**Macro and micro elements in sweet potatoes cultivated in Senegal and risk assessment**

**ABSTRACT**

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| --- |
| Leaves and tubers were harvested from a white sweet potato plantation located in a rural area in Senegal. The macro (Na, K, Mg, Ca) and micro (Fe, Ni, Cu, Zn and Cd) elements contents in the leaves, peels, and flesh of sweet potatoes were analyzed. The samples were wet digested, and the metals were analyzed by atomic absorption spectroscopy. Na concentrations were measured at 2547.30, 1079.15, and 754.2 mg/kg in leaves (I), peels (II), and flesh (III), respectively. Potassium was detected at concentrations of 19682.14, 12876.53, and 10326.44 mg/kg in I, II and III, respectively. The Mg concentration was measured to be 7601.36, 1458.66 and 729.85 mg/kg in samples I, II and III. Calcium was found at values ​​of 7677.51, 2683.96 and 1644.85 mg/kg in I, II and III, respectively. The iron concentrations were 126.53, 21.94 and 91.31 mg/kg in I, II and III. Nickel contents are 6.13 (I), 3.74 (II) and 9.09 mg/kg (III). Copper and zinc were found to be 5.38 (I), 3.28 (II) and 2.11 mg/kg (II) for Cu and 15.80 (I), 6.81 (II) and 6.01 mg/kg (II) for Zn. Cadmium contents are 2.48 (I), 1.80 (II) and 1.90 mg/kg (III). According to this study, sweet potato leaves have higher contents of all elements than peels and flesh. Na/K being less than 1, which is the recommended value in the three parts of the plant studied (0.129 (I), 0.084 (II) and 0.070 (III)). Thus the consumption of sweet potato and its leaves and peels could prevent high blood pressure. The Ca/Mg ratios for leaves and peels, which are 1.01 and 1.84, are within the recommended values ​​(between 1 and 2) to be beneficial for consumers. For the flesh, the Ca/Mg ratio value is 2.25 and is outside the recommended limits. |

*Keywords: Sweet potato, leaves, peel, heavy metal, atomic absorption spectroscopy, health risk.*

# Introduction

Sweet potato (*Ipomoea batatas L.*) is a vegetable belonging to the Convolvulaceae family, which is widely cultivated throughout the world and particularly in West Africa. The area sown worldwide is around 7.4 million hectares for an annual global production of 89.5 million tons in 2020 (FAO, 2020). In Senegal, production, which was 70,000 tons in 2016, has steadily increased to reach 110,600 tons in 2022 (ANSD, 2023). It is a food plant widely used in community nutrition improvement programs due to its high caloric value of 123 calories/100 grams. The tuber contains carbohydrates, minerals and various vitamins important for good nutrition (Guclu et al., 2023; Kp et al., 2012). Sweet potato leaves are used in several culinary specialties and are consumed in large quantities in Africa (Ayeleso et al., 2024; S. Laurie et al., 2015; Ngcobo et al., 2024), particularly in Tanzania and Malawi, which are among the largest producers in the world (Adam et al., 2015; Chambukira et al., 2025; Feukeng et al., 2024; Malley et al., 2025). Sweet potato is ranked among the most beneficial agricultural products for human consumption (Amoanimaa-Dede et al., 2019; Przybył et al., 2022). Both the consumption of its tubers and its leaves offer health benefits to consumers (Rivera-Espejel et al., 2019). There are several varieties that produce tubers whose flesh can be white, yellow, red, purple or orange (Ivane et al., 2024; Putri et al., 2024; X. Wang et al., 2024). The colorful flesh of the sweet potato, which contains high levels of carotene and anthocyanin, explains its use as an important food in human nutrition. Although the roots, peels, and leaves of sweet potatoes have different chemical compositions, they are edible due to their content of bioactive substances and nutrients (S. Wang et al., 2016). Sweet potato production and consumption vary considerably depending on the region. Soil conditions, fertilizer use, and manure use can impact harvest quality. Indeed, the use of manure helps improve soil quality by reducing heavy metal levels, which can inhibit the photosynthesis process essential for plant growth (Singh et al., 2010). In this process, chlorophyll can be destroyed by the replacement of the magnesium atom with a heavy metal atom, preventing this complex from playing its fundamental role in plant growth. In these cases, crops can be contaminated by heavy metals (Gzik et al., 2003; Shen et al., 2022). In this work we seek to study the quality of sweet potato harvests and by-products of this plant with regard to contamination by heavy metals and the risk to consumer health of the presence of these contaminants and the presence of micronutrients useful for nutrition.

# Materials and methods

## Instrumentation

All experiments were carried out using a Thermo Fischer Atomic Absorption 3000. The samples were run in triplicates and the values reported are mean of triplicates. Analytical conditions, limits of detection and the calibration variables obtained for the studied elements are given in Table 1.

## Reagents and standards

All solutions were prepared with distilled-deionized water (18MΩcm, Milli-Q, Millipore, Bedford, MA, USA). Sulfuric acid (H2SO4 , 98%), perchloric acid (HClO4, 70%) and nitric acid (HNO3 65%), from Sigma-Aldrich France, were used in the procedure of digestion of the samples. The analytical solutions were prepared from standard solution dilutions 1000 μgmL-1 of Na, K , Mg, Ca, Fe, Ni, Cu, Zn and Cd (Aldrich, France). All materials used were decontaminated in nitric acid solution 10% v/v by 24 h. Leaves and tubers were harvested from a white sweet potato plantation located in a rural area in Senegal.

## Extraction of heavy metals from leaves, peels and flesh of sweet potatoes

Five grams of leaves, peels or flesh of sweet potatoes were weighed and collected in a Kjeldahl flask. Wet digestion was carried out with an acid mixture (3:2:1 nitric acid, perchloric acid and sulfuric acid) for 4 hours to obtain a clear solution. The samples were cooled to room temperature and the volume was made up to 100 mL with ultra-pure water (Manrique et al., 2023). They are stored in the refrigerator in food grade polyethylene bottles previously washed with a 6N nitric acid solution.

**Table 1 : Analytical conditions and calibration curves for Na, K, Mg, Ca, Fe, Ni, Cu, Zn and Cd analysis by Atomic Absorption Spectroscopy.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Mineral | Wavelength (nm) | Range of detection (mg/L) | Correlation coefficient (R2) | Calibration curve equation |
| Sodium | 598 | 0.02-0.8 | 0.9902 | y = 117.82x +11.405 |
| Potassium | 766.5 | 0.03-1.6 | 0.9910 | y = 0.0479x - 0.0112 |
| Magnesium | 285.2 | 0.003-0.6 | 0.9914 | y = 0.4757x + 0.0033 |
| Calcium | 422.7 | 0.005-4 | 0.9976 | y = 0.0064x - 0.0026 |
| Iron | 248.3 | 0.05-0.8 | 0.9965 | y = 0.0268x + 0.0069 |
| Nickel | 232 | 0.09-8 | 0.9983 | y = 0.0162x + 0.0053 |
| Copper | 324.8 | 0.01-4 | 0.9983 | y = 0.1081x + 0.0029 |
| Zinc | 213.9 | 0.005-1.6 | 0.9935 | y = 0.1638x + 0.0048 |
| Cadmium | 228.8 | 0.004-1.8 | 0.9974 | y = 0.0685x +0.0015 |

## Human Health Risk Assessment

Consumption of leaves, peels and flesh of sweet potatoes containing heavy metals may pose a risk to human health. This risk can be assessed based on the estimated daily intake (EDI) (equation 1) of heavy metals, the target hazard quotient (THQ) (equation 2) and the hazard index (HI) (equation 3). To estimate the daily metal burden in the body of a consumer of a given body weight, the estimated daily intake (EDI) was calculated using the following equation 1 (Adefa & Tefera, 2020; Oladeji et al., 2024).

*EDI* = $\frac{Cn\*IR\*EF\*ED}{BW\*AT\*1000}$ equation 1

(*EDI* is the estimated daily intake of heavy metals ingested from an agricultural crop in mg/kg day, *Cn* is the concentration of heavy metal in agricultural crop measured in mg/kg, *IR* is the ingestion rate which is measured in mg/day, *EF* is the exposure frequency in days/year, *ED* is the exposure duration over years, *BW* is the body weight of the exposed individual in kg, *AT* is the time period over which the dose is averaged in days as seen in Table 2).

**Table 2. Exposure parameters for health risk assessment through various exposure pathways for plants** (US Environmental Protection Agency, 2004)

|  |  |  |
| --- | --- | --- |
| Parameter | Unit | Adult |
| Body weight | Kg | 70 |
| Exposure frequency (EF)  | days/year | 350 |
| Exposure duration (ED) | year | 30 |
| Ingestion rate (IR) | mg/day | 100 |
| Plant adherence factor (AF) | mg/cm2 | 0.07 |
| Dermal absorption factor (ABS) | None | 0.1 |
| Dermal exposure ratio (FE) | None | 0.61 |
| Average time (AT): For carcinogens  | Days | 365 x 70 |
| For Non-carcinogens | Days | 365 x ED |

## Target Hazard Quotient (THQ)

Prolonged exposure to heavy metals from agricultural crop may pose a carcinogenic risk to consumers. This risk is assessed using the target hazard quotient (THQ) method calculated, according to equation 2, as a percentage of the determined dose relative to the reference dose (RFD) (USEPA, 2013). If the THQ is less than 1, no risk to human health is expected; if the THQ is greater than 1, adverse health effects could occur. The THQ is calculated as the ratio of the average daily intake (EDI) to the reference dose (RFD, Table 3) (equation 2) :

$THQ= \frac{EDI}{RFD}$ equation 2

**Table 3. Reference doses (RFD) used for Fe, Ni, Cu, Zn and Cd.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Metal** | Fe | Ni | Cu | Zn | Cd  |
| **RFD (mg)** | 3 | 0.02 | 0.04 | 0.3 | 0.001 |

## Hazard Index

Consumption of leaves, peels and flesh of sweet potatoes containing several heavy metals can pose a significant risk to the consumer's health. Indeed, the effects of these different toxic metals can be additive. The hazard index (HI) is a tool for assessing the total non-carcinogenic risk induced by these metals on human health. The HI is calculated according to equation 3 using the sum of the individual THQ of each metal hazardous to human health. The health risk level is low if HI < 1, while the health risk is high if HI > 1.

$HI=\sum\_{}^{}THQ$ equation 3

**Table 4. Metal levels in triplicate (mg/Kg) and Provisional Tolerable Weekly Intake (PTWI) values for metals** (Agency for Toxic Substances and Disease Registry (ATSDR), 1994; Abd-Elghany et al., 2020)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Element (μg/Kg) | Leaves | Peels | Tubers | PTWI for a 70-kg Individual (mg/week) | LOD (mg/l) |
| Na | 2547.30 ± 0.008 | 1079.15 ± 0.02 | 754.20 ± 0.02 | 14000  | 0.030 |
| K | 19682.14 ± 0.72 | 12876.53 ± 0.17 | 10326.44 ± 0.10 | 24500 | 0.2 |
| Mg | 7601.36 ± 0.02 | 1458.66 ± 0.09 | 729.85 ± 0.01 | 2940 | 0.0008 |
| Ca | 7677.512 ± 0.11 | 2683.96 ± 0.09 | 1644.85 ± 0.18 | 8400 | 0.0007 |
| Fe | 126.53 ± 0.09 | 21.94 ± 0.04 | 91.31 ± 0.04 | 392 | 0.001 |
| Ni | 6.13 ± 0.08 | 3.74 ± 0.07 | 9.09 ± 0.07 | 2.450 | 0.0012 |
| Cu | 5.38 ± 0.02 | 3.28 ± 0.01 | 2.11 ± 0.01 | 245 | 0.001 |
| Zn | 15.80 ± 0.01 | 6.81 ± 0.01 | 6.01 ± 0.00 | 490 | 0.001 |
| Cd | 0.248 ± 0.01 | 0.180 ± 0.02 | 0.190 ± 0.01 | 0.490 | 0.0004 |

PTWI: Provisional Tolerable Weekly Intake**,**  LOD: Limit Of Detection.

# Results and Discussion

### Levels of minerals in leaves, peels and flesh of sweet potatoes.

Sweet potato leaves, peels and flesh contain minerals with varying contents (Table 4). Leaves are richest in sodium (2547.30 mg/kg), followed by peels (1079.15 mg/kg), with flesh being the least rich in sodium (754.20 mg/kg). Potassium is the most abundant element in all parts of the plant as observed in agricultural products (Audu & Aremu, 2012). Leaves are richer (19682.14 mg/Kg) than peels (12876.53 mg/Kg) which are richer than sweet potato flesh (10326.44 mg/Kg). These values ​​are consistent with the levels reported in a study of several sweet potato varieties grown in China (Zhao et al., 2024). The potassium-sodium ratios calculated for the different parts of the plant: leaves (0.129), peel (0.084), and flesh (0.073) are lower than the recommended value (1) for nutritional ratios. Indeed, a K/Na ratio lower than 1 is beneficial for the prevention of high blood pressure. Consuming different parts of this plant may be beneficial for consumers' cardiovascular health. Magnesium and calcium concentrations are higher in the leaves, which have levels of 7601.36 mg/kg and 7677.51 mg/kg, respectively. The peels revealed a lower presence of magnesium and calcium with respective contents of 1458.66 mg/Kg and 2683.96 mg/Kg. The sweet potato flesh was poorer in magnesium (729.85 mg/Kg) and calcium (1644.85 mg/Kg). These values ​​found are in the range of values ​​reported for several varieties of sweet potatoes (Awol, 2014; Lamaro et al., 2023; Zhao et al., 2024). The recommended calcium-magnesium ratio is between 1 and 2. The calcium-magnesium ratio values ​​calculated for the leaves (1.01) and peels (1.84) are consistent with the guideline value and confirm that the consumption of leaves and sweet potatoes is beneficial to consumers' health. The flesh of the sweet potato studied has a Ca/Mg ratio of 2.25, which is outside the recommended limits. The amounts of sodium, potassium, magnesium, and calcium present in the different parts of the plant can help ensure the necessary daily intake of these macronutrients.

The WHO has not defined a guideline value for iron in foods. However, it recommends intakes adapted according to the age and sex of the consumer. It sometimes recommends supplementation for certain categories of consumers such as pregnant women, children and the sick to avoid the effects of iron deficiency (Stoffel et al., 2020). Consuming sweet potato leaves is a good way to improve iron intake with a content of 126.53 mg/Kg. The iron contents of the peels (21.94 mg/Kg) and sweet potato flesh (91.31 mg/Kg) are lower, but these parts can also be consumed to contribute to the daily iron intake. These levels are comparable to values ​​reported for sweet potato varieties (Awol, 2014; Kambabazi et al., 2021).

Nickel element is toxic at low concentrations. Prolonged exposure can lead to various pathologies such as high blood pressure, cardiovascular disease, neurological deficits, and developmental disorders in children (Coogan et al., 1989; Ssempijja et al., 2020). The WHO has not established any standards for nickel. However, some authors have estimated the daily dietary intake of nickel to be between 70 μg and 400 μg (Nielsen, 2021). Ni content is higher in sweet potato flesh (9.09 mg/kg) than in leaves (6.13 mg/kg) and peels (3.74 mg/kg). These values ​​are higher than those reported for several sweet potato varieties grown in Asia (Moura et al., 2021).

The concentration of copper is higher in leaves with a value of 5.38 mg/Kg. The peels present a concentration of 3.28 mg/Kg, while the flesh of sweet potato contains copper at 2.11 mg/Kg. These values ​​are lower than the limit value of 20 mg/kg, defined by WHO/FAO (Mutune et al., 2014). Consumption of the different parts of the plant studied is safe from the point of view of the presence of copper.

The zinc content of sweet potato leaves (15.80 mg/Kg) differs significantly from the content in the peel (6.81 mg/Kg) and in the flesh of sweet potato (6.01 mg/Kg).These values ​​are comparable to those reported in the literature (S. M. Laurie et al., 2012). These Zn levels in the different parts of the sweet potato plant are well below the limit of 50 mg/kg recommended by the WHO (FAO/WHO, 2002). The zinc concentration of these samples does not pose any particular risk for the consumption of this plant and its byproducts.

Metallic cadmium is highly toxic and is slowly eliminated after ingestion. It can cause serious damage to the body. Its presence in crops must be closely monitored. In this study, cadmium concentrations were 0.248 mg/kg in leaves, 0.180 mg/kg in peels and 0.190 mg/kg in the flesh of sweet potatoes. The levels found for the three parts of this plant are higher than those reported for several varieties of sweet potatoes (Luis et al., 2014). As with all metals analyzed, it appears that the leaves are richer in cadmium. However, these values ​​are lower than the value set by the WHO, which is 0.490 mg/kg (FAO/WHO, 2006). These parts of the plant do not pose any problems for human health from the point of view of Cd concentration.

### Health Risk Assessment of Heavy Metals Analyzed

The health risks associated with the presence of metals in harvested crops are assessed by determining the estimated daily intake (EDI) of these elements in consumers. The estimated daily intake (EDI) includes the consumer's body weight, frequency, and duration of consumption. Table 5 presents the estimated daily intakes (EDI) of the different elements. The values ​​found for the heavy metals Fe, Ni, Zn, and Cd are lower than the reference doses, which suggests that the consumption of preparations based on sweet potato leaves, peel, or flesh does not pose a significant risk to consumer health..

**Table 5. Estimated daily intake (μg/Kg/day) according to the average concentration of each metal in leaves, peels and peeled tubers of white sweet potatoes for adults**

|  |  |  |  |
| --- | --- | --- | --- |
| **Part of plant** | **Leaves of sweet potato** | **Peels of sweet potato** | **Flesh of sweet potato** |
| Na | 1.495 | 6.34 x 10-1 | 4.43 x 10-1 |
| K | 11.55 | 7.56 | 6.06 |
| Mg | 4.46 | 8.56 x 10-1 | 4.28 x 10-1 |
| Ca | 4.51 | 1.58 | 9.66 x 10-1 |
| Fe | 7.43 x 10-2 | 1.29 x 10-2 | 5.36 x 10-2 |
| Ni | 3.60 x 10-3 | 2.20 x 10-3 | 5.34 x 10-3 |
| Cu | 3.16 x 10-3 | 1.93 x 10-3 | 1.24 x 10-3 |
| Zn | 9.27 x 10-3 | 4.00 x 10-3 | 3.52 x 10-3 |
| Cd | 1.46 x 10-4 | 1.06 x 10-4 | 1.11 x 10-4 |

### Non-carcinogenic risk assessment

Table 6 presents the non-carcinogenic risk quotient (THQ) and the non-carcinogenic risk index (HI). For all heavy metals Fe, Ni, Cu, Zn and Cd in the various organs of sweet potato, the THQ values ​​are all less than 1. These findings suggest that the consumption of preparations made from leaves, peels, or flesh of sweet potato poses no health risks to consumers. The HI values ​​are less than 1 for leaves, peels and flesh of sweet potato. This indicates that the combined effects of the various heavy metals in sweet potato and its byproducts preparations pose no long-term health risks to consumers. Our results are similar to those reported by other authors who report THQ and HI values ​​lower than 1 for numerous varieties of sweet potatoes (Huang et al., 2020; Liu et al., 2024).

**Table 6. HQ and HI (mg/kg/day) of each heavy metal in leaves, peels and peeled tubers for adults**

|  |  |  |  |
| --- | --- | --- | --- |
| **Element** | **THQ (Leaves)** | **THQ (Peels)** | **THQ (Flesh)** |
| Fe | 2.476 x 10-2 | 4.293 x 10-3 | 1.787 x 10-2 |
| Ni | 1.799 x 10-1 | 1.098 x 10-1 | 2.668 x 10-1 |
| Cu | 7.896 x 10-2 | 4.818 x 10-2 | 3.097 x 10-2 |
| Zn | 3.091 x 10-2 | 1.333 x 10-2 | 1.176 x 10-2 |
| Cd | 1.455 x 10-1 | 1.057 x 10-1 | 1.115 x 10-1 |
| **HI** | **4.602 x 10-1** | **2.812 x 10-1** | **4.390 x 10-1** |

THQ: Target Hazard Quotient, HI: Hazard Index.

# Conclusion

Analysis of leaves, peels and sweet potatoes flesh for mineral content show the present of macro-nutriments (Na, K, Ca, Mg) and micronutrients (Fe, Ni, Zn, Cd). Periodic assessment of metal concentrations in consumed crops and the creation of quality control criteria is essential for public health because of the high toxicity of certain micronutrients at a high level. In this study, the K/Na and Ca/Mg ratios, which are criteria to assess the risk on health, are within the guideline values ​​to ensure a benefit to consumer health. This study also revealed that the microelements (Fe, Ni, Zn, Cd) studied in sweet potato do not present any carcinogenic risk to consumers. Indeed, for the leaves, peels and flesh of sweet potato, the THQ is less than 1 for each micro-nutriment. It was also observed for each consumed part of the plant that the HI is less than 1. These results show that for this harvest there is no risk to consumer health.

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