Nativa, Sinop, v. 13, n. 4, p. 694-700, 2025.
Pesquisas Agrárias e Ambientais
DOI: https://doi.org/10.31413/nat.v13i4.19299

ISSN: 2318-7670

Carqueja and Tola high-Andean plants - Peru: Approximation of their bioactive compounds in aqueous and ethanolic extract

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Submitted: 03/13/2025; Accepted: 12/09/2025; Published: 12/29/2025.

ABSTRACT: Carqueja (*Baccharis trimera*) and Tola (*Parastrephia lepidophylla*) plants are used by inhabitants to alleviate different ills. This study evaluates total polyphenols, antioxidant activity, and flavonoids in the aqueous and ethanolic extracts. Tola exhibited a higher concentration of total polyphenols compared to Carqueja in ethanolic extracts (350.065 and 56.355 mg of Gallic Acid/g DW, respectively). The ethanolic extract of Tola showed superior antioxidant activity, as evidenced by DPPH and ABTS assays with mean 46.165 mg Trolox Equivalent/g DW (20 g/200 mL 80% ethanol) and 249.815 mg Trolox Equivalent/g DW (15 g/200 mL 80% ethanol), respectively. Carqueja showed lower values in both analyses. The ratio (20 g/200 mL) of the ethanolic extract of Tola demonstrated a mean of 298.86 mg of Quercetin equiv/g DW in total flavonoids. Additionally, HPLC analysis detected the presence of chlorogenic acid and quercetin, phenolic acids that may contribute to the observed antioxidant activity. FTIR spectra revealed characteristic peaks indicating the presence of phenolic compounds associated with proteins and carbohydrates in both plant extracts. In conclusion, the ethanolic extracts of Carqueja and Tola exhibit significant levels of total polyphenols, antioxidant activity, and total flavonoids, highlighting their potential as sources of bioactive compounds.
Keywords: *Baccharis trimera; Parastrephia lepidophylla;* polyphenols; antioxidant; flavonoids.

Carqueja e Tola plantas altoandinas - Peru: Aproximação de seus compostos bioativos em extrato aquoso e etanólico

RESUMO: As plantas Carqueja (*Baccharis trimera*) e Tola (*Parastrephia lepidophylla*) são usadas pelos habitantes para aliviar diferentes males. Este estudo avalia polifenóis totais, atividade antioxidante e flavonoides nos extratos aquosos e etanólicos. Tola apresentou maior concentração de polifenóis totais em comparação com Carqueja em extratos etanólicos (350,065 e 56,355 mg de ácido gálico/g DW, respectivamente). O extrato etanólico de Tola mostrou atividade antioxidante superior, conforme evidenciado pelos ensaios DPPH e ABTS com média de 46.165 mg de equivalente de Trolox/g DW (20 g/200 mL 80% etanol) e 249.815 mg de equivalente de Trolox/g DW (15 g/200 mL 80% etanol) do extrato etanólico de Tola demonstrou uma média de 298.86 mg de Quercetina equiv/g DW em flavonoides totais. Além disso, a análise por HPLC detectou a presença de ácido clorogénico e de quercetina, ácidos fenólicos que podem contribuir para a atividade antioxidante observada. Os espectros de FTIR revelaram picos característicos indicando a presença de compostos fenólicos associados a proteínas e carboidratos em ambos os extratos vegetais. Em conclusão, os extratos etanólicos de Carqueja e Tola apresentam níveis significativos de polifenóis totais, atividade antioxidante e flavonoides totais, destacando seu potencial como fontes de compostos bioativos.
Palavras-chave: *Baccharis trimera; Parastrephia lepidophylla;* polifenóis; antioxidantes; flavonoides.

1. INTRODUCTION

Certain plant species grow in habitats with altitudes ranging from 3000 to 5000 meters above sea level in countries such as Chile, Argentina, Peru, Bolivia, Ecuador, Colombia, and Venezuela (DI CIACCIO et al., 2018; TREVIZAN et al., 2020). These regions, called altiplano or punas, are found within the Andean region, and are characterized by their elevated altitude, high exposure to ultraviolet radiation, diminished oxygen levels, notable diurnal temperature fluctuations, and an average annual precipitation of 100 to 200 mm or even less (D'ALMEIDA et al., 2012; GAJARDO et al., 2016; DI CIACCIO et al., 2018). Plants inhabiting these ecosystems have evolved specific adaptations to endure environmental stressors, including the biosynthesis of secondary metabolites with potential pharmacological significance (KLEIER; LAMBRINOS, 2005). Secondary metabolites play pivotal roles in upholding human health, showing properties as antioxidants, anticancer agents, and antimicrobials, thus increasingly featuring in allopathic medicinal practices (MUEED et al., 2023).

Phenolic acids and flavonoids have been identified in diverse plant families endemic to these habitats, including but not limited to Labiatae, Compositae, Umbelliferae, Mirtaceae, Polygonaceae, and Asteraceae (WONGSA et al., 2022). Carqueja (*Baccharis trímera*) and Tola (*Parastrephia lepidophylla*) plants belonging to the Asteraceae family have been traditionally employed by many inhabitants of the Andean region to treat various ailments and have become of particular interest (MOREIRA-MUÑOZ et al., 2016; D'ALMEIDA et al., 2020; RETAMOZO et al., 2023; CARDENAS et al., 2025).

Ethnobotanical studies indicate that Carqueja (*Baccharis trímera*) is used for the treatment of diabetes, digestive and liver diseases (BARBOSA et al., 2020). According to Carrizo et al. (2020), it is used for treating various dermal conditions, such as burns and ulcers, in addition to exhibiting antibacterial activity against both Gram-positive and Gram-negative microorganisms. Additionally, the shrub-like species known as Tola (*Parastrephia lepidophylla*) has traditional medicinal applications in wound healing, extending to humans and animals. Other *Parastrephia* species are used for alleviating toothaches, bone fractures, and bruises (VILLAGRÁN et al., 2003). According to Tapia-Alejo (2021), Tola also works as an analgesic, potentially due to effects like those of morphine.

These uses have prompted scientific studies on various species of *Baccharis* and *Parastrephia*, primarily from Chile, Argentina, Bolivia, and Brazil. The extraction methodologies employed diverse aqueous media, infusions, and decoctions (Rojo et al., 2009; Sabir et al., 2017; De Almeida et al., 2021), as well as ethanolic, methanolic, and other extracts (GAJARDO et al., 2016; ECHIBURU-CHAU et al., 2017; RABELO; COSTA, 2018; CIFUENTES et al., 2019; TREVIZAN et al., 2020; CARRIZO et al., 2020; ROSERO et al., 2022; RETAMOZO et al., 2023). These investigations have identified multiple biological activities, including anti-inflammatory, antioxidant, antibacterial, antifungal, and acaricidal activities, attributed to the considerable presence of polyphenols and total flavonoids in these plants, thereby showing an interesting antioxidant potential (ECHIBURU-CHAU et al., 2017; DI CIACCIO et al., 2018; BARBOSA et al., 2020; ROSERO et al., 2022; SHARMA et al., 2022; CARDENAS et al., 2025). Given their solubility characteristics, these bioactive constituents are preferably extracted in polar solvents (MACHADO et al., 2013).

This prompts the necessity to deepen our understanding of the bioactive properties of Carqueja (*Baccharis trimera*) and Tola (*Parastrephia lepidophylla*), both members of the Asteraceae family and traditionally employed by our ancestors. Currently, there are no published studies on these Peruvian species, particularly those originating from Apurimac. Such investigations are pivotal for elucidating their therapeutic efficacy and facilitating their subsequent clinical application. Hence, this study aims to explain the total polyphenol content, antioxidant activity, total flavonoid content, and bioactive compound profile in ethanolic and aqueous extracts.

2. MATERIAL AND METHODS

2.1. Samples

The specimens of Carqueja (*Baccharis trimera*) and Tola (*Parastrephia lepidophylla*) were collected from the Parcco sector, Chapimarca District, Aymaraes Province, Apurímac Region, Peru, at an elevation of 3,888 to 3,980 meters above sea level (latitude -13°58´'' S, longitude -73° 2´'' W).

2.2. Reagents

1,1-Diphenly-2-picrylhydrazyl (DPPH), Folin-Ciocalteu, 3,4,5-trihydroxybenzoic acid (gallic acid), Na_2CO_3, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,2'-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS), ethanol, methanol, $AlCl_3$, acetonitrile (HPLC), 0.1% H_3PO_4, Chlorogenic acid, and Quercetin standards, $K_2S_2O_8$, $NaNO_2$, and 1N NaOH. They were acquired from Merck Peruvian S.A.

2.3. Extraction procedure

The sample collections were selected, dried in a fluidized bed dryer at 40°C for 30 min, milled using a disc mill, and stored in polyethylene bags at 4°C until extraction. Extraction was conducted using distilled water and 80% ethanol as solvents, with varying sample weights of 20 g and 15 g for Carqueja and Tola, respectively, resulting in eight distinct treatments (Table 1). Each treatment received 200 mL of solvent and underwent maceration under agitation for 24 hours at room temperature. Subsequently, filtration was performed using No. 1 filter paper, followed by centrifugation at 4°C, 3000 rpm for 10 min using a Consul 22R centrifuge. The supernatant was then recovered into 50 mL Falcon tubes and stored at 4°C until further analysis.

Table 1. Treatments for sample extraction.
Tabela 1. Tratamentos para extração de amostra.

Plant	Solvent	Ratio MP/solvent	Extract
Carqueja (*Baccharis trimera*)	Distilled	20 g/200 mL	Aqueous 20 g
	Distilled	15 g/200 mL	Aqueous 15 g
	80% ethanol	20 g/200 mL	Ethanolic 20 g
	80% ethanol	15 g/200 mL	Ethanolic 15 g
Tola (*Parastrephia lepidophylla*)	Distilled	20 g/200 mL	Aqueous 20 g
	Distilled	15 g/200 mL	Aqueous 15 g
	80% ethanol	20 g/200 mL	Ethanolic 20 g
	80% ethanol	15 g/200 mL	Ethanolic 15 g

2.4. Determination of total polyphenol

The spectrophotometric methodology outlined by Singleton et al. (1999) was employed with modifications, using 1N Folin-Ciocalteu, 7.5% Na_2CO_3, and gallic acid as a standard. A calibration curve was prepared with gallic acid at a concentration of 250 mg/L, from which diverse dilutions were prepared. Subsequently, 0.5 mL aliquots were dispensed into test tubes, to which 2.5 mL of Folin reagent and 2 mL of Na_2CO_3 were subsequently added. Following a 60-minute incubation period in darkness, absorbance was measured at 740 nm using a spectrophotometer (UV/VIS Genesys 10S, Thermo Scientific). The same procedure was replicated for the extracts. The results were expressed as milligrams of gallic acid equivalent (GAE) per gram of sample on a dry weight (D.W.).

2.5. Antioxidant Activity

2.5.1. DPPH method

The DPPH assay determines the radical scavenging capacity of compounds. This study used the methodology proposed by BONDET et al. (1997), utilizing Trolox as a standard. A calibration curve with Trolox at a concentration of 200 mg/L in 80% methanol served as the basis for subsequent dilutions to various concentrations. Each dilution (0.1 mL) was introduced into 2.9 mL of the DPPH solution, followed by vigorous agitation and a 1-hour incubation period in darkness. Subsequent absorbance readings at 517 nm using a spectrophotometer (UV/VIS Genesys 10S, Thermo Scientific), with 80% methanol as the blank. The same procedure was replicated for the extracts. The results were expressed in mg Trolox Equivalent/g of sample dry weight.

2.5.2. ABTS method

This study used the protocol proposed by Re et al. (1999) with modifications. The absorbance level was compared with the reference curve derived from Trolox. A calibration curve was prepared with Trolox at 200 mg/L, diluted with 80% methanol to different concentrations. A solution of 7.4 mM ABTS in distilled water with 2.6 mM $K_2S_2O_8$ in distilled water was prepared and allowed to incubate in darkness for 16 hours. The absorbance of this reagent was adjusted to 1.10±0.02 with methanol at room temperature at a wavelength of 734 nm using a spectrophotometer (UV/VIS Genesys 10S, Thermo Scientific). For the calibration curve, 300 µL of Trolox at different concentrations was taken. Then 5.7 mL of the ABTS reagent was added to a test tube, followed by vigorous agitation and a 1-hour incubation period in darkness. Finally, the absorbance was measured in a spectrophotometer at 734 nm. The same procedure was followed for the extracts. The results were expressed in mg Trolox Equivalent/g of sample dry weight.

2.6. Total flavonoids

The methodology described by Kim et al. (2003), with modifications, was implemented for the determination of total flavonoids. This approach was cross-validated against the standard calibration curve of quercetin, and the results were expressed in milligrams of Quercetin Equivalent per gram of sample on a dry weight basis. The following reagents were prepared for the quantification: 5% $NaNO_2$, 10% $AlCl_3$, 1 M NaOH, Mother Solution, and a 400 mg/L Quercetin Stock solution were prepared and subsequently diluted to various concentrations. 300 µL of Quercetin solutions at distinct concentrations were dispensed into test tubes. Subsequently, 0.3 mL of 5% $NaNO_2$ was added and vigorously mixed until combined, followed by the addition of 0.3 mL of 10% $AlCl_3$ after 3 minutes, and left to react for 6 minutes in darkness. Upon completion of the incubation, 2 mL of 1 M NaOH was added, and absorbance readings were promptly recorded at 510 nm using a spectrophotometer (UV/VIS Genesys 10S, Thermo Scientific) with distilled water as the blank.

2.7. Phenolic acids and flavonoids by HPLC

The analysis was conducted using an Agilent 1200 HPLC chromatograph with Chemstation V03.02 software, a Zorbax SB-Phenyl column (4.6 x 75 mm, 3.5 µm), and a Zorbax Eclipse XDB-C18 pre-column (4.6 x 12.5 mm x 5µm). The chromatographic conditions were set with a column flow rate of 0.500 mL/min employing 0.1% H_3PO_4 as Solvent A and Acetonitrile as Solvent B. The analysis commenced with an initial gradient composition of 5% B, followed by a linear gradient to 10% B at 2 minutes, 40% B at 10 minutes, 50% B at 15 minutes, and maintained 50% B until 22 minutes. Detection was accomplished via a Diode Array Detector (DAD) at wavelengths of 285 nm and 370 nm. The column temperature was maintained at 40.0°C throughout the 22-minute analysis, with a 10.0 µL injection volume. Chlorogenic Acid and Quercetin were used as reference standards (IVANESCU et al*.,* 2010).

2.8. FTIR

The infrared spectra of the components and dry samples of Carqueja and Tola were characterized using FTIR employing a Nicolet IS10 instrument (Thermo Scientific, Madison, WI, USA). This analytical technique characterized the microstructural compositions of both plants and evaluated the interactions among their constituents. Spectra were obtained in the mid-IR range of 400-4000 cm^{-1}, averaging 16 scans at a resolution of 4 cm^{-1} (OLIVEIRA et al., 2016).

2.9. Statistical analysis

Experimental data derived from the eight treatments were subjected to a completely randomized experimental design (CRD). Analysis of variance (ANOVA) was applied to discern significant differences, followed by Tukey's mean comparison test ($P \leq 0.05$) using the INFOSTAT software, version 2017 (InfoStat Group, Universidad Nacional de Córdoba, Argentina). The experimental results were reported as mean values ± standard deviation based on triplicate measurements.

3. RESULTS

3.1. Total polyphenols

The quantification of total polyphenols (Figure 1A) showed significant differences ($P \leq 0.05$) among plant species, extraction solvents, and raw material-to-solvent ratios. Ethanol extracts of Tola exhibited the highest concentrations at both extraction levels (20 g and 15 g), yielding 363.35 and 336.78 mg GAE/g dry weight, respectively. These values were followed by ethanolic extracts of Carqueja, which yielded 59.22 and 53.49 mg GAE/g dry weight.

3.2. Antioxidant activity

As shown in Figure 1B, antioxidant activity measured by DPPH displayed highly significant differences ($P \leq 0.05$) across species, extraction methods, and extraction ratios. A pattern consistent with total polyphenols was observed. Ethanolic extracts of Tola demonstrated the greatest activity (50.30 and 42.03 mg Trolox Equivalent/g dry weight), followed by ethanolic extracts of Carqueja (11.29 and 10.52 mg Trolox/g dry weight).

Similarly, ABTS activity (Figure 1C) differed significantly ($P \leq 0.05$) among treatments. Ethanolic extracts of Tola again presented the highest activity (212.84 and 286.79 mg Trolox Equivalent/g), followed by ethanolic extracts of Carqueja (49.19 and 48.53 mg Trolox/g). These results indicate the strong capacity of alcoholic extracts to neutralize cationic radicals (RAJAN et al., 2020).

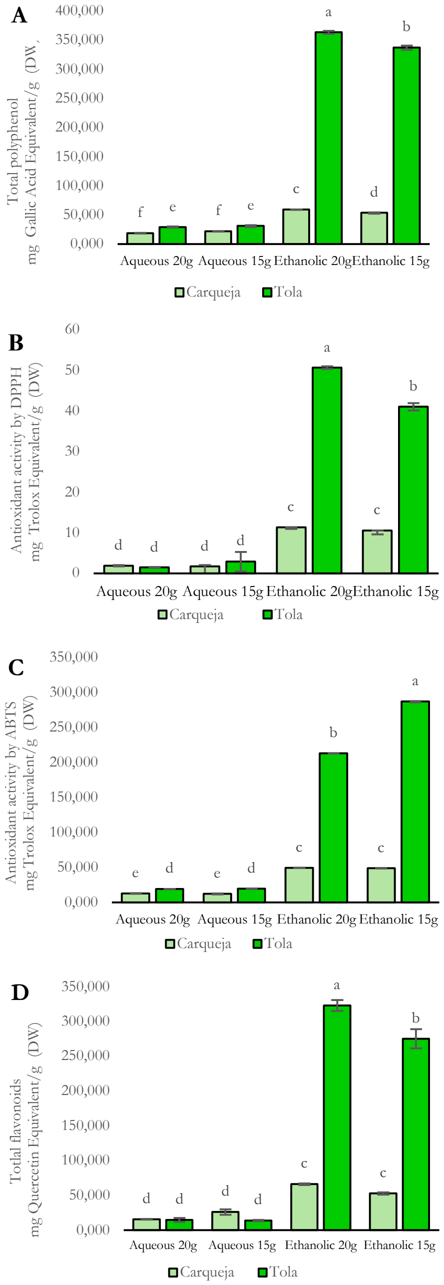

Figure 1. Total polyphenols (A), antioxidant activity (B, C), and total flavonoids (D) of aqueous and ethanolic extracts of Carqueja (*Baccharis trimera*) and Tola (*Parastrephia lepidophylla*). The mass-to-solvent ratio was 15 and 20 g/200 mL. Different letters above the bars indicate high significance **(P≤0.05).
Figura 1. Polifenóis totais (A), atividade antioxidante (B, C) e flavonoides totais (D) de extratos aquosos e etanólicos de Carqueja (*Baccharis trimera*) e de Tola (*Parastrephia lepidophylla*). As razões de massa-solvente foram de 15 e 20 g/200 mL. Letras diferentes acima das barras indicam alta significância ** (P≤0.05).

3.3. Total flavonoids

Significant differences (P ≤ 0.05) were also detected for total flavonoids (Figure 1D). Ethanolic extracts of Tola contained the highest levels (322.83 and 274.89 mg QE/g), followed by ethanolic extracts of Carqueja (65.90 and 52.60 mg QE/g).

Table 2 reports the Pearson correlation coefficients among total polyphenols, DPPH, ABTS, and total flavonoids. Strong positive correlations were found between total polyphenols and DPPH (0.99), between total polyphenols and ABTS (0.97), and between total flavonoids and both antioxidant assays (DPPH: 1.00; ABTS: 0.96).

Table 2. Pearson correlation between total polyphenols (TPF), DPPH, ABTS, and total flavonoids (TF) of aqueous and ethanolic extracts of Carqueja and Tola.
Tabela 2. Correlação de Pearson entre polifenóis totais (TPF), DPPH, ABTS e flavonoides totais (TF) de extratos aquosos e etanólicos de Carqueja e Tola.

	TPF	DPPH	ABTS	TF
TPF	1.00	0.0000024	0.000058	0.00000018
DPPH	0.99	1.00	0.00036	0.0000077
ABTS	0.97	0.95	1.00	0.00019
TF	1.00	1.00	0.96	1.00

3.4. Phenolic acids and flavonoids by HPLC

Table 3 summarizes the HPLC-quantified phenolic acids and flavonoids in aqueous and ethanolic extracts of Carqueja and Tola. In both species, ethanol extracts contained substantially higher concentrations of chlorogenic acid and quercetin.

3.5. FTIR

FTIR spectra (Figure 2) of dried Carqueja and Tola obtained within a range from 4000 to 400 cm^{-1}, showed similar vibrational profiles, with characteristic bands associated with phenolic – OH groups, carbohydrate-related C–H stretching, protein amide bands, aromatic C=C vibrations, and C–O stretching typical of flavonoids.

Table 3. Phenolic acids and flavonoids in aqueous and ethanolic extracts of Carqueja and Tola were determined by HPLC.
Tabela 3. Ácidos fenólicos e flavonoides em extratos aquosos e etanólicos de Carqueja e Tola determinados por HPLC.

Plant	Extract	Chlorogenic acid equivalent (mg/100 mL)	Quercetin equivalent (mg/100 mL)
Carqueja (*Baccharis trimera*)	Aqueous 20 g	0.0	5.0
	Aqueous 15 g	10.8	8.8
	Ethanolic 20 g	199.4	23.7
	Ethanolic 15 g	153.2	27.1
Tola (*Parastrephia lepidophylla*)	Aqueous 20 g	61.0	3.3
	Aqueous 15 g	27.1	2.5
	Ethanolic 20 g	151.9	35.8
	Ethanolic 15 g	171.3	15.6

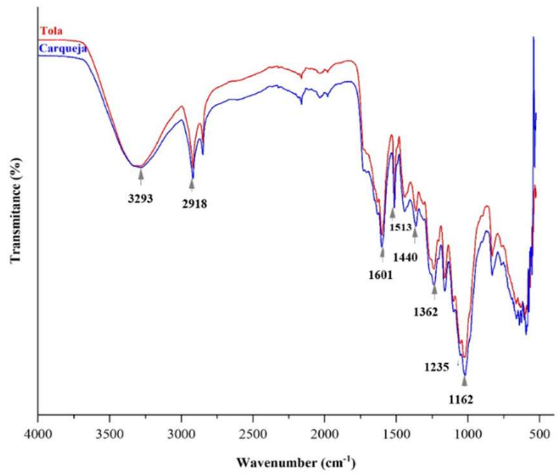

Figure 2. FTIR spectra of dried Carqueja (*Baccharis trimera*) and Tola (*Parastrephia lepidophylla*).
Figura 2. Espectros de FTIR de Carqueja (*Baccharis trimera*) e Tola (*Parastrephia lepidophylla*) secas.

4. DISCUSSION

4.1. Total polyphenols

Previous studies on *Baccharis trimera, Baccharis alnifolia, Baccharis tola*, and *Parastrephia lucida* have reported higher polyphenol yields, likely influenced by extraction temperature, duration, and plant-to-solvent ratios (SABIR et al., 2017; DE ALMEIDA et al., 2021; ROSERO et al., 2022). Reported values for related species from high-altitude ecosystems are close to those of the present study (Rojo et al., 2009; Trevizan et al., 2020) for aqueous extract. On the other hand, ethanolic extract reported of plants from highlands of Chile and Argentina like *Baccharis boliviensis*, *Baccharis tola* and (Meyen) Cabrera vary substantially (CIFUENTES et al*.,* 2019; TREVIZAN et al., 2020; CARRIZO et al*.,* 2020; ROSERO et al., 2022; CARDENAS et al., 2025).

Such discrepancies can be attributed to geographical origin, environmental conditions, extraction parameters, and solvent characteristics (MACHADO et al., 2013). Ethanol and water remain the most widely used solvents due to their polarity and effectiveness in mobilizing phenolic compounds (TAVARES et al., 2021).

4.2. Antioxidant activity

The superior antioxidant activity of ethanolic extracts observed in this study (Figures 1B and 1C) is consistent with their greater ability to donate hydrogen/electrons and stabilize free radicals (RAJAN et al., 2020). Findings from other Andean and Chilean species show comparable activity values after standardization in aqueous and ethanolic extracts (ROJO et al., 2009; TREVIZAN et al., 2020; ROSERO et al., 2022; CARDENAS et al., 2025). Solvent polarity plays a decisive role in the extraction of bioactive antioxidant constituents, including metal chelators and radical scavengers (SOUZA et al., 2022). Given the recognized role of oxidative stress in chronic diseases (WONGSA et al., 2022), these plant extracts may offer potential for preventive or functional applications.

4.3. Total flavonoids

Flavonoid levels reported here align with or fall within the ranges previously described for Baccharis and Parastrephia species (TREVIZAN et al., 2020; CARRIZO et al., 2020; ROSERO et al., 2022; CARDENAS et al., 2025). Other authors report slightly higher values in aqueous and ethanolic extracts (SABIR et al., 2017; ECHIBURU-CHAU et al., 2017; D'ALMEIDA et al., 2020). Extraction solvents, methods, and environmental conditions largely influence differences across studies. Polar solvents such as ethanol and water enhance the extraction of flavonoids and other phenolics (PALAIOGIANNIS et al., 2023). The strong correlations (Table 2) found between total flavonoids and antioxidant activity (DPPH: 1.00; ABTS: 0.96) confirm their significant contribution to free radical scavenging activity.

4.4. Phenolic acids and flavonoids by HPLC

The phenolic profiles obtained through HPLC agree with findings in *Baccharis trimera* and related species, also in *Parastrephia quadrangularis,* which commonly contain chlorogenic acid and flavonoids such as rutin, luteolin, and quercetin (SABIR et al., 2017; RABELO; COSTA, 2018; DE ALMEIDA et al., 2021; SHARMA et al., 2022; ROSERO et al., 2022; RETAMOZO et al., 2023; CARDENAS et al., 2025).

4.5. FTIR

Characteristic absorptions in the FTIR spectra, including broad O–H stretching (3420-3250 cm^{-1}), carbohydrate-related C–H vibrations (2990-2850 cm^{-1}), amide I and II bands (1600-1700 cm^{-1}, 1500-1570 cm^{-1} respectively), aromatic C=C stretching (1615-1590 cm^{-1}), and C–O vibrations (~1200 cm^{-1}) typical of flavonoids, corroborate the presence of polyphenols, terpenoids, and phenolic polymers complexed with carbohydrates and proteins (COATES, 2000; SHURVELL, 2006; PARK et al., 2015; WONGSA et al., 2022; MUEED et al., 2023). These functional groups confirm the chemical diversity and potential bioactivity of the studied samples.

5. CONCLUSIONS

This study demonstrates that both plant species and extraction conditions markedly influence the recovery of bioactive compounds in Carqueja (*Baccharis trimera*) and Tola (*Parastrephia lepidophylla*). Ethanolic extracts consistently yielded the highest levels of total polyphenols and flavonoids, particularly in Tola, which exhibited superior antioxidant activity in both DPPH and ABTS assays. These findings confirm the strong association between phenolic content and antioxidant capacity, as supported by the high Pearson correlation coefficients observed among total polyphenols, total flavonoids, and antioxidant responses.

HPLC analysis identified chlorogenic acid and quercetin as predominant components in ethanol extracts of both species, reinforcing the relevance of solvent polarity for efficient extraction of phenolic constituents. FTIR spectra further corroborated the presence of characteristic functional groups associated with polyphenols, flavonoids, proteins, and carbohydrates, supporting the chemical complexity and potential bioactivity of the extracts.

Overall, the results highlight Tola, especially under ethanolic extraction, as a promising natural source of antioxidant compounds. The marked influence of extraction parameters underscores the need for optimized extraction protocols to maximize the recovery of bioactive constituents from High-Andean species. These findings contribute to the understanding of the phytochemical and antioxidant potential of Carqueja and Tola and support their potential application in functional, nutraceutical, or preventive health products.

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Acknowledgements: The authors would like to express their gratitude to the Vicerrectorado de Investigación, Universidad Nacional Micaela Bastidas de Apurímac (UNAMBA), for their support through the funding provided from mining canon and over-canon fees (Resolution 237-2023-CU-UNAMBA)

Authors' contributions: E.Q.R. and E.A.Q.P.: conceptualization and methodology; L.S.S. and O.J.S.: data collection and statistical analysis; J.J.C.M. and G.CH.Q.: writing (original draft); J.J.C.M. and G.CH.Q.: writing (review and editing). All authors read and agreed to the published version of the manuscript.

Data availability: Study data can be obtained by email from the corresponding author. It is not available on the website as the research project is still under development.

Conflict of interest: The authors declare that they have no conflict of interest.