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Site Specific and Processing Effects on Oxalate–Mineral Ratios in Hibiscus from Kwilu Province / DR Congo

[Effets spécifiques des sites et des méthodes de cuisson sur les rapports oxalate-minéraux dans quelques espèces d'hibiscus de la province de Kwilu / République Démocratique du Congo]

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Abstract

This study examines the mineral composition and the oxalate-to-calcium, magnesium, and iron molar ratios in five Hibiscus species, considering both their provenance and traditional processing methods. Mineral analysis revealed the presence of Ca, Mg, K, P, Fe, Se, and trace amounts of Zn. The highest iron content was recorded in Hibiscus acetosella red shield (HARS) from Idiofa (0.71 g/100 g of dry material), while the lowest occurred in H. acetosella cranberry (HAC) from Kikwit (0.09 g/100 g). Selenium levels were greatest in HARS from Kikwit (0.53 g/100 g) and lowest in H. cannabinus (HC) from Idiofa (0.04 g/100 g). Potassium was most abundant in H. sabdariffa var. altissima (HSA) from Kikwit (0.96 g/100 g). The highest Ca and Mg concentrations were found in HSA and H. sabdariffa var. sabdariffa (HSS) from Kikwit, with 0.33 g/100 g Ca and 0.28 g/100 g Mg, respectively. Molar oxalate/Ca ratios were below 1 for all species except HC, indicating generally good calcium bioavailability. In contrast, oxalate/Fe ratios exceeded 1 in all species except HSA, suggesting limited iron bioavailability. Sun-drying increased oxalate–mineral molar ratios despite previously reported reductions in oxalate content, and oven-drying caused an even greater increase. Prolonged soaking of dried leaves resulted in substantial mineral losses and a marked rise in oxalate–mineral ratios. Conversely, the traditional use of artisanal potash reduced these ratios, thereby enhancing mineral bioavailability.

Keywords: Hibiscus, oxalate, calcium, magnesium, iron, bioavailability, traditional processing.

Résumé

Cette étude examine la composition minérale et les rapports molaires oxalate/calcium, magnésium et fer de cinq espèces d'Hibiscus, en tenant compte de leur provenance et des méthodes de transformation traditionnelles. L'analyse minérale a révélé la présence de Ca, Mg, K, P, Fe, Se et de traces de Zn. La teneur en fer la plus élevée a été observée chez Hibiscus acetosella red shield (HARS) d'Idiofa (0,71 g/100 g de matière sèche), tandis que la plus faible a été relevée chez H. acetosella cranberry (HAC) de Kikwit (0,09 g/100 g). Les teneurs en sélénium étaient les plus élevées chez HARS de Kikwit (0,53 g/100 g) et les plus faibles chez H. cannabinus (HC) d'Idiofa (0,04 g/100 g). Le potassium était le plus abondant chez H. sabdariffa var. altissima (HSA) de Kikwit (0,96 g/100 g). Les concentrations les plus élevées en calcium et en magnésium ont été trouvées chez HSA et H. sabdariffa var. sabdariffa (HSS) de Kikwit, avec respectivement 0,33 g/100 g de Ca et 0,28 g/100 g de Mg. Les rapports molaires oxalate/Ca étaient inférieurs à 1 pour toutes les espèces, à l'exception de HC, indiquant une bonne biodisponibilité du calcium. En revanche, les rapports oxalate/Fe étaient supérieurs à 1 pour toutes les espèces, sauf HSA, suggérant une biodisponibilité du fer limitée. Le séchage au soleil a augmenté les rapports molaires oxalate/minéraux malgré les réductions de teneur en oxalate précédemment observées, et le séchage au four a entraîné une augmentation encore plus importante. Le trempage prolongé des feuilles séchées a provoqué des pertes minérales substantielles et une forte augmentation des rapports oxalate/minéraux. À l'inverse, l'utilisation traditionnelle de potasse artisanale a réduit ces rapports, améliorant ainsi la biodisponibilité des minéraux.

Mots-clés: Hibiscus, oxalate, calcium, magnésium, fer, biodisponibilité, préparation traditionnelle

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1. Introduction

Green leafy vegetables are a cornerstone of diets in tropical regions, where they provide affordable, nutrient-dense sources of vitamins, minerals, and bioactive compounds. Their consumption is remarkably high across Africa: urban populations in Kenya consume more than 147 kg•person^{-1}•year^{-1}, while intake reaches 50 kg•person^{-1}•year^{-1} in Ethiopia and 40 kg•person^{-1}•year^{-1} in Ghana (Ruel et al., 2005; Dinssa et al., 2016). In the Kwilu Province of the Democratic Republic of Congo (DRC), leafy vegetables play an even more central role, with an estimated daily consumption of about 250 g per person (Grubben, 1975). Commonly consumed species include pigweed (Amaranthus spp.), cassava leaves (*Manihot esculenta*), sweet potato leaves (*Ipomoea batatas*), and several Hibiscus species, all valued for both their nutritional importance and their cultural relevance in local cuisines.

Despite their benefits, leafy vegetables also contain anti-nutritional factors such as oxalates, phytates, and cyanogenic glycosides. Oxalates are particularly noteworthy because of their strong ability to bind essential minerals. High oxalate levels, frequently reported in vegetables like amaranth and celosia, can substantially reduce the bioavailability of calcium, magnesium, and iron by forming insoluble complexes that are poorly absorbed in the human digestive tract (Radek & Savage, 2008). Elevated oxalate intake has also been associated with an increased risk of calcium oxalate kidney stones (Bahadoran et al., 2022), underscoring the importance of understanding oxalate–mineral interactions in widely consumed vegetables.

Previous studies have shown that several Hibiscus species cultivated in Kwilu Province contain considerable amounts of oxalates (Kayembe et al., 2018). Given the widespread consumption of these species, it is essential to understand how oxalates interact with nutritionally important minerals to assess their true dietary value. Oxalate readily forms insoluble salts with Ca, Mg, and Fe, thereby reducing their absorption and potentially contributing to mineral deficiencies in populations that rely heavily on plant-based diets. Moreover, traditional processing practices, such as sun-drying, oven-drying, prolonged soaking, and the use of artisanal potash, are known to influence oxalate levels and may therefore alter mineral bioavailability (Mabaya et al., 2025).

This study aims to determine the mineral composition of five Hibiscus species cultivated in the two principal production areas of Kwilu Province (Kikwit and Idiofa) and to assess the bioavailability of calcium, magnesium, and iron through oxalate-to-mineral molar ratios as influenced by traditional processing methods. By integrating mineral profiling with oxalate–mineral interaction analysis under realistic culinary practices, the study provides a comprehensive evaluation of the nutritional implications associated with the consumption of Hibiscus species in the DRC.

2. Material and methods

2.1. Material

Five species of *Hibiscus*, namely *H. sabdariffa var sabdariffa* (HSS), *H. sabdariffa var altisima* (HSA), *H. acetosella red shied* (HARS), *H. acetosella cranberry* (HAC), and *H. canabinus* (HC) were cultivated in experimental gardens in Kikwit and Idiofa. Collected leaves after 60 days were placed in airtight containers and taken to the laboratory for analysis. After washing and drying, they were grounded to give powders used for analysis.

2.2. Equipments

Sample preparation and analytical procedures were carried out using laboratory equipment selected to ensure precision and reproducibility throughout the study. Sample drying was performed in a HERAEUS GS forced-air drying oven, providing stable temperature control for moisture removal. Calcination of plant material was conducted in a NABERTHERM muffle furnace, which ensured uniform high-temperature treatment for ash production. All mass measurements were obtained using a SARTORIUS precision digital balance, guaranteeing high accuracy during reagent preparation and sample handling. Mineral composition was determined using an X POS III energy-dispersive X-ray fluorescence (ED-XRF) spectrometer, employing the “FP-Pellets CGEA” and “TQ-Pellets Fast” analytical methods for quantitative elemental analysis. Calibration and quality assurance were performed using certified reference materials (ISE870, ISE890, ISE919, ISE961, and SOIL-7), each containing known concentrations of target elements. The spectrometer was interfaced with a computer system for automated data acquisition, processing, and storage of spectral results.

2.3. Reagents

All reagents used in this study were analytical-grade chemicals supplied by HIMEDIA. The following compounds were employed: ammonium hydroxide (NH_4OH), calcium chloride ($CaCl_2$), hydrochloric acid (HCl), potassium permanganate ($KMnO_4$), sulfuric acid (H_2SO_4), phosphoric acid (H_3PO_4), potassium dichromate ($K_2Cr_2O_7$), ferrous sulfate heptahydrate ($FeSO_4{\bullet}7H_2O$), and 1,10-phenanthroline monohydrate ($C_{12}H_8N_2{\bullet}H_2O$).

2.4. Data analysis

All recorded data were first organized and cleaned using Microsoft Excel. Statistical analyses, including analysis of variance (ANOVA) and Tukey's post-hoc test, were performed using R software (R Foundation for Statistical Computing, Vienna, Austria). Graphical representations and additional data visualization were generated using OriginPro (OriginLab Corporation, Northampton, MA, USA). Statistical significance was established at $p < 0.05$.

2.5. Operating Procedures

Fresh leaves were washed with potable water and subjected to sun-drying for four consecutive days, following the traditional practice commonly used in rural households. To enable comparison with this indigenous method, a second batch of leaves was dried in a controlled environment using a laboratory oven set at 60 °C for 48 h.

Traditional potash was prepared according to the procedure described by Babayemi et al. (2010). Oil palm inflorescences were first dried at 80 °C for 72 h to remove moisture, then incinerated in a muffle furnace at 550 °C for 5 h until a uniform grey-white ash was obtained. After cooling, a 5 g portion of the ash was dissolved in 40 mL of distilled water and homogenized for 20 min following the method of Mabaya et al. (2025). The resulting mixture was filtered, and the clear supernatant was collected and used as traditional potash for subsequent treatments.

The soaking effect was evaluated by immersing 100 g of dried leaves in 300 mL of distilled water for 30 min, after which oxalate content was quantified. The influence of potash during cooking was assessed by adding 10 mL of the prepared potash solution to 100 g of leaves during thermal processing.

Oxalate content was determined by permanganometric titration using a standardized $KMnO_4$ solution, following established procedures (Kayembe et al., 2018; Karamad et al., 2019; Mabaya et al., 2025). Calibration was performed using seven oxalic acid solutions of known concentrations to ensure analytical accuracy.

Mineral analysis was conducted using X-ray fluorescence (XRF). One gram of each powdered sample was mixed with 100 mg of Fluxana binder, homogenized, and pressed into pellets using a SPECAC hydraulic press at 1000 kg. Elemental quantification was performed with an X POS III energy-dispersive X-ray fluorescence (ED-XRF) spectrometer using the "FP-Pellets CGEA" and "TQ-Pellets Fast" analytical methods. Certified reference materials (ISE870, ISE890, ISE919, ISE961, and SOIL-7) containing known concentrations of target elements were used for calibration and quality control (Qlihaa et al., 2016).

Molar ratios of oxalate to minerals — [Oxalate]/[Ca], [Oxalate]/[Ca + Mg], and [Oxalate]/[Fe] — were calculated using molecular weights of 88 $g{\bullet}mol^{-1}$ for oxalate, 40 $g{\bullet}mol^{-1}$ for Ca, 24.3 $g{\bullet}mol^{-1}$ for Mg, and 56 $g{\bullet}mol^{-1}$ for Fe, following the approach of Nwajagu et al. (2021).

3. Results and Discussion

3.1. Mineral content in the five species of Hibiscus

Minerals play essential roles in human physiology, contributing to enzymatic activation, cellular division and elongation, acid–base balance, and the structural integrity required for metabolic processes (Adediran et al., 2015; Arasaretnam, 2017). Understanding the mineral composition of Hibiscus species is therefore critical, particularly in regions where these leafy vegetables constitute a major dietary component and where micronutrient deficiencies remain prevalent. The present study revealed substantial levels of calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), iron (Fe), and selenium (Se) across the five Hibiscus species, confirming their nutritional relevance and aligning with previous reports from other African regions (Kayembe et al., 2018; Dinssa et al., 2016).

Iron concentrations varied markedly among species and between the two production sites. The highest Fe content was observed in *Hibiscus acetosella red shield* (HARS) from Idiofa (0.71 g/100 g of dry material), while the lowest occurred in *H. acetosella cranberry* (HAC) from Kikwit (0.09 g/100 g of dry material). These values fall within the range reported for *Hibiscus sabdariffa* leaves in Nigeria, Ghana, and Cameroon, where Fe concentrations typically range from 0.2 to 0.8 g/100 g of dry material (FAO, 2012; WHO, 2020).

Although Hibiscus species are often promoted as good sources of iron, the bioavailability of non-heme iron is strongly influenced by oxalate content, which can form insoluble iron oxalate complexes. In this study, oxalate/Fe molar ratios exceeded 1 in most species, indicating limited Fe bioavailability despite relatively high Fe concentrations. This finding is consistent with observations in other African leafy vegetables such as amaranth and celosia, where high oxalate levels significantly reduce iron absorption (Radek & Savage, 2008). For rural populations in Kwilu Province, where anemia prevalence remains high, these results highlight the importance of processing methods that reduce oxalate content to improve iron uptake.

Selenium, an essential trace element involved in antioxidant defense and thyroid function, was detected in meaningful quantities. HARS from Kikwit exhibited the highest Se content (0.53 g/100 g), whereas H. cannabinus (HC) from Idiofa showed the lowest (0.04 g/100 g). These values are comparable to Se levels reported in *H. sabdariffa* from West Africa (Ferreira et al., 2021). The higher Se content in Kikwit samples may reflect soil selenium availability, which is known to vary geographically (Bai et al., 2025). Given that Se deficiency is common in many African regions, Hibiscus species, particularly those grown in Kikwit, may contribute meaningfully to dietary Se intake.

Table I. Mineral content in g/100g of dry material of hibiscus species from Kikwit and Idiofa

Species	*K*	*Fe*	*Zn*	*Se*	*P*	*Ca*	*Mg*
HAC KKT	0,23 ± 0,02	0.09 ± 0.01	0.05 ± 0.01	0.25 ± 0.04	0.02 ± 0.01	0.22 ± 0.01	0.08 ± 0.05
HAC IDF	0,22 ±0,05	0.17 ± 0.10	0.08 ± 0.01	0.27 ± 0.01	0.07 ± 0.00	0.12 ± 0.00	0.11 ± 0.01
HSS KKT	0 .32 ±0.03	0.22 ± 0.03	0.05 ± 0.01	0.31 ± 0.05	-	0.33 ± 0.02	0,06 ± 0,03
HSS IDF	0.30 ± 0.06	0.41 ± 0.18	0.02 ± 0.01	0.43 ± 0.02	0.13 ± 0.00	0.20 ± 0.01	0.03 ± 0.01
HC KKT	0.33 ± 0.10	0.29 ± 0.01	0.03 ± 0.01	0.34 ± 0.04	0.03 ± 0.02	0.18 ± 0.00	0.28 ± 0.04
HC IDF	0.61±0.04	0.38 ± 0.03	0.02 ± 0.00	0.04 ± 0.01	0.03 ± 0.02	0,22±0,01	0.08 ± 0.02
HARS KKT	0.62 ± 0.02	0,71± 0,01	0.06 ± 0.01	0.53 ± 0.03	0.02±0.00	0.22 ± 0.00	0.03 ± 0,00
HARS IDF	0.71 ± 0.01	0,33 ± 0,05	0.01 ± 0,00	-	0.03 ± 0.02	0.25 ± 0.04	0.02 ± 0.01
HAS KKT	0.96 ± 0.04	0.31 ± 0.02	0.08 ± 0.01	0.51 ± 0.02	0.02 ± 0.00	0.33 ± 0.01	0.05 ± 0.03
HAS IDF	0.51 ± 0.31	0.44 ± 0.12	0.04 ± 0.02	0.45 ± 0.03	0.09 ± 0.00	0.14 ± 0.01	0.03 ± 0.02

HAC: *Hibiscus acetosella* cranberry HSS: *Hibiscus sabdariffa* var sabdariffa HC: *Hibiscus canabinus*
HARS: *Hibiscus acetosella* red shield HSA: *Hibiscus sabdariffa* var altissima KKT: Kikwit IDF: Idiofa

Potassium was the most abundant mineral across all species, with *H. sabdariffa* var. *altissima* (HSA) from Kikwit showing the highest concentration (0.96 g/100 g). These values exceed those reported for many African leafy vegetables, including cassava leaves and sweet potato leaves (FAO, 2012). K plays a central role in nerve transmission, muscle contraction, and osmotic regulation. The high K content of Hibiscus species suggests that they can contribute significantly to electrolyte balance, particularly in rural populations with limited dietary diversity.

Calcium and magnesium levels were highest in HSA and *H. sabdariffa* var. *sabdariffa* (HSS) from Kikwit (0.33 g/100 g of Ca and 0.28 g/100 g of Mg). These concentrations are comparable to those reported for H. sabdariffa in Nigeria and Benin (Liam et al., 2023). However, oxalate–mineral interactions must be considered. Oxalates readily bind Ca and Mg, forming insoluble salts that reduce absorption. Although the mineral content is high, the oxalate/Ca and oxalate/(Ca+Mg) molar ratios observed in this study suggest that bioavailability may be compromised, especially in species with elevated oxalate levels. This reinforces the need for processing methods, such as boiling with potash or prolonged soaking, that reduce oxalate concentration.

Phosphorus levels were generally higher in samples from Idiofa, with HSS IDF showing the highest value (0.13 g/100 g). P is essential for ATP synthesis, DNA structure, and cell membrane integrity (Ranjana et al., 2021). The P content observed here is consistent with values reported for *H. sabdariffa* in West Africa and meets FAO recommendations for leafy vegetables. Given its role in energy metabolism, adequate P intake from Hibiscus species may support the nutritional needs of rural populations engaged in physically demanding agricultural labor.

Across all minerals, samples from Kikwit generally exhibited higher concentrations than those from Idiofa, suggesting site-specific agro-ecological influences such as soil mineralization, organic matter content, and cultivation practices. Similar geographic variations have been reported for *H. sabdariffa* in Ghana, Nigeria, and Sudan (FAO, 2012; WHO, 2020).

In Kwilu Province, where Hibiscus species are consumed on a daily basis, the mineral composition observed in this study has important nutritional implications for rural populations. These leafy vegetables provide physiologically essential minerals that support metabolic, structural, and enzymatic functions; however, their nutritional contribution is moderated by the presence of oxalates, which can substantially reduce the bioavailability of key micronutrients such as calcium and iron. Traditional culinary practices, particularly boiling with artisanal potash, may help counteract these limitations by lowering oxalate concentrations and improving mineral accessibility. When compared with other African leafy vegetables commonly consumed in similar contexts, Hibiscus species remain nutritionally competitive and culturally significant, offering a valuable source of minerals within resource-limited settings. Overall, their mineral richness highlights the potential of Hibiscus to contribute meaningfully to the reduction of micronutrient deficiencies in rural communities, provided that appropriate processing methods are used to mitigate oxalate-related reductions in mineral bioavailability.

3.2. Oxalate/minerals molar ratios

The oxalate contents were assessed as a function of four parameters: the origin of the samples, the drying method, the effect of artisanal potash (Kompos in Kikongo language) and of prior soaking before cooking. This study showed that each of these parameters had a significant effect on total oxalate content (TO) of the samples. Furthermore, in the present work, we report the oxalate content in combination with the mineral content of leaves in order to deduce the bioavailability expressed by molar ratios of oxalate-Ca, Oxalate-Fe and Oxalate-Ca+Mg, because of the formation of insoluble oxalates.

Oxalate effect on dietary minerals limiting absorption has already been demonstrated (Oguezi et al., 2022; Bahadoran et al., 2022). Thus, a high oxalate content significantly reduces the absorption of minerals such as Fe, Ca, and Mg. We therefore evaluated the Oxalate-Ca, Oxalate/Ca+Mg, and Oxalate-Fe ratios in order to assess the bioavailability of these elements when hibiscus is consumed (Davis, 2019; Oguezi et al., 2022).

It was found that the molar Oxalate/Ca ratios are low and less than 1 in all species except H. canabinus (ratio > 1). This indicates good Ca bioavailability. The same is true for the Oxalate/Ca+Mg ratios (figure 1).

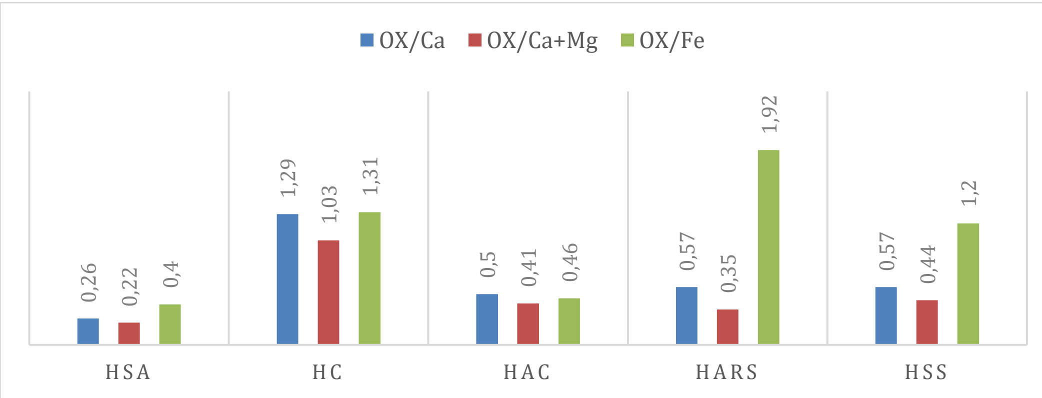

Figure 1. Oxalate-mineral ratios in five studied Hibiscus species

However, it appears that the molar ratios of oxalate to iron are greater than 1 in all species except Hibiscus sabdariffa var altissima. This result shows that repeated consumption of hibiscus limits iron absorption, a deficiency of which leads to anaemia. It is therefore advisable for the population to combine hibiscus consumption with other sources of iron such as red meat.

3.3. Influence of drying Hibiscus leaves on Oxalate - mineral molar ratio

In a previous study, we showed that sun-drying of different varieties of hibiscus, even if it does not reach the thermal decomposition temperature of oxalate, leads to photocatalyzed degradation in the presence of nitrates, resulting in a decrease in oxalate content of 3 to 29% for total oxalate and 56 to 87% for soluble oxalate (Mabaya et al., 2025).

We reproduced the traditional drying method carried out to assess this process impact on molar ratio and then the bioavailability of Ca, Mg and Fe. The figure 2 shows the variation of the malar ratio.

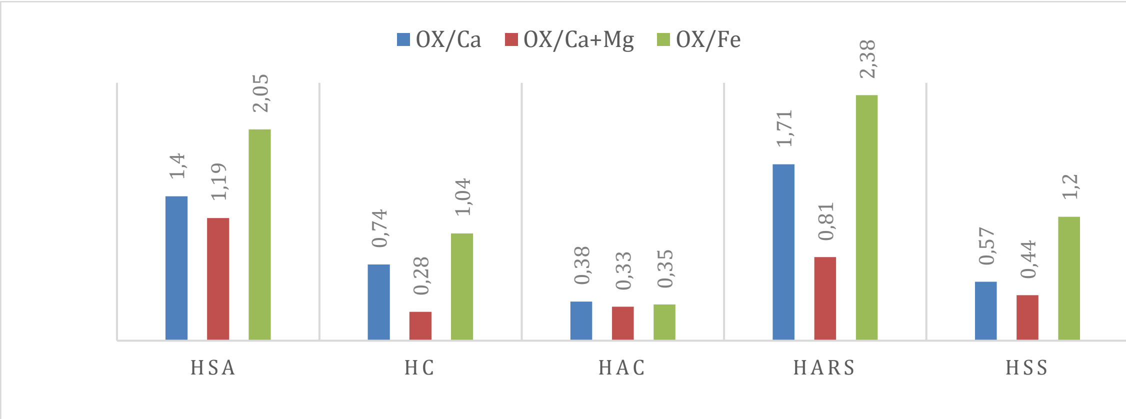

Figure 2. Oxalate to mineral Molar ratios in sun dried leaves of Hibiscus studied species

Sun-drying resulted in an increase in oxalate-mineral molar ratios despite the reported decrease in oxalate content in a previous study (Mabaya et al., 2025). The increase in oxalate-mineral molar ratios can be explained by a traditional practice of squeezing fresh hibiscus leaves firmly before drying them. This squeezing process undoubtedly causes a significant loss of minerals such as Ca, Mg, and Fe. The population should, therefore be advised to refrain from this practice, which not only causes a sharp decline in minerals content, but also leads to a decrease in their bioavailability as the molar ratio increases significantly.

The same observation was made during oven-drying, as it can be seen in figure 3 below.

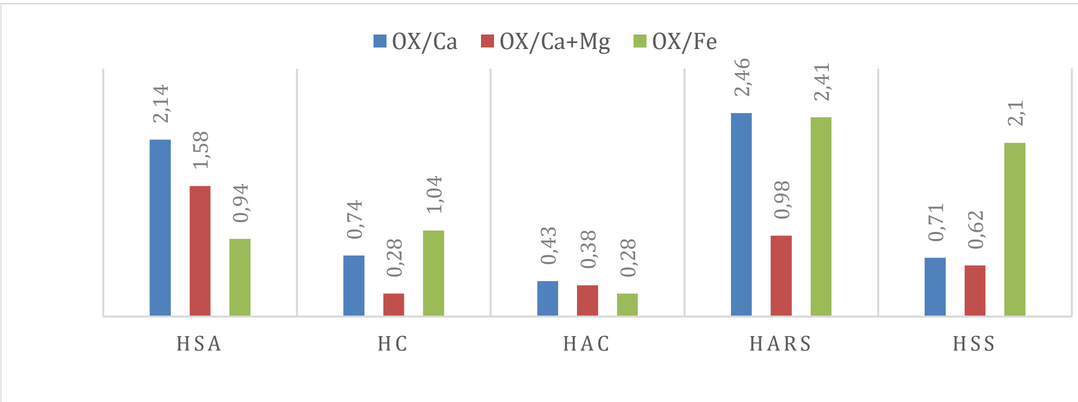

Figure 3. Oxalate to mineral Molar ratios in oven dried leaves of Hibiscus studied species

Increase in oxalate-to-mineral molar ratio is more pronounced after oven-drying than after sun- drying. Indeed, it has been shown that the action of solar UV rays causes photocatalytic degradation in the presence of nitrate ions during sun drying; this photodegradation does not occur during oven drying.

3.4. Effect of Soaking dried Hibiscus leaves prior cooking on Oxalate - mineral molar ratio

Before cooking, dried hibiscus leaves are soaked for more than an hour. We noticed that this prolonged soaking results in a significant loss of minerals, which leads to a significant increase in the molar ratio of oxalate to minerals (figure 4).

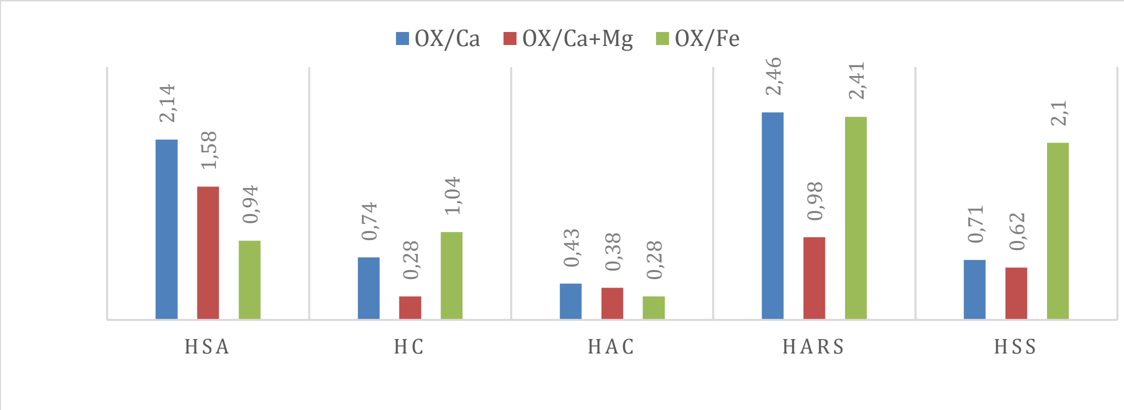

Figure 4. Oxalate to minerals molar ratios after dried leaves soaking

This high ratio significantly reduces the bioavailability of the remaining minerals. Therefore, the above-mentioned practice should be discouraged among the population. A very short soaking time, just long enough to rehydrate the leaves, is desirable in order to preserve minerals that are essential to the human body.

3.5. Artisanal Potash treatment of Hibiscus sample affected Oxalate to minerals molar ratios

The KOMPOS (water extract of male inflorescence of palm ash) used as condiment for reducing the acid taste of sorrel species had shown that its use leads to a marked reduction in total and soluble oxalates (Mabaya et al., 2025). This decrease in oxalates also explains the decrease in oxalate-to-mineral molar ratios (figure 5).

Figure 5 shows that all molar ratios are less than 1. This shows that the use of traditional potash increases the bioavailability of minerals., a practice that should therefore be encouraged and promoted among the populations of Kikwit and Idiofa in particular, and that of Kwilu Province in general.

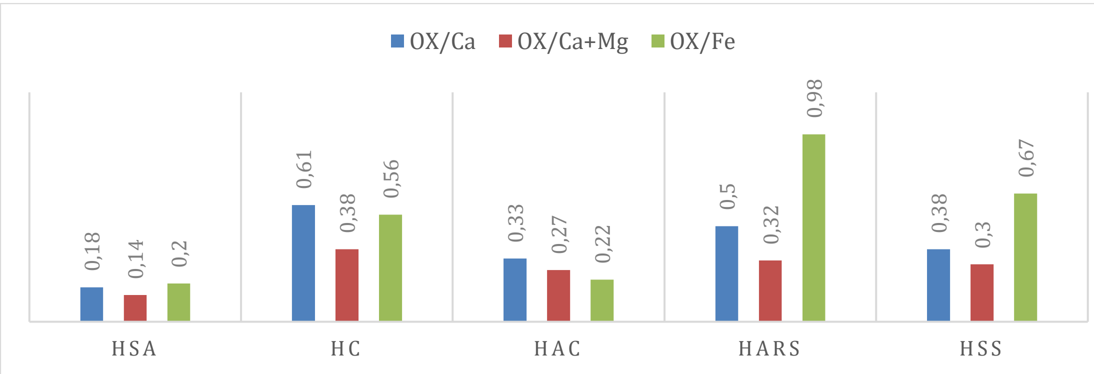

Figure 5. Oxalate to minerals molar ratios after Artisanal Potash use

4. Conclusion

This This study provides a comprehensive assessment of the mineral composition and oxalate–mineral interactions in five Hibiscus species cultivated in the two major production zones of Kwilu Province. The results demonstrate that these species contain nutritionally relevant levels of calcium, magnesium, potassium, phosphorus, iron, and selenium, although their concentrations vary according to species and agro-ecological origin, suggesting a strong influence of soil mineralization and local cultivation conditions. Despite their mineral richness, the high oxalate content observed in several species substantially reduces the bioavailability of key micronutrients, particularly calcium and iron, through the formation of insoluble oxalate–mineral complexes. Traditional processing practices such as sun-drying and soaking were shown to increase oxalate/mineral molar ratios, thereby further limiting mineral accessibility, whereas the use of indigenous potash significantly lowered these ratios and improved estimated mineral bioavailability. These findings have important nutritional implications for rural populations in Kwilu Province, where Hibiscus leaves are consumed daily and where micronutrient deficiencies remain a public-health concern. Promoting processing methods that reduce oxalate content, especially the culturally established use of artisanal potash, could enhance the nutritional value of these vegetables.

Future research should focus on quantifying the actual in vivo bioavailability of minerals after different processing methods, evaluating seasonal and soil-specific variations in mineral uptake, and comparing Hibiscus species with other commonly consumed African leafy vegetables in relation to FAO and WHO dietary recommendations. Additionally, exploring agronomic strategies to reduce oxalate accumulation while maintaining mineral density could further strengthen the nutritional contribution of Hibiscus species to food security in the region.

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Ethical consideration

The authors are committed to respect ethical principles in writing this paper

Authors contributions

O. S. M. collected and processed the samples; he also played an active role in laboratory analyses

J. S.K. played a major role in preparing the manuscript and revising It

O. M.S. analyzed and interpreted the results

M. S.N. has initiated and designed this research

Y. B.I. substantially contributed by supervising and chemicals providing

J. T. K. actively edited the manuscript

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