OPEN JOURNAL SYSTEMS
ISSN: 2595-4431

Brazilian **J**ournal of **E**nvironment, v.14, n.2. 299-316 (2026)

Brazilian Journal of Environment

Gomes et al

Revista Brasileira de Meio Ambiente

Chemical and biological potential of pruning residues from neotropical fruit species: a green chemistry-based approach

Luiz Rafael Silva Gomes[1], Sidney Mariano dos Santos[2], Claudia Andrea Lima Cardoso[3]*

[1]*Graduando em Química Industrial, Universidade Estadual de Mato Grosso do Sul, Brasil.*
[2]*PhD em Ciências da Saúde, Universidade Estadual de Mato Grosso do Sul, Brasil.*
[3]*PhD em Química, Universidade Estadual de Mato Grosso do Sul, Brasil.* (*Autor correspondente*: claudia@uems.br*)

Article History: Submitted: 16/06/2026 - Revised: 26/07/2026 - Accepted: 30/07/2026

A B S T R A C T

The integration of pruning residues from neotropical fruit species into the circular bioeconomy offers a sustainable pathway to transform agricultural waste into high-value bioproducts. This study evaluated the mineral profiles of dry leaves and branches, as well as the phytochemical, antioxidant capacity and photoprotective potential of aqueous extracts derived from separate leaves and branches of *Malpighia emarginata* (acerola), *Plinia cauliflora* (jaboticaba), *Eugenia uniflora* (pitanga), *Psidium guajava* (guava), and *Persea americana* (avocado) collected in Brazil. Biomass validation included macro and micronutrient analysis via atomic absorption spectrophotometry and turbidimetry. Total phenolic (TPC) and flavonoid (TFC) contents, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, and Sun Protection Factor (SPF) were measured by spectrophotometry. A robust bioactivity gradient (PC1 > 83%) was observed across all species, demonstrating that TPC and TFC are intrinsically linked to both radical scavenging and photoprotection. Foliar tissues consistently exhibited superior metabolic potency compared to branches, establishing a pronounced tissue-specific potency gap. These findings validate green aqueous extraction as a safe and effective bioprocess to recover specialized polar metabolites from pruning waste, positioning these neotropical residues as high-performance, sustainable ingredients for the global cosmeceutical and nutraceutical markets.

Keywords: Agro-industrial residues, Polyphenols, Antioxidants, Nutrients, Photoprotection.

Potencial químico e biológico dos resíduos da poda de espécies frutíferas neotropicais: uma abordagem baseada na química verde

R E S U M O

A integração de resíduos de poda de espécies frutíferas neotropicais na bioeconomia circular oferece um caminho sustentável para transformar resíduos agrícolas em bioprodutos de alto valor. Este estudo avaliou os perfis minerais de folhas e galhos secos, bem como o potencial fitoquímico, a capacidade antioxidante e o potencial fotoprotetor de extratos aquosos obtidos de folhas e galhos separados de *Malpighia emarginata* (acerola), *Plinia cauliflora* (jaboticaba), *Eugenia uniflora* (pitanga), *Psidium guajava* (goiaba) e *Persea americana* (abacate) coletados no Brasil. A validação da biomassa incluiu a análise de macro e micronutrientes por espectrofotometria de absorção atômica e turbidimetria. Os conteúdos de fenólicos totais (TPC) e flavonoides totais (TFC), a atividade de captura do radical 2,2-difenil-1-picrilhidrazila (DPPH) e o Fator de Proteção Solar (SPF) foram medidos por espectrofotometria. Um gradiente robusto de bioatividade (PC1 > 83%) foi observado em todas as espécies, demonstrando que o TPC e o TFC estão intrinsecamente ligados tanto à captura de radicais quanto à fotoproteção. Os tecidos foliares exibiram consistentemente uma potência metabólica superior em comparação com os galhos, estabelecendo uma lacuna pronunciada de potência específica do tecido. Esses achados validam a extração aquosa verde como um bioprocesso seguro e eficaz para recuperar metabólitos polares especializados de resíduos de poda, posicionando esses resíduos neotropicais como ingredientes sustentáveis de alto desempenho para os mercados globais de cosmecêuticos e nutracêuticos.

Palavras-Chaves: Resíduos agroindustriais, Polifenóis, Antioxidantes, Nutrientes, Fotoproteção.

Gomes, L. R. S., Santos, S. M. dos, & Cardoso, C. A. L. (2026). Chemical and biological potential of pruning residues from neotropical fruit species: a green chemistry-based approach. **Brazilian Journal of Environment (Rev. Bras. de Meio Ambiente)**, v.14, n.2, p.299-316.

Potencial químico y biológico de los residuos de poda de especies frutales neotropicales: un enfoque basado en la química verde

R E S U M E N

La integración de los residuos de poda de especies frutales neotropicales en la bioeconomía circular ofrece una vía sostenible para transformar los desechos agrícolas en bioproductos de alto valor. Este estudio evaluó los perfiles minerales de hojas y ramas secas, así como el potencial fitoquímico, la capacidad antioxidante y el potencial fotoprotector de extractos acuosos derivados de hojas y ramas separadas de *Malpighia emarginata* (acerola), *Plinia cauliflora* (jaboticaba), *Eugenia uniflora* (pitanga), *Psidium guajava* (guayaba) y *Persea americana* (aguacate) recolectadas en Brasil. La validación de la biomasa incluyó el análisis de macro y micronutrientes mediante espectrofotometría de absorción atómica y turbidimetría. El contenido de fenoles totales (TPC), los flavonoides totales (TFC), la actividad de captación del radical 2,2-difenil-1-picrilhidrazilo (DPPH) y el Factor de Protección Solar (SPF) se midieron por espectrofotometría. Se observó un gradiente de bioactividad robusto (PC1 > 83%) en todas las especies, lo que demuestra que el TPC y el TFC están intrínsecamente vinculados tanto a la captación de radicales como a la fotoprotección. Los tejidos foliares exhibieron consistentemente una potencia metabólica superior en comparación con las ramas, estableciendo una brecha pronunciada de potencia específica del tejido. Estos hallazgos validan la extracción acuosa verde como un bioproceso seguro y eficaz para recuperar metabolitos polares especializados a partir de residuos de poda, posicionando estos residuos neotropicales como ingredientes sostenibles de alto rendimiento para los mercados globales de cosmecéuticos y nutracéuticos.

Palabras clave: Residuos agroindustriales, Polifenoles, Antioxidantes, Nutrientes, Fotoprotección.

1. Introduction

Brazil is currently the world's third largest fruit producer, maintaining an annual output of approximately 40–43 million tonnes across an area of 1.9–2.3 million hectares (Bornal et al., 2021; Petry et al., 2025). This sector serves as a cornerstone of the national economy and social fabric, generating roughly 5–6 million jobs, which accounts for nearly 16% of the agricultural workforce, and reaching a Gross Production Value (GPV) of R$ 75 billion in 2023 (Bornal et al., 2021; Petry et al., 2025). Furthermore, fruit farming is deeply embedded in family agriculture, which constitutes 77% of rural establishments and provides 70% of the basic foodstuffs consumed internally (Luiz & Milani, 2022). While widespread crops like orange and banana dominate the volume (Petry et al., 2025), several other species hold strategic importance due to their high nutritional value and industrial potential.

Among these, acerola (*Malpighia emarginata* DC.) has positioned Brazil as the global leader in production, consumption, and export, with over 7,000 hectares cultivated and 42 distinct cultivars. Its prominence is largely driven by its industrial role as a superior natural source of Vitamin C (Farinelli et al., 2021; Ferreira et al., 2021). Within the Myrtaceae family, jaboticaba (*Plinia cauliflora* (Mart.) Kausel) stands as an iconic species of the Brazilian Atlantic Forest (Silva et al., 2019), while pitanga (*Eugenia uniflora* L.) is widely recognized for its adaptability (Franzon et al., 2018). Both are ubiquitous in domestic orchards, landscaping, and local fresh markets. Guava (*Psidium guajava* L.) further represents a critical industrial asset, utilized extensively for pulp and confectionery, being cultivated over 20,000 hectares and yielding around 460,000 tonnes annually (Vitti et al., 2020; Petry et al., 2025). Finally, avocado (*Persea americana* Mill.) has seen a significant production surge; in 2019, Brazil accounted for 243,000 tonnes, ranking seventh globally and contributing 3.4% to the total world supply (Fischer & Firmino, 2023).

Despite the high productivity of these species, routine orchard management generates substantial volumes of agricultural byproducts, particularly pruning residues. These materials are traditionally discarded, burned, or left to decompose in the field, leading to the loss of valuable biomass and increasing environmental burdens. While specific data on pruning waste for these neotropical species remain scarce, estimates in the European Union fruit industry suggest a potential availability of approximately 25 million metric tonnes of dry matter per year (Libutti et al., 2021). From a circular bioeconomy perspective, these residues serve as

concentrated reservoirs of secondary metabolites synthesized by plants as adaptive responses to environmental stressors. The strategic repurposing of biomass as high-value bioproducts offers a sustainable pathway to mitigate waste and provide innovative inputs for the pharmaceutical and cosmeceutical industries, aligning with the United Nations Agenda 2030 for Sustainable Development, particularly Goal 12, which advocates for more sustainable production models and the reduction of waste across industrial chains (Sharma & Malaviya, 2023).

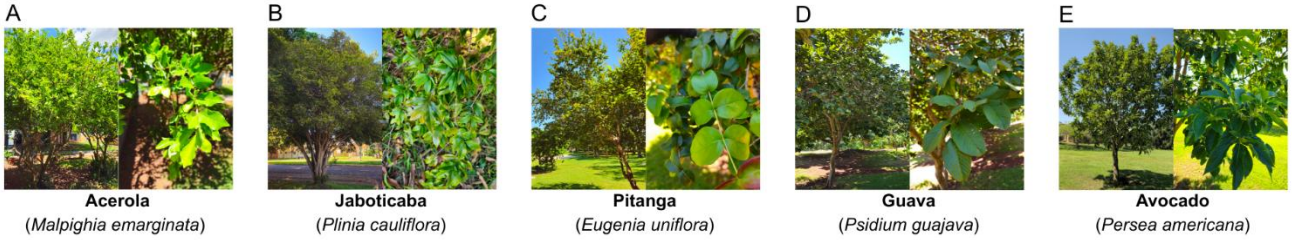
In light of this potential, the objectives of this study were to quantify the macro and micronutrient profiles in the dried leaves and branches of *M. emarginata*, *P. cauliflora*, *E. uniflora*, *P. guajava*, and *P. americana*. Furthermore, we sought to produce aqueous extracts from both organs at concentrations of 2%, 5%, and 10% (w/v) to evaluate their total phenolic and flavonoid content, antioxidant activity, and sun protection factor (SPF).

2. Material and Methods

2.1 Plant material and registration

Pruning residues (leaves and branches) from acerola (*M. emarginata*), jaboticaba (*P. cauliflora*), pitanga (*E. uniflora*), guava (*P. guajava*), and avocado (*P. americana*) were collected in Dourados, Mato Grosso do Sul, Brazil (22°11'46" S, 54°55'48" W), in August 2025. Figure 1A–E shows the specimens.

Figure 1 - Representative images of the five neotropical fruit tree species evaluated in the study
Figura 1 – Imagens representativas das cinco espécies de árvores frutíferas neotropicais avaliadas no estudo



Source: Prepared by the authors
Fonte: Elaborado pelos autores

The study was registered with the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SisGen) under registration number A990F39.

2.2 Sample processing and aqueous extraction

Cleaned leaves and branches were dried separately in a forced-air circulation oven (Solab, Brazil) at 45 °C until a constant weight was achieved. The percentage of moisture content (MC %) was calculated using formula: MC (%) = $[(M_i - M_f)/ M_i] \times 100$. Where M_i represents the initial mass and M_f represents the final mass. Following dehydration, the plant materials were individually ground in a knife mill (Fortinox, Brazil). Aqueous extracts of leaves and branches were prepared using distilled water at concentrations of 2%, 5%, and 10% (w/v). The mixture was maintained for 24 hours at 20 °C to ensure optimal extraction. Subsequently, the extracts were filtered and utilized immediately for all subsequent analyses.

2.3 Total phenolic content (TPC)

Total phenolic compounds were quantified via the Folin–Ciocalteu method (Singleton & Rossi, 1965), as modified by Djeridane et al. (2006). The protocol involved mixing 1 mL of extract with 0.5 mL of Folin–Ciocalteu reagent (1:10 v/v) and 1 mL of distilled water. Following a 1-min interval, 1.5 mL of 20% (w/v) sodium carbonate was added. After 120 min of incubation at room temperature, absorbance was read at 760 nm (BEL Photonics, Brazil). Quantification followed a gallic acid calibration curve (10–1000 μg mL^{-1}; $y = 0.0015x + 0.0008$; $R^2 = 0.9875$), with results expressed as μg gallic acid equivalents per milliliter (μg GAE mL^{-1}). Extraction solvent replaced the sample for the blank, and all analyses were performed in triplicate.

2.4 Total flavonoid content (TFC)

Total flavonoid content was measured using the aluminum chloride colorimetric method (Christ & Müller, 1960), adapted by Djeridane et al. (2006). Briefly, 1 mL of sample was reacted with 1 mL of aluminum chloride (2% w/v in methanol). After a 15-min incubation at room temperature, the absorbance was recorded at 430 nm using a spectrophotometer (BEL Photonics, Brazil). Quantification was performed using a rutin standard curve (10–50 μg mL^{-1}; $y = 0.0105x + 0.0019$; $R^2 = 0.9990$), with results expressed as micrograms of rutin equivalents per milliliter (μg RE mL^{-1}). For the blank, the sample was replaced with the extraction solvent. All tests were conducted in triplicate.

2.5 DPPH radical scavenging activity

The antioxidant capacity was evaluated through the sequestration of the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical, based on the method by Blois (1958) with adaptations by Capanoglu et al. (2008). Aliquots of 100 μL of each extract were mixed with 2000 μL of a 0.1 mmol L^{-1} methanolic DPPH solution. The mixture was incubated in the dark for 30 min, and the absorbance was subsequently measured at 517 nm (BEL Photonics, Brazil). The radical scavenging activity was determined as a percentage of inhibition (%I) and calculated as follows: $\%I = [(AbsC - AbsS) / AbsC] \times 100$. Where AbsC corresponds to the absorbance of the control (extraction solvent replacing the sample) and AbsS represents the absorbance of the sample. All assays were performed in triplicate.

2.6 UV-Vis scanning and determination of the Sun Protection Factor (SPF)

The UV-Vis scanning of the aqueous extracts was performed in duplicate using a spectrophotometer (BEL Photonics, Brazil). Absorbance measurements were recorded from 200 to 800 nm, with a 1 nm resolution, using a quartz cuvette.

The SPF was determined based on absorbance readings from 290 to 320 nm at 5 nm intervals, applying the methodology by Mansur et al. (1986). The values were calculated using the equation $SPF = CF \times \Sigma (290\text{-}320\ nm)\ EE(\lambda) \times I(\lambda) \times Abs(\lambda)$, where CF represents the correction factor (=10), $EE(\lambda) \times I(\lambda)$ values remained constant as previously described by Sayre et al. (1979) with $EE(\lambda)$ corresponding to the erythemal efficiency spectrum and $I(\lambda)$ represents the solar light intensity spectrum; and $Abs(\lambda)$ indicates the absorbance of the solution at each wavelength.

2.7 Plant tissue nutrient analysis

Dry leaves and branches underwent nitric-perchloric wet digestion, for the determination of macro and micronutrients. The concentrations of calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) were measured by atomic absorption spectrophotometry (Perkin Elmer, United States of America), and sulfur (S) was determined through barium sulfate turbidimetry. Nutrient concentrations were expressed in g kg^{-1} for macronutrients and mg kg^{-1} for micronutrients, based on the dry matter weight (Malavolta et al., 1997).

2.8 Statistical analysis

All statistical computations and data visualizations were executed using R software (version 4.5.3) within the RStudio integrated development environment (version 2026.01.2+418). Hierarchical clustering analysis (HCA) was performed using the Euclidean distance matrix and the unweighted pair-group method with arithmetic mean (UPGMA) linkage method, and the resulting dataset was visualized as a two-way hierarchical clustering heatmap using the vegan and pheatmap packages. Radar charts were generated to compare multi-variable profiles across samples using the fmsb and scales packages.

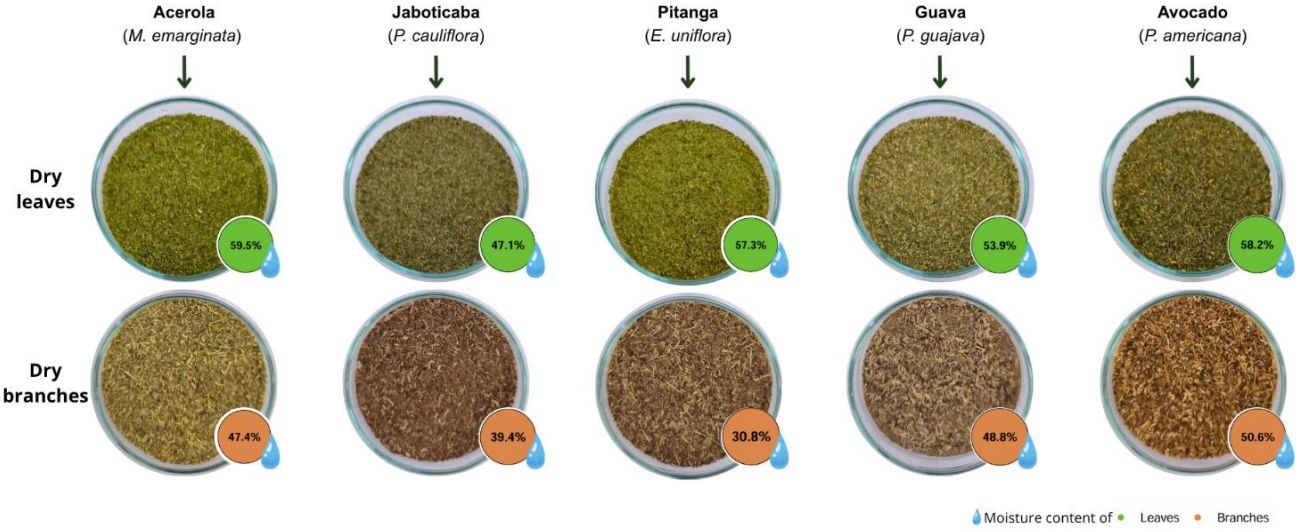
Principal Component Analysis (PCA) was calculated based on a correlation matrix to assess data variance, and the multivariate structures were projected via biplot graphs using the FactoMineR and factoextra packages. Comparative ultraviolet spectral profiles within the 200 to 400 nm wavelength range were mapped as two-dimensional contour and three-dimensional surface response graphs using the plotly and ggplot2 packages.

3. Results

3.1 Moisture content

The moisture content of the pruning residues varied across the five neotropical species and between the respective botanical organs (Figure 2). Overall, foliar tissues exhibited higher moisture levels compared to branches. The moisture content in leaves ranged from 47.12 ± 1.13% in jaboticaba to 59.48 ± 0.17% in acerola. In contrast, the branches showed a lower water retention, with values spanning from 30.75 ± 0.08% in pitanga to 50.62 ± 0.22% in avocado.

Figure 2 - Processed dry biomass (leaves and branches), and the respective moisture content (%) for each botanical organ
Figura 2 – Biomassa seca processada (folhas e galhos) e o respectivo teor de umidade (%) para cada órgão botânico



Fonte: Elaborado pelos autores
Source: Prepared by the authors

In Figure 2, it is possible to observe distinct shades of green pigmentation in the leaf samples, caused by the presence of photosynthetic pigments such as chlorophyll, and brown tones on the branches, where these pigments are not abundant.

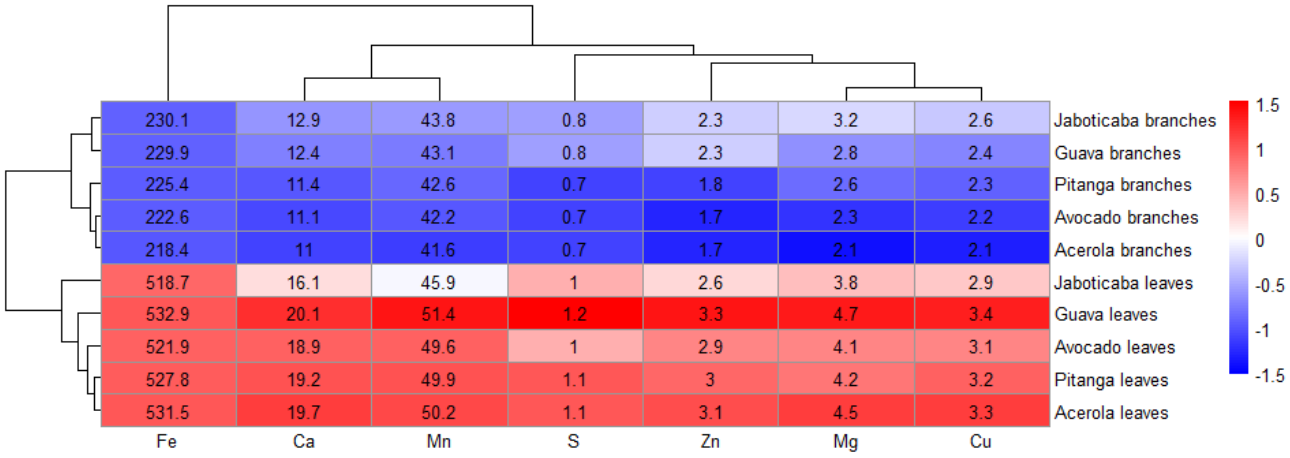
3.2 Macro and micronutrient profile of dried biomass

The elemental analysis of the dried biomass revealed a distinct nutritional partitioning between plant organs, with leaf tissues consistently exhibiting a higher accumulation of both macro (Ca, Mg and S) and micronutrients (Fe, Mn, Zn and Cu) compared to branches. While the differences in mineral concentration between leaves of different species, as well as between branches of different species, were relatively narrow, a clear organ-specific hierarchy was established.

This distribution is visualized in the hierarchical clustering heatmap (Figure 3), where the samples are segregated into two primary clusters: a high-concentration cluster (red) corresponding to leaf tissues and a low-concentration cluster (blue) corresponding to branch tissues.

Figure 3 - Hierarchical clustering heatmap of macro and micronutrient concentrations in the dried biomass (leaves and branches) of acerola, jaboticaba, pitanga, guava, and avocado. The color scale represents the standardized concentration levels, ranging from blue (lower concentration) to red (higher concentration). The numerical values within each cell represent the specific elemental concentrations for Iron (Fe), Calcium (Ca), Manganese (Mn), Sulfur (S), Zinc (Zn), Magnesium (Mg), and Copper (Cu)

Figura 3 – Mapa de calor de agrupamento hierárquico das concentrações de macro e micronutrientes na biomassa seca (folhas e galhos) de acerola, jaboticaba, pitanga, goiaba e abacate. A escala de cores representa os níveis de concentração padronizados, variando do azul (menor concentração) ao vermelho (maior concentração). Os valores numéricos dentro de cada célula representam as concentrações elementares específicas de Ferro (Fe), Cálcio (Ca), Manganês (Mn), Enxofre (S), Zinco (Zn), Magnésio (Mg) e Cobre (Cu)



Source: Prepared by the authors
Fonte: Elaborado pelos autores

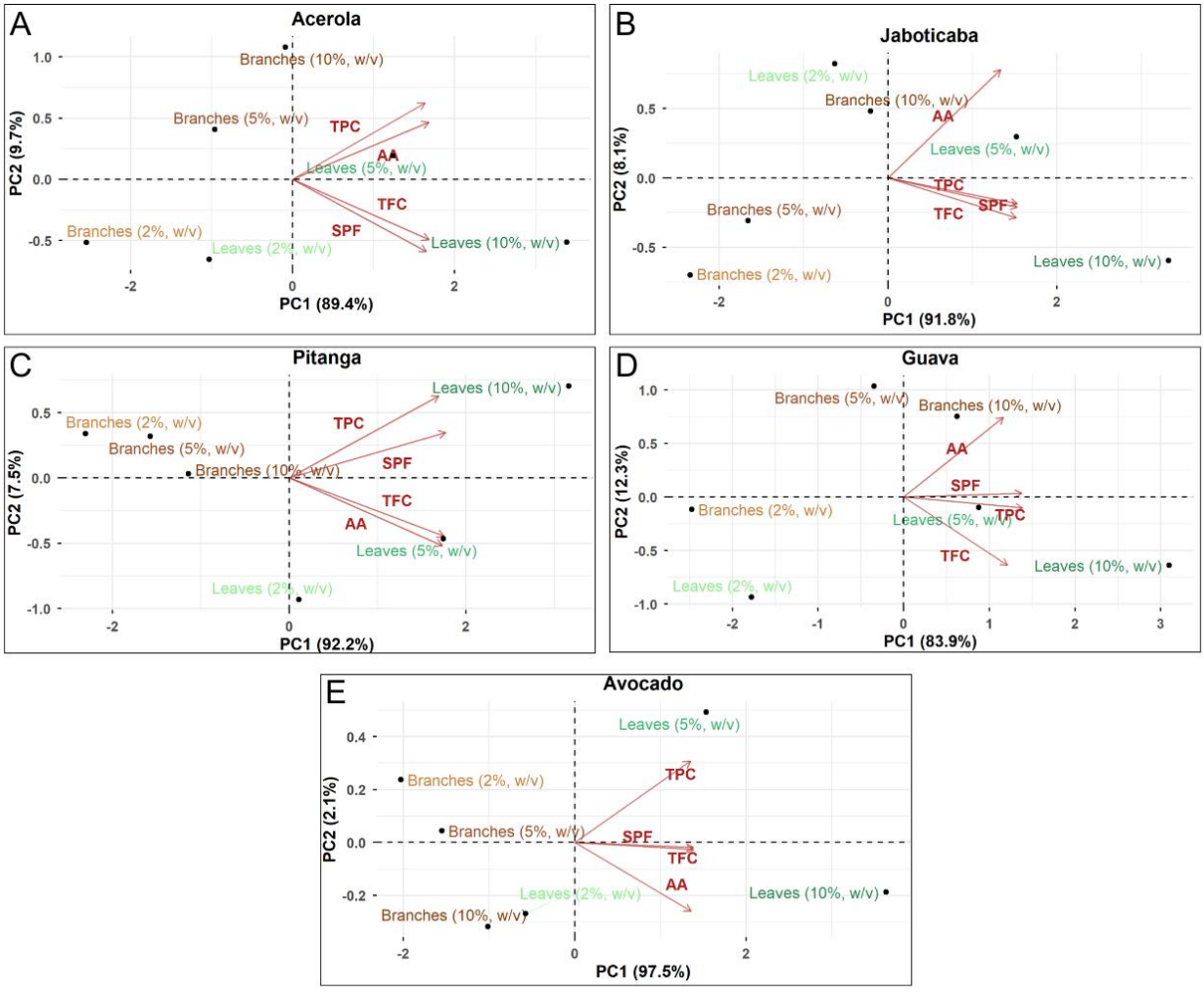
Among the studied species, guava leaves were particularly noteworthy for presenting the highest concentrations for all analyzed elements, including Fe (532.9 mg kg^{-1}), Ca (20.1 g kg^{-1}), Mn (51.4 mg kg^{-1}), S (1.2 g kg^{-1}), Zn (3.3 mg kg^{-1}), Mg (4.7 g kg^{-1}), and Cu (3.4 mg kg^{-1}). This superior mineral density in guava leaves highlights its potential as a more concentrated source of essential nutrients relative to the other horticultural species evaluated.

3.3. Phytochemical quantification, antioxidant potential, and photoprotective capacity

The spectrophotometric characterization of all 5 species revealed a dose-dependent and organ-specific profile for all evaluated parameters. Overall, the aqueous extracts from leaves consistently outperformed those from branches across all concentrations for TPC, TFC, Antioxidant Activity (AA), and SPF (Tables S1-S5). The Principal Component Analysis (PCA) biplots for the five species (acerola, jaboticaba, pitanga, guava, and avocado) demonstrated a remarkably consistent trend in the distribution of their bioactive properties (Figures 4A-E).

Figure 4 - Principal Component Analysis (PCA) biplots of aqueous extracts from five fruit species: (A) acerola, (B) jaboticaba, (C) pitanga, (D) guava, and (E) avocado. The biplots illustrate the distribution of samples based on organ (leaves and branches) and concentration (2%, 5%, and 10%, m/v). The vectors represent the analyzed variables: Total Phenolic Content (TPC), Total Flavonoid Content (TFC), Antioxidant Activity (AA), and Sun Protection Factor (SPF). PC1 and PC2 indicate the first and second principal components, respectively, with their corresponding percentages of explained variance

Figura 4 – Biplots da Análise de Componentes Principais (PCA) de extratos aquosos de cinco espécies de frutas: (A) acerola, (B) jaboticaba, (C) pitanga, (D) goiaba e (E) abacate. Os biplots ilustram a distribuição das amostras com base no órgão (folhas e galhos) e na concentração (2%, 5% e 10% m/v). Os vetores representam as variáveis analisadas: Teor de Fenóis Totais (TPC), Teor de Flavonoides Totais (TFC), Atividade Antioxidante (AA) e Fator de Proteção Solar (FPS). PC1 e PC2 indicam o primeiro e o segundo componentes principais, respectivamente, com suas respectivas porcentagens de variância



Source: Prepared by the authors
Fonte: Elaborado pelos autores

In all cases, the first principal component (PC1) served as the primary axis for discriminating extract potency, accounting for an exceptionally high percentage of the total variance: 89.4% for acerola, 91.8% for jaboticaba, 92.2% for pitanga, 83.9% for guava, and 97.5% for avocado. The factor loadings for the four

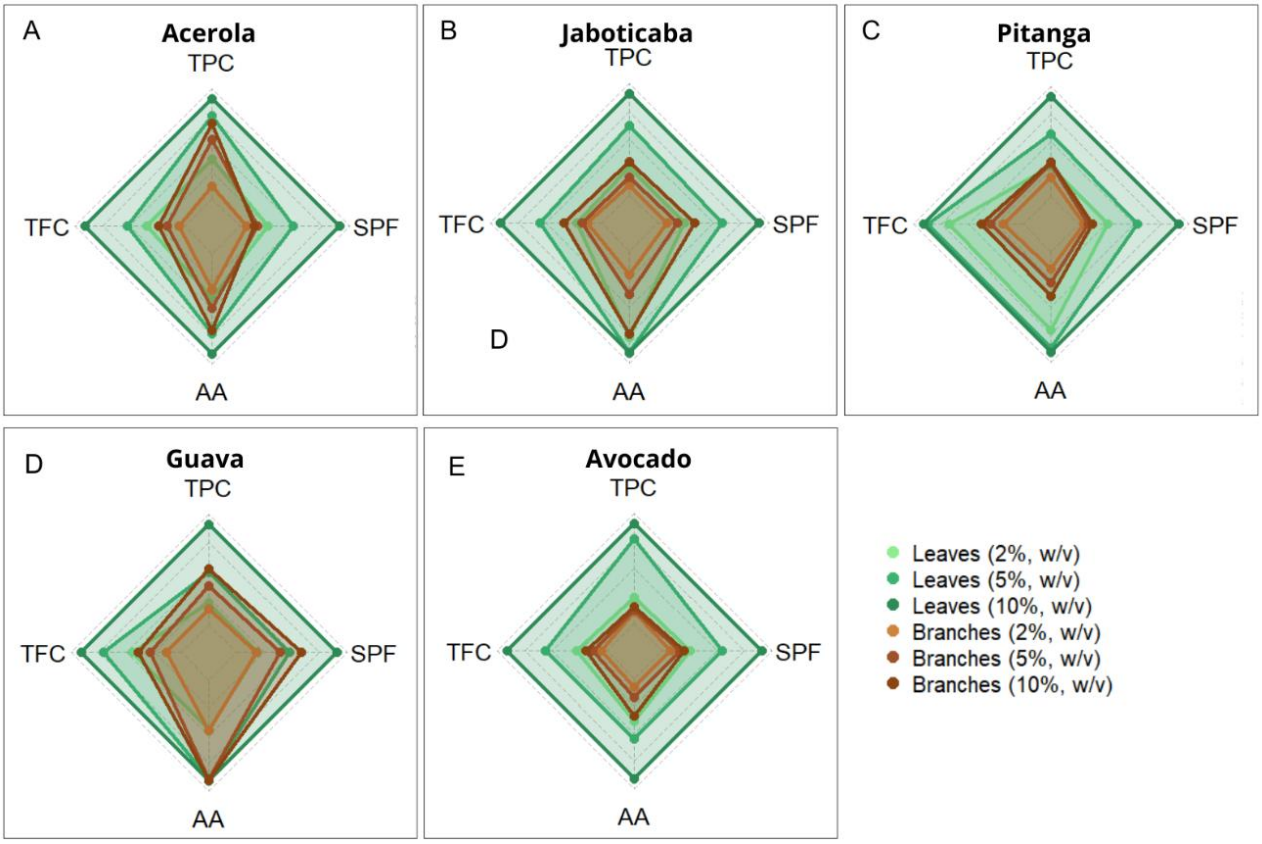
analyzed variables (TPC, TFC, AA and SPF) were strongly and positively correlated with the right side of the horizontal axis (PC1 > 0). This alignment indicates that PC1 represents a gradient of bioactivity, where movement to the right reflects a simultaneous increase in all evaluated phytochemical and photoprotective parameters.

Consequently, a clear organ-specific and dose-dependent segregation was observed across all species. The 10% and 5% leaf extracts were consistently positioned at the far right of the biplot, identifying them as the most bioactive samples. In contrast, the 2% branch extracts were clustered at the far left of the biplot, representing the lowest thresholds of phenolic accumulation and antioxidant capacity.

Interestingly, the PCA reveals that the chemical discrepancy between leaves and branches is so pronounced in certain species that the highest concentration of branch extracts (10%) fails to reach the coordinates occupied by even the lowest concentration of leaf extracts (2%). This potency gap was most evident in pitanga and avocado, where the leaves maintained a distinct and superior bioactive cluster regardless of concentration. In contrast, for acerola and jaboticaba, the 2% leaf extracts occupied coordinates similar to those of the higher-concentration branch extracts, suggesting a narrower margin of superiority. A unique behavior was observed in guava, where the 10% branch concentration shared similar coordinates with the 5% leaf extracts, indicating a partial overlap in their phytochemical profiles.

The multi-parameter performance of the extracts was further visualized using radar charts (Figures 5A-E), which provide a comprehensive bioactive footprint of each sample. This analysis confirms a consistent hierarchical superiority of leaf extracts over branch extracts across all species, as well as a clear dose-dependent increase for every evaluated variable.

Figure 5 - Comparative radar charts illustrating the bioactive signatures of aqueous extracts
Figura 5 – Gráficos de radar comparativos ilustrando as assinaturas bioativas de extratos aquosos



Source: Prepared by the authors
Fonte: Elaborado pelos autores

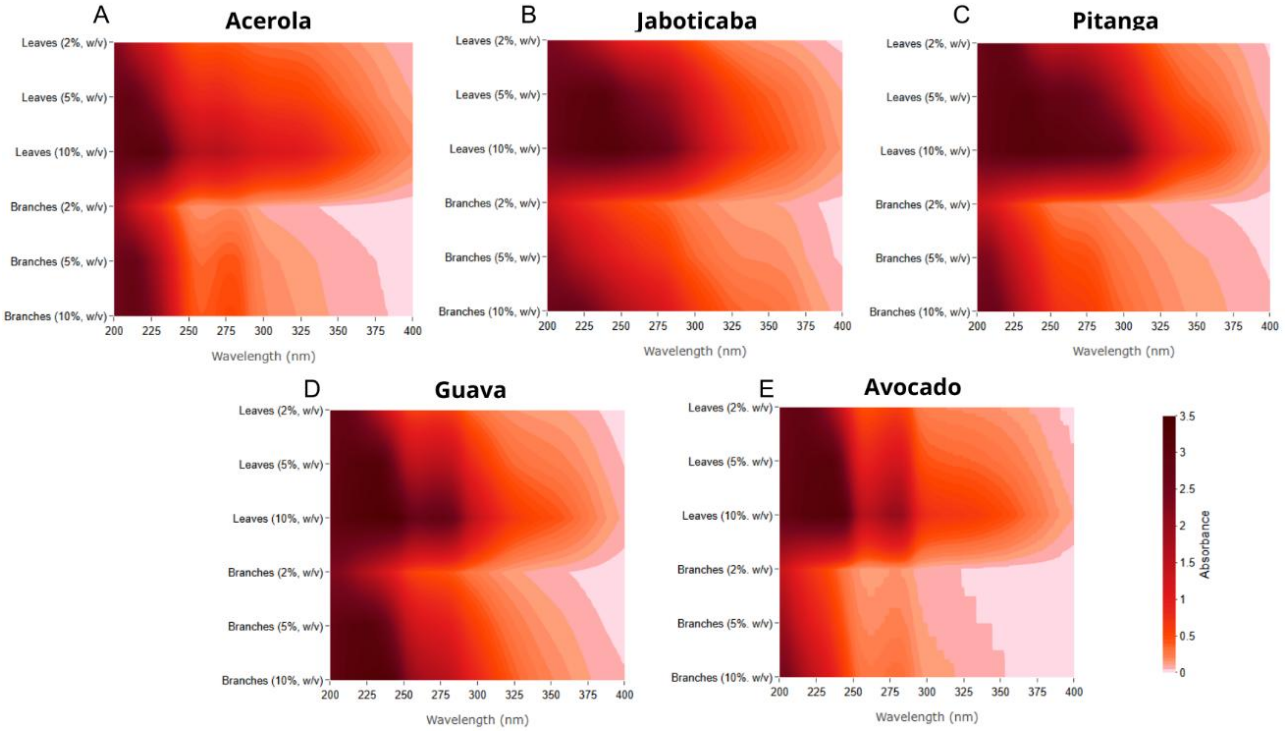
Legend: (A) acerola, (B) jaboticaba, (C) pitanga, (D) guava, and (E) avocado. Each axis represents a distinct analytical parameter: Total Phenolic Content (TPC), Total Flavonoid Content (TFC), Antioxidant Activity (AA), and Sun Protection Factor (SPF). Green lines represent leaf extracts and brown lines represent branch extracts, with line shading intensity corresponding to the increasing concentrations of 2%, 5%, and 10% (m/v)
Legenda: (A) acerola, (B) jaboticaba, (C) pitanga, (D) goiaba e (E) abacate. Cada eixo representa um parâmetro analítico distinto: Teor de Fenóis Totais (TPC), Teor de Flavonoides Totais (TFC), Atividade Antioxidante (AA) e Fator de Proteção Solar (FPS). As linhas verdes representam extratos de folhas e as linhas marrons representam extratos de galhos, com a intensidade do sombreamento da linha correspondendo ao aumento das concentrações de 2%, 5% e 10% (m/v)

In numerical terms, the TPC reached its maximum in avocado leaf extracts, with values ranging from 162.80 to 625.91 μg GAE mL^{-1}. Corroborating the earlier PCA findings, the radar charts for pitanga and avocado illustrate that all branch concentrations are entirely contained within the area defined by the lowest leaf concentration (2%). Visually, this is represented by all brown lines (branches) remaining internal to the 2% leaf boundary (green line), highlighting a significant potency gap where even the most concentrated branch extract fails to reach the threshold of the most dilute leaf extract.

Conversely, for the other species, a more pronounced overlap was observed between the distinct organs. In these cases, the 2% leaf concentrations exhibited performance levels comparable to the 10% branch concentrations, particularly regarding TPC and antioxidant capacity. Regarding specific chemical classes and biological activities, pitanga leaves demonstrated the highest accumulation of TFC, with values between 71.26 and 90.74 μg RE mL^{-1}, while also achieving the greatest radical scavenging capacity with DPPH inhibition ranging from 71.26% to 90.74%.

The most expressive photoprotective results were recorded for jaboticaba leaf extracts, which yielded SPF values between 10.10 and 38.01. These signatures reinforce that while leaves are universally the superior source of bioactive compounds, the magnitude of this superiority and the degree of organ-specific differentiation are highly species-dependent. This photoprotective capacity is further supported by the comparative spectral profiles obtained through UV scanning between 200 and 400 nm (Figures 6A-E). The absorbance intensity is illustrated via contour heatmaps, where darker regions represent higher absorbance values, providing a visual correlation between extract concentration and absorbance in UV regions.

Figure 6 - Comparative UV spectral profiles (200–400 nm) of aqueous extracts from (A) acerola, (B) jaboticaba, (C) pitanga, (D) guava, and (E) avocado. The heatmaps illustrate absorbance intensity as a function of wavelength for both leaves and branches at 2%, 5%, and 10% (m/v) concentrations. Color intensity indicates absorbance levels
Figura 6 – Perfis espectrais UV comparativos (200–400 nm) de extratos aquosos de (A) acerola, (B) jaboticaba, (C) pitanga, (D) goiaba e (E) abacate. Os mapas de calor ilustram a intensidade de absorbância em função do comprimento de onda para folhas e galhos nas concentrações de 2%, 5% e 10% (m/v). A intensidade da cor indica os níveis de absorbância



Source: Prepared by the authors
Fonte: Elaborado pelos autores

Within these wavelengths, prominent absorption peaks were observed at approximately 250 and 275 nm, particularly in the leaf extracts. While jaboticaba and pitanga exhibited a more homogeneous and intense absorption throughout the 200–300 nm range at higher concentrations, a more defined isolation of individual peaks was characteristic of the acerola, guava and avocado profiles. Generally, the absorbance intensity followed a strict dose-dependent pattern for both organs; however, leaf extracts consistently displayed higher absorbance across the entire spectrum compared to branch extracts. This robust absorption in the UV-C (200–290 nm) and UV-B (290–320 nm) regions corroborates the elevated SPF values and highlights the potential of these aqueous leaf extracts as natural ultraviolet filters. No significant absorption peaks were detected in the visible range between 400 and 800 nm.

4. Discussion

The valorization of pruning waste from neotropical fruit species, such as acerola, jaboticaba, pitanga, guava, and avocado, represents a central strategy for the circular bioeconomy by transforming traditionally discarded agricultural byproducts into reservoirs of bioactive compounds with high added value (Aliaño-González et al., 2022). Even when utilized, this material is typically only crushed and reused as organic

compost, soil cover, or as biofuel for energy generation (Reyes-Martín et al., 2022). However, these residues serve as concentrated reservoirs of secondary metabolites synthesized through complex adaptive pathways in response to environmental stressors, allowing them to be strategically repurposed as high-value bioproducts (Palazon & Alcalde, 2025). The integration of mineral profiles, bioactive performance, and phytochemical accumulation dictates the overall quality of this biomass, positioning it as a sustainable source for the cosmeceutical and nutraceutical industries.

The heterogeneity in moisture and mineral distribution reflects the distinct physiological roles of leaves and branches (Ievinsh, 2023; Sultanbawa & Sultanbawa, 2023). Foliar tissues exhibited significantly higher moisture levels (up to 59.48% in acerola) compared to branches, a characteristic consistent with the intense metabolic turnover of photosynthetic machinery (Lawson & Milliken, 2023). This moisture regulation is intrinsically linked to nutrient concentration; the hierarchical clustering heatmap (Figure 3) confirms a high-concentration cluster in leaves, particularly in guava, which showed the highest levels of all analyzed elements. Elevated contents of these minerals, including Mg, Mn, Zn, and Fe, have also been described in different guava cultivars worldwide (Sahal et al., 2025).

The presence of macronutrients (Ca, Mg, S) and micronutrients (Fe, Mn, Zn, Cu) in these tissues is essential for maintaining cell wall integrity and mediating cell signaling pathways (Tariq et al., 2023). Although the occurrence of these nutrients is not species-specific, as they are also reported in various tissues of acerola (Laurindo et al., 2024), jaboticaba (Fernandes et al., 2022), pitanga (Pereira et al., 2022), and avocado (Araújo et al., 2018), they play a pivotal role in the synthesis of UV-absorbing pigments, such as chlorophylls and carotenoids, and serve as indispensable cofactors for antioxidant enzymes (Tariq et al., 2023). Furthermore, they act as enzymatic cofactors in the biosynthetic pathways of phenols and flavonoids, which independently mitigate oxidative stress and minimize structural and oxidative damage induced by UV radiation (Tariq et al., 2023).

From a bioprocessing standpoint, the standardization of extracts based on dry weight served as a fundamental step to ensure that the measured chemical potency reflects the intrinsic secondary metabolism of the biomass rather than dilution artifacts stemming from environmental moisture fluctuations at the time of harvest (Sethiya et al., 2025). The selection of water as the primary solvent in this study aligns with the principles of Green Chemistry, prioritizing safety, cost-effectiveness, and environmental sustainability in the extraction of natural products (Gallina et al., 2022). Beyond its ecological advantages, water effectively recovers a wide range of polar bioactive compounds, such as phenolic acids and glycosylated flavonoids, which are the primary drivers of the observed antioxidant and photoprotective activities. Although the use of more modern extraction protocols, such as ultrasound-assisted, microwave-assisted or subcritical extraction, may enhance industrial yields (Gallina et al., 2022), the use of aqueous systems ensures superior biocompatibility and streamlines the integration of these bioinputs into topical cosmeceutical formulations. This strategy effectively bypasses the toxicity concerns and laborious purification processes associated with organic solvents (Zhou et al., 2019), preserving the biochemical integrity of the pruning residues while demonstrating the feasibility of developing high-performance, water-based botanical ingredients for the global market.

The PCA revealed a robust gradient of bioactivity across all species (PC1 > 83%), demonstrating that total phenolic and flavonoid contents are intrinsically linked to both antioxidant capacity and photoprotective efficacy. This synergy is explained by the dual role of polyphenols, which act both as chemical filters for UV radiation and as scavengers of radiation-induced free radicals (Mutha et al., 2021; Li et al., 2023). A key finding of this study is the potency gap observed in species like pitanga and avocado, where the bioactivity of leaf tissues is so concentrated that even highly diluted leaf extracts outperform the most concentrated branch preparations. Such tissue-specific metabolic partitioning is well-documented within fruit-bearing species (Li et al., 2016). Although mainstream agro-industrial residue research predominantly focuses on fruits and their processing byproducts, recent investigations have increasingly explored the valorization of foliar and, less frequently, lignified branch tissues.

This anatomical partitioning dictates distinct phytochemical profiles among the studied species. For instance, pitanga leaves are characterized by a prominent accumulation of myricetin and quercetin glycosides alongside chlorogenic, gallic, and quinic acids (Garmus et al., 2019), demonstrating a major metabolic overlap with the foliar profile of guava, which features guaijaverin, avicularin, kaempferol, and chlorogenic acid (Kareem & Kadhim, 2024; Sahal et al., 2025). Acerola tissues expand upon this shared polyphenol blueprint by harboring a high diversity of structural subclasses, including monomeric catechins, anthocyanins, and flavones such as apigenin and luteolin (Laurindo et al., 2024), while avocado profiles similarly integrate these pathways through the biosynthesis of rutin, catechin, luteolin glycosides, and cinnamic acid derivatives (Castro-López et al., 2019). The jaboticaba, in turn, provides a clear model for intra-plant partitioning, where its leaves exhibit a higher density of flavonols, specifically quercetin and myricetin derivatives, whereas the more lignified branches are distinctively enriched with condensed and hydrolyzable tannins, flavan-3-ol derivatives, ellagic acid, and complex ellagitannins such as castalagin and casuarictin (Fernandes et al., 2022; Paula et al., 2021).

These specialized phytochemical profiles and their subsequent antioxidant performance are heavily influenced by the extraction parameters and solvent systems employed. Literature reports evaluating different extraction methods confirm that aqueous and hydroalcoholic systems, including traditional infusions, decoctions, and macerations, efficiently recover substantial quantities of total phenolics and flavonoids. Consequently, the high concentration of these polar secondary metabolites directly translates into the robust antioxidant capacity observed in the leaf extracts of acerola (Barros et al., 2020), jaboticaba (Paula et al., 2021), pitanga (Schumacher et al., 2015; Zanusso et al., 2023), guava (Sahal et al., 2025), and avocado (Oboh et al., 2016). This consensus validates the use of green aqueous extraction protocols to successfully capture the bioactive potential of these pruning residues.

In plants, phenolic compounds accumulate primarily beneath the epidermal layer of leaves following exposure to UVB radiation. They act as both ultraviolet filters and antioxidants, mitigating damage to DNA, lipids, and proteins (Singh et al., 2023). Translating this biological protective mechanism to the present study, the observed correlation between the ultraviolet spectral profiles from 200 to 400 nm and the calculated SPF values validates these aqueous extracts as effective natural ultraviolet filters, particularly those derived from leaves. The prominent absorption peaks in the UVC and UVB regions, notably in jaboticaba extracts exhibiting an SPF of up to 38.01, strongly suggest the presence of chromophores capable of attenuating high energy radiation.

This photoprotective capacity is intrinsically linked to the specific structural properties of secondary metabolites. For instance, the basic flavonoid structure, represented by flavones, can exhibit UVB absorption levels 15 times greater than their UVA absorption (Csepregi & Hideg, 2018). Spectrophotometrically, flavonoids display two major absorption bands: band II from 240 to 295 nm and band I from 300 to 380 nm, frequently extending into a tail that reaches 400 to 450 nm (Taniguchi et al., 2023). Generally, subclasses such as flavonols, flavones, flavanones, catechins, and isoflavones exhibit typical absorption maxima between 240 to 280 nm and 300 to 400 nm (Csepregi & Hideg, 2018; Li et al., 2023; Ghazi, 2022). Consequently, there is a direct structural link between robust absorption in the UVB range and the presence of molecules like hydroxybenzoic acids and dihydroflavonols (Csepregi & Hideg, 2018). Furthermore, specific structural features, such as the presence of a C2 to C3 double bond, a C4 oxo group, and multiple hydroxyl substitutions on the B ring (catechol structure), synergistically increase absorption at longer ultraviolet wavelengths while simultaneously enhancing the radical scavenging capacity against reactive oxygen species (Csepregi & Hideg, 2018).

5. Conclusion

This study demonstrates that pruning wastes from neotropical fruit species are not mere agricultural byproducts, but highly concentrated, sustainable reservoirs of valuable bioactive compounds. The distinct tissue specific metabolic partitioning reveals that foliar tissues, driven by a rich mineral matrix and a high density of structurally diverse phenols and flavonoids, possess superior antioxidant capacities and photoprotective properties. Ultimately, these findings validate the strategic repurposing of pruning residues as high performance, biocompatible ingredients, bridging the gap between agricultural waste management and the demands of the global cosmeceutical and nutraceutical industries within a circular bioeconomy framework.

6. Acknowledgments

The authors acknowledge the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) (Finance Code 001) and the Rede BioDiversa Centro-Oeste (CAPES Project No. 88887.964845/2024-00 and Process No. 88887.129820/2025-00; and FUNDECT Process No. 83/034.923/2024) for the postdoctoral fellowship awarded to SMS; and the Universidade Estadual de Mato Grosso do Sul and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the research grant awarded to CALC (Process No. 306065/2025-8) and the undergraduate research fellowship awarded to LRSG (Bolsista PIBIC–CNPq/UEMS, MS, Brasil).

7. References

Aliaño-González, M., Gabaston, J., Ortíz-Somovilla, V., & Cantos-Villar, E. (2022). Wood waste from fruit trees: biomolecules and their applications in agri-food industry. **Biomolecules**, 12 (2). https://doi.org/10.3390/biom12020238

Araújo, R. G., Rodriguez Jasso, R. M., Ruiz, H. A., Pintado, M. M. E., & Aguilar, C. N. (2018). Avocado by-products: Nutritional and functional properties. **Trends in Food Science & Technology**, 80, 51-60. https://doi.org/10.1016/j.tifs.2018.07.027

Barros, B.R.S., do Nascimento, D.K.D., de Araújo, D.R.C., da Costa Batista, F.R., de Oliveira Lima, A.M.N., da Cruz Filho, I.J., de Oliveira, M.L., & de Melo, C.M.L. (2020). Phytochemical analysis, nutritional profile and immunostimulatory activity of aqueous extract from *Malpighia emarginata* DC leaves. **Biocatalysis and Agricultural Biotechnology**, 23, 101442. https://doi.org/10.1016/J.BCAB.2019.101442

Blois, M.S. (1958). Antioxidant determinations by the use of a stable free radical. **Nature**, 181, 1199-1200. https://doi.org/10.1038/1811199a0

Bornal, D.R., Silvestrini, M.M., Pio, L.A.S., Costa, A.C., Peche, P.M., & Ramos, M.C.P. (2021). Brazilian position in the international fresh fruit trade network. **Revista Brasileira de Fruticultura**, 43 (5), e-021. https://doi.org/10.1590/0100-29452021021

Capanoglu, E., Beekwilder, J., Boyacioglu, D., Hall, R., & De Vos, R. (2008). Changes in antioxidant and metabolite profiles during production of tomato paste. **Journal of Agricultural and Food Chemistry**, 56 (3), 964–973.

Castro-López, C., Bautista-Hernández, I., González-Hernández, M. D., Martínez-Ávila, G. C. G., Rojas, R.,

Gutiérrez-Díez, A., Medina-Herrera, N., & Aguirre-Arzola, V. E. (2019). Polyphenolic profile and antioxidant activity of leaf purified hydroalcoholic extracts from seven mexican *Persea americana* cultivars. **Molecules,** 24 (1), 173. https://doi.org/10.3390/molecules24010173

Christ, B., & Müller, K.H. (1960). Zur serienmäßigen Bestimmung des Gehaltes an Flavonol-Derivaten in Drogen. **Archiv der Pharmazie**, 293 (12), 1033. https://doi.org/10.1002/ARDP.19602931202

Csepregi, K., & Hideg, É. (2018). Phenolic compound diversity explored in the context of photo-oxidative stress protection. **Phytochemical Analysis**, 29 (2), 129-136. https://doi.org/10.1002/pca.2720

Djeridane, A., Yousfi, M., Nadjemi, B., Boutassouna, D., Stocker, P., & Vidal, N. (2006). Antioxidant activity of some algerian medicinal plants extracts containing phenolic compounds. **Food Chemistry**, 97 (4), 654. https://doi.org/10.1016/J.FOODCHEM.2005.04.028

Farinelli, D., Portarena, S., da Silva, D.F., Traini, C., da Silva, G.M., da Silva, E.C., da Veiga, J.F., Pollegioni, P., & Villa, F. (2021). Variability of fruit quality among 103 acerola (*Malpighia emarginata* D. C.) phenotypes from the subtropical region of Brazil. **Agriculture**, 11 (11), 1078. https://doi.org/10.3390/AGRICULTURE11111078

Fernandes, I.A.A., Maciel, G.M., Maroldi, W.V., Bortolini, D.G., Pedro, A.C., & Haminiuk, C.W.I. (2022). Bioactive compounds, health promotion properties and technological applications of Jabuticaba: A literature overview. **Measurement: Food**, 8, 100057. https://doi.org/10.1016/j.meafoo.2022.100057

Ferreira, I.C., Pereira da Silva, V., Vilvert, J.C., de França Souza, F., de Freitas, S.T., & dos Santos Lima, M., (2021). Brazilian varieties of acerola (*Malpighia emarginata* DC.) produced under tropical semi-arid conditions: Bioactive phenolic compounds, sugars, organic acids, and antioxidant capacity **Journal of Food Biochemistry**, 45 (8), e13829. https://doi.org/10.1111/JFBC.13829

Fischer, I.H., & Firmino, C. A. (2023). Main diseases of avocado in Brazil. **Revisão Anual de Patologias de Plantas**, 29, 106-130. https://doi.org/10.31976/0104-038321v290005

Franzon, R.C., Carpenedo, S., Raseira, M. do C.B., & Viñoly, M.D. (2018). Pitanga—*Eugenia uniflora* L. **Exotic Fruits**, 333–338. https://doi.org/10.1016/B978-0-12-803138-4.00044-7

Gallina, L., Cravotto, C., Capaldi, G., Grillo, G., & Cravotto, G., 2022. Plant extraction in water: towards highly efficient industrial applications. **Processes**, 10 (11), 2233. https://doi.org/10.3390/pr10112233

Garmus, T.T., Kopf, S.F.M., Paula, J.T., Aguiar, A.C., Duarte, G.H.B., Eberlin, M.N., & Cabral, F.A. (2019). Ethanolic and hydroalcoholic extracts of pitanga leaves (*Eugenia uniflora* L.) and their fractionation by supercritical technology. **Brazilian Journal of Chemical Engineering**, 36 (2), 1041. https://doi.org/10.1590/0104-6632.20190362S20180159

Ghazi, S. (2022). Do the polyphenolic compounds from natural products can protect the skin from ultraviolet rays? **Results in Chemistry**, 4, 100428. https://doi.org/10.1016/J.RECHEM.2022.100428

Ievinsh, G. (2023). Water content of plant tissues: so simple that almost forgotten? **Plants**, 12 (6), 1238. https://doi.org/10.3390/plants12061238

Kareem, A. T., & Kadhim, E. J. (2024). *Psidium guajava*: A review on its pharmacological and phytochemical constituents. **Biomedical & Pharmacology Journal**, 17 (2), 1079-1090. https://dx.doi.org/10.13005/bpj/2924

Laurindo, L. F., Takeda, L. N., Machado, N. M., Otoboni, A. M. M. B., Goulart, R. A., Catharin, V. C. S., Silva, L. R., Barbalho, S. M., & Direito, R. (2024). Health benefits of acerola (*Malpighia* spp) and its by-products: A comprehensive review of nutrient-rich composition, pharmacological potential, and industrial applications. **Food Bioscience**, 62, 105422. https://doi.org/10.1016/j.fbio.2024.105422

Lawson, T., & Milliken, A.L. (2023). Photosynthesis – beyond the leaf. **New Phytologist**, 238 (1), 55. https://doi.org/10.1111/NPH.18671

Li, D., Heiling, S., Baldwin, I. T., & Gaquerel, E. (2016). Illuminating a plant's tissue-specific metabolic diversity using computational metabolomics and information theory. **Proceedings of the National Academy of Sciences of the United States of America**, 113 (47), E7610. https://doi.org/10.1073/pnas.1610218113

Li, L., Chong, L., Huang, T., Ma, Y., Li, Y., & Ding, H. (2023). Natural products and extracts from plants as natural UV filters for sunscreens: A review. **Animal Models and Experimental Medicine**, 6 (3), 183-195. https://doi.org/10.1002/AME2.12295

Libutti, A., Cammerino, A. R. B., & Monteleone, M. (2021). Management of Residues from Fruit Tree Pruning: A Trade-Off between Soil Quality and Energy Use. **Agronomy**, 11 (2), 236. https://doi.org/10.3390/agronomy11020236

Luiz, J., & Milani, C. (2022). Brazilian Foreign Policy and Family Farming: Internationalisation Processes through the Analysis of 'Forums and Arenas'. **Contexto Internacional**, 44 (1). https://doi.org/10.1590/s0102-8529.20224401e20200101

Malavolta, E., Vitti, G.C., & Oliveira, S.A. (1997). Avaliação do estado nutricional das plantas (2a ed.). Piracicaba: Potafos.

Mansur, J.S., Breder, M.N.R., Mansur, M.C.A., & Azulay, R.D. (1986). Determinação do fator de proteção solar por espectrofotometria. **Anais Brasileiros de Dermatologia**, 61 (3), 121-124.

Mutha, R. E., Tatiya, A. U., & Surana, S. J. (2021). Flavonoids as natural phenolic compounds and their role in therapeutics: an overview. **Future Journal of Pharmaceutical Sciences**, 7 (1), 25. https://doi.org/10.1186/s43094-020-00161-8

Oboh, G., Odubanjo, V. O., Bello, F., Ademosun, A. O., Oyeleye, S. I., Nwanna, E. E., & Ademiluyi, A. O. (2016). Aqueous extracts of avocado pear (*Persea americana* Mill.) leaves and seeds exhibit anti-cholinesterases and antioxidant activities in vitro. **Journal of Basic and Clinical Physiology and Pharmacology**, 27 (2), 131. https://doi.org/10.1515/jbcpp-2015-0049

Palazon, J., & Alcalde, M. A. (2025). Secondary metabolites in plants. **Plants**, 14 (14), 2146. https://doi.org/10.3390/plants14142146

Paula, P.L., de Oliveira Lemos, A. S., Campos, L. M., Ferreira, T. G., Freitas de Souza, T., Queiroz, L. S.,

Machado Resende Guedes, M. C., Martins, M. M., Goulart Filho, L. R., Macedo, G. C., Tavares, G. D., Rocha, V. N., Leite Denadai, Â. M., & Fabri, R. L. (2021). Pharmacological investigation of antioxidant and anti-inflammatory activities of leaves and branches extracts from *Plinia cauliflora* (Jaboticaba). **Journal of Ethnopharmacology**, 280, 114463. https://doi.org/10.1016/j.jep.2021.114463

Pereira, E. S., Raphaelli, C. O., Vinholes, J. R., Ribeiro, J. A., Fiorentini, A. M., Nora, L., & Vizzotto, M. (2022). *Eugenia uniflora* L. fruit: A review on its chemical composition and bioactivity. **The Natural Products Journal**, 12 (2), e070921196205. https://doi.org/10.2174/2210315511666210907095136

Petry, H., Baratti, A., Brighenti, A., Gonzatto, M., Citadin, I., & Souza, A. (2025). Brazilian fruit agribusiness. **Fruit Crops Science Journal**. https://doi.org/10.1590/3085-89092025001

Reyes-Martín, M. P., Ortiz-Bernad, I., Lallena, A. M., San-Emeterio, L. M., Martínez-Cartas, M. L., & Ondoño, E. F. (2022). Reuse of pruning waste from subtropical fruit trees and urban gardens as a source of nutrients: changes in the physical, chemical, and biological properties of the soil. **Applied Sciences**, 12 (1), 193. https://doi.org/10.3390/app12010193

Sahal, A., Chaudhary, S., Hussain, A., Arora, S., Dobhal, A., Ahmad, W., Kumar, V., & Kumar, S. (2025). A comprehensive review on the nutritional composition, bioactive potential, encapsulation techniques, and food system applications of guava (*Psidium guajava* L.) leaves. **Grain & Oil Science and Technology**, 8 (1), 64. https://doi.org/10.1016/j.gaost.2024.12.003

Sayre, R.M., Agin, P.P., LeVee, G.J., & Marlowe, E. (1979). A comparison of in vivo and in vitro testing of sunscreening formulas. **Photochemistry and Photobiology**, 29 (3), 559. https://doi.org/10.1111/j.1751-1097.1979.tb07090.x

Schumacher, N. S. G., Colomeu, T. C., De Figueiredo, D., Carvalho, V. D. C., Cazarin, C. B. B., Prado, M. A., Meletti, L. M. M., & Zollner, R. D. L. (2015). Identification and antioxidant activity of the extracts of *Eugenia uniflora* leaves. characterization of the anti-inflammatory properties of aqueous extract on diabetes expression in an experimental model of spontaneous type 1 diabetes (NOD Mice). **Antioxidants**, 4 (4), 662. https://doi.org/10.3390/antiox4040662

Sethiya, N.K., Agarwal, G., Bhargava, S., Rana, V.S., Kumar, B., Singhal, M., Bisht, D., & Patil, U.K. (2025). Preparation of extracts and their standardization. **Wiley**, 75–89. https://doi.org/10.1002/9781119769484

Sharma, R., & Malaviya, P. (2023). Ecosystem services and climate action from a circular bioeconomy perspective. **Renewable and Sustainable Energy Reviews**, 175, 113164. https://doi.org/10.1016/J.RSER.2023.113164

Silva, J.A.A., Teixeira, G.H. de A., Martins, A.B.G., Citadin, I., Wagner Júnior, A., & Danner, M.A. (2019). Advances in the propagation of jabuticaba tree. **Revista Brasileira de Fruticultura**, 41 (3). https://doi.org/10.1590/0100-29452019024

Singh, P., Singh, A., & Choudhary, K. (2023). Revisiting the role of phenylpropanoids in plant defense against UV-B stress. **Plant Stress**, 7, 100143. https://doi.org/10.1016/j.stress.2023.100143

Singleton, V.L., & Rossi, J.A. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic

acid reagents. **American Journal of Enology and Viticulture**, 16, 144. https://doi.org/10.5344/AJEV.1965.16.3.144

Sultanbawa, F., & Sultanbawa, Y. (2023). Mineral nutrient-rich plants – Do they occur? **Applied Food Research**, 3 (2), 100347. https://doi.org/10.1016/j.afres.2023.100347

Taniguchi, M., LaRocca, C., Bernat, J., & Lindsey, J. (2023). Digital database of absorption spectra of diverse flavonoids enables structural comparisons and quantitative evaluations. **Journal of Natural Products**, 86 (4), 1087. https://doi.org/10.1021/acs.jnatprod.2c00720

Tariq, A., Zeng, F., Graciano, C., Ullah, A., Sadia, S., Ahmed, Z., Murtaza, G., Ismoilov, K., & Zhang, Z. (2023). Regulation of metabolites by nutrients in plants. **Wiley**, 1–18. https://doi.org/10.1002/9781119803041.CH1

Vitti, K.A., de Lima, L.M., & Filho, J.G.M. (2020). Agricultural and economic characterization of guava production in Brazil. **Revista Brasileira de Fruticultura**, 42 (1), e-447. https://doi.org/10.1590/0100-29452020447

Zanusso, P.W., Mariño, P.A., Maldaner, G., & Gonçalves, R.P. (2023). Avaliação fitoquímica de extratos das folhas de *Eugenia uniflora* L. **Research, Society and Development**, 12 (4), e14012441060. https://doi.org/10.33448/RSD-V12I4.41060

Zhou, F., Hearne, Z., & Li, C-J. (2019). Water - the greenest solvent overall. **Current Opinion In Green And Sustainable Chemistry**, 18, 118-123. https://doi.org/10.1016/j.cogsc.2019.05.004