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Muktadhar Reang
Plant Taxonomy and Biodiversity Lab, Department of Botany, Tripura University, Suryamaninagar, Tripura, India

Dipan Sarma
Plant Taxonomy and Biodiversity Lab, Department of Botany, Tripura University, Suryamaninagar, Tripura, India

Badal Kumar Datta
Plant Taxonomy and Biodiversity Lab, Department of Botany, Tripura University, Suryamaninagar, Tripura, India

Corresponding Author:
Dipan Sarma
Plant Taxonomy and Biodiversity Lab, Department of Botany, Tripura University, Suryamaninagar, Tripura, India

Traditional uses, nutritional and antioxidant evaluation of neglected underutilized wild edible plants for domestication and conservation

Muktadhar Reang, Dipan Sarma and Badal Kumar Datta

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Abstract
In this present study, Wild edible plants (WEPs) that include five spices/condiments (*Alpinia nigra, Zanthoxylum rhetsa, Ocimum americanum, Trachyspermum roxburghianum, Homalomena aromatica*), four vegetables (*Neptunia oleracea, Oroxylum indicum, Leucaena leucocephala, Senegalia pennata*), and one fruit (*Flacourtia indica*), were studied for traditional uses, proximate composition, and antioxidant activity. Proximate analysis revealed the presence of carbohydrate (3.65-13.34%), crude protein (1.23-10.43%), and crude fat (0.05-2.38%), with corresponding energy values. Elemental analysis through EDS spectrum indicated the presence of abundant potassium (up to 34.15 mg/g), calcium, magnesium, phosphorus, and iron, highlighting that WEPs are sources of natural micronutrients. DPPH radical scavenging analysis showed that *Leucaena leucocephala*, *Zanthoxylum rhetsa*, and *Oroxylum indicum* exhibited strong antioxidant activity with IC_{50} values of 125.4-196.25 µg/mL. Despite their nutritional and functional benefits, these species remain underutilized due to limited awareness, harvesting challenges, and socio-cultural perceptions that hinder domestication and conservation efforts.

Keywords: Wild edible plants, neglected crops, antioxidant activity, mineral content, domestication

1. Introduction
Today's global food systems are facing multiple, interacting challenges due to a rapidly growing population, micronutrient deficiencies, loss of agrobiodiversity, climate change, and excessive dependence on a small number of staple crops. These stresses have highlighted the vulnerability of local food security and nutrition, especially in marginalized and rural communities that rely on a diverse range of local plant resources (Nkwonta *et al*., 2023; Knez *et al*., 2024) [1, 2]. The utilization of wild edible plants (WES) is typically limited to a specific area, resulting in underutilized and neglected food sources. Neglected and underutilized species, which are often locally important wild or semi-domesticated edible plants overlooked by mainstream agriculture, offer a tangible route to strengthen food and nutrition security. WES are frequently well-adapted to local agro-ecological conditions, and contribute to dietary diversity through micronutrients, fiber, protein, and bioactive phytochemicals that are not always present in major staples (Knez *et al*., 2024; Ndlovu *et al*., 2024) [2, 3].
Underutilized and neglected wild edible plants (WES) are increasingly recognized as "Future Smart Foods" due to their potential to combat hunger and malnutrition by enhancing dietary diversity and providing adequate nourishment. These plants, often integral to the diets of rural and indigenous communities, offer a sustainable alternative to conventional crops, contributing to food security and resilience against climate change (Bhatia *et al*., 2018; Yesuph *et al*., 2025) [4, 5]. Despite their importance, the nutritional profiles of many wild edible plants remain underexplored. While these plants are traditionally valued for their taste and medicinal properties, comprehensive analyses of their proximate composition and antioxidant potential are limited (Casas *et al*., 2024) [6]. Understanding these nutritional components is crucial for assessing their role as dietary supplements and evaluating their food safety properties, especially in communities where they have been traditionally utilized.
In India, wild edible plants play a vital role in the diets of rural populations, serving as key ingredients in traditional foods and cuisines. These communities often rely heavily on nearby forests for their food supply, with forests acting as storehouses of resources providing not only food but also medicines, housing materials, and fuel (Konsam *et al*., 2016; Hazarika *et al*., 2018) [7, 8]. Nutritional analysis of underutilized food plants provides a comprehensive evaluation of dietary content and health benefits, including protein, carbohydrate, fat, and mineral composition (Odeku *et al*., 2024; Kaur *et al*., 2025) [9, 10].

The examination of other bioactive compounds and antioxidant levels provides valuable insights into the potential of native wild edible plants as sustainable and nutritious food sources, encouraging their conservation and large-scale utilization (Rumicha *et al*., 2025) [11]. According to the Food and Agriculture Organization (FAO, 2017) [12], promoting indigenous food systems and utilizing wild plants is crucial due to their local availability, affordability, and safety. The primary objective of this study is to analyze the nutritional components of underutilized food plants, enabling the effective utilization and domestication of native wild edible plants. This is particularly significant in addressing undernutrition, poverty, and malnutrition; hence, the dynamic conservation of underutilized and neglected bioresources is essential.

2. Materials and Methods

2.1. Study Area

A preliminary market survey revealed that numerous lesser-known wild plant species are highly valued by local communities in Tripura, NE India. Tripura, the third smallest hilly state, covering an area of 10, 486 km² and is situated between 22˚57′-24˚32′ N latitude and 91˚10′-92˚20′ E longitude. The total forest cover is 6, 292.681 km², which is approximately 60% of the state's total area (Debnath *et al*., 2016; Reang *et al*., 2023) [13, 14]. The foothills of the Himalayan state of North-East India are well known for their rich floral and faunal diversity (Sarma and Debnath, 2016) [15]. The abundance of lesser-known wild plants has enabled the ethnic communities of Tripura to depend on indigenous plant resources as a vital component of their food and income. Many of these species are in strong demand for local communities in rural markets. While some plants are harvested directly from forests, others are semi-domesticated or cultivated under traditional shifting cultivation, also known as jhum practices. Such dependence is particularly prevalent in areas with rich cultural resources but limited economic opportunities, especially in the state's remote areas (Das *et al*., 2009) [16]

2.2. Preparation of Plant sample

Proximate analysis provides a quantitative assessment of major macronutrients in food samples, including moisture, ash, protein, fat, and carbohydrates, which collectively define the nutritional composition of edible materials (Thangaraj *et al*., 2016) [17]. These parameters are crucial for assessing dietary quality and are frequently reported on food product labels and in quality control evaluations within the food industry. For sample preparation, plant materials were thoroughly rinsed under running tap water to remove adhering soil and debris, followed by shade-drying to minimize photo-degradation of bioactive compounds. The partially dried samples were then oven-dried at 60˚C overnight to achieve constant weight and reduce moisture content. The desiccated material was finely ground into homogeneous powder using a mechanical grinder and subsequently stored in airtight containers under refrigerated conditions to prevent oxidative deterioration prior to nutritional analysis.

2.3. Evaluation of Proximate Composition

Moisture Content: Moisture content was determined using fresh plant samples weighing 10 g. The samples were oven-dried at 60 °C overnight, cooled to room temperature, and weighed. The moisture percentage was calculated based on the weight loss (Sadasivam & Manickam, 2008) [18].

Total Carbohydrate: Total carbohydrate was estimated from dried powdered samples (Hedge & Hofreiter, 1962) [19]. Briefly, 100 mg of the sample was placed in boiling tubes and hydrolyzed with 5 ml of 2.5 N HCl for 3 hours. After cooling to room temperature, the hydrolysate was neutralized with sodium carbonate pellets, and the volume was adjusted to 10 ml. The mixture was centrifuged at 5000 rpm for 15 minutes, and the supernatant was collected. Aliquots of 1 ml were mixed with 4 ml of 2% anthrone reagent (w/v in concentrated H_2SO_4) and heated in a boiling water bath for 10 minutes. Absorbance was measured at 630 nm using a spectrophotometer, with glucose as the standard.

Crude Protein: Crude protein content was determined using 500 mg of dried powdered samples (Lowry, 1951) [20]. The sample was homogenized in 10 mL of 0.1 M potassium phosphate buffer (pH 7.5) using a pestle and mortar, and then centrifuged at 5000 rpm for 15 minutes. The pellet was discarded, and the supernatant was collected. Take 1ml of the supernatant and mix with 5 ml of reagent “C” (prepared by combining reagents “A” and “B” in a 50:1 v/v ratio; reagent “A” = 2% Na_2CO_3 + 0.1 N NaOH, reagent “B” = 0.5% $CuSO_4$ + 1% Na-K tartrate). The solution was shaken vigorously and left to stand for 20 minutes. Then, 0.5 ml of Folin-Ciocalteu reagent was added, and the mixture was incubated in the dark at room temperature for 30 minutes. Absorbance was measured at 660 nm using a spectrophotometer, with bovine serum albumin (BSA) as the standard.

Crude Fat: Fat content was determined using 2 g of the dried sample (AOAC, 1960) [21]. Petroleum ether was added, and the mixture was allowed to stand for 24 hours. The solvent was then evaporated to dryness, and the test tubes were weighed before and after to determine crude fat content.

Ash Content: Ash content was determined using 2 g of dried powdered samples (AOAC, 1965) [22]. The material was placed in a crucible and incinerated at 450˚C to remove organic matter. The remaining inorganic residue, representing the ash content, was weighed. The initial weight of the empty crucible was recorded, followed by the final weight after ashing to calculate ash concentration.

The *total energy* value in kcal/100g was estimated using the method described by FAO (FAO, 2003) as shown below: Energy = (4×Crude protein) × (4×Carbohydrate) + (9×Crude fats).

2.4. Determination of element composition

To determine the proportion of elemental components in the ash, 2 g of dried powdered sample was mineralized in a muffle furnace at 450 °C. The chemical composition of major ash constituents-such as Na, P, S, K, Mn, Fe, Mg, Ca, Cr, Co, Cu, Ni, Zn, and Pb-can be identified using an analytical scanning electron microscope (SEM) coupled with energy dispersive spectroscopy (EDS) (Reang *et al*., 2023) [14]. This approach provides a novel method for both qualitative identification and quantitative measurement of minerals (Liu *et al*., 2021) [23]. The EDS technique is particularly useful for analyzing elements such as calcium and potassium in food samples, including fruits, vegetables, and spices (Md Noh *et al*., 2023) [24].

2.5. Antioxidant Activity Evaluation

The free radical scavenging potential of the extracts was assessed using the DPPH (2, 2-diphenyl-1-picrylhydrazyl)

assay with slight modifications (Sarma *et al*., 2025) [25]. In this assay, DPPH in ethanol exhibits a deep violet color, which gradually changes to a yellowish hue upon interaction with antioxidants. An ethanol solution of DPPH (0.5 mL, 0.5 mM) was mixed with varying concentrations of the extract (100-500 µg/mL). The mixtures were thoroughly mixed and incubated in the dark at room temperature for 30 minutes. The decrease in absorbance was recorded at 517 nm using a spectrophotometer. The IC_{50} value, representing the concentration required to inhibit 50% of DPPH radicals, was determined using a standard calibration curve. Ascorbic acid was used as the positive control for comparison.

The percentage of DPPH radical scavenging activity was determined by the equation:

$$\text{DPPH radical scavenging activity (\%)} = \frac{A_0 - A_1}{A_0} \times 100$$

[A_0 (absorbance of the control), A_1 (absorbance of the extractives/standard), percentage of inhibition was then plotted against concentration, and the IC_{50} was derived from the graph.].

3. Results

3.1. Selection of neglected and underutilized species for nutrient analysis

The species selected for nutrient analysis were neglected and underutilized plants available in local markets, which have the potential to serve as alternative sources to commercial vegetables, fruits, and spices (Table 1). These species are highly valued by local communities, occur primarily in the wild, and are cultivated to a limited extent. Assessing their nutritional components will help identify species suitable for large-scale cultivation, thereby promoting sustainable development in the food sector (Figure 1).

Table 1: List of selected wild edible plant species based on 3 categories (Spice, Vegetable and Fruits)

Edible categories	Species name	Family	Vernacular name*	Part used	Mode of Preparation
Spices	*Alpinia nigra* (Gaertn.) Burtt	Zingiberaceae	Thrai (Rea), Tara (Ben)	Stem Pith	Stem pith is often cooked with various dishes.
	Zanthoxylum rhetsa (Roxb.) DC.	Rutaceae	Muiching (Rea),	Leaf	Leaves are added and cooked in various cuisines.
	Ocimum americanum L.	Lamiaceae	Manda (Rea), Ban tulsi (Ben)	Leaf and Stem	Leaf and stem are cooked along with any cuisine.
	Trachyspermum roxburghianum (DC.) H.Wolff	Apiaceae	Khundrupui (Rea)	Leaf and Stem	Leaf and stem are cooked along with any cuisine.
	Homalomena aromatica Schott	Araceae	Kaimaitru (Rea), Gandagi (Ben)	Stolon	Young fresh stolon is added to a certain dish.
Vegetables	*Neptunia oleracea* Lour.	Fabaceae	Thoraiha (Rea)	Leaf and Stem	Leaf and stem are stir-fried and eaten as a side dish.
	Oroxylum indicum (L.) Benth. ex Kurz	Bignoniaceae	Taukharung (Rea)	Fruit	The fruit skin was peeled, and the pulp was stir-fried and eaten.
	Leucaena leucocephala (Lam.) de Wit	Fabaceae	Wakre ste (Rea)	Fruit	Fruit is boiled mildly and mixed with salads.
	Senegalia pennata (L.) Maslin	Fabaceae	Muikambu (Rea)	Leaf	Young leaf is eaten by steaming.
Fruit	*Flacourtia indica* (Burm.f.) Merr.	Salicaceae	Pahela (Rea), Tokroi (Ben)	Fruit	Fruit is eaten when ripe.

*Vernacular names: Reang (Rea), Bengali (Ben)

Fig 1: (A) *Alpinia nigra* (B) *Zanthoxylum rhetsa* (C) *Ocimum americanum* (D) *Trachyspermum roxburghianum* (E) *Homalomena aromatica* (F) *Neptunia oleracea* (G) *Oroxylum indicum* (H) *Leucaena leucocephala* (I) *Senegalia pennata*

3.2. Proximate composition and nutritional values of selected species

The proximate composition of the selected bioresource species is presented in Table 2. Across the ten studied samples, total carbohydrate content ranged from 3.65% to 13.34%, crude protein from 1.23% to 10.43%, crude fat from 0.05% to 2.375%, total energy from 41.055 kcal to 79.86 kcal, moisture content (fresh weight) from 73.81% to 94.95%, and ash content (dry weight) from 7.61% to 42.16%.

Among the species, *Oroxylum indicum* had the highest carbohydrate content (13.34%), followed by *Flacourtia indica* (13.23%) and *Homalomena aromatica* (8.88%), while *Zanthoxylum rhetsa* had the lowest (3.65%). *Trachyspermum roxburghianum* exhibited the highest protein content (10.43%), followed by *Homalomena aromatica* (9.74%) and *Neptunia oleracea* (8.74%), with *Ocimum americanum* showing the lowest (1.23%). Crude fat was highest in *Flacourtia indica* (4.25%), followed by *Senegalia pennata* (3.375%) and *Zanthoxylum rhetsa* (2.975%), with *Homalomena aromatica* having the lowest (1.525%).

The highest total energy was recorded in *Flacourtia indica* (107.97 kcal), followed by *Oroxylum indicum* (106.855 kcal) and *Homalomena aromatica* (88.205 kcal), while *Alpinia nigra* had the lowest (41.055 kcal). Moisture content was highest in *Alpinia nigra* (94.95%), *Homalomena aromatica* (94.21%), and *Oroxylum indicum* (89.5%), and lowest in

Zanthoxylum rhetsa (73.81%). Ash content was highest in *Trachyspermum roxburghianum* (42.16%), *Neptunia oleracea* (37.8%), and *Homalomena aromatica* (36.98%), while *Senegalia pennata* showed the lowest (7.68%).

Table 2: Proximate composition of the selected wild edible plant species

Species	Carbohydrate (%)	Protein (%)	Fats (%)	Total Energy (%)	Moisture (%)	Ash (%)
Alpinia nigra	3.93±0.67	2.34±0.06	1.775 ± 0.08	41.055	94.95±0.24	34.78±1.13
Zanthoxylum rhetsa	3.65±0.37	3.82±0.1	2.975±0.4	56.655	73.81±0.34	35.16±1.17
Ocimum americanum	5.21±0.70	1.23±0.04	2.375 ± 0.02	47.135	86.49±0.30	21.77±1.59
Trachyspermum roxburghianum	4.81 ± 0.09	10.43 ± 0.19	2.1 ± 0.05	79.86	89.29 ± 0.77	42.16±2.13
Homalomena aromatica	8.88±0.69	9.74±0.05	1.525±0.39	88.205	94.21±0.31	36.98±0.8
Neptunia oleracea	6.88 ± 0.05	8.74 ± 0.46	1.825 ± 0.08	78.905	82.25 ± 0.26	37.8±1.97
Oroxylum indicum	13.34±0.29	8.48±0.05	2.175±0.4	106.855	89.5±0.15	12.15±1.08
Leucaena leucocephala	5.14±0.23	5.88±0.02	1.91±0.7	61.27	78.1±0.65	12.13±1.61
Senegalia pennata	4.27±0.26	3.96±0.39	3.375±0.18	63.295	80±0.42	7.68±0.71
Flacourtia indica	13.23±0.28	4.20±0.02	4.25±0.28	107.97	76.17±0.87	25.07±0.22

*Each Triplicate experimental data (n=3) is represented as Mean ± standard deviation

3.3. Micronutrient analysis

The quantitative concentration (wt%) of six main element constituents has been studied in ten selected wild edible plant species. The chemical composition of the basic ash components (Mg, P, K, Ca, Fe, Cl) was determined by energy dispersive spectrometry (EDS). X-ray microanalysis data are presented in the form of standard protocols, which contain the microstructure picture of the studied sample. The data, including weighting and atomic correlation spectra, as well as histograms, were recorded as shown in Figure 2 & 3.

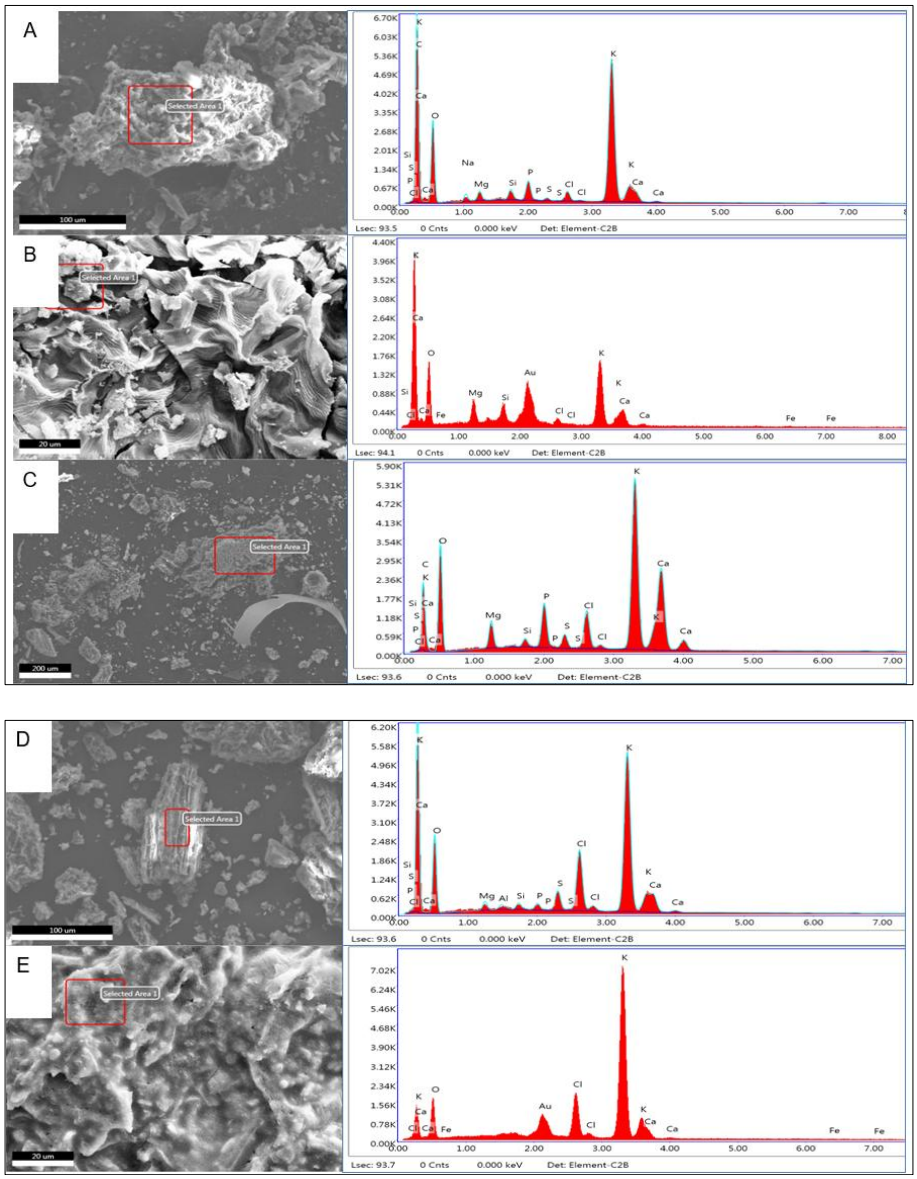

Fig 2: Microstructure picture and X-ray spectrum lines that show the elements presence in the analyzing area of the studied sample: A) *Alpinia nigra* B) *Zanthoxylum rhetsa* C) *Ocimum americanum* D) *Trachyspermum roxburghianum* E)*Homalomena aromatic*

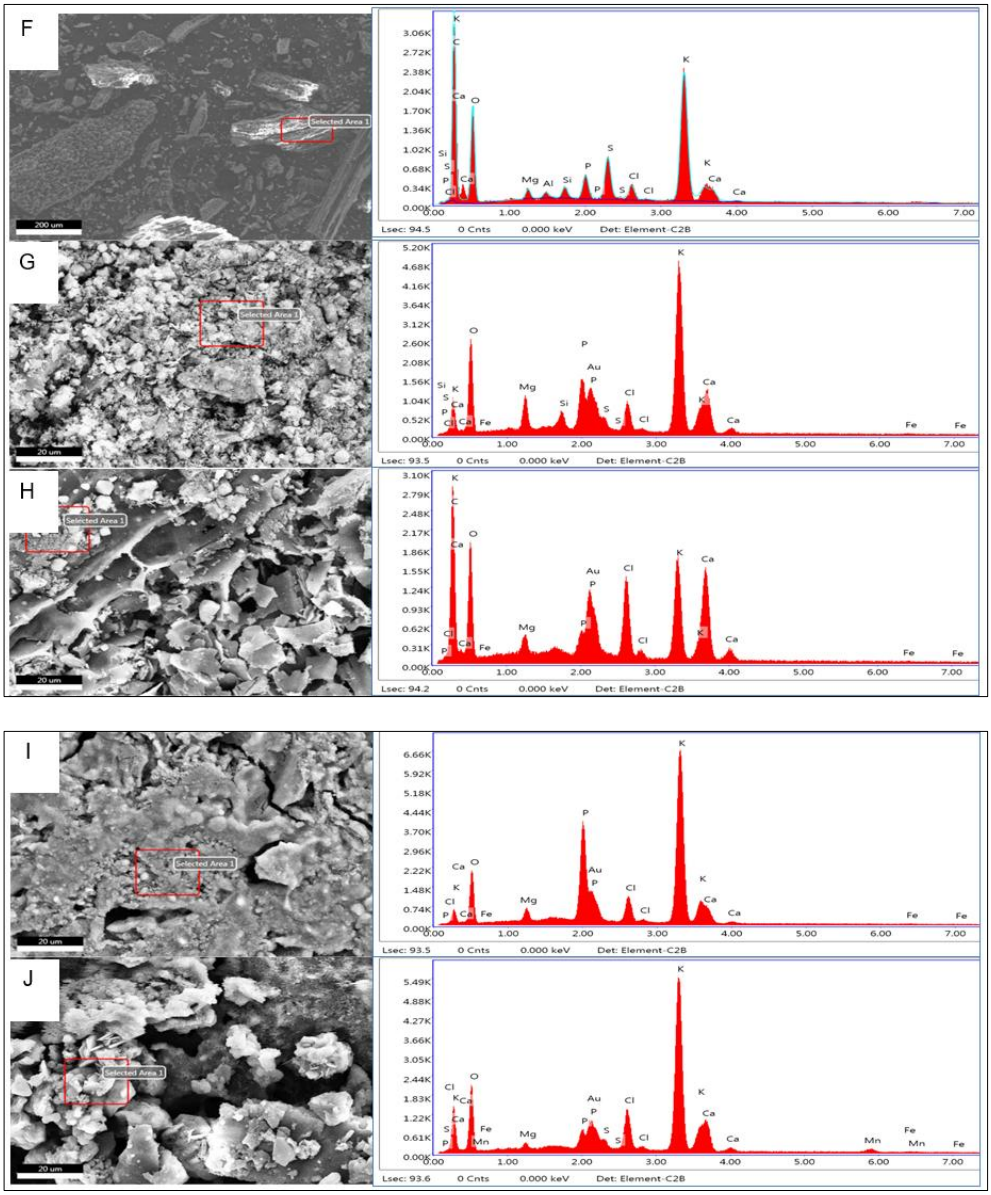

Fig 3: Microstructure picture and X-ray spectrum lines that show the elements presence in the analyzing area of the studied sample: F) *Neptunia oleracea* G) *Oroxylum indicum* H) *Leucaena leucocephala* I) *Senegalia pennata* J) *Flacourtia indica*

The elemental analysis of ten wild edible plant species (Table 3) revealed considerable variation in the concentrations of essential macro- and microelements, including magnesium (Mg), phosphorus (P), potassium (K), calcium (Ca), iron (Fe), and chlorine (Cl). Among the species analyzed, *Homalomena aromatica* exhibited the highest potassium content (42%), indicating its potential as a rich dietary source of this vital electrolyte. *Senegalia pennata* and *Ficus indica* also contained substantial levels of potassium (34.15% and 31.84%, respectively), which are beneficial for maintaining cellular osmotic balance and cardiovascular health.

Oroxylum indicum demonstrated a relatively high concentration of both magnesium (4.27%) and phosphorus (5.09%), suggesting its nutritional significance in bone development and energy metabolism. Similarly, *Ocimum americanum* was found to be rich in calcium (13.23%) and potassium (20.89%), highlighting its contribution to bone health and neuromuscular function. In contrast, *Trachyspermum roxburghianum* and *Neptunia oleracea* displayed comparatively lower mineral contents across most elements analyzed. Iron was detected in measurable amounts in several species, notably *Oroxylum indicum* (0.28%) and *Homalomena aromatica* (0.23%), implying potential roles in combating iron deficiency and anemia. Chlorine concentrations varied widely, with *Homalomena aromatica* showing the highest level (8.58%), followed by *F. indica* (5.88%) and *Leucaena leucocephala* (5.53%) (Table 3 and Figure 4).

Table 3: Quantitative Wt (%) of element constituents in the ash sample

Sl. No.	Weight (%) of the 10 studied species						
	Species	Mg	P	K	Ca	Fe	Cl
1	*Alpinia nigra*	1.03	1.72	18.23	1.57	-	0.97
2	*Zanthoxylum rhetsa*	2.94	-	9.55	2.71	0.21	0.75
3	*Ocimum americanum*	2.98	3.81	20.89	13.23	-	3.61
4	*Trachyspermum roxburghianum*	0.74	0.48	17.02	2.36	-	4.84
5	*Homalomena aromatica*	-	-	42	2.66	0.23	8.58
6	*Neptunia oleracea*	0.88	1.76	14.64	1.53	-	1.24
7	*Oroxylum indicum*	4.27	5.09	25.12	7.73	0.28	3.51
8	*Leucaena leucocephala*	2.28	1.35	8.79	9.28	0.17	5.53
9	*Senegalia pennata*	2.19	12.17	34.15	3.78	0.11	4.19
10	*F. indica*	1.23	2.11	31.84	7.09	0.2	5.88

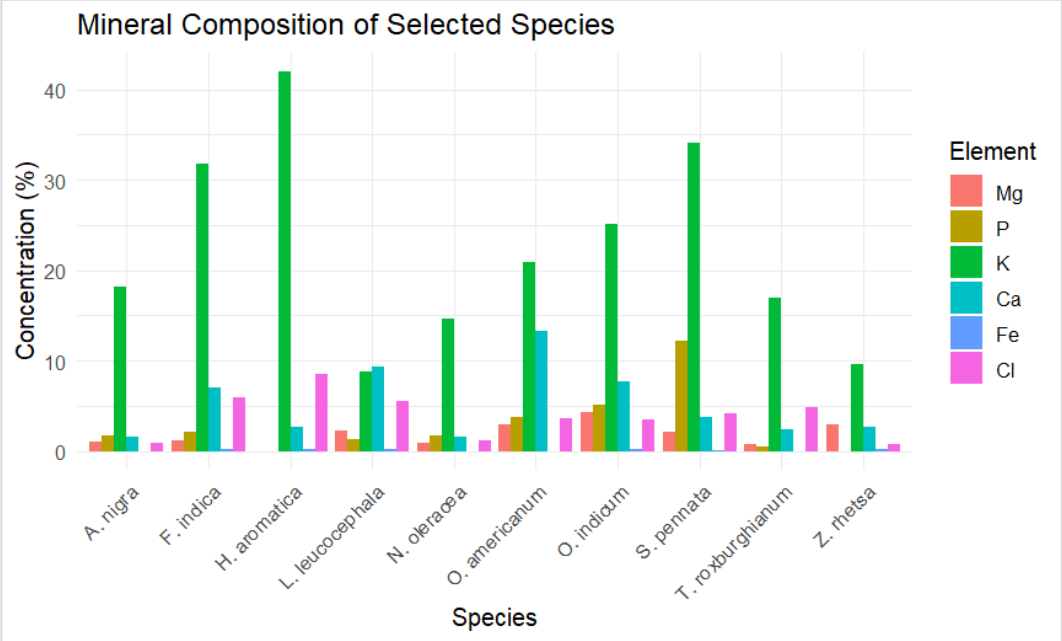

Fig 4: Graph showing proportionate concentration (Wt %) of the 5 main elements in 10 studied samples

3.4. DPPH Radical Scavenging Activity

The DPPH radical scavenging assay revealed a concentration-dependent increase in antioxidant activity across all studied plant extracts (Figure 5). Among them, *Leucaena leucocephala* exhibited the highest scavenging activity, reaching 93.33% inhibition at 300 µg/mL, comparable to the standard vitamin C, and showed the lowest IC_{50} value (125.40 ± 1.78 µg/mL), indicating strong free radical neutralizing potential. *Zanthoxylum rhetsa*, *Ocimum americanum*, *Oroxylum indicum*, and *Homalomena aromatica* also displayed high scavenging efficiencies (>90% at 400-500 µg/mL) with moderate IC_{50} values (162.24-365.15 µg/mL), suggesting substantial antioxidant capacity. *Alpinia nigra*, *Senegalia pennata*, *Neptunia oleracea*, and *Ficus indica* exhibited relatively weaker activities, showing less than 52% inhibition even at the highest concentration, with IC_{50} values exceeding 440 µg/mL. *Trachyspermum roxburghianum* showed moderate activity (74.22% at 500 µg/mL; IC_{50} = 305.87 ± 2.04 µg/mL).

Although none of the plant extracts surpassed the scavenging ability of vitamin C (IC_{50} = 47.07 ± 2.56 µg/mL), several species, particularly *L. leucocephala* and *Z. rhetsa*, demonstrated notable antioxidant potentials. These variations may be attributed to differences in phytochemical composition, particularly the presence of phenolic and flavonoid compounds. The findings highlight certain wild edible plants as valuable sources of natural antioxidants.

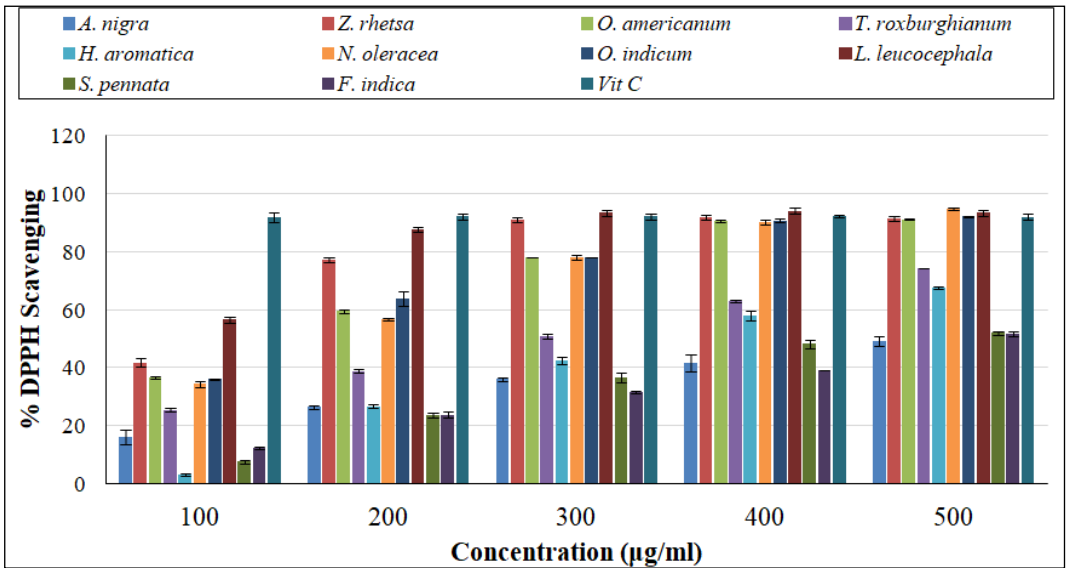

Fig 5: (%) DPPH scavenging for each species along with the standard antioxidant

Our results show that *L. leucocephala* possessed the lowest IC_{50} (125.4±1.78) value, followed by *Z. rhetsa,* which indicates a high antioxidant activity; whereas *F. indica* fruit extract demonstrated a higher IC_{50} (485.44±5.82), suggesting low antioxidant activity (Table 5). The decreasing order of free radical scavenging activity, in terms of IC50 value, of the studied plant extracts was as follows: Vit. C> *L. leucocephala* > *Z. rhetsa* > *O. indicum* > *O. americanum* > *N. oleracea* > *T. roxburghianum* > *H. aromatica* > *S. pennata* > *A. nigra* > *F. indica.*

Table 5: IC_{50} value of DPPH Scavenging assay for the studied sample

Sample name	IC_{50} (µg/ml)
A. nigra	456.86±1.01
Z. rhetsa	162.24±1.04
O. americanum	198.78±0.42
T. roxburghianum	305.87±2.04
H. aromatica	365.15±2.83
N. oleracea	202.18±2.89
O. indicum	196.25±3.12
L. leucocephala	125.4±1.78
S. pennata	444.96±4.22
F. indica	485.44±5.82
Vit C	47.07±2.56

*Experimental data represented as Mean ± standard deviation

4. Discussion

4.1. Nutritional contribution of underutilized and neglected food plants

After collecting and analyzing wild edible plants from local markets, we found that they can serve as excellent alternatives to commercial vegetables, fruits, and spices. These wild plants not only offer diverse flavors and textures but also provide multiple health benefits. The species investigated for their nutritional value include five spices/condiments (*A. nigra, Z. rhetsa, O. americanum, T. roxburghianum*, and *H. aromatica*); four vegetables (*N. oleracea*, *O. indicum*, *L. leucocephala*, and *S. pennata*); and one fruit (*F. indica*). All of these are nutrient-rich and can be easily incorporated into various dishes. Promoting the use of these plants in diets can enhance sustainability while encouraging the conservation and utilization of underutilized and neglected food plants.

The proximate analysis revealed that these WESs possess substantial nutritional value. The carbohydrate content ranged from 3.65% to 13.34%, crude protein from 1.23% to 10.43%, and crude fat from 0.05% to 2.38%. These values are comparable to those reported in previous studies on WEPs from Northeast India and various regions (Sundriyal *et al*., 2001; Hazarika and Nautiyal, 2012; Ningombam *et al*., 2012; Brahma *et al*., 2014; Goswami *et al*., 2023) [26-30]. A study reported crude protein contents ranging from 2.55% to 23.14% in selected wild plants (Tadesse *et al*., 2025) [31], while Yimer *et al*. (2023) [32] observed protein levels between 4.0% and 21.7% in wild edible plants. The energy values derived from these macronutrients, calculated using standard conversion factors (4 kcal/g for protein and carbohydrates; 9 kcal/g for fat) (Yiblet & Adamu, 2023) [33], indicate that these WEPs can significantly contribute to daily energy requirements. According to the Food and Agriculture Organization (FAO, 2003) [12], the standard energy conversion factors are 4 kcal/g for protein, 9 kcal/g for fat, and 4 kcal/g for carbohydrate. Carbohydrates, lipids, and proteins are macronutrients that must be consumed in significant amounts. Carbohydrates serve as the primary energy source in human diets, providing 4 kcal/g of energy. Proteins, composed of essential amino acids that must be obtained through diet, perform diverse biological functions and also provide 4 kcal/g of energy. Oils and fats, meanwhile, are concentrated sources of dietary energy, delivering 9 kcal/g (ICMR, 2011) [34].

Minerals are essential micronutrients required in small quantities for vital physiological and biochemical processes that maintain human health and biological activity. In our study, six micronutrients were analyzed: Mg, P, K, Ca, Fe, and Cl. Among these, potassium (K) was found in the highest concentration, reaching up to 34.15% (34.15 mg/g). Species with notably high potassium content included *S. pennata, F. indica, O. indicum, O. americanum, A. nigra, T. roxburghianum,* and *N. oleracea*, whereas the lowest levels were observed in *Z. rhetsa*. These results align with the general mean composition of minerals typically reported in fruits and vegetables, which include Ca (10-170 mg/100 g), P (12-125 mg/100 g), Fe (0.2-8 mg/100 g), and K (200-600 mg/100 g) (Guerrero *et al*., 1998; Seal *et al*., 2017) [35, 36].

Free radicals are known to promote oxidation of proteins, DNA, and lipids, leading to damage and loss of function in biological membranes and enzymes, and ultimately generating harmful toxins. Secondary metabolites in plants, although non-nutritive, play a crucial role in treating various ailments due to their antioxidant activity (Pizzino *et al*., 2017) [37]. Antioxidants play a crucial role in scavenging free radicals (Talang *et al*., 2023) [38], which are implicated in the onset of various diseases, including cancer, neurological disorders, and inflammatory conditions (Bhatt *et al*., 2018) [39]. In our findings, wild vegetables such as *L. leucocephala* and *O. indicum*, along with herbs and spices like *Z. rhetsa* and *O. americanum*, demonstrated antioxidant activity, suggesting a strong correlation with their antioxidant capacity. This finding is consistent with those of Yimer *et al*. (2023) [40], reported that wild edible plants are rich in antioxidants, including phenols, flavonoids, vitamin C, and carotenoids. The presence of these bioactive compounds suggests that these WEPs could play a role in mitigating oxidative stress-related diseases, such as cancer, cardiovascular diseases, and neurodegenerative disorders. Our study's findings are consistent with other researchers that highlighted that edible wild plants enhance nutritional quality by providing essential minerals, fiber, vitamins, and other vital nutrients (Hailu *et al*., 2016) [41].

4.2. Needs for conservation and domestication

The study highlights the vital importance of conserving and domesticating neglected and underutilized wild edible plants (WEPs), which serve as valuable reservoirs of nutrition, traditional knowledge, and biodiversity. Although these species exhibit rich nutrient profiles and medicinal properties, their reliance on wild collection makes them vulnerable to overexploitation, habitat destruction, and climate-induced stresses (Bharucha & Pretty, 2010; Padulosi *et al*., 2013) [42, 43]. The gradual loss of their natural populations threatens not only ecosystem balance but also local food and nutritional security, particularly among indigenous and rural communities who depend on them for sustenance (Heywood, 2011) [44].

Conservation strategies must therefore integrate both in-situ and ex-situ approaches. In-situ conservation ensures the maintenance of natural populations within their native habitats, such as community-managed forests and protected biodiversity zones, whereas ex-situ methods, such as seed banking, tissue culture, and cultivation in botanical gardens to safeguard genetic material outside natural ecosystems (Maxted *et al*., 2012; Fajinmi *et al*., 2025) [45, 46]. Such combined approaches can preserve genetic diversity and allow for future restoration or domestication efforts.

Domestication of promising species can play a pivotal role in enhancing local livelihoods and promoting food system resilience. By introducing these WEPs into small-scale and sustainable agricultural systems, the dependency on conventional crops can be reduced, thereby diversifying diets and enhancing climate resilience (Jaenicke & Höschle-Zeledon, 2006; Azam-Ali, 2010) [47, 48]. Moreover,

domestication promotes the standardization of yield and quality, enabling the integration of these plants into local markets and value chains (Mabhaudhi *et al*., 2017) [49].

Empowering local and tribal communities through participatory conservation programs and capacity-building initiatives is equally crucial. Encouraging community-based propagation, nursery establishment, and documentation of traditional ethnobotanical knowledge can create socio-economic incentives for conservation (Grivetti & Ogle, 2000) [50]. These efforts, focused on policy frameworks that promote biodiversity-based livelihoods, would ensure the sustainable use and protection of these invaluable resources for future generations.

4.3. Traditional Knowledge and Sustainable Livelihood

Our findings emphasize the importance of preserving and utilizing traditional knowledge to promote sustainable food systems. Tripura is inhabited by various indigenous communities (Sarma & Datta, 2021) [50], who rely on the sale of wild edible resources for economic support and livelihood, as the forests of Tripura are rich in bioresources. While jhum cultivation remains the primary source of income, its benefits are temporary, as the same land can only be cultivated once every 3-4 years after harvesting (Shangpliang, 2019) [51]. The limitation of a single harvest cycle restricts livelihoods, compelling communities to depend on temporary employment or foraging for WES for the rest of the year.

Consequently, selling wild edible plants becomes a crucial economic activity, often conducted in village markets, along highways, or through middlemen who exchange resources for cash. However, the greatest economic returns are achieved in larger city markets, where product value is significantly higher compared to local or roadside sales (Chaudhury *et al*., 2021) [52]. Thus, market linkages can provide the poor communities with an opportunity to maximize their earnings from wild edible plants. Strengthening these market linkages is also crucial for increasing the visibility and acceptance of wild edible plants in mainstream markets (Raj *et al*., 2018) [53]. These native species, which grow naturally in forests, are often region-specific and well-adapted to the local climate and soil. As a result, wild vegetables are healthier, being purely organic and free from chemical fertilizers (Sundriyal & Sundriyal, 2001) [26]. They are also affordable, attracting growing consumer interest. Importantly, many of these underutilized vegetables are rich in essential nutrients, highlighting their potential to contribute to nutrition security. Therefore, promoting the cultivation and consumption of neglected and underutilized wild edible plants is a promising pathway to build sustainable food systems.

5. Conclusion and Future Prospects

The present study highlights the significant nutritional and functional potential of underutilized and neglected wild edible plants (WEPs), emphasizing their macronutrient composition, essential mineral content, and antioxidant capacities. These findings demonstrate that WEPs can serve as valuable sources of dietary energy, proteins, fats, micronutrients, and bioactive compounds, thereby supporting both nutritional security and health-promoting effects. Incorporating these species into regular diets can enhance nutritional intake while providing natural antioxidants that may help mitigate oxidative stress-related disorders.

Beyond nutritional benefits, promoting and cultivating WEPs can contribute to broader sustainable development goals. Native wild plants generally require fewer agricultural inputs, such as water, fertilizers, and pesticides are particularly suitable for traditional and low-resource farming practices. Their cultivation not only supports local food systems but also contributes to biodiversity conservation and the stability of ecosystems. Encouraging the utilization of these species can thus foster resilient agro-ecological landscapes while providing alternative income sources for local communities. A crucial challenge for achieving long-term impact is that promoting these neglected wild edible plants requires policy making, extension programs, and public awareness campaigns to foster their adoption, domestication, cultivation, and consumption. Future research should focus on detailed phytochemical profiling, bioavailability studies, and clinical validation of health benefits to strengthen the evidence base for their functional properties. Additionally, exploring the potential for large-scale cultivation and market integration can facilitate sustainable utilization of WEPs, ensuring both nutritional security and conservation of underutilized plant genetic resources.

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8. Declarations

8.1 Conflict of interest: None.

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