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GC–MS characterization, antioxidant capacity, and nutritional prospects of Utebe Ekpo (*Eryngium foetidum L.*) cultivated in Ikono, Akwa Ibom State, Nigeria: An underexplored functional food resource

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Abstract

Eryngium foetidum L., locally known as Utebe Ekpo in southern Nigeria, is a tropical leafy herb traditionally consumed as a spice and medicinal plant, yet remains underexplored as a functional food. This study evaluated the phytochemical composition, nutritional profile, Fatty Acid Methyl Ester (FAME) constituents, and antioxidant capacity of *E. foetidum* leaves cultivated in Ikono, Akwa Ibom State, Nigeria, using standard analytical and spectrometric methods. Quantitative phytochemical analysis revealed polyphenols as the predominant secondary metabolites (11.67±0.33%), followed by flavonoids (7.40±0.12%), alongside steroidal and triterpenoid saponins, coumarins, carotenoids, and alkaloids in lower proportions. Proximate analysis showed a high moisture content (88.20±1.15%) and a nutritionally balanced composition, including carbohydrates (40.00 mg/100 g), crude protein (40.58 mg/100 g), crude fiber (26.67 mg/100 g), and fat (2.43 mg/100 g), yielding a total metabolic energy value of 1970.33 kJ/100 g. Anti-nutritional factors, such as oxalates, phytates, and cyanogenic compounds, were present at concentrations below 1 mg/100 g, indicating a minimal dietary risk. The leaves were particularly rich in vitamins A (1038.31 mg/100 g), C, B-complex vitamins, E, and D, as well as essential minerals including potassium (331.33 mg/100 g), magnesium, zinc, phosphorus, and copper. GC–MS analysis of FAMEs identified twelve compounds, with hexadecanoic acid and methyl esters of linoleic and oleic acids as dominant constituents. Antioxidant assays demonstrated moderate radical scavenging activity, with IC_{50} values of 28.11 µg/mL (DPPH) and 6.73 µg/mL (ABTS), relative to ascorbic acid. The high total phenolic (1205.11 µg/mL GAE) and flavonoid (128.16 µg/mL QE) contents substantiate the antioxidant potential of the plant. Collectively, these findings position *E. foetidum* as a promising indigenous functional food; however, further mechanistic and clinical studies are required before its therapeutic application in chronic disease management can be recommended.

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Introduction

The exploration of phytochemical-rich foods as sources of bioactive compounds has gained increasing scientific attention due to their potential roles in mitigating oxidative stress and diet-related chronic diseases. This growing interest is driven by rising global concerns over nutritional inadequacies, metabolic disorders, and oxidative imbalance associated with modern dietary patterns [1,2]. Under investigated indigenous plant resources represent an untapped reservoir of nutritionally and pharmacologically valuable compounds with promising implications for public health and sustainable food systems.

Eryngium foetidum L. is a perennial herbaceous plant belonging to the family Apiaceae, typically reaching heights of 30-60 cm. It is widely distributed in tropical regions and is known by various vernacular names, including culantro, Mexican coriander, and cilantro sabanero [1]. In southern Nigeria, particularly among the Ibibio people of Akwa Ibom State, the plant is locally referred to as *Utebe Ekpo* and is commonly cultivated and consumed in Ikono and Abak Local Government Areas. Beyond its culinary significance, *E. foetidum* has a long history of use in traditional medicine across tropical regions, where it is employed for the management of inflammation, infections, and digestive disorders [1].

Previous studies conducted mainly in Latin America and the Caribbean have reported that *E. foetidum* is nutritionally rich and contains diverse bioactive constituents, including essential vitamins, minerals, flavonoids, phenolic compounds, phytosterols, triterpenes, and other secondary metabolites associated with antioxidant and health-promoting effects [1-3]. Despite its ethnobotanical relevance, comprehensive scientific data on the phytochemical composition, antioxidant activity, and nutritional value of *E. foetidum* cultivated under specific agro-ecological conditions in Nigeria remain limited.

Environmental factors such as soil composition, climate, and cultivation practices are known to influence the biochemical profile and bioactivity of medicinal and food plants. Therefore, region-specific studies are essential to accurately assess the functional food potential of *E. foetidum* grown in Ikono, Akwa Ibom State. Addressing this knowledge gap is particularly important given emerging evidence that the antioxidant and nutraceutical properties of the plant are closely linked to its polyphenolic and vitamin content [2].

Ikono is an agrarian community where crop cultivation plays a central role in local livelihoods. The scientific validation and promotion of indigenous vegetables such as *E. foetidum* could contribute meaningfully to food security, nutritional diversification, healthcare resilience, and local economic sustainability. Such efforts align with global objectives focused on sustainable agriculture, biodiversity conservation, and the valorization of underutilized plant resources [5].

Against this backdrop, the present study investigates the GC–MS fatty acid profile, antioxidant capacity, and nutritional composition of *E. foetidum* leaves cultivated in Ikono, Akwa Ibom State, Nigeria. The findings aim to provide a scientific basis for the plant's classification as a functional food and to encourage its sustainable utilization and wider acceptance in nutrition and health-related applications.

Materials and methods

Collection and identification of plant material

Fresh leaves of *Utebe Ekpo* (*Eryngium foetidum* L.) were harvested from a forested area in Nnung Ukim Ikot Etefia, Ikono Local Government Area, Akwa Ibom State, Nigeria. The samples were collected in the early hours of the day to minimize metabolic degradation. Immediately after collection, the leaves were rinsed thoroughly with clean running water to remove adhering soil and debris and subsequently stored under refrigerated conditions before analysis. Botanical authentication was carried out by Dr. Imoh I. Johnny, a taxonomist at the University of Uyo, Nigeria. A voucher specimen (MBC/VS/01) was deposited in the Herbarium of the Department of Medical Biochemistry, Alex Ekwueme Federal University, Ndufu-Alike, Nigeria, for future reference.

Preparation and processing of plant material

Fresh *E. foetidum* leaves (500 g) were washed with running tap water to eliminate surface contaminants and chopped into smaller portions. The samples were freeze-dried for six hours to preserve thermolabile bioactive constituents and prevent enzymatic degradation. The dried leaves were pulverized using a laboratory mortar and pestle to obtain a fine powder. The powdered samples were stored in sterile, airtight polyethylene containers under controlled conditions to prevent moisture absorption and contamination. Aliquots of the powdered material were subsequently used for proximate analysis, mineral determination, vitamin profiling, phytochemical quantification, anti-nutrient evaluation, and antioxidant assays using standard analytical procedures [5,6].

Quantitative phytochemical analysis

Quantitative determination of phytochemical constituents, including saponins, polyphenols, flavonoids, alkaloids, carotenoids, sesquiterpenoids, and cardiac glycosides, was conducted following established standard methods. Saponin content was determined using the method described, with modifications as reported by [6-9]. Column chromatography using silica gel (mesh size 368) was employed for the separation of flavonoids, alkaloids, and sesquiterpene lactones, followed by extraction with ethyl acetate and gravimetric quantification. Alkaloids were further quantified using alkaline precipitation and gravimetric techniques, while sesquiterpenes were estimated through double extraction and gravimetric analysis [10].

Proximate composition analysis

Proximate parameters, including moisture content, ash, crude fat, crude protein, crude fiber, and carbohydrate, were determined in accordance with standard procedures outlined by the Association of Official Analytical Chemists (AOAC) [11].

Determination of anti-nutritional factors

Anti-nutritional components present in the powdered leaf sample were quantified using established protocols as follows: tannins were estimated using the Folin–Denis spectrophotometric method, oxalates were determined according to the procedure described by [11,12]; phytates were quantified using a standard method [11]; and hydrocyanic acid (HCN) content was assessed by alkaline titration [12,13].

Vitamin analysis

Water-soluble vitamins, including thiamine (B_1), riboflavin (B_2), niacin (B_3), pyridoxine (B_6), biotin, folic acid, and cyanocobalamin (B_{12}), were quantified using High-Performance Liquid Chromatography (HPLC) as described. Fat-soluble vitamins were similarly determined using HPLC following the protocol reported. Total vitamin C (ascorbic acid plus dehydroascorbic acid) was measured using UV-visible spectrophotometry as described. Briefly, ascorbic acid was oxidized to dehydroascorbic acid using bromine water in an acidic medium. The filtrate was reacted with 2,4-dinitrophenylhydrazine and incubated at 37°C for 3 h. After cooling, 85% sulfuric acid was added to produce a red-colored complex, which was measured at 521 nm, yielding a recovery rate of 78% for total vitamin C. Vitamin A was determined spectrophotometrically using iodine in 1,2-dichloroethane as a chromogenic agent to eliminate interference from vitamin D_2 and β-carotene [26], and results were cross-validated using the method described. Total vitamin E content was quantified using HPLC as described [14-16].

Mineral element analysis

Mineral analysis was performed using Atomic Absorption Spectrometry (AAS). One gram of powdered *E. foetidum* leaf sample was placed in a porcelain crucible and ashed in a muffle furnace at 300°C for 6 h. The ash was allowed to cool to room temperature (30±2°C) and digested with 20 mL of 4 M nitric acid (HNO_3) and perchloric acid (60%). The digest was diluted to a final volume of 100 mL with deionized water. Concentrations of Fe, Zn, Se, Mn, Co, Li, Sr, Cr, Na, K, Mg, Cu, and Ni were determined using AAS according to established methods [16].

Energy value determination

The metabolizable energy value (kJ/100 g) was calculated using the Atwater general factors as follows:

Energy (kJ/100 g) = [37× Fat] + [17× Carbohydrate] + [17 × Protein] (1)

Fourier transform infrared (FTIR) analysis

Functional groups present in the bioactive constituents of *E. foetidum* were identified using a Bruker Alpha II FTIR spectrometer (USA). Spectra were recorded in absorbance mode over the wavenumber range of 4000–500 cm^{-1} to identify characteristic functional groups corresponding to specific phytochemical classes [15].

GC–MS analysis

Phytochemical constituents were further characterized using Gas Chromatography–Mass Spectrometry (GC–MS) analysis performed on an Agilent 7890A GC system coupled with a mass spectrometer. Compounds were identified based on their retention times, mass-to-charge ratios (m/z), molecular ion peaks (M^+), and fragmentation patterns, following the protocol as described [17,18].

Determination of Total Phenolic Content (TPC)

Total phenolic content was determined using the Folin–Ciocalteu colorimetric method. Ten grams of the dried powdered sample were extracted with 100 mL of methanol. One milliliter of the extract was mixed with 10 mL of deionized water, 2 mL of Folin–Ciocalteu reagent, and 3 mL of sodium carbonate solution. The mixture was incubated at room temperature for 90 min for color development, and absorbance was measured at 760 nm using a UV-visible spectrophotometer. Gallic acid was used to construct a standard calibration curve, and results were expressed as mg Gallic Acid Equivalents (GAE) per gram of extract [18,19].

Determination of total flavonoid content (TFC)

Total flavonoid content was assessed using the aluminum chloride colorimetric method as described in. Quercetin served as the reference standard, and results were expressed as mg Quercetin Equivalents (QE) per gram of extract [19].

In Vitro antioxidant assays

DPPH radical scavenging assay: The antioxidant activity of the methanol extract was evaluated using the DPPH radical scavenging assay with slight modifications [19]. A DPPH solution was prepared by dissolving 1 g of DPPH in 10 mL of 98.1% (v/v) methanol. Serial dilutions of the extract (100–600 µg/mL) were prepared and mixed with the DPPH solution. Absorbance was measured at 517 nm, with ascorbic acid serving as the positive control. The percentage radical scavenging activity was calculated as:

$$\%\text{DPPH Scavenging} = \frac{(Abs_c - Abs_E)}{Abs_c} \times 100 \quad (2)$$

where Absc is the absorbance of the control, and Absg is the absorbance of the extract.

ABTS radical scavenging assay: ABTS radical cation was generated by mixing 5 mM ABTS solution with 1 mM potassium persulfate and incubating the mixture in the dark for 24 h. The solution was diluted with methanol to obtain an absorbance of 0.70±0.02 at 734 nm. Thereafter, 100 µL of extract or Trolox standard (100-600 µg/mL) was mixed with 3 mL of ABTS solution. Absorbance was recorded after 6 min at 745 nm against a methanol blank [19]. The percentage ABTS scavenging activity was calculated as:

$$\%\text{ABTS Scavenging} = \frac{(Abs_c - Abs_E)}{Abs_c} \times 100 \quad (3)$$

Statistical analysis

All experiments were conducted in triplicate (n=3). Results are presented as mean ± Standard Error of the Mean (SEM). Data were analyzed using one-way analysis of variance (ANOVA), and differences were considered statistically significant at $p<0.05$.

Results

FTIR characterization of bioactive functional groups

Fourier Transform Infrared (FTIR) spectroscopy was employed to identify functional groups associated with bioactive compounds in the *Eryngium foetidum* leaf extract. The FTIR spectrum revealed a broad absorption band at 3241.05 cm^{-1}, corresponding to O–H stretching vibrations typical of hydroxyl groups found in phenolic compounds and alcohols. Prominent absorption peaks at 2920.93, 2901.53, and 2851.05 cm^{-1} were attributed to aliphatic C–H stretching vibrations of alkanes. A strong band observed at 1622.22 cm^{-1} is characteristic of C=C stretching vibrations of aromatic rings and/or N–H bending of amide groups.

The fingerprint region (1500–500 cm^{-1}) exhibited several distinct peaks at 1442.55, 1320.60, 1228.25, 1107.56, 1010.06, 778.68, and 568.11 cm^{-1}, indicating the presence of C–O, C–N, and aromatic skeletal vibrations. These absorption features collectively suggest the presence of alcohols, phenols, alkanes,

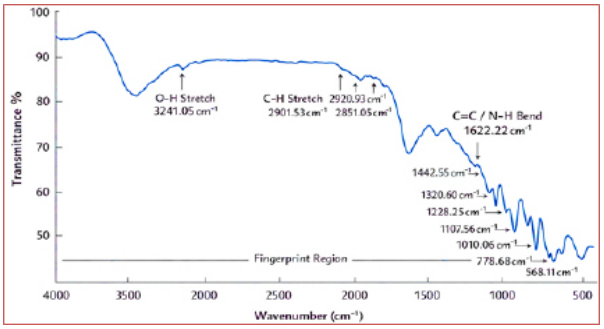

Figure 1: FTIR spectrum of bioactive compounds from *Eryngium foetidum.*

Total phenolic and flavonoid contents

The total phenolic content (TPC) of the *E. foetidum* methanol extract was quantified as 1205.11 µg/mL Gallic Acid Equivalents (GAE) per 100 g dry weight, based on the gallic acid calibration curve (y=0.0062x+0.1344; R^2=0.7351). Total Flavonoid Content (TFC) was determined to be 128.16 µg/mL quercetin equivalents (QE) per 100 g dry weight using the quercetin standard curve (y=0.0003x+0.55; R^2=0.8204). Statistical analysis showed that the phenolic and flavonoid contents of the extract were not significantly different from their respective standard controls (p>0.05). These results indicate that *E. foetidum* contains appreciable quantities of phenolic and flavonoid compounds (Figure 2a and b).

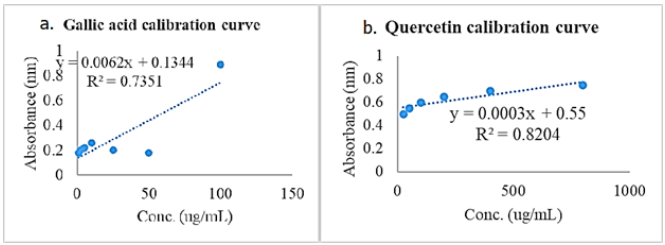

Figure 2: Calibration curves for **(a)**; gallic acid used for Total Phenolic Content (TPC) determination and **(b)**; quercetin used for Total Flavonoid Content (TFC) determination, showing linear regression equations and coefficients of determination (R^2).

In Vitro antioxidant activity

The antioxidant potential of *E. foetidum* leaf extract was evaluated using DPPH and ABTS radical scavenging assays. The extract exhibited IC_{50} values of 28.11 µg/mL for DPPH radicals and 6.73 µg/mL for ABTS radicals. In comparison, the standard antioxidant, ascorbic acid, showed IC_{50} values of 8.22 µg/mL (DPPH) and 4.24 µg/mL (ABTS) (Table 1). Although the extract demonstrated higher IC_{50} values than ascorbic acid, indicating comparatively lower radical scavenging potency, the differences between the extract and the control were not statistically significant (p>0.05). This suggests that *E. foetidum* possesses substantial antioxidant capacity.

Table 1: Antioxidant activity of *E. foetidum* leaf extract.

Sample	DPPH IC_{50} (µg/mL)	ABTS IC_{50} (µg/mL)
Extract	28.11	6.73
Ascorbic acid	8.22	4.24

GC–MS profiling of phytochemical constituents

Gas Chromatography–Mass Spectrometry (GC–MS) analysis of the methanol leaf extract of *E. foetidum* revealed the presence of twelve bioactive compounds (Figure 3 & Table 2). The identified constituents were predominantly Fatty Acid Methyl Esters (FAMEs), along with one diterpene alcohol. The major compounds included hexadecanoic acid methyl ester (24.75%), 9,12-octadecadienoic acid methyl ester (28.68%), 8,11-octadecadienoic acid methyl ester (20.81%), and 9,12-octadecadienoic acid (Z, Z)-methyl ester (11.99%). Phytol (9.73%), a diterpene alcohol, was also detected. Minor components included methyl tetradecanoate, methyl stearate, and methyl nonadecanoate.

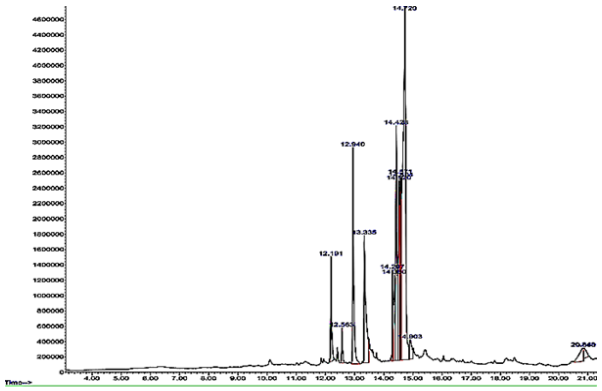

Figure 3: GC–MS chromatogram of bioactive compounds from *Eryngium foetidum.*

Table 2: GC-MS profiles of bioactive compounds from *E. foetidium.*

Pk #	RT (min)	Area (%)	Compound identified	m/z	Class
1	12.19	0.55	Methyl tetradecanoate	242	FAME
2	12.054	0.29	9-Dodecenoic acid, methyl ester E	212	FAME
3	13.58	24.75	Hexadecanoic acid, methyl ester	270	FAME
4	14.52	28.68	9,12-Octadecadienoic acid, methyl ester	294	FAME
5	14.65	20.81	8,11-Octadecadienoic acid, methyl ester	294.5	FAME
6	14.72	11.99	9,12-Octadecadienoic acid (Z, Z)- methyl Ester	294.5	FAME
7	14.8	10.52	6-Octadecenoicacid, methyl ester, (Z)-	296.5	FAME
8	14.9	2.2	Methyl stearate	298	FAME
9	15	0.2	Methyl 18 methylnonadecanoate	326	FAME
10	15.3	2.62	9,12-Octadecadienoic acid, methyl ester	294.5	FAME
11	15.36	4.02	9,12,15-Octadecatrienoic acid, methyl esters, (Z, Z,Z)	292	FAME
12	20.43	9.73	Phytol	296	Dipertene alcohol

Pk #: Peak Number; RT: Retention Time; FAME: Fatty Acid Methyl Esters; m/z: Molecular Ion

Quantitative phytochemical composition

Quantitative phytochemical analysis showed that *E. foetidum* leaves contained high levels of polyphenols (11.67±0.33 mg/g) and total flavonoids (7.40±0.12 mg/g). Steroidal saponins (5.20±0.17 mg/g) and triterpenoid saponins (4.87±0.24 mg/g) were also present in substantial amounts. Other phytochemicals detected included coumarins (3.50±0.06 mg/g), polyacetylenes (3.55±0.12 mg/g), tannins (1.67±0.29 mg/g), xanthonoids (1.05±0.11 mg/g), volatile organic acids (0.88±0.02 mg/g), and carotenoids (0.73±0.01 mg/g). Alkaloids were present at very low concentrations (0.04±0.00 mg/g). The results demonstrate a chemically diverse phytochemical profile (Table 3).

Table 3: Phytochemical composition of *E. foetidum* (mg/g).

Constituent	Mean±SEM
Polyphenols	11.67±0.33
Total flavonoids	7.40±0.12
Steroidal saponins	5.20±0.17
Triterpenoid	4.87±0.24
Coumarins	3.50±0.06
Total carotenoids	0.73±0.01
Alkaloids	0.04±0.00
Tannins	1.67±0.29
Polyacetylenes	3.55±0.12
Total xanthonoids	1.05±0.11
Volatile organic acids	0.88±0.02

Values are mean ± SEM (n=3).

Proximate composition

Proximate analysis revealed that *E. foetidum* leaves are nutritionally rich (Table 4). The sample contained high levels of protein (40.58±0.58 mg/100 g) and carbohydrates (40.00±0.58 mg/100 g), alongside considerable crude fiber content (26.67±0.88 mg/100 g). Total fat content was low (2.43±0.03 mg/100 g). Moisture content was high in fresh leaves (88.20±1.15%) but reduced in dried samples (11.90±0.21%). Ash content was 10.75±0.66 mg/100 g, reflecting substantial mineral presence. The calculated energy value was 1970.33±7.80 kJ/100 g.

Table 4: Proximate composition of *E. foetidum*.

Component	Mean ± SEM
Carbohydrates	40.00±0.58
Crude fiber	26.67±0.88
Total fat	2.43±0.03
Total proteins	40.58±0.58
Moisture content (Fresh)	88.20±1.15
Moisture content (Dry)	11.90±0.21
Total ash	10.75±0.66
Energy (KJ/100g)	1970.33±7.80

Note. Values are mean ± SEM of three determinations.

Anti-nutrient and vitamin composition

Anti-nutrient analysis showed low concentrations of phytates (0.51±0.02 mg/100 g), oxalates (0.27±0.01 mg/100 g), and cyanates (0.04±0.01 mg/100 g) (Table 5). Vitamin analysis revealed a high vitamin A content (1038.31±8.66 mg/100 g), followed by vitamin C (169.00±2.60 mg/100 g), vitamin B_2 (59.00±1.21 mg/100 g), vitamin E (30.33±0.69 mg/100 g), and vitamin B_1 (8.71±0.26 mg/100 g). Lower concentrations of vitamins B_6, B_{12}, and D were also detected (Table 6).

Table 5: Anti-Nutrient Composition of *E. foetidium.*

Anti-nutrient	Mean ± SEM
Oxalates	0.27±0.01
Phytates	0.51±0.02
Cyanates	0.04±0.01

Values are mean ± SEM (n=3).

Table 6: Vitamin Composition of *E. foetidium.*

Vitamin	Mean± SEM
Vitamin A	1038.31±8.66
Vitamin C	169.00±2.60
Vitamin B2	59.00±1.21
Vitamin E	30.33±0.69
Vitamin B1	8.71±0.26
Vitamin B6	1.83±0.03
Vitamin B12	0.13±0.01
Vitamin D	0.22±0.01

Values are mean ± SEM (n=3).

Mineral composition

The mineral composition of *E. foetidum* leaves, expressed on a dry matter basis, is presented in (Table 7). Potassium was the most abundant mineral (331.33±6.96% w/w DMB), followed by zinc (280.20±0.00% w/w DMB), magnesium (126.67±0.88% w/w DMB), and phosphorus (63.67±1.86% w/w DMB). Moderate levels of copper and boron were observed, while calcium, iron, sodium, selenium, and manganese were present in smaller quantities. These results indicate a nutritionally significant mineral profile.

Table 7: Mineral composition of *E. foetidum* (% w/w DMB).

Minerals	Mean ± SEM
Potassium (K)	331.33 ± 6.96
Zinc (Zn)	280.20 ± 0.00
Magnesium (Mg)	126.67 ± 0.88
Phosphorus (P)	63.67 ± 1.86
Copper (Cu)	57.52 ± 0.20
Boron (Bo)	30.33 ± 2.40
Iron (Fe)	0.22 ±0.03
Sodium (Na)	0.28 ± 0.02
Selenium (Se)	0.18 ± 0.02
Manganese (Mn)	0.24 ± 0.02
Calcium (Ca)	1.26 ± 0.02

Values are mean ± SEM (n=3).

Discussion

Phytochemicals from underutilized edible plants are increasingly recognized as valuable sources of nutraceuticals due to their roles in metabolic regulation, antioxidant defense, and cellular protection. In regions facing rising burdens of oxidative stress–related diseases and micronutrient deficiencies, the exploration of affordable, locally available plant resources is

of considerable public health importance. *Eryngium foetidum* (locally known as Utebe Ekpo in South–South Nigeria) is one such plant with significant ethnobotanical relevance but limited scientific characterization. The present study provides the first comprehensive evaluation of the phytochemical composition, antioxidant activity, and nutritional profile of *E. foetidum* cultivated in Ikono, Akwa Ibom State. The findings strongly support its potential development as a functional food and nutraceutical resource for dietary and health interventions in resource-limited settings.

The phytochemical analysis of *E. foetidum* revealed a diverse spectrum of bioactive secondary metabolites, underscoring its therapeutic potential. Notably, the high polyphenol content (11.67±0.33 mg/g) positions the plant as a rich source of antioxidant compounds. Polyphenols are well established for their ability to neutralize Reactive Oxygen Species (ROS), modulate inflammatory pathways, and reduce the risk of chronic diseases. Compared with other widely studied leafy vegetables such as *Ocimum gratissimum* and *Moringa oleifera*, the polyphenol abundance in *E. foetidum* highlights its promise as an alternative antioxidant-rich dietary source. The presence of both steroidal (5.20±0.17 mg/g) and triterpenoid saponins (4.87±0.24 mg/g) suggests potential immunomodulatory, hypocholesterolemic, and anti-inflammatory effects. These activities are comparable to those reported for saponin-rich medicinal plants such as *Panax ginseng* [17,18]. Importantly, the combined saponin levels remain well below toxicity thresholds, supporting the safety of *E. foetidum* for regular dietary consumption.

Flavonoids (7.40±0.12 mg/g) further strengthen the plant's pharmacological profile. These compounds are known for their strong antioxidants, anti-inflammatory, antimicrobial, and hepatoprotective properties, largely through ROS scavenging and inhibition of pro-inflammatory cytokines. The flavonoid content of *E. foetidum* aligns with reports from flavonoid-rich plants such as *Ginkgo biloba* and green tea, reinforcing its relevance in oxidative stress mitigation [20,21]. Other detected phytochemicals contribute complementary bioactivities. Coumarins (3.50±0.06 mg/g) are associated with anticoagulants and antiviral effects, consistent with findings in *Angelica archangelica*. Polyacetylenes (3.55±0.12 mg/g) are particularly noteworthy due to their documented cytotoxic and antimicrobial activities, suggesting possible anticancer relevance. Xanthonoids (1.05±0.11 mg/g), although present in smaller amounts, are known for antimalarial and neuroprotective properties, as reported in *Garcinia mangostana*. Moderate tannin levels (1.67±0.29 mg/g) indicate mild astringency, which may be beneficial for gastrointestinal health without significantly impairing protein digestibility. Carotenoids (0.73±0.01 mg/g) contribute to visual health and immune support, while the negligible alkaloid content (0.04±0.00 mg/g) minimizes toxicity risks commonly associated with alkaloid-rich plants. Additionally, volatile organic acids (0.88±0.02 mg/g) may enhance antimicrobial and preservative properties, supporting the plant's traditional culinary use [22].

The proximate composition of *E. foetidum* revealed a nutritionally dense profile characterized by balanced macronutrients. The protein content (40.58±0.58 mg/100 g) exceeds that reported for common leafy vegetables such as spinach and kale, highlighting its potential role as a plant-based protein supplement, particularly in regions where animal protein is scarce or unaffordable [20,22-25]. Proteins are essential for tissue repair, enzymatic activity, and immune competence, making this finding nutritionally significant. Carbohydrates (40.00±0.58 mg/100 g) and crude fiber (26.67±0.88 mg/100 g) constitute the bulk of the dry matter. The high fiber content surpasses that of vegetables such as lettuce and cabbage, suggesting benefits for gastrointestinal health, glycemic control, and cholesterol reduction. The low-fat content (2.43±0.03 mg/100 g) further supports its suitability for low-fat diets and cardiovascular health [26]. Moisture content was high in fresh samples (88.20±1.15%) but markedly reduced upon drying (11.90±0.21%), a characteristic typical of leafy vegetables. High moisture contributes to hydration and low caloric density but necessitates appropriate post-harvest handling to prevent spoilage [27]. The ash content (10.75±0.66 mg/100 g) reflects substantial mineral availability, reinforcing the nutritional value of *E. foetidum*. The calculated energy value (1970.33±7.80 kJ/100 g) classifies the plant as a moderate energy source, primarily derived from proteins and carbohydrates. The anti-nutrient composition of *E. foetidum* was remarkably low, supporting its safety for human consumption. Oxalate levels (0.27±0.01 mg/100 g) were negligible compared to those found in spinach and amaranth, significantly reducing the risk of calcium oxalated kidney stone formation. Similarly, the phytate content (0.51±0.02 mg/100 g) was far lower than levels reported in cereals and legumes, indicating minimal interference with mineral bioavailability [28-30].

Cyanates were detected only in trace amounts (0.04±0.01 mg/100 g), well below WHO safety thresholds. This contrasts sharply with cyanogenic plants such as cassava and eliminates the need for detoxification processing. Collectively, the low anti-nutrient levels enhance the nutritional accessibility and safety profile of *E. foetidum*, supporting its suitability for regular dietary inclusion. The vitamin profile of *E. foetidum* further underscores its nutritional importance. The exceptionally high vitamin A content (1038.31±8.66 mg/100 g) exceeds levels reported in many commonly consumed leafy vegetables. Given the global prevalence of vitamin A deficiency and its association with visual impairment and immune dysfunction, *E. foetidum* may serve as a valuable dietary intervention. Vitamin C content (169.00±2.60 mg/100 g) was also substantial, comparable to that of citrus fruits. Vitamin C enhances iron absorption, supports immune defense, and acts as a potent antioxidant. The presence of riboflavin (59.00±1.21 mg/100 g) and thiamine (8.71±0.26 mg/100 g) at appreciable levels further supports its role in energy metabolism and nervous system function. Vitamin E (30.33±0.69 mg/100 g), a lipid-soluble antioxidant, contributes to cellular protection against oxidative damage and compares favorably with other antioxidant-rich vegetables. Trace amounts of vitamins B6, B12, and D expand the micronutrient spectrum of *E. foetidum*, enhancing its overall nutritional relevance. The mineral analysis revealed potassium as the most abundant element (331.33±6.96% w/w DMB), supporting roles in fluid balance, nerve transmission, and cardiovascular health. Zinc (280.20±0.00% w/w DMB) was also present at high levels, highlighting the plant's potential to address zinc deficiency and support immune function, particularly in populations with limited access to animal-derived foods [30].

Magnesium (126.67±0.88% w/w DMB) and phosphorus (63.67±1.86% w/w DMB) contribute to enzymatic activity, energy metabolism, and skeletal health [31]. Copper and boron, though less emphasized nutritionally, play important roles in iron metabolism, collagen synthesis, and bone health. Calcium levels, while lower than in some leafy greens [31,32], still contribute meaningfully to daily requirements. The low sodium-to-potassium ratio further enhances the antihypertensive potential of *E. foetidum*. The high total phenolic content (1205.11 µg/

mL GAE/100 g) and flavonoid content (128.16 µg/mL QE/100 g) confirm *E. foetidum* as a reservoir of antioxidant compounds. These findings correlate strongly with the observed antioxidant activities in DPPH and ABTS assays. Although the DPPH IC_{50} was higher than that of ascorbic acid, the ABTS scavenging activity was comparable, suggesting effective electron-donating capacity. GC–MS analysis further revealed that the extract was dominated by fatty acid methyl esters, particularly methyl hexadecanoate and methyl linoleate, which are known for anti-inflammatory and antioxidant properties. The identification of phytol, a bioactive diterpene alcohol, provides additional mechanistic support for the antioxidant and anti-inflammatory activities observed.

Conclusion

The present study demonstrates that *Eryngium foetidum* leaves possess a rich and diverse phytochemical profile, alongside substantial amounts of essential nutrients, vitamins, and bioactive fatty acids, collectively contributing to their antioxidant potential. The high levels of polyphenols and flavonoids, coupled with low concentrations of anti-nutritional factors, highlight the suitability of this plant as a valuable component of functional foods and nutraceutical formulations. The appreciable vitamins and mineral contents further underscore its nutritional significance and potential role in improving dietary quality. Antioxidant assays revealed moderate free radical–scavenging activity, with values that were comparable, though slightly lower, than those of standard antioxidants such as ascorbic acid. To the best of our knowledge, this study represents one of the few comprehensive evaluations of the phytochemical, nutritional, and antioxidant properties of *E. foetidum* leaves from this region. Collectively, the findings suggest that *E. foetidum* may contribute to the modulation of oxidative stress and support dietary management of chronic diseases. However, further validation through *in vivo* studies and clinical investigations is necessary to substantiate these in vitro observations. Future research should focus on the isolation and characterization of key bioactive compounds, their bioavailability, and the underlying mechanisms of action to fully explore their therapeutic potential.

Declarations

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Data availability: Data will be made available on genuine request.

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