UNIVERSIDADE FEDERAL DE JUIZ DE FORA
CAMPUS GOVERNADOR VALADARES
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS APLICADAS À SAÚDE

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Plantas alimentícias não convencionais: Perfil de nutrientes, antinutrientes e compostos bioativos

Governador Valadares

2025

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Dissertação apresentada ao Programa de Pós-Graduação em Ciências Aplicadas à Saúde, da Universidade Federal de Juiz de Fora, Campus Governador Valadares, como requisito parcial à obtenção do título de Mestre em Ciências Aplicadas à Saúde, área de concentração Biociências.

Orientador: Leandro de Morais Cardoso

Governador Valadares
2025

Ficha catalográfica elaborada através do programa de geração
automática da Biblioteca Universitária da UFJF,
com os dados fornecidos pelo(a) autor(a)

Nazareth, Rafaele Sobral Santos.
PLANTAS ALIMENTÍCIAS NÃO CONVENCIONAIS : Perfil de nutrientes, antinutrientes e compostos bioativos / Rafaele Sobral Santos Nazareth. -- 2025.
52 f.

Orientador: Leandro de Morais Cardoso
Dissertação (mestrado acadêmico) - Universidade Federal de Juiz de Fora, Campus Avançado de Governador Valadares, Instituto de Ciências da Vida - ICV. Programa de Pós-Graduação em Ciências Aplicadas à Saúde, 2025.

1. Cromatografia líquida de alta eficiência. 2. Capacidade antioxidante. 3. Espectrofotometria atômica. 4. Antinutrientes. 5. Compostos bioativos. I. Cardoso, Leandro de Morais , orient. II. Título.

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Aprovada em 12 de março de 2025.

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AGRADECIMENTOS

A Deus, pois sem Ele nada do que foi feito se fez.

Ao meu companheiro de todas as horas, Jonathan, que sempre trouxe palavras de entusiasmo quando o cansaço parecia dominar, e por todo o seu amor e cuidado, meu muito obrigada.

Aos meus filhos, Samuel e Alice, minhas “vitaminas” diárias.

Aos meus pais, Edson e Branca, pelo amor e apoio incondicional que sempre me deram. Agradeço também aos meus irmãos, Polyana e Rafael, pelo constante aconchego e incentivo em todos os momentos.

Minha gratidão se estende a Maiara, Noemi e Lucélia pela ajuda incansável e pelo comprometimento com as análises realizadas, sem as quais este trabalho não teria sido possível.

À Gleice, pelo seu generoso coração e cuidado ao dedicar seu tempo para coletar repetidamente as amostras comigo, demonstrando um alto comprometimento para garantir que eu obtivesse as amostras no tempo necessário.

Ao orientador Leandro, sou grata por todo o conhecimento compartilhado, pelas palavras de paz.

Agradeço à Ceres pela disponibilização do laboratório de análise de vitaminas. Agradeço também aos técnicos de laboratório pelo suporte e ajuda ao longo de todo o trabalho.

Aos demais professores, meu sincero agradecimento por todo o conhecimento transmitido e pela promoção da educação gratuita e de qualidade em meio a tantos desafios.

À banca examinadora, gratidão por disponibilizarem seu tempo e experiências para aprimorar esta pesquisa. À Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) e à Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), expresso minha gratidão pelo apoio financeiro (bolsa e financiamento do projeto) e pela oportunidade de expandir meus conhecimentos, fazendo da ciência uma longa jornada que desejo percorrer por muitos anos.

“E o Senhor te guiará continuamente, e fartará a tua alma em lugares áridos, e fortificará os teus ossos; e serás como um jardim regado, e como um manancial, cujas águas nunca faltam”.

Isaías 58:11.

RESUMO

As plantas alimentícias não convencionais (PANC) representam uma alternativa promissora para combater a insegurança alimentar, especialmente em países de baixa renda. No entanto, ainda há uma lacuna significativa no conhecimento sobre sua composição nutricional. Este estudo analisou a composição centesimal, o teor de minerais, vitaminas A, C e E, carotenoides, capacidade antioxidante, compostos fenólicos totais e antinutrientes (fitatos e oxalatos) em folhas de *Bidens pilosa*, *Turnera subulata*, *Costus spicatus* e nas folhas e talos de *Talinum fruticosum*, coletadas no Vale do Médio Rio Doce, MG. A composição centesimal foi determinada por métodos padrão, enquanto os minerais foram analisados por espectrometria de absorção e emissão atômica. Compostos fenólicos e capacidade antioxidante *in vitro* foram quantificados pelos métodos DPPH e ABTS, e as vitaminas, carotenoides, fitatos e oxalatos foram analisados por cromatografia líquida de alta eficiência. Para comparação entre as espécies, utilizou-se análise de variância (ANOVA). Os resultados indicaram uma variação nutricional significativa entre as PANC, com teores elevados de proteínas, minerais e vitaminas A, C e E, superando os níveis observados em hortaliças convencionais, como alface, brócolis, couve e espinafre. Além disso, essas plantas demonstraram uma capacidade antioxidante expressiva, reforçando seu potencial para diversificação alimentar e enriquecimento nutricional.
Os talos de *T. fruticosum* e as folhas de *B. pilosa* e *C. spicatus* apresentaram elevados teores de umidade (> 90%). No que diz respeito ao teor proteico, *T. subulata* e as folhas de *T. fruticosum* destacaram-se, com valores de (6,72 g/100g e 3,24 g/100g). Em relação à densidade energética total, *T. subulata* apresentou o maior valor entre as PANC estudadas (97 Kcal/100g), sendo uma excelente fonte energética vegetal. Os talos e as folhas de *T. fruticosum* e *T. subulata* demonstraram ser boas fontes de vitamina C (11,21 mg/100g, 12,41 mg/100g e 10,60 mg/100g) e vitamina E (4122 µg/100g, 3685 µg/100g e 1170 µg/100g), respectivamente. Além disso, *B. pilosa* e *T. subulata* apresentaram altos teores de β-caroteno, com 26,57 mg/100g e 10,42 mg/100g. No que se refere aos minerais, *B. pilosa* mostrou-se uma fonte significativa de cálcio (16,8 mg/100g), ferro (1,97 mg/100g), magnésio (3,24 mg/100g) e zinco (0,467 mg/100g). Entre os compostos bioativos, *T. subulata* e *C. spicatus* apresentaram os maiores teores de compostos fenólicos totais, com 12,16 mg AGE/g e 11,72 mg AGE/g. A capacidade antioxidante, avaliada pelo método DPPH, foi mais elevada em *C. spicatus* (18,83 µmol Trolox/g) e *T. subulata* (17,13 µmol Trolox/g). A análise dos antinutrientes revelou que o oxalato foi identificado em todas as amostras, sendo *T. subulata* e *B. pilosa* as que apresentaram os maiores conteúdos, com 26,57 mg e 12,05 mg, respectivamente. Já os fitatos foram detectados apenas em *B. pilosa* e *C. spicatus*. Em conclusão, as PANC analisadas foram fontes de nutrientes, o que reforça o potencial delas como complemento nutricional.

Palavras-chave: *Bidens pilosa, Costus spicatus, Talinum fruticosum, Turnera subulata*, Perfil Nutricional.

ABSTRACT

Unconventional food plants (UFP) represent a promising alternative to combat food insecurity, especially in low-income countries. However, there is still a significant gap in knowledge regarding their nutritional composition. This study analyzed the centesimal composition, mineral content, vitamins A, C, and E, carotenoids, antioxidant activity, total phenolic compounds, and antinutrients (phytates and oxalates) in the leaves of *Bidens pilosa*, *Turnera subulata*, *Costus spicatus*, and the leaves and stems of *Talinum fruticosum*, collected in the Vale do Middle Rio Doce, MG, Brazil. The centesimal composition was determined using standard methods, while minerals were analyzed by atomic absorption and emission spectrometry. Phenolic compounds and antioxidant capacity were quantified using the DPPH and ABTS methods, while vitamins, carotenoids, phytates, and oxalates were analyzed by high-performance liquid chromatography (HPLC). Analysis of variance (ANOVA) was used for species comparisons. The results indicated significant nutritional variation among the UFP, with high levels of proteins, minerals, and vitamins A, C, and E, surpassing the levels found in conventional vegetables such as lettuce, broccoli, kale, and spinach. Additionally, these plants exhibited notable antioxidant capacity, reinforcing their potential for dietary diversification and nutritional enrichment. The stems of *T. fruticosum* and the leaves of *B. pilosa* and *C. spicatus* showed high moisture content (>90%). Regarding protein content, *T. subulata* and the leaves of *T. fruticosum* stood out, with values of 6.72 mg/100g and 3.24 mg/100g, respectively. In terms of total energy density, *T. subulata* had the highest value among the studied UFP (97 Kcal/100g), making it an excellent plant-based energy source.

The stems and leaves of *T. fruticosum* and *T. subulata* proved to be good sources of vitamin C (11.21 mg/100g, 12.41 mg/100g, and 10.60 mg/100g) and vitamin E (4122 µg/100g, 3685 µg/100g, and 1170 µg/100g), respectively. Furthermore, *B. pilosa* and *T. subulata* exhibited high levels of β-carotene, with 26.57 mg/100g and 10.42 mg/100g. Regarding minerals, *B. pilosa* proved to be a significant source of calcium (16.8 mg/100g), iron (1.97 mg/100g), magnesium (3.24 mg/100g), and zinc (0.467 mg/100g). Among bioactive compounds, *T. subulata* and *C. spicatus* had the highest levels of total phenolic compounds, with 12.16 mg GAE/g and 11.72 mg GAE/g. Antioxidant capacity, assessed by the DPPH method, was highest in *C. spicatus* (18.83 µmol Trolox/g) and *T. subulata* (17.13 µmol Trolox/g).

The antinutrient analysis revealed that oxalate was present in all samples, with *T. subulata* and *B. pilosa* showing the highest levels, at 26.57 mg and 12.05 mg, respectively. Phytates were detected only in *B. pilosa* and *C. spicatus*. In conclusion, the analyzed UFP were rich sources of nutrients, reinforcing their potential as a nutritional supplement.

Keywords: *Bidens pilosa, Costus spicatus, Talinum fruticosum, Turnera subulata*, Nutritional Profile.

Sumário

1 INTRODUÇÃO

A alimentação adequada e saudável é um direito humano fundamental, assegurado por políticas públicas que visam garantir o acesso a uma dieta equilibrada e nutricionalmente adequada (Guerra, 2022; Lange, 2017; Oliveira *et al*., 2022). No Brasil, a insegurança alimentar atinge 33,1 milhões de pessoas, evidenciando limitações estruturais no acesso a alimentos de qualidade (II VIGISAN, 2022). Paralelamente, a transição alimentar, caracterizada pelo aumento do consumo de ultraprocessados e a redução da ingestão de frutas e hortaliças, tem impulsionado a prevalência de obesidade, diabetes e doenças cardiovasculares (Ribeiro, Bógus; Watanabe, 2015; Chen *et al*., 2020; Elizabeth *et al*., 2020; Embling *et al*., 2021; Pagliai *et al*., 2021; Mtenga; Ripanda, 2022; Dai *et al*., 2024; Lane *et al*., 2024). Além disso, a baixa diversidade alimentar compromete a oferta de nutrientes essenciais (Kinupp, 2007; De Almeida Penzo; Bastos, 2021).

Diante desse cenário, estratégias para ampliar a diversidade e sustentabilidade alimentar, através do estímulo ao uso da biodiversidade brasileira, é essencial para mitigar impactos na saúde pública. O Brasil abriga uma das maiores biodiversidades alimentares globais, com mais de 46 mil espécies vegetais, das quais 43% são nativas (Tuler, Peixoto; Silva, 2019; Valente, 2020). Entretanto, apenas cerca de 3 mil possuem potencial alimentício reconhecido, e menos de 10% foram caracterizadas nutricionalmente (Kelen *et al*., 2015; Da Silva Theis *et al*., 2020).

As Plantas Alimentícias Não Convencionais (PANC) englobam espécies comestíveis subutilizadas, frequentemente classificadas como invasoras, mas com elevado potencial nutricional (Biondo *et al*., 2018; Jesus *et al*., 2020). Destacam-se pela resistência a condições ambientais adversas, facilidade de cultivo, ampla disponibilidade e baixo custo (Abreu; Diniz, 2017; Jesus *et al*., 2020). Além disso, são fontes expressivas de proteínas, vitaminas, minerais, fibras e compostos bioativos, contribuindo para a diversificação alimentar, promoção da saúde e mitigação de doenças crônicas (Shahidi; Ambigaipalan, 2015; Moura *et al*., 2021; Petropoulos, Ferreira; Barros, 2018; Da Silva Rodrigues, Pereira-Filho, 2023).

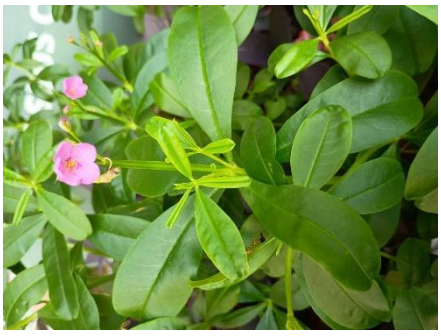
Apesar de seu elevado valor nutricional, as PANC ainda apresentam baixa inserção na alimentação cotidiana (Kinupp; de Barros, 2007). No Vale do Médio Rio Doce, em Minas Gerais, espécies como *Talinum fruticosum*, *Bidens pilosa*, *Costus spicatus* e *Turnera subulata* são encontradas em abundância. O clima tropical e a alta

diversidade ambiental da região favorecem a ocorrência dessas plantas, reforçando seu potencial para a segurança alimentar e nutricional.

1.1 *Talinum fruticosum*

Talinum fruticosum (Figura 1), conhecida popularmente como beldroega-gorda, maria-gorda e bredo (Santos *et al*., 2024), é uma planta herbácea perene, nativa de regiões tropicais e subtropicais das Américas (Leite *et al*., 2009; Khaing; Moe, 2019). Pertencente à família *Talinaceae*, pode atingir entre 30 e 100 cm de altura, apresentando folhas suculentas, ovaladas e verde-escuras, além de pequenas flores rosadas agrupadas em cachos (Shivanna, 2019; Albuquerque, Coelho; Melo, 2022; Edema-Eyen *et al*., 2023). Seus frutos são cápsulas que contêm pequenas sementes (Efretuei; Ekwere, 2022).

Figura 1 - Representação da Beldroega gorda (*Talinum fruticosum*).



Fonte: Autores.

Adaptada a climas tropicais, *T. fruticosum* pode crescer ao longo de todo o ano, embora seu desenvolvimento seja reduzido em regiões com estações bem definidas (Akinwunmi; Omotayo, 2016). Suas folhas e brotos são consumidos em saladas, refogados e sopas, sendo uma fonte relevante de vitaminas, minerais e antioxidantes. No entanto, há uma escassez de estudos detalhando sua composição nutricional, compostos bioativos e antinutrientes (Leite *et al*., 2009).

1.2 *Bidens pilosa*

Bidens pilosa, conhecida como picão-preto, é uma erva anual originária das regiões tropicais e centrais das Américas, amplamente distribuída devido à sua robustez, alta capacidade reprodutiva e adaptabilidade (Arthur; Naidoo; Cooposamy,

2012; Borella, 2019). Pertencente à família *Asteraceae*, pode atingir entre 20 e 180 cm de altura, apresentando caules quadrangulares com ramos peludos e dispersos (Figura 2). Suas folhas são alternadas, compostas por 3 a 5 folíolos pinados, sustentados por pecíolos de 10 a 70 mm de comprimento (Wahjudi, 2023; Kato-Noguchi; Kurniadie, 2024).

Figura 2 - Representação do Picão Preto (*Bidens pilosa*).

Fonte: Ministério da Saúde 2022.

Rica em fitoquímicos, minerais e aminoácidos essenciais (Alikwe, Ohimain; Omotosho, 2014), *B. pilosa* é consumida tanto por humanos quanto por animais (Kuo, 2021). Suas folhas são amplamente utilizadas em preparações alimentícias e bebidas (Orech *et al*., 2007; Kuo, 2021). Além disso, folhas, flores, caules e brotos jovens são consumidos em diversas regiões, sendo incorporados a sopas, ensopados e saladas (Bhatt, Sharma; Pandey, 2009). Em algumas localidades, a planta também é usada para o preparo de bebidas, sucos ou chás, como o chá Ladakhi nas regiões do Himalaia (Bartolome; Villaseñor, 2013; Kissanga *et al*., 2021). Apesar de seu potencial nutricional, *B. pilosa* ainda é pouco explorada, demandando pesquisas que aprofundem o conhecimento sobre suas propriedades nutricionais e antinutricionais (Mtenga; Ripanda, 2022).

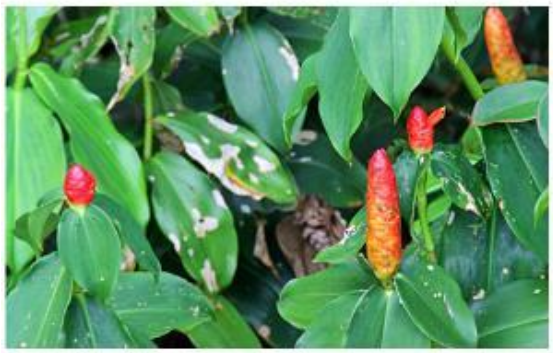
1.3 *Costus spicatus*

Costus spicatus, conhecido como cana-do-brejo, cana-de-macaco, cana-mansa, canarana, pacová e cana-branca (Boorhem *et al*., 1999), é uma planta perene da família *Costaceae*, caracterizada por crescimento cespitoso e altura entre 1,0 e 2,0

metros. Apresenta caules espirais, folhas alternadas de formato oval a lanceolado e flores amarelas com brácteas vermelhas (Figura 3) (Lorenzi; Matos, 2008).

A espécie é nativa de grande parte do Brasil, com ocorrência predominante na Mata Atlântica e na região Amazônica, além de estar amplamente distribuída em áreas tropicais e subtropicais (Lorenzi; Matos, 2008; Quintans Junior, 2010; Moreno *et al*., 2021). Suas folhas são consumidas em algumas regiões como alimento e em preparações como sucos e chás. No entanto, há uma lacuna na literatura quanto à sua composição nutricional, evidenciando a necessidade de estudos que aprofundem o conhecimento sobre seu valor alimentar (Andrade-Cetto; Heinrich, 2005; Lorenzi; Matos, 2008; Putri *et al*., 2016).

Figura 3 - Representação da Cana-do-brejo (*Costus spicatus*).



Fonte: Rojas-Sandoval; Acevedo-Rodríguez, 2015.

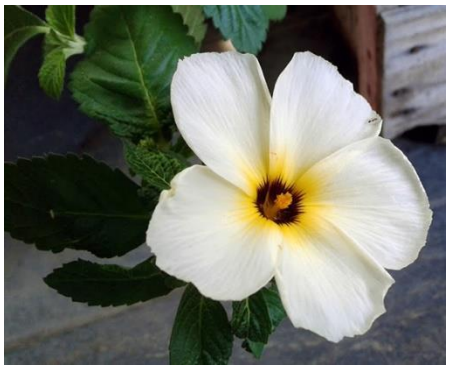
1.4 *Turnera subulata*

Turnera subulata, conhecida como chanana ou "flor-do-guarujá", é uma planta perene que varia de erva a subarbusto. Suas flores são solitárias, com corola branco-amarelada e base púrpura, enquanto suas folhas apresentam coloração verde-clara e textura suave (Souza; Lorenzi, 2005). Pertencente à família *Turneraceae*, que compreende 12 gêneros e cerca de 220 espécies distribuídas principalmente nas Américas e em algumas regiões da África, *T. subulata* destaca-se pela facilidade de cultivo e adaptação climática, sendo amplamente encontrada no Brasil (Figura 4).

Embora amplamente cultivada como planta ornamental, *Turnera subulata* destaca-se pelo seu potencial como planta alimentícia (Arbo, 2010; Thulin *et al.*, 2012). Suas propriedades incluem efeitos anti-inflamatórios, antioxidantes e

benefícios para a imunidade e digestão, reforçando seu potencial em terapias complementares (Souza *et al.*, 2016; Luz *et al.*, 2022).

Figura 4. Representação da Chanana (*Turnera Subulata*)



Fonte: Herbário HUNI/UNIRIO (2024).

Suas folhas e flores são utilizadas em diversas preparações, como chás, saladas, doces, geleias e temperos, evidenciando sua versatilidade e valor funcional na alimentação (Kinupp; Lorenzi, 2014). No entanto, apesar de seu uso tradicional e dos benefícios sugeridos, ainda há uma escassez de estudos científicos que aprofundem a caracterização de suas propriedades nutricionais, destacando a necessidade de mais pesquisas para validar e ampliar seu potencial alimentar e terapêutico (Saravanan *et al.*, 2018).

2 OBJETIVOS

2.1 Objetivo geral

Avaliar o perfil de nutrientes, antinutrientes e compostos bioativos em *Talinum fruticosum* (folhas e talos), *Turnera subulata* (folhas), *Costus spicatus* (folhas) e *Bidens pilosa* (folhas), disponíveis no Vale do Médio Rio Doce, Minas Gerais, Brasil.

2.2 Objetivos Específicos

- Analisar a composição centesimal das quatro PANC.
- Determinar a concentração de compostos fenólicos totais e a capacidade antioxidante das PANC.
- Analisar a concentração de carotenoides.
- Avaliar os teores de vitaminas C e E.

- Quantificar os minerais essenciais (Na, Mg, Al, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Mo e Cd) presentes nas PANC.

3 RESULTADOS

Os resultados dessa dissertação são organizados no seguinte artigo científico estruturado com base nas instruções aos autores preconizadas pelo respectivo periódico.

Unconventional Food Plants: Nutrient, Antinutrient, and Bioactive Compound Profile of Four Species in Minas Gerais, Brazil, de autoria de Nazareth, *et al.,* 2025, submetido ao periódico Journal of Food Composition and Analysis, qualis CAPES Interdisciplinar A2.

3.1 Artigo Científico

Unconventional Food Plants: Nutrient, Antinutrient, and Bioactive Compound Profile of Four Species in Minas Gerais, Brazil

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Highlights

- **Unconventional food Plants** contribute to food security and nutrition.
- *B. pilosa* leaves are an excellent source of iron, calcium, and magnesium.
- *T. subulata has a notable total energy value and is a good source of protein*.

- *Costus spicatus* has high antioxidant capacity, along with antinutrients like oxalates and phytates.
- *T. fruticosum* stems and leaves are sources of α-tocopherol, β-carotene, and ascorbic acid.

ABSTRACT

This study investigated the chemical composition in the leaves of *Bidens pilosa*, *Costus spicatus*, and *Turnera subulata*, as well as the leaves and stems of *Talinum fruticosum*, collected from the Middle Rio Doce region, Minas Gerais, Brazil. The sample composition was analyzed according to standardized methods from the Adolfo Lutz Institute (2008). Vitamin E was quantified by HPLC with fluorescence detection (HPLC-FL), while vitamin C, carotenoids, oxalates, and phytates were analyzed by HPLC with diode-array detection (HPLC-DAD). Mineral content was determined using inductively coupled plasma atomic emission spectrometry (ICP-AES). Phenolic compounds and antioxidant capacity were assessed through spectrophotometric methods (DPPH and ABTS assays).. The results revealed significant nutritional variation among the species, with nutrient levels exceeding those of conventional vegetables. Additionally, these plants exhibited notable antioxidant capacity, emphasizing their potential for dietary diversification and nutritional enrichment. Antinutrient analysis showed species-dependent variations in oxalate and phytate concentrations. *T. subulata* had higher oxalate levels than *T. fruticosum* leaves, while *B. pilosa* exhibited lower phytate concentrations than *C. spicatus*. No phytates were detected in *T. subulata* or in the leaves and stems of *T. fruticosum*. The results indicate that the analyzed plants possess significant nutritional potential for human consumption. However, these findings also reveal a need for further research to fully characterize their nutritional profile and potential applications

Keywords: *Bidens pilosa, Costus spicatus, Talinum fruticosum, Turnera subulata*, Nutritional Profile.

1 INTRODUCTION

Food is a fundamental human right, essential for health and well-being (Guerra, 2022; Masum, Ahmad; Aziz, 2024). In Brazil, despite public policies aimed at ensuring adequate nutrition, 33.1 million people experience food insecurity (FAO, 2021; II VIGISAN, 2022). This issue has been exacerbated by the increased consumption of ultra-processed foods and the decline in fruit and vegetable intake, both of which contribute to the incidence of non-communicable chronic diseases (Mtenga; Ripanda, 2022; Da *et al*., 2024; Lane *et al*., 2024).

Unconventional food plants (UFP) represent a viable alternative for dietary diversification and nutritional quality improvement, particularly in food insecurity

scenarios (Knez, Ranić; Gurinović, 2024; Ojuederie *et al*., 2024). These plants stand out for their accessibility, sustainability, resilience to adverse environmental conditions, and low cultivation cost (Abreu; Diniz, 2017; FAO, 2019; Joseph *et al*., 2023). Furthermore, their nutritional and functional composition grants them a significant role in disease prevention and management, contributing to food security and health promotion (Shahidi; Ambigaipalan, 2015; Muscolo *et al*., 2024; Talucder *et al*., 2024). Despite their potential, these species remain underutilized and are rarely integrated into daily diets, leading to negative impacts on nutrition and health (Leal, Alves; Hanazaki, 2018; Ranić; Gurinović, 2024; Ndlovu *et al*., 2024).

The Middle Rio Doce region, in Minas Gerais, Brazil, features a tropical climate and a rich environmental diversity, harboring various UFP with potential for human nutrition and food security. Among the notable species are *Talinum fruticosum*, *Bidens pilosa*, *Costus spicatus*, and *Turnera subulata*. These species are widely incorporated into human diets, commonly consumed in salads, sautéed dishes, and beverages across various regions, including Nigeria, South Africa, Ghana, Malawi, and India (Oduntan *et al*., 2016; Essack, Odhav; Mellem, 2017; Obeng *et al*., 2020; Cooke *et al*., 2024; Arumugam *et al*., 2023).

The nutritional composition and bioactive compound concentration in UFP are influenced by environmental factors, such as climate, soil, and agricultural management, highlighting the need for additional studies to better understand these variations and optimize their use in human nutrition (FAO, 2019; Soares *et al*., 2019). Moreover, within the same species, these variations occur due to physiological differences among plant organs. Leaves are more adapted to oxidative stress protection, while stems play a crucial role in water transport. The interaction between genetics, environment, and metabolic function also significantly influences the composition of these bioactive compounds (Kumari *et al*., 2022).

Despite the increasing recognition of UFP in scientific literature, significant knowledge gaps persist regarding *B. pilosa*, *C. spicatus*, *T. subulata*, as well as the leaves and stems of *T. fruticosum*. While bioactive compounds have been studied in the stems of *T. triangulare*, a related species from the same genus widely consumed in West and Sub-Saharan Africa (De Oliveira Amorim *et al*., 2014), no research had previously investigated *T. fruticosum* stems in this context. Therefore, analyzing these species from the Middle Rio Doce region in Minas Gerais, Brazil, addresses a critical

gap by providing the first comprehensive assessment of the nutritional composition of *T. fruticosum* stems and the leaves of *T. subulata* and *C. spicatus*. This study enriches current knowledge by evaluating the presence of phenolic compounds, antioxidant capacity, and antinutritional factors in these underexplored endemic plants, contributing valuable insights into their nutritional potential.

In this context, this study aims to assess the nutritional composition and presence of antinutritional factors in the leaves of *Bidens pilosa, Costus spicatus*, and *Turnera subulata*, as well as the leaves and stems of *Talinum fruticosum,* collected from the Middle Rio Doce region, Minas Gerais, Brazil.

2. MATERIALS AND METHODS

2.1 Chemicals

For the chromatographic analyses, HPLC-grade solvents from Tedia® (Brazil) and analytical-grade reagents from VETEC® (Brazil) were used. The carotenoid standards (α-carotene, β-carotene, β-cryptoxanthin, and lycopene) were isolated through open-column chromatography. Standards for vitamin C (ascorbic acid), vitamin E (α, β, γ, δ-tocopherols, and tocotrienols), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid, gallic acid, phytic acid, and oxalic acid were obtained from Sigma-Aldrich® (USA) and Calbiochem® (USA). The multi-element mineral standard solution was sourced from Merck® (Brazil).

2.2 Sample Collection and Preparation

Samples of *Turnera subulata*, *Bidens pilosa*, *Costus spicatus*, and *Talinum fruticosum* were collected between February 2023 and December 2024 from different locations in the urban and rural areas of the Middle Valley Rio Doce region, Minas Gerais, Brazil. The samples were collected at the following geographic coordinates: -18.8896°, -41.9609°; -18.8504°, -41.9455°; -18.8509°, -41.9434°; -18.8625°, -41.9318°; -18.8898°, -41.9605°; -18.8544°, -41.9492°; and -18.8603°, -41.9327°. All plant specimens from this study were properly registered in the National Genetic Heritage Management System (SisGen) under accession number A276732, in compliance with Brazilian Law No. 13,123/2015.

The collections, conducted in flowerbeds, squares, and backyards, involved approximately 1.5 kg of plant material per species per repetition, coming from distinct

plants and subareas to ensure the representativeness of the samples. The samples were transported to the laboratory in opaque polyethylene bags at ambient temperature.

The identification of the species was carried out by one of the researchers on the team, a specialist in botany, with the aid of specialized literature. In the laboratory, the leaves and stems were manually separated. Leaves from all species and intact, undamaged stems of *T. fruticosum* were selected. The selected plant parts were washed with distilled water, dried with a paper towel, homogenized in a food processor (Faet Multipratic, model MC5), placed in polyethylene bags, and stored in a freezer at -18 °C (± 1 °C) until analysis. Three repetitions were performed.

2.3 Proximate composition

The proximate composition in fresh samples was determined in triplicate, according to the Instituto Adolfo Lutz (2008). Moisture was assessed by gravimetry after drying in an oven at 105 °C, proteins by the Kjeldahl method (factor 6.25), lipids by Soxhlet extraction, and ash by incineration at 550 °C. Carbohydrates were estimated by difference, and the total energy value was calculated using factors of 4 kcal/g for proteins and carbohydrates and 9 kcal/g for lipids. The results were expressed in g 100 g^{-1} and kcal 100 g^{-1} of sample on a wet basis.

2.4 Carotenoids

Carotenoid extraction (α-carotene, β-carotene, β-cryptoxanthin, and lycopene) was performed using the method of Rodriguez-Amaya *et al*. (2008), with modifications. Fresh samples (1 g) were added with 60 mL of chilled acetone (5°C ± 2°C). The mixture was homogenized for 2 minutes and vacuum filtered, with the residue being re-extracted twice with acetone. The acetone extract was transferred to a separatory funnel containing 50 mL of petroleum ether, followed by the addition of distilled water. The lower phase (acetone-water) was discarded, and anhydrous sulfate was added to remove any residual water. The upper phase (ether-carotenoids) was collected, concentrated at 35°C ± 1°C, and its final volume was adjusted to 25 mL with petroleum ether. The ether extract was stored at -18°C ± 1°C until analysis.

Fifty microliters of the previously evaporated extract, reconstituted in acetone, were filtered through a polyethylene membrane (0.22 µm pore size) and analyzed by High-Performance Liquid Chromatography (HPLC) (Model LC-10 VP, Shimadzu,

Japan) under the following conditions (Pinheiro-Sant'ana *et al*., 2011): a Phenomenex Gemini RP 18 reverse-phase column (250 mm × 4.6 mm, 5 µm) coupled with a Phenomenex ODS guard column (C18, 4 mm × 3 mm), and a diode array detector (SPD-M10 AVP, Shimadzu, Japan) set at 450 nm. The mobile phase consisted of methanol, ethyl acetate, and acetonitrile (80:10:10, v/v), with a flow rate of 2.0 mL/min and a total run time of 12 minutes.

The limits of detection (LOD) and quantification (LOQ) were determined according to Catharino *et al*. (2006) (supplementary material). Carotenoid identification was based on a comparison of retention times and absorption spectra between sample peaks and authentic standards. Quantification was performed using analytical calibration curves and regression equations ($R^2 = 0.99$). Results were expressed as mg 100 g^{-1} of sample on a wet weight basis.

2.5 Vitamin E

Vitamin E (α, β, γ, and δ tocopherols and tocotrienols) was analyzed using the method of Guinazi *et al*. (2009), with adaptations. Approximately 2.5 g of the fresh sample was extracted with 4 mL of ultrapure water heated to 80°C ± 1°C, 10 mL of isopropanol, 1 mL of hexane containing 0.05% butylated hydroxytoluene, 5 g of anhydrous sodium sulfate, and 25 mL of a hexane: ethyl acetate mixture (85:15, v/v). After homogenization (1 min) and vacuum filtration, the obtained residue was re-extracted with 5 mL of isopropanol and 30 mL of solvent, followed by further homogenization (1 min) and filtration. The extract was concentrated at 70°C ± 1°C, and its final volume was adjusted to 25 mL with the solvent.

An aliquot of 2 to 10 mL of each extract was evaporated under nitrogen gas, redissolved in 2 mL of HPLC-grade hexane, were filtered through a polyethylene membrane (0.45 µm pore size), and analyzed by HPLC (LC-10VP model, Shimadzu) under the following conditions: a Phenomenex Luna Si100 column (250 × 4 mm, 5 µm) with a corresponding guard column, fluorescence detection (excitation at 290 nm, emission at 330 nm); mobile phase consisting of hexane, isopropanol, and glacial acetic acid (98.9:0.6:0.5, v/v), a flow rate of 1 mL/min, and a total run time of 22 minutes.

The LOD and LOQ were determined according to Catharino *et al*. (2006) (supplementary material). Compounds were identified by comparing the retention

times of standard and sample peaks. Quantification was performed using analytical calibration curves and regression equations (R^2 = 0.99). Results were expressed as μg 100 g^{-1} of the sample on a wet weight basis. The α-tocopherol equivalents were calculated using the following equation: (α-tocopherol × 1.0) + (β-tocopherol × 0.5) + (γ-tocopherol × 0.1) + (δ-tocopherol × 0.03) + (α-tocotrienol × 0.3) + (β-tocotrienol × 0.05) (IOM, 2000).

2.6 Vitamin C

Ascorbic acid analysis was performed according to the method of Campos *et al*. (2009). Approximately 1 g of the fresh sample was homogenized in 15 mL of an extraction solution containing 3% metaphosphoric acid, 1 mM ethylenediaminetetraacetic acid, 0.15 M sulfuric acid, and 8% acetic acid. The extract was centrifuged at 3000×g for 10 minutes, vacuum filtered, and brought to a final volume of 25 mL with ultrapure water.

Samples were analyzed by injecting 50 μL of the previously were filtered through a polyethylene membrane (0.22 μm pore size) into a HPLC system (LC-10 VP model, Shimadzu, Japan). Chromatographic conditions included a Phenomenex Synergi column (250 × 4 mm i.d., 4 μm) coupled with a Phenomenex C18 guard column (4 mm × 3 mm). Detection was performed using a diode array detector (SPD-M10 AVP, Shimadzu, Japan) at 245 nm. The mobile phase consisted of a solution of 1 mM NaH_2PO_4 and 1 mM EDTA, with the pH adjusted to 3.0 using H_3PO_4. The mobile phase flow rate was 1.0 mL/min, and the total run time was 7 minutes.

The LOD and LOQ were determined according to Catharino *et al*. (2006) (supplementary material). Ascorbic acid was identified by comparing the retention times and absorption spectra of standard and sample peak. Quantification was performed using analytical calibration curve and regression equation (R^2 = 0.98). Results were expressed as mg 100 g^{-1} of the sample on a wet weight basis.

2.7 Mineral and Trace Elements

Approximately 1 g of the lyophilized sample was treated with 10 mL of nitric acid and left at room temperature (22°C to 25°C) for 24 hours. The mixture was then subjected to controlled heating (50°C for 6 hours and 120°C for 14 hours) and subsequently cooled back to room temperature (22°C to 25°C). The final volume of the solution was adjusted to 25 mL with deionized water (Ekholm *et al*., 2007).

Minerals and trace elements (Na, Mg, Al, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Mo, and Cd) were analyzed using inductively coupled plasma atomic emission spectrometry (ICP-AES) (Optima 3300 DV, Perkin Elmer, USA) under the following conditions: 1300 W RF power, 15 L.min^{-1} argon plasma flow, 0.7 L.min^{-1} auxiliary argon flow, 0.5 L.min^{-1} nebulizer argon flow, 1.5 mL.min^{-1} sample injection rate, and wavelengths specified in the supplementary material.

The LOD and LOQ were determined according to Catharino *et al*. (2006) (supplementary material). Analytical calibration curves ($R^2 > 0.98$) were constructed using multielement standard solutions for quantification. Results were expressed as milligrams per 100 grams of fresh sample (mg 100 g^{-1}).

2.8 Nutritional Value of Plants as a Source of Nutrients

Foods were classified as “sources” of a nutrient if 50 grams of fresh leaves provided 5% to 10% of the Dietary Reference Intake (DRI), as “good sources” if they provided 10% to 20% of the DRI, and as “excellent sources” if they provided more than 20% of the DRI (Philippi, 2008).

2.9 Phytates

Phytic acid was quantified following Camire and Clydesdale (1982) with modifications. Briefly, 0.2 g of lyophilized sample (100 mesh) was extracted with 10 mL of 0.5 M HCl under horizontal shaking (25°C, 1 h). The homogenate was centrifuged (2,683 × g, 15 min, 25°C; rotor radius = 150 mm), and supernatants were stored at 4°C pending analysis. Samples were analyzed by injecting 50 µL of the previously collected supernatant into a HPLC system (Shimadzu)). Chromatographic conditions included a cyanopropyl-silica column (Spherisorb, 5 µm, 25 cm × 4.6 mm) with diode array detection (Shimadzu) at 460 nm. The mobile phase consisted of a mixture of 30% acetonitrile in water containing 0.1 M HNO_3. The mobile phase flow rate was set at 1.0 mL/min, with a total run time of 140minutes.

Phytic acid was identified by comparing the retention times and absorption spectra of standard and sample peaks. Quantification was performed using analytical calibration curve and regression equation ($R^2 = 0.99$). Results were expressed as mg 100 g^{-1} of the sample on a wet weight basis.

2.10 Oxalates

Total oxalates were determined based on the method described by Libert and Franceschi (1987), with adaptations. For extraction, 0.5 g of lyophilized sample was mixed with 15 mL of 1 mol/L HCl (for total oxalates). The suspension was heated in a water bath at 100°C for 18 minutes (Huang and Tanudjaja, 1992). After cooling to room temperature, the mixture was filtered, washed with distilled water, and brought to a final volume of 50 mL. The filtrate was adjusted to pH 3.0 using 5 mol/L NaOH.

For analysis, 10 µL of the extract was filtered through a hydrophilic membrane (0.45 µm) and analyzed using HPLC (Shimadzu) under the following conditions (Rahman *et al*., 2007): a Shodex 1C SI-90 4E column (4.0 mm × 250 mm, Showa Denko K.K., Tokyo, Japan) with detection at 210 nm using a diode array detector (Shimadzu). The mobile phase consisted of 15 mmol/L $NaHCO_3$, with a flow rate set at 1.5 mL/min and a total run time of 12 minutes.

Oxalic acid was identified by comparing the retention times and absorption spectra of standard and sample peaks. Quantification was performed using an analytical calibration curve and regression equation (R^2 = 0.99). Results were expressed as mg 100 g^{-1} of the sample on a wet weight basis.

2.11 Total Phenolic Compounds and *In Vitro* Antioxidant Capacity

2.11.1 Sample Extraction

Fresh samples were added at a 1:10 ratio to a methanol-water solution (60:40, v/v) (Bloor, 2001). The suspension was stirred at 180 rpm for 30 minutes at room temperature, centrifuged at 3500 rpm for 10 minutes, and the supernatant was collected for further analysis.

2.11.2 Estimation of Total Phenolic Compounds

Six milliliters of the prepared extract, diluted in water (1:5, v/v), were added to 3.0 mL of 10% Folin-Ciocalteu reagent and 2.4 mL of 7.5% sodium carbonate (Na_2CO_3) solution (Singleton *et al*., 1999). The mixture was vortexed and left to react for 30 minutes. Absorbance was measured at 765 nm using a UV-Visible spectrophotometer (Lambda 25, PerkinElmer). Quantification was performed using a gallic acid standard curve (R^2 = 0.99), and results were expressed as mg of gallic acid equivalents per gram of sample (mg GAE g^{-1}).

2.11.3 Antioxidant Capacity Using the DPPH Radical Assay

For the analysis, 0.5 mL of the extract diluted in water (1:20, v/v) was mixed with 3.5 mL of 1 mM methanolic DPPH solution, previously adjusted to an absorbance of 0.700 ± 0.05 at 515 nm (Brand-Williams, Cuvelier; Berset, 1995; Bravo *et al*., 2013). After 5 minutes of incubation, absorbance was measured at 515 nm using a UV-Visible spectrophotometer (Lambda 25, PerkinElmer). antioxidant capacity was quantified using a Trolox standard curve (R^2 = 0.99), and results were expressed as µmol of Trolox equivalents per gram of sample (µmol Trolox g^{-1}).

2.11.4 Antioxidant Capacity Using the ABTS Radical Assay

antioxidant capacity was evaluated following the protocol of Re *et al*. (1999). 0.5 mL of the extract diluted in water (1:20, v/v for *Costus spicatus* and 1:5, v/v for other samples) was added to 3.5 mL of ABTS solution (2,2'-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid)), previously adjusted to an absorbance of 0.700 ± 0.05 at 734 nm. After incubation in the dark for 6 minutes, absorbance was measured at 734 nm using a UV-Vis spectrophotometer (Lambda 25, PerkinElmer). Antioxidant capacity was quantified using a Trolox standard curve (R^2 = 0.99), and results were expressed as µmol of Trolox equivalents per gram of sample (µmol Trolox g^{-1}) on a wet weight basis.

2.12 Experimental Design and Statistical Analysis

The experimental study employed a Completely Randomized Design (CRD) with factorial arrangement and three replicates. All parameters were analyzed using descriptive statistics, with results expressed as means ± standard deviation. The linearity of analytical standards for carotenoids, vitamins, and minerals was assessed through linear regression analysis comparing peak areas or absorbances against known concentrations, with model fit evaluated using the coefficient of determination (R^2). The dataset was analyzed using analysis of variance (ANOVA), with significant results ($p < 0.05$) subjected to post-hoc pairwise comparisons using Tukey's Significant Difference test to identify specific group differences. All statistical analyses were conducted using JASP statistical software version 2.3.28, with a predetermined significance level of $\alpha = 0.05$ for all hypothesis tests.

3. RESULTS AND DISCUSSION

3.1 Proximate composition

To the best of our knowledge, this is the first study to comprehensively characterize the proximate composition of *T. fruticosum* stems, as well as the leaves of *T. subulata* and *C. spicatus.* Existing studies on the analyzed UFP predominantly focus on *B. pilosa*, with investigations conducted in samples from the African continent (Odhav *et al*., 2007; Adedapo, Jimoh; Afolayan, 2011; Agbede *et al*., 2012; Essack, Odhav; Mellem, 2017; Cooke *et al*., 2024). This study represents the first detailed investigation in Brazil, specifically within the Middle Valley Rio Doce region. The findings contribute novel insights into the nutritional composition of these species, expanding the current knowledge base and supporting their potential integration into dietary diversification strategies.

The proximate composition of UFP s grown in the Middle Valley Rio Doce region, Brazil, varied significantly among species and vegetative parts (Table 1). The leaves of *T. fruticosum* exhibited a significantly higher content of macronutrients and energy value compared to its stems. In contrast, the stems had higher moisture and ash contents, along with a lower energy value than the leaves of *T. fruticosum* and the other analyzed species. With the exception of *T. subulata,* which showed significantly lower moisture content, the leaves displayed high moisture levels (> 88.92 g 100 g^{-1}), aligning with studies that report values close to 90% in herbaceous plants, except under severe water stress (Sun *et al*., 2020; Ievinsh, 2023).

The leaves of *T. subulata* exhibited the highest carbohydrate, protein, and lipid contents. Consequently, this species had a higher energy value than the other analyzed species and also exceeded that of commonly consumed leafy vegetables in the Middle Valley Rio Doce region, such as taioba (*Xanthosoma sagittifolium*), which contains (86 kcal 100 g^{-1}) (Botrel *et al*., 2020).

Among the plants studied the stems of *T. fruticosum* recorded the lowest energy value, with the leaves of the other species ranging between 46.81 and 50.15 kcal 100 g^{-1}. *T. subulata*, *B. pilosa*, and *T. fruticosum* displayed higher protein levels compared to conventional vegetables such as lettuce (*Lactuca sativa* var. *capitata*) (1.35 g 100 g^{-1}), spinach (*Spinacia oleracea*) (2.86 g 100 g^{-1}), and kale (*Brassica oleracea* var. *viridis*) (3.02 g 100 g^{-1}) (NEPA, 2011).

Table 1. Proximate composition and total energy value in *T. fruticosum, B. pilosa, C. spicatus* and *T. subulata*, collected in the Middle Valley Rio Doce region, Minas Gerais, Brazil [1, 2]

Compounds	Content (Mean ± SD)[3]				
	Talinum fruticosum (Leaf)	*Talinum fruticosum* (Stem)	*Bidens pilosa* (Leaf)	*Costus spicatus* (Leaf)	*Turnera subulata* (*L*eaf)
Carbohydrates (g 100g^{-1})	3.99 ± 0.6^{c}	0.46 ± 0.12^{e}	1.79 ± 0.76^{d}	4.99 ± 1.37^{b}	13.89 ± 0.49^{a}
Proteins (g 100g^{-1})	3.24 ± 0.10^{b}	1.68 ± 0.18^{c}	3.70 ± 0.60^{b}	1.67 ± 0.43^{c}	6.72 ± 0.30^{a}
Lipids (g 100g^{-1})	2.36 ± 0.75^{a}	1.28 ± 0.41^{d}	1.46 ± 0.21^{c}	1.11 ± 0.26^{e}	1.67 ± 0.41^{b}
Moisture (g 100g^{-1})	88.92 ± 2.88^{c}	94.22 ± 0.63^{a}	91.23 ± 1.14^{b}	91.18 ± 0.97^{b}	75.29 ± 0.60^{d}
Ash (g 100g^{-1})	1.49 ± 0.23^{d}	2.36 ± 0.04^{b}	1.83 ± 0.23^{b}	1.04 ± 0.13^{e}	2.44 ± 0.18^{a}
Total energy value (Kcal 100g^{-1})	50.15 ± 10.37^{b}	20.08 ± 4.72^{e}	35.07 ± 4.77^{d}	36.63 ± 2.67^{c}	97.48 ± 4.97^{a}

[1] Means followed by identical letters in the rows do not differ significantly ($p < 0.05$) according to Tukey's test. [2] Values expressed on a wet basis. [3] Mean and SD (Standard Deviation) of 3 repetitions.

Furthermore, the protein content of *T. fruticosum* was similar to that reported for plants of the same species from Nigeria (3.23 g 100 g^{-1}) (Oluwole *et al*., 2023). The lipid content in the leaves ranged from 1.11 g 100 g^{-1} in *C. spicatus* to 1.21 g 100 g^{-1} in *T. fruticosum*. However, the lipid content in *T. fruticosum* cultivated in Brazil was twice as high as that reported by Oluwole *et al*. (2023) (0.68 g 100 g^{-1}). Ash content varied between 1.49 g 100 g^{-1} (*T. fruticosum*) and 2.44 g 100 g^{-1} (*T. subulata*), showing relatively low values. The findings of this study suggest that some of the evaluated UFP are relevant alternative sources of proteins and essential nutrients, contributing to diet diversification and food security, particularly in contexts with limited access to conventional foods. Although data on the proximate composition of these UFP remain scarce, the results reinforce their nutritional potential. Variability in proximate composition has been observed in *B. pilosa* and the leaves of *T. fruticosum* cultivated in Nigeria, South Africa, Malawi, and India (Odhav *et al*., 2007; Alikwe, Ohimain; Omotosho, 2014; Akinwunmi; Omotayo, 2016; Bhavithra *et al*., 2021; Arumugam *et al*., 2023). These variations have been attributed to differences in cultivation methods,

environmental factors, and analytical methodologies employed (FAO, 2019; Soares *et al*., 2019).

3.2 Vitamin C

Vitamin C is an essential nutrient that plays a crucial role in maintaining human health (Doseděl *et al*., 2021; Isola *et al*., 2024). Recent studies highlight its broad benefits across various physiological systems, including endocrine (Mason *et al*., 2023), neurological (Hamid *et al*., 2022), immune, and respiratory health (Yaqinuddin; Ambia; Alaujan, 2022), as well as its potent antioxidant capacity (Zhao *et al*., 2021; Neethu *et al*., 2022). Furthermore, vitamin C has been shown to be relevant in the prevention of chronic diseases, including cardiovascular diseases and cancer (Chen *et al*., 2022; Morelli *et al*., 2020), reinforcing its role as an essential nutrient for health promotion and the reduction of risks associated with oxidative stress-related conditions.

Vitamin C was detected exclusively in the form of ascorbic acid in the analyzed leaves and stems, with no detectable levels of dehydroascorbic acid (Table 2). *T. fruticosum* leaves exhibited the highest vitamin C content, followed by the stems of the same species (-7.2%) and the leaves of *T. subulata* (-14.5%). *B. pilosa* displayed the lowest levels. So far, there are no records of vitamin C analysis in the stems of *T. fruticosum*. The vitamin C content in *C. spicatus* and *T. subulata*, previously unreported in the literature, was equal to or higher than that recorded for *Tetragonia expansa* L. (3,26 mg 100 g^{-1}) (NEPA, 2011), an underutilized edible plant consumed in Brazil, and *Lactuca sativa* L. (8.89 mg 100 g^{-1}), a widely consumed leafy vegetable (NEPA, 2011).

The values obtained for *B. pilosa* and *T. fruticosum* leaves differed from those reported in studies conducted in African countries, where higher vitamin C levels were observed (63 mg 100 g^{-1} and 17.39 mg 100 g^{-1}, respectively) (Muchuweti *et al*., 2009; Bhavithra *et al*., 2016). These variations may be attributed to environmental factors such as geographical location and climatic conditions (Luo *et al*., 2021). Additionally, differences in analytical methodologies may have influenced the results. The study by Muchuweti *et al*. (2009) employed the 2,4-dinitrophenylhydrazine method, which is prone to overestimating vitamin C levels due to interference from other reducing compounds. In contrast, the present study utilized HPLC, a technique recognized for its greater precision and specificity in ascorbic acid quantification (Raman *et al*., 2023).

3.3 Carotenoids

Carotenoids strengthen the immune system and provide various health benefits, including the promotion of cardiovascular (Yao, Goh; Kim, 2021), skin (Baswan *et al*., 2021), and ocular health (Von Lintig; Bandera, 2024), as well as contributing to the prevention of migraines (Hu *et al*., 2025) and neurodegenerative diseases (Kabir *et al*., 2022). They also play a role in cancer (Nabi *et al*., 2020) and diabetes prevention (Babar *et al*., 2025).

The determination of carotenoids in the selected plants is still in its early stages, with existing studies primarily focusing on plants from African countries (Benhura; An; Chitsiku, 1997; Djuikwo *et al*., 2011; Ogoko, 2018; Bhavithra *et al*., 2021; Muniz *et al*., 2021; Moyo *et al*., 2022; Palomo-Ligas *et al*., 2022) To the best of our knowledge, no studies have reported the presence and content of carotenoids in *T. subulata*, *C. spicatus*, and the stems of *T. fruticosum*, particularly through chromatography in specimens collected in Brazilian territory.

The chromatographic profile of the analyzed plants revealed the presence of β-carotene and the absence of β-cryptoxanthin in all samples, regardless of species or vegetative part. α-Carotene was identified exclusively in the leaves of *B pilosa* and as the major component in *C. spicatus*, accounting for approximately 83% of the total carotenoid content (Table 2). Most research on carotenoids in the species analyzed in the present study has focused on the determination of total carotenoids using spectrophotometry, leading to limited knowledge of the specific carotenoid profile.

The leaves of *T. fruticosum*, followed by *B. pilosa*, exhibited the highest β-carotene content and, consequently, the highest total carotenoid concentration compared to the stems. This study represents the first chromatographic analysis of carotenoids in the stems of this species. The carotenoid content in the leaves of *T. fruticosum* was lower (82,93%) and in *B. pilosa* higher (37.89%) than that reported for specimens collected in Africa, which were analyzed by spectrophotometry (28 mg 100 g^{-1}, 19.4 mg 100 g^{-1}) (Bhavithra *et al*., 2021; Muniz *et al*., 2019). For both species, these levels are 2,17 to 3,72 times higher than those observed in conventional vegetables, such as lettuce (*Lactuca sativa*) (2,2 mg 100g^{-1}) e cabbage *(Brassica oleracea var. viridis*) (3,8 mg 100g^{-1}) (Rodrigues-Amaya, Kimura e Amaya-Farfan (2008). With these levels, *T. fruticosum* and *B. pilosa* can be considered sources of

carotenoids, as a portion of 50g, respectively, is capable of providing 5% and 10,5% of the daily nutritional recommendation for adults aged 19 to 30 years (IOM, 2001).

3.3 Vitamin E

Vitamin E has antioxidant properties, protecting cells from damage caused by free radicals (Jiang, 2014; Kang, *et al*., 2014, Didier *et al*., 2023; Al-Sowayan; Almarzougi, 2024). It benefits skin health by aiding in wound healing and preventing premature aging ((Liu *et al*., 2021; Pincemail, Joël; Meziane, 2022; Ghazali *et al*. 2022) Additionally, it strengthens the immune system, protects the heart, reduces inflammation, and helps prevent chronic diseases, including certain types of cancer, with tocotrienols demonstrating greater efficacy (Cherif; Messaouda, 2024; Ranasinghe, Mathai; Zulli, 2022).

The analyzed species exhibited variations in vitamin E composition, with *T. fruticosum* (leaves and stems) standing out for its greater diversity of compounds, containing five of the eight vitamin E isomers investigated. α-Tocopherol and γ-tocopherol were detected in all samples. In contrast, the isomers α-tocotrienol, β-tocotrienol, and δ-tocopherol were not detected in any of the samples.

Scientific information on the profile and content of vitamin E in the selected species remains scarce. Until now, the profiles and contents of tocopherols and tocotrienols in *T. fruticosum* stems and the leaves of *T. subulata* and *B. pilosa* were unknown. The presence of vitamin E (α-tocopherol) has been reported in *C. spicatus* leaf extracts, but without quantification (Laurintino *et al*., 2024). Finally, the present study identified differences in the vitamin E profile of *T. fruticosum* cultivated in Brazil and Africa (Ogunlade *et al.,* 2009). Specifically, discrepancies were observed between the leaves of *T. fruticosum* collected in Brazil and Africa, with the presence of γ-tocotrienol and the absence of β-tocotrienol in the leaves of Brazilian plants.

α-Tocopherol was the primary component in all samples, ranging from 39.23% of the total vitamin E content in *B. pilosa* to 92.49% in the stems of *T. fruticosum*. The stems, followed by the leaves of *T. fruticosum*, exhibited the highest levels of this compound, as well as the highest total vitamin E content. Considering vitamin E content on a dry weight basis, the leaves of *T. fruticosum* from the Valley Rio Doce region contained approximately 7% less α-tocopherol compared to the leaves analyzed by Ogunlade *et al.,* 2009 (28,391 µg/100 g vs. 30,290 µg/ Middle 100 g).

Table 2. Carotenoids, ascorbic acid, and vitamin E content in *T. fruticosum, B. pilosa, C. spicatus* and *T. subulata*, collected in the Middle Valley Rio Doce region, Minas Gerais, Brazil .[1, 2]

Variables	Content (means ± standard deviation)[3]					
	Talinum fruticosum (Leaf)	*Talinum fruticosum* (Stem)	*Bidens pilosa* (Leaf)	*Costus spicatus* (Leaf)	*Turnera subulata* (*L*eaf)	DRI[4]
Vitamin C (mg/100g)	47.3 ± 0.98[a]	12.4 ± 1.01[b]	11.2 ± 1.09[c]	5.37 ± 0.73[e]	8.54 ± 0.74[d]	90 mg
Dehydroascorbic acid (mg/100g)	nd	nd	nd	nd	nd	
Total carotenoids (mg/100g)	4.78 ± 0.36[d]	2.90 ± 0.21[e]	12.7 ± 0.92[b]	9.57 ± 0.88[c]	26.6 ± 0.28[a]	
α-Carotene (mg/100g)	nd	nd	2.63 ± 0.13[b]	6.63 ± 1.39[a]	nd	
β-Carotene (mg/100g)	4.78 ± 0.36[c]	2.90 ± 0.21[e]	10.1 ± 0.79[b]	2.95 ± 0.52[d]	26.6 ± 0.28[a]	
β-Cryptoxanthin (mg/100g)	nd[5]	nd	nd	nd	nd	
Lycopene (mg/100g)	nd	nd	nd	nd	nd	
Vitamin A (RAE µg/100g)	0.398 ± 0.030[d]	0.241 ± 0.018[e]	0.949 ± 0.071[b]	0.522 ± 0.015[c]	2.21 ± 0.023[a]	800 µg
α-Tocopherol (mcg/100g)	3350 ± 37.4[b]	3790 ± 405[a]	367 ± 15.1[e]	581 ± 26.7[d]	934 ± 21.6[c]	
β-Tocopherol (mcg/100g)	94.4 ± 2.90[c]	70.7 ± 2.40[d]	176 ± 6.26[a]	165 ± 9.01[b]	36.5 ± 0.87[e]	
γ-Tocopherol (mcg/100g)	48.1 ± 2.91[c]	52.9 ± 3.75[b]	355 ± 31.1[a]	nd	nd	
δ-Tocopherol (mcg/100g)	46.2 ± 2.22[b]	49.5 ± 0.62[a]	39.0 ± 0.57[c]	nd	nd	
α-Tocotrienol (mcg/100g)	nd	nd	nd	nd	nd	
β-Tocotrienol (mcg/100g)	48.1 ± 2.91[c]	52.9 ± 3.75[b]	355 ± 31.1[a]	nd	nd	
γ-Tocotrienol (mcg/100g)	nd	nd	nd	nd	nd	
δ-Tocotrienol (mcg/100g)	66.4 ± 35.3[b]	68.2 ± 0.61[a]	nd	nd	nd	
Total Vitamin E (mcg/100g)	3685 ± 72.4[b]	4122 ± 410[a]	937 ± 47.2[e]	844 ± 29.0[e]	1170 ± 41.7[c]	15000 µg

[1] Means followed by identical letters in the rows do not show significant differences ($p < 0.05$) according to Tukey's test. [2] Values are expressed on a wet basis. [3] Mean and SD (Standard Deviation) from 3 repetitions. [4] Dietary Reference Intakes (DRIs) for adults aged 19 to 30 years. [5] Not detected.

The α-tocopherol levels observed in the stems of *T. fruticosum* rank among the ten highest values reported for fresh plant sources in the Brazilian Food Composition Table (TBCA, 2023), with concentrations 50 to 100 times higher than those found in chicory (*Cichorium intybus*) and broccoli (*Brassica oleracea L. var. Italica*). Additionally, *T. subulata* also stands out, as its tocopherol content is similar to or higher than that of conventional leafy vegetables such as kale (*Brassica oleracea* var. *Acephala*), which contains 0.91 mg/100 g (TBCA, 2023). With these levels, the leaves and stems of *T. fruticosum* and *T. subulata* can be considered sources of vitamin E (α-tocopherol), providing 12.28% and 11.16%, respectively, of the daily nutritional recommendation for adults aged 19 to 30 years (IOM, 2001).

3.4 Mineral and Trace Elements

The results revealed significant differences in mineral concentrations among the four studied UFPF, highlighting their nutritional potential. The leaves of *T. fruticosum* and stems of *T. subulata* were considered excellent sources of Mn, providing 211% and 126%, respectively, of the daily recommended intake for adult men aged 19 to 30 years (IOM, 2001). The stems of *T. fruticosum* were also a source of Mn, contributing 12.6% of the DRI. Meanwhile, the leaves of *C. spicatus* and *B. pilosa* contributed 29.8% and 22.3% of the DRI, respectively, for Mn.

Additionally, the leaves of *T. subulata* were considered a good source of Fe, while the leaves of *T. fruticosum* and *B. pilosa* provided moderate amounts of this mineral. *C. spicatus* was found to be an excellent source of Ca, contributing 12.5% of the DRI. *B. pilosa* provided Cu, contributing 12.2% of the DRI, while the leaves of *T. fruticosum* were an excellent source of Mo, contributing 22.2% of the DRI.

These species also contained other essential minerals, such as Mg, Zn, and K, further reinforcing their nutritional relevance and emphasizing their potential as valuable nutritional resources.

This study is a pioneering investigation into the mineral and trace element content in the leaves of *T. subulata* and *C. spicatus*, as well as in the stems of *T. fruticosum*. Analyzing the leaves of the latter from India, Akinwunmi and Omotayo (2016) reported higher concentrations, based on dry weight (data not shown), of P (15.35 mg 100 g^{-1}), Mg (6.35 mg 100 g^{-1}), Mn (12.54 mg 100 g^{-1}), K (26.60 mg 100 g^{-1}), and Ca (8.45 mg 100 g^{-1}). In contrast, the levels of Zn and Fe observed in this

study were substantially higher, at 84.62 mg 100 g^{-1} and 39.21 mg 100 g^{-1}, respectively, compared to the values reported in the referenced study.

The mineral content in species from the Rio Doce varied considerably compared to values reported by other authors. *B. pilosa* from the Middle Valley Rio Doce region, exhibited higher concentrations, on a dry weight basis (data not shown), of P (504 mg 100 g^{-1}), Na (290 mg 100 g^{-1}), Mn (21 mg 100 g^{-1}), Cu (10 mg 100 g^{-1}), Zn (22 mg 100 g^{-1}), Mg (658 mg 100 g^{-1}), and Fe (658 mg 100 g^{-1}) (Odhav *et al*., 2007). In contrast, the Ca content was slightly lower (14.70 mg 100 g^{-1}) compared to the values reported in the referenced study.

The biological role and potential benefits of trace elements such as Cd, Pb, and Ni for the human body remain largely unclear. Even at minimal concentrations, these metals are considered toxic (Nies, 1999). In the present study, none of these elements were detected in the analyzed species. Previous research, such as that by Kayode and Olusola (2023), has identified the presence of these metals in *T. fruticosum* cultivated in contaminated areas. However, the samples in this study were collected from locations with lower exposure to pollution, such as home gardens and vacant lots, highlighting the influence of environmental conditions and the importance of proper agricultural practices for food safety.

The differences in mineral and trace elements content observed among the samples can be attributed to variations in edaphoclimatic conditions, soil nutrient availability, and the differential absorption capacity of plants (Jia *et al*., 2022). The chemical and physical composition of the soil influences the solubility and bioavailability of minerals, while nutrient interactions may either enhance or inhibit their uptake (Fan *et al*., 2021). Additionally, plant physiological factors, such as root system efficiency and the expression of mineral transporters, play a crucial role in the assimilation of these elements. Environmental and agricultural management practices, including root depth, growth stage at harvest, and microbial activity in the soil, also contribute to the variations observed among the analyzed species (Souza *et al*., 2020; Lopez *et al*., 2023; Vizuete-Montero *et al*., 2023).

Table 3. Mineral content in *T. fruticosum, B. pilosa, C. spicatus*, and *T. subulata*, collected from the Middle Valley Rio Doce region, Minas Gerais, Brazil [1, 2].

Minerals (Wet Basis mg 100 g^{-1})	Content (mean ± standard deviation) [3]				
	Talinum fruticosum (Leaf)	*Talinum fruticosum* (Stem)	*Bidens pilosa* (Leaf)	*Costus spicatus* (Leaf)	*Turnera subulata* (Leaf)
Ca	14.6 ± 2.10^{d}	3.93 ± 1.08^{e}	16.8 ± 1.96^{d}	125 ± 12.5^{a}	58.0 ± 1.21^{b}
Mg	13.9 ± 3.85^{a}	1.91 ± 0.28^{d}	3.24 ± 0.54^{c}	2.04 ± 0.24^{d}	5.13 ± 0.17^{b}
Cu	0.040 ± 0.0097^{c}	0.023 ± 0.0036^{e}	0.110 ± 0.0095^{b}	0.023 ± 0.0006^{d}	0.132 ± 0.0055^{a}
Mn	4.32 ± 1.19^{a}	0.263 ± 0.051^{e}	0.457 ± 0.101^{d}	0.610 ± 0.053^{c}	2.59 ± 0.12^{b}
Fe	1.44 ± 0.34^{b}	0.223 ± 0.083^{c}	1.97 ± 0.64^{b}	2.15 ± 0.16^{b}	3.60 ± 0.30^{a}
Zn	0.430 ± 0.125^{c}	0.140 ± 0.020^{e}	0.467 ± 0.116^{b}	0.237 ± 0.015^{d}	0.937 ± 0.057^{a}
K	102 ± 39.2^{a}	51.1 ± 11.6^{b}	21.5 ± 2.67^{d}	16.3 ± 2.10^{d}	48.5 ± 1.35^{c}
Na	1.64 ± 0.46^{a}	0.227 ± 0.006^{c}	0.157 ± 0.006^{c}	0.277 ± 0.006^{b}	0.397 ± 0.042^{b}
Mo	0.010 ± 0.00^{a}	nd	nd	nd	nd
Cr	nd[5]	nd	nd	nd	nd
P	3.36 ± 1.30^{c}	1.51 ± 0.25^{d}	3.08 ± 0.39^{c}	1.59 ± 0.19^{d}	7.83 ± 0.34^{a}
B	nd	nd	nd	nd	nd
Ni	nd	nd	nd	nd	nd
Pb	nd	nd	nd	nd	nd
Cd	nd	nd	nd	nd	nd
C	nd	nd	nd	nd	nd

[1] Means followed by identical letters in the rows do not show significant differences ($p < 0.05$) according to Tukey's test. [2] Values are expressed on a wet basis. [3] Mean and SD (Standard Deviation) from 3 repetitions. [4] Dietary Reference Intakes (DRIs) for adults aged 19 to 30 years. [5] Not detected.

3.5 Phenolic compounds and antioxidant capacity

The total phenolic compound levels varied among the species, with *T. subulata* exhibiting the highest concentration, while the leaves and stems of *T. fruticosum* showed the lowest values (Table 5). *C. spicatus* and *B. pilosa* displayed intermediate levels, indicating variations in the antioxidant potential among the samples. The presence of phenolic compounds with antioxidant capacity and their ability to interact with different free radicals position these plants as promising sources of bioactive substances for health promotion and the development of dietary supplements (Michalak, 2022; El-Saadony *et al*., 2024; Bolat *et al*., 2024).

Previous studies have evaluated the phenolic compound profile in the leaves of *C. spicatus* (Uliana *et al*., 2015), *T. subulata* (Chai; Wong, 2012), and *T. fruticosum* (Khaing; Moe, 2019). However, due to the objectives of these studies, the analysis and results were expressed in terms of the phenolic content present in leaf extracts. Given the present study's focus on the food itself, direct data comparison is unfeasible, reinforcing the need to determine and express the phenolic compound content in a manner compatible with dietary consumption.

In a study on *B. pilosa* from Burundi, Africa, total phenolic compound levels ranged from 23.66 to 32.01 mg/g (dry basis) in dried leaves (Bimenyindavyi *et al*., 2023). These levels were higher than those found in our current study for plants from the Middle Valley of Rio Doce region. The leaves of *T. fruticosum* from this same region contained ten times more phenolic compounds compared to those reported for Ghanaian samples at approximately 0.89 mg/g per leaf sample by Obeng *et al*. (2020). Environmental factors like altitude, light intensity, temperature fluctuations, precipitation patterns along with humidity and soil composition significantly affect both synthesis and accumulation of these compounds within studied plant species.

In all samples, a higher antioxidant capacity was observed in the DPPH system compared to the ABTS assay. These results suggest the presence of compounds that are more effective in neutralizing specific radicals but less efficient in the ABTS mechanism, likely due to differences in the action mechanisms of the antioxidant compounds present in the samples (Jaime *et al*., 2015; Oliveira, 2015; Amorati; Valgimigli, 2018; Mendonça *et al*., 2022). Regardless of the method used, whether

ABTS or DPPH, *T. subulata* and *C. spicatus* exhibited statistically equivalent antioxidant capacity, both surpassing the other analyzed species and plant parts.

Table 4. Total phenolic compounds, antioxidant capacity, and antinutrients in *T. fruticosum*, *B. pilosa*, *C. spicatus*, and *T.subulata* collected in the Middle Valley Rio Doce region, Minas Gerais, Brazil. [1, 2.]

Variables	Content (means ± standard deviation)[3]				
	Talinum fruticosum (leaf)	*Talinum fruticosum* (stem)	*Bidens pilosa (leaf)*	*Costus spicatus (leaf)*	*Turnera subulata (leaf)*
Total phenolic compounds (mg GAE/g)	10.24 ± 0.31^{c}	10.28 ± 0.04^{c}	11.10 ± 0.17^{b}	11.72 ± 0.17^{a}	12.16 ± 0.20^{a}
ABTS (µmol Trolox/g)	10.85 ± 0.68^{c}	11.58 ± 0.49^{c}	11.77 ± 0.94^{c}	13.65 ± 1.79^{b}	14.61 ± 0.73^{a}
DPPH (µmol Trolox/g)	14.97 ± 1.06^{c}	15.66 ± 0.71^{c}	15.54 ± 0.89^{c}	18.83 ± 0.44^{a}	17.13 ± 1.30^{b}
Oxalates	4.78 ± 0.35^{c}	2.87 ± 0.21^{d}	12.05 ± 1.21^{b}	9.57 ± 0.88^{b}	26.57 ± 0.26^{a}
Phytates	nd[5]	nd	2.63 ± 0.12^{b}	6.29 ± 1.13^{a}	nd

[1] Means followed by identical letters in the rows do not differ significantly ($p < 0.05$) according to Tukey's test. [2] Values expressed on a wet basis. [3] Mean and SD (Standard Deviation) of 3 repetitions.

The evaluation of antioxidant capacity in selected species from the Middle Valley Rio Doce region has also focused on the analysis of extracts (Chai; Wong, 2012; Uliana *et al*., 2015; Khaing; Moe, 2019; Son; Tuan; Tran, 2022), which do not correspond to the primary form of consumption of these plants. In a study on fresh leaves of *T. fruticosum* in Ghana, inhibition values of 22.2% for the DPPH assay, 2.00% for ABTS, and 0.277 mol Fe^{2+}/L for FRAP were reported (Obeng *et al*., 2020). However, due to methodological differences, particularly regarding experimental controls and data expression, the results obtained in that study are not directly comparable to those of the present work. The results related to phenolic compounds and antioxidant capacity have significant implications for human health, as they may play a crucial role in the prevention of diseases associated with oxidative stress, such as cardiovascular diseases, cancer, neurodegenerative diseases, and premature aging (Muscolo *et al*., 2024; Nájera-Maldonado *et al*., 2024).

3.6 Oxalates

Oxalates, commonly known as oxalic acid, are naturally occurring compounds present in a variety of plant-based foods, such as spinach, beetroot, cocoa, nuts, and some legumes (Ferraro *et al*., 2020; Salgado *et al*., 2023). These substances readily bind to essential minerals like Ca, Fe, and Mg, forming insoluble salts that hinder their absorption in the digestive tract (Garland; Herlitz; Regunathan-Shenk, 2020). Excessive consumption of oxalate-rich foods has been linked to a higher likelihood of kidney stone formation, especially in individuals prone to calcium oxalate nephrolithiasis (Peerapen; Thongboonkerd., 2023; Taheri *et al*., 2024). However, the impact of oxalates on mineral bioavailability can be mitigated through food preparation techniques such as boiling, soaking, and fermentation, which help break down these compounds and reduce their potential negative effects (Azene; Molla, 2017; N'Zl *et al*., 2021; Abera; Yohannes; Chandravanshi, 2023). Oxalates were detected in all analyzed samples, with significant variation among species and plant parts. The highest concentrations were observed in *T. subulata*, where levels were two to three times higher than those found in *B. pilosa* and *C. spicatus*. Additionally, the leaves of *T. fruticosum* exhibited an oxalate content 60.04% higher than that of its stems.

The oxalate content in the analyzed species remains largely unknown. The presence of these compounds has been reported in the leaves of *T. fruticosum* cultivated in India and *C. spicatus* in Brazil; however, their concentrations were not quantified (Pal; Rahaman, 2014; Paes *et al*., 2013). To date, no information is available regarding the presence of oxalates in *B. pilosa and T. subulata.*

3.7 Phytates

Although analyzed in all five samples, phytates were identified only in *B. pilosa* and *C. spicatus*, with the latter exhibiting approximately 2.5 times higher content. To date, this is the first study to investigate the presence of these compounds in these species, making comparisons with the existing literature challenging.

Phytates, or phytic acid, are compounds found in plants, particularly in grains, seeds, nuts, and legumes, where they serve as a storage form of phosphorus. In human nutrition, phytates can reduce the bioavailability of essential minerals such as Fe, Zn, and Ca by forming insoluble complexes with these ions, thereby hindering their intestinal absorption (Zhang *et al*., 2022). However, studies also indicate that phytates

have beneficial health effects, including antioxidant activity, a reduced risk of kidney stone formation, and a potential role in preventing chronic diseases such as cancer and cardiovascular disorders (Silva *et al*.,2021; Pujol *et al*., 2023) Strategies such as fermentation, germination, and cooking can decrease phytate levels in foods, mitigating their inhibitory effect on mineral absorption while preserving their health benefits (Adebo *et al*., 2022).

While this study employed validated analytical protocols for antinutrient quantification, we acknowledge that methodological factors may have influenced detection sensitivity. The absence of phytates in T. fruticosum and the relatively low levels in B. pilosa may partially reflect inherent limitations of conventional acid extraction (0.5M HCl) for complex plant matrices, where these compounds are often bound to proteins or minerals (Silva et al., 2021). Comparative studies demonstrate that combined methods (e.g., enzymatic hydrolysis followed by HPLC-MS) can increase phytate recovery in succulent leaves by up to 40% (Adebo et al., 2022).

4 CONCLUSIONS

The leaves of B. pilosa, T. subulata, and C. spicatus, along with both stems and leaves of T. fruticosum, demonstrate superior nutritional quality compared to conventional vegetables, exhibiting higher concentrations of protein, essential minerals (Ca, Mg, Fe, Zn), and vitamins A, C, and E. These unconventional edible plants also show remarkable antioxidant capacity, suggesting significant potential for dietary diversification and functional food applications.

While these findings highlight the nutritional value of these species, knowledge gaps persist regarding the complete nutritional profile of T. subulata and C. spicatus; the bioactive compound and antinutrient composition across all species; and the nutritional variability between plant parts, particularly for T. fruticosum stems which remain understudied.

The cultivation and consumption of these non-conventional edible plants could substantially contribute to food security and public health in Brazil. Their integration into local diets represents a sustainable approach to biodiversity utilization while addressing nutritional deficiencies. However, comprehensive studies are needed to fully characterize these species and develop strategies for their effective incorporation into food systems.

5. FUNDING/FINANCIAL DISCLOSURES

Leandro de Morais Cardoso was supported by Minas Gerais Research Support Foundation - FAPEMIG [APQ-00720-18].

6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

7. CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Rafaele Sobral Santos Nazareth, Noemi Lopes de Souza, Maiara Rodrigues Salvador, and Lucélia Vieira Pereira: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ceres Mattos Della Lucia: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Leandro de Morais Cardoso: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

8. DATA AVAILABILITY

Data included in article/supp. material/referenced in article.

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SUPPLEMENTARY TABLE

Table 1: Concentration maximum of elements in standard solution, wavelengths for analysis, LOD[a] and LOQ[b].

Element	Concentration maximum in standard solution (mg/L)	Wavelengths (nm)	LOD (µg/L)	LOQ (µg/L)
Ca	80	318	0.02	0.2
Fe	2.0	260	2	20
Mg	80	285	0.1	1
Mn	2.0	259	0.4	4
Cu	1.0	225	0.4	4
Zn	1.0	214	1	10
Se	0.5	196	50	500
Mo	0.5	202	3	30
Cr	0.5	268	2	20
P	39	214	30	300
K	100	405	20	200
Na	20	590	3	30
Cd	1.0	214	1	10
Al	1.0	308	3	30
Ni	1.0	232	6	60

[a] LOD: Limit of detection; [b] LOQ: Limit of quantification

4 CONSIDERAÇÕES FINAIS

As plantas alimentícias não convencionais analisadas (*B. pilosa*, *T. subulata*, *C. spicatus* e *T. fruticosum*) apresentam um perfil nutricional promissor, especialmente em suas folhas, com teores mais elevados de proteínas, minerais e vitaminas A, C e E em comparação com hortaliças convencionais. Além disso, essas espécies demonstraram significativa capacidade antioxidante, evidenciando seu potencial para a diversificação alimentar. No entanto, ainda existem lacunas substanciais no conhecimento sobre sua composição nutricional detalhada, especialmente para *T. subulata* e *C. spicatus*, bem como sobre os teores de compostos bioativos e antinutrientes. A escassez de estudos é ainda mais acentuada na análise dos caules de *T. fruticosum*, ressaltando a necessidade de investigações adicionais sobre as variações nutricionais entre diferentes partes dessas plantas.

Esses achados destacam a importância de incentivar o consumo de plantas alimentícias não convencionais como estratégia para fortalecer a segurança alimentar e a saúde pública. Sua inclusão na dieta contribui para o uso sustentável da biodiversidade brasileira, ao mesmo tempo em que estimula novas pesquisas para preencher lacunas existentes e favorecer sua integração nos sistemas alimentares.

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