Biochemical Specialization Across Plant Parts of Three Ethiopian Medicinal Enset (*Ensete ventricosum*) Landraces: Implications for Nutrition, Safety, and Traditional Medicine

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Abstract

Background

Ensete ventricosum is a multipurpose staple crop central to food security in Ethiopia and is traditionally referred to as “the tree against hunger.” In the Gedeo Zone, specific landraces; Kake, Kerse, and Mundo, are widely consumed and used in ethnomedicine to treat bone fractures, wounds, abdominal pain, and skin ailments. Despite their importance, the biochemical basis underlying these part-specific traditional applications remains insufficiently characterized.

Objective

This study aimed to quantitatively evaluate and compare the proximate composition, macro- and micronutrient profiles, and heavy metal content of different plant parts (corm, pseudostem, leaf, and midrib) of three Ethiopian enset landraces to assess their nutritional value, safety, and traditional therapeutic relevance.

Methods

Proximate composition was determined following standard AOAC protocols, with crude protein quantified using the Kjeldahl method. Macro-, micro-, and heavy metal elements were analyzed using Inductively Coupled Plasma–Optical Emission Spectrometry (ICP-OES).

Results

Distinct part-specific biochemical specialization was observed among the landraces. Corms of Kake and Mundo were particularly rich in zinc (88–121 mg/kg) and phosphorus (up to 2,986 mg/kg), supporting their traditional use in bone healing and wound recovery. Leaves across all landraces exhibited high crude protein content (16.0–19.6%), iron concentrations exceeding 1,000 mg/kg, and elevated calcium levels (up to 10,119 mg/kg), indicating strong nutritional potential. The midrib of Kerse showed notably high magnesium content (1,847 mg/kg), consistent with its traditional use for alleviating abdominal pain. Toxic heavy metals, including arsenic, were below detectable limits, while all other metals remained within internationally acceptable safety thresholds.

Conclusion

The findings provide robust scientific validation for the part-specific traditional uses of Ethiopian enset landraces and confirm their nutritional safety. The observed biochemical diversity highlights the importance of conserving enset genetic resources and demonstrates that indigenous knowledge effectively guides the identification of nutritionally and therapeutically valuable plant parts. These results reinforce the role of Ensete ventricosum in food security, nutrition, and ethnomedicine.

Introduction

Ensuring sustainable food security and adequate nutrition remains a major global challenge, particularly in regions vulnerable to climate change, land degradation, and population growth (FAO, 2017; HLPE, 2020). In sub-Saharan Africa, indigenous and underutilized crops play a critical role in enhancing dietary diversity, nutritional resilience, and livelihood security (Chivenge et al., 2015; Mabhaudhi et al., 2019). Ethiopia is a global center of crop diversity, where traditional food systems continue to rely heavily on locally adapted species that are resilient to environmental stresses (Vavilov, 1951; Asfaw, 2000).

Among these crops, Ensete ventricosum (Welw.) Cheesman, commonly known as enset, is a perennial, multipurpose species cultivated primarily in southern and southwestern Ethiopia. Often referred to as "the tree against hunger," enset supports the food security of more than 20 million people and provides a reliable food source during periods of climatic instability and crop failure (Brandt et al., 1997; Negash & Niehof, 2004). Unlike annual cereals, enset can be harvested at any stage of growth, contributing to household food security through temporal flexibility and year-round availability (Tsegaye & Struik, 2001).

In addition to its role as a staple food, enset is deeply embedded in Ethiopian indigenous knowledge systems and ethnomedicine. Different landraces and plant parts including the corm, pseudostem, leaf, and midrib are selectively used for dietary, medicinal, and cultural purposes (Brandt et al., 1997; Negash, 2010). In the Gedeo Zone of southern Ethiopia, landraces such as Kake, Kerse, and Mundo are traditionally used to treat bone fractures, wounds, abdominal disorders, and skin ailments. These practices are based on long-standing empirical knowledge transmitted across generations, yet their biochemical and nutritional foundations remain poorly documented in the scientific literature.

Previous research on enset has predominantly focused on agronomy, propagation, fermentation processes, and carbohydrate-based food products such as kocho and bulla (Tsegaye & Struik, 2002; Hunduma et al., 2014). While these studies underscore enset's importance as an energy-rich crop, comprehensive evaluations of its broader nutritional composition particularly protein, macro- and micronutrients, and mineral safety, are limited (Bosha et al., 2016; Abebe et al., 2020). Moreover, most nutritional studies treat enset as a homogeneous crop, overlooking biochemical differentiation among landraces and plant organs that may underpin both nutritional quality and traditional therapeutic use.

From a food science and nutrition perspective, part-specific biochemical specialization is critical, as nutrient partitioning within plant organs influences dietary quality, functional properties, and bioavailability (White & Broadley, 2009). Minerals such as calcium, phosphorus, magnesium, iron, and zinc are essential for bone health, wound healing, enzymatic function, and immune regulation (WHO & FAO, 2004; Soetan et al., 2010). Conversely, exposure to toxic heavy metals through food consumption poses significant public health risks, particularly in communities relying heavily on plant-based diets (Alloway, 2013). Rigorous assessment of both beneficial nutrients and potentially harmful elements is therefore essential for validating the safety and nutritional value of indigenous food resources.

Increasing evidence suggests that indigenous knowledge systems often provide reliable indicators of nutritionally and therapeutically valuable plant resources (Pieroni & Quave, 2014; Albuquerque et al., 2019). Scientific validation of traditional use patterns not only strengthens their credibility but also supports biodiversity conservation, sustainable use of landraces, and the integration of indigenous crops into nutrition-sensitive food systems (Johns & Eyzaguirre, 2006; FAO, 2019).

Against this background, the present study aimed to quantitatively analyze and compare the proximate composition, macro- and micronutrient profiles, and heavy metal content of different plant parts (corm, pseudostem, leaf, and midrib) of three Ethiopian enset landraces: Kake, Kerse, and Mundo, traditionally used for food and ethnomedicine in the Gedeo Zone. By linking biochemical specialization with indigenous use patterns, this study seeks to provide scientific evidence supporting the nutritional value, safety, and therapeutic relevance of Ensete ventricosum, while highlighting the importance of conserving its genetic and cultural diversity.

Materials and Methods

Study Area and Plant Material

The study was conducted using three traditionally important enset (*Ensete ventricosum* (Welw.) Cheesman) landraces; Kake, Kerse, and Mundo, cultivated in the Gedeo Zone of southern Ethiopia. The area is characterized by enset-based agroforestry systems and long-established indigenous knowledge related to enset utilization. Mature, healthy plants of each landrace were selected based on local farmers' recommendations and traditional use history.

Consistent with indigenous taxonomy, the three landraces exhibited distinct phenotypic markers. The Kake landrace displayed conspicuous red-purple anthocyanin pigmentation in its pseudostem and leaf surfaces (Fig. 1). Upon cutting, only the Mundo pseudostem exuded a pink-red sap. Sensory evaluation by farmers consistently identified Kerse leaves as distinctly bitter compared to the other landraces.

A B

Sample Collection and Preparation

Four plant parts; corm, pseudostem, leaf, and midrib, were harvested from each landrace. Samples were thoroughly washed with distilled water to remove soil and debris, chopped into small pieces, and air-dried under shade before being oven-dried at a controlled temperature until constant weight was achieved. Dried samples were ground into fine powder using a laboratory mill and stored in airtight containers prior to analysis.

Proximate Composition Analysis

Proximate composition analyses, including moisture, ash, crude fat, crude fiber, and carbohydrate content, were conducted following standard methods of the Association of Official Analytical Chemists (AOAC). Crude protein content was determined using the Kjeldahl method, and protein values were calculated by multiplying total nitrogen by a conversion factor of 6.25.

Mineral and Heavy Metal Analysis

Macro- and micronutrients (including Ca, Mg, P, Fe, Zn) as well as heavy metals were quantified using Inductively Coupled Plasma–Optical Emission Spectrometry (ICP-OES). Prior to analysis, samples were digested using appropriate acid digestion protocols. Calibration standards and quality control samples were used to ensure analytical accuracy. Heavy metal concentrations were evaluated against international food safety standards.

Data Analysis

All analyses were performed in triplicate. Data were expressed as mean ± standard deviation. Comparative evaluation among landraces and plant parts was conducted using descriptive statistical methods to identify patterns of biochemical specialization.

Results

The comprehensive laboratory analysis produced detailed proximate, macro-, and micronutrient, and heavy metal profiles of the three *Enset vetricosume* landraces (Kake (KK), Kerse (K), and Mundo (M)) across four distinct plant parts: Corm (R), Pseudostrem (S), Leaf (L), and Midrib (D). Key metrics measured include proximate composition (moisture, ash, crude protein, crude fat, crude fiber, and carbohydrate), macronutrients, micronutrients, and heavy metals.

Proximate composition analysis

Marked variation in proximate composition was observed among plant parts and landraces. Leaves of all landraces exhibited the highest crude protein content (16.0–19.6%), while corms and pseudostems were dominated by carbohydrate fractions, reflecting their primary role as energy sources(Table 1). Fiber and ash contents also varied significantly across plant organs, indicating differential nutrient partitioning. The standard deviation (SD) values across replicate analyses were generally low, indicating robust reproducibility and analytical precision.

Crude Protein: The highest protein content was observed in leaf parts. Kake leaf (KKL) and Kerse leaf (KL) exhibited protein levels of 19.59% and 18.70%, respectively, followed by Mundo leaf (ML) at 16.03%. In contrast, corms and pseudostem parts showed much lower protein: pseudostem ranged from 4.40% in Kake to 5.78% (Mundo), and corms ranged from 4.81% (Kake) to 8.86% (Mundo).

Crude Fiber: Midribs exhibited the highest fiber concentrations. Kake midrib (KKM) and Kerse midrib (KM) containing 40.50% and 39.50%, respectively. Leaves also had high fiber content (KKL: 32.90%; KL: 31.10%), whereas corms and pseudostems were structurally lower, with fiber values generally below 6.5%, consistent with their storage function.

Ash Content

Indicative of total mineral content, ash was most abundant in midribs and leaves. The highest ash values were recorded in Kerse midrib (14.99%) and Kake midrib (14.86%), while the leaves of all three landraces ranged around ~ 11.0–11.7%. Meanwhile, corms had the lowest ash content, consistently below 5.0%.

Crude Fat

Lipid content was very low. Fat was detectable only in corm and pseudostem parts (0.22–0.32%) and was below the detection limit in both leaves and midribs.

Carbohydrates

Calculated by difference, carbohydrate content was highest in the corms and pseudostems aligning with their role as storage organs.

Energy value

Using Atwater conversion factors, the calculated energy values (kcal/100 g) were predominantly driven from carbohydrate content (see Table 1). Energy ranged from 266.5 kcal/100 g in Kake midrib (KkM) to 368.5 kcal/100 g in Kake corm (KkR).

Table 1
Mean Proximate Composition and Nutritional Values of *Ensete vetricosum* Landraces and Plant Parts (Mean ± SD, n = 3).

Landrace	Plant Part	Lab Code	Crude Protein (%)	Crude Fiber (%)	Ash (%)	Crude Fat (%)	Carbohydrates* (%)	Energy Value (kcal/100 g)
Kake	Corm	KKR	4.81 ± 0.44	3.45 ± 0.64	4.95 ± 0.10	0.29 ± 0.01	86.50	368.5
	Pseudostem	KKS	4.40 ± 0.27	6.25 ± 2.48	4.95 ± 0.10	0.22 ± 0.01	84.18	357.0
	Leaf	KKL	19.59 ± 1.01	32.90 ± 4.38	11.69 ± 0.46	–	35.82	315.3
	Midrib	KKM	6.13 ± 0.26	40.50 ± 1.84	14.86 ± 0.26	–	38.51	266.5
Kerse	Corm	KR	6.74 ± 0.35	3.30 ± 0.99	3.96 ± 0.05	0.22 ± 0.01	85.78	365.8
	Pseudostem	KS	5.20 ± 0.07	4.05 ± 1.77	6.58 ± 0.09	0.32 ± 0.01	83.85	358.3
	Leaf	KL	18.70 ± 0.73	31.10 ± 4.53	11.59 ± 0.18	–	38.61	313.2
	Midrib	KM	7.48 ± 0.83	39.50 ± 2.69	14.99 ± 0.04	–	38.03	272.4
Mundo	Corm	MR	8.86 ± 0.73	5.45 ± 0.35	3.68 ± 0.45	0.26 ± 0.01	81.75	362.2
	Pseudostem	MS	5.78 ± 0.31	4.50 ± 2.12	4.15 ± 0.10	0.27 ± 0.01	85.30	364.4
	Leaf	ML	16.03 ± 0.84	28.70 ± 0.42	10.99 ± 0.05	–	44.28	321.2
	Midrib	MM	8.84 ± 0.20	16.75 ± 0.92	7.42 ± 0.20	–	66.99	341.0

Note: *Carbohydrates calculated by difference: 100 - (Moisture + Protein + Fat + Ash + Fiber). Note: Moisture content was determined and subtracted, values not shown for brevity, and – means not detected,

Macro- and micronutrient composition

Distinct part-specific mineral profiles were identified. Corms of the Kake and Mundo landraces contained notably high concentrations of phosphorus (up to 2,986 mg/kg) and zinc (88–121 mg/kg). Leaves across all landraces were particularly rich in calcium (up to 10,119 mg/kg) and iron (> 1,000 mg/kg). The midrib of the Kerse landrace showed elevated magnesium content (1,847 mg/kg), distinguishing it from other landraces and plant parts. These differences reflected the functional specialization of the tissues as storage, structural, or photosynthetic organs(Table 2).

Macronutrients

Potassium (K) was the most abundant macronutrient in all samples and dominated the mineral profile. The highest concentrations were found in the leaves, with Mundo leaf (ML) containing 33,690 mg/kg and Kake leaf (KKL) 31,188 mg/kg, consistent with K's role in photosynthesis and stomata regulation.

Calcium (Ca) levels were exceptionally high in the leaves, with Kake leaf (KKL) containing a remarkable high concentration with 10,119 mg/kg, significantly exciding values observed in pseudostrems and corms ($p < 0.05$). Midribs also showed elevated Ca levels due to their structural reinforcement function.

Magnesium (Mg) followed a similar pattern, with the highest concentration recorded in leaf tissue: Mundo leaf (ML) 2,640 mg/kg and Kake leaf (KKL) (2,365 mg/kg). This is consistent with Mg's essential role in chlorophyll structure and photosynthesis metabolism.

Phosphorus (P) displayed a contrasting distribution, with maximum accumulation in the corms, particularly Kake corm (KKR), which contained 2,986 mg/kg. This reflects the corms' function as a storage organ for metabolic energy phosphorylated compounds.

Micronutrients

Iron (Fe) was predominantly accumulated in leaf parts across all landraces. Mundo leaf (ML) (1,144 mg/kg) and Kake leaf (KKL) (1,046 mg/kg) showed values substantially higher by several orders of magnitude than those recorded in corms or pseudosterms. This aligns with Fe's involvement in chloroplast electron transport.

Zinc (Zn) exhibited its highest concentrations in the corm tissues. Mundo corm (MR) was exceptionally rich in Zn (121 mg/kg), followed by Kake corm (KKR) (88 mg/kg). The elevated Zn content in corms may reflect its role enzymatic function and carbohydrate metabolism.

Manganese (Mn) and **Copper (Cu)** were occurred in moderate amounts across all samples, with generally higher concentrations observed in the leaves and midribs than in corms and pseudosterms. Leaf tissue which supports intense metabolic activity contained the highest Mn concentrations (up to 61 mg/kg in ML) and Cu concentrations (up to 8.5 mg/kg in KKL).

These mineral distribution patterns demonstrate a clear differentiation between metabolically active tissues (leaves), structural tissues (midribs), and storage organs (corms), supporting functional specialization within the enset plant.

Table 2

Macro‑ and micronutrient concentrations (mg/kg DW) in three *Enset vetricosum* landraces and plant parts (mean ± SD, n = 3).

Landrace	Plant Part	Lab Code	K	Ca	Mg	P	Fe	Zn	Mn	Cu
Kake	Corm	KKR	17,944 ± 472 a	829 ± 17 c	620 ± 15 c	2,017 ± 30 a	44 ± 3 d	11 ± 1 a	25 ± 1 c	1 ± 0 b
	Pseudostem	KKS	20,887 ± 178 b	1,268 ± 14 c	712 ± 27 d	2,015 ± 67 b	68 ± 1 d	8 ± 1 c	22 ± 1 d	1 ± 0 c
	Leaf	KKL	31,107 ± a	**10,160 ± 29 a**	2,345 ± 32 a	1,706 ± 80 c	716 ± 14 a	28 ± 1 b	609 ± 8 a	5 ± 1 a
	Midrib	KKM	43,788 ± 740 c	8,366 ± 92 b	1,730 ± 21 b	1,694 ± 88 c	406 ± 3 b	22 ± 1 c	285 ± 3 b	1 ± 0 b
Kerse	Corm	KR	15,741 ± 114 c	876 ± 16 c	898 ± 22 e	2,986 ± 57 c	41 ± 2 d	88 ± 1 c	39 ± 1 c	4 ± 1 c
	Pseudostem	KS	25,932 ± 252 b	1,058 ± 6 b	762 ± 12 b	2,323 ± 47 c	66 ± 2 b	6 ± 1 c	22 ± 1 c	1 ± 0 b
	Leaf	KL	31,189 ± 288 a	10,012 ± 166 a	2,365 ± 11 a	1,836 ± 14 c	1,046 ± 6 a	43 ± 1 b	630 ± 7 a	4 ± 1 a
	Midrib	KM	50,588 ± 605 c	11,078 ± 33 b	1,609 ± 30 b	970 ± 43 c	1,204 ± 15 b	70 ± 1 c	321 ± 5 b	3 ± 1 b
Mundo	Corm	MR	8,581 ± 210 d	665 ± 1 c	1,790 ± 15 b	1,834 ± 34 c	34 ± 1 d	**121 ± 2 a**	44 ± 1 c	4.0 ± 1 b
	Pseudostem	MS	14,311 ± 474c	1,553 ± 30c	1,487 ± 11c	1,684 ± 103c	36 ± 1 d	5 ± 1 c	38 ± 1c	ND
	Leaf	ML	**33,704 ± 677 a**	5,264 ± 120 b	**2,640 ± 45a**	2,226 ± 126 b	**1,144 ± 11 a**	22 ± 1 b	451 ± 1a	6 ± 1 a
	Midrib	MM	22,511 ± 421c	2,432 ± 53 b	1,873 ± 24 b	2,142 ± 17 c	309 ± 5 c	12 ± 1 c	60 ± 1 b	2 ± 1 b

Note: Different superscript letters within a column indicate significant differences ($P < 0.05$). The highest value for each element is shown in bold.

Heavy Metal Concentrations

Toxic heavy metals, including arsenic, were below detectable limits in all samples analyzed(Table 3). Other heavy metals were present at concentrations well below internationally accepted safety thresholds(FAO/WHO, 2021), indicating that the examined enset plant parts are safe for both dietary consumption and traditional medicinal use.

The concentrations of potentially toxic elements including Pb, Cd, As, Cr, Ni, Co and Hg were either below detection limits (BDLs) (Table 3) or well within the safe thresholds defined by international food safety standards (FAO/WHO, 2021) and supported by similar findings reported by Rehman *et al.*, (2024). Arsenic remained undetectable (< 0.002 mg/kg) across all samples, indicating mineral geogenic or anthropogenic contamination in the studied areas. Cadmium and mercury were largely undetected or present only in trace amounts, suggesting a low environmental burden and limited exposure pathways. Small traces of chromium and nickel appeared in a few corm and leaf samples, but all values are negligible (< 10 mg/kg DW) and far below toxicological concern. Overall, the extremely low heavy metal levels suggest minimum environmental contamination and confirm that the evaluated enset landraces are safe for traditional food consumption and medical applications.

Table 3
Heavy Metals concentrations in Enset vetricosum (mg.kg DW) (mean ± SD, n = 3).

Landrace & Part	As	Cd	Hg	Ni
All Kake (KK) Parts	< 0.002	0.06–1.07	< 0.008–2.94	0.59–1.69
All Kerse (K) Parts	< 0.002	< 0.001–0.15	< 0.008–0.52	0.18–0.42
All Mundo (M) Parts	< 0.002–0.11	0.02–0.87	< 0.008–1.72	< 0.003–1.94

Note: Value represent the observed concentration ranges across all sampled plant parts.

Functional Nutrient Density Analysis

Beyond absolute concentrations, functional nutrient density differed markedly among enset plant parts, reflecting distinct physiological and nutritional roles(Table 4). The combined enrichment of calcium, phosphorus, and zinc in corm tissues, particularly in the Kake and Mundo landraces, indicates a mineral profile well aligned with skeletal metabolism and tissue repair. These minerals act synergistically in bone mineralization and wound healing, suggesting that corm tissues represent a concentrated functional nutrient reservoir rather than solely a carbohydrate storage organ.

Leaf tissues across all landraces exhibited high protein–iron–calcium density, positioning them as nutritionally valuable plant parts with potential relevance for addressing micronutrient deficiencies. The co-occurrence of iron and protein is especially significant in plant-based diets, where iron bioavailability is often constrained. The midrib of the Kerse landrace displayed a distinct magnesium-dominant profile, reinforcing functional differentiation at the organ level.

Table 4
Functional Nutrient Density Index of Enset Plant Parts

Plant part	Key nutrients	Functional implication
Corm	Ca, P, Zn	Bone healing, wound recovery
Leaf	Protein, Fe, Ca	Nutritional supplementation, recovery
Midrib	Mg	Gastrointestinal regulation

The one-way ANOVA followed by Tukey's HSD test ($p < 0.05$) revealed significant variation among landraces for most of macro and micronutrients, notably K, Ca, Mg, Fe, Zn, and crude protein content. A significant landrace and plant part interaction was also observed, demonstrating that nutrient distribution is both organicspecific and genotypicdependent. Kake exhibited the highest Fe and crude protein concentrations, particularly in the leaves suggesting strong micronutrient accumulation potential. Mundo showed elevated Ca and Mg levels in the corm, indicating superior mineral storage in underground tissues. Kerse, though comparatively moderate in primarily macro-nutrients, exhibited the highest Mn and Zn levels in the pseudostem. This compositional heterogeneity underscores the biochemical diversity within enset (*Enset vetricosum*) landraces cultivated across the Gedeo Zone. Such diversity suggests potential nutritional complementary, supporting the plant's longstanding ethnobotanical and dietary significance.

Contribution to Dietary Requirements

When interpreted in the context of human nutrition, the mineral concentrations observed suggest that selected enset plant parts can make meaningful contributions to daily dietary requirements. Based on dry matter content, enset leaves have the potential to supply a substantial proportion of recommended daily intakes for calcium and iron, while corm tissues contribute appreciable levels of phosphorus and zinc. These findings highlight enset's role not only as a food security crop but also as a nutritionally functional species capable of supporting mineral intake in enset-dependent communities.

Heavy Metal Safety Margin Assessment

Heavy metal concentrations in all analyzed samples were either below detection limits or substantially lower than internationally accepted maximum permissible levels. The absence of detectable arsenic and the low concentrations of other potentially toxic elements indicate a wide safety margin for both dietary and traditional medicinal use. This safety profile is particularly important given the frequent and long-term consumption of enset-based foods and preparations in southern Ethiopia.

Discussion

Taken together, the results demonstrate that nutrient partitioning in enset is neither random nor uniform across landraces. Instead, it reflects a highly structured biochemical architecture that closely mirrors indigenous, part-specific use. The following discussion interprets these patterns in nutritional, ethnomedicinal, and conservation contexts.

Biochemical Specialization and Part-Specific Nutritional Roles

The present study demonstrates clear part-specific biochemical specialization across the three Ethiopian enset landraces examined, supporting the hypothesis that traditional use patterns are underpinned by measurable nutritional and mineral differences. Such nutrient partitioning among plant organs is well documented in perennial crops and is increasingly recognized as a key determinant of functional food value (White & Broadley, 2009; Ma et al., 2015). In enset, this specialization appears to be both landrace-dependent and organ-specific, reflecting genetic diversity and long-term human selection.

The corms of Kake and Mundo exhibited particularly high concentrations of phosphorus and zinc. Phosphorus is a critical structural component of bone tissue and plays a central role in energy metabolism and cellular repair processes, while zinc is essential for collagen synthesis, immune modulation, and wound healing (Prasad, 2013; Soetan et al., 2010). The elevated levels of these minerals provide a strong biochemical rationale for the traditional use of enset corms in the treatment of bone fractures and wounds, as reported in the Gedeo Zone. Similar associations between zinc-rich plant tissues and wound-healing properties have been reported in other traditional medicinal plants (Gupta et al., 2019).

Nutritional Potential of Enset Leaves

The leaves of all three enset landraces showed notably high crude protein content, along with elevated iron and calcium concentrations. Leafy plant tissues are widely recognized as important sources of dietary protein and minerals in plant-based diets, particularly in low-income settings (Burlingame et al., 2009). The protein levels observed in enset leaves compare favorably with those reported for several commonly consumed leafy vegetables in sub-Saharan Africa (Uusiku et al., 2010), indicating their potential contribution to dietary protein intake.

Iron concentrations exceeding 1,000 mg/kg and calcium levels surpassing 10,000 mg/kg suggest that enset leaves may play a significant role in addressing micronutrient deficiencies. Iron deficiency anemia and inadequate calcium intake remain major public health challenges in Ethiopia (WHO, 2016). Although mineral bioavailability was not assessed in this study, the high mineral density observed supports the nutritional relevance of enset leaves and aligns with traditional practices of using leaf-based preparations for strengthening and recovery. Similar findings have been reported in studies linking mineral-rich plant leaves to improved nutritional outcomes (Gibson et al., 2010).

Magnesium and Gastrointestinal Uses of the Midrib

The elevated magnesium content observed in the midrib of the Kerse landrace is particularly noteworthy. Magnesium plays a key role in smooth muscle relaxation, neuromuscular transmission, and gastrointestinal motility (Rosanoff et al., 2012). Its association with alleviation of abdominal pain and digestive discomfort is well established in clinical and nutritional literature (Baaij et al., 2015). The high magnesium concentration measured in Kerse midrib provides a plausible biochemical explanation for its traditional use in managing abdominal ailments, reinforcing the functional relevance of landrace-specific mineral profiles.

Food Safety and Heavy Metal Assessment

From a food safety perspective, the absence of detectable arsenic and the presence of other heavy metals within internationally accepted limits is a critical finding. Contamination of plant-based foods with toxic metals poses significant health risks, particularly in regions where staple crops constitute a large proportion of daily intake (Alloway, 2013; WHO & FAO, 2011). The results of this study indicate that the examined enset landraces and plant parts are safe for both dietary and traditional medicinal use under current conditions.

These findings are consistent with previous reports indicating relatively low heavy metal accumulation in enset compared to other root and tuber crops (Abebe et al., 2020). However, continued monitoring remains important, especially in the context of increasing agricultural intensification and environmental change.

Indigenous Knowledge as a Guide for Functional Food Discovery

The strong correspondence between traditional use patterns and biochemical composition observed in this study supports growing evidence that indigenous knowledge systems are reliable guides for identifying nutritionally and therapeutically valuable plant resources (Pieroni & Quave, 2014; Albuquerque et al., 2019). Rather than being anecdotal, such knowledge often reflects long-term empirical experimentation and selective use.

Validating indigenous practices through rigorous food science approaches not only enhances their scientific credibility but also contributes to the conservation of landraces that are at risk of erosion due to agricultural modernization (Negash, 2010). The documented biochemical diversity among enset landraces further underscores the importance of conserving genetic resources for future food and nutrition security.

Implications for Food Security and Nutrition-Sensitive Agriculture

The biochemical diversity revealed in this study highlights enset's potential beyond its traditional role as a carbohydrate-rich staple. By providing protein, essential minerals, and safe functional plant parts, enset represents a valuable component of nutrition-sensitive agricultural systems aimed at addressing hidden hunger and micronutrient deficiencies (FAO, 2019; HLPE, 2020). Promoting diversified use of enset plant parts, guided by both indigenous knowledge and scientific evidence, may enhance dietary quality and resilience in enset-growing regions.

Functional Implications of Nutrient Partitioning

The observed organ-specific nutrient distribution reflects adaptive nutrient partitioning typical of perennial crops. Leaves, as primary sites of photosynthesis and metabolic activity, accumulated higher protein and mineral concentrations essential for enzymatic and physiological functions. Corm tissues, which serve as storage and regenerative organs, were enriched in phosphorus and zinc, nutrients closely linked to cellular proliferation and structural integrity. The magnesium-rich midrib likely reflects its role in solute transport and osmotic regulation.

Importantly, the alignment between nutrient density and traditional use patterns suggests that indigenous knowledge functions as a practical framework for identifying functional plant tissues. Rather than being anecdotal, such knowledge appears to reflect long-term empirical optimization of nutritional and therapeutic outcomes.

Conclusion

This study demonstrates clear biochemical specialization across plant parts and landraces of *Ensete ventricosum*, providing strong scientific evidence in support of its traditional nutritional and medicinal uses in southern Ethiopia. Distinct distributions of essential minerals and macronutrients among the corm, leaf, and midrib were closely aligned with indigenous use patterns, confirming that traditional knowledge effectively identifies functionally important plant parts.

The high concentrations of phosphorus and zinc in the corms of selected landraces support their traditional application in bone healing and wound recovery, while the protein-, calcium-, and iron-rich leaves highlight the broader nutritional potential of enset beyond its role as a starch-based staple. The elevated magnesium content observed in the midrib of one landrace further explains its use in managing abdominal discomfort. Importantly, the absence of detectable arsenic and the presence of other heavy metals within acceptable safety limits confirm that these plant parts are safe for dietary and therapeutic use under current conditions.

Beyond validating traditional practices, the observed biochemical diversity underscores the importance of conserving enset landraces as valuable genetic resources for food and nutrition security. Integrating indigenous knowledge with rigorous food composition and safety assessments can guide the sustainable use and promotion of underutilized crops such as enset within nutrition-sensitive agricultural systems. Future research should focus on mineral bioavailability, functional properties, and processing effects to further enhance the contribution of *Ensete ventricosum* to resilient and culturally grounded food systems.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. **Promotion of diversified enset use:**
   Nutritionally rich plant parts such as leaves and midribs should be promoted alongside traditional corm-based foods to enhance dietary diversity and micronutrient intake.
2. **Integration into nutrition-sensitive agriculture:**
   Enset landraces with superior mineral and protein profiles should be integrated into food and nutrition programs aimed at addressing micronutrient deficiencies in enset-growing regions.
3. **Conservation of enset genetic resources:**
   The observed biochemical diversity among landraces highlights the need for conservation strategies that protect both genetic diversity and associated indigenous knowledge.
4. **Further research:**

Future studies should investigate mineral bioavailability, functional properties, and the effects of traditional processing and fermentation on nutrient retention and safety.

5. **Policy and extension support:**

Agricultural extension services and policymakers should recognize enset as a multifunctional crop with nutritional and therapeutic value and support its sustainable cultivation and utilization.

Declarations

Authors' Contributions

Mitiku Muanenda: Conceptualization, Investigation (field sample collection), Formal Analysis (statistical analysis), Writing – Original Draft Preparation.
Workineh Mengesha Fereja: Conceptualization, Investigation (laboratory analysis), Writing – Review & Editing.
Firehiwot Belyneh Usamo: Writing – Review & Editing.

All authors have read and approved the final version of the manuscript.

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Figures

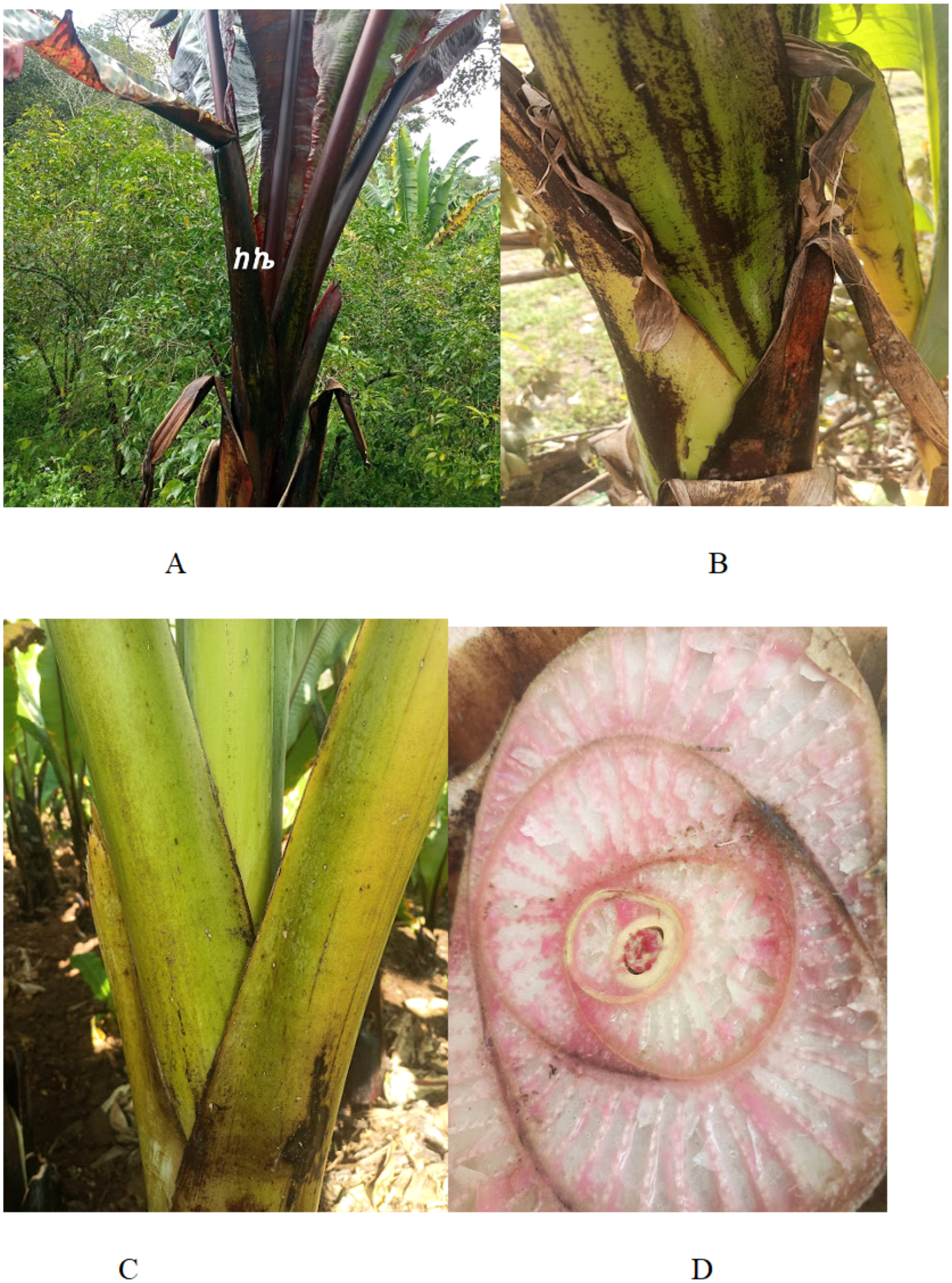

Figure 1

Diagnostic phenotypic traits of the three Enset landraces. (A) Kake: Red-purple pseudostem and leaf pigmentation. (B) Kerse: Bitter-tasting leaf (with icon of tasting). (C) Mundo: pseudostem. (D) Mundo- Pink-red exudate from cut pseudostem.