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Caracterização físico-química e avaliação da viabilidade tecnológica de Plantas Alimentícias Não Convencionais disponíveis no Vale do Médio Rio Doce - MG

Governador Valadares
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Dissertação apresentada ao Programa Pós-Graduação em Ciências Aplicadas à Saúde da Universidade Federal de Juiz de Fora, como requisito parcial à obtenção do título de Mestre em Ciências da Saúde. Área de concentração: Biomateriais e Inovação em saúde.

Orientador: Leandro de Morais Cardoso
Coorientadora: Daniela da Silva Oliveira

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RESUMO

O Brasil é rico em biodiversidade com potencial alimentício e pouco é feito para valorização e uso real dessas riquezas nacionais. Caruru (*Amaranthus spinosus*), trapoeraba (*Commelina benghalensis*), coração-magoado (*Iresine herbstii*), ora-pro-nóbis (*Pereskia aculeata*) e beldroega (*Portulaca umbraticola*) são plantas alimentícias não convencionais disponíveis no território Vale do médio Rio Doce, Minas Gerais, Brasil. Entretanto, são escassos os estudos para conhecimento dos seus constituintes e aplicabilidade. Dessa forma, o objetivo deste estudo foi avaliar os componentes nutricionais da *A. spinosus, C. benghalensis, I. herbstii, P. aculeata* e *P. umbraticola*, e verificar a viabilidade tecnológica das farinhas de *I. herbstii*, *P. aculeata* e *P. umbraticola*. Foram realizadas análises da composição centesimal (proteínas, lipídeos, umidade, cinzas, fibra alimentar total e carboidratos), micronutrientes (carotenoides, vitamina E e vitamina C por Cromatografia Líquida de Alta Eficiência e minerais (P, Ca, Mg, Na, K, Fe, Mn, Cu, Cr, Se, Zn e Mo) por espectrometria de emissão atômica com plasma indutivamente acoplado), compostos fenólicos totais e atividade antioxidante (ABTS e DPPH). Também foi avaliado a viabilidade tecnológica (umidade, solubilidade, higroscopicidade, colorimetria, pH e tempo de molhabilidade) das farinhas elaboradas. As folhas de A. *spinosus* e *C. benghalensis* apresentaram elevados teores de umidade (>83,3 g/100g), β-caroteno (6,94 mg/100g) e minerais como potássio (>708,8 mg/100g) e ferro (>4,0 mg/100g). As folhas de *A. spinosus* também apresentaram alto teor de fibra alimentar (10,20 g/100g), baixo teor de lipídios e reduzido valor energético total. As folhas de *C. benghalensis* revelaram-se fontes de potássio (1399,31 mg/100g), cálcio (163 mg/100g) e ácido ascórbico (23,61 mg/100g). As farinhas apresentaram alto conteúdo de proteínas (>20g/100g), sendo a farinha de *P. umbraticola* fonte de ácido ascórbico (26,21 mg/100g) para adultos. Além disso, as farinhas avaliadas foram consideradas ricas em vitamina A (>1557,1 µg/100g). A *P. aculeata* desidratada apresentou redução da capacidade antioxidante e dos compostos fenólicos em comparação com as folhas *in natura*, sugerindo que os antioxidantes podem ter sido degradados durante o processamento térmico para produzir a farinha. Em termos de viabilidade tecnológica, todas as farinhas apresentaram características satisfatórias que as tornam adequadas para serem utilizadas na fabricação de outros alimentos. Este estudo demonstra o potencial nutricional e

tecnológico das plantas alimentícias não convencionais disponíveis no território Vale do médio Rio Doce, Minas Gerais, Brasil.

Palavras-chave: Cromatografia Líquida de Alta Eficiência; Capacidade antioxidante; ABTS; DPPH; Espectrometria de emissão atômica.

ABSTRACT

Brazil is rich in biodiversity with food potential, yet little is done to valorize and make real use of these national treasures. Caruru (*Amaranthus spinosus*), trapoeraba (*Commelina benghalensis*), coração-magoado (*Iresine herbstii*), ora-pro-nóbis (*Pereskia aculeata*), and beldroega (*Portulaca umbraticola*) are unconventional edible plants available in the Vale do Médio Rio Doce region of Minas Gerais, Brazil. However, there is a scarcity of studies to understand their constituents and applicability. Thus, the aim of this study was to assess the nutritional components of *A. spinosus, C. benghalensis, I. herbstii, P. aculeata,* and *P. umbraticola*, and to verify the technological feasibility of flours made from *I. herbstii, P. aculeata,* and *P. umbraticola*. Analyses were conducted on proximate composition (proteins, lipids, moisture, ash, total dietary fiber, and carbohydrates), micronutrients (carotenoids, vitamin E, and vitamin C by High-Performance Liquid Chromatography, and minerals (P, Ca, Mg, Na, K, Fe, Mn, Cu, Cr, Se, Zn, and Mo) by Inductively Coupled Plasma Atomic Emission Spectrometry, total phenolic compounds, and antioxidant activity (ABTS and DPPH). The technological viability (moisture, solubility, hygroscopicity, colorimetry, pH, and wetting time) of the produced flours was also evaluated. The leaves of *A. spinosus* and *C. benghalensis* exhibited high moisture content (>83.3 g/100g), β-carotene (6.94 mg/100g), and minerals like potassium (>708.8 mg/100g) and iron (>4.0 mg/100g). *A. spinosus* leaves also had a high content of dietary fiber (10.20 g/100g), low lipid content, and reduced total energy value. *C. benghalensis* leaves were found to be sources of potassium (1399.31 mg/100g), calcium (163 mg/100g), and ascorbic acid (23.61 mg/100g). The flours had a high protein content (>20g/100g), with *P. umbraticola* flour being a source of ascorbic acid (26.21 mg/100g) for adults. Additionally, the evaluated flours were considered rich in vitamin A (>1557.1 µg/100g). Dehydrated *P. aculeata* showed a reduction in antioxidant capacity and phenolic compounds compared to the fresh leaves, suggesting that antioxidants may have been degraded during the thermal processing to produce the flour. In terms of technological viability, all the flours exhibited satisfactory characteristics, making them suitable for use in the production of other foods. This study demonstrates the nutritional and technological potential of unconventional edible plants available in the Vale do Médio Rio Doce region of Minas Gerais, Brazil.

Keywords: High Performance Liquid Chromatography; Antioxidant capacity; ABTS; DPPH; Atomic emission spectrometry.

SUMÁRIO

1 INTRODUÇÃO

A nutrição humana é um direito fundamental à vida e a garantia desse direito dentro da capacidade do ecossistema se torna um desafio. A soberania alimentar é definida como o direito que os povos possuem de definirem as políticas, com autonomia sobre o que produzir, para quem produzir e em que condições produzir, sendo um princípio crucial para a garantia de segurança alimentar e nutricional (Brasil, 2006; Wittman, 2011; Milião, *et al*., 2022).

O Brasil possui uma rica biodiversidade, especialmente no que diz respeito à fitodiversidade com potencial alimentício. Entretanto, pouco é feito para valorização e uso real dessas riquezas (Kinupp, 2009). As alterações nos padrões alimentares caracterizados pelo elevado consumo de produtos industrializados e *fast-foods,* fez com que as pessoas perdessem o conhecimento sobre as propriedades dessa diversidade e o estímulo ao consumo fossem reduzidos (Heller; Keoleian; Willett, 2013).

As plantas alimentícias não convencionais (PANCs) são caracterizadas por plantas e partes de plantas que são comestíveis, entretanto, pouco utilizadas no cardápio alimentar das populações (Kinupp; de Barros, 2007). São plantas resistentes às mudanças ambientais, de fácil acesso e cultivo, baixo custo de produção e não dependem de fertilizantes ou derivados para seu desenvolvimento. Se destacam ainda por serem fontes potentes de proteínas, vitaminas, minerais, fibras alimentares e compostos bioativos que podem ser utilizados como aditivos alimentares, tratamento de doenças e promoção da saúde (Shahidi; Ambigaipalan, 2015; Moura, *et al.*, 2021). Dentre as PANCs que o Brasil possui, destacam-se o A*maranthus spinosus, Commelina benghalensis, Iresine herbstii, Pereskia aculeata* e *Portulaca umbraticola.*

Amaranthus spinosus L, conhecido popularmente como caruru (Figura 1) ou caruru-espinho, é uma planta originária das planícies tropicais da América do Sul e Central e foi introduzida em outras regiões do mundo de clima tropicais e subtropicais (Paniagua-Zambrana, *et al*., 2020). A planta pertence à família *Amaranthaceae* e é uma espécie herbácea anual, medindo cerca de 1,5 m de altura quando totalmente madura, apresentando caule robusto e avermelhado com axila-folha com um par fino de espinhos de até 2,5 cm de comprimento e flores verdes (Paniagua-Zambrana, *et al*., 2020). Informações sobre o perfil de

carotenoides, vitamina E e vitamina C nas folhas de *Amaranthus spinosus* são consideravelmente ausentes ou indisponíveis na literatura.

Figura 1 - Representação do Caruru (*Amaranthus spinosus*).

Fonte: Paisagismo Brasil, 2016.

Commelina benghalensis, conhecida como trapoeraba (Figura 2) ou trapoeraba-de-bengala, é um membro da família *Commelinaceae* e é nativa da Ásia tropical e subtropical e da África, tendo também sido amplamente introduzida em outras áreas do planeta, incluindo América do Norte e do Sul (Ezeabara, Chukwu, Okeke, 2019; Orni *et al*., 2018). A planta atinge a altura de até 50 cm de comprimento, apresentando pequenas flores violeta-azuladas, e possui folhas ovais a lanceoladas, com venação paralela, margens inteiras, além de pubescência cobrindo suas regiões superior e inferior (Ghosh *et al.,* 2019).

A *C. benghalensis* é uma planta perene considerada erva daninha devido a sua facilidade em se proliferar e dificuldade em seu controle (Webster *et al*., 2005). Pode ser encontrada em beiras de estradas, terrenos baldios, assentamentos e campos de cultivo. Suas folhas são amplamente utilizadas no tratamento de icterícia, picada de cobra, inflamações de pele, diarreia, febre e distúrbios mentais (Ghosh *et al.,* 2019). Segundo Batool e colaboradores (2020), a trapoeraba apresenta teores elevados de compostos bioativos, importantes para promoção da saúde e prevenção de doenças. Também é rica em β-caroteno, luteína e vitamina A, sendo estes, elementos importantes para prevenir deficiências nutricionais (Raju, *et al*., 2007).

Figura 2 - Representação da trapoeraba (*Commelina benghalensis*).

Fonte: Agrolink, 2023.

A *Iresine herbstii* (Figura 3) é uma planta alimentícia não convencional herbácea, originária da América do Sul, mais especificamente do Brasil, e presente atualmente em diversas partes do mundo, como áreas tropicais da Ásia e da Índia. Pertencente à família *Amaranthaceae*, subfamília *Gomphrenoideae* e do gênero *Iresine*, essa PANC é conhecida popularmente como coração-magoado, folha-sangue, planta-dinheiro, moela de galinha, folha de sangue de ervas e bife de vaca (Ribeiro, 2010; Dipankar; Murugan; Devi, 2011; Santacruz, 2011; Andleeb *et al*., 2020).

Figura 3 - Representação da coração-magoado (*Iresine herbstii*).

Fonte: Plants, 2023.

A planta coração-magoado é caracterizada morfologicamente por caule e folhas avermelhadas em formato de coração e de brilho acentuado. Durante o seu período de vida, pode medir de 1 a 2 metros de comprimento, apresentando ramificações em toda a sua extensão. Devido a sua presença notória oriunda de suas cores vibrantes e o seu fácil cultivo, a *I. herbstii* é amplamente utilizada de forma ornamental, decorando ambientes internos e externos, e também em combinação com outras plantas, contrastando com cores e texturas (Dipankar; Murugan; Devi, 2011; Fu; Huang; Lin, 2012; Chaudhuri; Sevanan, 2012; Santacruz, 2011).

As folhas de *I. herbstii* são largamente utilizadas na medicina popular, atuando como agente antimicrobiano, cicatrização de feridas, febre, problemas renais, anemias e tratamento de cânceres. Na Nigéria, além do consumo humano, essa planta é fornecida a animais, tais como gado e ovelhas, no intuito de aumentar a produção de sangue. Além disso, contêm substâncias bioativas que ajudam a prevenir doenças cardiovasculares que contribuem para a promoção da saúde. Spórna-Kucab *et al*., (2020) relatam seu alto potencial para uso como corante em produtos alimentícios, devido à presença elevada de betacianinas, sendo pigmentos vegetais naturais com função antioxidante. No norte dos Andes Peruanos, a *I. herbstii* é tradicionalmente utilizada em rituais para expulsar os maus espíritos do corpo e diagnosticar doenças. Embora seja uma planta promissora, são escassos os estudos na literatura sobre essa planta alimentícia não convencional (Nencini, *et al*., 2006; Dipankar; Murugan; Devi, 2011; Dipankar; Murugan, 2012; Chaudhuri; Sevanan, 2012; Nwezw; Nwachukwu; Adieme, 2016; Rahmayeni, *et al.,* 2021).

A *Pereskia aculeata* é uma planta alimentícia não convencional conhecida popularmente como ora-pro-nóbis (Figura 4), nativa do Brasil e presente em diversos países da América Latina (Pinto, *et al*., 2015). Seu nome significa “rogai por nós”, devido ao fato dos fiéis rezarem aos seus pés para obterem seus benefícios. Pode ser encontrada também pelo nome de rosa madeira, flor de maio, groselha de barbados, bredo-de-espinho e roseira brava (Conceição, *et al.,* 2014; Hoff, *et al*., 2022).

Figura 4 - Representação da ora-pro-nóbis (*Pereskia aculeata*).

Fonte: A planta da vez, 2020.

Caracteriza-se por ser uma cactácea trepadeira que pode chegar a atingir 10 metros de comprimento, apresentando ramos longos e espinhosos e folhas elípticas e carnosas (Barreira *et al*., 2020). A ora-pro-nóbis é uma planta perene e em sua floração, apresenta flores brancas e delicadas, e que dependendo da forma de manejo, condições de solo e clima, também pode apresentar frutos comestíveis de cores alaranjadas e sabor ácido quando maduros (Cruz, *et al*., 2020; Hoff, *et al*., 2022).

As folhas da ora-pro-nóbis são utilizadas na culinária há várias gerações, sendo conhecida como “carne de pobre” devido ao seu alto teor de proteínas e composição balanceada de aminoácidos. Suas folhas são consumidas refogadas, adicionadas a molhos, caldos, massas alimentícias, mexidos, recheios, saladas e omeletes. Elas também são utilizadas para a produção de farinhas incorporadas a diferentes preparações (De Almeida, *et al*., 2014; Barreira, *et al*., 2015; Garcia, *et al.,* 2019; Maciel; Yoshida; Goycoolea, 2019; Barreira, *et al*., 2020).

A *P. aculeata* é rica em proteínas, vitaminas A e C, fibras e minerais - destacando-se o cálcio e o ferro - e compostos bioativos, sendo mais elevados do que em plantas convencionais. Devido ao seu alto valor nutricional, seu consumo pode contribuir para o fortalecimento do sistema imunológico, combatendo os radicais livres do organismo e protegendo as células do estresse oxidativo,

resultando assim, na promoção da saúde dos indivíduos (Takeiti, *et al*., 2009; Garcia, *et al.,* 2019; Fink, *et al*., 2018; Barreira, *et al*., 2020).

A *Portulaca umbraticola* (Figura 5), também conhecida como beldroega, onze-horas e portulaca-do-campo, é uma planta alimentícia não convencional da família *Portulacaceae*, gênero *Portulaca*, que se encontra distribuída mundialmente, principalmente nas áreas subtropicais das Américas e da África (Coelho; Giulietti, 2010; Jia, *et al*., 2017; Sandí; Zúñiga; Carrodeguas, 2022).

Figura 5 - Representação da beldroega (*Portulaca umbraticola*).

Fonte: Unirio, 2023.

Originária da América do Sul, a *Portulaca umbraticola* caracteriza-se como uma planta herbácea, suculenta, com folhas carnudas e achatadas em formato obovada (De Melo, *et al*., 2023). Apresenta caules que variam de 10 a 50 cm de comprimento, variando sua cor entre o verde e o vermelho, dependendo do estágio de vida. Suas flores geralmente são únicas com cinco pétalas, alternando suas cores em vermelho, laranja, rosa, branco e amarelo. Devido à beleza de suas flores e o crescimento rápido, é frequentemente utilizada para fins ornamentais, tanto em vias públicas quanto em residências (Jia, *et al*., 2017; Passos, 2023).

Na culinária, a beldroega é utilizada de forma integral ou separada, seja suas folhas, flores, ramos e sementes. Pode ser consumida crua ou cozida em diversos pratos, principalmente em saladas (Passos, 2023). Além disso, possuem nutrientes essenciais e antioxidantes com funções importantes para a promoção da saúde.

Embora seja uma planta promissora, são escassos os estudos na literatura sobre essa planta alimentícia não convencional (De Melo, *et al*., 2023).

Amaranthus spinosus, Commelina benghalensis, Iresine herbstii, Pereskia aculeata e *Portulaca umbraticola* fazem parte da lista de plantas alimentícias não convencionais disponíveis no território do Médio Rio Doce, Minas Gerais, Brasil. Entretanto, não há dados na literatura sobre o perfil nutricional para comparar se ele é semelhante ao perfil observado em outras regiões e contribuir para um melhor aproveitamento e utilização dessas espécies como fonte nutricional.

Devido à lacuna técnico-científica existente a respeito dessa fitodiversidade, especialmente no que diz respeito a seus componentes e aplicabilidade em nível de comercialização, essas riquezas são pouco conhecidas e utilizadas no cotidiano alimentar das populações (Filho, 2015; Oliveira, *et al.,* 2019; De Jesus, *et al.,* 2020).

O consumo de frutas e vegetais pela maioria das populações ainda não atende às recomendações da Organização Mundial da Saúde para uma dieta saudável (Mason-d'croz, *et al.,* 2019; Kalmpourtzidou; Eilander; Talsma, 2020). Uma solução viável para aumentar a ingestão desses alimentos é a incorporação de frutas e vegetais desidratados na alimentação, haja vista a concentração de nutrientes. Essa técnica torna-se uma importante ferramenta para alcançar as ingestões diárias recomendadas, contribuindo para a promoção da saúde e a segurança alimentar (Huang, *et al.,* 2023).

Plantas com índices de umidade elevados possuem tempo de uso reduzido, devido à facilidade em deterioração por micro-organismo, necessitando de maiores cuidados pós-colheita. A secagem é um método comum, barato e rápido para conservar frutas e vegetais caracterizados por alto teor de umidade e perecibilidade, mantendo a qualidade e a segurança dos alimentos, resultando no produto seco e muito utilizado como farinhas (Tan, *et al.,* 2021; Huang, *et al.,* 2023).

A caracterização de plantas alimentícias não convencionais, tanto em seu estado *in natura*, quanto na forma desidratada, transformada em farinha, revela-se de extrema importância para fins de análise nutricional e para avaliar sua viabilidade tecnológica como ingrediente em produtos alimentícios futuros. Dessa forma, o conhecimento dessas PANCs é de suma importância, haja vista o potencial para a promoção da saúde pública, uma vez que estas espécies podem contribuir para a saúde da população, dieta e fornecimento de nutrientes essenciais. Além disso, ampliar as informações sobre os perfis nutricionais dessas PANCs pode contribuir

para aumentar a inclusão dessas plantas na dieta dos brasileiros, fortalecendo a soberania alimentar e a sustentabilidade ambiental.

1.1 Objetivos

1.1.1 Objetivo geral

Avaliar os constituintes químicos e a viabilidade tecnológica de plantas alimentícias não convencionais disponíveis no Vale do Médio Rio Doce, Minas Gerais, Brasil.

1.1.2 Objetivo específicos

- Avaliar a composição centesimal de cinco plantas alimentícias não convencionais disponíveis no Vale do Médio Rio Doce, Minas Gerais, Brasil.
- Determinar a concentração de compostos fenólicos totais e a atividade antioxidante das PANCs;
- Analisar a concentração de carotenoides, vitaminas (vitamina C e vitamina E) e minerais (P, Ca, Mg, Na, K, Fe, Mn, Cu, Cr, Se, Zn e Mo) das PANCs;
- Analisar a estabilidade dos compostos fenólicos totais, atividade antioxidante, carotenoides, vitamina E e vitamina C de farinhas elaboradas através da desidratação em estufa de três PANCs;
- Analisar a viabilidade tecnológica das farinhas elaboradas através da desidratação em estufa de três PANCs.

2 ARTIGOS CIENTÍFICOS

Os resultados dessa dissertação são organizados nos seguintes artigos científicos estruturados com base nas instruções aos autores preconizadas pelos respectivos periódicos.

Artigo científico 1: Nutritional aspects of non-conventional edible plants from Brazil: Caruru (*Amaranthus spinosus L*) and trapoeraba (*Commelina benghalensis*) de autoria de Pereira, *et al.,* 2023, publicado no periódico *Food Research International*, qualis CAPES Interdisciplinar A1.

Artigo científico 2: Aspectos nutricionais e viabilidade tecnológica de plantas alimentícias não convencionais do Brasil: coração-magoado (*Iresine herbstii*), ora-pro-nóbis (*Pereskia aculeata)* e beldroega (*Portulaca umbraticola*), para submissão no periódico *Nutrients,* qualis CAPES Interdisciplinar A1.

2.1 Artigo científico 1

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Nutritional aspects of non-conventional edible plants from Brazil: Caruru (*Amaranthus spinosus* L) and trapoeraba (*Commelina benghalensis*)

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ABSTRACT

Caruru (*Amaranthus spinosus* L) and trapoeraba (*Commelina benghalensis*) are NCEPs introduced into Brazil and are widely used by certain communities. Given the lack of information on carotenoids, vitamins, and minerals present in *A. spinosus* and *C. benghalensis* grown in Brazil, this study aimed to determine the proximate composition and the micronutrient profile of these two NCEPs obtained from family farming in the Middle Doce River (*Médio Rio Doce*) region in the state of Minas Gerais, Brazil. The proximate composition was evaluated using AOAC methods, vitamin E by HPLC with fluorescence detection, vitamin C and carotenoids by HPLC-DAD, and minerals by atomic emission spectrometry with inductively coupled plasma. In summary, the leaves of *A. spinosus* exhibited a high content of dietary fiber (10.20 g.100 g^{-1}), potassium (708.8 mg·100 g^{-1}), iron (4.0 mg·100 g^{-1}) and β-carotene (6.94 mg·100 g^{-1}), while the leaves of *C. benghalensis* were sources of potassium (1399.31 mg·100 g^{-1}), iron (5.7 mg·100 g^{-1}), calcium (163 mg·100 g^{-1}), zinc (1.3 mg·100 g^{-1}), ascorbic acid (23.61 mg·100 g^{-1}), and β-carotene (31.33 mg·100 g^{-1}). It was therefore concluded that *C. benghalensis* and *A. spinosus*, especially, presented excellent potential as important nutritional sources for human consumption, highlighting the gap existing between the available technical and scientific material, thus making them an important and necessary axis of research.

1. Introduction

Planet Earth has an enormous biodiversity with food potential which is still little explored. Of the approximately 300,000 known edible plant species, only 150 to 200 are used by humans, with 60% of the calories and protein obtained from ingesting plants coming from three main sources – rice, corn, and wheat (FAO, 2004). This limited consumption pattern restricted to only few species of plants, cultivated in specific areas of the planet, greatly diminishes the pillars of food security and the potential nutritional gains for human health, especially considering the autonomy of choice, availability, access, and use of these foods (Alonso, Cockx, & Swinnen, 2018).

One way to circumvent this problem is to popularize the use of non-conventional edible plants (NCEP), which are plants normally found in urban areas, especially in crevices on asphalt, backyards, sidewalks, and vacant lots. NCEPs may be native, exotic, spontaneous, wild, or cultivated, being traditionally consumed or used therapeutically in some regions or cultures, and have great economic and nutritional potential (Silva et al., 2021).

Brazil has one of the greatest biodiversity in the world, hosting such plants as *caruru* (*Amaranthus spinosus* L) and *trapoeraba* (*Commelina benghalensis*). These NCEP were introduced into the country and are recurrently cited by local family farmers from the Middle Doce River (*Médio Rio Doce*) region (Brazil) as used and important in human food. *A. spinosus* is a plant originating from the tropical lowland of South and Central America and was introduced into other tropical and subtropical

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regions of the world (Paniagua-Zambrana, Bussmann, Echeverría, & Romero, 2020). The plant belongs to the Amaranthaceae family and is an annual herbaceous species measuring around 1.5 m tall when fully mature, presenting a stout, reddish stem with the leaf-axil bearing a pair of fine spines up to 2.5 cm long, and green flowers (Paniagua-Zambrana et al., 2020). *C. benghalensis* is a member of the Commelinaceae family and is native to tropical and subtropical Asia and Africa, also having been widely introduced to other areas of the planet, including North and South America (Ezeabara, Chukwu, & Okeke, 2019; Orni, Shetu, Khan, Rashed, & Dash, 2018). The plant reaches a height up to 50 cm long, presenting small bluish-violet flowers, and has leaves that are ovate to lanceolate, with parallel venation, whole margins, as well as pubescence covering its top and bottom regions, (Ghosh, Dutta, Biswas, Biswas, Hazra, Nag, & Chatterjee, 2019).

Information on the profile of carotenoids, vitamin E, and vitamin C in *A. spinosus* and *C. benghalensis* leaves is, to the best of our knowledge, considerably lacking or unavailable in the literature. Some studies using samples collected from African and Asian have been evaluated to identify the proximate composition and mineral content of *C. benghalensis* (Ezeabara et al., 2019; El-Hamid & El Bous, 2019) and *A. spinosus* (Ogie-Odia, Mensah, Ehilen, & Eseigbe, 2022; Raman, Joshi, & Rana, 2022; Hassan et al., 2020; Oluwole Surukite, Makinde Sunday, Ogun Mautin, & Nwachukwu Ifeanyi, 2020; Hakizimana, Maniragaba, & Nshimiyimana, 2019; Sarker & Oba, 2019; Rjeibi, Ben Saad, Ncib, Souid, & Alimi, 2017).

Information about the nutritional profile of *A. spinosus* and *C. benghalensis* leaves cultivated in Brazil is still little known. Studies reveal extensive variability in the chemical composition of this NCEP when cultivated in different locations. Therefore, it is important to deepen the knowledge about the basic nutrient profile of *A. spinosus* and *C. benghalensis*, including macronutrients, vitamins, and minerals, due to the potential for the promotion of public health, since these species can contribute to the population's diet and supply of vital nutrient. In addition, expanding information on the nutritional profiles of these NCEPs can contribute to increasing the inclusion of these plants in the diet of Brazilians.

Given the lack of information on nutritional value of *A. spinosus* and *C. benghalensis* grown in Brazil, the objective of this study was to determine the proximate composition and the micronutrient profile (carotenoids, vitamin C, vitamin E, and minerals) of the *A. spinosus* and *C. benghalensis* obtained from family farming in the Middle Doce River region, in Minas Gerais, Brazil.

2. Materials and methods

2.1. Chemicals and reagents

Analytical-grade reagents purchased from VETEC (Brazil) were used for the extraction of carotenoids and vitamins. High-performance liquid chromatography (HPLC) grade reagents (acetone, hexane, isopropyl alcohol, and glacial acetic acid) purchased from Tedia (Brazil) were used for analyzing carotenoids and vitamins. For the analysis of the mineral profile, nitric acid (HNO_3) was purchased from Sigma Aldrich (Germany).

The carotenoids (α-carotene, β-carotene, β-cryptoxanthin, and lycopene) and vitamin C (ascorbic acid) standards were purchased from Sigma–Aldrich (USA). The vitamin E standards (α, β, γ, and δ-tocopherols and tocotrienols) were acquired from Calbiochem®, EMD Biosciences, Inc. (USA). Standard multi-element solutions of minerals were purchased from Merck (Brazil).

2.2. Collection and preparation of samples

The specimens of *A. spinosus* and *C. benghalensis* were collected in December 2018 on a tract of the family farm in the district of Chonim de Cima (latitude 18° 38′ 42″ S, and longitude 42° 2′ 16″ W), in the municipality of Governador Valadares, in Minas Gerais state, Brazil. To obtain each repetition, the collection area was divided into sub-areas, wherein in each sub-area, approximately 1 kg of the sample was collected from different plants.

The leaves were collected by a project researcher and by family farmers through the *Centro Agroecológico Tamanduá* (*CAT*), which provides technical advice and promotes rural extension to rural communities and agrarian reform settlements in the Middle Doce River region. The samples were identified with the help of specialized bibliography by a specialist in botany on the research team (Paniagua-Zambrana et al., 2020; Ghosh et al., 2019).

The plants were transported to the laboratory in polyethylene bags at room temperature. The intact leaves were selected and those with yellow or damaged parts were discarded. The selected leaves were then washed in running water for dirt remover and excess water was carefully removed with paper towels before being homogenized in a food processor (Philips, RI 7625 model, Brazil), packed in polyethylene bags, and stored in a freezer (−18 °C ± 1 °C). Vitamin analyses occurred within 48 h following the homogenization of the samples and the analyses of proximate composition within seven days after the former.

2.3. Proximate composition analysis

Moisture, ash, protein, lipids, and total dietary fiber (AOAC, 2016) were determined in fresh leaves. Moisture was determined using an oven at 105 °C and ash was quantified using a muffle furnace (Quimis, Q320M model, Brazil) at 550 °C. Protein content was determined by the micro Kjeldahl method; total dietary fiber by the gravimetric non-enzymatic method, respectively, while lipid concentration was performed in a Soxhlet extractor (Eletrothermo, 500WX model, Brazil). The carbohydrates were estimated using the following equation:

100 - (% moisture - % lipids - % protein - % of total dietary fiber - % ash).

The total energy value was estimated considering the conversion factors of 4 kcal.g^{-1} of proteins or carbohydrates, and 9 kcal.g^{-1} of lipids (Mahan & Raymond, 2018). The results of proximate composition were expressed in grams per hundred grams of fresh sample (g.100 g^{-1}).

2.4. Extraction and analysis of minerals

The leaves frozen were subjected to the lyophilization process in equipment (Freezone 6 model, Labconco brand), at a pressure of 1 mbar and a temperature of 60 °C for 72 h. Approximately 1 g of lyophilized samples were digested in tubes containing nitric acid according to Ekholm et al. (2007). The content of minerals and trace elements (Na, Mg, Al, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Se, Mo, and Cd) was analyzed by inductively coupled plasma atomic emission spectrometry (Optima 3300 DV, Perkin Elmer, USA). The analysis was performed under the following conditions: 1300 W of power, plasma argon flow rate of 15 L·min^{-1}, auxiliary argon flow rate of 0.7 L·min^{-1}, nebulizer argon flow rate of 0.5 L·min^{-1}, and rate of sample introduction of 1.5 mL·min^{-1}. The following analytical wavelengths were employed: Na at 590 nm, Mg at 285 nm, Al at 308 nm, K at 405 nm, Ca at 318 nm, Cr at 268 nm, Mn at 259 nm, Fe at 260 nm, Ni at 232 nm, Cu at 255 nm, Zn at 214 nm, Se at 196 nm, Mo at 202 nm, and Cd at 214 nm.

Standard multi-element solutions were used for quantifying the components in the samples. The maximum concentration of elements in the standard solution was as follow: K 100 mg·mL^{-1}; Mg and Ca 80 mg·mL^{-1}; Na 20 mg·mL^{-1}; Mn and Fe 2 mg·mL^{-1}; Al, Ni, Cu, Zn, and Cd 1 mg·mL^{-1}; Cr, Se, and Mo 0.5 mg·mL^{-1}. The analytical curves, with R^2 greater than 0.982, were obtained from the analysis of six standard multi-element solutions with different concentrations. The results of mineral content were expressed in milligrams per hundred grams of fresh sample (mg·100 g^{-1}).

2.5. Extraction and analysis of carotenoids, vitamin C, and vitamin E

During the extraction and analysis of carotenoids and vitamins, the fresh leaves and extracts were kept protected from solar and artificial lights by using amber glass, aluminum sheets, and blackout curtains. Additionally, the extracts were protected from oxygen using flasks with lids in a nitrogen environment.

The carotenoids (i.e., α-carotene, β-carotene, β-cryptoxanthin, and lycopene) were extracted in acetone and transferred to petroleum ether (Rodríguez-Amaya, Kimura, Godoy, & Amaya-Farfan, 2008). The chromatographic conditions used for carotenoid analyses included a HPLC system (Shimadzu, SCL 10AT VP, Japan) with detection by diode-array (Shimadzu, SPD-M10A, Japan) at 450 nm, a Phenomenex Gemini RP18 chromatographic column (250 mm × 4.6 mm, 5 μm) equipped with a Phenomenex ODS (C18) guard column (4 mm × 3 mm); the mobile phase consisting of methanol: ethyl acetate: acetonitrile (70:20:10, v/v/v), with a flow of 1.7 mL·min^{-1} and a running time of 11 min (Pinheiro-Sant'Ana et al., 2011).

The extraction of ascorbic acid (AA) and conversion of AA to dehydroascorbic acid (DHA) were performed in a buffer solution of 3% metaphosphoric acid, 8% acetic acid, 0.3 N sulfuric acid, and 1 mM EDTA (Campos, Ribeiro, Della Lucia, Pinheiro-Sant'Ana, & Stringheta, 2009). The chromatographic conditions used included a HPLC-DAD system, detection at 250 nm; chromatographic column RP-18 Synergi Hydro 100 (250 mm × 4 mm, 4 μm) equipped with a Phenomenex ODS guard column (C18) (4 mm × 3 mm); mobile phase composed of ultrapure water containing NaH_2PO_4, 1 mM EDTA and adjusted to pH 3.0 with H_3PO_4; the flow of the mobile phase of 1.0 mL·min^{-1} and a running time 7 min.

The vitamin E isomers (α-, β-, γ- and δ-tocopherol and tocotrienol) were extracted with a solution of hexane: ethyl acetate (85:15, v/v) (Pinheiro-Sant'Ana et al., 2011). The chromatographic conditions used for the analyses included a HPLC system (Shimadzu, SCL 10AD VP, Japan), a fluorescence detector (Shimadzu, RF-10A XL, Japan) with excitation at 290 nm and emission at 330 nm; Phenomenex Luna SI100 chromatography column (250 mm × 4 mm, 5 μm) equipped with a Phenomenex SI100 guard column (4 mm × 3 mm); mobile phase composed of hexane: isopropanol: glacial acetic acid (98.9: 0.6: 0.5, v/v/v) continuously degassed with helium gas; mobile phase flow of 1 mL·min^{-1} and a running time 20 min.

Qualitative identification of the compounds was performed by comparing the retention times obtained for standards and samples analyzed under the same conditions. Additionally, the vitamin E isomers were identified by co-chromatography, while the carotenoid isomers and AA were identified by comparing the absorption spectra of the standard and the peaks of interest in the samples using the DAD.

External standard curves constructed by injection, in duplicate, of six increasing concentrations of standard solutions which were used for quantifying the compounds. Regression equations were obtained from the correlation between the peak areas and the concentrations of each injected compound. The final concentration was obtained by correcting calculations for the dilutions and concentrations performed during the extraction and analysis procedures.

2.6. Nutritional value of the NCEPs as source of nutrients

The plants were classified as "sources" of a nutrient if 50 g of fresh leaves provide 5–10% of the Dietary Reference Intake (DRI), as "good sources" if they provide 10–20% of the DRI and as "excellent sources" if supplying more than 20% of the DRI (Philippi, 2008).

2.7. Quality control of analytical methods of minerals, carotenoids and vitamins

The methods used to analyze minerals and vitamins were previously validated for repeatability, and recovery (Campos et al., 2009; Gomes & Oliveira, 2011; Pinheiro-Sant'Ana et al., 2011; Paula Filho et al., 2015; Rodriguez-Amaya, Kimura, & Amaya-Farfan, 2008). Additionally, the limit of detection (LOD) was done by successive dilutions of the minerals, carotenoid, and vitamin standards followed by the determination of the smallest detectable amount as three times the value of the amplitude of the baseline noise. The limit of quantification (LOQ) was considered as being 10 times the LOD (Catharino, Godoy, & Lima-Pallone, 2006). Considering carotenoids and vitamins, LOD ranged between 0.021 and 12.321 μg.mL^{-1}, and LOQ ranged from 0.251 to 123.24 μg.mL^{-1}, while for minerals, LOD ranged from 0.02 to 50 μg.mL^{-1}, and LOQ from 0.2 to 500 μg.mL^{-1} (supplementary material). The linearity range of the compounds analyzed presented ratios greater than 60 times between the maximum and minimum injected concentrations, and the correlation coefficients (R^2) were greater than 0.997.

2.8. Experimental design and statistical analysis of the data

All chemical analyses were performed in three repetitions. Descriptive statistics (means and standard deviations) were performed for each parameter. To evaluate the linearity range of the analytical patterns of carotenoids, vitamins, and minerals, the data obtained after the analysis (peak areas or absorbances) and the concentrations of each compound were used for linear regression analysis and the calculation of the determination coefficient (R^2). Statistical analyses were performed using the SPSS software.

3. Results and discussion

3.1. Proximate composition

Information on the proximate composition of Brazilian specimens of *A. spinosus* and *C. benghalensis* is considerably scarce in the literature (Table 1). This demonstrates the incipience of information regarding basic aspects of these plants and reinforces the necessity for research that seeks to expand knowledge about their chemical constituents while valuing the cultural heritage related to the use of plants as food.

The leaves of *A. spinosus* and *C. benghalensis* presented high moisture content, which contributes to their faster deterioration, thus reducing their shelf life (Hasan et al., 2019). As such, the insertion and use of these non-conventional edible plants in the human diet require care in post-harvest handling, with storage under refrigeration or consumption within a few hours following harvest.

C. benghalensis leaves had approximately twice less fiber, protein, and ash, with about twice as many carbohydrates and lipids as observed in the leaves of *C. benghalensis* and *C. diffusa* harvested from Nigerian soil (Ezeabara et al., 2019). Regarding *A. spinosus*, the proximate composition was similar to that observed in *A. spinosus* leaves harvested in Bangladesh (Sarker & Oba, 2019).

The leaves of *C. benghalensis* and, mainly, of *A. spinosus* exhibited a

Table 1
Proximate composition and total energy value of leaves of *Amaranthus spinosus* and *Commelina benghalensis* (Governador Valadares, Brazil).

Variables[a]	Content (Mean ± SD[c])	
	A. spinosus	*C.benghalensis*
Moisture (g.100 g^{-1})	83.30 ± 2.43	83.39 ± 3.50
Total dietary fiber (g.100 g^{-1})	10.20 ± 1.23	1.30 ± 0.09
Ash (g.100 g^{-1})	5.18 ± 0.79	0.98 ± 0.01
Lipids (g.100 g^{-1})	0.47 ± 0.03	1.44 ± 0.09
Carbohydrates (g.100 g^{-1}) [d]	0.85 ± 0.05	10.99 ± 1.46
Proteins (g.100 g^{-1})	5.40 ± 0.98	1.90 ± 0.20
Total Energy Value (kcal.100 g^{-1}) [d]	29.23 ± 1.50	64.52 ± 4.52

[a]Values expressed on a wet basis.
[b]Mean of 3 repetitions.
[c]Standard deviation.
[d]Estimated content.

low lipid content and reduced total energy value, which permits the inclusion of these plants in low-fat and low-calorie diets. The leaves of *A. spinosus* were also revealed to be a good source content of dietary fiber. This content was four to ten times higher than that observed in conventional leafy vegetables recognized as sources of fiber by the population, such as lettuce (*Lactuca sativa)* and watercress (*Nasturtium officinale*) (NEPA, 2011). Dietary fibers are carbohydrates that provide beneficial effects for the homeostasis of human body systems, contributing especially to a reduction in the risk of developing obesity and metabolic diseases (O'Grady, O'Connor, & Shanahan, 2019; Cronin, Joyce, O'Toole, & O'Connor, 2021). Thus, as a source of dietary fiber, *A. spinosus* can be an important ally to human health.

3.2. Minerals

In nutritional terms, the consumption of 50 g of fresh leaves of *A. spinosus* can contribute to supplying more than 20% of the iron recommendations and approximately 10% of the potassium recommendations for a male adult aged between 19 and 30 years (IOM, 1997,2001,2004) (Table 2). The same amount of *C benghalensis* can supply between 5 and 10% of the daily recommendation of calcium and zinc; 14% and 35% of the potassium and iron recommendations, respectively.

In addition, samples of *A. spinosus* and *C. benghalensis* showed as manganese in content that can supply between 5 and 10% of the recommendations for this nutrient. Finally, potentially harmful minerals such as aluminum and nickel were detected, however, in unquantifiable concentrations. The mineral profile observed in *A. spinosus* and *C. benghalensis* demonstrated the potential of these plants to reduce the risk of developing hidden hunger, characterized by malnutrition of micronutrients such as iron, iodine, and zinc (FAO, 2018). In this way, they can provide a diversity of essential minerals for the proper maintenance of healthy tissues and the normal functioning of the human body, without exposure to harmful minerals.

C. benghalensis collected within the territory of the Middle Doce River region contained more iron and potassium than plants from Nigeria (Umoh, Dan, & Etim, 2014) (7.98 mg·100 g^{-1} and 2.08 mg·100 g^{-1}, respectively). These authors identified even higher levels of calcium, magnesium, copper, manganese, and zinc in plants harvested from Nigerian soil (1431.6 mg·100 g^{-1}; 220.8 mg·100 g^{-1}; 2.72 mg·100 g^{-1}; 7.98 mg·100 g^{-1}; 2.68 mg·100 g^{-1}, respectively).

Compared to *A. spinosus* collected in Bangladesh (Sarker & Oba, 2019), the Brazilian samples had similar values of potassium (645 mg·100 g^{-1}) and an iron concentration approximately three times higher (1.49 mg·100 g^{-1}). However, they had lower levels of calcium (268 mg·100 g^{-1}), manganese (0.97 mg·100 g^{-1}), magnesium (288 mg·100 g^{-1}), copper (0.137 mg·100 g^{-1}), molybdenum (0.035 mg·100 g^{-1}), and zinc (1135 mg·100 g^{-1}).

Mineral analysis revealed high variability in the content of these nutrients between plants from different locations, which may be due to differences in climate, management, water condition, and nutrition of the soil where the samples were collected. As an example, we cite the fact that the samples of *A. spinosus* from the territory of the Middle Doce River region grew naturally, without human interference in their development, whereas those analyzed by Sarker and Oba (2019) were cultivated in an experimental area, with fertilizer, irrigation and weed control.

Table 2
Mineral content in leaves of *Amaranthus spinosus* L and *Commelina benghalensis* (Governador Valadares, Brazil).[a,b]

Minerals	Mineral content in mg·100 g^{-1} (Mean ± SD[c])		DRI[e] (mg)
	A. spinosus	*C. benghalensis*	
Calcium	85.7 ± 6.1	163 ± 12.3	1000
Iron	4.0 ± 0.2	5.7 ± 0.37	8
Magnesium	13.7 ± 0.9	25.5 ± 1.8	355
Manganese	0.22 ± 0.01	0.19 ± 0.01	2.3
Selenium	0.002 ± 0.0001	0.001 ± 0.0001	0.055
Copper	0.05 ± 0.008	0.02 ± 0.001	0.9
Molybdenum	0.002 ± 0.0000	0.0001 ± 0.0000	0.045
Zinc	0.94 ± 0.02	1.3 ± 0.06	11
Sodium	5.1 ± 0.4	10.2 ± 0.8	1500
Potassium	708.8 ± 31.7	1399.31 ± 63.4	4700
Chrome	0.001 ± 0.000	0.001 ± 0.000	0.035
Aluminum	Trace	Trace	–
Cadmium	0.001 ± 0.000	0.001 ± 0.000	–
Nickel	Trace	Trace	–

[a]Values expressed on a wet basis.
[b]Mean of 3 repetitions.
[c]Standard Deviation.
[d]Not detected.
[e]Dietary Reference Intakes for a male adult aged between 19 and 30 years.

3.3. Carotenoids and vitamins

3.3.1. Qualitative composition

Analysis methods permitted a good resolution of the peaks, which assured adequate quantification of the compounds in the leaves of *C. benghalensis* and *A. spinosus* (Fig. 1A-E). Importantly, information on the chromatographic profiles of the carotenoid and vitamin analyses in leaves of *C. benghalensis* and *A. spinosus*, obtained by HPLC, is not available in the literature, which did not allow comparisons to be made with the chromatographic profiles achieved in this study.

Vitamin and carotenoid profiles in leaves of *A. spinosus* and *C. benghalensis* were similar in regards to the presence of α-tocopherol (RT: 5.4 min), γ-tocopherol (RT: 8.8 min), δ-tocopherol (RT: 16.8 min), β-cryptoxanthin (RT: 3.5 min), and β-carotene (RT: 9.05 min). Ascorbic acid (RT: 3.4 min) and γ-tocotrienol (RT: 19.9) were identified only in *C. benghalensis*.

3.3.2. Contents of carotenoids and vitamins

There are few reports in the literature on the concentration of carotenoids, vitamin C, and vitamin E in leaves of *C. benghalensis* and *A. spinosus* obtained with robust methodologies, such as HPLC. The scarcity of this information highlights the importance of further studies in the area, especially the NCEP present in the micro-region of the Middle Doce River.

The leaves of *C. benghalensis* showed total contents of vitamin C, E, and carotenoids in higher levels than those found in *A. spinosus* (Table 3). However, the latter stood out with a higher content of α-tocopherol, the only homolog with function of vitamin E and which also acts as an antioxidant, thus preventing disorders related to oxidative stress (Primo et al., 2021). The α-tocopherol content of both plants was at least three times higher than that found in lettuce (*Tetragonia expansa*) and spinach (*Brassica oleracea)* (1.83 and 1.52 mg·100 g^{-1}, respectively) (TBCA, 2020), which are among the leafy vegetables with the highest contents of this vitamin.

Regarding vitamin C and carotenoids, the contents observed in this study places the leaves of *C. benghalensis* as a rich source of these compounds, while the leaves of *A. spinosus* were presented as a valuable source of β-carotene. The antioxidant and anti-inflammatory properties of nutrients such as β-carotene and ascorbic acid contribute to the regulation of free radicals and, thus, can help in inhibiting cellular oxidation. These biological functions are important factors in the prevention of premature aging, diabetes, atherosclerosis, and tumors (Jayedi, Rashidy-Pour, Parohan, Zargar, & Shab-Bidar, 2018; Johra, Bepari, Bristy, & Reza, 2020). Therefore, by presenting relevant contents of these compounds, these NCEPs can aid in reducing the dysregulation of the body's oxidative balance and, therefore, the pathogenesis of certain chronic diseases.

Vitamin C was not detected in the leaves of *A. spinosus*, differing from the study carried out by Sarker and Oba (2019), who found 44.62 mg·100 g^{-1} of the vitamin. It is noteworthy that the analysis performed

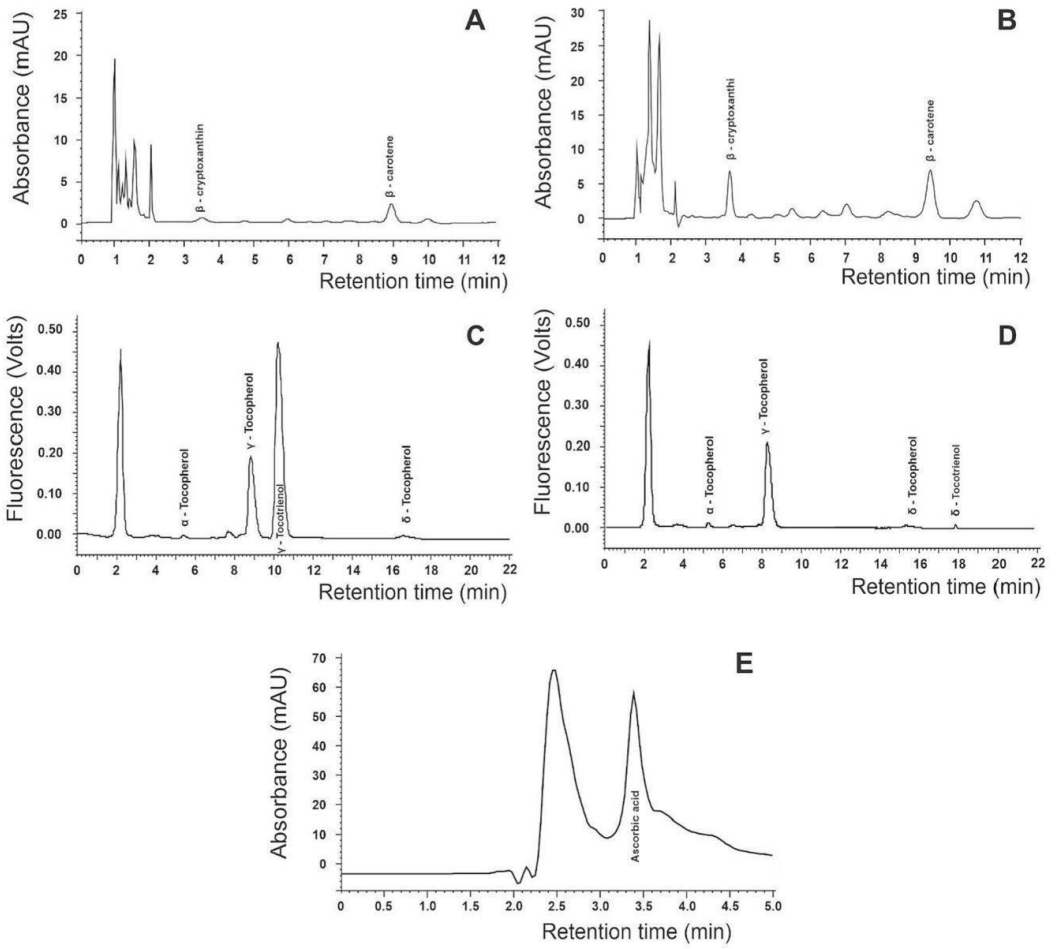

Fig. 1. HPLC analysis of carotenoids (A) and vitamin E (C) in leaves of *A. spinosus*; and carotenoids (B), vitamin E (D), and vitamin C (E) in leaves of *C. benghalensis* (Governador Valadares, Minas Gerais, Brazil). Chromatographic conditions: as described in the Material and methods section.

by Sarker and Oba (2019) was spectrophotometry, which is less sensitive in the exact identification of compounds compared to high-performance liquid chromatography. On the other hand, *C. benghalensis* showed a high content of vitamin C, and the consumption of 50 g of fresh leaves of this plant can provide 13.14% of the recommended daily values of these nutrients for an adult male between 19 and 30 years of age (IOM, 2000).

The vitamin C content in *C. benghalensis* was lower than that found in *Commelina diffusa* Burm harvested from Indian soil (44.80 mg·100 g^{-1}) (Kamble, 2019), and about 50–80% lower than that observed in broccoli (*Brassica oleracea*) and watercress (*Nasturtium officinale*) (34.3 mg·100 g^{-1}; 60.1 mg·100 g^{-1}, respectively) (NEPA, 2011). It is noteworthy, therefore, that broccoli and watercress are conventional edible plants widely recognized as important sources of vitamin C.

The leaves of *C. benghalensis* showed a higher concentration of carotenoids than the leaves of *A. spinosus*, with a predominance of β-carotene. In a study carried out with *C. benghalensis* harvested in Nigeria, a β-carotene equivalent content was found to be 7 times higher. Nevertheless, the study did so by using an analytical spectrophotometric method which is not able to discriminate between the contents of each isomer of carotenoids, as was achieved in our study. Finally, *C. benghalensis* exhibited a lower β-carotene content than that reported by Raju, Varakumar, Lakshminarayana, Krishnakantha, and Baskaran (2007) in a study with Indian plants analyzed by HPLC (92.82 mg·100 g^{-1}).

The observed contents place the leaves of *C. benghalensis* as being rich in ascorbic acid and β-carotene, and the leaves of *A. spinosus* as rich in β-carotene, which are important nutrients in the control of oxidative stress and inflammatory diseases, contributing to the prevention of premature aging, diabetes, atherosclerosis, and tumors (Jayedi et al., 2018; Johra et al., 2020). Therefore, by presenting relevant contents of these compounds, these NCEPs can help to reduce the risk of imbalance in the body's oxidative balance and its potential consequences.

4. Conclusions

The leaves of *A. spinosus* and *C. benghalensis* showed high levels of

Table 3
Carotenoid and vitamin composition of *Amaranthus spinosus* and *Commelina benghalensis leaves* (Governador Valadares, Brazil).[a,b]

Compounds	Content (Mean ± SD[c])		*DRI*[e]
	A. spinosus	*C. benghalensis*	
Vitamin E Total (*μg.100 g*$^{-1}$)	22.23 ± 0.23	24.79 ± 0.23	–
α-tocopherol (μg.100 g^{-1})	7.75 ± 0.20	4.64 ± 0.61	15.000 μg
α-tocotrienol (μg.100 g^{-1})	ND[d]	ND[d]	–
β-tocopherol (μg.100 g^{-1})	ND[d]	ND[d]	–
β-tocotrienol (μg.100 g^{-1})	ND[d]	ND[d]	–
γ-tocopherol (μg.100 g^{-1})	6.87 ± 0.55	10.75 ± 0.30	–
γ-tocotrienol (μg.100 g^{-1})	4.34 ± 0.13	ND[d]	–
δ-tocopherol (μg.100 g^{-1})	3.27 ± 0.02	0.71 ± 0.03	–
δ-tocotrienol (μg.100 g^{-1})	ND[d]	8.69 ± 0.39	–
Total vitamin C	ND[d]	23.61 ± 1.09	–
Ascorbic acid (mg·100 g^{-1})	ND[d]	23.61 ± 1.09	90 mg
Dehydroascorbic acid (mg·100 g^{-1})	ND[d]	ND[d]	–
Total carotenoids (mg·100 g^{-1})	7.19 ± 3.61	31.97 ± 4.42	–
α-carotene (mg·100 g^{-1})	ND[d]	ND[d]	–
β-carotene (mg·100 g^{-1})	6.94 ± 5.13	31.33 ± 6.29	–
β-cryptoxanthin (mg·100 g^{-1})	0.25 ± 0.01	0.64 ± 0.04	–
Lycopene (mg·100 g^{-1})	ND[d]	ND[d]	–

[a] Values expressed on a wet basis.
[b] Mean of 3 repetitions.
[c] Standard Deviation.
[d] Not detected.
[e] Dietary Reference Intakes for a male adult aged between 19 and 30 years.

moisture, β-carotene and minerals such as potassium and iron. The leaves of *A. spinosus* also presented a high content of dietary fiber, a low content of lipids, and a reduced total energy value. The leaves of *C. benghalensis* proved to be sources of potassium, calcium and ascorbic acid.

Given the approach of the present study, non-conventional edible plants, especially *A. spinosus* and *C. benghalensis*, present themselves as excellent nutritional and functional sources for human consumption. The gap between existing technical and scientific material was also highlighted in this work, demonstrating their importance and applicability in this area of research, since they permit the detection of important nutrients while accurately discriminating these constituents. In sum, the contributions made by this study can stimulate the consumption of these plants, valuing their cultural heritage as traditional food items.

CRediT authorship contribution statement

Lucélia Vieira Pereira: Investigation, Writing – original draft, Writing – review & editing. **Maiara Rodrigues Salvador:** Investigation, Writing – original draft, Writing – review & editing. **Beatriz Souza Silva:** Investigation, Writing – original draft. **Helena Maria Pinheiro-Sant'Ana:** Resources, Funding acquisition. **Ceres Mattos Della Lucia:** Resources, Writing – review & editing, Funding acquisition. **Reinaldo Duque Brasil Landulfo Teixeira:** Resources, Writing – review & editing, Funding acquisition. **Leandro de Morais Cardoso:** Conceptualization, Formal analysis, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodres.2023.112583.

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Article

Nutritional aspects and technological viability of unconventional food plants from Brazil: coração-magoado (*Iresine herbstii*), ora-pro-nóbis (*Pereskia aculeata*), and beldroega (*Portulaca umbraticola*)

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Abstract: Brazil is rich in biodiversity with food potential, yet little is done to appreciate and utilize these national riches. Coração-magoado (*Iresine herbstii*), ora-pro-nóbis (*Pereskia aculeata*), and beldroega (*Portulaca umbraticola*) are unconventional food plants available in the Vale do Médio Rio Doce, Minas Gerais, Brazil. However, there is a scarcity of studies to understand their constituents and applicability. Therefore, the aim of this study was to evaluate the nutritional and bioactive components of *I. herbstii, P. aculeata*, and *P. umbraticola*, and assess the technological feasibility of their flours. Analyses were conducted for proximate composition (proteins, lipids, moisture, ash, and carbohydrates), micronutrients (carotenoids, vitamin E, and vitamin C), total phenolic compounds, and antioxidant activity (ABTS and DPPH). Technological viability (moisture, solubility, hygroscopicity, colorimetry, pH, and wettability time) of the developed flours was also assessed. The flours showed a high protein content, with *P. umbraticola* flour considered a source of ascorbic acid for adults. Furthermore, the evaluated flours are considered rich in vitamin A. Dehydrated *P. aculeata* showed a reduction in antioxidant capacity and phenolic compounds compared to fresh leaves, suggesting that antioxidants may have degraded during thermal processing to produce the flour. In terms of technological viability, all flours exhibited satisfactory characteristics, making them suitable for use in the manufacture of other foods. This study demonstrates the nutritional potential of fresh leaves and flours from unconventional food plants available in the Vale do Médio Rio Doce, Minas Gerais, Brazil.

Keywords: High-Performance Liquid Chromatography; Antioxidant Capacity; ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid)); DPPH (2,2-diphenyl-1-picrylhydrazyl); Atomic Emission Spectrometry.)

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1. Introduction

Unconventional food plants (UFPs) are characterized by plants and plant parts that are edible but are underutilized in the diets of populations (Kinupp; de Barros, 2007). These plants are resilient to environmental changes, easily accessible and cultivated, have low production costs, and do not depend on fertilizers or derivatives for their development. They also stand out as sources of proteins, vitamins, minerals, dietary fibers, and bioactive compounds essential for the prevention, promotion, and recovery of human health (Shahidi; Ambigaipalan, 2015; Moura, et al., 2021).

Brazil is a country with unparalleled botanical wealth, housing a vast diversity of UFPs such as *Iresine herbstii* (coração-magoado), *Portulaca umbraticola* (beldroega), and *Pereskia aculeata* (ora-pro-nobis), whose nutritional properties and culinary potential remain largely unexplored (Oliveira, et al., 2019; De Jesus, et al., 2020). I. herbstii is an herbaceous plant often used for indoor and outdoor decoration (Dipankar; Murugan; Devi, 2011; Fu, Huang & Lin, 2012). On the other hand, P. aculeata and P. umbraticola, UFPs native to Brazil, although more recognized by the population and used in human nutrition, are still underutilized in urban populations despite their unique characteristics and ability to enrich the diet with essential nutrients (Filho, 2015; De Jesus, et al., 2020).

Among the factors contributing to the underutilization of UFPs is a lack of knowledge about their nutritional benefits and the various ways to incorporate them into everyday diets. Additionally, the perception that they are "weeds" or "wild herbs" hinders acceptance and consumption, associating them with something outside the dietary norm. Lastly, the lack of commercialization and challenges in preservation due to perishability impede their availability (Moura, et al., 2021; Milião, et al., 2022). One strategy to promote UFP consumption is the transformation of fresh plants into flour, expanding their usage possibilities and making them more accessible, encouraging inclusion in diets, and consequently exploring their health benefits.

It is known that the cultivation location influences the nutritional value of plants due to various interconnected factors, including soil quality, climatic conditions, management practices, altitude, and cultivation season (Zhang, et al., 2021). There is a scarcity of data in the literature regarding the nutritional profile and technological feasibility of these UFPs to compare whether they are similar to profiles observed in other regions, contributing to better utilization of these species as a nutritional source. Due to the existing technical-scientific gap regarding this phytodiversity, especially concerning its components and commercial applicability, these riches are poorly known and utilized in the daily diets of populations (Filho, 2015; Oliveira, et al., 2019; De Jesus, et al., 2020; Hoff, et al., 2022).

The consumption of fruits and vegetables by the majority of populations still does not meet the World Health Organization's recommendations for a healthy diet (Mason-d'croz, et al., 2019; Kalmpourtzidou; Eilander; Talsma, 2020). A viable solution to increase the intake of these foods is the incorporation of dehydrated fruits and vegetables into diets due to nutrient concentration. This technique becomes an important tool to achieve recommended daily intakes, contributing to health promotion and food security (Huang, et al., 2023).

Plants with high moisture content have a reduced usage time due to the ease of deterioration by microorganisms, requiring greater post-harvest care. Drying is a common, inexpensive, and rapid method to preserve fruits and vegetables characterized by high moisture content and perishability, maintaining the quality and safety of food, resulting in a widely used dried product such as flour (Tan, et al., 2021; Huang, et al., 2023).

The characterization of unconventional food plants, both in their fresh and dehydrated forms transformed into flour, is of utmost importance for nutritional analysis and to assess their technological feasibility as ingredients in future food products. This approach aims to promote the appreciation of cultural heritage associated with food and encourage the consumption of these foods. In this regard, the objective of this research was to evaluate the chemical constituents and technological feasibility of

unconventional food plants available in the Vale do Médio Rio Doce, Minas Gerais, Brazil.

2. Materials and Methods

2.1 Chemicals and reagents

All chromatographic analyses were conducted using HPLC-grade solvents purchased from Tedia (Brazil), including acetone, hexane, isopropanol, and glacial acetic acid. The remaining reagents were all of analytical grade and obtained from VETEC (Brazil).

For the analysis of carotenoids and vitamin C, standards (α-carotene, β-carotene, and ascorbic acid) were obtained from Sigma-Aldrich (USA). Vitamin E standards (α, β, γ, and δ-tocopherols and tocotrienols) were acquired from Calbiochem® (USA). The standard solution for multielement mineral analysis was procured from Merck (Brazil). For the analysis of antioxidant activity and total phenolic compounds, trolox and gallic acid standards were acquired from Sigma-Aldrich (USA).

2.2 Sample Collection

Samples of I. *herbstii, P. aculeata,* and *P. umbraticola* were collected from January to July 2023 in the Vale do Médio Rio Doce region, state of Minas Gerais, Brazil, covering both urban (-18º51′26″S 41º57′07″W; -18º52′27″S 41º57′00″W) and rural areas (-18º51′28″S 41º50′20″W). For each species, approximately 2.5 kg of samples from distinct plant areas were collected.

Species identification was performed by one of the researchers, an expert in botany, with the assistance of specialized literature (Kinupp; Lorenzi, 2014; Botrel et al., 2017).

2.3 Sample Processing

The samples were transported to the laboratory in polyethylene bags with laminated layers at room temperature. Subsequently, branches and leaves with defects and injuries were discarded, and the selected leaves were washed in distilled water and dried with paper towels.

For flour production, a portion of the selected fresh leaves was subjected to drying at 65 °C in an air-circulated oven. The drying process was completed when a consistent weight was maintained in successive weighings. Then, the dried leaves were ground in a blender and sifted using an electromagnetic shaker for particle size analysis, standardizing the particles to 250 μm. The flours and fresh leaves were stored in polyethylene packaging with laminated layers, with the flours kept in desiccators and the fresh leaves in a freezer (-18 °C ± 1 °C) until the analyses were conducted, which were performed in triplicate.

2.4 Proximate Composition

The proximate composition (moisture, proteins, lipids, ash, and carbohydrates) of fresh leaves and flours was determined in triplicate according to the methodology of the Adolfo Lutz Institute (2008). Moisture was determined by gravimetry after direct drying in an oven at 105 °C. Proteins were determined by the Kjeldahl method, with protein content estimated using a factor of 6.25. Lipids were determined by gravimetry after intermittent extraction with petroleum ether in a Soxhlet apparatus. Ash was determined by incineration in a muffle furnace at 550 ºC. Carbohydrate concentration was estimated by difference, subtracting the values obtained for moisture, proteins, lipids, and ash from 100%. The calculation of the total energy value was estimated using conversion factors of 4 kcal/g for carbohydrates, 4 kcal/g for protein, and 9 kcal/g for lipids.

2.5 Micronutrient Analyses

Analyses of carotenoids (α-carotene, β-carotene, lycopene, and β-cryptoxanthin), vitamin C (ascorbic acid), and vitamin E (α-, β-, γ-, δ-tocopherols and tocotrienols) were conducted on fresh leaves and flours. Samples were protected from sunlight and artificial light using amber glass and aluminum foil during manipulation.

2.5.1 Carotenoids

Carotenoids were extracted and analyzed according to the methods proposed by Rodriguez-Amaya et al., (2008) and Pinheiro-Sant'Ana et al., (2011), respectively. Approximately 1 g of fresh leaves and flours were added to 60 mL of cooled acetone (5 °C ± 2 °C), homogenized and crushed using a microgrinder, and then vacuum-filtered using a Büchner funnel with filter paper. The filtrate was transferred in three fractions to a separating funnel containing 20 mL of petroleum ether. After each fraction transfer, distilled water was added for phase separation (upper: carotenoids in petroleum ether; lower: acetone and water), with the lower phase discarded. After the third wash with distilled water, a spatula of anhydrous sodium sulfate was added to remove any remaining water residue. The extract was added to a 25 mL volumetric flask and completed with petroleum ether to reach the volume. The extract was stored in a hermetically sealed amber glass bottle and stored at -18 ± 1°C until analysis. Before injection, the pigments were transferred back to acetone by pipetting 2 mL of the sample dissolved in petroleum ether and dried under nitrogen flow. Subsequently, 2 mL of HPLC-grade acetone were added to the dried sample. The samples were filtered using Millex HV filter units, polyethylene, 0.22 μm porosity, and added to vials, injecting 50 μL of the samples into the chromatographic column.

Carotenoids were analyzed by High-Performance Liquid Chromatography (Model LC-10VP, Shimadzu, Japan), under the following chromatographic conditions: Phenomenex Gemini RP 18 reverse-phase chromatographic column (250 mm x 4.6 mm, 5 μm) equipped with a Phenomenex ODS guard column (C18), 4 mm x 3 mm; Photodiode Array Detector (Model SPD-M10 AVP, Shimadzu, Japan), at 450 nm; mobile phase – methanol: ethyl acetate: acetonitrile (80:10:10, v/v); mobile phase flow rate: 2.0 mL/minute; run time: 12 minutes.

The compounds were identified by comparing the retention times and absorption spectra obtained for the standards and the samples analyzed under the same conditions. Carotenoid quantification was performed using analytical curves and regression equations constructed by injecting, in triplicate, five standard solutions with different concentrations.

2.5.2 Ascorbic Acid

The analysis of ascorbic acid was carried out according to the methodology of Campos et al., (2009). Approximately 1 gram of leaves and flours were crushed in 15 mL of extracting solution (3% metaphosphoric acid (MPA), 1 mM EDTA, 0.15 M sulfuric acid (H2SO4) diluted to 90%, and 8% acetic acid) using a microgrinder. The obtained extract was centrifuged at 3000 g for 10 minutes and vacuum-filtered using a Buchner funnel with filter paper. Subsequently, it was added to a 25 mL volumetric flask and completed with ultrapure water to reach the volume. The extract was stored in a hermetically sealed amber glass bottle and stored at -18 ± 1°C until analysis. Analyses were performed by injecting 50 μL of the previously filtered extracts into the High-Performance Liquid Chromatography system (Model LC-10VP, Shimadzu, Japan), under the following chromatographic conditions: Phenomenex Synergi chromatographic column (250 x 4 mm i.d., 4 μm) equipped with a Phenomenex C18 guard column, 4 mm x 3 mm; Photodiode Array Detector (Model SPD-M10 AVP, Shimadzu, Japan); mobile phase 1 mM NaH2PO4 and 1 mM EDTA, pH adjusted to 3.0 with H3PO4; mobile phase flow rate: 1.0 mL/minute; run time: 7 minutes. Chromatograms were read at a wavelength of 245 nm.

The compounds were identified by comparing the retention times and absorption spectra obtained for the standards and the samples analyzed under the same conditions. Vitamin C quantification was performed using analytical curves and regression equations constructed by injecting, in duplicate, six solutions of standards with different concentrations.

2.5.3 Vitamin E

The analysis of eight components of vitamin E (α, β, γ, and δ-tocopherols and tocotrienols) in leaves and flours was performed using the adapted methodology of Guinazi et al., (2009). Approximately 2.5 g of leaves and 1 g of flours were weighed and added to 4 mL of heated ultrapure water (approximately 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 extraction solvent mixture (hexane: ethyl acetate, 85:15, v/v). After this process, each sample was homogenized for 1 minute in a microgrinder and vacuum-filtered using a Buchner funnel with filter paper. The extraction step was repeated by adding 5 mL of isopropanol and 30 mL of the solvent mixture, then homogenizing and filtering again under vacuum. Subsequently, the extract was concentrated in a rotary evaporator at 70 °C ± 1 °C, and the volume was completed to 10 mL with the solvent mixture in a volumetric flask. The extract was stored in a hermetically sealed amber glass bottle and stored at -18 ± 1°C until analysis. Before injection, approximately 5 mL of the extract was dried under nitrogen gas, then redissolved in 2 mL of HPLC-grade hexane, filtered through 0.45 μm porosity filter units, and added to vials.

Analyses were performed by injecting 30 μL of the extracts into the High-Performance Liquid Chromatography system (Model LC-10VP, Shimadzu, Japan), under the following chromatographic conditions: Phenomenex Luna Si100 chromatographic column (250 x 4 mm i.d., 5 μm), equipped with a Phenomenex Si100 guard column (4 mm × 3 mm); Fluorescence Detector (excitation at 290 nm and emission at 330 nm) (Model RF-10A XL, Shimadzu, Japan); mobile phase - hexane: isopropanol: glacial acetic acid (98.9:0.6:0.5, v/v); mobile phase flow rate: 1.0 mL/minute; run time: 22 minutes.

The compounds were identified by comparing the retention times obtained for the standards and the samples analyzed under the same conditions. Vitamin E quantification was performed using analytical curves and regression equations constructed by injecting, in duplicate, six solutions of standards with different concentrations. The equivalents of α-tocopherol were calculated using the 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). From the identified components of vitamin E, the total vitamin E content was quantified by summing its constituents.

2.5.4 Retention of Carotenoids and Vitamins

After obtaining the data, the retention of carotenoids, vitamin C, and vitamin E in the flours was calculated using the following equation: Retention (%) = (Concentration of the nutrient in the dehydrated flour x 100) / Concentration of the nutrient in the fresh leaves converted to a dry basis.

2.6 Estimation of Total Phenolic Compounds and Evaluation of In Vitro Antioxidant Capacity

2.6.1 Extraction of Extracts

The extracts from fresh leaves and dehydrated flours were prepared as described by Bloor (2001). Extraction was carried out by adding the sample to a mixture of methanol:water (60:40 v/v) at a ratio of 1:10 (sample:solvent). The suspension was stirred for 30 minutes at a speed of 180 rpm at room temperature. Subsequently, the suspension was centrifuged at 3500 rpm for 10 minutes, and the supernatant was collected. Fractions

of the supernatant were diluted in distilled water to obtain extracts at concentrations of 1:100, 1:40, 1:20, 1:10, and 1:5 (v/v).

2.6.2 Estimation of Total Phenolic Compounds

The concentration of total phenolic compounds in the extracts was determined according to Singleton et al., (1999), with adaptations. In a test tube, 0.6 mL of the extract (1:20 (v/v) for I. herbstii and dehydrated P. umbraticola, and 1:5 (v/v) for the other samples) was added to 3.0 mL of 10% Folin-Ciocalteau solution and 2.4 mL of 7.5% sodium carbonate (Na2CO3) solution. The mixture was vortexed and then allowed to stand for 30 minutes. Absorbance was read on a UV-visible spectrophotometer (Lambda 25, PerkinElmer) at 765 nm. The quantification of total phenolics was performed using a standard curve (R2=0.99) of gallic acid, and the results were expressed in milligrams of gallic acid equivalents per gram of sample (mg GAE/g).

2.6.3 Evaluation of Antioxidant Capacity by ABTS Radical Assay (2,2'-Azinobis-(3-Ethylbenzothiazoline-6-Sulfonic Acid))

Antioxidant activity was determined according to the method proposed by Re et al., (1999). The ABTS radical was prepared by mixing 7 mmol/L of ABTS with 2.45 mmol/L of potassium persulfate and distilled water in a ratio of 40:40:20 (v/v/v), respectively. The mixture was kept in amber glass for 16 hours under refrigeration and darkness. Subsequently, the ABTS radical was adjusted with 80% ethanol to an absorbance of 0.700 ± 0.05 at a wavelength of 734 nm. Then, 0.5 mL of the extract (1:20 (v/v) for dehydrated P. aculeata and fresh and dehydrated P. umbraticola and I. herbstii; 1:100 (v/v) for dehydrated P. umbraticola and I. herbstii; and 1:5 (v/v) for fresh P. umbraticola) was added to 3.5 mL of the adjusted ABTS radical. After 6 minutes of reaction in the absence of light, absorbance was read on a UV-visible spectrophotometer (Lambda 25, PerkinElmer) at 734 nm. Quantification was performed using a standard curve (R2=0.99) of Trolox, and the results were expressed in micromoles of Trolox per gram of sample (μmol Trolox/g).

2.6.4 Evaluation of Antioxidant Capacity by DPPH Radical Assay (2,2-Diphenyl-1-Picrylhydrazyl)

The determination of antioxidant activity by the DPPH radical assay was carried out following the methodologies of Brand-Williams, Cuvelier, and Berset (1995) and Bravo et al., (2013), with adaptations. A 1 mM methanolic solution of DPPH, adjusted with 80% ethanol to an absorbance of 0.700 ± 0.05 at a wavelength of 515 nm, was prepared. Subsequently, 0.5 mL of the extract (dilution 1:100 (v/v) for fresh P. aculeata and dehydrated P. umbraticola; 1:20 (v/v) for dehydrated P. aculeata and fresh I. herbstii; and 1:5 (v/v) for fresh P. umbraticola and dehydrated I. herbstii) was added to 3.5 mL of the DPPH radical solution. After mixing, the reaction time was waited (10 minutes for fresh P. aculeata and dehydrated P. umbraticola; 20 minutes for fresh I. herbstii and dehydrated P. umbraticola and P. aculeata; and 30 minutes for dehydrated I. herbstii), and absorbance was measured on a UV-visible spectrophotometer (Lambda 25, PerkinElmer) at 515 nm. Quantification was performed using a standard curve (R2=0.99) of Trolox, and the results were expressed in micromoles of Trolox per gram of sample (μmol Trolox/g).

2.7 Technological Analysis of Flours

The flours obtained by dehydration were analyzed for moisture (described in section 2.4), solubility, hygroscopicity, pH, colorimetry, and wetting time.

2.7.1 Solubility

The ability of the flour to mix with water at room temperature was determined according to Souza et al., (2015). A sample of 0.5 grams of flour was added to a container with 50 mL of distilled water. The suspension was stirred at 100 rpm for 30 minutes and

then centrifuged at 1700 rpm for 5 minutes. An aliquot of supernatant (25 mL) was collected and dried in an oven at 105°C until a constant weight was obtained. The percentage of mass of the solubilized sample in the aliquot was calculated relative to the dry mass of the sample.

2.7.2 Hygroscopicity

The ability of the material to absorb moisture from the environment was determined according to Cai and Corke (2000) and Ibrahim Silva et al., (2013). The samples were placed in Petri dishes and stored in desiccators containing saturated NaCl solutions (75% relative humidity). After one week, the samples were weighed, and hygroscopicity was expressed as grams of moisture absorbed per 100 g of dry solids (g/100g).

2.7.3 pH

The pH was measured by mixing 5 g of the samples with 50 mL of distilled water, stirring for 1 hour. After the procedure, direct readings were taken on a calibrated digital pH meter (SevenCompact, Mettler Toledo) before analysis (IAL, 2008).

2.7.4 Colorimetry

Color parameters a* and b* L* were determined using a colorimeter (CM-5, Minolta). Parameter a* characterizes the redness (+a*) to green (-a*), b* from yellow (+b*) to blue (-b*), and L* the brightness from white (L=100) to black (L=0). The color saturation was calculated using the Chroma obtained through the equation: $C=\sqrt{(a^2+b^2)}$. The hue chromaticity angle, hue, was calculated using the equation: $H^o=\arctan b^*/a^*$.

2.7.5 Wetting Time

Wetting time measures the time (in seconds) for all particles of a product to become submerged in water. For this, 1 g of the sample was added to 200 mL of distilled water. The suspension was left without agitation, and the time taken (in seconds) for all particles to submerge was measured (Lannes; Medeiros, 2003).

2.8 Experimental Design and Statistical Analysis

For the study, a Completely Randomized Design (CRD) was used in a factorial scheme with three plants and two processes, with three repetitions. The data were tabulated in Microsoft Excel®, and the results were expressed as mean ± standard deviation. Linear regression analysis was employed to assess the linearity range and calculate the coefficient of determination (R2) of the analytical standards for vitamins and minerals. The obtained data were analyzed through analysis of variance (ANOVA), followed by the Tukey test at a 5% significance level. Statistical analyses were performed using the Jamovi 2.4.8 *software*.

3. Results and Discussion

The graphical representation of unconventional edible plants collected for analysis in the Vale do Médio Rio Doce territory, Minas Gerais, Brazil, is available in Figure 1.

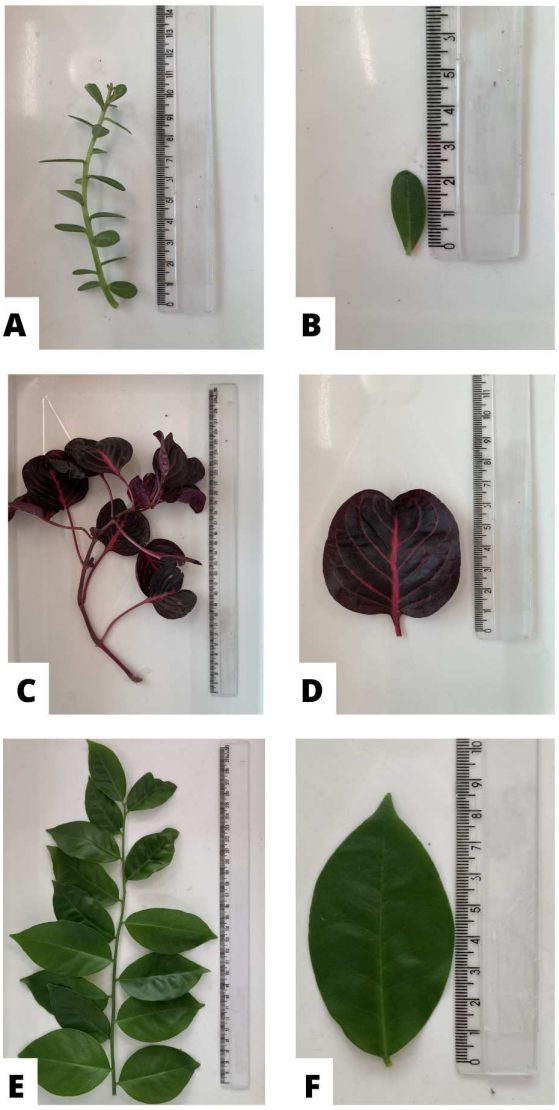

Figure 1. Branch (A) and leaf (B) of purslane (*Portulaca umbraticola*); Branch (C) and leaf (D) of bloodleaf (*Iresine herbstii*); Branch (E) and leaf (F) of rose cactus (*Pereskia aculeata*) collected in the Vale do Médio Rio Doce territory, Minas Gerais, Brazil.

3.1 Proximate Composition

Non-conventional edible plants (PANCs) collected from the Vale do Médio Rio Doce territory (Brazil), both in their natural state and in flour form, showed high variability in proximate composition (Table 1). The leaves in their natural state exhibited high moisture content (> 87%), which was reduced to < 5% in the flours. The reduction of moisture in flours, to levels compliant with Brazilian legislation (< 15%), imparts an extended shelf life to the flours, facilitating their transportation, handling, and consumption (Zambrano et al., 2019; Brazil, 2022).

The leaves of *I. herbstii and P. aculeat*a showed higher protein content compared to conventional vegetables such as kale (*Brassica oleracea* var. a*cephala* - 2.9 g/100g), lettuce (*Lactuca sativa* - 0.6 g/100g), broccoli (*Brassica oleracea* - 3.6 g/100g), and spinach (*Tetragonia expansa* - 2.0 g/100g). The flours of these PANCs exhibited high protein content, especially *P. umbraticola* flour, which had three times more protein than polished wheat flour (9.8 g/100g) (NEPA, 2011). The protein content of the flours was

similar to that observed in dehydrated I. herbstii in southeast Nigeria (22.85 g/100g) (Nwezw; Nwachukwu; Adieme, 2016) and within the range observed in P. aculeata flour in Brazil (17 g/100g to 28.4 g/100g) (Da Silva et al., 2014; Silva et al., 2018; Takeiti et al., 2009).

The high protein content makes these PANCs important tools in the diets of populations, especially those where protein consumption is generally low. Among the many qualities of unconventional edible plants, easy access, cultivation, and low production costs stand out (Shahidi; Ambigaipalan, 2015; Moura et al., 2021). Thus, these flours can contribute to preventing protein malnutrition-related diseases and contribute to the food sovereignty of populations.

The lipid content in the leaves in their natural state and in the flours was reduced, favoring the use of these plants in low-fat diets. Regarding ashes, P. aculeata leaves had the highest index when compared to the samples in their natural state, and P. umbraticola flour when compared to other flours ($p<0.05$). The carbohydrate content was reduced in P. aculeata and P. umbraticola leaves compared to I. herbstii, which had five times more carbohydrates. Among the flours, the total energy value was similar, and among the leaves, I. herbstii presented twice as many kilocalories compared to P. umbraticola ($p>0.05$).

When studying I. herbstii in flour form in Nigeria, Nwezw, Nwachukwu, and Adieme (2016) found 18.58 g/100g of ashes and 1.50 g/100g of lipids, similar to the findings in this study. In the study by Oliveira et al. (2019), 2.90 g/100g of ashes, 0.40 g/100g of lipids, 6.70 g/100g of carbohydrates, and 42 kcal/100g were observed in P. aculeata leaves in their natural state, while Botrel et al. (2020) found 2.33 g/100g of ashes, 0.51 g/100g of lipids, 2.65 g/100g of carbohydrates, and 22.62 kcal/100g of total energy value, these studies were conducted with plants from Brazil. The ash and lipid content are similar to the present research, with only differences in carbohydrates and total energy value. It is worth noting that these variations are expected due to various factors, such as climatic conditions, management practices, and soil conditions.

3.2 Carotenoid and Vitamin Content

The qualitative profile of vitamin E isomers in the flours was not affected by dehydration, remaining similar to that observed in the plants in their natural state (Table 2). Thus, the following isomers were quantified in P. aculeata products: α-tocopherol, α-tocotrienol, β-tocopherol, and γ-tocopherol; in I. herbstii: α-tocopherol, β-tocopherol, and δ-tocotrienol. In P. umbraticola, both in its natural state and as flour, the presence of α-tocopherol, γ-tocopherol, and δ-tocopherol was observed. The isomers β-tocotrienol and γ-tocotrienol were not found in any of the evaluated plants.

α-Tocopherol was the main vitamin E isomer present in PANCs, with the highest content found in P. aculeata. Vitamin E acts as an antioxidant, playing a crucial role in the prevention and treatment of various conditions, including cancer, cardiovascular diseases, neurological disorders, and aging-related processes (Shahidi et al., 2021). Specifically, α-tocopherol plays an important role in preventing and treating cardiovascular diseases due to its ability to inhibit the oxidation of LDL cholesterol, thereby reducing the formation of fat plaques in the arteries (Shahidi et al., 2021).

The concentrations of total vitamin E and α-tocopherol equivalent in the leaves, both in their natural and dehydrated states, varied significantly ($p<0.05$), with the highest concentration observed in P. aculeata samples. Information on the content and profile of vitamin E in I. herbstii and P. umbraticola in their natural state is not available in the literature.

Studies related to the analyzed PANCs in this study are scarce. In the natural leaves of Brazilian P. aculeata, other authors observed total vitamin E content ranging from 438.68 μg/100g to 1390 μg/100g, which encompasses the content observed in this study (Oliveira et al., 2019; Barreira et al., 2020). A study analyzing Nigerian I. herbstii flour found 32.4 mg/100g of vitamin E (Nwezw; Nwachukwu; Adieme, 2016). There is no

literature data regarding the evaluation of vitamin E concentration in dehydrated P. aculeata and P. umbraticola species.

The flours of I. herbstii and P. aculeata showed the highest percentage of vitamin E retention, with δ-tocotrienol being the isomer that retained the most after heat treatment. P. aculeata flour can supply 21.09% of the daily vitamin E recommendation in 100 grams of flour.

The leaves and flour of P. umbraticola showed significantly higher ascorbic acid content than the other samples ($p<0.05$) (Table 2). When evaluating P. oleracea from the UK, a purslane similar to that in this study, 140 mg/100g on a dry basis was found, higher than in dehydrated P. umbraticola from Vale do Médio Rio Doce, Brazil (Nemzer; Al-taher; Abshiru, 2020). Studies on P. umbraticola are not available in the literature. Studies demonstrate that the vitamin C content in P. aculeata varies widely, ranging from its absence to contents of 185.80 mg/100g (Takeiti et al., 2009; Neves et al., 2021; Barreira et al., 2020). The ascorbic acid content in I. herbstii in its natural state is unknown. The ascorbic acid content in the flour was higher than that found in I. herbstii flour harvested in Nigeria (2.47 mg/100g) (Nwezw; Nwachukwu; Adieme, 2016). The vitamin C concentration found in P. umbraticola is similar to that found in broccoli (Brassica oleracea - 34.3 mg/100g) and higher than that found in lettuce (Lactuca sativa - 11 mg/100g), these being traditional vegetables in the Brazilian diet (NEPA, 2011).

Considering the intake of a 20 g portion of flour (2 tablespoons), P. umbraticola provides 22.4% of the daily recommended ascorbic acid for adults (90 mg/day). Thus, P. umbraticola flour is considered a source of ascorbic acid for adults (Brazil, 1998; IOM, 2000).

Ascorbic acid plays crucial physiological and metabolic functions in the human body, and its acquisition is exclusively through diet. Its deficiency is known to cause scurvy, a condition characterized by tissue fragility, poor healing, and vulnerability of blood vessels. Additionally, ascorbic acid acts as a potent antioxidant, combating oxidative stress by donating and transferring electrons and regenerating other antioxidants in the body, such as α-tocopherol. In addition to these benefits, ascorbic acid promotes the absorption of iron, calcium, and folic acid, contributing to the promotion of a healthy immune system (Caritá et al., 2020; Njus et al., 2020). Thus, P. umbraticola flour can contribute to the regulation of the body's homeostasis, promoting health, and acting in the prevention of non-communicable chronic diseases.

The flours of I. herbstii and P. aculeata showed the highest percentage of ascorbic acid retention. This reduction in ascorbic acid concentration occurs due to the sensitivity of this vitamin to heat, meaning that its concentration and efficacy decrease when exposed to higher temperatures (Yan et al., 2021). The dehydration process involves heat, and even though this research used lower temperatures to prevent these losses, it still resulted in the degradation of this compound.

The carotenoid content in the leaves in their natural state was similar between P. aculeata and P. umbraticola ($p>0.05$) (Table 2). α-Carotene was not found in I. herbstii, and there was no statistically significant difference between P. aculeata and P. umbraticola ($p>0.05$). Regarding β-carotene, the results were similar. Studies have shown concentrations of 4.64 mg/100g (Neves et al., 2021), 3.33 mg/100g (Oliveira et al., 2019), 3.15 mg/100g (Barreira et al., 2020), and 2.3 mg/100g (Takeiti et al., 2009) of carotenoids in the natural leaves of Brazilian P. aculeata, these concentrations being lower than those found in this study.

The concentrations of carotenoids in the flours showed statistically significant differences ($p<0.05$), with the highest concentration observed in P. umbraticola leaves. α-Carotene was not detected in I. herbstii, and the content in P. aculeata and P. umbraticola did not show statistically significant differences ($p>0.05$). β-Cryptoxanthin and lycopene were not detected in any of the samples analyzed. Regarding β-carotene, the results were similar. Nigerian I. herbstii flour was evaluated, and 1.70 mg/100g of carotenoids were found, and in dehydrated Brazilian P. aculeata, a concentration of 0.07 mg/100g was found, these levels being lower than those found in PANCs from Vale do

Médio Rio Doce, Brazil (Trentin; Bampi; Dinon, 2020). There are no reports in the literature regarding the concentration of carotenoids in the leaves of I. herbstii and P. umbraticola in their natural and dehydrated states.

A portion of 20 g of flours (2 tablespoons) of I. herbstii, P. aculeata, and P. umbraticola provides approximately 760 μg, 1095 μg, and 1000 μg of RAE, representing 80%, 115.26%, and 105.3%, respectively, of the daily recommended vitamin A for an adult male (950 μg RAE). Thus, the evaluated flours can be classified as rich in vitamin A (Brazil, 1998; IOM, 2001).

Among the carotenoids that can be converted into vitamin A after being consumed by the human body, β-carotene stands out for its high pro-vitamin activity. This is due to the molecular structure of β-carotene, which is equivalent to two molecules of retinol (vitamin A) (Barreira et al., 2019). Carotenoids play various roles in the body, with antioxidant activity, increased red blood cell production, and increased immunity being prominent (Nwezw; Nwachukwu; Adieme, 2016). This compound was predominant in all analyzed samples, representing approximately 85% of the carotenoid composition of P. aculeata flour. This predominance significantly contributes to health promotion through the consumption of the analyzed plants, acting in the prevention of imbalances in the body and, consequently, aiding in the reduction of the risk of various diseases.

The flours of I. herbstii and P. aculeata showed the highest percentage of carotenoid retention. Among the factors that influence the degradation of carotenoids, exposure to oxygen, moisture, light, and higher temperatures stands out (Yan et al., 2021). Even taking due precautions regarding handling, thermal processing, and storage, the flours showed significant losses of this compound. This result propels research in search of the ideal drying temperature, aiming to minimize the loss of these essential nutrients.

3.3 Antioxidant Activity and Total Phenolic Compounds

The evaluation of antioxidant activity using the ABTS assay indicated better free radical neutralization capacity in the natural samples of P. aculeata compared to other leaves (Table 3). Regarding the flours, I. herbstii demonstrated the highest antioxidant action in the DPPH assay. In the evaluation of total phenolic compounds, the natural leaves of P. aculeata and I. herbstii showed the highest concentrations, these being quite similar ($p>0.05$); and among the flours, the highest concentration was found in Portulaca umbraticola.

Plants have numerous compounds with different chemical structures. When evaluating the antioxidant capacity of plant tissues, it is essential to employ more than one assay method, such as ABTS and DPPH, considering that antioxidant compounds act through different mechanisms, resulting in different antioxidant activities in chemical tests (Alves et al., 2010; Munteanu and Apetrei, 2021; Pohanka, 2023).

I. herbstii has high levels of acylated betacyanin, an antioxidant that plays an important role in protection against damage caused by free radicals. This characteristic may have contributed to its prominence in the antioxidant capacity and concentration of assessed phenolic compounds. Betacyanins are part of the group called anthocyanins, characterized by strong coloring ranging from purple to red. This detail can contribute to the development of food products that require natural antioxidants and/or color aggregation (Cai; Sun; Corke, 2001; Spórna-Kucab et al., 2020).

Dehydrated P. aculeata showed a reduction in antioxidant capacity and phenolic compounds compared to the leaves in their natural state. Plants have numerous different antioxidants with distinct mechanisms of action, and many of them are sensitive to heat. Thus, the antioxidants present in P. aculeata may have been degraded during thermal processing, resulting in the loss of their antioxidant capacity and composition of phenolic compounds (Huang et al., 2023; Rahaman et al., 2023).

Evaluating fresh leaves of Brazilian P. aculeata, Silva et al. (2018) found 4.49 g Trolox/g of sample by DPPH and 0.26 g GAE/g for total phenolic compounds; Neves et al. (2021) observed 0.07 mg GAE/g, these results being lower than those observed in this

research. A higher result was found by Oliveira et al. (2019), indicating 7.86 mg GAE/g. In a study evaluating dehydrated leaves of I. herbstii from Nigeria, 0.064 g GAE/g of phenolic compound flour was found, reduced compared to that observed in the PANC from the Médio Rio Doce territory, Brazil (Nwezw; Nwachukwu; Adieme, 2016). In Garcia et al.'s (2019) study, an inhibitory concentration of 72.9 μg/mL Trolox extract for DPPH and 40.5 μg/mL Trolox extract for ABTS was found in Brazilian P. aculeata flour. For total phenolic compounds, Souza et al. (2016) observed 15.04 mg GAE/g of extract and an inhibitory concentration of 7.09 mg/mL ascorbic acid extract for DPPH from plants also harvested in Brazilian soil. To date, there are no studies evaluating the antioxidant capacity and total phenolic compounds in P. umbraticola, making this study pioneering.

The methods for assessing antioxidant capacity (ABTS and DPPH) and the content of total phenolic compounds vary among the few studies found, presenting different methodologies, and the results are expressed in different units, making it difficult to compare this research with other studies.

3.4 Technological Analyses of Flours

3.4.1 Colorimetric Analysis

All flours had a slightly dark color, with brightness (L*) closer to black (Figure 3, Table 4). I. herbstii flour showed a* parameter tending towards red (+a*), while P. aculeata and P. umbraticola flours tended towards green (-a*). All flours showed a b* value tending towards yellow color (+b).

Figure 3. Flour from the leaves of *Pereskia aculeata* (A), *Iresine herbstii* (B), and *Portulaca umbraticola* (C) collected in the Vale do Médio Rio Doce territory, Minas Gerais, Brazil.

3.4.1 Colorimetric Analysis

A variation from 6.63 to 10.50 was observed when evaluating Chroma, indicating that the flours have low saturation of their color when compared to their brightness. The hue angle (h°) indicated that the flours of P. aculeata and P. umbraticola show a color variation tending towards blue, as they are close to the angle of 270°. On the other hand, I. herbstii showed a tendency towards red, being close to the angle of 0°.

Color in food is a fundamental parameter for marketing and use as an ingredient in the formulation of other products. When it reaches the consumer, it is the first quality parameter evaluated, contributing to the choice and acceptance of the product (Pathare; Opara; Al-said, 2013; Firentini; Kinchla; Nolden, 2020; Fadhil, et al., 2022).

Studies on the colorimetric profile of flours obtained from I. herbstii and P. umbraticola are unavailable. Trentin, Bampi, and Dinon (2020) assessed the colors of P. aculeata flour obtained by drying at 60 °C and found L* 28.93, a* -4.42, and b* 15.86.

3.4.2 Hygroscopicity and Solubility

The prepared flours exhibited good water solubility, with Pereskia aculeata flour standing out, followed by Iresine herbstii and Portulaca umbraticola flours (Table 5). This characteristic indicates the potential use of the flours in the production of other foods, especially those requiring low temperatures for preparation or as ingredients for water-soluble formulations, such as soups and sauces (Santana, Filho, & Egea, 2017; Recharla, et al., 2017).

The hygroscopicity results obtained from the flours were satisfactory, considering that levels below 20% are considered low hygroscopicity, which is a desirable characteristic. Hygroscopicity is an important parameter to assess in flours as it is associated with product preservation and shelf life, measuring the material's ability to absorb moisture from the environment (Daza, et al., 2016; Tontul; Topuz, 2017).

3.4.3 pH and Wettability Time

All the flours were classified as having low acidity (Table 5), falling within the ranges established by Dionisio, et al., (2016). This is an excellent result concerning their use in food products, as low acidity tends not to interfere with taste. Low acidity also contributes to preventing the growth of microorganisms, extending the shelf life of the flours (Andrés-Bello, et al., 2013).

The best wettability time was observed in Pereskia aculeata flour, followed by Iresine herbstii flour, and finally, Portulaca umbraticola flour. These results demonstrate that all the studied flours have a good water absorption capacity, allowing their use in the formulation of other food products. This capacity contributes to the stability of their formulation, directly impacting handling, packaging, transportation, storage, and commercialization (Lee, et al., 2014; Fitzpatrick, et al., 2017).

Table 1. Proximate composition and total energy value of fresh and dehydrated leaves of *Portulaca umbraticola*, *Iresine herbstii*, and *Pereskia aculeata*, collected in the Vale do Médio Rio Doce territory, Minas Gerais, Brazil.

Variables	Content (mean[a] ± standard deviation)					
	Iresini herbstii in natura	*Iresini herbstii* dehydrated	*Pereskia aculeata In natura*	*Pereskia aculeata* dehydrated	*Portulaca Umbraticola in natura*	*Portulaca Umbraticola* dehydrated
Moisture ($g.100^{-1}$)	$87,67 \pm 0,74^{b}$	$2,10 \pm 0,29^{a}$	$90,38 \pm 2,17^{b}$	$5,09 \pm 0,45^{a}$	$95,35 \pm 0,22^{c}$	$3,10 \pm 0,70^{a}$
Protein ($g.100^{-1}$)	$4,95 \pm 0,89^{b}$	$20,16 \pm 2,14^{a}$	$6,15 \pm 0,91^{b}$	$22,09 \pm 0,56^{c}$	$2,55 \pm 0,25^{b}$	$28,05 \pm 0,39^{d}$
Lipids ($g.100^{-1}$)	$1,06 \pm 0,34^{b}$	$3,62 \pm 0,55^{a}$	$0,31 \pm 0,17^{b}$	$4,83 \pm 0,65^{a}$	$1,16 \pm 0,45^{b}$	$8,92 \pm 1,19^{c}$
Ash ($g.100^{-1}$)	$1,98 \pm 0,31^{b}$	$17,98 \pm 1,0^{c}$	$2,36 \pm 0,04^{b}$	$14,96 \pm 0,25^{a}$	$0,88 \pm 0,17^{b}$	$25,06 \pm 1,01^{d}$
Carbohydrates ($g.100^{-1}$)	$4,35 \pm 1,61^{b}$	$56,94 \pm 1,90^{a}$	$0,80 \pm 2,65^{b}$	$53,03 \pm 1,10^{a}$	$0,06 \pm 0,45^{b}$	$34,86 \pm 1,45^{c}$
Total energy value ($Kcal.100^{-1}$)	$46,70 \pm 4,69^{b}$	$340,98 \pm 6,43^{a}$	$30,63 \pm 8,96^{b}$	$343,99 \pm 3,58^{a}$	$20,90 \pm 3,07^{b}$	$331,92 \pm 6,65^{a}$

[a]The average of three repetitions. Means followed by the same letters in the same line for a variable do not differ from each other by the Tukey test at the 5% significance level.

Table 2. Carotenoids, ascorbic acid, and vitamin E content of fresh and dehydrated leaves of Portulaca umbraticola, Iresine herbstii, and Pereskia aculeata, collected in the Vale do Médio Rio Doce region, Minas Gerais, Brazil.

Variables	Content (mean[a] ± standard deviation)								
	Iresini herbstii in natura	*Iresini herbstii* dehydrated	RT	*Pereskia aculeata In natura*	*Pereskia aculeata* dehydrated	RT	*Portulaca Umbraticola in natura*	*Portulaca Umbraticola* dehydrated	RT
Vitamin E Total (μg.100^{-1})	686,2 ± 7,9^{b}	2620,2 ± 11,2^{b}	47,1 ± 2,5	1066,6 ± 26,3^{d}	5196,9 ± 199,8^{e}	46,8 ± 1,3	351,2 ± 12,7^{f}	1557,1 ± 59,7^{a}	20,6 ± 0,1
α-tocopherol (μg.100^{-1})	288,7 ± 4,7^{b}	19,6 ± 0,4^{c}	0,8 ± 0,0	632,8 ± 38,7^{d}	1993,2 ± 106,5^{e}	30,4 ± 2,9	272,7 ± 12,8^{b}	921,5 ± 34,6^{a}	15,5 ± 0,3
α-tocotrienol (μg.100^{-1})	ND	ND		87,6 ± 6,4^{b}	547,6 ± 10,3^{a}	60,3 ± 4,7	ND	ND	
β-*tocopherol (μg.100^{-1})*	292,1 ± 9,8^{b}	1832,8 ± 83,3^{a}	77,4 ± 5,8	226,0 ± 26,6^{b}	1852,7 ± 59,0^{a}	79,5 ± 9,3	ND	ND	
β-*tocotrienol (μg.100^{-1})*	ND	ND		ND	ND		ND	ND	
γ-tocopherol (μg.100^{-1})	ND	ND		120,2 ± 2,7^{b}	803,4 ± 77,6^{c}	64,3 ± 7,0	32,1 ± 0,4^{b}	562,9 ± 38,3^{a}	81,6 ± 5,1
γ-tocotrienol (μg.100^{-1})	ND	ND		ND	ND		ND	ND	
δ-tocopherol (μg.100^{-1})	ND	ND		ND	ND		24,9 ± 0,0^{a}	72,7 ± 0,4^{b}	13,6 ± 0,0
δ-tocotrienol (μg.100^{-1})	105,5 ± 1,3^{c}	767,80 ± 28,20^{b}	89,7 ± 3,9	ND	ND		18,6 ± 0,2^{a}	ND	
Ascorbic acid (mg.100^{-1})	8,3 ± 3,5^{c}	26,21 ± 6,64^{b}	46,4 ± 29,9	6,7 ± 0,2^{c}	30,2 ± 1,8^{b}	43,4± 3,4	33,6 ± 2,9^{b}	100,8 ± 7,1^{a}	14,0 ± 2,0
Total carotenoids (mg.100^{-1})	11,3 ± 0,5^{b}	45,62 ± 2,96^{c}	49,4 ± 3,6	16,8 ± 1,5^{b}	77,4 ± 5,5^{a}	44,7 ± 6,6	24,6 ± 4,1^{b}	80,0 ± 8,5^{a}	15,45 ± 3,6
α-carotene (mg.100^{-1})	ND	ND		2,1 ± 0,4^{b}	11,7 ± 4,9^{a}	10,3 ± 2,5	5,8 ± 2,7^{b}	20,0 ± 5,9^{a}	19,0 ± 10,9

β-carotene (mg.100^{-1})	11,3 ± 0,5^{b}	45,6 ± 2,9^{a}	49,4 ± 3,6	14,7± 1,0^{b}	65,7 ± 10,3^{a}	43,4 ± 9,2	18,8 ± 5,2^{b}	60,0 ± 7,0^{a}	14,9 ± 2,8
β-criptoxantina (mg.100^{-1})	ND	ND		ND	ND		ND	ND	
Lycopene (mg.100^{-1})	ND	ND		ND	ND		ND	ND	
Vitamin A (RAE µg.100^{-1})	948,25 ± 48,1	3801,2 ± 246,3		1224,8 ± 90,2	5477,6 ± 865,6		1574,3 ± 148,5	5000,1 ± 584,8	

[a]The average of three repetitions. Means followed by the same letters in the same line for a variable do not differ from each other by the Tukey test at a 5% significance level. RT: retention. ND: not detected.

Table 3. Antioxidant activity (ABTS and DPPH) and total phenolic compounds of fresh and dehydrated leaves of Portulaca umbraticola, Iresine herbstii, and Pereskia aculeata, collected in the Vale do Médio Rio Doce region, Minas Gerais, Brazil.

Variables	Content (mean[a] ± standard deviation)					
	Iresini herbstii in natura	*Iresini herbstii* dehydrated	*Pereskia aculeata In natura*	*Pereskia aculeata* dehydrated	*Portulaca Umbraticola in natura*	*Portulaca Umbraticola* dehydrated
Antioxidant activity ABTS (µmol Trolox/g)	6,73 ± 1,16[a]	45,16 ± 2,89[c]	8,86 ± 0,48[a]	2,82 ± 0,32[a]	0,75 ± 0,10[a]	37,05 ± 6,0[b]
Antioxidant activity DPPH (µmol Trolox/g)	4,94 ± 0,94[a]	2,04 ± 1,01[a]	13,17 ± 2,70[c]	2,62 ± 0,14[a]	0,48 ± 0,03[a]	25,11 ± 2,38[d]
Total phenolic compounds (mg GAE/g)	2,02 ± 0,31[a]	8,09 ± 1,28[c]	1,98 ± 0,32[a]	0,81 ± 0,21[a]	0,18 ± 0,06[a]	5,50 ± 0,24[d]

[a]The average of three repetitions. Means followed by the same letters in the same line for a variable do not differ from each other by the Tukey test at a 5% significance level.

Table 4. Colorimetric analysis of the flours from Portulaca umbraticola, Iresine herbstii, and Pereskia aculeata, collected in the Vale do Médio Rio Doce region, Minas Gerais, Brazil.

Variables	Content (mean[a] ± standard deviation)		
	Iresine herbstii dehydrated	*Pereskia aculeata* dehydrated	*Portulaca Umbraticola* dehydrated
L*	41,98 ± 0,02[a]	44,61 ± 0,88[b]	47,98 ± 0,22[c]
a*	4,32 ± 0,23[a]	-1,06 ± 0,02[b]	-0,48 ± 0,04[c]
b*	5,03 ± 0,18[b]	9,04 ± 1,09[a]	10,49 ± 0,10[a]
C*	6,63 ± 0,05[b]	9,10 ± 1,08[a]	10,50 ± 0,10[a]
h°	49,39 ± 2,46[a]	276,75 ± 1,0[b]	272,62 ± 0,20[c]

[a]The average of three repetitions. Means followed by the same letters in the same line for a variable do not differ from each other by the Tukey test at a 5% significance level.

Table 5. Technological analyses of the flours from Portulaca umbraticola, Iresine herbstii, and Pereskia aculeata, collected in the Vale do Médio Rio Doce region, Minas Gerais, Brazil.

Varriables	Content (mean[a] ± standard deviation)		
	Iresine herbstii dehydrated	*Pereskia aculeata* dehydrated	*Portulaca umbraticola* dehydrated
pH	6,92 ± 0,03[a]	5,69 ± 0,05[b]	4,81 ± 0,08[c]
Solubility (%)	87,13 ± 0,81[a]	92,35 ± 0,72[b]	83,92 ± 2,87[a]
Hygroscopicity (%)	6,17 ± 1,14[a]	5,61 ± 2,16[b]	8,72 ± 1,23[c]
Wettability time (seconds)	55 ± 07[a]	26 ± 03[a]	89 ± 18[b]

[a]The average of three repetitions. Means followed by the same letters in the same line for a variable do not differ from each other by the Tukey test at a 5% significance level.

4. Conclusion

The developed flours have a high protein content, potentially contributing to the prevention of diseases related to protein malnutrition. Portulaca umbraticola flour is considered a source of ascorbic acid for adults, contributing to the body's balance and promoting health, thereby aiding in the prevention of non-communicable chronic diseases. Additionally, the evaluated flours are considered rich in vitamin A, contributing to the body's homeostasis. Dehydrated Pereskia aculeata showed a reduction in antioxidant capacity and phenolic compounds compared to fresh leaves, suggesting that antioxidants may have degraded during the thermal processing to produce the flour. In terms of technological feasibility, all the flours exhibited satisfactory characteristics, making them suitable for use in the production of other foods.

This study is a pioneer in the nutritional characterization and technological evaluation of Iresine herbstii and Portulaca umbraticola, demonstrating the nutritional potential of both fresh leaves and developed flours of unconventional food plants available in the Vale do Médio Rio Doce territory, Minas Gerais, Brazil. The lack of available technical and scientific information about these plants highlights the importance of further research to understand their constituents and promote their consumption, thus valuing the cultural heritage related to food.

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3. CONCLUSÃO

As folhas de *A. spinosus* e *C. benghalensis* apresentaram elevados teores de umidade, β-caroteno e minerais como potássio e ferro. As folhas de *A. spinosus* também apresentaram alto teor de fibra alimentar, baixo teor de lipídios e reduzido valor energético total. As folhas de *C. benghalensis* revelaram-se fontes de potássio, cálcio e ácido ascórbico.

As farinhas elaboradas apresentam alto conteúdo de proteínas, podendo contribuir para a prevenção de doenças relacionadas à desnutrição proteica. A farinha de *P. umbraticola* é considerada fonte de ácido ascórbico para adultos, contribuindo para o equilíbrio do organismo e promovendo a saúde, o que, por sua vez, ajuda na prevenção de doenças crônicas não transmissíveis. Além disso, as farinhas avaliadas são consideradas ricas em vitamina A, atuando na homeostase do organismo. A *Pereskia aculeata* desidratada apresentou redução da capacidade antioxidante e dos compostos fenólicos em comparação com as folhas *in natura*, sugerindo que os antioxidantes podem ter sido degradados durante o processamento térmico para produzir a farinha. Em termos de viabilidade tecnológica, todas as farinhas apresentaram características satisfatórias que as tornam adequadas para serem utilizadas na fabricação de outros alimentos.

Este estudo demonstra o potencial nutricional e tecnológico das plantas alimentícias não convencionais (*Amaranthus spinosus, Commelina benghalensis, Iresine herbstii, Pereskia aculeata* e *Portulaca umbraticola*) disponíveis no território Vale do médio Rio Doce, Minas Gerais, Brasil. Ressalta-se a falta de informações técnicas e científicas disponíveis sobre essas plantas, tornando-as um importante e necessário eixo de pesquisa, a fim de possibilitar o conhecimento dos seus constituintes de maneira a estimular o seu consumo, valorizando o patrimônio cultural relacionado à alimentação.

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