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ESSENTIAL MINERAL COMPOSITION OF RICE (*ORYZA SATIVA* L.) AND LETTUCE (*LACTUCA SATIVA* L.) GROWN IN THE LOWLANDS OF THE CITY OF DALOA, CÔTE D'IVOIRE

Bahi Aristide Armand *, Ohou-Yao Marie Jeanne, Akessé Djamatché Paul, Koné Oumar, Kouamé Léonard Kouadio, Akpètou Lazare and Dongui Bini Kouamé

Laboratory of Environmental Sciences and Technologies (LSTE), Université Jean Lorougnon Guédé, BP 150 Daloa, Côte d'Ivoire.
* Corresponding Author

ORCID Details
Bahi Aristide Armand: https://orcid.org/0009-0003-1473-3862

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ABSTRACT

Micronutrient deficiency remains widespread in West Africa, where plant foods supply most mineral intake, yet the mineral value of rice and lettuce grown together in the urban lowlands of Daloa is poorly documented. This study aimed to determine the essential mineral contents of both crops, identify factors structuring their variability using multivariate statistics, and estimate their contribution to recommended daily intakes. Thirty stations in ten lowlands of Daloa were sampled from January 2024 to January 2025. Plant material was oven-dried, ground and dry-ashed at 600 °C, and Ca, Mg, Fe, Zn, Se and Mn were determined by flame atomic absorption spectrometry. Data were analysed with R for descriptive statistics, correlation analysis, Principal Component Analysis and Hierarchical Ascending Classification. Mineral contents varied widely, with Ca as the most abundant element (mean 887.72 mg/kg) and coefficients of variation ranging from 50.84% for Mg to 269.74% for Fe. Ca and Mg were strongly correlated (r=0.798), Fe, Zn and Se formed a second correlated group, and Mn behaved independently. The first two principal components explained 73.5% of total variance and separated stations into three groups reflecting a gradient of mineral richness, including a rice-specific group with very high Mn linked to waterlogging. Lettuce was richer than rice in Ca, Fe and Zn on dry-weight basis, but on fresh-weight basis only lettuce iron covered 39.3% of RDI per 100 g. Mineral contents are governed mainly by growing site rather than crop type, indicating that improving mineral quality requires better management of soil and water conditions.

Keywords: Essential minerals; Rice; Lettuce; Lowlands; Nutritional value; Daloa.

1 INTRODUCTION

Micronutrient deficiency remains a major public health problem in sub-Saharan Africa. Iron, zinc and calcium are the elements most often lacking [1]. Diets in the region rely on a small number of staple foods. Animal products are scarce or costly. Plant foods therefore supply most of the mineral intake [2].

Rice is the main cereal consumed in Côte d'Ivoire. It is eaten daily and in large portions. Its grain is nevertheless a poor mineral source. Milling removes the bran, where most minerals are stored [3]. Lettuce is eaten in smaller amounts. It is consumed raw, so no mineral is lost in cooking water. Leaf tissue also concentrates cations such as calcium and iron [4].

Leafy vegetables of Côte d'Ivoire are known to be mineral-rich. Calcium contents from 1546 to 5663 mg/100 g of dry matter have been reported [2]. A survey carried out in Daloa gave iron contents of 15 to 40 mg/100 g [5]. Data on rice and lettuce grown in the same lowlands are still lacking.

Lowlands, locally called bas-fonds, are cultivated all year round in Daloa. Rice occupies the wetter central parts. Vegetables are grown on the raised margins. These lowlands supply a large share of the urban food markets. They are also exposed to urban pressure. Runoff, domestic waste and market effluents reach them [6].

Soil conditions govern mineral uptake by plants. Soil pH controls the solubility of most micronutrients [7]. Waterlogging creates reducing conditions that mobilise iron and manganese [8]. Fertiliser inputs also modify leaf mineral content [9]. These conditions differ from one lowland to another [10].

Few studies have compared rice and lettuce grown side by side. Fewer still have used multivariate statistics for this purpose. The present work addresses this gap. Three objectives were set. The first was to measure the essential mineral contents of both crops. The second was to identify the factors structuring their spatial variability. The third was to estimate their contribution to recommended daily intakes.

2 MATERIAL AND METHODS

2.1 Study Area

The study was conducted in the city of Daloa, in central-western Côte d'Ivoire. Daloa is a fast-growing urban centre of the Haut-Sassandra region. The climate is humid tropical, with a long rainy season. Lowlands remain waterlogged for much of the year. Thirty sampling stations were selected across ten lowlands of the city (Fig. 1). The stations cover a range of urban and peri-urban settings. They include residential districts, roadsides, market areas, slaughterhouse surroundings and the vicinity of the municipal landfill.

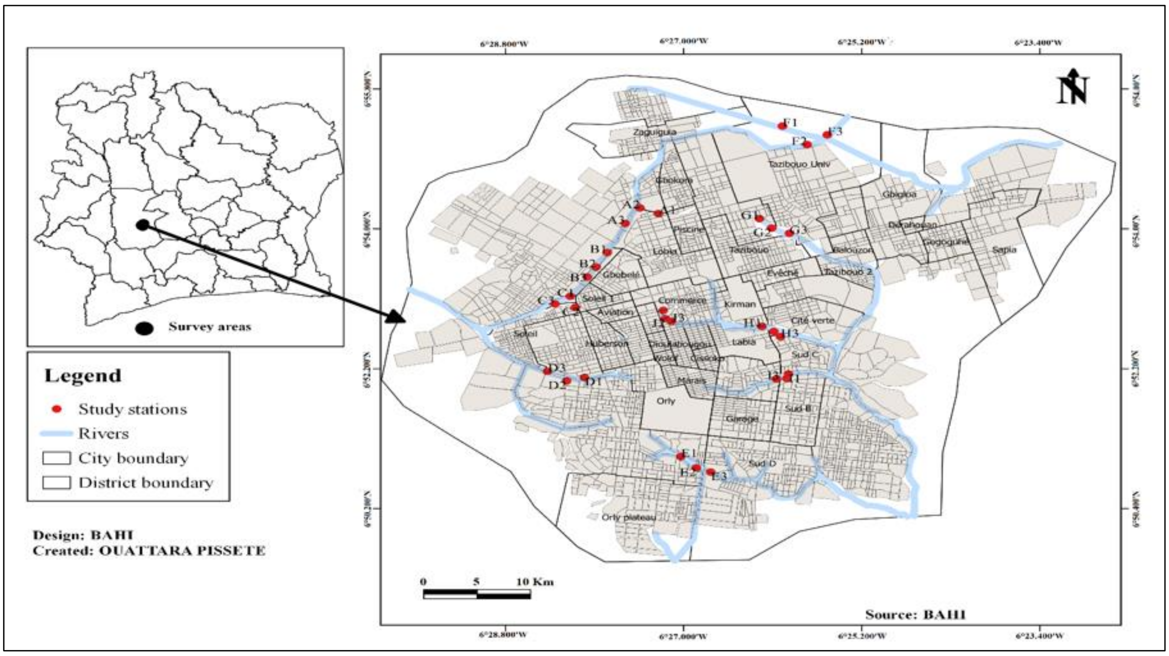

Figure 1: Map of the city of Daloa showing the sampling sites [6]

2.2 Sampling

The sampling campaign focused on rice and lettuce grown in the lowlands. Stations A2, A3, C1, D1, D2, E2, H2, I1, I2, I3, J1, J2 and J3 were located in lettuce plots. Stations A1, B1, B2, B3, C2, C3, D3, E1, E3, F1, F2, F3, G1, G2, G3, H1 and H3 were located in rice plots. This stratification ensured a representative assessment of both cropping systems. It also accounted for spatial variability between lowlands.

Six campaigns were carried out, one every two months, from January 2024 to January 2025. Plants were collected at maturity. Only the edible parts were retained: grain for rice and leaves for lettuce. Several sub-samples were taken at different points of each plot. They were pooled into one composite sample per station. Samples were placed in clean polyethylene bags and labelled. Geographical coordinates were recorded at each station using a Garmin GPS device.

2.3 Mineral Analysis

Analyses were performed at the EDP laboratory of INP-HB. Samples were rinsed with distilled water to remove adhering soil. They were then dried to constant weight and ground to 0.1 mm. Moisture and dry matter contents were determined by oven drying.

A test portion of 0.3 to 0.5 g of dry matter was placed in a crucible. It was ashed at 600 °C for 5 h until a white ash was obtained. The ash was taken up in 5 mL of 1 N nitric acid. The solution was evaporated to dryness on a sand bath. The residue received 5 mL of 1 N hydrochloric acid and was returned to the furnace at 400 °C for 30 min. It was then recovered with 10 mL of 0.1 N hydrochloric acid. The rinsing step was repeated three times. The solution was made up to 50 mL and filtered through 0.45 µm Whatman paper. The procedure follows official methods [11,12].

Calcium, magnesium, iron, zinc, selenium and manganese were determined by air-acetylene flame atomic absorption spectrometry, on a VARIAN AAS 20 instrument. Calibration standards were prepared at 0.5, 1.0, 1.5 and 2.0 mg/L. Standards were run before the samples. Lanthanum chloride was added to suppress calcium and potassium interference. Reagent blanks and duplicate determinations were used for quality control. Contents are expressed in mg/kg of dry weight.

2.4 Statistical Analyses

Data were first recorded in Microsoft Excel and then processed with R software. Values below the detection limit were treated as non-detected. They were replaced by half of the lowest detected value of the element. Descriptive statistics were computed for each element. The coefficient of variation was used to compare dispersion between elements.

Factorability of the dataset was assessed through a correlation matrix. Data were log-transformed before multivariate analysis, because distributions were strongly skewed. Variables were then standardised. A Principal Component Analysis (PCA) was performed, followed by a Hierarchical Ascending Classification (HAC) using Ward's method. Contents of the two crops were compared with the Mann-Whitney test at the 5 % level.

3 RESULTS AND DISCUSSION

3.1 Overall Variation of Mineral Contents

Table 1 presents the minimum, maximum, mean, standard deviation and coefficient of variation of the six elements. The results show contrasting levels of dispersion between elements.

Calcium was by far the most abundant element, with a mean of 887.72 mg/kg. Magnesium followed, with 386.23 mg/kg. Both elements are macro-nutrients absorbed in large amounts by plants. They accumulate in cell walls and vacuoles, mainly in leaf tissue [4]. Magnesium showed the lowest coefficient of variation of the dataset (CV = 50.84 %). This relative stability suggests a fairly uniform uptake across stations. Magnesium is a mobile element within the plant, which limits extreme accumulation.

Calcium showed a higher dispersion (CV = 75.61 %), with values from 87.78 to 3320.84 mg/kg. Calcium availability depends closely on soil pH and on the cation exchange capacity of the substrate [7]. Such variability is therefore expected between lowlands with different soils.

Selenium showed a comparable dispersion (CV = 77.29 %) but at very low levels, with a mean of 0.20 mg/kg. Selenium is an essential trace element whose plant content mirrors that of the soil. Its low concentration is consistent with the weathered tropical soils of the region.

Zinc showed strong variability (CV = 146.05 %). Contents remained low overall, with a mean of 3.88 mg/kg. Zinc uptake is limited in soils with a high organic matter content, where the element is readily complexed.

Manganese and iron showed the highest dispersions, with CV of 203.17 % and 269.74 % respectively. Both elements are redox-sensitive. Their solubility rises sharply under the reducing conditions caused by waterlogging [8]. Alternating flooding and drainage in the lowlands therefore generates strong contrasts between stations [13]. For iron, part of the highest values may also result from fine soil particles remaining on the leaves after washing. This contamination is a recognised limitation in the analysis of leafy vegetables. Iron and manganese results should therefore be interpreted with caution.

Overall, the dataset shows a marked heterogeneity of the studied environment. This pattern is typical of tropical agroecosystems, where edaphic, hydrological and human factors interact strongly [10].

Table 1: Statistical summary of mineral contents in the studied plants (mg/kg dry weight)

Element	Minimum	Maximum	Mean	Standard deviation	CV (%)
Ca	87.78	3320.84	887.72	671.21	75.61
Mg	49.17	706.92	386.23	196.36	50.84
Fe	0.48	2235.12	153.23	413.32	269.74
Zn	0.02	23.71	3.88	5.67	146.05
Se	0.01	0.72	0.20	0.15	77.29
Mn	0.19	80.46	9.00	18.29	203.17

Ca: calcium; Mg: magnesium; Fe: iron; Zn: zinc; Se: selenium; Mn: manganese; CV: coefficient of variation. n = 30.

3.2 Correlations between Mineral Elements

The correlation matrix is presented in Table 2. It reveals a partial structuring of the relationships between elements.

A strong positive correlation was found between calcium and magnesium (r = 0.798). These two divalent cations share the same uptake pathways and the same transport route to the leaves. Their joint accumulation is therefore expected [4].

A second group of correlated elements was identified. Iron was closely linked to selenium (r = 0.744) and to zinc (r = 0.717). Zinc and selenium were also correlated (r = 0.564). These three elements are trace elements whose availability depends on soil redox conditions and organic matter [8]. Their joint variation suggests a common control by the substrate rather than by the plant.

Manganese showed no significant correlation with any other element. Its highest coefficient did not exceed 0.198. This independence indicates a specific control. Manganese solubility responds mainly to waterlogging and to the resulting reducing conditions [13]. It therefore varies according to the water regime of each plot, and not with the general mineral richness of the site.

The correlation between calcium and zinc was moderate (r = 0.515). It reflects the partial overlap between the two groups of elements described above.

Table 2: Correlation matrix of mineral elements in the studied plants

	Ca	Mg	Fe	Zn	Se	Mn
Ca	1					
Mg	0.798	1				
Fe	0.184	-0.020	1			
Zn	0.515	0.428	0.717	1		
Se	0.194	0.150	0.744	0.564	1	
Mn	0.198	-0.049	0.094	0.056	0.003	1

Pearson correlation coefficients. Ca: calcium; Mg: magnesium; Fe: iron; Zn: zinc; Se: selenium; Mn: manganese.

3.3 Structuring of Sampling Sites using Principal Component Analysis (PCA)

3.3.1 Correlation Circle

The first two factorial axes explain 73.5 % of the total variance. The first axis accounts for 56.2 % and the second for 17.3 % (Fig. 2).

All six elements are positively correlated with axis 1. Calcium (0.86), zinc (0.88), iron (0.78) and magnesium (0.74) show the strongest contributions. This axis can therefore be read as a gradient of overall mineral richness. Stations on its positive side are rich in all elements. Those on its negative side are poor in all of them.

Axis 2 separates two groups of variables. Calcium and magnesium contribute positively. Selenium and manganese contribute negatively. This axis therefore opposes the macro-elements to the redox-sensitive trace elements. It expresses the difference between uptake driven by soil fertility and uptake driven by the water regime.

The quality of representation was highest for calcium (cos2 = 0.90) and magnesium (cos2 = 0.82). It was lowest for manganese (cos2 = 0.51). Manganese is therefore only partly described by the first factorial plane. This result confirms its independent behaviour, already shown by the correlation matrix.

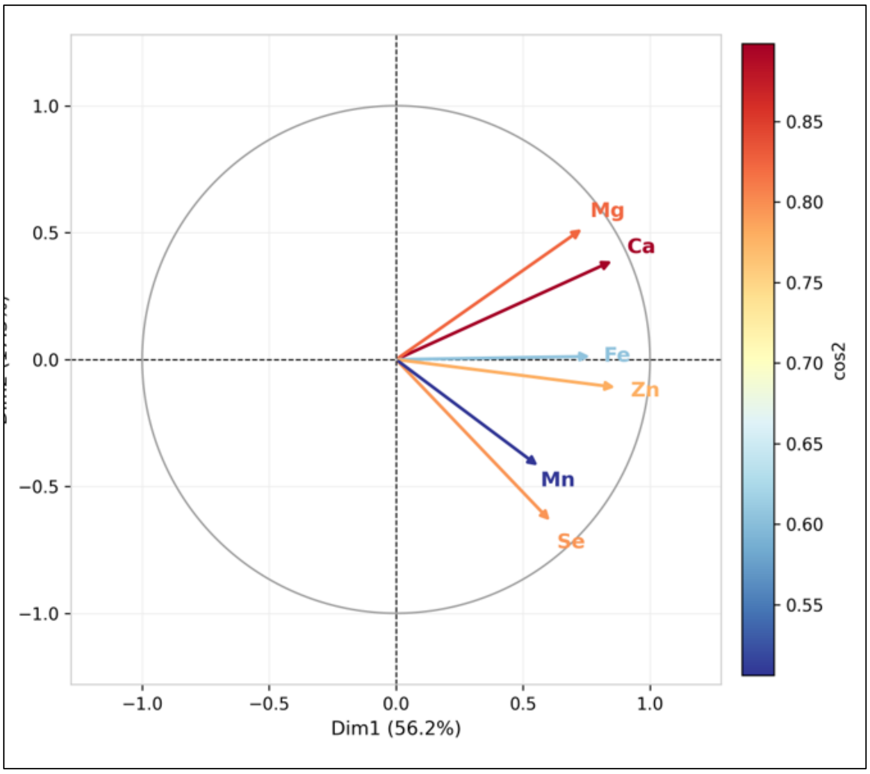

Figure 2: Correlation circle of the studied mineral elements

3.3.2 Projection of Sampling Sites on the PCA Factorial Plane

The projection of the stations onto the factorial plane reveals three distinct groups (Fig. 3).

The first group is located on the negative side of axis 1. It comprises stations A2, B1, D1, D3, F2, G2, H1, H3 and I3. These stations show the lowest contents for all elements. Mean calcium reached only 315.47 mg/kg and mean zinc 0.49 mg/kg. They correspond to mineral-poor environments. The group brings together six rice stations and three lettuce stations. This mixture indicates that the observed poverty depends on the site rather than on the crop [10].

The second group lies in the lower part of the plane. It includes stations E1, E3, F1, G1 and G3. Its mineral contents are intermediate, but its manganese content is very high, with a mean of 33.85 mg/kg. This value is nearly four times the overall mean. All five stations are rice plots. Rice is grown in the wettest parts of the lowlands. The prolonged waterlogging of these plots creates reducing conditions that release manganese into the soil solution [8,13]. This group therefore reflects a genuine effect of the cropping system on a single element.

The third group occupies the positive side of axis 1. It gathers stations A1, A3, B2, B3, C1, C2, C3, D2, E2, F3, H2, I1, I2, J1, J2 and J3. It is the richest group for calcium (1307.45 mg/kg), magnesium (528.66 mg/kg), iron (264.75 mg/kg) and zinc (6.72 mg/kg). Lettuce stations dominate, with ten of the sixteen sites. The higher mineral content of leaf tissue explains this dominance. The presence of six rice stations nevertheless shows that some lowlands are rich whatever the crop grown.

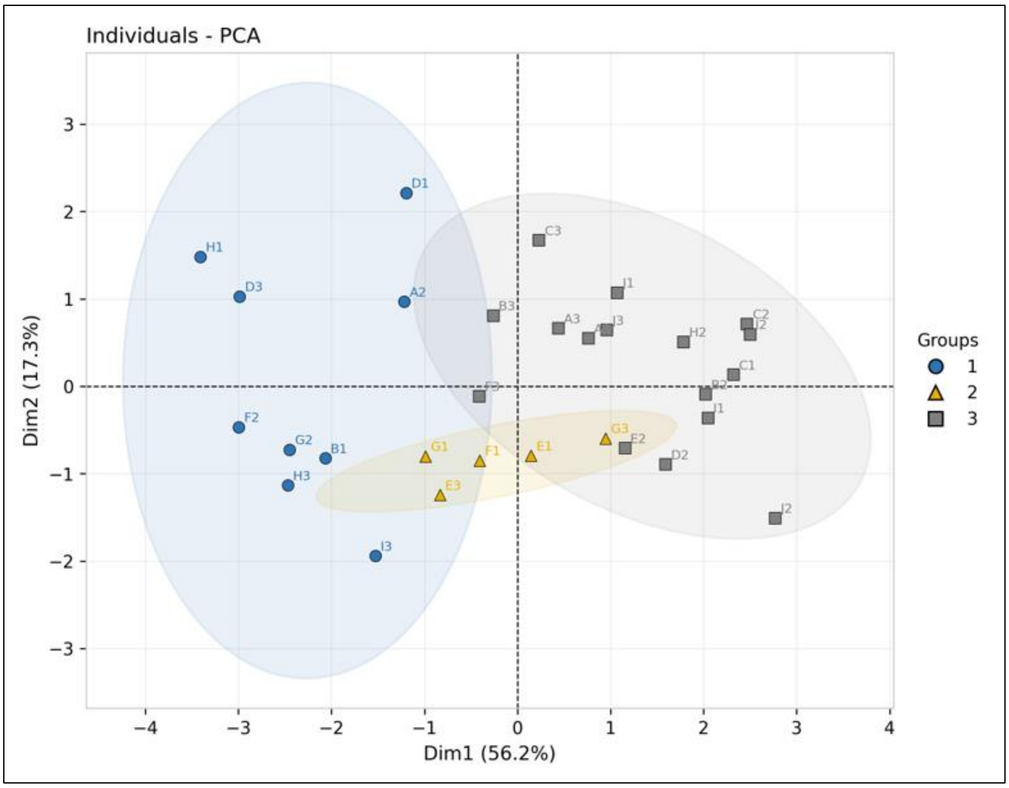

Figure 3: Projection of sampling stations on the factorial plane

Overall, the spatial organisation of the stations follows a continuous gradient of mineral richness. Crop type contributes to this structuring but remains a secondary factor. The coexistence of rice and lettuce within the same groups points to a dominant role of local conditions. Similar conclusions have been drawn for other tropical agroecosystems, where environmental conditions govern variability more than the crop itself [10].

3.3.3 Structuring of Sampling Sites using Hierarchical Ascending Classification (HAC)

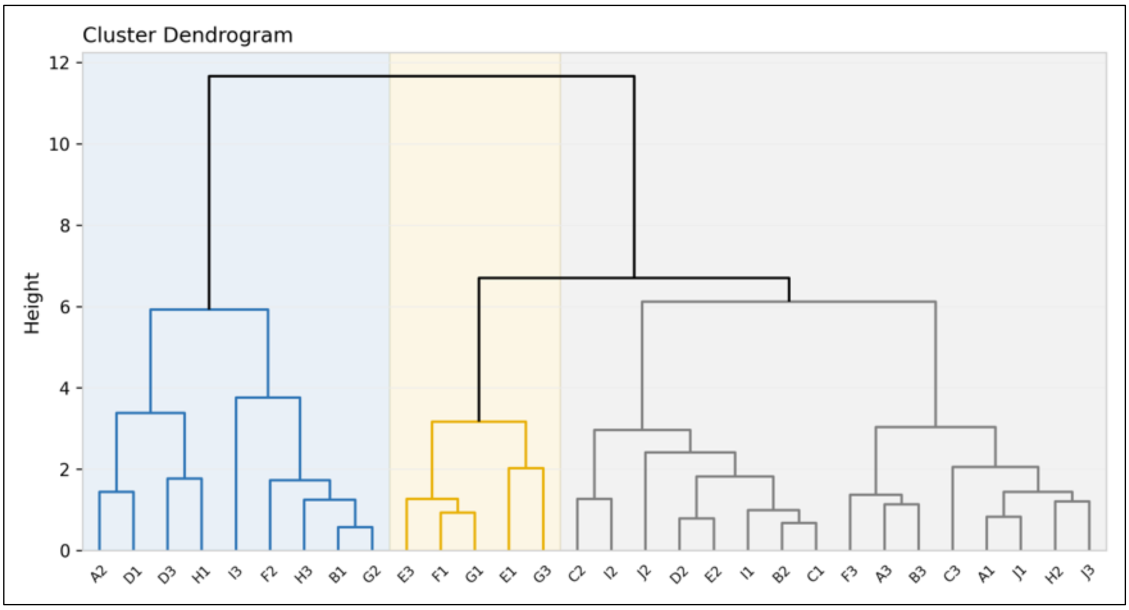

Figure 4: Dendrogram of sampling stations obtained from Hierarchical Ascending Classification (HAC)

Fig. 4 shows the dendrogram obtained by Hierarchical Ascending Classification. The analysis confirms the three groups identified by the PCA. The agreement between the two methods strengthens the reliability of the results.

The dendrogram separates the mineral-poor stations at the highest level. The manganese-rich rice stations then split from the mineral-rich group. This hierarchy shows that overall mineral richness is the primary criterion of similarity. The water regime acts as a secondary criterion.

Stations from both cropping systems appear within the same clusters. Similarities between sites are therefore driven mainly by environmental conditions. This finding supports the conclusion drawn from the factorial analysis.

3.4 Comparison of the Two Crops and Nutritional Contribution

Table 3 compares the mineral contents of the two crops. Lettuce was richer than rice in four of the six elements. The difference was significant for iron ($p < 0.001$), zinc ($p = 0.003$) and calcium ($p = 0.033$). It was not significant for magnesium ($p = 0.112$) or selenium ($p = 0.090$). Manganese was the only element more concentrated in rice, but the difference was not significant ($p = 0.893$).

The advantage of lettuce is explained by the nature of the harvested organ. Leaves accumulate cations throughout the growth cycle. Grain is a storage organ that is naturally poor in minerals, and milling removes its richest outer layers [3].

Table 3: Mineral contents of rice and lettuce and comparison between the two crops (mg/kg dry weight)

Element	Rice (n = 17)	Lettuce (n = 13)	p
Ca	748.16 ± 770.12	1070.22 ± 484.07	0.033 *
Mg	335.90 ± 188.31	452.05 ± 193.96	0.112 NS
Fe	21.66 ± 38.82	325.28 ± 595.18	< 0.001 ***
Zn	1.51 ± 1.74	6.98 ± 7.43	0.003 **
Se	0.15 ± 0.10	0.26 ± 0.19	0.090 NS
Mn	12.48 ± 23.44	4.45 ± 6.01	0.893 NS

Values are means ± standard deviation. p: probability of the Mann-Whitney test. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; NS: not significant.

The nutritional contribution of the two crops was estimated on a fresh-weight basis (Table 4). Mean dry matter reached 27.83 % in rice and 10.99 % in lettuce. Lettuce is therefore mostly water, which strongly reduces its contribution per portion.

A 100 g fresh portion of lettuce covered 39.3 % of the iron reference intake. The same portion of rice covered only 6.6 %. Lettuce is thus the better source of iron among the two crops. This contribution must nevertheless be read with care. Iron in leafy vegetables is non-haem iron, which is poorly absorbed. Phytates and polyphenols further reduce its absorption. Part of the measured iron may also come from residual soil particles.

For calcium and magnesium, the ranking is reversed on a fresh-weight basis. Rice supplied 2.1 % of the calcium reference intake against 1.2 % for lettuce. The higher dry matter content of rice explains this reversal. It shows that a comparison based on dry weight alone can be misleading.

Table 4: Contribution of a 100 g fresh portion of rice and lettuce to recommended daily intakes

Element	RDI (adult)	Rice (per 100 g FW)	% RDI	Lettuce (per 100 g FW)	% RDI
Ca	1000 mg	20.82 mg	2.1	11.76 mg	1.2
Mg	260 mg	9.35 mg	3.6	4.97 mg	1.9
Fe	9.1 mg	0.60 mg	6.6	3.57 mg	39.3
Zn	7.0 mg	0.04 mg	0.6	0.08 mg	1.1
Se	34 µg	4.2 µg	12.4	2.9 µg	8.4
Mn	3.0 mg	0.35 mg	11.6	0.05 mg	1.6

FW: fresh weight. Values calculated from mean dry-weight contents and mean dry matter (27.83 % for rice, 10.99 % for lettuce). Reference intakes for adult men [1,14]. The iron value assumes 15 % dietary bioavailability.

Contributions to zinc requirements were low for both crops, below 1.5 % per portion. Selenium reached 12.4 % in rice and 8.4 % in lettuce, and manganese 11.6 % in rice. Neither crop can therefore cover the requirements for iron or zinc on its own. Improving these intakes will depend on dietary diversity and on the choice of complementary foods.

3.5 Comparison with Similar Studies

The calcium contents measured here are lower than those reported for traditional leafy vegetables in Côte d'Ivoire [2]. Cultivated lettuce is a milder accumulator than amaranth or jute mallow. The values obtained for lettuce are, however, close to those reported for Daloa vegetables [5].

The iron contents of rice fall within the range reported for African rice [3]. Zinc contents are below the international biofortification target of 28 mg/kg for polished grain [3]. Locally grown rice therefore remains a weak source of zinc.

The dominant role of the site over the crop has also been reported for surface waters at the same stations [6]. Redox potential, pH and electrical conductivity were identified there as the main drivers of variability. The mineral gradient observed in the plants follows the same logic. Comparable observations have been made in lowland rice systems of West Africa [15] and in tropical paddy fields, where water management governs the mobility of redox-sensitive elements [13].

A limitation of this study should be noted. One composite sample was analysed per crop and per station. This design describes differences between lowlands well. It does not allow the variance to be partitioned between a site effect and a crop effect. Mineral bioavailability was not measured either. Future work should combine paired soil, water and plant sampling with bioavailability assays.

4 CONCLUSION

This study characterised the essential mineral contents of rice and lettuce grown in the lowlands of Daloa. Calcium was the most abundant element and magnesium the most stable. Iron and manganese showed the widest variability, in line with their redox sensitivity.

The correlation analysis identified two groups of elements. Calcium and magnesium varied together. Iron, zinc and selenium formed a second group. Manganese behaved independently.

Principal Component Analysis and Hierarchical Ascending Classification separated the stations into three groups. These groups reflect a gradient of mineral richness. One group brought together rice plots with high manganese contents, linked to prolonged waterlogging. Rice and lettuce stations coexisted within the other groups. The growing site therefore governs mineral content more than the crop does.

Lettuce was richer than rice in calcium, iron and zinc on a dry-weight basis. On a fresh-weight basis, its contribution fell sharply because of its high water content. Only iron remained a meaningful contribution. These results show that the mineral quality of lowland crops in Daloa depends mainly on local soil and water conditions. Their improvement requires better management of these environments.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The author declares no conflict of interest regarding this manuscript.

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