heavy metals supports their use as safe carrier oils in drug delivery systems and other therapeutic formulations. From an economic standpoint, the findings support the development of localized value chains for avocado oil production in Nigeria. By leveraging the unique strengths of each cultivasr, producers can diversify product offerings and tap into export markets demanding clean-label, nutrient-rich oils.

3.5 Future Research Directions

While this study provides foundational data, future research should explore:

(i) Seasonal and geographical variations in mineral uptake
(ii) Bioavailability of minerals in oil matrices
(iii) Synergistic effects of mineral and lipid components on health outcomes
(iv) Optimization of extraction methods to preserve trace elements

Such investigations will further enhance the scientific and commercial value of Nigerian avocado oils and contribute to global efforts in sustainable nutrition and food safety.

4.0 Conclusion

This study provides a comprehensive evaluation of the mineral and heavy metal content of avocado oils extracted from Hass, Maluma, and *Persea schiedeana* cultivars grown on the Mambila Plateau, Nigeria. The results reveal that Maluma oil possesses the highest concentrations of essential minerals—including calcium, magnesium, potassium, zinc, and iron—making it a strong candidate for functional food and nutraceutical applications. *Persea schiedeana* stands out for its elevated phosphorus content, while Hass offers a balanced elemental profile suitable for general consumption.

Importantly, all three oils were found to be within WHO/FAO permissible limits for heavy metals, including lead, cadmium, arsenic, and mercury. This confirms their safety for human use and supports their inclusion in health-sensitive formulations such as cosmetics, therapeutic oils, and fortified foods.

The findings underscore the influence of cultivar and agro-ecological conditions on the elemental composition of avocado oil. They also highlight the untapped potential of Nigerian-grown varieties in both domestic and international markets. By integrating nutritional value with toxicological safety, this study lays the groundwork for the strategic development of avocado oil as a high-value agricultural product in Nigeria.

Future research should explore seasonal variations, bioavailability of minerals, and the interaction between lipid and elemental components to further optimize the health benefits and industrial versatility of these oils.

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Declaration

Conflict of interest

No conflict of interest declared by the authors.

Availability of Data

Data shall be made available upon request.

Ethical Consideration

The sensory evaluation involved voluntary adult panellists who provided informed consent. The study posed no health risk, and all food samples were prepared following standard food safety and hygiene practices. No clinical procedures or personal data collection were involved.

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Availability of Data

Data shall be made available upon request

Author Contributions

John Stanley conceived and designed the study, coordinated sample collection, and led data interpretation and manuscript drafting. Victoria John Danjuma carried out oil extraction, laboratory analyses, and data acquisition. Oyeyipo Titilayo Oluwakemi contributed to mineral and heavy metal analysis and quality control. Solomon James Efkah performed statistical analysis, supported result interpretation, and critically reviewed the manuscript. All authors approved the final version.