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Heavy Metal Profiling of Cashew Apple Products: Evaluating Safety and Nutritional Value

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Abstract

Heavy metals in food products pose significant health risks and require evaluation for safety and nutritional quality. Cashew apple juice and its concentrate were analyzed for manganese (Mn), chromium (Cr), cadmium (Cd), lead (Pb), zinc (Zn), and iron (Fe) using atomic absorption spectrophotometry. Results showed that essential metals such as Mn (0.123–0.145 mg/100 g), Cr (0.223–0.334 mg/100 g), Zn (2.84–5.21 mg/100 g), and Fe (0.41–17.54 mg/100 g) were present in nutritionally beneficial amounts, while toxic metals Cd (0.012–0.022 mg/100 g) and Pb (0.034–0.055 mg/100 g) remained below WHO guideline limits. Based on these findings, both cashew apple juice and its concentrate are safe for consumption and provide meaningful contributions to daily mineral intake.

Keywords: Cashew apple juice, Concentrate, Heavy metals, Nutritional value, Food safety, Atomic absorption spectrophotometry

Introduction

Heavy metals are elements with relatively high atomic weights and densities that distinguish them from lighter, non-metallic elements. Their persistence in the environment and capacity to bioaccumulate render them a significant concern in food safety and public health research (Izah et al., 2016; Omoyajowo et al., 2017). Although trace amounts of certain metals are essential for human metabolism, elevated concentrations can lead to toxicity, organ damage, and increased risk of chronic diseases (WHO, 2006). Heavy metal profiling of food products—including fruit juices—remains a critical step in assessing dietary exposure and ensuring compliance with regulatory safety standards such as those established by the World Health Organization (WHO).

Fruit juices are widely consumed for their perceived nutritional benefits, including micronutrient content and antioxidant properties. Cashew apple juice, derived from the accessory fruit of Anacardium occidentale, is particularly rich in vitamins, minerals, and bioactive compounds (Aluko et al., 2023). Prior research has documented its phenolic content, mineral composition, and bioaccessibility of essential elements like iron, copper, and zinc (de Lima et al., 2014). However, the susceptibility of fruit juices to heavy metal contamination—originating from environmental deposition, uptake during cultivation, and processing—necessitates systematic evaluation. Contemporary studies have reported detectable levels of potentially toxic elements such as lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni) in commercially available juices, raising concerns about cumulative exposure and health risks, especially for vulnerable populations like infants and children.

The presence of heavy metals in fruit products has been linked to multiple pathways of environmental contamination. Soil composition, irrigation with contaminated water, atmospheric deposition from industrial emissions, and processing equipment are all recognized vectors by which metals enter the food chain (Izah et al., 2016; Omoyajowo et al., 2017). In Nigeria, studies on fruits and fruit derivatives have documented measurable concentrations of metals such as zinc (Zn), iron (Fe), and chromium in edible plant tissues and juices; however, many findings also indicate that these concentrations often remain within permissible limits established by WHO and other regulatory bodies. Yet, occasional exceedances of chromium and nickel in apples and other fruits underscore the need for ongoing surveillance and quality control.

Furthermore, comparative analyses of heavy metal levels in diverse fruit juices highlight variability by region, fruit type, and processing method. For example, trace metals such as Pb, As, and Hg have been found in some processed fruit beverages at concentrations above drinking water standards, prompting evaluations of potential non-carcinogenic and carcinogenic risks associated with regular consumption (e.g., recent work on market juices in West Africa) (Doe et al., 2024). These insights emphasize the importance of fruit-specific investigations that consider both essential and toxic elements to inform risk assessment and consumer safety.

In this context, cashew apple juice—though nutritionally valuable—warrants targeted investigation for its heavy metal profile due to variability in its mineral content across geographic regions, cultivation practices, and processing conditions. This study therefore quantifies and compares key heavy metals in cashew apple juice and its concentrate, benchmarked against WHO drinking-water standards and dietary reference values. Such evaluation not only contributes to safety assessment but also informs understanding of the nutritional value and public health implications of these widely consumed products.

Experimental Methods

Determination of Heavy Metals

Heavy metals were determined using Atomic Absorption Spectrophotometry (AAS) following sample preparation by dry ashing in a muffle furnace. The ash obtained was dissolved in 10 mL of 1 N HCl, made up to 50 mL with distilled water, filtered, and analyzed using AAS. Analyses should be performed in triplicate and reported as mean ± standard deviation.

Statistical Analysis

Descriptive statistical method was used to analyses the data and t-test at $P<0.05$ level of significance. The SPSS used was version 25.

Results and Discussions

Results

Table 1: Comparative Heavy Metal Profile of Cashew Apple Juice and Cashew Apple Juice Concentrate

Heavy metals (mg/100 g)	Cashew Apple Juice	Cashew Apple Juice Concentrates	Recommended standard in water (mg/L), WHO 2005	WHO 2005 Daily value
Manganese (Mn)	0.123	0.145	0.5	2.3 mg
Chromium (Cr)	0.223	0.334	-	120 µg
Cadmium (Cd)	0.012	0.022	0.05	0.05 mg
Lead (Pb)	0.034	0.055	0.1	-
Zinc (Zn)	5.21	2.84	-	11 mg
Iron (Fe)	17.54	0.41	0.5	18 mg

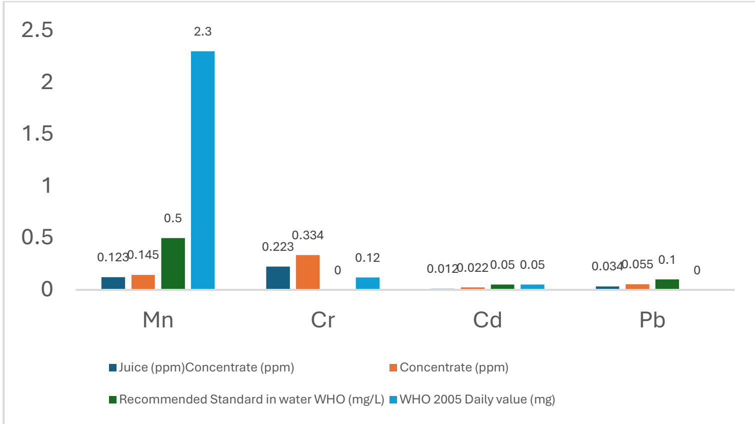

Fig. 1: Heavy metals (Mn, Cr, Cd and Pb) in cashew apple juice and its concentrate (ppm)

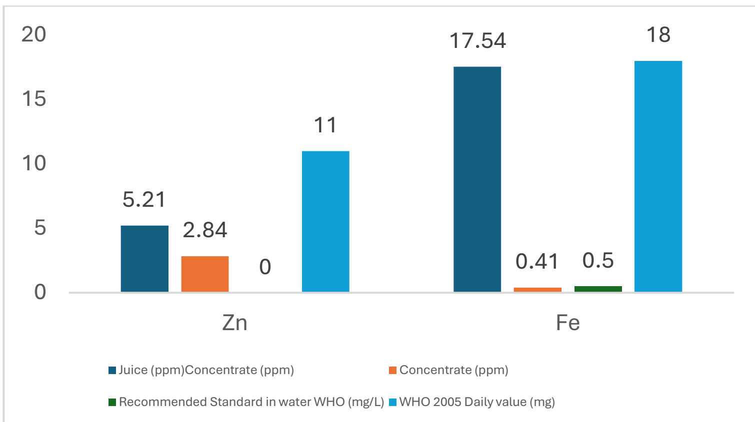

Fig. 2: Heavy metals (Zn and Fe) in cashew apple juice and its concentrate (ppm)

Discussion

The concentrations of selected heavy metals in cashew apple juice and its concentrate are summarized in Table 1 and visualized in Figure 1. The metals analyzed include manganese (Mn), chromium (Cr), cadmium (Cd), lead (Pb), zinc (Zn), and iron (Fe). Comparisons were made against WHO drinking-water standards and recommended daily values.

Figure 1 shows that manganese concentration was slightly higher in the concentrate (0.145 mg/100 g) than in the juice (0.123 mg/100 g). Both values are well below the WHO water standard (0.5 mg/L) and the recommended daily intake (2.3 mg), indicating that both products are safe and contribute beneficially to dietary manganese intake. Chromium content increased in the concentrate (0.334 mg/100 g) relative to the juice (0.223 mg/100 g), as depicted in Figure 1. Although WHO does not specify a water standard for chromium, the values remain well below the daily intake recommendation of 120 µg, suggesting that both the juice and concentrate provide chromium safely for human consumption.

Figure 1 illustrates that cadmium and lead concentrations remained low in both juice and concentrate. Cadmium was 0.012 and 0.022 mg/100 g, while lead was 0.034 and 0.055 mg/100 g for juice and concentrate, respectively. These values are below WHO guideline limits (0.05 mg/L for Cd and 0.1 mg/L for Pb), indicating minimal risk of toxicity even after concentration.

Zinc levels decreased in the concentrate (2.84 mg/100 g) compared to the juice (5.21 mg/100 g), as visualized in Figure 2. Despite this reduction, both products contribute meaningfully to the recommended daily intake of 11 mg, reinforcing the nutritional value of cashew apple products. Iron content was substantially higher in the juice (17.54 mg/100 g) than in the concentrate (0.41 mg/100 g), as clearly seen in Figure 2. The present study did not investigate the mechanism responsible for this difference; therefore, no specific processing-related cause was assigned from the available data. Nonetheless, the juice alone can fulfill nearly the entire daily requirement of 18 mg, confirming its suitability as a dietary iron source.

Figure 2 demonstrates the effects of concentration on mineral composition. While essential metals such as manganese and chromium are slightly enriched in the concentrate, zinc and iron are reduced. Toxic metals, including cadmium and lead, remain well below WHO safety thresholds, confirming the safety of both cashew apple juice and its concentrate. This comparison emphasizes that proper processing preserves both safety and nutritional quality.

The safety and nutritional value of cashew apple juice and its concentrate are closely linked to their heavy metal composition. In this study, essential metals such as manganese (Mn), chromium (Cr), zinc (Zn), and iron (Fe) were quantified alongside toxic metals including cadmium (Cd) and lead (Pb). Essential metals contribute to key physiological and metabolic functions in humans. For instance, manganese is a cofactor for several enzymes involved in metabolism and antioxidant defense (Valko *et al.*, 2005), while zinc plays a critical role in immune function, wound healing, and growth (WHO, 2003). Iron, particularly abundant in the juice (17.54 mg/100 g), is necessary for hemoglobin synthesis and oxygen transport, and contributes substantially to the daily recommended intake (WHO, 2006). Chromium, although present in smaller amounts, is important for glucose metabolism and insulin regulation (Florea & Büsselberg, 2006). The retention of these essential metals in both the juice and concentrate highlights the products' nutritional value.

From a safety perspective, the measured concentrations of toxic metals were well below WHO guidelines for drinking water and dietary limits (WHO, 2005). Cadmium levels were 0.012 mg/100 g in juice and 0.022 mg/100 g in concentrate, below the WHO limit of 0.05 mg/L. Lead concentrations were similarly low (0.034 mg/100 g in juice and 0.055 mg/100 g in concentrate) compared with the permissible 0.1 mg/L threshold. Chronic exposure to these toxic metals can cause renal, neurological, and hematological disorders (Järup, 2003; Wani et al., 2015).

The low concentrations observed in cashew apple products indicate minimal health risk, confirming that both juice and concentrate are safe for consumption.

Taken together, Figures 1 and 2 show that concentration did not affect all measured metals uniformly. Because metal determination was carried out after dry ashing, the values represent total measured metal content rather than mineral bioavailability. Consequently, the lower zinc and iron concentrations in the concentrate should not be attributed to binding interactions, and the present data do not establish a specific mechanism for the observed differences. Further investigation of individual processing steps would be required to explain these changes.

Overall, the combined evaluation of heavy metal content confirms that cashew apple juice and its concentrate are nutritionally beneficial and safe for consumption. Essential metals contribute significantly to human dietary requirements, whereas toxic metals remain below harmful thresholds. These findings support the inclusion of cashew apple products in diets as a safe source of key minerals, while emphasizing the importance of routine monitoring to ensure continued compliance with safety standards.

Conclusions

The results of this study demonstrate that both cashew apple juice and its concentrate contain essential heavy metals - manganese (Mn), chromium (Cr), zinc (Zn), and iron (Fe) - at concentrations that contribute positively to human nutrition, while toxic metals - cadmium (Cd) and lead (Pb) - remain below WHO guideline limits. Manganese and chromium were slightly higher in the concentrate, whereas zinc and iron were lower. Since the study did not investigate the mechanism responsible for these changes, the differences are reported without attributing them to thermal volatilization, binding interactions, or altered bioavailability.

Cadmium and lead concentrations were minimal in both juice and concentrate, remaining well below the WHO recommended limits of 0.05 mg/L for cadmium and 0.1 mg/L for lead. These findings indicate that consumption of cashew apple juice and its concentrate does not pose a substantial risk of heavy metal toxicity, corroborating previous assessments of safety in fruit-based beverages (Järup, 2003; Wani et al., 2015). The bar chart analysis illustrates the effects of processing, highlighting the balance between nutritional enrichment and safety compliance.

Generally, the combined evaluation of essential and toxic heavy metals confirms that cashew apple juice and its concentrate are both nutritionally valuable and safe for consumption. The juice is particularly rich in iron, providing nearly the full daily requirement, while all other essential metals contribute meaningfully to dietary intake. The low levels of toxic metals underscore the effectiveness of safe agricultural practices and controlled processing. These findings support the inclusion of cashew apple products in human diets as a reliable source of key micronutrients, while emphasizing the importance of routine monitoring and quality control to ensure sustained safety and nutritional quality.

Supplementary Material

Not applicable.

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