Is there a relationship between the concentration of phenolic compounds and the versatility of medicinal plants in the Caatinga biome?

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Research

Abstract

Background: This study investigates whether the concentration of phenolic compounds—specifically phenols, tannins, and flavonoids—correlates with the medicinal versatility of woody plant species in the Caatinga, a seasonally dry tropical forest in northeastern Brazil. Given the well-documented bioactivity of phenolic compounds, we tested the hypothesis that higher concentrations are associated with a broader range of medicinal uses.

Methods: We selected 20 woody medicinal plant species and classified them into high- and low-versatility groups based on their Relative Importance (RI) values drawn from the ethnobotanical literature. Stem bark samples were collected from Catimbau National Park, Pernambuco, Brazil. Methanolic extracts were analyzed for total phenolics using the Folin-Ciocalteu assay, for tannins using casein precipitation, and for flavonoids using the aluminum chloride complexation method.

Results: Contrary to our hypothesis, no statistically significant differences in phenolic compound concentrations were observed between high- and low-versatility groups. While highly versatile species such as *Astronium urundeuva* (232.85 mg TAE/100 g DM) and *Anadenanthera colubrina* (254.24 mg TAE/100 g DM) exhibited elevated levels of total phenolics, some less versatile species as *Mimosa tenuiflora* (244.86 mg TAE/100 g DM) and *Schinopsis brasiliensis* (219.85 mg TAE/100 g DM) showed similarly high values. A similar pattern was observed for tannins and flavonoid concentrations.

Conclusions: Although phenolic compounds contribute to the pharmacological potential of medicinal plants, their concentrations do not account for greater medicinal versatility in the Caatinga. Other factors—such as ecological availability,

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cultural preferences, and traditional knowledge systems—likely play a more decisive role. These findings highlight the need for integrative approaches in ethnopharmacological research that move beyond chemical profiles alone.

Keywords: Ethnobotany; Ethnopharmacology; Flavonoids; Phenols; Phytochemistry; Seasonal dry forests; Tannins; Woody Plants

Background

Contemporary research has increasingly emphasized the pharmacological relevance of secondary metabolites produced by plants, particularly phenolic compounds such as tannins, flavonoids, and coumarins. These molecules exhibit a broad spectrum of biological activities—including anti-inflammatory, antioxidant, antimicrobial, and antifungal effects—which support their importance as therapeutic agents and their influential role in shaping human medicinal plant use (Rahman *et al*. 2021; Kumar *et al*. 2019; Durazzo *et al*. 2019).

Plants biosynthesize secondary metabolites, as integral components of their physiological processes, which are essential for survival and reproduction in diverse environments. These compounds may be upregulated in response to biotic and abiotic stressors, including herbivory, pathogen attack, water deficit, low soil fertility, or salinity. The type and intensity of metabolite production vary across species and are shaped by environmental pressures (Isah 2019; Yang *et al*. 2018).

Interest in the phytochemical and ethnopharmacological aspects of plant use has been growing within ethnobotanical research, particularly as it relates to local ecological knowledge (Castro *et al*. 2014; Ribeiro *et al*. 2014). The Caatinga biome, a seasonally dry tropical forest characterized by irregular rainfall and pronounced environmental stress, offers edaphoclimatic conditions favorable for the biosynthesis of phenolic compounds, including tannins and flavonoids (Albuquerque *et al*. 2012).

Such compounds have been consistently identified in numerous plant species widely used in traditional medicine in the Caatinga, with their therapeutic effectiveness often attributed to these phytochemicals (Almeida *et al*. 2005, 2011; Araújo *et al*. 2008). Furthermore, studies have suggested significant correlations between phenolic content and the pharmacological efficacy of medicinal plants (Amorim *et al*. 2021; Chaves *et al*. 2013; Sobrinho *et al*. 2011).

The medicinal value of a plant is often assessed by its versatility, which refers to the range of therapeutic uses attributed to it. This versatility can be quantified using the Relative Importance Index (RI), which integrates both the number of body systems treated and the number of therapeutic uses cited, serving as a proxy for cultural salience and medicinal relevance (e.g., Albuquerque *et al*. 2007; Bennett & Prance 2000; Souza *et al*. 2016).

A systematic review encompassing 385 woody medicinal angiosperms from the Caatinga revealed a strong association between high RI values and their widespread popular use, reinforcing the utility of the RI metric for identifying culturally and pharmacologically important plants with bioprospecting potential (see Albuquerque *et al*. 2007). Several Caatinga plant species are known to accumulate substantial levels of phenolic compounds. *Mimosa tenuiflora* (Willd.) Poir., commonly known as jurema preta, is rich in total phenolics, flavonoids, and tannins (Silva *et al*. 2017). *Cenostigma microphyllum* (Mart. ex G. Don) Gagnon & G.P. Lewis also contains high concentrations of phenolics and tannins, particularly in its leaves (Albergaria *et al*. 2021). Similarly, *Libidibia ferrea* (Mart. ex Tul.) L.P. Queiroz (pau-ferro or jucá) contains bioactive phenolics, such as gallic acid, and flavonoids, including kaempferol and quercetin (Castro *et al*. 2014). Other species, including *Sideroxylon obtusifolium* (Roem. & Schult.) T.D. Penn. and *Schinopsis brasiliensis* Engl., are also reported to contain diverse phenolic compounds (Castro *et al*. 2014).

Considering the recognized pharmacological properties of phenolic compounds and their diverse biological functions (Sun *et al*. 2023), it is plausible to hypothesize that plants with higher medicinal versatility also exhibit higher concentrations of these compounds. However, this potential relationship remains unexplored in the context of the Caatinga. To address this gap, the present study investigates whether the concentrations of phenolic compounds—specifically total phenols, tannins, and flavonoids—are associated with the medicinal versatility of woody plant species used by local communities in the Caatinga. We hypothesize that more versatile species exhibit higher concentrations of these bioactive compounds. By bridging the fields of chemical ecology and ethnopharmacology, this study aims to deepen our understanding of the phytochemical underpinnings of traditional plant use in a uniquely adapted ecosystem.

Materials and Methods

Plant species

To investigate whether the concentration of phenolic compounds explains the versatility of medicinal tree species, we utilized a list of medicinal tree species from Caatinga, as published by Campos & Albuquerque (2021). These authors calculated the Relative Importance Index (RI) for 147 species, including woody species, palm trees, and cacti, used medicinally in the Caatinga. RI values ranging from 0 to 2 indicate species versatility, with values closer to 2 indicating higher versatility for medicinal use (Bennett & Prance 2000). The relative importance index (RI) was calculated using the formula IR = ((REL MP + REL BS)/2) × 100, where MP represents the number of medicinal properties and REL MP is the relative value of the medicinal properties normalized to a maximum of 1. BS refers to the number of body systems treated, and REL BS is the relative value of the body systems treated normalized to a maximum of 1. We selected 20 woody plant species from this list to perform phytochemical analyses, focusing on the quantification of total phenols, tannins, and flavonoids. We classified ten species as the most versatile, with RI values closer to 2, and ten species as the least versatile, with RI values closer to 1 (Table 1).

Table 1. List of woody medicinal plants from the Caatinga selected according to Relative Importance (RI) values, from Campos & Albuquerque (2021).

Family	Species	Popular name	Relative Importance Index (RI)	Voucher	Herbarium
Anacardiaceae	*Astronium urundeuva* (M.Allemão) Engl.	Aroeira	1.94	92517	IPA
Fabaceae	*Libidibia ferrea* (Mart. ex Tul.) L.P.Queiroz	Pau-ferro	1.74	91696	IPA
Fabaceae	*Anadenanthera colubrina* (Vell.) Brenan	Angico	1.69	91649	IPA
Olacaceae	*Ximenia americana* L.	Ameixa-da-praia	1.37	91787	IPA
Bignoniaceae	*Handroanthus impetiginosus* (Mart. ex DC.) Mattos	Ipê-roxo	1.27	86867	IPA
Anacardiaceae	*Anacardium occidentale* L.	Cajueiro	1.26	93683	IPA
Rhamnaceae	*Sarcomphalus joazeiro* (Mart.) Hauenschild	Juazeiro	1.23	82935	IPA
Fabaceae	*Hymenaea courbaril* L.	Jatobá	1.22	91630	IPA
Sapotaceae	*Sideroxylon obtusifolium* (Roem. & Schult.) T.D.Penn.	Quixaba	1.18	84076	IPA
Fabaceae	*Cenostigma pyramidale* (Tul.) Gagnon & G.P. Lewis	Caatingueira	1.09	55339	UFP
Apocynaceae	*Aspidosperma pyrifolium* Mart. & Zucc.	Pereiro	0.92	93686	IPA
Fabaceae	*Mimosa tenuiflora* (Willd.) Poir.	Jurema preta	0.74	82895	UFP
Burseraceae	*Commiphora leptophloeos* (Mart.) J.B.Gillett	Amburana-de-cambão	0.72	91663	IPA
Anacardiaceae	*Schinopsis brasiliensis* Engl.	Baraúna	0.62	91697	IPA
Fabaceae	*Senegalia bahiensis* (Benth.) Seigler & Ebinger	Calumbi	0.36	91697	IPA
Fabaceae	*Peltogyne pauciflora* Benth.	Pau-de-morro	0.29	93435	IPA
Fabaceae	*Piptadenia retusa* (Jacq.) P.G.Ribeiro, Seigler & Ebinger	Jurema branca	0.21	91656	IPA
Malpighiaceae	*Byrsonima gardneriana* A. Juss.	Murici	0.21	93437	IPA
Erythroxylaceae	*Erythroxylum revolutum* Mart.	Quebra-facão	0.15	91560	IPA
Fabaceae	*Pityrocarpa moniliformis* (Benth.) Luckow & R.W. Jobson	Catanduva	0.14	91651	IPA

Collection of plant material

Samples of the listed species (Table 1) were collected within Catimbau National Park (8°24'00"" " to 8°36'35" S; 37°0'30" to 37°1'40""" W), during the dry season (October/2021), within the permanent study plots of the PELD Catimbau Project (Long-Term Ecological Project) (see https://www.peldcatimbau.org/). Voucher material of the species collected in the Park was deposited in the IPA herbarium (Dárdano de Andrade Lima) and the UFP herbarium (Geraldo Mariz - Federal University of Pernambuco). The study complied with Brazilian legislation on access to genetic heritage (Law No. 13,123/2015; Decree No. 8,772/2016), which regulates the implementation of the Nagoya Protocol in Brazil, and was registered in the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SisGen) under code A3F792C. No associated traditional knowledge was accessed.

This Park, located in Pernambuco, Northeast Brazil, has a hot, semi-arid climate (BSh, according to the Köppen classification) (Alvares *et al*. 2013). Indigenous populations and surrounding rural communities sustain a subsistence relationship with the region's flora, engaging in activities such as hunting, logging, collecting firewood, and utilizing plant resources (Rito *et al*. 2017). The samples consisted of stem bark, the plant organ traditionally employed for therapeutic purposes in all studied species (Albuquerque *et al*. 2007; 2012). Although secondary metabolite concentrations may vary among organs, focusing on the medicinally relevant tissue ensures that our chemical analyses reflect the compounds used in traditional practices. At least three individuals of each species were selected, spaced 3-5 m apart. Bark samples were collected from each individual, forming a composite sample of 500 g. Bark samples were collected at breast height (approximately 1.30 m above ground level) from all individuals of the species. The samples were placed in labeled paper bags and dried in an oven with forced air circulation at 25 °C. Subsequently, they were processed at the Plant Physiology Laboratory (UFPE) using a Willey knife mill (R-TE-650/1, Tecnal) to obtain a powder.

Preparation of crude extract for phytochemical analysis

Bark powder (500 mg) from each species was extracted in 50 mL beakers containing 25 mL of 80% methanol (v/v; 80% methanol + 20% water). This hydroalcoholic solvent was chosen because it allows broad extraction of phenolic compounds, which exhibit varying polarities (Dai & Mumper, 2010; Spigno *et al*. 2007). The mixture was gently heated below the boiling point of the solvent on a hot plate (TE-0851; Tecnal, Männedorf, Switzerland) for 30 min. Extracts were filtered through qualitative filter paper (Unifil, 80 g/m²) into 50 mL volumetric flasks. The residues were washed with an additional 25 mL of the same solvent, filtered again, and the final volume was adjusted to 50 mL with the solvent (Amorim *et al*. 2012). Extractions for each species were performed in triplicate for subsequent determination of total phenols, tannins, and flavonoids.

Determination of the Total Phenolic (TPC) and Total Tannin Content (TTC)

The total phenolic content (TPC) was determined using the Folin-Ciocalteu method (Amorim *et al*. 2012). Aliquots of the extracts (0.125 - 0.25 mL) were pipetted into 25 mL volumetric flasks. Subsequently, 1.25 mL of 10% (v/v) Folin-Ciocalteu reagent and 7.5% (w/v) aqueous sodium carbonate solution (2.5 mL) were added. The final volume of the flasks was filled with deionized water, and the samples were left to react in the dark for 30 min. Absorbance was measured at 760 nm using a Genesys 10S spectrophotometer (Thermo Fisher Scientific, Waltham, MA, USA). Total tannin content (TTC) was quantified using the residual phenol content obtained via the casein precipitation method, followed by the Folin-Ciocalteu method with some modifications (Amorim *et al*. 2012). Aliquots of the extracts (6 mL) were pipetted into Erlenmeyer flasks containing 1 g of casein powder and 12 mL of deionized water. The samples were mechanically stirred for three hours at room temperature and were protected from light. After filtration, aliquots of the resulting solution were used to quantify residual phenols via the Folin-Ciocalteu method. The amount of TTC was determined by comparing the total and residual phenols. TPC and TTC were estimated using the calibration curve obtained by preparing a standard tannic acid solution (0.1 mg/mL). TPC and TTC were expressed in milligrams of tannic acid equivalents per gram of dry matter (mg TAE/100 g DM). The calibration equation for tannic acid was $y = 0.154 x + 0.076$ ($R^2 = 0.977$).

Determination of Total Flavonoid Contents (TFC)

The total flavonoid content (TFC) was determined using a previously described method (Amorim *et al*. 2012). Aliquots of the extracts (1 mL) were pipetted into 25 mL volumetric flasks. Then, 0.6 mL of glacial acetic acid and 10 mL of 20% (v/v) methanolic pyridine solution were added, followed by 2.5 mL of 5% (w/v) methanolic aluminum chloride solution. The final volume of each flask was filled with deionized water and shaken appropriately. The reaction was performed in the dark for 30 min, and the absorbance was measured at 420 nm using a spectrophotometer. The TFC was estimated using the calibration curve obtained by preparing the standard rutin solution (0.5 mg/mL). The amount of TFC was expressed in milligrams of rutin equivalents per gram of dry matter (mg RE/100 g DM). The calibration equation for rutin was y = 0.518x + 0.046 (R^2 = 0.999).

Data Analysis

Species were divided into two groups based on RI values:

Group 1: The ten most versatile plants with RI > 1 (high); Group 0: The ten less versatile plants, with RI < 1 (low), as shown in Table 1.

Data were analyzed for normality using the Shapiro-Wilk test and homoscedasticity using the Bartlett test. Subsequently, Analysis of Variance (ANOVA) was conducted to compare the average levels of each compound class (total phenols, tannins, and flavonoids) between the two plant groups (high and low RI). Statistical analyses were performed using the R software at a significance level of 5% ($p < 0.05$). Principal component analysis (PCA) was performed to identify potential clusters (PC). Data were transformed (logarithm) for standardization owing to the different scale magnitudes. The importance level of each PC was determined using the Broken-stick method, where eigenvalues exceeding the expected values were retained for interpretation. Analyses were performed using OriginPro 2018 software.

Results

Content of phenolic compounds

The total amounts of the phenols, tannins, and flavonoids are listed in Table 2. Among the most versatile plants, *Anadenanthera colubrina* exhibited the highest total phenol content (254.244 mg TAE/100 g DM) and was the third species listed, based on its relative importance value (RI = 1.69). As for the species *Astronium urundeuva*, which has the highest relative importance value on the list (RI = 1.94), it presented 232.846 mg TAE/100 g DM (Table 2).

Table 2. Average content of phenolic compounds (total phenols, tannins, and flavonoids) with standard deviation, quantified in woody medicinal plants listed as more versatile (RI > 1) and less versatile (RI < 1), collected in the Catimbau National Park, Pernambuco - Brazil. (n = 3/species). RI= Relative Importance.

Species	RI	Total phenols (mg TAE/100 g DM)	Tannins (mg TAE/100 g DM)	Flavonoids (mg RE/100 g DM)
Astronium urundeuva	1.94	232.846 ± 1.598	159.931 ± 3.663	2.010 ± 0.129
Libidibia ferrea	1.74	164.556 ± 1.841	163.483 ± 1.393	1.214 ± 0.037
Anadenanthera colubrina	1.69	254.244 ± 1.008	244.104 ± 0.977	1.511 ± 0.595
Ximenia americana	1.37	175.525 ± 6.786	131.921 ± 7.680	2.257 ± 0.019
Handroanthus impetiginosus	1.27	57.450 ± 0.950	49.572 ± 1.187	1.920 ± 0.012
Anacardium occidentale	1.26	138.125 ± 4.329	106.684 ± 5.886	1.720 ± 0.032
Sarcomphalus joazeiro	1.23	10.475 ± 0.397	8.591 ± 0.879	0.329 ± 0.030
Hymenaea courbaril	1.22	110.996 ± 1.153	105.768 ± 1.312	1.974 ± 0.423
Sideroxylon obtusifolium	1.18	96.000 ± 2.344	92.991 ± 2.790	0.745 ± 0.102
Cenostigma pyramidale	1.09	90.716 ± 2.077	88.679 ± 2.385	1.447 ± 0.094
Aspidosperma pyrifolium	0.92	46.303 ± 1.948	38.403 ± 1.252	1.079 ± 0.031
Mimosa tenuiflora	0.74	244.857 ± 6.045	199.099 ± 1.998	2.231 ± 0.046
Commiphora leptophloeos	0.72	63.674 ± 3.444	62.965 ± 3.544	1.083 ± 0.059
Schinopsis brasiliensis	0.62	219.847 ± 6.599	208.164 ± 6.564	2.904 ± 0.145
Senegalia bahiensis	0.36	23.453 ± 1.011	18.646 ± 1.202	0.993 ± 0.002
Peltogyne pauciflora	0.29	102.446 ± 2.557	96.686 ± 2.240	0.949 ± 0.027
Piptadenia retusa	0.21	24.770 ± 0.408	21.564 ± 0.329	0.501 ± 0.011
Byrsonima gardneriana	0.21	192.232 ± 24.021	187.711 ± 21.572	1.041 ± 0.128
Erythroxylum revolutum	0.15	84.996 ± 2.705	79.336 ± 2.562	1.113 ± 0.029
Pityrocarpa moniliformis	0.14	126.232 ± 1.033	122.621 ± 1.077	0.982 ± 0.068

In contrast, among the less versatile plants, *Mimosa tenuiflora*, ranked twelfth due to its assigned RI value (RI = 0.74), showed a high total phenol content (244.857 mg TAE/100 g DM), similar to *A. colubrina*. Additionally, *Schinopsis brasiliensis* (RI = 0.62), also listed among the less versatile species, exhibited a total phenol content of 219.847 mg TAE/100 g DM, which was comparable to that of *A. urundeuva*, considered a more versatile species. Similar trends were observed for tannin levels. Among the most versatile plants, *A. colubrina* and *Libidibia ferrea* (third and second positions according to RI values) exhibited 244.104 mg and 163.483 mg TAE/100 g DM), respectively. Contrary to the least versatile plants, *S. brasiliensis* and *M. tenuiflora* (fourteenth and twelfth positions according to the RI values) exhibited 208.164 mg and 199.099 mg TAE/100 g DM, respectively (Table 2).

The species with the highest flavonoid levels within the most versatile group were *Ximenia americana* (RI = 0.37) and *A. urundeuva* (2.257 and 2.010 mg RE/100 g DM, respectively). Similarly, in the less versatile group, *S. brasiliensis* and *M. tenuiflora* exhibited 2.904 mg and 2.231 mg RE/100 g DM, respectively, which were comparable to those found in the more versatile species (Table 1).

Phenol concentration and medicinal plant versatility

The variation in phenolic compound levels among plant samples, grouped according to the relative importance index (RI), was analyzed using principal component analysis (PCA) (Fig. 1). The analysis indicates that more versatile species (high RI) tend to cluster in the positive region of PC1 (87.7%), being associated with higher tannin and total phenol levels, while less versatile species (low RI) present greater dispersion in the graph, with less association with phenolic compounds, especially tannins. However, it is possible to observe an overlap between the ellipses, which represent 95% confidence, indicating that the groups share similar characteristics in part of the data, specifically in the levels of phenolic compounds in both groups.

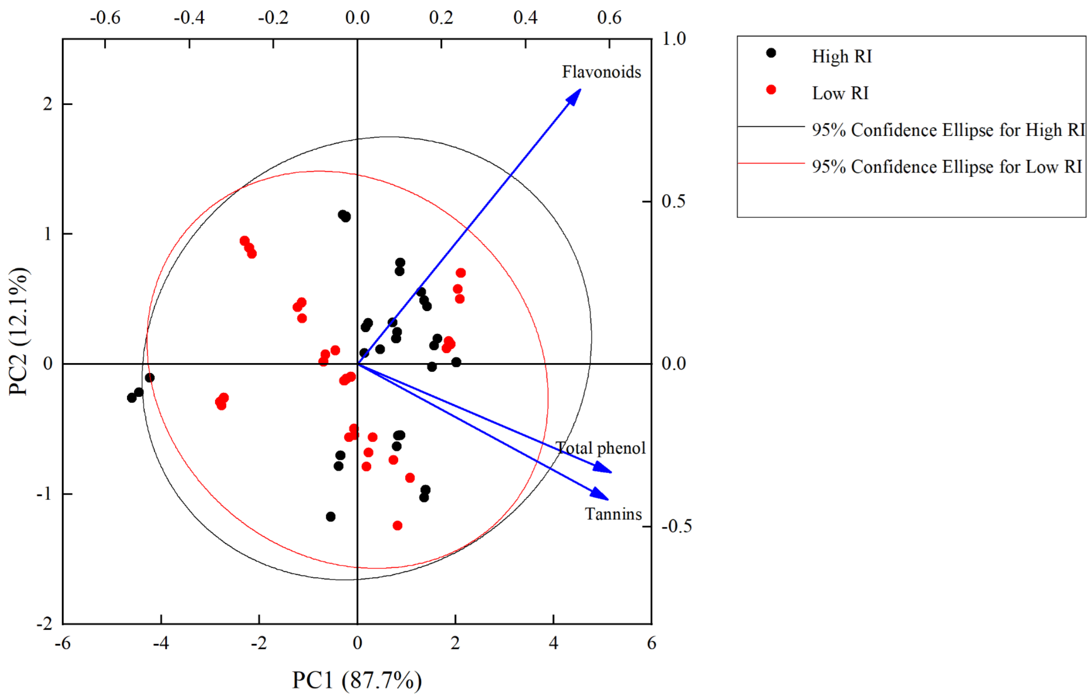

Figure 1. Principal component analysis (PCA) based on the entire data set of phenols, tannins, and flavonoids in groups of woody medicinal plants in relation to versatility (high and low RI), collected in the Catimbau National Park, Brazil (n = 3/species). RI = Relative Importance Index.

According to Figure 2, the group of species with the highest (RI) presented higher average contents of total phenols, tannins, and flavonoids compared to the group with low RI. However, according to the analysis of variance (*p*-values), there were no significant differences in the total amounts of phenols, tannins, or flavonoids between the plant groups (Table 3).

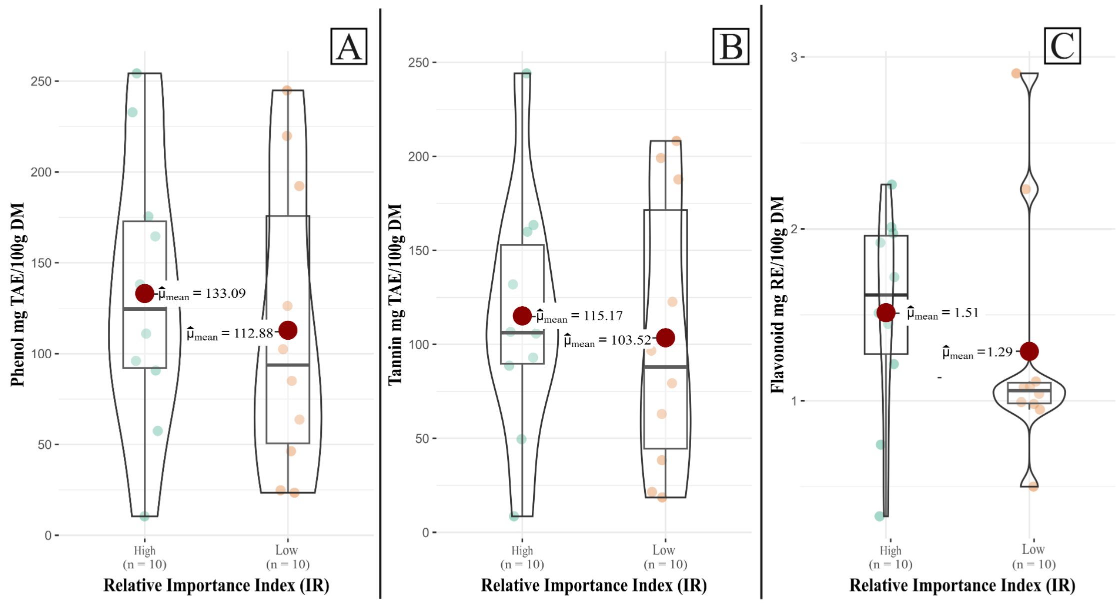

Figure 2. Average content of total phenols (A), tannins (B), and flavonoids (C) in groups of woody medicinal plants in relation to versatility (high and low RI), collected in the Catimbau National Park, Brazil. RI= Relative Importance.

The amount of phenols in the group with the highest versatility was 133.093 ± 75.910 mg TAE/100 g DM, while in the group with the lowest versatility, it was 112.881 ± 80.854 mg TAE/100 g DM (Fig. 2A). A similar pattern was observed for total tannins among plant groups, with the amount in the most versatile group being 115.172 ± 65.199 mg TAE/100 g DM, and in the least versatile group it was 103.519 ± 73.011 mg TAE/100 g DM (Fig. 2B). The same trend was observed for flavonoids. The mean value for the group with the highest versatility was 1.513 ± 0.606 mg RE/100 g DM, while in the group with the lowest versatility, it was 1.288 ± 0.714 mg RE/100 g DM (Fig. 2C). Details of the statistical analyses are presented in Table 3.

Table 3. Average content of phenolic compounds (total phenols, tannins, and flavonoids) followed by standard deviation (SD) along with p-value (ANOVA) in the groups of most versatile (high RI) and least versatile (low RI) woody medicinal plants collected in the National Park of Catimbau, Pernambuco - Brazil. RI= Relative Importance. (n = 3/species).

Phenolic content	**RI**	**Mean (± SD)**	***p* (< 0.05)**
Total phenols (mg TAE/100 g DM)	Hight	133.093 ± 75.910	0.571
	Low	112.881 ± 80.854	
Tannins (mg TAE/100 g DM)	Hight	115.172 ± 65.199	0.711
	Low	103.519 ± 73.011	
Flavonoids (mg RE/100 g DM)	Hight	1.513 ± 0.606	0.457
	Low	1.288 ± 0.714	

Discussion

The initial hypothesis of this study, based on prior research (see Araújo *et al*. 2008; Siqueira *et al*. 2012), proposed that medicinal plants with higher versatility in the Caatinga would exhibit elevated concentrations of phenolic compounds. Contrary to this expectation, our findings revealed no statistically significant differences in phenolic content between species with high and low Relative Importance (RI) values. This divergence from the original hypothesis may reflect the intricate and context-dependent nature of the relationship between chemical composition and therapeutic use.

Our results are consistent with Monteiro *et al*. (2014), who also reported no direct correlation between tannin concentration and plant use value. Such findings reinforce the argument that chemical richness alone cannot fully explain patterns of medicinal plant use. Instead, cultural preferences, ecological availability, and the structure of local medical systems must be considered in a more integrative framework. One plausible explanation for these results lies in the scale of previous studies. Earlier work often focused on localized contexts, assessing whether specific bioactivities could be linked to the presence of phenolic compounds in particular plants (see Albuquerque *et al*. 2012; Araújo *et al*. 2008). In contrast, our study aimed to test this association at a broader regional level, using an updated and comprehensive database of medicinal species in the Caatinga (Campos & Albuquerque, 2021). However, the phytochemical data generated here did not corroborate the hypothesized pattern, underscoring the complexity of chemical ecology and ethnopharmacology.

The case of *Sarcomphalus joazeiro* illustrates this well. Despite being among the most versatile species in our dataset, it exhibited low phenolic concentrations (Table 2). Previous studies attribute its pharmacological efficacy to saponins rather than phenolics (Andrade *et al*. 2019a, 2019b), exemplifying how bioactivity may result from compound classes not examined in this study. Other examples further complicate the relationship between phenolic content and versatility. *Anadenanthera colubrina*, with the third-highest RI value (1.69), exhibited the highest levels of total phenols and tannins. In contrast, less versatile species such as *Mimosa tenuiflora* (RI = 0.74) and *Schinopsis brasiliensis* (RI = 0.62) also showed exceptionally high concentrations of these compounds, comparable to those in *A. colubrina* and *Astronium urundeuva*, both high-RI species (Table 1). Notably, *M. tenuiflora* and *A. colubrina* have been widely studied for their antioxidant, anti-inflammatory, antimicrobial, and wound-healing activities.

In *A. colubrina*, ethanolic leaf extracts have demonstrated potent antioxidant and anti-inflammatory effects, attributed to their high phenolic content (Junior *et al*. 2020). The bark extract has also shown promise in managing diabetes mellitus (Costa *et al*. 2020). Likewise, *M. tenuiflora* exhibited elevated levels of total phenols and flavonoids in this study, aligning with previous research that indicates its antimicrobial activity, likely due to the presence of flavonoids and tannins (Ferreira *et al*. 2021). Moreover, its bark extract has been shown to inhibit aflatoxin B1 production, which is attributed to condensed tannins (Hernandez *et al*. 2021). Conversely, *Byrsonima gardneriana*, a species with a low RI (0.21), exhibited phenolic levels comparable to *A. colubrina* (Table 3), further challenging the assumption that versatility and phenolic content are directly linked.

Similarly, no significant differences were found in flavonoid content between high—and low—RI groups. Flavonoids, although widespread in the Fabaceae family, were present at concentrations approximately 80% lower than those of total phenols and tannins. This trend supports Araújo *et al*. (2008), who found no clear link between flavonoid levels and indications for anti-inflammatory use across different plant groups. This study represents the first attempt to systematically assess the relationship between phenolic content—specifically total phenols, tannins, and flavonoids—and medicinal versatility among woody Caatinga species at a regional scale. Among the most versatile species, *Ximenia americana* and *A. urundeuva* showed the highest flavonoid concentrations. However, less versatile species such as *S. brasiliensis* and *M. tenuiflora* also had comparably high levels (Table 2), emphasizing again that phenolic abundance alone does not explain medicinal importance.

A. urundeuva, the species with the highest RI (1.94), also exhibited the highest levels of total phenols and flavonoids. It is one of the most extensively studied Caatinga species in terms of phenolic composition and pharmacological activity. Its bark extract is rich in phenolics and exhibits strong antioxidant activity (Sousa *et al*. 2022), with documented antiviral and antifungal properties (Cecilio *et al*. 2016; Oliveira *et al*. 2017). *S. brasiliensis* (RI = 0.62), despite being less versatile, is traditionally used to treat pain, inflammation, and infections. Research has confirmed its high phenolic content and associated pharmacological properties, including antioxidant, anti-inflammatory, analgesic, and antimicrobial activities (Linhares *et al*. 2022; Santos *et al*. 2017, 2018; Luz *et al*. 2018).

In *X. americana* (RI = 1.37), phenolic compounds, including condensed tannins, flavonols, and flavone glycosides, have been linked to antioxidant, antibacterial, and antiaging effects (Bakrim *et al*. 2022). A comparative analysis of its aqueous and methanolic extracts revealed that the aqueous extract had the highest phenolic content and antioxidant activity. In contrast, the methanolic extract demonstrated stronger anti-inflammatory effects (Shettar *et al*. 2015). The findings from this study also contribute to our understanding of chemical ecology in arid and semi-arid environments. In such regions, plants often invest more in the synthesis of high-molecular-weight phenolics, such as tannins, which provide robust protection against environmental stressors. In contrast, flavonoids tend to be synthesized in smaller quantities and are more commonly concentrated in leaves (Feeny 1976; Gottlieb 1987). Our results confirm that tannins predominate in the Caatinga, aligning with previous observations (Araújo *et al*. 2008).

Conclusion

Taken together, these results suggest that the concentrations of total phenols, tannins, and flavonoids are not decisive predictors of a species' medicinal versatility. Instead, versatility is shaped more by the contextual dynamics of local medical systems and cultural knowledge, which influence how species are selected and valued. The RI values observed in this study reflect a relatively balanced distribution of high and low versatility across the sampled species, independent of phenolic content.

Declarations

List of abbreviations: ANOVA: Analysis of Variance; CPI: Conservation Priority Index; PCA: Principal component analysis; RI: Relative Importance Index; TFC: Total Flavonoid Content; TPC: Total Phenolic Content; TTC: Total Tannin Content.

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