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Chemical and nutritional characterization of edible *Heinsia crinita, Xylopia aethiopica, Piper guineense, Monodora myristica and Dorstenia convexa* plants from Angola

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ABSTRACT

The endemic plants from Angola, *Heinsia crinita* (*H. critina*), *Xylopia aethiopica* (*X. aethiopica*), *Piper guineense* (*P. guineense*), *Monodora myristica* (*M. myristica*), and *Dorstenia convexa* (*D. convexa*) play a significant role in traditional medicine and culinary applications. The aim of this study is to carry out a comprehensive nutritional characterization of different parts from five plants. Results showed the nutrient and elemental composition of these plants varies significantly, with the two types of roots containing abundant carbohydrates (43.48 % in *D. convexa*), while the seeds and pods are rich in proteins and lipids, among the highest content in *M. myristica*, 13.70 % and 38.07 %, respectively. The highest concentrations of essential amino acids (EAAs) were leucine, with the limiting types being methionine, cysteine and valine, among that *H. crinita* root had the highest EAAs (39.45 %). A total of 33 fatty acids were identified from these plants, of which oleic acid (C18:1n9) and linoleic acid (C18:2n6) were the major monounsaturated and polyunsaturated fatty acids (MUFAs, PUFAs), respectively, while C24:1n9 was found only in the *P. guineense* seeds and broken *X. aethiopica* pods. All plants are particularly rich in potassium (K), while zinc (Zn) and iron (Fe) are the main microminerals. As for antioxidant capability, the whole *X. aethiopica* pods showed the best level in 2,2-Diphenyl-1-picrylhydrazyl (DPPH) and ferric reducing (FRAP), while *D. convexa* roots contained the best performance in trolox equivalent (TEAC). In conclude, these plants can be excavated to apply in food flavors and supplement, making them to further commercialize.

1. Introduction

Although the large number of plant species are consumed, Africa has very little scientifically explored medicinal flora, creating an urgent need to better define them with therapeutic and nutraceutical effects. In the last decades, the chemical composition and nutritional value of some Angolan plants which are traditionally used by rural communities as food, spice and medicine has been evaluated (Chipaca-Domingos et al., 2023; Tlhapi et al., 2024). Advances in analytical chemistry have made it possible to resolve plants properties whose chemical composition is still partially known or poorly characterized. In this sense, the endemic and popular Angolan plants, *Heinsia crinita (H. critina), Xylopia aethiopica (X. aethiopica), Piper guineense (P. guineense), Monodora myristica (M. myristica), and Dorstenia convexa (D. convexa)*, play a significant biochemical and physiological role in traditional medicine and culinary applications. According to Angolan folk medicine, these plant

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extracts show potential health benefits such as antioxidant, anti-inflammatory, wound healing activity, anti-tumor, anti-viral and neuroprotective properties (Santos et al., 2020; Zou et al., 2025), and have been used for centuries in cooking (improvement of sensory properties) as well as inhibitors of oxidative degradation (food preservation) (Ojimelukwe, 2023). Thus, they are important to the local population because of their crucial benefits. Despite their extensive local use as spices and herbal medicines, it remains a significant lack of scientific understanding of their properties, which limits their broader utilization and commercialization. Until now, the chemical composition and proximate constituents of these plants were not well analyzed, and even some of them were completely in limbo.

From a nutritional point of view, just *X. aethiopica*, *P. guineense* and *M. myristica* are partially characterized. Evuen et al. (2022) evaluated the mineral composition, phytochemicals and other constituents of *X. aethiopica* and *P. guineense* and found them to be rich in carbohydrates (81.24 %) and proteins (4.83 %), minerals (magnesium, zinc, iron, selenium, copper, calcium, manganese, and molybdenum) as well as flavonoids, phenolic acids and alkaloids. In the case of *M. myristica*, there has analyzed peptides, fatty acids and essential oils, and results have shown that these components are present in large quantities in seeds (Ekeanyanwu et al., 2021), which has attracted a great deal of interest from researchers. In this context, there is limited available information on these plants and further research to assess their nutritional properties and socio-economic potential is needed. Moreover, besides the phenolic group, there is no other chemical information from any part of *D. convexa* and *H. crinite* plants. Boumba and colleages characterized the polyphenols in the ethanolic extract of *H. crinita*, and found it to be rich in phenolics, mainly rutin, isoquercitrin, quercetin and kaempferol (Boumba et al., 2022). These polyphenolic compounds are the key components for its anti-inflammatory, analgesic and antioxidant effects (Xue et al., 2023; Yan et al., 2023; Zhu et al., 2023). In addition, some reports suggest that the extractions from *H. crinita* have antimicrobial activity, anti-oxidative stress, anti-plasmodial activity (cyclic enol ether terpenoids) and anticholinesterase activity (plant alkaloids) (Iwara et al., 2023; Oboh et al., 2021; Tshibangu et al., 2017). Among other four plants (*X. aethiopic*, *D. convexa*, *P. guineense*, *M. myristic*), physiological activity studies have shown that they exhibit similar efficacy in the above areas, mainly highlighting in antioxidant, antimicrobial and antimalarial (Boumba et al., 2022). For these Angolan plants, the key components are peptides, hydrocarbons, acids and esters, which enable them to exert well-known biological properties (Tlhapi et al., 2024). Therefore, scientific research is urgently needed to determine the chemical composition of these plants.

The aim of this research is to figure out the chemical composition (in terms of protein, lipid and carbohydrates content as well as amino acid, fatty acid and minerals profile) together with the antioxidant activity of *H. critina and D. convexa* roots*, P. guineense* and *M. myristica* seeds *and D. convexa* pods in whole and broke stages. One of the distinguishing features of these plants is their phytochemical composition, which is useful in making people aware of their nutritional value as well as their potential uses. This study will address existing gaps in knowledge regarding their chemical composition and provide the latest foundational data for future research and development. Additionally, the data obtained will help optimize the use of these resources and promote their broader application in food flavors, pharmaceuticals, cosmetics, and other related fields, enhancing their commercialization potential. This work will offer benefits to encourage further research to uncover additional bioactivity.

2. Materials and methods

2.1. Raw material

The five plants were harvested in the northern region of Angolan (city of Uige) by herbalists in 2023. Plants were dried at 40–50 °C and purchased in the local market in December 2023. After pre-selection, they were packaged and transported to the laboratory. The studied plant parts were two types of roots (*H. crinita* and *D. convexa*), two types of seeds (*P. guineense* and *M. myristica*), and the pods of *X. aethiopica* in two states: whole pods and broke pods, as shown in Fig. 1. Once in the laboratory, these samples were ground, homogenized and stored in sealed plastic bags at room temperature (20–25 °C), shielded from light until further analyses.

2.2. Moisture and ash content

To determine the moisture and ash content, standardized procedures were conducted in accordance with AOAC methods. Specifically, moisture content was assessed using AOAC Official Method 930.15 (AOAC Official, 2023), which involves drying the sample at 105 °C to measure loss on drying. Ash content was determined following AOAC Official Method 942.05 (AOAC Official, 2023), which entails incinerating the sample to quantify the inorganic residue.

2.3. Protein profile

2.3.1. Protein content

The Dumas technique, outlined in AOAC protocols and detailed by Pereira et al. (2023) and Zou, Hu, Ni, et al. (2022) was employed to determine the total protein content. Approximately 5 mg of samples were combusted at high temperatures, causing rapid oxidation of organic compounds and the production of several gases such as O_2, CO_2, H_2O, N_2 and nitrogen oxides. These gases were then filtered to remove O_2, CO_2 and H_2O, and the remaining nitrogen was converted to N_2 using a copper reduction column at elevated temperatures. Pure helium served as the mobile phase, and gas chromatography, specifically utilizing the FISONS Carlo Erba EA1108 Elemental Analysis Unit with a thermal conductivity detector, was employed to quantify total nitrogen content, among that the detection limit was set at 10 ppm. The nitrogen content of proteins is usually assumed to be 16 %, which corresponds to a common conversion factor of 6.25 (i.e., 100/16). However, the nitrogen content of plant proteins is usually lower than this, around 18 % (corresponding to a conversion factor of 5.5). This is because the amino acid composition of plant proteins is different from that of animal or bacterial proteins, with a higher proportion of amino acids containing less nitrogen. Although the commonly used nitrogen-to-protein conversion factor is 6.25, Zhang et al. (2020) concludes that a factor of 5.5 is more appropriate for calculating protein content in plant samples like these.

2.3.2. Amino acids profile

The amino acid composition was analyzed using a high-performance liquid chromatography–mass spectrometry (HPLC-MS) system (1260 series, Agilent, Palo Alto, CA, USA), including essential amino acids—histidine (His), isoleucine (Ile), leucine (Leu), lysine (Lys), methionine (Met), phenylalanine (Phe), threonine (Thr), and valine (Val), as well as non-essential amino acids—cysteine (Cys), tyrosine (Tyr), glycine (Gly), arginine (Arg), proline (Pro), aspartic acid (Asp), glutamic acid (Glu), alanine (Ala), and serine (Ser) by referring method of Rawat and Saini (2023). This system was coupled with a compact mass detector (Triple Quad 3500; AB SCIEX INSTRUMENTS, Foster City, CA, USA) featuring an electrospray ionization source (ESI) and utilizing Turbo V™ in both positive and negative modes, with nitrogen as the nebulizer and collision gas. Separation was conducted using a C18 column (Phenomenex Luna, 150 mm × 2 mm x 3 μm). Samples (50 mg) were hydrolyzed in 1 mL of 6 N HCl at 112 °C for 22 h in a test tube. The resulting hydrolysate was eluted at a flow rate of 300 μL/min, with a column temperature of 30 °C, and an injection volume of 10 μL. Gradient elution was performed using a solvent mixture: 0.1 % acetic acid in water (A), 0.1 % acetic acid in acetonitrile (B). The data were processed using Analyst 1.6.2 Software (AB Sciex, Foster City, CA).

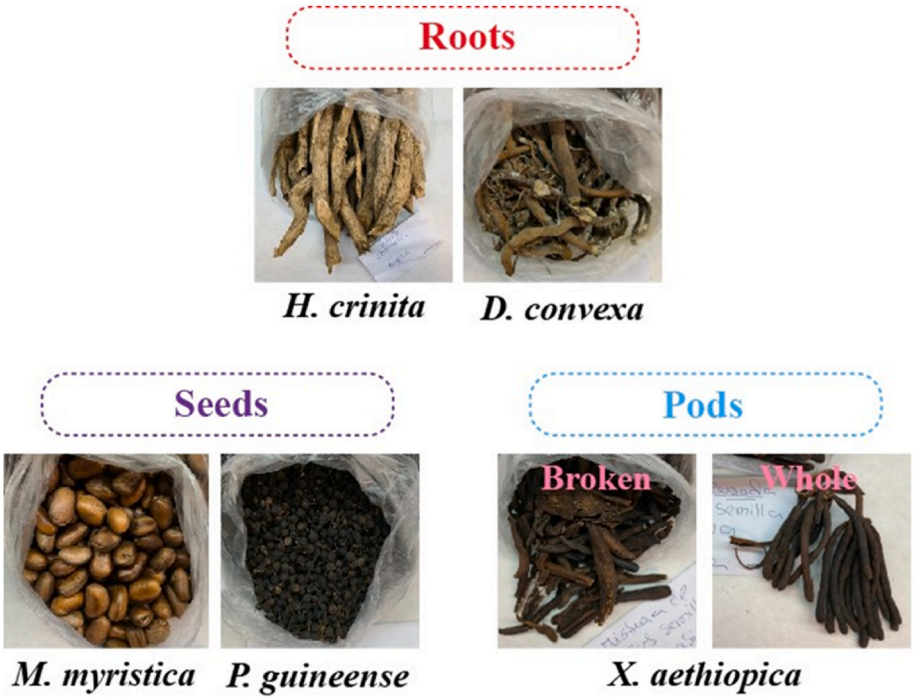

Fig. 1. Original matrix for *Heinsia crinite*, *Dorstenia convexa*, *Piper quineense*, *Monodora myristica* and *Xylophia aethiopia*.

2.4. Lipid profile

2.4.1. Lipid content

Soxhlet apparatus (Büchi Labortechnik AG, Flawil, Switzerland) was employed to determine total lipid content by referring method of Bouafia et al. (2020). In each raw material sample (1 g), was extracted using n-hexane as a solvent with a liquid-solid ratio of 120:1 for 2 h. Following extraction, the extract was concentrated via complete solvent removal using a rotary evaporator. Lipid content was determined by the weight difference between the liquid content and raw sample.

2.4.2. Fatty acids profile

To determine the volatile fatty acids, the oil sample extracted via Soxhlet extraction underwent an esterification/transesterification reaction by referring method of Conlon et al. (2024). In summary, the lipid phases were suspended in 1 mL of toluene and 2 mL of sulfuric acid (1 % in methanol), and the mixture was incubated at 50 °C overnight. Subsequently, the samples were cooled in darkness, followed by the addition of 5 mL of a 5 % sodium chloride solution. After stirring for 30 min, 5 mL of hexane was added, and the resulting mixture was stored in darkness until two distinct layers formed. The supernatant, containing fatty acids, was collected and combined with an additional 5 mL of hexane. Once the fatty acids-containing supernatants were pooled, 4 mL of water (2 % sodium bicarbonate) were added, and the mixture was frozen overnight. The liquid phase (hexane) was then collected and frozen for subsequent analysis. For fatty acids analysis, a gas chromatograph (Agilent 7820A) equipped with an Agilent HP-88 column (60 m × 250 μm × 0.25 μm) and a flame ionization detector was utilized. The chromatographic method employed two temperature programs: the first with a ramp of 5 °C/min until reaching 220 °C, held for 15 min; the second with a ramp of 40 °C/min until reaching 250 °C, held for 2 min. Helium served as the carrier gas (1 mL/min). Fatty acid identification was conducted using external standards, and fatty acid composition was determined using corresponding calibration curves.

2.5. Carbohydrate content

Referring to the method of Fernandes et al. (2021) with some modifications, 72 % H_2SO_4 (w/w) was used to hydrolyze the polysaccharides in the samples (0.5 g) to monosaccharides. The monosaccharides were quantified by comparing the standards with the help of HPLC (Dionex ICS 3000, Sunnyvale, CA, USA), including some of the major monosaccharides, such as ribose-5-phosphate (R5P), rhamnose (Rha), arabinose (Ara), glucose (Glc), xylose (Xyl), fructose (Fru), sucrose (Suc), Sorbitol (Sor) and maltose (Mal). The carbohydrate content was obtained by summing these monosaccharides.

2.6. Macro- and micromineral content

The concentration of macro elements [calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P) and sodium (Na)] and microelements [iron (Fe), manganese (Mn), copper (Cu), chromium (Cr), cobalt (Co), nickel (Ni) and zinc (Zn)] were simultaneously analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES) using a PerkinElmer Optima 4300 DV spectrometer (Shelton, CT, USA). The spectrometer was equipped with an AS-90 autosampler, axial system, a high dynamic range detector, and a crossflow type nebulizer for pneumatic nebulization. The ICP-OES assessment was conducted following the procedure described by Millos et al. (2009). Prior to ICP-OES analyses, samples were digested with HNO_3 and H_2O_2 using a Multiwave 3000 oven (Anton Paar, Graz, Austria), equipped with eight digestion vessels. Subsequently, the elements were analyzed by ICP-OES.

2.7. Extraction yield of bioactive compounds

The extraction method of Tzimas et al. (2021) with some modifications was used for subsequent analyses of all samples. Specifically, 1 g of each sample was extracted with 20 mL of 50 % EtOH solution acidified with 0.1 % formic acid. The mixture was subjected to mechanical agitation using a magnetic stirrer for 3 h at 750 rpm in a water bath maintained at 30 °C. After overnight maceration, the resulting mixtures were transferred to Falcon tubes to be centrifugated at 5000 rpm (2795 g) for 7 min. The supernatant was then collected and stored at −20 °C for future analysis. The dry weight was quantified using a gravimetric method. One milliliter was dried at 105 °C for 24 h. The dried extract weight was then expressed as grams of extract per 100 g of biomass (g

extract/100 g dry weight). The yield (%) was calculated using the following formula (1):

$$\text{Yield}\ (\%) = \frac{P_{t=24\ h} - P_{t=0}}{\left(\frac{msw \times Va}{Vsv}\right) \times \left(\frac{100 - MCsw}{100}\right)} \times 100 \qquad \text{Equation (1)}$$

Where $P_{t\ =\ 0}$ represents the mass of the crucible before adding the extracted solution, $P_{t\ =\ 24h}$ denotes the mass of the crucible after 24 h of drying, msw signifies the mass of the dry sample, Va indicates the volume of the extracted solution aliquot (1 mL), Vsv represents the volume of solvents used for extraction (5 mL), and MCsw corresponds to the moisture content (%) of each sample.

2.8. Determination of antioxidant capacity

There were several methods used to evaluate antioxidant capacity (AC). These spectrophotometric techniques differ in their reaction mechanisms (electron transfer or hydrogen atom transfer) and sensitivity to various radicals (Shahidi & Zhong, 2015; Zou et al., 2022). All methods were compared with the scavenging ability of Trolox, an analog of vitamin E. The assays were performed in triplicate, with their standard deviation, and as an internal control parameter for method precision. It was established that the values of the percentage relative standard deviation (RSD %), calculated for the three repetitions, remained below 10 %.

2.8.1. Trolox equivalent antioxidant capacity (TEAC)

The assay was conducted following the method developed by (Re et al., 1999) with some modifications. The assay was performed in a transparent 96-well microplate, and absorbance was read for 6 min at 734 nm. The standard was a Trolox solution (20–320 μM). The results are expressed as a Trolox Equivalent Antioxidant Capacity (TEAC) index.

2.8.2. Ferric reducing antioxidant power (FRAP)

The assay was carried out in a 96-well microplate, following the adaptation by Firuzi et al. (2005) and read at a wavelength of 593 nm by Synergy HTX multi-mode reader (Bio-Tek, Winooski, VT, USA). A calibration curve was created using Trolox as a reference, with concentrations ranging from 9.37 to 75 μg/mL. The results are expressed in mg TE/g of dry weight.

2.8.3. 2,2-Diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity

The DPPH radical (30 mg) was dissolved in 10 mL of methanol and diluted 1/40 for the analysis. Samples (50 μL) were mixed with 200 μL of DPPH solution in the 96-well plate and incubated at room temperature in the dark for 30 min. The absorbance values of the blank and samples were measured at 515 nm at once after mixing (t = 0) and after 30 min using a Synergy HTX multi-mode reader (Bio-Tek, Winooski, VT, USA). The percentage DPPH radical scavenging activity of the samples were calculated using the following equation (2):

$$\%\boldsymbol{I} = \frac{\text{Absorbance of blank}\ (t=0) - \text{Absorbance of sample}\ (t=60)}{\text{Absorbance of blank}\ (t=0)} \times 100 \qquad \text{Equation (2)}$$

The DPPH scavenging activity (%) versus extract concentration (mg/mL) was plotted for all plants samples to model the data. Both linear and non-linear methods (as described by Equations (3) and (4), respectively) were employed to fit the experimental data.

$$\boldsymbol{Y} = a * X + b \qquad \text{Equation (3)}$$

$$\boldsymbol{Y} = a * \ln(X) + b \qquad \text{Equation (4)}$$

where, *a* and *b* represent the model parameters.

From these studies, the model parameters and determination coefficients (R^2) were obtained for each sample. Additionally, the effective concentration value (IC_{50}), which indicates the extract concentration required to scavenge 50 % of DPPH radicals, was determined. The assays were performed in triplicate, and the results are expressed in TEAC index, along with their standard deviation.

2.8.4. Assessment of relative antioxidant activity using IC_{50}

To determine the relative antioxidant capacity of TEAC and DPPH assays, the TEAC index was calculated as the ratio of the IC_{50} value of the Trolox standard to that of the sample. IC_{50} values were derived from linear regression of inhibition curves, and calculations were performed using MS Excel. Higher TEAC values represent increased antioxidant efficacy of the sample when compared to the standard, providing a clear measure of relative activity.

$$\boldsymbol{TEAC}_{\boldsymbol{TEAC/DPPH}} = \frac{IC_{50}\ (\text{trolox})}{IC_{50}\ (\text{sample})} \qquad \text{Equation (5)}$$

2.9. Statistical analysis

All the experiments were operated for triplicates and data were dealt with original (statistical analysis was executed using one-way analysis of variance, $p < 0.05$).

3. Results and discussion

3.1. Nutritional composition

The nutritional composition (protein, lipids, carbohydrates, humidity and ash content) of each Angolan plant is shown in Table 1. Results revealed distinct variations in key nutritional components, reflecting their diverse nutritional profiles and potential applications in food and health industries. These results indicated that several parameters varied significantly ($p < 0.05$) between these plants. Moisture and ash content provide important insights into the freshness, shelf life and mineral composition of plant samples. In the selected plants, moisture content ranged from 13.66 % to 23.55 %, with *D. convexa* roots displaying a notably higher value. Additionally, ash content levels ranged from 2.17 % in *M. myristica* to 7.06 % in *P. guineense* seeds, with similar values observed across the other samples (3.38 %, 4.71 % from *H. crinite* and *D. convexa* roots, respectively; 3.36 %, 5.32 % from whole and broken *X. aethiopiea* pods, respectively).

Protein content varied across the plant samples, with seeds showing the highest levels. *M. myristica* seeds contained the highest protein content (13.70 %), followed by *P. guineense* seeds (12.52 %), which is consistent with values of same plants reported in some literature (Ojinnaka & Chidiebere, 2016; Ekeanyanwu, 2013). In contrast, roots from *H. crinita* and *D. convexa*, showed lower protein levels, 5.19 % and 5.43 %, respectively. Lipid content was also high in seeds and pods, among that *M. myristica* seeds contained the highest lipid levels (37.79 %), followed whole pods of *X. aethiopica* (29.99 %) and *P. guineense* seeds (23.43 %). There is a distinguished difference of lipid content between two pods of *X. aethiopica*, where the whole pods (29.99 %) contained higher level than broken pods (23.12 %). As showed in Fategbe et al. (2021), the broken pods of *X. aethiopica* also contained less lipid than the whole pods, suggesting that lipid content is concentrated more in the seeds than in the pod itself. For two roots (*H. crinita* and *D. convexa*), they exhibited low content of lipid, while their carbohydrate contents were the highest levels, 32.74 % and 43.48 %, respectively. Thus, roots predominantly serve as carbohydrate sources, while seeds exhibit high protein and lipid content. The differences in the moisture content, ash, lipid, protein and carbohydrate were statistically significant ($p < 0.05$).

These results are comparable with some plant data presented in the literature (Fategbe et al., 2021; Tomori et al., 2023; Ugoma et al., 2023). However, variations in the nutritional profiles of plants were evident

Table 1
Nutritional and elemental composition of Angola plants (g/100 g raw biomass).

Nutritional composition	Roots		Seeds		Pods	
	H. crinita	*D. convexa*	*P. guineense*	*M. myristica*	*X. aethiopiea whole*	*X. aethiopiea broken*
Humidity	15.40 ± 1.30	23.55 ± 0.86	20.14 ± 0.81	13.66 ± 0.55	15.01 ± 1.08	13.72 ± 1.01
Ash	3.37 ± 0.79	3.36 ± 0.70	7.05 ± 0.05	5.31 ± 0.15	2.16 ± 0.04	4.71 ± 0.01
Protein	5.19 ± 0.17	5.43 ± 0.31	12.52 ± 0.53	13.70 ± 0.62	10.03 ± 0.64	8.38 ± 0.50
Lipids	12.43 ± 0.30	14.55 ± 2.84	23.43 ± 2.10	38.07 ± 0.67	29.99 ± 1.65	23.12 ± 2.21
Carbohydrates	32.74 ± 2.14	43.48 ± 0.50	29.78 ± 1.07	23.52 ± 0.65	19.58 ± 1.05	18.67 ± 0.73
Elemental composition						
C	43.94 ± 0.46	26.05 ± 0.52	45.57 ± 0.28	55.87 ± 1.04	50.98 ± 0.31	53.15 ± 0.67
N	0.94 ± 0.03	0.99 ± 0.06	2.28 ± 0.10	2.49 ± 0.11	1.82 ± 0.12	1.52 ± 0.09
C:N ratio	46.61	26.44	20.04	22.46	27.95	34.96

Note: mean values (± standard deviation) are calculated from three replicates (n = 3) for each sample (*Heinsia crinite, Dorstenia convexa, Piper quineense, Monodora myristica* and *Xylophia aethiopia*).

across studies. Such differences are largely influenced by environmental factors, including soil quality, climate, water availability, and sunlight exposure, which plays critical roles in nutrient uptake, metabolic activity, and the synthesis of proteins, lipids and carbohydrates. In conclusion, these results provide specific contents of several nutrition to direct that Angolan plants are used in an efficient way.

3.2. Elemental composition

The elemental composition, specifically carbon (C), nitrogen (N) and ratio of carbon-to-nitrogen (C:N) (also collected in Table 1), varied widely across different plant parts (roots, seeds, and pods). Elemental analysis is a useful tool to understand the nutritional and ecological roles of plants, as C, N and their ratios are indicators of energy content, protein levels, and nutrient cycling potential (Tessier & Raynal, 2003; Xu et al., 2020). Carbon content, which contributes significantly to an energy value of plant, varied from 26.05 % in *D. convexa* roots to 55.87 % in *M. myristica* seeds, with the latter having the highest carbon concentration. High carbon levels were also observed in *X. aethiopica*, with broken and whole pods being 53.15 and 50.98 g per 100 g, respectively. *D. convexa* roots had the lowest carbon content, likely due to it high moisture level, which is consistent with above results of humidity. Nitrogen content, indicative of protein levels, ranged from 0.94 % in *H. crinita* roots to 2.49 % in *M. myristica* seeds that also had the highest nitrogen concentration, which is consistent with their high protein results (13.70 g/100 g). *P. guineense* seeds also showed a relatively high nitrogen level (2.28 g/100 g), supporting it protein-rich profile (12.52 g/100 g). In contrast, *H. crinita* and *D. convexa* roots had lower nitrogen levels (0.94 and 0.99 g/100 g, respectively), aligning with their lower protein content, which suggests it function a limited role in high-protein diets. In this study, the C:N ratio ranged from 20.04 in *P. guineense* seeds to 46.61 in *H. crinita* roots. According to nutritional data, the seeds

Table 2
Amino acids profile.

g AA/100 g protein	Roots		Seeds		Pods and seeds	
	H. crinita	*D. convexa*	*P. guineense*	*M. myristica*	*X. aethiopiea W*	*X. aethiopiea B*
∑EAA	**39.45 ± 2.88**	**25.58 ± 0.79**	**34.26 ± 1.01**	**35.52 ± 0.87**	**37.57 ± 2.02**	**37.5 ± 1.57**
His	3.26 ± 0.15	2.46 ± 0.16	2.09 ± 0.05	2.46 ± 0.04	2.64 ± 0.08	2.94 ± 0.12
Ile	5.72 ± 0.23	3.68 ± 0.08	5.34 ± 0.05	4.97 ± 0.15	5.75 ± 0.45	5.90 ± 0.26
Leu	8.36 ± 0.44	4.90 ± 0.07	10.18 ± 0.13	8.57 ± 0.13	8.60 ± 0.52	9.00 ± 0.38
Lys	5.79 ± 0.16	5.40 ± 0.03	3.77 ± 0.11	6.89 ± 0.20	6.10 ± 0.20	4.96 ± 0.12
Meth	0.62 ± 0.21	0.18 ± 0.02	0.48 ± 0.25	0.05 ± 0.02	0.12 ± 0.04	0.19 ± 0.09
Phe	5.26 ± 0.48	3.55 ± 0.12	5.17 ± 0.24	5.17 ± 0.10	5.79 ± 0.38	6.11 ± 0.28
Thr	3.95 ± 0.22	2.62 ± 0.11	3.66 ± 0.12	3.72 ± 0.06	4.04 ± 0.19	4.33 ± 0.15
Val	6.50 ± 0.99	2.78 ± 0.21	3.59 ± 0.06	3.70 ± 0.17	4.53 ± 0.17	3.92 ± 0.17
∑n-EAA	**60.54 ± 3.52**	**74.42 ± 3.98**	**65.73 ± 4.40**	**64.47 ± 2.08**	**64.42 ± 2.50**	**62.64 ± 2.16**
Ala	6.83 ± 0.36	6.73 ± 0.27	8.73 ± 0.68	6.46 ± 0.10	8.10 ± 0.06	8.28 ± 0.36
Arg	3.21 ± 0.24	2.57 ± 0.04	3.85 ± 0.01	9.59 ± 0.34	7.09 ± 0.44	5.49 ± 0.19
Asp	10.65 ± 0.54	18.76 ± 0.64	15.27 ± 1.39	10.14 ± 0.15	10.14 ± 0.10	10.85 ± 0.21
Cys	2.36 ± 0.15	0.51 ± 0.09	0.54 ± 0.01	1.22 ± 0.09	0.43 ± 0.04	0.44 ± 0.04
Glu	9.90 ± 0.28	18.61 ± 0.68	13.20 ± 1.01	16.48 ± 0.44	13.79 ± 0.33	13.18 ± 0.35
Gly	6.44 ± 0.57	7.82 ± 0.63	7.54 ± 0.90	6.31 ± 0.59	7.37 ± 0.73	7.94 ± 0.20
Pro	10.78 ± 0.35	10.76 ± 0.46	7.63 ± 0.24	6.12 ± 0.10	5.96 ± 0.22	5.78 ± 0.03
Ser	8.62 ± 0.70	5.62 ± 0.62	5.80 ± 0.11	4.72 ± 0.14	5.93 ± 0.45	6.49 ± 0.19
Tyr	1.74 ± 0.32	3.03 ± 0.56	3.17 ± 0.06	3.43 ± 0.13	3.62 ± 0.12	4.20 ± 0.60
CS (%)						
His	148	112	95	112	120	134
Ile	106	68	99	92	106	109
Leu	97	57	118	100	100	105
Lys	83	77	54	98	87	71
Meth + Cys	52	12	18	22	10	11
Phe + Tyr	75	71	90	93	101	111
Thr	84	56	78	79	86	92
Val	98	42	54	56	69	59

Note: mean ± standard deviation (n = 3); His = histidine, Ile = isoleucine, Leu = leucine, Lys = lysine, Met + Cys = methionine + cysteine, Phe + Tyr = phenylalanine + tyrosine, Thr = threonine, Val = valine.

presented the lowest C:N ratio, indicating a higher nitrogen concentration relative to carbon. In contrast, *H. crinita* roots, with the highest C:N ratio of 46.61, contained a relatively low nitrogen content and a high carbon level, as higher than *D. convexa* roots (26.44). Intermediate C:N ratios were found in whole pods (27.95) and broken pods (34.96) of *X. aethiopica*, suggesting a moderate rate of decomposition and balanced nutrient release potential. Comparison of these elements with other plants provides insight into the growth and development of Angolan plants, as well as a further assessment of their nutrient composition.

3.3. Amino acid profile

Amino acids (AAs) not only play an important role in plant growth and development, but also provide a rich source of nutrition for human beings, among that AAs composition is present in Table 2. Eight essential amino acids (EAAs) and nine non-essential amino acids (n-EAAs) were identified and quantified in Angolan plants, with values expressed as grams of amino acids per 100 g of protein. The total EAAs content ranged from 25.58 g/100 g in *D. convexa* roots to 39.45 g/100 g in *H. crinite*, presenting the largest difference between these plants. Two seeds *of P. guineense* and *M. myristica* had similar EAAs values (34.26 and 35.53 g/100 g protein, respectively), which is comparable to the values found in *X. aethiopiea* (37.57 and 37.35 g/100 g protein in whole and broken pods, respectively). Leucine appeared to be the most concentrated levels of EAAs, and aspartic acid and glutamic acid were as the main contents of non-EAAs in these samples. Except for *H. crinita* roots, where proline was the most abundant amino acid for all plant samples. Regarding the AAs profile, the results are comparable across the two root species (*H. crinita* and *D. convexa*), the two seed species (*P. guineense* and *M. myristica*), and both whole and broken pods of *X. aethiopica*. There are some discrepancies with AAs composition by comparing with the previous literature about these plants (Ojinnaka et al., 2016; Okagu et al., 2018; Ekeanyanwu, 2013). In order to evaluate the nutritional value of these AAs compositions, the chemical score of EAAs were calculated to compare with egg scoring pattern, including histidine (His), isoleucine (Ile), leucine (Leu), lysine (Lys), methionine + cysteine (Met + Cys), phenylalanine + tyrosine (Phe + tyr), tryptophan (Trp), threonine (Thr) and valine (Val). The chemical score is a valuable tool for assessing protein nutritional quality, as it indicates the capacity of plants to provide EAAs that the human body cannot synthesize. As shown in Table 2, the results showed that sulfur amino acids (methionine + cysteine) were the limiting AAs in these Angola plants, followed by valine in the seeds (*P. guineense* and *M. myristica)*, *X. aethiopica* broken pods and *D. convexa* root. Both whole and broken pods of *X. aethiopica* had the best profile of EAAs, although they presented deficiency in some amino acids. Histidine presented the highest score (>100 %) in some samples, except *Piper guineense* (95 %). Furthermore, histidine is used in the treatment of cardiovascular diseases due to its physiological role as an antioxidant, helping to neutralize free radicals such as hydroxyl radicals and singlet oxygen (Wade & Tucker, 1998). In a summary, these Angolan plants have abundant EAAs composition, indicating they are suitable to use for food supplement in human beings.

3.4. Fatty acids profile

By analyzing the types and concentrations of fatty acids in these plants, the results can assess their nutritional value and safety for consumption, with particular emphasis on beneficial ones, as shown in Table 3. A total of 33 types of fatty acids were identified, comprising 14 saturated fatty acids (SFAs), 6 monounsaturated fatty acids (MUFAs)

Table 3
Fatty acids profile.

Fatty acids		Roots (mg/100 g)		Seeds (mg/100 g)		Pods and seeds (mg/100 g)	
∑SFA		*H. crinita*	*D. convexa*	*P. guineense*	*M. myristica*	*X. aethiopiea W*	*X. aethiopiea B*
C6:0	Caproic acid	<1.99*	<1.99	<1.99	<19.86	2.58 ± 0.37	14.16 ± 1.98
C8:0	Caprylic acid	<0.87	<0.87	<0.87	<8.66	2.09 ± 0.82	<4.32
C10:0	Capric acid	<1.15	<1.15	<1.15	<11.50	<1.15	<1.15
C11:0	Hendecanoic acid	<0.73	<0.73	<0.73	15.84 ± 7.89	6.41 ± 0.91	1.78 ± 0.44
C12:0	Lauric acid	<1.13	<1.13	17.27 ± 6.05	12.85 ± 0.70	3.10 ± 0.56	2.92 ± 0.90
C13:0	Tridecylic acid	<0.72	<0.72	<0.72	<7.20	<0.72	<0.72
C14:0	Myristic acid	2.57 ± 1.28	<1.14	6.34 ± 1.51	12.98 ± 0.51	2.98 ± 0.92	2.74 ± 0.90
C15:0	Pentadecanoic acid	3.57 ± 0.77	<0.46	17.42 ± 4.15	<4.60	5.51 ± 1.80	5.13 ± 1.44
C16:0	Palmitic acid	17.68 ± 1.53	17.25 ± 10.58	232.32 ± 49.47	238.38 ± 48.72	387.37 ± 5.19	56.95 ± 22.40
C17:0	Margaric acid	6.35 ± 2.01	<0.49	<0.49	8.39 ± 2.58	21.29 ± 2.66	<0.49
C18:0	Stearic acid	12.59 ± 2.18	3.64 ± 0.60	39.13 ± 23.71	239.73 ± 75.56	125.47 ± 9.29	53.21 ± 4.01
C21:0	Heneicosanoic acid	<0.45	<0.45	<0.45	<4.50	<0.45	<0.45
C23:0	Tricosanoic acid	<0.77	<0.77	<0.77	<7.72	<0.77	<0.77
C24:0	Lignoceric acid	<1.11	<1.11	3.30 ± 0.68	<11.12	2.03 ± 0.52	2.15 ± 0.54
∑MUFA							
C14:1n5	Myristoleic acid	<0.49	<0.49	13.48 ± 3.37	8.03 ± 2.28	<0.49	<0.49
C15:1n5	cis-10-pentadecenoic acid	<0.40	<0.40	<0.40	<4.04	3.07 ± 0.56	20.14 ± 0.66
C16:1n7	Palmitoleic acid	1.81 ± 0.82	1.91 ± 0.02	<0.60	14.32 ± 0.85	2.61 ± 0.94	<0.60
C17:1n7	cis-10-heptadecanoic acid	<0.50	<0.50	4.66 ± 0.69	<5.04	1.87 ± 0.40	<0.50
C18:1n9 trans	Elaidic acid	<0.52	<0.52	<0.52	<5.16	<0.52	<0.52
C18:1n9 cis	Oleic acid	14.31 ± 4.37	3.96 ± 2.18	42.90 ± 8.55	1075.87 ± 393.78	553.76 ± 36.97	31.95 ± 6.70
C20:1n9	cis-11-eicosenoic acid	1.25 ± 0.12	<0.50	8.91 ± 7.01	24.11 ± 1.81	6.39 ± 1.51	<0.50
C24:1n9	Nervonic acid	<0.63	<0.63	4.40 ± 2.20	<6.26	<0.63	6.06 ± 0.63
∑PUFA							
C18:2n6 trans	Linolelaidic acid	<0.60	<0.60	<0.60	<6.00	<0.60	<0.60
C18:2n6 cis	Linoleic acid	3.73 ± 0.17	2.57 ± 1.13	161.24 ± 23.73	2846.10 ± 628.28	286.23 ± 42.77	31.11 ± 3.08
C18:3n6	γ-Linolenic acid	<0.50	8.50 ± 1.91	<0.50	<5.00	1.32 ± 0.31	<0.50
C20:2n6	cis-11,14-eicosadienoic acid	<0.68	<0.68	1.28 ± 0.13	<6.80	5.64 ± 1.21	<0.68
C20:3n6	Dihomo-γ-linolenic Acid (DGLA)	<0.53	<0.53	<0.53	<5.26	<0.53	<0.53
C20:4n6	Arachidonic acid	<0.65	<0.65	<0.65	<6.48	<0.65	<0.65
C20:5n3	Timnodonic acid (EPA)	<0.78	<0.78	<0.78	<7.84	<0.78	<0.78
C22:2n6	cis-13,16-docosadienoic acid	<0.46	<0.46	<0.46	<4.56	<0.46	<0.46
C22:6n3	Cervonic acid (DHA)	<0.75	<0.75	<0.75	<7.48	<0.75	1.03 ± 0.40

Note: *Detection limit of the equipment. Mean and standard deviation of fatty acid data (mg/g fresh sample). SFAs = Saturated Fatty Acids, MUFAs = Monounsaturated Fatty Acids, PUFAs = Polyunsaturated Fatty Acids.

and 8 polyunsaturated fatty acids (PUFAs). Oleic acid (C18:1n9) and linoleic acid (C18:2n6) were the predominant MUFAs and PUFAs, respectively, with *M. myristica* seeds showing the highest levels (1075.87 mg/100 g for oleic acid and 2846.10 mg/100 g for linoleic acid). Linoleic acid (C18:2n6), also known as ω-6, is an essential fatty acid that presents in all these plants, while their content varied significantly across the samples ($p < 0.05$). For two seeds, they had abundant unsaturated fatty acids then other plants, while two roots (*H. crinite* and *D. convexa*) presented the lowest overall fatty acid levels. In addition, the *X. aethiopica* showed the significant variation in linoleic acid content, from 31.11 to 286.23 mg/100 g in broken and whole pods, respectively. Some PUFAs such as linoleic acid and arachidonic acid known as vitamin F are required for the growth and protection of the skin (Huber et al., 2020). The high PUFAs to SFAs ratio of 5.59 in *M. myristica* is due to its great PUFAs content, indicating that they maybe have some extraordinary functions. This ratio is considered beneficial for health, as diets rich in PUFAs have been shown to be inversely associated with the risk of various diseases. Fatty acid C24:1n9 is relatively uncommon, and was found only in *P. guineense* and *X. aethiopica* broken pods. Due to its unique structure, it could be regarded not only as a nutritional fatty acid but also as a nutraceutical with properties similar to long-chain PUFAs (Zhang et al., 2024). In conclusion, these essential PUFAs are worthy to be focused to explore their great function for human health.

3.5. Macro- and microminerals

As shown in Table 4, the mineral composition was evaluated to reveal substantial variability across different plant parts, which is favorable to underscore their potential nutritional benefits. Analysis of each mineral showed that all species were notably rich in potassium (K), with *P. guineense* seeds containing the highest content (23.13 g/kg), a stark contrast to the lower level of K in *M. myristica* seeds (6.32 g/kg). In case of *X. aethiopiea,* K levels also varied significantly between two different states of pods, with the whole and broken pods containing 10.38 g/kg and 18.06 g/kg, respectively. This contrasted with lower levels of K found in *H. crinite* roots (6.28 g/kg) and *D. convexa* roots (7.96 g/kg). Notably, *H. crinita* roots contained the highest calcium (Ca) concentration (11.95 g/kg). Although no studies were found specifically analyzing the mineral content of these roots, *H. crinita* and *D. convexa* stand out as a mineral-rich source, especially when compared to other species such as cassava (*Manihot esculenta*) roots (Charles et al., 2005). In comparing the results for two seeds, all analyzed minerals in *M. myristica* and *P. guineense* were found to be higher than values reported in the literature, except for Ca, which was lower in both species compared to published same plant data (M. C. et al., 2016; Nkwocha et al., 2019). A similar trend was observed with *X. aethiopica*, in both whole and broken forms, which also exhibited lower levels of Ca than those same plant values reported in the literature (Barminas et al., 1999; Fategbe et al., 2021). The relatively similar levels of magnesium (Mg) and sodium (Na) were observed across all samples align with typical macronutrient profiles reported in these and other plant-based sources, which often present these minerals within a narrow range. Among the microminerals, zinc (Zn) was particularly notable, especially in the root samples, with *H. crinite* and *D. convexa* containing 30.85 and 24.08 mg/kg, respectively, followed closely by *P. guineense* seeds (21.66 mg/kg). Moreover, *D. convexa* roots had the highest iron (Fe) content among the samples, with a concentration of 661.71 mg/kg. These values are comparable with previous data of same plant reported in the literature (Barminas et al., 1999; Fategbe et al., 2021; Nkwocha et al., 2019; Ojinnaka et al., 2016). These mineral elements are important active substances for maintaining the health of the human body, among that many of them are essential components of enzymes, as well as Mg and Na are vital for the growth and maintenance of tissues and bones.

3.6. Antioxidant activity

Antioxidants derived from herbal raw materials have gained significant attention recently for their health-promoting properties in preventing chronic non-communicable diseases. Three vitro methods (DPPH, TEAC and FRAP) were used to assess the antioxidant activity of six samples, and the results are showed in Fig. 2. To interpret these results and enable a more effective comparison between these plants, an index was calculated by taking the ratio of the IC_{50} between the Trolox and each sample. In contrast, antioxidant activity in the FRAP assay was measured in mg of Trolox equivalents per gram of dry extract. The comparison of bioactive compounds and antioxidant activity between different plants revealed several significant findings. For two roots, *H. crinita* and *D. convexa* showed no significant differences in DPPH activity ($p < 0.05$). However, TEAC ratio was significantly higher in *D. convexa* (1445.10 TEAC value) and FRAP values were higher in *H. crinite* (167.55 mg TE/g DW), suggesting that the antioxidant capacity may vary depending on the specific redox reactions involved (Shahidi & Zhong, 2015). In two seeds, *P. guineense* exhibited a significantly higher yield (18.7 %), but lower TEAC value ratio compared to *M. myristica* (377.72 TEAC value). In addition, no significant differences were observed in DPPH and FRAP values between the two seed samples ($p <$

Table 4
Mineral composition.

Element	Roots		Seeds		Pods	
	H. crinita	D. convexa	P. guineense	M. myristica	X. aethiopiea W	X. aethiopiea B
Macro elements (mg/k g FW)						
Ca	11954.90 ± 135.12	1711.29 ± 64.26	2041.82 ± 113.15	1134.71 ± 33.15	1753.17 ± 56.65	2502.84 ± 65.24
K	6279.87 ± 57.47	7958.79 ± 80.67	23129.77 ± 402.88	6321.63 ± 128.69	18057.74 ± 518.00	10379.44 ± 471.70
Mg	1113.60 ± 3.07	1552.18 ±43.99	2557.42 ± 43.29	2194.01 ± 61.36	1951.51 ± 23.29	2374.98 ± 94.86
Na	338.02 ± 4.90	245.13 ± 0.57	237.46 ± 5.21	225.98 ± 2.90	273.16 ± 10.29	2077.27 ± 108.47
P	951.00 ± 7.43	1632.03 ± 56.65	2674.22 ± 27.88	2960.09 ± 39.82	1248.84 ± 19.91	1650.31 ± 44.98
S	1207.62 ± 20.26	697.05 ± 9.45	1345.22 ± 15.64	1126.31 ± 26.57	918.13 ± 26.26	1033.08 ± 35.80
Micro elements (mg/kg FW)						
Fe	91.91 ± 5.76	661.71 ± 28.97	217.86 ± 9.56	70.23 ± 2.12	149.86 ± 13.68	59.11 ± 1.70
Mn	85.78 ± 0.43	22.67 ± 1.02	41.83 ± 2.70	11.58 ± 1.13	85.62 ± 1.74	69.77 ± 3.38
Cu	4.10 ± 0.02	0.71 ± 0.03	13.44 ± 0.12	10.92 ± 0.41	7.44 ± 0.04	8.48 ± 0.15
Cr	1.65 ± 0.03	1.19 ± 0.06	1.44 ± 0.02	2.98 ± 0.23	0.56 ± 0.05	0.39 ± 0.06
Co	0.80 ± 0.01	0.13 ± 0.01	0.10 ± 0.02	<0.10	0.29 ± 0.06	0.22 ± 0.02
Cd	0.45 ± 0.01	0.08 ± 0.01	0.05 ± 0.05	–	–	–
Ni	1.86 ± 0.07	0.64 ± 0.04	2.44 ± 0.12	1.38 ± 0.04	2.63 ± 0.26	0.86 ± 0.06
Zn	30.85 ± 0.40	24.08 ± 0.65	21.66 ± 1.38	10.22 ± 0.01	4.72 ± 0.59	5.73 ± 0.09

Note: mean and standard deviation for mineral content (in mg/kg fresh weight) across different parts of selected Angola plants, including roots (*Heinsia crinita* and *Dorstenia convexa*), seeds (*Piper guineense* and *Monodora myristica*), and pods (whole and broken) of *Xylopia aethiopica*.

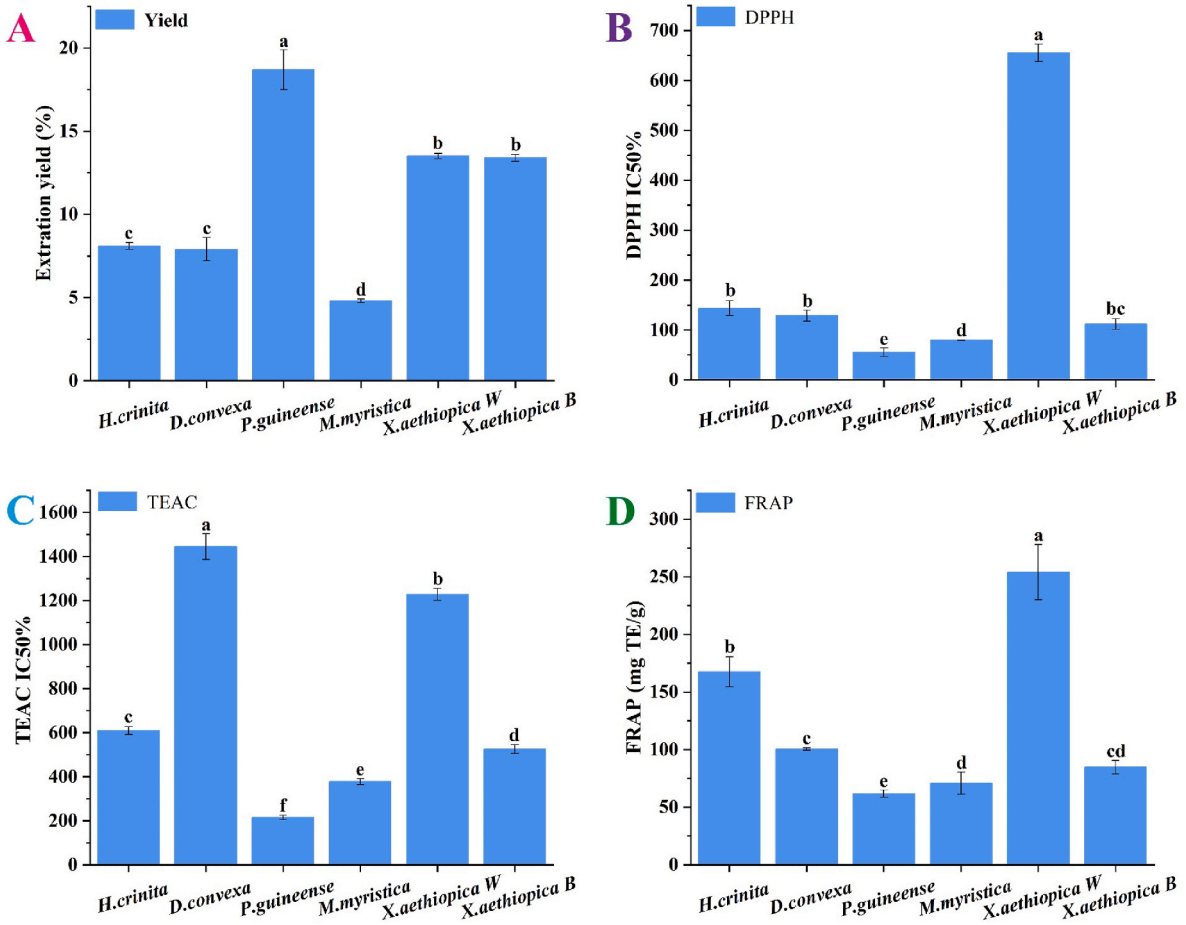

Fig. 2. Extraction yield and antioxidant activities of bioactive compounds from six Angola plant samples. (A) Extraction yield; (B) DPPH; (C) TEAC; (D)FRAP. Letter ãd represent significant difference ($p < 0.05$).

0.05). For the *X. aethiopica* sample, the yield percentages were similar for both whole and broken pods, showing 13.50 % and 13.40 % respectively, indicating no significant difference in extract yield ($p < 0.05$). However, antioxidant activities were also significantly higher in whole pods ($p < 0.05$), which is attributed to that it contained the much more amounts of seeds. Specifically, TEAC value was 1228.29 for whole pods and 525.69 for broken pods. In addition, DPPH radical scavenging activity ratio was higher in whole pods (655.18 TEAC value) than in broken pods (112.23 TEAC value), as well as FRAP values showed a substantial difference with whole pods exhibiting 254.01 mg TE/g DW compared to 84.69 mg TE/g DW in broken pods. The observations show that the pod integrity plays a critical role in preserving bioactive compounds and antioxidant activity, suggesting that the seeds within it likely contain a higher antioxidative composition compared to its outer shell. Differences in extraction methods (e.g., solvents, time, temperatures) and the different ways results are expressed (mg/mL extract, mM TW/g dry weight, TEAC and DPPH values) makethe comparison of our results with those from other studies more difficult. Nonetheless, the lowest values were found in some literature for DPPH and TEAC in *M. myristica* (Feyisayo, 2013; Irondi et al., 2023; Moukette et al., 2015), *P. guineense* ((Ukom et al., 2023) and *X. aethiopica* (Sulaimon et al., 2020). There was no literature found about the antioxidant activity in *H. crinite* and *D. convexa* roots, but these samples were in line with others roots like *Beta vulgaris* roots (125.10 trolox equivalents by DPPH method), higher than *Echinacea* roots (63.8 TEAC index) and coffee roots (156.7 FRAP equivalents) (Acidri et al., 2020; Hu and Kitts, 2000; Sreeramulu & Raghunath, 2010).

4. Conclusions

There are sharp compositional differences in the nutrient and elemental composition of these Angolan plants, with *D. convexa* roots having the highest water content (23.55 %), which is consistent with it has the lowest carbon content, thus requiring attention to its preservation. As for protein levels, two seeds of *M. myristica* (13.70 %) and *P. guineense* (12.52 %) had the highest content, showing greater than twofold quantities compared to two roots with the lowest level, *H. crinita* (5.19 %) and *D. convexa* (5.43 %). In terms of C and N elemental composition, both seeds exhibited high C and N levels, which supports their protein-rich character. In addition, two kinds of seeds exhibited high lipid content, followed by *X. aethiopica* pods, among its broken type was significantly lower than whole type, suggesting that the lipid substance was more concentrated in its inside seeds. Thus, two roots provide abundant carbohydrates, while the seeds and pods are a rich source of proteins and lipids. Comparing these plants AAs, the root of *H. crinita* had the highest content of EAAs (39.45 g AAs/100 g protein), followed by *X. aethiopica* pods and two seeds, even though protein quantity of *H. crinita* showed the lowest level. For all these plants, the highest concentrations of AAs were leucine, aspartic acid and glutamic acid, except for *H. crinita* roots containing the highest proline. According to the chemical score of EAAs, sulfur amino acids (methionine + cysteine) and valine (except for *H. crinita*) were the limiting AAs in these Angola plants. For fatty acid types and concentrations, a total of 33 fatty acids including SFAs (14), MUFAs (6) and PUFAs (8) were identified from these plants, with oleic acid (C18:1n9) and linoleic acid (C18:2n6) being the major MUFAs and PUFAs, respectively. In addition, two seeds

exhibited abundant unsaturated fatty acids, and C24:1n9 was found in *P. guineense* and *X. aethiopica* broken pods. All of these plants were particularly rich in K, while Zn and Fe were the main microminerals. As for antioxidant ability, DPPH, TEAC and FRAP of these plants varied widely, with *X. aethiopica* whole pods having the best activity, while *D. convexa* roots showing the highest performance in terms of TEAC, which is largely related to the active compounds present in them. There was a great need to further identify as well as explore the key active components present in these plants, so as to further facilitate their application in medicine and food supplement.

CRediT authorship contribution statement

Carla Cameselle: Writing – original draft, Methodology, Investigation, Formal analysis. **Pengren Zou:** Writing – original draft, Methodology, Investigation, Formal analysis. **Ziyang Jia:** Investigation. **Honória S. Chipaca-Domingos:** Investigation. **Carlos Kiangebeni Zeye:** Investigation. **Benevides Costa Pessela:** Investigation. **Celia Costas:** Methodology, Investigation. **Paz Otero:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Jesus Simal-Gandara:** Supervision, Resources, Funding acquisition.

Declaration of competing interest

Authors declare that there is no conflict of interest.

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Data availability

Data will be made available on request.

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