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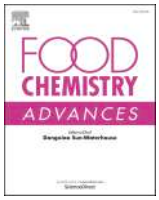

Nutritional insecurities in rural communities of Tanzania: the roles of wild edible foods (WEFs) in supplementing household nutrition

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ABSTRACT

Wild edible foods (WEFs) are currently consumed in various local communities in Tanzania. Despite their prevalence, there is a lack of comprehensive information regarding their nutritional profile. To address this gap, a study was conducted to assess their role in supporting local dietary. We identified 36 WEFs, including 12 wild fruits, 18 vegetables, and 6 wild edible mushrooms. The majority of participants (74.9 %) indicated that WEFs are regularly consumed within households. Laboratory analysis identified significant nutritional variability among WEFs, with *Justicia heterocarpa* exhibiting the highest Ca (863.5 mg/100 g) and Mg (430.8 mg/100 g). *Solanum nigrum* highest K (984.7 mg/100 g) and Fe (44.4 mg/100 g). Proximate analysis revealed that *Justicia heterocarpa* had the highest moisture content (87.9 %) and crude protein (5.3 %). *Passiflora edulis* displayed the highest ash content (8.9 %), whereas *Cyphomandra betacea* had the highest crude fibre (39.4 %). Phenolic, flavonoid, and tannin contents were highest in *S. nigrum* (8.15 mgGAE/g), *J. heterocarpa* (147.12 mgQE/g), and *A. spinosus* (58.29 mgTAE/g), respectively. Vitamin C, B1, and B2 were highest in *C. betacea* (27.2 mg/100 g), *S. nigrum* (0.59 mg/100 g), and *G. paviflora* (22.15 mg/100 g), respectively. The noted nutritional profile of the studied WEFs indicates their potential to supplement basic dietary needs, offering alternative source of nutrients.

1. Introduction

The consumption of nutrient-deficient food amid ongoing food insecurity has become a critical focus in many sub-Saharan African countries (Msuhaa & Kissoly, 2024). Approximately 2.4 billion people in rural areas of developing sub-Saharan Africa suffer from nutrient deficiencies (Duguma, 2020; Nishimwe et al., 2024) as they lack access to nutritious, safe, and sufficient food throughout the year (Mkonda & He, 2017; Nishimwe et al., 2024). Diets in rural households are often monotonous and lack diversity, predominantly consisting of staple cereal crops with low nutrient content (Mbwana & Bundala, 2023). This challenge poses a significant barrier to achieving the United Nations Sustainable Development Goal 2 (SDG2), which aims to eliminate hunger by 2030, as outlined in the United Nations report (UN, 2023). A food survey report indicated that semi-arid regions suffer from over 50 % food deficit (Mkonda & He, 2017). In Tanzania, over 40 % of children and women are underweight, indicating high rates of stunting and frequent illnesses due to poor nutrition (Mbwana & Bundala, 2023; Olesen et al., 2024). The rural population in Tanzania faces a high prevalence of undernutrition (Mbwana & Bundala, 2023), making access to nutrient-rich food a significant challenge for many rural households (Duguma, 2020). In response to these challenges, Tanzania has initiated several programs, including a national food security program aimed at addressing food insecurity (Mutungi et al., 2023). These efforts have faced numerous barriers that hinder the targeted goals (Balagaye & Pessa, 2022; Mumuni & Aleer, 2023). Key obstacles include climatic factors affecting agricultural productivity (Mkonda & He, 2017) and the limited purchasing power of the rural poor (Balagaye & Pessa, 2022). Reports from the Tanzania Food and Nutrition Centre (TFNC) highlight a steady decline in consumer purchasing power over the years (Du Plessis et al., 2022), exacerbated by low wages among rural communities, who often struggle with food shortages. Other challenges include crop failures due to climate change (Benítez et al., 2023), inadequate food storage infrastructure, food deficits, and the unsustainable sale of food at prices that do not support long-term food security (te Lintelo & Pittore, 2021; Ndhlovu, 2024). These issues have contributed to widespread hunger and nutrient-deficient diets, particularly in semi-arid regions, including Tanzania (Kitole et al., 2024; Mumuni & Aleer, 2023). A significant proportion of the population in these areas suffers from severe malnutrition (Oluoch et al., 2023),

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including deficiencies in essential nutrients.

The scarcity and unreliable supply of nutritious food have led to the search for affordable and alternative sources of healthy food (Duguma, 2020). Governments in many sub-Saharan African countries are increasingly exploring alternative ways to address nutrient deficiencies, such as promoting the use of locally available food resources, particularly wild edible foods (WEFs) (Duguma, 2020). WEFs have the potential to serve as nutritional supplements, improving nutrition at the household level (te Lintelo & Pittore, 2021; Beckstead et al., 2022). WEFs are defined as plants with at least one edible component, such as leaves, roots, or fruits, which grow naturally on farmland without human intervention (Lyamuya et al., 2023; Shirsat & Koche, 2024). These plants are considered valuable for household food security and nutrition, supplementing staple foods and addressing seasonal food shortages, particularly in dry regions (Duguma, 2020; Mgalula, 2024). WEFs are rich in nutrients, vitamins, and minerals that are typically lacking in common staple diets (Mwamatope et al., 2023). Furthermore, they are economically affordable and often of equal quality to domesticated varieties (Msuya et al., 2010; Sharma et al., 2024). WEFs are rich in essential nutrients and have significant potential for improving dietary and nutritional outcomes, particularly for low-income households (Oduor et al., 2023). Currently, the WEFs are increasingly recognized as a valuable alternative source of healthy, nutritious food (Lyamuya et al., 2023; Mwamatope et al., 2023). Their importance is growing in rural communities, with rising interest in incorporating them into diets to enhance nutrition and food security (Duguma, 2020; Mwamatope et al., 2023; Tesfay et al., 2024). They are vital in addressing food insecurity, especially in regions where conventional food sources are scarce (Sharma et al., 2024; Tesfay et al., 2024). Beyond their nutritional benefits, WEFs are gaining popularity for their potential to boost immunity and their low cost. Numerous studies highlight the importance of WEFs as alternative nutrient sources (Angami et al., 2024; Pachuau et al., 2020), providing a balanced and healthy diet. These plants are rich in dietary fibers, essential nutrients, and vitamins, making them an invaluable resource for maintaining good nutritional health (Gogoi et al., 2024).

Previous studies conducted in neighbouring regions with similar climatic conditions have demonstrated the potential of wild edible foods (WEFs) in supporting local food sources. For example, Mwanjala et al. (2024) highlighted the nutritional value of wild yam in the Mtwara rural district of Tanzania. The study found that wild yam provided valuable nutrients, including vitamin C (18.9–26.4 mg/100 g), total phenolics (60.28–122.51 mg GAE/g), and total flavonoids (599–1240.4 mg RUE/g). The yam's proximate composition included carbohydrate content ranging from 21.02 % to 23.57 %, crude protein between 1.0 % and 1.5 %, crude lipids between 0.46 % and 0.68 %, and crude fiber ranging from 11.26 % to 13.52 %. The energy value was recorded between 97.26 and 101.1 Kcal/100 g. Additionally, vitamin C levels varied between 18.9 and 26.4 mg/100 g, beta-carotene from 4.15 to 17.8 μg/g, and lycopene from 6.89 to 9.10 μg/g. Similarly, Mwamatope et al. (2023) reported the significant role of wild fruits, particularly Piliostigma thonningii in Malawi, which contained high amounts of total phenolics (1675.33 ± 12.34) and flavonoids (649.67 ± 2.08). The study emphasized that WEFs can be used to create value-added products rich in phytochemicals. In northern Uganda, Nyero et al. (2023) highlighted the essential food supplementing capabilities of wild edible plants, particularly those consumed by rural communities. In Ethiopia, Duguma (2020) observed that commonly consumed WEFs are crucial food supplements, particularly during times of food scarcity or famine. Oduor et al. (2023) in Kenya also recorded notable levels of elemental nutrients, including calcium, magnesium, iron, zinc, and potassium, in locally consumed WEFs, contributing to the reduction of malnutrition in the region. Furthermore, Nishimwe et al. (2024) in Rwanda identified G. buchananii and M. holstii as valuable WEFs, with high vitamin C content and mineral richness, making them suitable for use in the food industry. Beyond their nutritional benefits, Tahir et al. (2023) noted the ethnobotanical significance of WEFs, highlighting species like Flacourtia indica and Carissa spinarum with high use values. Similarly, Mgalula (2024) in Tanzania emphasized the medicinal properties of WEFs, with species such as Vitex mombassae and Strychnos spinosa being frequently utilized for their health benefits. Vainio-Mattila (2000), in his analysis of wild vegetables used by local communities in the Usambara Mountains of Tanzania, documented 73 species from 26 different families. Species like S. nigrum, L. cornuta, and A. spinosus were frequently used and preferred as edible foods.

Despite the significant reliance of local communities on wild edible plants (WEFs), there is a lack of specific studies detailing their nutritional profiles in the Lushoto district of Tanzania. As a result, the potential of these plants to contribute to dietary supplementation is largely overlooked in the region. To address this knowledge gap, a household study was conducted with two main objectives: (i) to identify the WEFs available in the district, and (ii) to analyze their nutritional profiles. The goal of the study was to create a comprehensive baseline dataset that would highlight the nutrient contents of these WEFs. The study also aims to promote the use of WEFs as a sustainable and accessible nutritional source for households. Additionally, by documenting the nutritional benefits of these plants, the research could help raise awareness among local communities and policymakers about the value of incorporating WEFs into local dietary systems.

2. Materials and methods

2.1. Study site

The present study was conducted in Lushoto District, located in the northern part of the Tanga Region in Tanzania. It lies between latitudes 4°25′ and 4°55′ south of the Equator and longitudes 30°10′ and 38°35′ east of Greenwich. Lushoto is bordered by the Republic of Kenya to the northeast, Kilimanjaro Region to the northwest, Korogwe District to the south, Bumbuli District to the southeast, and Mkinga and Muheza Districts to the east (URT, 2023). The district is situated in the western section of the Usambara Mountains, a region known for its exceptional biodiversity and endemism (Makonyo & Zahor, 2023). The landscape of Lushoto is dominated by the Western Usambara Mountains, which range in elevation from 300 to 2100 m above sea level. The district's topography is primarily characterized by highlands, which account for approximately 75 % (1725 km^2) of the total area. These highlands are situated at elevations between 1000 and 2100 m above sea level. The remaining 25 % of the district, comprising 575 km^2, consists of lowlands located at altitudes ranging from 300 to 600 m above sea level. Notably, the mountains and their lower slopes encompass around 90 % of Lushoto's total area. Lushoto's economy is largely dependent on its natural resources, including agriculture and forestry. The district experiences a bimodal rainfall pattern, with short rains occurring from October to December and long rains from March to June. The highland areas receive an average annual rainfall ranging from 800 to 2000 mm, while the lowland regions receive between 500 and 800 mm of rainfall per year. The heaviest rainfall during the long rainy season typically occurs in April (URT, 2023). The district is divided into five agro-ecological zones: humid warm, dry hot, humid cold, dry warm, and dry cold. These zones are classified based on altitude, rainfall, temperature, and humidity levels. Lushoto is situated in the western part of the Usambara Mountains, which are recognized for their high biodiversity and endemic species. The forests in the district cover a total area of 44,685 hectares, representing 12 % of the district's total land area. These forests include government-designated reserves, such as a Central Government Forest Reserve covering 42,000 hectares, a District Forest Reserve of 1200 hectares, and a Village Land Forest Reserve of 1485 hectares. The forests in the region are a mix of dense and open forests, including shrub, bush, and thick forest areas (URT, 2023). Efforts to combat deforestation in the Usambara Mountains have been ongoing, with the government initiating a reforestation program under Order No. 1 of 2000. This

initiative aims to protect the forested areas and preserve the habitats of species that are globally recognized for their biodiversity. The Usambara Mountains are an integral part of the Eastern Arc Mountain Range, crucial for biodiversity conservation, water catchment, medicinal plant sources, and carbon credit generation (URT, 2023). The selection of this district for the study was based on its proximity to the Usambara mountain range, which is noted for its high levels of endemism and abundant wild edible food plants (WEFs). The communities living near these forests rely heavily on WEFs, utilizing them at a relatively high rate. The district is home to three main ethnic groups: the Sambaa, Pare, and Mbugu. The local Sambaa language is particularly rich in botanical and ecological terminology related to edible wild plants. The study focused on two divisions, Soni and Bumbuli, and selected two wards, Mponde and Funta. From each ward, two villages were chosen for the study: Kweminyasa, Mahange, Funta, and Balangai (Fig. 1).

2.2. Research design

The present study utilized a mixed-methods approach within a phased research framework. Phase I, which employed a qualitative approach, aimed to document and describe the wild edible foods (WEFs) commonly used by local communities in the study area. The initial step involved a free listing of wild plant species used for food across different categories (fruits, vegetables, and other foods). For each identified species, participants shared details about the parts of the plant used, consumption, and seasonal availability. These discussions were facilitated by a trained research team, which was recruited from the local communities and was fluent in Swahili and Sambaa. After the discussions, a comprehensive list of all WEFs was compiled. To select participants, a purposive sampling technique was used, choosing 30 individuals based on their knowledge of the topic, at least three years of

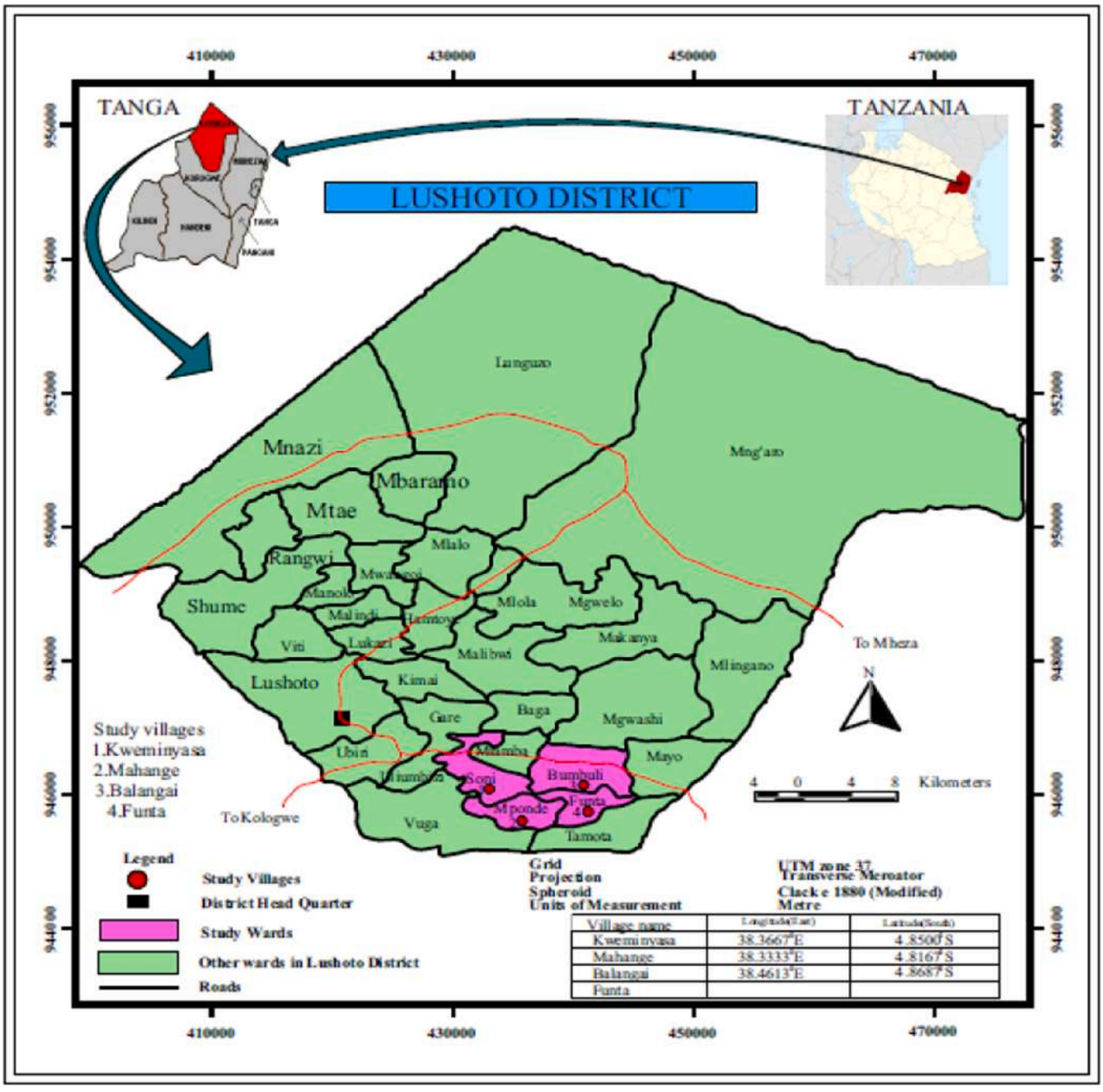

Fig. 1. A map showing the surveyed areas in Lushoto district, Tanzania generated using QGIS.

residency in the village, and their willingness to participate. Village leaders, such as Village Executive Officers and Village Chairpersons, helped identify suitable participants. Informed consent was obtained from all participants prior to their involvement in the study. Additionally, local development agents (DAs), familiar with the villages, were consulted to ensure the inclusion of knowledgeable individuals. Village leaders accompanied the research team in each village to ensure that the study adhered to local traditions and norms. Interviews were conducted in Kiswahili and Sambaa, and later translated into English. Phase II involved laboratory analysis to quantify the nutritional profiles of selected WEFs.

2.3. Data collection tools

The present study employed a variety of data collection methods, including structured and semi-structured questionnaires (SSQs), focus group discussions (FGDs), and key informant interviews (KIs). A household survey was also conducted to identify the wild edible foods (WEFs) commonly consumed in the region. A checklist with key points was developed to create an inventory of available WEFs and guide the discussions. Key informants were selected based on their expertise and experience with WEFs in the local context. These informants included traditional herbal healers, village elders, and foresters from the surveyed area. The SSQs, FGDs, and KIs provided detailed information on the commonly consumed WEFs and their contribution to household food security. To gather data on local perceptions regarding WEF consumption and the socio-demographic characteristics of households, a multi-stage sampling approach was employed. The sampling process started with the division level, followed by wards, then villages, and finally individual households, with a focus on proximity to the forest. The study was conducted in two divisions, Soni and Bumbuli, and two wards, Mponde and Funta, with two villages selected from each ward. This resulted in a total of four villages: Kweminyasa, Mahange, Funta, and Balangai (Fig. 1).

2.4. Identification of WEFs

WEFs were identified by both their local and botanical names with assistance from local botanists and relevant taxonomic references, such as regional floras. For species that were challenging to identify in the field, specimens were collected and assigned voucher numbers (GKM001 to GKM036) for further identification at the Department of Forestry and Food Science, Sokoine University of Agriculture, Tanzania. These specimens were also botanically authenticated at the National Herbarium (NHT) in Arusha, Tanzania. Additionally, the scientific names of each species were cross-checked using World Flora Online (WFO, 2022) and The Plant List (http://www.theplantlist.org).

2.5. Sampling of WEFs

A random sampling technique was used to collect 1 kg of the edible portions of the selected WEFs. The collector traversed the collection site, stopping at random intervals to harvest any observed WEFs. This approach ensured that samples were gathered from various locations within the site, promoting representativeness. Care was taken to select fruits at similar stages of maturity. For the leafy vegetables only the leaves were collected, ensuring they were at the maturity stage typically consumed locally. A similar approach was used for the fruits with whole ripe fruits hand-picked from trees encountered during the walk. Once collected, the WEFs were sorted, carefully washed, packaged in zip-lock polythene bags, and stored in cool boxes with ice for transportation for further analysis to the Department of Forestry and Food Science at Sokoine University of Agriculture, Tanzania.

2.6. Sample preparation

A 0.5 g portion of the pulp from each cleaned WEFs was cut into pieces and oven-dried at temperatures between 40 °C and 50 °C until a constant weight was reached. After drying, the WEFs were ground into powder and stored in airtight containers with proper identification before being deep-frozen for subsequent chemical analysis. The nutritional profiles of the selected WEFs were evaluated by analyzing their contents of essential nutrients, proximate composition, phytochemical analysis and vitamins.

2.7. Selection of WEFs for nutritional analysis

Based on information gathered from respondents, including traditional herbal healers, village elders, foresters, and vendors from the indigenous community, we identified the most consumed and marketed WEFs, as well as those reported to have medicinal properties. To deepen our findings, a market survey was conducted in major markets where WEFs are sold and consumed. After identifying the most commonly consumed and marketed WEFs, we selected them for further nutritional analysis to gain more insights into their role as food supplements in local communities. These WEFs are in high demand due to their perceived health benefits, reinforcing their potential as valuable dietary supplements. Understanding the nutritional composition of these WEFs is crucial, as it offers valuable information on their role in enhancing dietary diversity and improving community health.

2.8. Elemental analysis in WEFs

The contents of essential nutrients, including sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), and iron (Fe), were quantitatively analysed using an atomic absorption spectrophotometer (model UNICAM 919, Spectronic Unicam, Rochester, New York, USA). These elements were selected due to their critical roles in various biological functions within the human body, making them important for evaluating the nutritional value of wild edible foods (WEFs). For example, potassium (K) is vital for maintaining osmotic balance and regulating nerve signals, while calcium (Ca) is crucial for neuromuscular function and bone mineralization. Magnesium (Mg) contributes to energy production and ATP synthesis, sodium (Na) aids in nutrient absorption, and iron (Fe) is essential for oxygen transport and preventing anemia. The operating conditions for determining the elements under analysis were established using specific wavelengths for each element: sodium (Na) at 330.2 nm, potassium (K) at 404.4 nm, magnesium (Mg) at 285.2 nm, calcium (Ca) at 422.7 nm, and iron (Fe) at 248.3 nm. The system's software-controlled automatic temperature regulation enables precise positioning and optimization of each Hollow Cathode Lamp (HCL), as well as adjustment of the spectral bandwidth for accurate analysis. Furthermore, standard stock solutions (1000 mg/L) were used to prepare working standards for each element. The accuracy of the quantified results was validated by analysing standard reference materials of plant origin (NIST SRM-1515, USA). A detailed description of the elemental analysis and quality control procedures can be found in Pipoyan et al. (2018). During the analysis, blanks were run intermittently to ensure high-quality results, and washing procedures were performed regularly. Precision was assessed by conducting replicate analyses, where each sample was analyzed three times, and the average values were reported. The recoveries for the analyzed elements ranged from 98 % for Na, 99 % for Fe, 100 % for Ca and K, and 101 % for Mg. The correlation values (R^2) for the elements were as follows: Na (0.996), K (0.992), Mg (0.9984), Ca (0.997), and Fe (0.998). The detection limits for the elements were 0.042 mg/L for Na, 0.065 mg/L for K, 0.001 mg/L for Mg, 0.003 mg/L for Ca, and 0.006 mg/L for Fe, while the quantification limits were 0.140 mg/L for Na, 0.215 mg/L for K, 0.004 mg/L for Mg, 0.01 mg/L for Ca, and 0.018 mg/L for Fe. To optimize elemental extraction from the WEFs, a double acid digestion method was used. In a polytetrafluoroethylene

vessel, 0.5 g of moisture-free powdered sample was combined with 9 ml of nitric acid (HNO_3), 0.5 mL of hydrochloric acid (HCl), and 1 mL of hydrogen peroxide (H_2O_2). The mixture underwent a double acid digestion process using a microwave digestion system (Anton Paar, Multiwave Go). The digestion was carried out at a temperature of 180 °C, under a pressure of 35 bar, with a 5-minute ramp time and a 20-minute holding time, to ensure efficient breakdown of the samples. All glassware made of Pyrex and plastic vessels and containers were thoroughly cleaned to prevent contamination. They were treated with a 1 % dilute nitric acid solution, then rinsed multiple times with double-distilled water, and air-dried. This cleaning process ensured that no impurities affected the results. Calibration standards and sample dilutions were prepared using double-distilled water to maintain accuracy and consistency throughout the analysis.

2.9. Proximate composition analysis

The proximate composition of the wild edible foods (WEFs) was analyzed, including ash content (AC), moisture content (MC), crude protein (TP), and crude fiber (CF), using standard methods outlined in AOAC 1980 (Horwitz & Latimer, 2006). To measure ash content (AC), which represents the inorganic residue remaining after the combustion and oxidation of organic matter, plant samples were heated at 500–600 °C in a muffle furnace. The procedure involved placing 1 g of the dried sample in a clean, pre-weighed porcelain crucible, heating it for 5–6 h, and then cooling it in a desiccator. The crucible with the resulting greyish-white ash was then weighed, and the ash content percentage was determined using the allometric method suggested by Nielsen (2017). Moisture content (MC) was determined by oven-drying at 100 ± 5 °C until a constant weight was achieved. Crude protein (TP) was estimated using Lowry's Method (Lowry et al., 1951), a widely used procedure due to its sensitivity and consistency. This method is based on the reaction between the phenolic groups of tyrosine and tryptophan residues in a protein with the Folin-Ciocalteau reagent, forming a blue-purple complex that absorbs light at 660 nm. The intensity of the color indicates the amount of these aromatic amino acids in the protein, which varies across different protein types. Total crude fat (TCF) was estimated using the Soxhlet method (Evans, 2002), with petroleum benzene as the solvent. Total calorific value (TCV) was measured with an Auto Bomb Calorimeter (Doyle et al., 2007). Carbohydrate content (CC) was assessed using the phenol-sulfuric acid method (Nielsen, 2017). Crude fiber (CF) was determined by measuring the weight loss after igniting fat-free samples, which were digested with 1.25 % H_2SO_4 and NaOH solutions.

2.10. Qualitative and quantitative phytochemical analysis

2.10.1. Quantitative analysis

Quantitative analysis of phytochemical components, including total phenol content (TPC), total flavonoid content (TFC), calorific values (CV), and tannin content (TTC), was conducted using standard methodologies (Evans, 2002; Harborne, 1998; Kokate et al., 2002; Sofowora, 1993). To determine the total phenol content (TPC), the Folin-Ciocalteu method was employed (Bhalodia et al., 2011; Patel et al., 2010). In this procedure, 5 g of the sample was weighed and ground using a pestle and mortar with ten times the volume of 80 % ethanol, then centrifuged at 10,000 rpm for 20 min. The supernatant was collected, and the residue was re-extracted with five times the volume of 80 % ethanol. The combined supernatant was evaporated to dryness, and the residue was dissolved in 5 mL of distilled water. A series of test tubes were prepared by pipetting 1 mL of the extract along with varying concentrations of gallic acid (0.1, 0.2, 0.4, 0.6, 0.8, and 1 mg/mL), with water used as the blank. The volume was adjusted to 5 mL, followed by the addition of 0.5 mL of Folin's reagent to all tubes, which were then shaken well. After 5 min, 2 mL of 20 % sodium carbonate solution was added, followed by thorough mixing and incubation for 2 h at room temperature. The absorbance was measured at 750 nm, and a calibration curve was used to calculate the total phenol content, expressed as mg of gallic acid equivalent per gram of dry mass (mg GAE/g). For the total flavonoid content (TFC), an aluminum chloride colorimetric assay was used (Patel et al., 2012; Satishkumar et al., 2015). The procedure involved adding 1 mL of the solvent extract or aliquot to 1 mL of quercetin solution, with varying concentrations of quercetin (0.1, 0.2, 0.4, 0.6, 0.8, and 1 mg/mL) placed into a series of test tubes. To each tube, 4 mL of distilled water and 0.3 mL of 5 % sodium nitrite solution were added. After 5 min, 0.3 mL of 10 % aluminum chloride was introduced, and the mixture was incubated for 6 min. Then, 2 mL of 1 M NaOH was added, and the final volume was adjusted to 10 mL with distilled water. The resulting orange-yellow color was measured for absorbance at 510 nm using a UV–visible spectrophotometer. The blank was prepared with distilled water, and quercetin served as the standard. The TFC was calculated in mg of quercetin equivalent per gram of dry mass (mg QE/g). The tannin content (TTC) was analyzed using a modified version of the Folin-Ciocalteu method (Prabhavathi et al., 2016). In this method, 1 mL of the sample extract was combined with 3 mL of distilled water, 0.5 mL of Folin-Ciocalteu's reagent, and 0.5 mL of 35 % sodium carbonate solution. Absorbance was measured at 725 nm, with tannic acid dilutions (0 to 1 mg/mL) used as standard solutions. The tannin content was expressed in mg of tannic acid equivalent per gram of extract (mg TAE/g).

Qualitative analysis

The study utilized qualitative analysis to detect the presence or absence of various phytoconstituents, including saponins, alkaloids, terpenoids, steroids, cardiac glycosides, phlobatannins, anthocyanins, betacyanins, and quinones in the wild edible foods (WEFs) under investigation. The analysis of these compounds is crucial for ensuring food safety and quality, while also minimizing any potential toxic or harmful effects that could impact food security. Several standard tests were employed to identify these phytochemicals. The Foam test was used to detect saponins, while Mayer's test was applied to identify alkaloids. Terpenoids and steroids were tested using the Salkowski test. Cardiac glycosides were assessed with the Keller-Killiani test. The Hydrochloric acid test was used to identify phlobatannins, and anthocyanins were tested using the Borntrager's test. The presence of quinones was determined using Borntrager's test, and betacyanins were detected using the Sodium hydroxide test. The detailed procedures for conducting these tests are described by Maheshwaran et al. (2024) and Okuna et al. (2024), ensuring that the methodologies are scientifically validated and effective for screening the phytochemical profiles of the WEFs.

2.11. Determination of vitamins

Vitamin C content was determined using the titrimetric method as outlined by da Silva et al. (2017). In this procedure, 20 mL of the extract was mixed with 2–3 drops of a 1 % starch indicator and titrated with a 20 % CuSO4 solution until a dark endpoint was reached. The iodine solution (0.005 mol/L) and copper sulfate solution were used, where 1 mL of iodine solution was equivalent to 0.88 mg of ascorbic acid. The concentration of ascorbic acid in the sample was calculated from the amount of iodine solution used during the titration and was expressed as mg/100 g. For the quantification of thiamine (Vitamin B1) and riboflavin (Vitamin B2), colorimetric analysis was employed as described by Al-Ward and Hussein (2016) and Okwu and Josiah (2006). To measure Vitamin B1, 10 mL of the filtrate was combined with 10 mL of potassium dichromate, and the absorbance was measured at 507 nm. A calibration curve was constructed using different concentrations of standard solutions, and a blank sample was prepared using distilled water. For Vitamin B2, 10 mL of the extract was mixed with 10 mL of 5 % potassium permanganate in a 50 mL volumetric flask, followed by the slow addition of 10 mL of 30 % H_2O_2. This mixture was heated in a hot water bath for 30 min. Afterward, 2 mL of 40 % sodium sulfate was added, and the

volume was adjusted to 50 mL with distilled water. The absorbance was then measured at 450 nm. The concentrations of Vitamin B1 and Vitamin B2 were reported as mg/100 g of dry weight.

2.12. Statistical analysis

The descriptive statistics (mean and standard deviation) was used to summarize and describe the households' socio-demographic data. Chi-square tests of proportion were used to establish associations on the perceptions of consumption of WEFs between those who consume and those do not. Similarly, data on nutritional analysis, one-way ANOVA was used to determine significance, difference among WEFs. The Duncan Multiple Range Test was used as a post hoc test to compare means at a 5 % significance level ($p < 0.05$). Data normality was assessed using the Shapiro–Wilks test, while Levene's test was applied to evaluate homogeneity of variance. Due to the complexity of drawing conclusions from a single method, multiple analytical approaches were employed to examine the relationships between variables. An integrated approach using Pearson correlation, Hierarchal cluster analysis (HCA) and Principal Component Analysis (PCA) was applied. PCA reduced the dimensionality by extracting principal components (PCs) from a larger set of variables, revealing multivariate patterns based on eigenvalues. All statistical analyses were carried out using SPSS version 20.

3. Results

3.1. Documentation of WEFs

A total of 36 wild edible foods (WEFs) were identified as commonly consumed by households in the survey areas, including 12 wild fruits, 18 wild vegetables, and 6 wild edible mushrooms. The vegetable group was the most diverse, comprising 18 species, followed by the fruit group with 12 species, and the mushroom group with 6 species, which were commonly consumed (Supplementary Table 1). The study revealed that 27.8 % of the identified WEFs were frequently consumed by households throughout the year, while the remaining 69.5 % were consumed seasonally, (46.2 % from November to March during the rainy season, and 23.3 % dry season), particularly during periods of food scarcity. Approximately 86 % of the WEFs were consumed domestically, while the rest were sold in local markets to supplement household income. Among the notable WEFs commonly consumed were *Cyphomandra betacea* (25.3 %), *Passiflora edulis* (21.4 %), and *Vangueria infausta* (10.3 %) among the wild fruits, and *Launaea cornuta* (21.6 %), *Galinsoga paviflora* (19.4 %), *Solanum nigrum* (16.2 %), *Sonchus luxurians* (12.9 %), *Amaranthus spinosus* (8.7 %), *Justicia heterocarpa* (7.2 %), and *Ipomoea cairica* (6.4 %) among the wild vegetables. Other species were reported by fewer than 5 % of households. These widely consumed species were selected for further chemical analysis due to their significance as food supplements in local communities.

A significant proportion of participants (74.9 %) disagreed with the statement that WEFs are difficult to find in their communities. A higher percentage of households (80.6 %) consumed WEFs compared to those who did not ($\chi^2 = 17.068$, $p = 0.002$). Furthermore, more than three-quarters (76.4 %) of participants believed that some WEFs were important to their community's cultural identity, with 22.6 % strongly agreeing. The percentage of households strongly believing in the cultural significance of WEFs was significantly higher among WEF-consuming households (48.2 %) compared to non-consuming households ($\chi^2 = 20.388$, $p = 0.000$). Regarding the potential benefits of including WEFs in their diets, more than half (78.3 %) of WEF consumers believed that WEFs could improve their dietary quality. As a result, the majority (58.2 %) agreed that they consume WEFs because they cannot afford more expensive food options due to poverty. The identified WEFs offer valuable insights for their use as important food supplements that can enhance the nutritional profile of local communities in the hilly areas of Lushoto, Tanzania. These WEFs have the potential to contribute to promoting natural nutrient remedies while improving food security.

3.2. Elemental nutrient analysis

Nutritional contents among the studied WEFs varied significantly ($F9,49 = 38.13$, $p = 0.000$), with potassium (K) showing the highest levels, ranging from 221.6 to 984.7 mg/100 g, while iron (Fe) exhibited the lowest, ranging from 2.1 to 44.4 mg/100 g (Table 1). Sodium (Na) was highest in *Sonchus luxurians* (296.4 mg/100 g) and lowest in *Vangueria infausta* (46.3 mg/100 g). Potassium levels were highest in *Solanum nigrum* (984.7 mg/100 g) and lowest in *Vangueria infausta* (221.6 mg/100 g). Magnesium (Mg) content was highest in *Justicia heterocarpa* (430.8 mg/100 g) and lowest in *Passiflora edulis* (48.8 mg/100 g). Calcium (Ca) was highest in *Justicia heterocarpa* (863.5 mg/100 g) and lowest in *Cyphomandra betacea* (45.1 mg/100 g). Iron (Fe) content was highest in *Solanum nigrum* (44.4 mg/100 g) and lowest in *Vangueria infausta* (2.1 mg/100 g). Notable contributors to sodium (Na) among the WEFs included *Sonchus luxurians, Launaea cornuta, Amaranthus spinosus,* and *Passiflora edulis*. For potassium (K), significant contributors were *Solanum nigrum, Launaea cornuta, Amaranthus spinosus,* and *Justicia heterocarpa*. High magnesium (Mg) content was primarily contributed by *Justicia heterocarpa, Launaea cornuta, Solanum nigrum,* and *Sonchus luxurians*. Calcium (Ca) was mainly contributed by *Justicia heterocarpa, Solanum nigrum, Launaea cornuta,* and *Galinsoga paviflora*. Iron (Fe) was primarily contributed by *Solanum nigrum, Launaea cornuta,* and *Sonchus luxurians.* Species such as *Launaea cornuta, Solanum nigrum, Sonchus luxurians,* and *Justicia heterocarpa* exhibited multiple nutritional contributions, highlighting their potential as valuable WEFs for food security and nutrition in rural communities. Additionally, the Na/K ratio for the analyzed WEFs was found to be less than one (Table 1), indicating that these WEFs could play a significant role in blood pressure regulation, as a Na/K ratio lower than one is associated with the prevention of hypertension. The findings suggest that species with high nutrient contents should be prioritized for household consumption, offering implications for dietary recommendations.

3.3. Proximate composition analysis

The composition of moisture content (MC), ash content (AC), crude fiber (CF), and crude protein (CP) varied significantly ($F = 277.96$; $p = 0.02$) among the studied WEFs as indicated in Supplementary Fig. 1. The highest moisture content was recorded in Justicia heterocarpa (87.9 %), and the lowest in Ipomoea cairica (6.4 %). The highest crude fiber (FC) content was found in Cyphomandra betacea (39.4 %), while the lowest was in Launaea cornuta (2.11 %). Crude protein (CP) and ash content (AC) showed lower compositions across all WEFs, with the highest CP in Justicia heterocarpa (5.3 %) and the highest AC in Passiflora edulis (8.9 %). The proximate composition of the WEFs revealed that moisture content (MC) ranged from 6.4 % to 87.9 %, while ash content (AC) ranged from 0.02 % to 8.9 %. Crude fiber (CF) ranged from 2.11 % to 39.4 %, and crude protein (CP) ranged from 1.2 % to 5.3 %. WEFs with the highest moisture content included Justicia heterocarpa (87.9 %), Cyphomandra betacea (82.8 %), Vangueria infausta (79.7 %), and Galinsoga paviflora (79.2 %). The highest ash content was found in Passiflora edulis (8.9 %), Cyphomandra betacea (4.88 %), and Ipomoea cairica (4.8 %). Cyphomandra betacea (39.4 %), Sonchus luxurians (37.7 %), and Solanum nigrum (36.2 %) had the highest crude fiber content. For crude protein, Justicia heterocarpa (5.3 %), Vangueria infausta (4.87 %), and Passiflora edulis (4.8 %) were the top contributors (Supplementary Fig. 1). These WEFs demonstrate considerable proximate composition with potential to enhance food diversity among local communities.

Table 1
Elememtal composition and vitamins of common consumed WEFs in the hilly areas of Lushoto, Tanzania.

Name of the WEFs	Vitamins (mg/100 g)			Mineral content (mg/100 g)				
	Vitamin C	Viamin B1	Viamin B2	Ca	Mg	K	Na	Fe
A. spinosus	1.6 ± 0.06 *g*	0.13±0.07^{a}	0.33±0.07^{a}	152.9 ± 0.74^{efg}	103.5 ± 3.00 *g*	816.2 ± 0.30^{hi}	138.2 ± 0.67^{dg}	12.5 ± 0.08^{fh}
C. betacea	27.2 ± 0.11^{b}	0.37±0.21^{b}	0.57±0.33^{cd}	45.1 ± 0.34^{ab}	88.6 ± 1.88^{d}	292.1 ± 1.71^{efg}	62.4 ± 2.83^{b}	2.6 ± 0.46^{fg}
G. paviflora	3.2 ± 0.07^{e}	0.51±0.24^{c}	0.24±0.03^{a}	572.4 ± 0.29^{gh}	133.6 ± 4.33^{ad}	672.1 ± 1.23^{cf}	63.1 ± 2.71^{b}	18.3 ± 0.12^{a}
I. cairica	5.5 ± 0.10^{a}	0.54±1.03^{c}	0.63±0.92^{cd}	103.3 ± 0.03^{h}	115.6 ± 2.00^{k}	614.2 ± 3.03^{cf}	74.0 ± 2.09^{b}	12.3 ± 0.15^{fh}
J. heterocarpa	2.4 ± 0.07^{j}	0.16±0.09^{d}	17.85±1.98^{e}	863.5 ± 0.07^{e}	430.8 ± 2.12^{cd}	732.6 ± 1.01^{b}	56.1 ± 1.87^{e}	16.5 ± 0.07^{eg}
L. *cornuta*	6.6 ± 0.07^{a}	0.11±0.06^{a}	22.15±1.78^{b}	628.8 ± 0.64^{ef}	358.8 ± 2.54^{bf}	822.6 ± 5.28^{hi}	156.2 ± 1.65^{h}	28.6 ± 0.05^{dj}
P. edulis	6.4 ± 0.12^{a}	0.11±0.02^{a}	0.45±0.29^{ab}	54.3 ± 1.40^{ab}	48.8 ± 2.44^{i}	366.8 ± 0.42^{fg}	128.2 ± 1.86^{h}	3.9 ± 0.11^{i}
S. luxurians	4.8 ± 0.04^{c}	0.42±0.19^{ab}	5.66±1.76^{d}	179.7 ± 1.53^{fgh}	290.1 ± 0.69^{l}	357.6 ± 0.35^{fg}	296.4 ± 3.18^{h}	28.2 ± 0.10^{dj}
S. nigrum	10.6 ± 0.15^{h}	0.59±0.23^{c}	2.24±0.65b^{c}	697.8 ± 0.59^{ef}	350.3 ± 4.23^{bf}	984.7 ± 6.09^{ag}	70.2 ± 0.55^{b}	44.4 ± 0.11^{ag}
V. infausta	14.8 ± 0.08^{f}	0.31±0.13^{b}	0.66±0.92^{cd}	172.6 ± 0.57^{fgh}	65.9 ± 1.78^{ab}	221.6 ± 3.59^{efg}	46.3 ± 2.78^{e}	2.1 ± 0.15^{fg}

*Values with different lower-case superscript letters in a column are significantly different among the WEFs at $p < 0.05$.
Values are expressed as mean ± SD with three replications ($n = 3$) for each experiment.

3.4. Phytochemical analysis

3.4.1. Quantitative analysis

The quantitative analysis of phytochemical components namely total phenolic content (TPC), total flavonoid content (TFC), total calorific value (TCV), and total tannin content (TTC) is illustrated in Fig. 2. The results indicated significant variation among the studied wild edible foods (WEFs), with statistical analysis showing a highly significant difference ($F = 282.35$; $p = 0.000$). Among the WEFs, Passiflora edulis exhibited the highest TCV, with an energy value of 458.6 kcal/100 g, while *G. paviflora* (298.8 kcal/100 g showed the lowest. Other species with notably high calorific values included Amaranthus spinosus (398.9 kcal/100 g) and Vangueria infausta (373.1 kcal/100 g), highlighting their potential as energy-rich food sources for local communities. In terms of total phenolic content, Solanum nigrum recorded the highest value at 8.15 mg GAE/g, followed by Cyphomandra betacea (6.89 mg GAE/g) and lowest in *V. infausta* (3.25 mg GAE/g). These compounds are known for their antioxidant properties, which can help reduce oxidative stress and inflammation, making these species particularly beneficial for promoting health and preventing chronic diseases. For total flavonoid content, Justicia heterocarpa led with the highest concentration at 147.12 mg QE/g, and lowest noted by *I. cairica* (9.04 mg QE/g). Flavonoids contribute to numerous biological activities including anti-inflammatory, anti-carcinogenic, and heart-protective effects, thus their abundance in these WEFs underscores their nutritional and medicinal relevance. As for tannin content, A. spinosus and S. luxurians both exhibited the highest TTC at 58.29 mg TAE/g, while *J. heterocarpa* recorded the lowest (27.66 mg TAE/g). Tannins play a role in digestive health and possess antimicrobial properties, further emphasizing the functional food potential of these plants. The variation in phytochemical

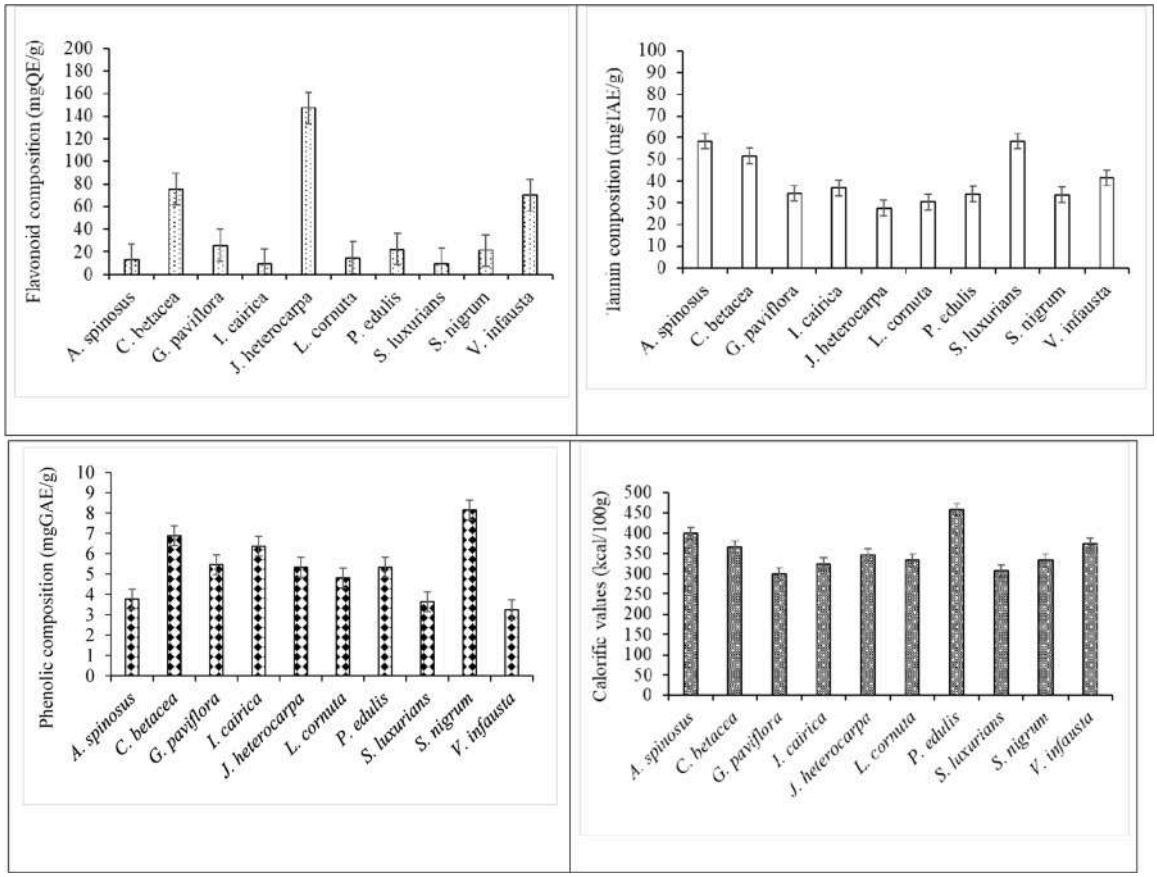

Fig. 2. Phytochemical constituents of all investigated WEFs in the hilly areas of Lushoto, Tanzania.

composition across the different species reveals the diverse nutritional benefits that these WEFs.

3.4.2. Qualitative analysis

To complement the quantitative phytochemical analysis, a qualitative assessment was also conducted to evaluate the presence and relative abundance of several key phytochemicals in the studied wild edible foods (WEFs). These included saponins, alkaloids, terpenoids, steroids, cardiac glycosides, phlobatannins, anthocyanins, betacyanins, oxalates, and quinones. The analysis was carried out using aqueous extracts of the WEFs, and the results were recorded using symbolic representations in Table 2, where '+++' indicates high concentration, '++' moderate, '+' low, and '–' signifies absence. The qualitative analysis revealed a relatively high presence of beneficial phytochemicals such as terpenoids, steroids, phlobatannins, and anthocyanins across many of the examined WEFs. Specifically, *Passiflora edulis* exhibited a notably high concentration of terpenoids (+++), while *Sonchus luxurians* showed a moderate level (++). These findings are consistent with the known aromatic properties and flavor-enhancing compounds found in many WEFs, especially those used in traditional culinary practices. Phlobatannins and steroids were also detected in significant amounts in several species, suggesting potential antioxidant and antimicrobial benefits. Anthocyanins, which are known for their strong antioxidant activity and role in reducing oxidative stress, were present in moderate to high levels in various samples. Interestingly, the study observed a complete absence ('–') of several compounds across all WEFs analyzed, including saponins, alkaloids, betacyanins, oxalates, and quinones. This absence may indicate a lower toxicity profile of these wild foods, as compounds like oxalates and certain alkaloids are known to contribute to antinutritional or toxic effects when present in large amounts. The lack of these potentially harmful phytochemicals reinforces the safety and nutritional viability of WEFs for human consumption. It also suggests that WEFs could serve as functional foods offering health benefits beyond basic nutrition due to the presence of beneficial bioactive compounds without the risks associated with toxic constituents.

3.5. Vitamins analysis

Vitamin C, B1 (thiamine), and B2 (riboflavin) levels varied notably across the analyzed wild edible foods (WEFs), with one-way ANOVA confirming statistically significant differences. Cyphomandra betacea recorded the highest vitamin C content (27.2 mg/100 g), followed by Solanum nigrum (19.4 mg/100 g) and Vangueria infausta (14.8 mg/100 g). For vitamin B1, S. nigrum had the highest content (0.59 mg/100 g), with Ipomoea cairica (0.54 mg/100 g) and Passiflora edulis (0.51 mg/100 g) also showing notable amounts (Table 1). In terms of vitamin B2, Galinsoga paviflora led with 22.15 mg/100 g, followed by Sonchus luxurians (17.85 mg/100 g). These results demonstrate that most WEFs possess considerable vitamin content, suggesting their potential to serve as important supplementary sources of essential nutrients. Their inclusion in local diets could improve nutritional intake, especially in rural communities where access to commercial food products is limited.

3.6. Correlation analysis of WEFs

3.6.1. Pearson's correlation

The positive correlations were observed between Ca and K ($r = 69.6$ %), Ca and Mg ($r = 82.8$ %), Ca and Fe ($r = 75.7$ %), and K and Fe ($r = 70.4$ %). Similarly, proximate compositions showed positive correlations with each other, with the highest correlation between CF and CP ($r = 79.6$ %). Furthermore, significant correlations were observed between proximate contents and elemental (macro and micronutrients), with the highest correlations between Mg and AC ($r = 86$ %), Ca and AC ($r = 73.1$ %), and Fe and AC ($r = 76$ %). Additionally, the analysis also identified negative correlations between proximate contents and certain elemental nutrients (Mg, Ca, K, and Fe) as indicated in Supplementary Table 2. These negative correlations indicate that higher concentrations of proximate contents may result in lower levels of elemental nutrients. The complex interaction between proximate contents and elemental nutrients should be balanced to avoid potential nutrient suppression.

3.6.2. Cluster analysis

Hierarchical cluster analysis (HCA) using the Ward method and the Rescaled Distance Cluster Combined method was conducted to explore the interrelationships between the studied nutritional among WEFs. The dendrogram presented in Fig. 3 illustrates a clustering pattern of variables. The HCA divided the investigated nutrients parameters into three primary clusters, each with distinct characteristics. The first cluster consisted of proximate contents (ash content (AC), crude protein (CP), iron (Fe), and vitamin C, B1 and B2, TFC and TPC (Fig. 3A). The second cluster included CF, TTC, MC and Na while the third cluster composed of K, Ca and Mg. Similarly, among studied WEFs plants *P. edulis, C. betacea* and *V. infausta* made up the first cluster, and *A. spinosus* and *I. cairica* formed the second meanwhile L. *cornuta, J. heterocarpa, S. nigrum* and *G. paviflora* formed cluster three (Fig. 3B). This relationship and noted clustering in nutrients and studied WEFs highlights the importance of carefully considering the selection of plants as potential nutrient sources.

3.6.3. Principal component analysis

Principal Component Analysis (PCA) using the Rotation and Oblimin with Kaiser Normalization method was performed to validate the findings from both the Pearson correlation and Hierarchical Cluster Analysis (HCA). PCA helps reduce the complexity of large datasets by extracting a

Table 2
Qualitative analysis of phytochemical constituents of common consumed WEFs in the hilly areas of Lushoto, Tanzania.

Phytoconstituents	Biochemical test	Common consumed WEFs									
		A. spinosus	*C. betacea*	*G. paviflora*	*I. cairica*	*J. heterocarpa*	L. *cornuta*	*P. edulis*	*S. luxurians*	*S. nigrum*	*V. infausta*
Saponins	Foam test	+	–	+	–	–	–	–	–	–	–
Alkaloids	Mayer's test	–	–	–	–	–	–	+	–	–	–
Terpenoids	Salkowski test	+	+	+	+	+	+	+++	++	+	++
Cardiac glycosides	Keller-Killiani test	+	+	+	+	+	–	+	–	+	+
Steroids	Salkowski test	+	+	+	+	+	+	+	+	+	+
Phlobatannins	Hydrochloric acid test	+	+	+	–	+	+	+	+	–	+
Anthocyanins	Hydrochloric acid test	+	+	–	+	+	+	+	+	+	+
Betacyanins	Sodium hydroxide Test	+	–	+	–	–	+	+	+	+	–
Quinones	Borntrager's test	+	+	–	+	–	–	+	–	–	–

'+++' denoting high concentration, '++'denoting moderate concentration, '+' denoting small concentration, and '-' denoting absence.

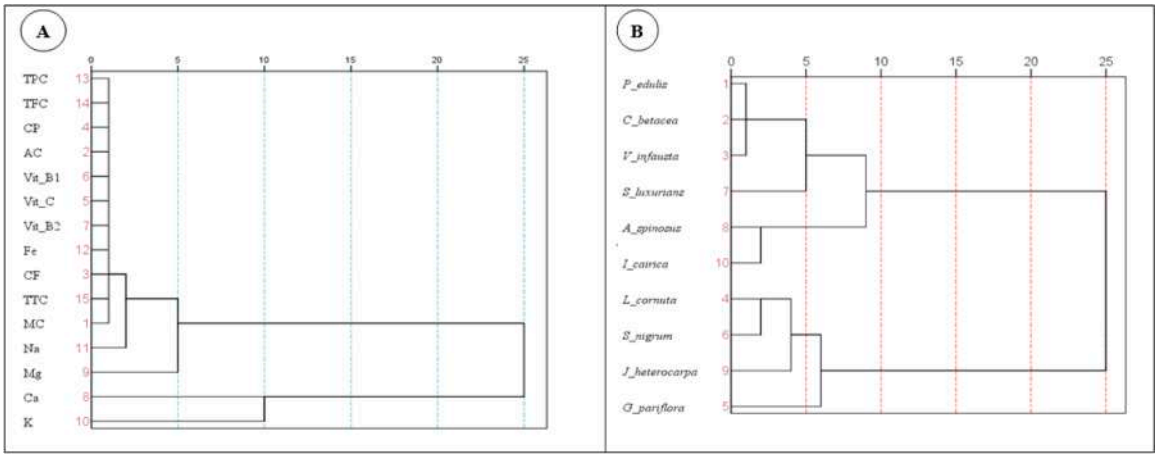

Fig. 3. Hierarchical dendrogram depicts clustering of nutritional contents (**A**), and studied WEFs (**B**) in the hilly areas of Lushoto, Tanzania.

smaller set of independent "latent" variables, providing a clearer understanding of the interrelationships between nutritional components and WEFs. The analysis identified three principal components (PCs), each with an eigenvalue greater than 1, accounting for the total variance in the data. PC1 explained the largest proportion of variance (78.79 %), while PC4 explained the least (43.08 %). The variables with the highest loadings in PC1 included calcium (Ca) at 90 %, potassium (K) at 74 %, and magnesium (Mg) at 94 %. PC2 was strongly loaded by crude fiber (CF) at 87 % and crude protein (CP) at 89 %. PC3 was primarily loaded by sodium (Na) at 95 % (Fig. 4A). Similarly, for studied WEFs *P. edulis* and *V. infausta* strongly loaded in PC1. *A. spinosus* and *I. cairica* strongly loaded in PC2, while *G. paviflora* loaded in PC3 (Fig. 4B). Such results suggest that the proper acquisition of nutritional contents requires a combination of several interaction among WEFs.

4. Discussion

4.1. Documentation of WEFs

The current study identified 31 WEFs that are commonly consumed by local communities in the hilly regions of Lushoto, Tanzania. These foods serve as important nutritional supplements and contribute significantly to household incomes. It was found that 38.2 % of households harvest WEFs daily to supplement their diets, while 46.8 % consume them three to four times a week, and 15 % consume them only occasionally. The study noted that the contribution of WEFs varied both by species and household, with 78.8 % of households that consumed WEFs reported that they made a major contribution to their diets and overall food consumption. Among the frequently consumed WEFs, fruits such as C. betacea, P. edulis, and V. infausta, as well as vegetables like L. cornuta, G. paviflora, S. nigrum, S. luxurians, A. spinosus, J. heterocarpa, and I. cairica, were highly collected for daily consumption. Their importance lies in their dual role as both sources of essential nutrition and food security, highlighting their potential for integration into dietary practices as functional foods. These WEFs can help address gaps in food security while promoting better health and well-being within the community. This information can help promote WEFs as functional foods that could play a crucial role in improving food security and health outcomes. The variety of WEFs and their categorization into different food types, such as fruits, vegetables, and mushrooms, suggests that these foods can contribute to increasing dietary diversity in local communities. This diversity is particularly important in areas experiencing food insecurity, as highlighted by Oduor et al. (2023) and Kaale et al. (2023), who emphasize that the availability of diverse WEFs offers an opportunity to enhance food supplementation, particularly for children in regions facing food shortages. The study noted that, WEFs have the potential to bridge the gaps in food security and dietary diversity, making them essential for improving the nutritional status of vulnerable populations.

The high demand for WEFs is primarily attributed to their nutritional value, availability, and taste, as noted by Kaale et al. (2023) and Nishimwe et al. (2024). Many of the species identified in the study need to be

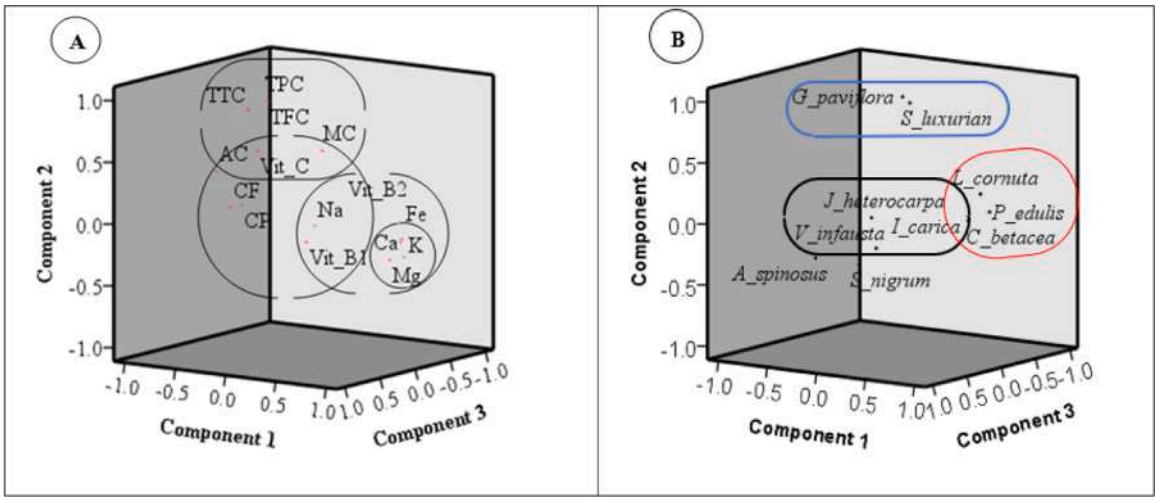

Fig. 4. PCA loadings of nutritional contents (**A**) and studied WEFs (**B**) in the hilly areas of Lushoto, Tanzania.

prioritized for conservation and sustainable management to ensure their continued availability for future generations. The availability of these WEFs in local markets is seasonal, with some fruits, like M. arboreus and S. comorensis, being available only for a few months. However, some respondents in focus group discussions (FGDs) and interviews reported that the medicinal properties of these WEFs have increased their consumption. Although this was not fully investigated in this study, it was pointed out that people are encouraged to consume more WEFs, particularly fruits, due to their perceived immunity-boosting properties. As a result, the consumption of fruits has gained more attention in recent years, with families in the region consuming larger quantities of WEFs. This increase in consumption is partly due to the belief that WEFs are less likely to be contaminated by toxic chemicals compared to cultivated fruits, as highlighted in previous studies (Mwanjala et al., 2024; Nyero et al., 2023).

The findings from the interviews clearly demonstrated that WEFs are among the foods that households rely on most during times of food scarcity. In fact, the majority of respondents (67.9 %) agreed that WEFs are especially important during famine or food insecurity. Furthermore, more than 86 % of respondents agreed on the general importance of WEFs in their diets. Despite their nutritional value, the study also revealed concerns about the sustainability of WEFs. Respondents noted that many of the trees and plants providing these wild foods are under threat due to overexploitation by humans, making them harder to find. WEFs like C. betacea, and V. infausta are heavily harvested for market supply, which makes them rare and occasionally difficult to obtain. This observation is consistent with the findings of Tesfay et al. (2024), who warned that the ethnomedicinal significance of certain WEFs could lead to the extinction of some species if conservation efforts are not implemented. Therefore, this study recommends that the collection of these WEFs be closely monitored to ensure their sustainable use. The present study emphasizes the critical role of WEFs in enhancing food security and providing essential nutrition to households in Lushoto. These foods contribute not only to the dietary needs of local communities but also offer economic benefits by supplementing household incomes. However, the overexploitation of certain WEF species poses a risk to their availability, making it crucial to prioritize conservation and sustainable management efforts. Further research into the medicinal properties of these WEFs could also open up new possibilities for their use in health and wellness. Integrating these wild foods into local diets, while ensuring their sustainability, has the potential to significantly improve food security and overall well-being for the communities that depend on them.

4.2. Nutritional analysis of WEFs

4.2.1. Elemental analysis

WEFs are known to provide natural essential elements that contribute to food quality and health. They are rich in key nutrients such as calcium (Ca), magnesium (Mg), and potassium (K), which are vital for growth, development, and overall well-being (Mwanjala et al., 2024, 2024). These nutrients, along with carbohydrates, vitamins, and proteins make WEFs an important part of the diet (Duguma 2020; Nyero et al., 2023). The analysis of WEFs consumed by local communities in Lushoto, Tanzania revealed significant levels of essential elements (Table 1). The study highlighted the mineral content of these WEFs, with *J. heterocarpa, S. nigrum,* L. *cornuta* and *G. paviflora*. having the high contribution to Ca contents. *S.* luxurians having the highest sodium (Na) content, and S. nigrum recording the highest potassium (K) levels. J. heterocarpa exhibited the highest magnesium (Mg) contents, while Solanum nigrum had the highest iron (Fe) levels. These WEFs are key contributors to the elemental nutritional, providing essential minerals that play critical roles in various physiological processes. Special attention should be given to vegetables, as they represent a diverse group of WEFs with potential health benefits. The nutritional content found in this study aligns with findings reported by AlJuhaimi et al. (2024), who investigated the accumulation of element contents in wild fruits. For example, Justicia heterocarpa (863.5 mg/100 g), Solanum nigrum (697.8 mg/100 g), Launaea cornuta (628.8 mg/100 g), and Galinsoga paviflora (572.4 mg/100 g) were found to have high Ca levels, surpassing the nutritional values of cultivated fruits like bananas and oranges, as reported by Vicente et al. (2014). These WEFs thus provide viable alternatives for addressing nutrient deficiencies and improving dietary balance, particularly in tribal communities. Additionally, Ngurthankhumi (2024) emphasized the role of WEFs as functional foods, underlining their importance in enhancing nutrition and supporting health. The nutritional analysis of WEFs in this study is consistent with findings from Mwanjala et al. (2024) in Tanzania's Mtwara rural district, as well as Kaale et al. (2023) in semiarid central Tanzania. These results are comparable to studies on wild edible fruits in Malawi (Mwamatope et al. 2023) and Uganda (Nyero et al. 2023). A slight variation in nutritional content was observed when comparing these findings to studies of selected wild fruits in Kenya (Oduor et al., 2023) and Rwanda (Nishimwe et al. 2024), which may be attributed to differences in location, species composition and environmental conditions. The high levels of essential elements such as sodium (Na), magnesium (Mg), potassium (K), calcium (Ca), and iron (Fe) found in the WEFs in the study area highlight their potential to contribute to food security and improve nutrition. These elements are vital for key metabolic functions. For instance, iron (Fe) is a crucial component of haemoglobin, myoglobin, ferritin, and cytochrome enzymes, playing an essential role in oxygen transport to tissues and acting as a cofactor for various redox enzymes. These nutrients are integral to physiological processes such as protein synthesis, energy release, and enzyme activation (Ngurthankhumi, 2024).

4.2.2. Proximate composition

The study demonstrated considerable variation in proximate nutritional components namely moisture content (MC), ash content (AC), crude fiber (CF), and crude protein (CP) among the evaluated WEFs. These variations underscore the nutritional relevance of WEFs in supporting food and nutrition security, particularly in resource-limited rural areas. Justicia heterocarpa and Cyphomandra betacea recorded high moisture content, indicating their potential role in hydration and freshness of diets. High ash content, which represents total mineral content, observed in Passiflora edulis and Ipomoea cairica, suggesting they are mineral-dense species that could enhance micronutrient intake. In terms of crude fiber, Sonchus luxurians, C. betacea, and Solanum nigrum were notable contributors, that could support gastrointestinal health and reducing the risk of metabolic disorders. J. heterocarpa, Vangueria infausta, and P. edulis demonstrated significant levels of crude protein, essential for body tissue repair and immune function. The recorded values were consistent with those reported in similar studies (Biswas et al., 2022; Haq et al., 2024; Mokria et al., 2022; Ngurthankhumi et al., 2024; Tesfay et al., 2024), reinforcing the reliability of these findings. Importantly, these results reflect the capacity of WEFs to serve as complementary sources of essential proximate composition often missing from staple-based diets. Given their local availability, cultural acceptance, and nutritional richness, these species hold substantial potential for promoting dietary diversity and resilience against food insecurity. Prioritizing their integration into food systems could offer sustainable, low-cost nutrition strategies for vulnerable populations.

4.2.3. Phytochemical analysis

The current study highlights the significant contribution of wild edible foods (WEFs) to phytochemical components, with species such as Solanum nigrum, Justicia heterocarpa, Amaranthus spinosus, and Cyphomandra betacea consistently showing high levels across various phytochemical categories. This suggests their potential as valuable dietary supplements, particularly in rural Tanzanian communities, where access to conventional sources of nutrition may be limited. These findings emphasize the importance of incorporating underutilized plants

into local food systems to enhance food security and promote healthier diets. The study also revealed that the high phytochemical content in WEFs plays a role in supplementing food enrichment and may contribute to human health by reducing the risks associated with various health issues. These results align with Swai et al. (2025), who found that Justicia heterocarpa serves as a sustainable food source in Tanzania's regions experiencing nutritional deficiencies, with significant levels of phenolic compounds. The slight variability in the phytochemical composition across WEF species can be attributed to factors such as genetic differences, agroecological conditions, and altitude, as noted by Ngurthankhumi et al. (2024). This variability underscores the adaptability of WEFs to different environments, enhancing their potential as a food security resource in areas with limited access to diverse food sources. Qualitative analysis of phytochemicals like saponins, alkaloids, terpenoids, steroids, cardiac glycosides, phlobatannins, anthocyanins, betacyanins, oxalates, and quinones revealed lower concentrations, with many compounds being absent in the WEF samples (Table 2). This is significant because evaluating the presence of these compounds is crucial for understanding both their health benefits and potential risks. For example, saponins offer antimicrobial, anti-inflammatory, and cholesterol-lowering properties, but excessive amounts can lead to gastrointestinal irritation (Thakur et al., 2020). Similarly, alkaloids can have beneficial pharmacological effects but can also be toxic in high doses. Terpenoids contribute to flavor and aroma while possessing antioxidant and antimicrobial properties (Ranaweera et al., 2021), and phlobatannins, though antioxidants, may have antinutritional effects by inhibiting digestive enzymes (Samaraweera et al., 2023). The studied WEFs suggest that these plants are generally safe for consumption, offering valuable health benefits without the toxicity risks that might be present in higher concentrations.

4.2.4. Vitamin analysis

The levels of essential vitamins vitamin C (ascorbic acid), vitamin B1 (thiamine), and vitamin B2 (riboflavin) varied significantly across the analyzed WEFs. Among the WEFs, Cyphomandra betacea exhibited the highest concentration of vitamin C at 27.2 mg/100 g, suggesting its potential as a valuable source of this essential antioxidant. Other species with relatively high vitamin C content included Solanum nigrum (19.4 mg/100 g) and Vangueria infausta (14.8 mg/100 g), both of which also contribute significantly to daily vitamin requirements, especially in rural communities where access to conventional fruits may be limited. Insufficient intake can lead to scurvy, characterized by fatigue and capillary fragility, as outlined by Li et al. (2007). Regarding vitamin B1 content, Solanum nigrum again emerged as a prominent contributor, recording the highest level at 0.59 mg/100 g. It was followed closely by Ipomoea cairica (0.54 mg/100 g) and Passiflora edulis (0.51 mg/100 g). These values underscore the role of WEFs in supporting nerve function and energy metabolism through thiamine intake. For vitamin B2, Galinsoga paviflora led with a substantial concentration of 22.15 mg/100 g, followed by Sonchus luxurians at 17.85 mg/100 g. Riboflavin plays a critical role in cellular respiration and the maintenance of healthy skin and vision, and the significant levels found in these species highlight their dietary importance. These results align with earlier studies among WEFS (Biswas et al. 2022; Ngurthankhumi et al. 2024). Vitamins are essential for energy metabolism, playing a critical role in growth, development, and cellular functions, as emphasized by Badar and Iliyas (2010). Overall, the findings demonstrated that most of the studied WEFs contained appreciable levels of essential vitamins, reinforcing their nutritional value. These WEFs can serve as natural, accessible, and sustainable dietary supplements, particularly in rural areas where food security and micronutrient deficiencies are pressing concerns. Their integration into local diets could enhance the intake of key vitamins, reduce reliance on commercial supplements, and help bridge nutritional gaps caused by limited access to conventional vegetables and fruits. This study emphasizes the need to promote the use of vitamin-rich wild edible species such as C. betacea, S. nigrum, and G. paviflora as complementary food sources. Their nutritional contributions are particularly vital in improving the overall health and resilience of communities affected by poverty and food scarcity

4.2.5. Correlation analysis

The relationships among the nutritional variables studied in wild edible foods (WEFs) were critically examined using Pearson's correlation, Hierarchical Cluster Analysis (HCA), and Principal Component Analysis (PCA). The correlation coefficients ranged from weak to strong, revealing varying degrees of association between nutrients (Supplementary Table 2). The observed positive correlations indicate that many of the nutrients are closely associated, such that the presence of one tends to rise or fall alongside others, reflecting a significant level of nutritional interdependence within the WEFs. This interconnectedness supports the idea that WEFs are complex nutrient systems, where changes in one component can influence others. However, some significant negative correlations were detected between proximate contents (e.g., carbohydrates, proteins, fats) and specific elemental nutrients such as magnesium (Mg), calcium (Ca), potassium (K), and iron (Fe). These inverse relationships imply that higher levels of proximate contents might suppress the concentration of certain micronutrients. This finding is critical, as it underscores a potential nutritional trade-off within WEFs: enhancing energy-yielding nutrients may come at the cost of reducing essential minerals. Therefore, a balanced approach must be adopted in the selection and promotion of WEFs to optimize their overall nutritional contribution. HCA further supported the correlation findings by grouping similar nutrients and WEF species based on their shared nutritional profiles (Fig. 3). The clustering patterns indicate that certain WEFs have closely related nutritional compositions, which can be used to predict their combined dietary potential. This pattern is consistent with earlier findings by Malunguja and Devi (2022), who observed nutrient clustering in relation to environmental factors. Such groupings can inform conservation strategies, helping prioritize species that contribute complementary nutrients. Moreover, PCA confirmed these relationships by reducing the dataset into principal components that clearly aligned with the patterns seen in both correlation and HCA. This triangulation of methods enhances confidence in the results and highlights the importance of considering nutrient interrelationships when assessing the dietary value of WEFs. Ultimately, these findings emphasize the need for a comprehensive nutrient database on WEFs to guide their sustainable use and promote food security, especially in local communities reliant on traditional food systems.

5. Conclusion and recommendations

5.1. Conclusion

The nutritional analysis of WEFs in Lushoto, Tanzania, demonstrates their potential to alleviate common nutrient deficiencies. The study noted that WEFs like Cyphomandra betacea, Passiflora edulis, Vangueria infausta, Launaea cornuta, Galinsoga paviflora, Solanum nigrum, Sonchus luxurians, Amaranthus spinosus, Justicia heterocarpa, and Ipomoea cairica possess valuable nutritional profile that can significantly improve the health of local communities. These species contribute essential nutrients that can help bridge gaps in food security and dietary diversity. The findings further underscore the role of WEFs in addressing food insecurity and malnutrition, particularly in regions experiencing food shortages. These plants present an affordable and effective alternative to traditional food sources, making them a practical solution for combating nutrient deficiencies. Therefore, advocating for the inclusion of WEFs in local food systems should be a priority for policymakers. Such integration could lead to the development of more comprehensive food security strategies that recognize WEFs as vital supplementary food sources. WEFs should be managed sustainably to ensure their long-term availability, thus enhancing dietary diversity and improving overall health in the area.

5.2. Recommendations

We recommend the following:

(i) Local communities in Tanzania facing a shortage of nutritious food should be encouraged to integrate wild edible foods (WEFs) into their daily diets as alternative food sources;
(ii) Nutrition policies should prioritize the promotion of WEFs as a fundamental aspect of food and nutrition security;
(iii) The incorporation of WEFs into markets, alongside the development of a functional and efficient value chain, is essential for improving their availability and consumption; and
(iv) Government funding for projects should prioritize this underutilized nutritional resource by identifying communities that frequently consume WEFs and supporting NGOs and research institutions in implementing more targeted, food-based initiatives.

Ethics approval and consent of participant

The study received ethical approval from the University Research Ethics Committee prior to data collection. Permission was granted by the Lushoto District Administration, and verbal consent was obtained from the informants after explaining the purpose of the study with the help of local translators and a botanist.

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CRediT authorship contribution statement

Gisandu K. Malunguja: Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Lulu Luflenge:** Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Philipina F. Shayo:** Writing – review & editing, Visualization, Validation, Formal analysis, Data curation.

Declaration of competing interest

Authors declare that they do not have any conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.focha.2025.101065.

Data availability

Data will be made available on request.

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