Traditional use of *Achyrocline satureioides* in coal mining areas

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Research

Abstract

Background: Mineral extraction areas are a significant environmental concern due to the contamination of soil, water, and plant resources. In these areas, some medicinal plant species have the potential to bioaccumulate trace elements. The medicinal species *Achyrocline satureioides* (Lam.) DC is a species that occurs naturally in roadsides and mining areas and has a bioaccumulating capacity. Given this situation, this study aimed to understand the traditional use of *Achyrocline satureioides* in coal-mined areas in southern Brazil and to analyze whether it occurs in areas contaminated by mining and potentially dangerous to the food security of local communities.

Methods: We conducted 194 semi-structured interviews in the coal-mining region of Santa Catarina to understand where people collected the species, the frequency of consumption, and its associated traditional use. We also analyzed the soil in the collection areas to determine whether the areas were contaminated with trace elements from coal mining.

Results: As a result, we found that the six collection areas for the species indicated by the interviewees had high concentrations of barium, cadmium, and lead. Among the interviewees, 81.4% of people reported consuming *Achyrocline satureioides*, with the highest consumption reported by women and older individuals.

Conclusions: These results highlight the importance of investigating food safety in mined areas and its potential impacts on human health. Our studies have shown that human populations are consuming medicinal species with the potential to accumulate trace elements from areas contaminated by mining.

Keywords: Ethnobotany, Ecotoxicology, Food safety, Mining

Resumo

Contexto: As áreas de extração mineral são uma preocupação ambiental significativa devido à contaminação do solo, água e recursos vegetais. Nessas áreas, algumas espécies de plantas medicinais apresentam potencial bioacumulador de elementos-traço. A espécie medicinal *Achyrocline satureioides* (Lam.) DC é uma espécie que ocorre naturalmente em beiras de estrada e áreas mineradas e apresenta capacidade bioacumuladora. Diante desta situação, o presente estudo teve como objetivo compreender o uso tradicional de *Achyrocline satureioides* em áreas mineradas para extração de carvão do sul do Brasil e analisar se ela ocorre em áreas contaminadas pela mineração e potencialmente perigosas para a segurança alimentar das comunidades locais.

Metodologia: Foram realizadas 194 entrevistas semi-estruturadas na região carbonífera de Santa Catarina, para compreender onde as pessoas realizavam a coleta da espécie, frequência de consumo e o uso tradicional associado. Também realizamos a análise do solo das áreas de coleta para saber se as áreas apresentavam contaminação por elementos-traço oriundos da mineração de carvão.

Resultados: Como resultado encontramos que as seis áreas de coleta da espécie indicadas pelos entrevistados apresentavam concentração elevada de bário, cádmio, chumbo, e níquel. Entre os entrevistados, 81,4% das pessoas afirmaram consumir *Achyrocline satureioides*, sendo que o maior consumo foi citado por mulheres e pessoas com idade maior.

Conclusão: Estes resultados destacam a importância da investigação da segurança alimentar em áreas mineradas, e seus possíveis impactos para a saúde humana. Nossos estudos mostraram que as populações humanas estão consumindo espécies medicinais com potencial acumulador de elementos-traços de áreas contaminadas pela mineração.

Palavras-chave: Etnobotânica, Ecotoxicologia, Segurança alimentar, Mineração

Background

The traditional use of plant species for medicinal purposes has a long-standing presence in human history for centuries (Rocha *et al.* 2021), often serving as the primary form of healthcare (e.g., prevention, treatment, rehabilitation, and palliative care), mainly due to their ability to synthesize secondary metabolites with extraordinary therapeutic potential against various diseases (Kumar *et al.* 2022). The World Health Organization estimates that more than 80% of the world's population depends on herbal remedies used as traditional medicine (Ekor 2014, Mukherjee 2002, Bandaranayake 2006). This traditional use goes beyond a purely utilitarian view and involves various social, environmental, and cultural layers, often representing an ancestral connection, full of memories and cultural identification, associated with physical and mental well-being (Ellen 2023, Kumar et al., 2022).

Traditional plant-based medicines are often more accessible and affordable, with fewer side effects compared to synthetic alternative medicines (Karimi *et al.* 2015). In Brazil, a country with vast biocultural and plant diversity, there are numerous traditional populations whose practices are rooted in the traditional use of medicinal plant species, such as Indigenous Peoples, Quilombola Communities, Benzedeiras (traditional healers), Romani People, Fishermen and Fisherwomen and Local Communities (Albuquerque *et al.* 2019, Diegues 2000). In these communities, women and older individuals tend to possess greater knowledge of medicinal plant species and rely more frequently on these resources for healthcare (Albuquerque et al., 2019). This knowledge, transmitted intergenerationally, constitutes a strategic element for maintaining community health and preserving local biocultural heritage (Silva & Santos 2024, Martins 2023).

Among the most commonly used botanical families, Asteraceae (formerly known as Compositae) stands out as the one with the highest number of plant species reported to have medicinal uses worldwide (Sharma *et al.* 2022). In ethnobotany, the scientific field that studies the traditional uses of species, Asteraceae species are frequently cited for a variety of purposes (Renner *et al.* 2006). These include treatments that benefit from the antimicrobial, anti-inflammatory, antioxidant, anticancer, antidiabetic, hepatoprotective, and antiparasitic properties of some species, due to the presence of oils, polyphenolic compounds, lignans, saponins, phenolic acids, polysaccharides, sterols, and terpenoids (Koc *et al.* 2015, Rolink & Olas 2021). Because of their importance, Asteraceae species have been extensively studied and are widely recommended in herbal treatments (Sharma *et al.* 2022).

Among the species belonging to Asteraceae, the medicinal species *Achyrocline satureioides* (Lam.) DC is a good example of this widespread traditional and current use, being one of the 100 plants of greatest relative importance in medicinal ethnobotany studies in Latin America (Medeiros *et al.* 2013). *A. satureioides*, also popularly known as "marcela" in Portuguese, is a native species from the subtropical and temperate regions of southeastern South America, occurring mainly in countries such as Argentina, Uruguay, and northeastern to southern Brazil. It is a perennial herbaceous plant (Lorenzi & Matos 2008) with an annual life cycle, with branches that can reach up to 1.5 m in height and alternate, entire, sessile linear, lanceolate leaves up to 12 cm long by 1.8 cm wide (Fachinetto *et al.* 2007), as well as densely pilose (Uruguay 2003). It has capitulum-type inflorescences with numerous golden-yellow flowers and glabrous, brown achene-type fruit (Castro & Chemale 1995, Uruguay 2003).

One of its main traditional uses is associated with its antispasmodic biochemical activity, a favorable characteristic for the treatment of digestive problems (Barata *et al.* 2009). The species also has antitumor, analgesic, anti-inflammatory, antispasmodic, antiviral, and antibacterial properties (Lorenzi & Matos 2008, Barata *et al.* 2009). *Achyrocline satureioides* is rich in elements essential for human health but has the potential to accumulate non-essential elements that can be harmful (Galvan 2018). It's also a central species in the colonization of new areas and in the recruitment of other species (Lorenzi & Matos 2008, Barata *et al.* 2009) and is commonly found in coastal regions with stony and sandy soils (Uruguay 2003). Its flowers are often visited by different types of arthropods, with wasps and flies being the main pollinators (Freitas & Sazima 2012).

However, increased deforestation, loss of biodiversity and the expansion of contaminated areas have jeopardized the use of medicinal species (Blanco *et al.* 2023). Among these causes, the expansion of contaminated areas has received special attention in recent years. Some of the main factors associated with these contaminations are industrial activities, the incorrect disposal of waste, and mining (Blanco *et al.* 2023, Candeias *et al.* 2019). Solid mining in Latin America is an activity that has gained special attention since the 1920s, as one of the most exploited regions, mainly by the global north (Candeias *et al.* 2019). In these locations, contamination by trace elements (e.g., aluminum, cadmium, lead, zinc) can jeopardize food security for people, including those in traditional communities. Trace elements can be precursors to diseases, such as kidney disease, osteoporosis, and increased risk of cancer (breast, lung, prostate) (Yang *et al.* 2024).

Food security is the right of all people to access safe and nutritious food throughout their lives, meeting their nutritional and cultural needs (FAO 2019). This concept is enshrined in the Rome Declaration on World Food Security and access to safe traditional medicines and medicinal practices. This concept is also reinforced in more recent FAO documents, such as the 2024 report, which highlights that approximately 2.8 billion people worldwide lack access to a healthy diet and safe traditional medicinal practices, highlighting persistent global food and medicinal insecurity.

Areas with rural populations have often been the focus of mining industries, which generates a series of socio-environmental conflicts in such locations (Zárate-Rueda *et al.* 2021). In Brazil, the situation is no different. Over the last 40 years, the country has experienced an exponential increase in mined areas, with regions such as the south receiving particular attention (MapBiomas 2022). The southern region of Brazil is characterized by phytophysiognomies typical of the Atlantic Forest and Pampa ecosystems and is rich in important minerals, with coal being one of the main resources extracted in the area (Belloli et al., 2002). The coal-bearing region of southern Brazil crosses the states of Rio Grande do Sul, Santa Catarina, and Paraná, reaching countries such as Argentina and Uruguay (Blanco 2023). The coal mining peak in the region occurred between 1960 and 1980 (Blanco 2023), with Santa Catarina and Rio Grande do Sul states accounting for 99% of Brazil's coal mining (Belloli *et al.* 2002).

Currently, the region has several abandoned coal mining areas with no plans for restoration (Rocha-Nicoleite *et al.* 2018), as well as a mosaic of mining areas, urban centers, and diverse human groups (Blanco *et al.* 2020a, Blanco *et al.* 2020b). Studies have shown that *Achyrocline satureioides* has been found in mineral extraction areas and highways (Galvan *et al.* 2019, Blanco *et al.* 2021). The species has shown a predisposition for bioaccumulation of elements such as aluminum, copper, nickel, manganese and zinc in its flowers (Cantarelli *et al.* 2010, Galvan *et al.* 2019). The flowers are the main part of the species that is consumed, mainly for the preparation of infusions (Galvan *et al.* 2019).

Given this context, the present study aimed to investigate the use of *Achyrocline satureioides*, popularly known as "marcela" or "macela", in mined areas of southern Brazil, and to assess the potential food safety risks for people who consume this plant. The hypotheses were: 1) Populations living in coal mining areas are frequently collecting and consuming *Achyrocline satureioides* from contaminated areas; 2) Women are the group that most frequently consumes *Achyrocline satureioides* from coal mining areas contaminated by trace elements; 3) Older individuals more frequently consume *Achyrocline satureioides* from mined areas contaminated by trace elements.

Materials and Methods

Authorizations and interviews

To conduct this research, informed consent was obtained from the interviewees (CAAE: 80660217.1.0000.0121). Semi-structured interviews were conducted with residents of communities located within a maximum distance of 300 m from coal mining areas in Santa Catarina. The interviews were conducted individually between February and March 2019. In total, there were 14 local communities (Vila Funil, Rio Carvão, Barreiros, Guaitá, Cidade Alta, Vila Visconde, São Sebastião Alto, Vila São Jorge, Rio Fiorita, Volta Redonda, Campo Morozini, Santa Luzia, Santa Augusta, and São Sebastião), belonging to six municipalities (Criciúma, Forquilhinha, Siderópolis, Treviso, Urussanga, and Lauro Müller). These communities were selected because they are located in areas with a history (past and present) of coal mining (Figure 1).

Figure 1. Map showing the location of communities in the coal region of the state of Santa Catarina, Brazil: 1) Barreiros; 2) Guaitá; 3) Rio Cravão; 4) Volta Redonda; 5) Rio Morozini; 6) Vila Funil; 7) Vila Visconde; 8) Vila São Jorge; 9) Rio Fiorita; 10) Santa Luzia; 11) São Sebastião; 12) Santa Augusta; 13) São Sebastião; e 14) Cidade Alta.

Within each community, home visits were conducted only once, and interviews were conducted exclusively with those interested in participating in the study. Respondents were asked if they knew and consumed Achyrocline satureioides D.C. (a specimen of the species was deposited in the herbarium of the Educação, Ciência e Tecnologia do Amazonas, voucher EAFM16712), where they usually collected it, and how often they consumed it (Supplementary Material 1, Figure 2). To measure the frequency of *A. satureioides* consumption, each respondent answered how many glasses (200 mL) they drank per week. Three levels were used to classify the frequency of *A. satureioides* consumption among respondents: low (one glass once a week or less), medium (one or two glasses, 2–3 times during the week), and high (two or more glasses, 4–7 times a week or more) (De Godoy *et al.* 2013; Blanco *et al.* 2022).

Figure 2. Collection of *Achyrocline satureioides* (Lam.) DC in coal mining areas. The first image shows one of the collection areas for this species in southern Brazil, in the municipality of Urussanga, Santa Catarina. The second image shows the species used by communities in southern Brazil.

Soil collection

Soil collection was carried out in six mined areas with the occurrence of *A. satureioides*. Three of these areas (Lauro Muller at 28° 32' 34.6'' S and 049° 29' 34.8'' W, Urussanga at 27° 31' 56.9'' S and 048° 30' 44.4'' W, and Treviso at 28° 29' 54.1'' S and 049° 22' 57.9'' W), were areas where Al, Ba, Cd, Cr, Cu, Pb, Mn and Zn had already been detected in the soil as a result of coal mining (Campos *et al.* 2010, Hugen *et al.* 2013, Souza *et al.* 2016), and with no record of other anthropogenic activities that could affect soil composition. These areas were among those cited by respondents as collection sites for *Achyrocline satureioides*. The other three areas (Lauro Muller at 28° 32' 33.2'' S and 049° 20' 53.6'' W, Urussanga at 28° 32' 34.5'' S and 049° 29' 34.8'' W, and Treviso at 28° 29' 54.7'' S and 049° 22' 57.5'' W) were close to mining areas but had no record of mineral exploration or other anthropic activity (Figure 3). The distance between mined and unmined areas was a maximum of 10 km. Two transects were surveyed in each of the six collection areas, and soil was obtained through three subsamples, collected with the aid of an auger, at a depth of 20 cm. In total, 60 soil samples were obtained (30 samples from mined areas and 30 samples from unmined areas).

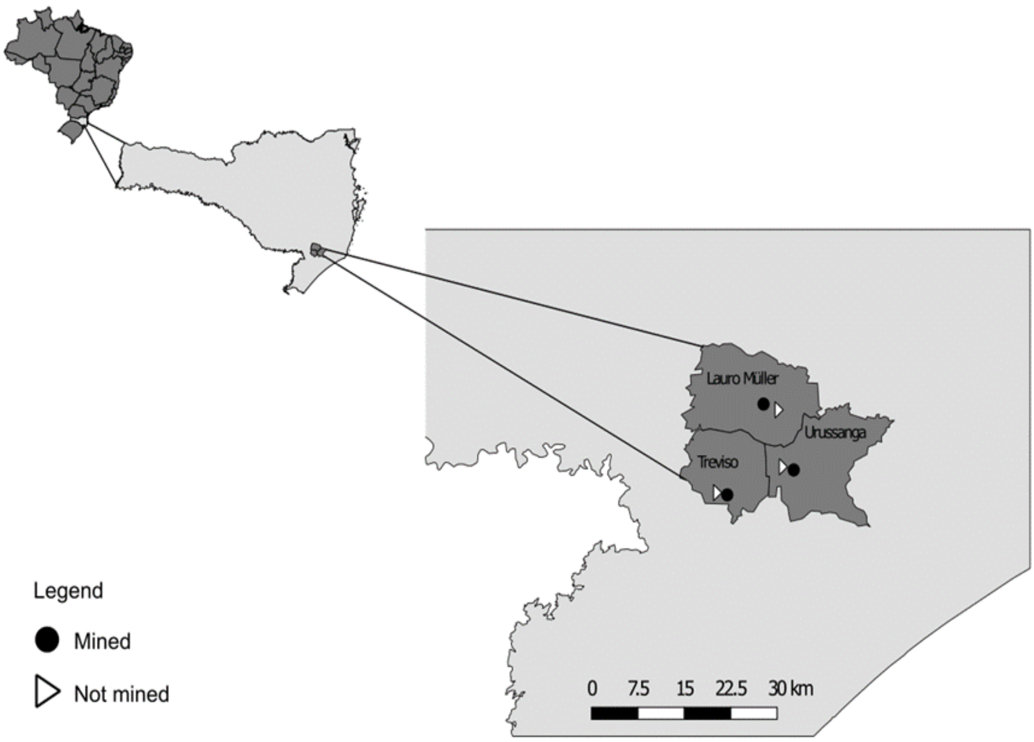

Figure 3. Map of collection areas in southern Brazil. Ten soil samples were collected from each of the six locations identified on the map. Triangles represent unmined areas, and circles represent areas mined for coal extraction.

Soil preparation and analysis

After pulverizing the soil samples in an agate mortar to obtain a fine powder and sieving them through a 0.149 mm sieve, the soil was subjected to acid digestion, following the USEPA 3050 B method (USEPA 1996). The reliability of the method was measured using CRM-Agro E2002a reference soil material (EMBRAPA 2015) and cell samples for the Qualitative Detection Limit (QDL) (Table 1). Next, the Instrument Detection Limits (IDL) were calculated according to APHA (2017). All analyses were performed in duplicate (Table 1).

Finally, the contents of Al, Ba, Cd, Cr, Cu, Pb, Mn, and Zn were quantified using an inductively coupled plasma optical emission spectrometer (ICP-OES), and the Ni content was quantified using an air-acetylene flame atomic absorption spectrometer (F-AAS).

Statistical analysis

Descriptive and qualitative methods were used to analyze the interviews, and proportion graphs were organized. To analyze whether there was a difference between the concentrations of trace elements in the soil of mined and unmined areas, an ANOVA was run in the R software. The difference in consumption frequency between men and women and between age groups was also analyzed. Boxplots were used for graphical representation, and their construction was also developed in R (R Core Team 2021).

Table 1. Reference value for Al, Ba, Cd, Cr, Cu, Mn, Ni, Pb and Zn using as parameters the information from CRM-Agro E2002a (EMBRAPA 2015) and the Instrumental Detection Limit (IDL) (APHA 2017). Thirteen elements were quantified by ICP-OES, except for Ni, which was quantified by F-AAS.

Trace elements	Samples (mg.kg-1)	Reference material (mg.kg-1)	Instrument Detection Limits (IDL)
Al	58.20 (g.kg-1)	†	0.61
Ba	7.12	†	0.04
Cd	86.02	94.0 ± 11.4	0.03
Cr	77.49	120.0 ± 30	0.03
Cu	8.56	8.8 ± 4.0	0.09
Mn	76.28	130.0 ± 20	1.18
Ni	6.87	†	0.12
Pb	104.50	173.8 ± 18.8	0.51
Zn	6.09	†	0.19

Note: The symbol (†) means that the trace elements were not present in the reference material CRM-Agro E2002a Brazilian Agricultural Research Corporation (EMBRAPA 2015).

Results

A total of 193 interviews were conducted in fourteen local communities in the coal-mining region of Santa Catarina, southern Brazil, with an average of 14 residents (± 5.4) interviewed per location. Among the interviewees, 95% said they were familiar with the plant *Achyrocline satureioides,* and 81% said they used it. Regarding frequency of use: 73.9% reported they consumed it infrequently (i.e., one glass once a week or less), 17.6% consumed it moderately frequently (i.e., one or two glasses, 2–3 times during the week), and 8.5% consumed it frequently (i.e., two or more glasses, 4–7 times a week or more). Most respondents were residents of the municipality of Treviso (36%), followed by: Siderópolis (25%), Lauro Muller (18%), Urussanga (13%), and Criciúma (8%). Among the associated medicinal uses of *Achyrocline satureioides*, the main ones were: stomach ailments (73 respondents), aid digestion (6.22% of respondents), stomach pain (3.63% of respondents). Additionally, 13.47% of respondents reported using the species for various purposes, while 17.62% indicated that they did not know the reason for using the herb. Furthermore, 4.15% of respondents reported using the plant to treat menstrual cramps, and 3.11% reported using it as a sedative (Figure 4).

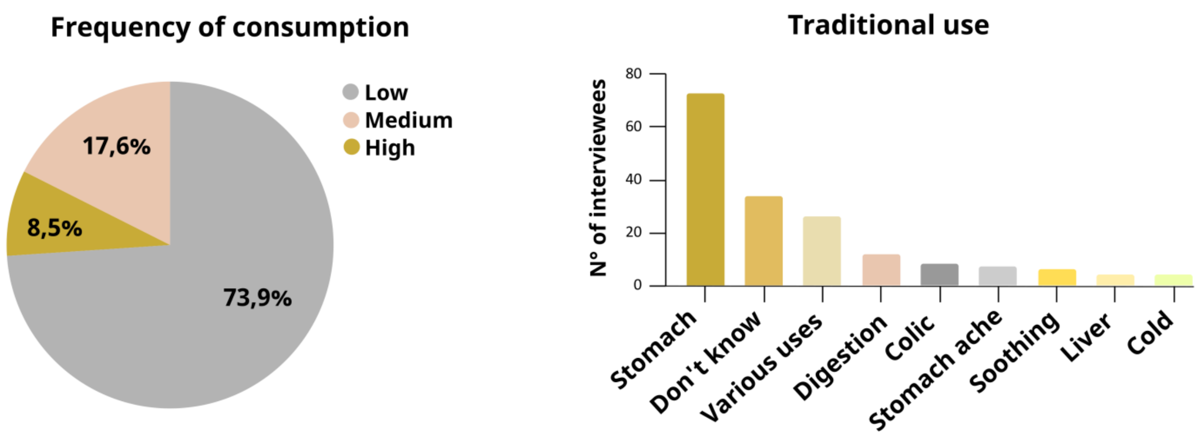

Figure 4. Frequency of consumption and associated traditional use of *Achyrocline satureioides* (Lam.) DC in coal mining areas in southern Brazil (for 164 respondents who reported consuming the plant).

Of the respondents, 126 identified as female and 74 as male. Among women, 83% reported consuming *A. satureioides*, with 32.5% consuming it at medium or high frequency and 67.5% at low frequency. Among men, 65.2% reported using the species for medicinal purposes, with 79.7% consuming it infrequently and 20.3% consuming it at moderate or high frequency. Analysis of consumption frequency between men and women showed that women exhibited higher low and medium consumption, while no difference was observed between men and women for high-frequency consumption (Figure 5; Supplementary Material 2).

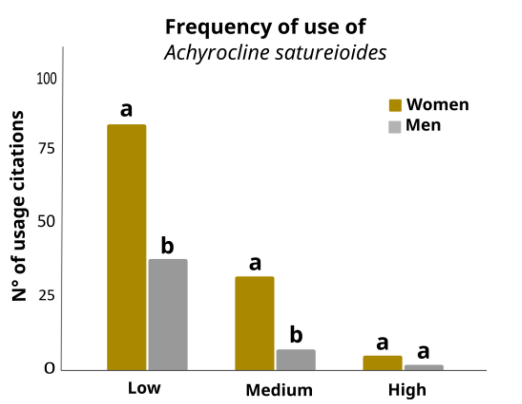

Figure 5. Frequency of *Achyrocline satureioides* (Lam.) DC consumption in coal-mined areas in southern Brazil. The image shows the percentage of women and means who consumed *Achyrocline satureioides* (Lam.) DC with low, high and medium frequency. Different letters indicate statistical difference (p < 0.05).

Respondents' ages ranged from 15 to 86 years, with a mean age of 53 years (±17.8). Among those reporting consumption of *Achyrocline satureioides*, 74.2% were over 50 years old. Analysis by age group revealed that high-frequency consumption differed significantly from low- and medium-frequency consumption, indicating that individuals over 50 tend to consume *A. satureioides* more frequently (Figure 6; Supplementary Material 3).

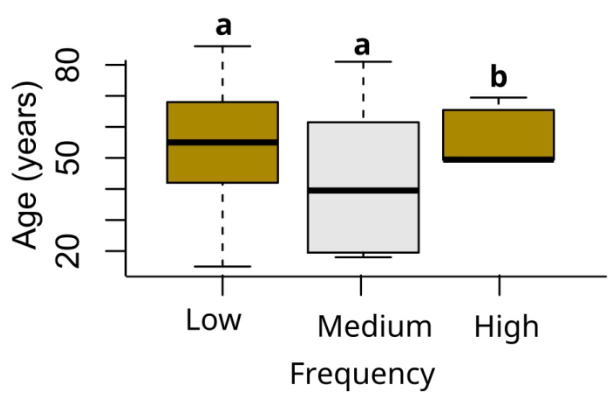

Figure 6. Relationship between the age of respondents and the frequency of use of *Achyrocline satureioides* (Lam.) DC in coal-mined areas in southern Brazil.

Regarding the soil analysis where the species occur and are collected, values above those indicated for the soil of Santa Catarina were found for four trace elements: barium, cadmium, lead, and nickel. There was no significant difference in the concentration of trace elements between mined and unmined areas, except for chromium, which had a higher concentration in mined areas. Elements that presented concentrations well above those indicated for the soil of Santa Catarina included: cadmium, copper, nickel and zinc (Figure 7; Table 2)

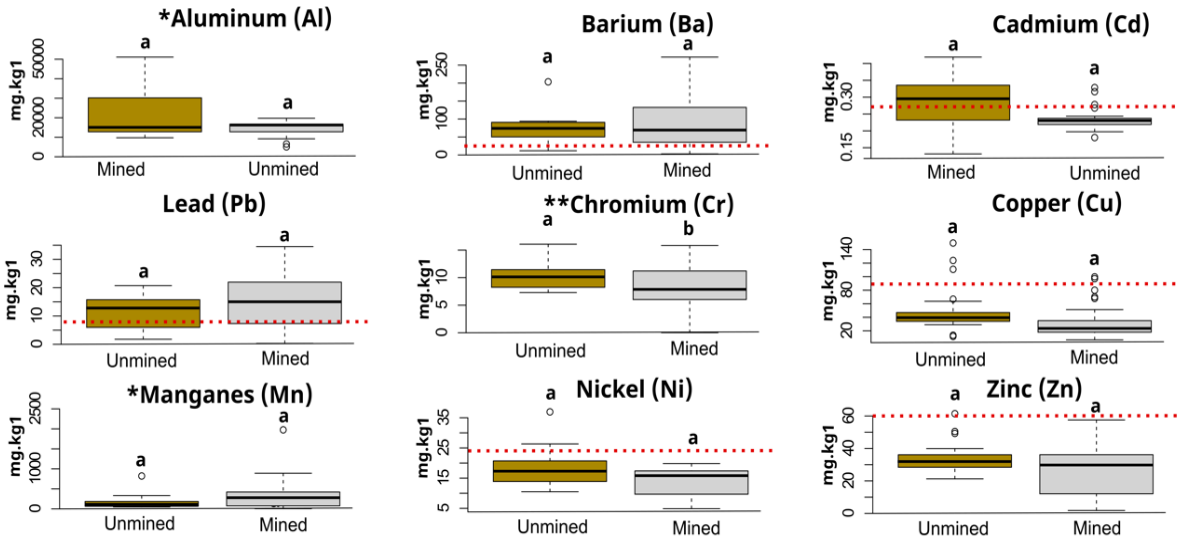

Figure 7. Trace element concentration found in soil from areas mined for coal extraction and *Achyrocline satureioides* (Lam.) DC collection and in soil from non-mined areas. In red, the Quality Guidance Values for soil in Santa Catarina (IMA, 2025). *Does not present Quality Guidance Values; **Quality Guidance Value is 43.2 mg.kg-1; a and b indicate whether there was a statistical difference between the values found, with the same letter indicating no difference and different letters indicating a statistical difference.

Table 2. ANOVA results for comparing the concentration of trace elements in mined areas versus their concentration in non-mined areas of the coal region of southern Brazil.

Trace Element and Area	Pr(>F)	F value
Aluminum from mined area *versus* aluminum from non-mined area	0.195	1.764
Barium from mined area *versus* barium from non-mined area	0.104	2.828
Cadmium from mined area *versus* cadmium from non-mined area	0.507	0.452
Lead from mined area *versus* lead from non-mined area	0.348	0.913
Chromium from mined area *versus* chromium from non-mined area	0.0289	5.306
Copper from mined area *versus* copper from non-mined area	0.91	0.013
Manganese from mined area *versus* manganese from non-mined area	0.935	0.007
Nickel from mined area *versus* nickel from non-mined area	0.231	1.5
Zinc from mined area *versus* zinc from non-mined area	0.0679	3.606

Discussion

Residents of the coal-mining region in southern Brazil use *Achyrocline satureioides* (Lam.) DC for medicinal purposes, primarily to treat digestive system disorders. Traditional use of this species for similar purposes is also observed in Argentina, Colombia, Bolivia, Venezuela, Chile, and Uruguay (Bianchi *et al.* 2023, Retta *et al.* 2012). The main medicinal applications reported in these countries include the treatment of digestive disorders, menstrual cramps, and the improvement of digestion after meals (Stolz *et al.* 2014). The plant is commonly used as an infusion, often consumed alongside the traditional drinking of chimarrão (*Ilex paraguariensis*) (Souza & Dias 2018). Pharmacological studies have demonstrated that infusion of *A. satureioides* exhibits antispasmodic, anti-inflammatory, antiviral, sedative, hepatoprotective, and analgesic effects (Bianchi *et al.* 2023, Stolz *et al.* 2014). More recently, in vitro studies have also pointed to the benefits of using the species in reducing cell mortality and oxidative stress in neural cells (Cruz *et al.* 2024).

A. satureioides for consumption is obtained in areas that have been mined for coal extraction. Soil analyses of these areas showed that both mined areas and nearby non-mined areas have barium and cadmium levels above what is considered safe for the region, and mined areas showed elevated cadmium levels (IMA 2025). This same situation has been observed in other studies in the region, indicating that trace elements from mineral extraction activities are reaching non-mined regions, probably through a leaching process (Blanco *et al.* 2023). This situation serves as a warning regarding the food security of communities that collect and consume these species and highlights the importance of conducting further studies on the impact of this consumption on human health. The present study did not analyze the concentration of trace elements in the species itself, but previous studies, carried out in the same regions as the present study, have already demonstrated the bioaccumulative capacity of the species for elements such as cadmium and lead (Galvan *et al.* 2019, Del Vitto *et al.* 2009). These same elements were found in high concentrations in the soils of the locations where communities collect *A. satureioides*.

Trace elements such as zinc and copper are necessary in small concentrations for humans (Rocha 2021). Zinc is important for bone and muscle growth, acts as a catalytic component of enzymes, and plays a role in other basic functions in the human body. It acts as a cofactor in several enzymes involved in protein synthesis, cell division and antioxidant processes, in addition to playing a crucial role in immune function (Zhu *et al.* 2024, He *et al.* 2024). Copper aids in energy production, neurotransmitter function, and protects cells against oxidative damage caused by free radicals (Zoroddua *et al.* 2019). However, although these are essential elements for humans, excessive intake can cause discomfort and health problems, such as: abdominal pain, cramps, nausea, diarrhea, and vomiting; in more severe cases of toxicity, it may even contribute to the development of Parkinson's disease. (Fraga 2005). In the present study, the copper and zinc values were at concentrations very close to the suggested limit for the region, and studies with *A. satureioides* showed that the species accumulates these elements in its inflorescences and maintains them at high concentrations even after infusion preparation (Galvan *et al.* 2019). Based on these results, we highlight the importance of conducting studies on the possible impacts (positive, negative, or neutral) of consumption of these elements on human health.

We also find elements in the soil that are not essential to humans but can be toxic, such as cadmium, lead, barium, and nickel (Fraga 2005). Given that barium, cadmium, and lead are present at levels higher than recommended for the soil in the region. High lead consumption can cause diseases such as: paralysis of physiological functions, respiratory syndromes (e.g., asthma, lung cancer, chronic obstructive pulmonary disease) and nervous, renal, and cardiovascular disorders (Dong & Li 2023, Raj & Das 2023). As the duration of exposure to this element increases, the likelihood of the population developing chronic and more severe diseases also rises (Dong & Li 2023, Raj & Das 2023). In India, local populations in coal mining areas have shown high concentrations of lead in their blood, with the main source of contamination being the consumption of medicinal plants growing in contaminated soils (Raj & Das 2023). In coal mining areas with high cadmium concentrations, a direct correlation has been observed between cadmium exposure and an increase in diseases such as kidney disease, osteoporosis and increased risk of cancer (breast, lung, prostate) (Yang *et al.* 2024).

Similar to lead and cadmium, barium is an element that, when consumed in high concentrations, can cause gastrointestinal effects (gastric pain, nausea, vomiting, and diarrhea), metabolic disturbances (hypokalemia leading to ventricular tachycardia, hypertension and/or hypotension, muscle weakness, and paralysis), as well as cardiovascular, musculoskeletal, and neurological effects (tremors, seizures, and mydriasis) (Peana *et al.* 2021). High nickel consumption has been associated with allergic reactions, cancers of the digestive system and infectious diseases (Zambelli & Ciurli 2013). In areas mined for coal extraction, the main source of trace element contamination has been through the consumption of food and medicinal plants growing in contaminated soils and water contamination (Blanco *et al.* 2022). Ancient cultural practices, such as the use of medicinal plants, may be seriously threatened by contamination and the failure to rehabilitate mined areas (Blanco *et al.* 2023). Practices once associated with well-being and health may, in fact, serve as a gateway to disease (Zank *et al.* 2022).

In local and traditional communities, women and older individuals are often reported as the main consumers and knowledge holders regarding the use of medicinal plant species (Albuquerque *et al.* 2017). In the present study, we observed that *A. satureioides* is predominantly consumed by women, with low to moderate consumption being the most common. However, the overall number of women consuming the plant, regardless of frequency, was higher than that of men. Studies have shown that women and children are among the groups most affected by trace element contamination in mined areas, exhibiting a higher incidence of diseases such as neurological disorders and bone demineralization (Yang *et al.* 2024). A recent study reported that residents living in coal-mining regions of China are ingesting cadmium at levels 4.5 times higher than the recommended limit for human health, with 85% of this intake occurring through food consumption collection of coal-mined areas contaminated by trace elements (Lu *et al.* 2021).

Older individuals and those with longer residence in mining areas tend to be more affected by the impacts of mining activities and trace element contamination (Guo *et al.* 2023). In South Africa, these seniors living in mining regions have exhibited high levels of chronic respiratory symptoms and diseases (Nkosi *et al.* 2015). In coal mining areas in China, this age group has shown greater predisposition to chronic inflammation, respiratory problems, and digestive system cancers (Guo *et al.* 2023). In the present study, elderly participants reported more frequent use and consumption of *A. satureioides*, indicating the need for further studies on the potential health impacts on this age group in these areas.

The consumption of medicinal plants, such as *A. satureioides*, is an ancient practice widespread across all continents where these species occur. In many cases, such treatment may serve as the primary alternative therapy for economically vulnerable populations worldwide. However, in mining areas with high levels of trace element contamination, consuming these species may represent a gateway to other diseases. Therefore, studying plants collected and used in mining areas is highly relevant for assessing impacts on local public health, particularly for species that are widely consumed and hold significant social and cultural value, as is the case with *Achyrocline satureioides*.

Public Health Implications and Recommendations

The results found in this study, and in others conducted in the region (Galvan *et al.* 2019, Blanco *et al.* 2023), raise an alert about the importance of further investigating the impacts of mining on public health. The first aspect concerns the mining processes in the region: since 2000, a public civil action (Ação Civil Pública (ACP) nº 93.8000533-4) has been carried out in the region, seeking the remediation of contaminated areas. However, little progress has been made in analyzing the impacts of trace elements (both in the extent of contaminated areas and in the processes of biomagnification and bioaccumulation). In this sense, we highlight the urgency of conducting analyses of trace element concentrations in mined and non-mined areas. This should be followed by a study indicating the natural and safe concentrations of these elements for the region. Many of the trace elements studied in this work do not have comparison parameters to determine whether the values found are above or below a safe level for the region (e.g., aluminum, chromium, and manganese).

Based on this data, it is important to understand whether the food and medicinal resources most frequently consumed by local populations are bioaccumulating trace elements and whether these levels represent a real risk to public health. International studies have pointed to a growing concern in this regard and have shown a direct relationship between the consumption of bioaccumulative species and their harmful effects on human populations; however, in Brazil and Latin America as a whole, these studies are still scarce.

In addition to this situation, it is extremely urgent that we begin the process of a just energy transition in southern Brazil, as is happening throughout the world. The extraction of coal as an energy source is a practice that no longer corresponds to the current climatic reality, especially in a country like Brazil that has several alternative energy sources.

Conclusion

The collection and consumption of *Achyrocline satureioides* from areas mined for coal extraction and contaminated by trace elements raises an alert about the importance of further investigations into their possible impacts on human health. Likewise, the concentration of trace elements in areas that have not been mined shows that this contamination may be reaching increasingly distant areas, and its impacts may be diverse. The study of bioaccumulation and biomagnification in mined and contaminated areas is an important step towards the recovery of these areas and the analysis of possible risks to human health in mined areas.

Declarations

Ethics approval and consent to participate: The development of the study followed the ethical and legal guidelines for the development of research on traditional knowledge. The project was approved by the Ethics Committee for Research with Human Beings of the Federal University of Santa Catarina (CEPSH) under the number: 80660217.1.0000.0121 de 21/06/2018. The participation of interviewees was subject to the acceptance of the Free and Informed Consent Form. The project was registered with SISGEN under the number AB9A76B

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Supplementary material

Supplementary material 1. Mean contents (mg.kg-1) and standard deviation of Al, Ba, Cd, Cr, Cu, Pb, Mn, and Zn in soil from mined and non-mined areas of Santa Catarina. P and T values from comparisons between trace element concentrations in mined and non-mined areas are presented, as well as the total permitted trace element concentrations for the state of Santa Catarina. SD: Standard deviation; VRQ SC: Quality reference values for Santa Catarina.

Soil Trace Elements	**Non-Mined Soil (mg.kg^{-1})**	**SD**	**Mined Soil (mg.kg^{-1})**	**SD**	**VRQ SC (mg.kg^{-1})**
Al	14594.98	5132.04	16453.97	2235.53	†
Ba	68.80	36.78	88.85	68.09	35,42
Cd	0.29	0.08	0.23	0.02	0.12
Cr	10.46	2.98	8.18	3.48	43,2
Cu	41.63	12.11	22.13	9.91	93,44
Mn	87.92	69.49	308.22	224.96	†
Ni	18.05	5.50	13.86	4.23	24.87
Pb	11.86	5.51	15.80	9.69	8.51
Zn	33.88	8.12	27.41	14.79	60.88

Note: †No reference value.

Supplementary material 2. Result of the ANOVA statistical analysis on the difference in frequency of use by gender of interviewee who mentioned using *Achyrocline satureioides* D.C. in coal-mined areas in southern Brazil.

Trace element and area	**Pr(>F)**	**F value**
Low consumption by women *versus* low consumption by men	0.0195	1.564
Medium consumption by women *versus* average consumption by men	0.0104	2.568
Frequent consumption by women *versus* frequent consumption by men	0.507	0.352

Supplementary material 3. Result of the ANOVA statistical analysis on the difference in frequency of use by age of the interviewee who reported using *Achyrocline satureioides* D.C. in coal-mined areas in southern Brazil.

Parameters analyzed	**Pr(>F)**	**F value**
Age *versus* high frequency of consumption	0.00392	8.525
Age *versus* average frequency of consumption	0.06	9.256
Age *versus* low frequency of consumption	0.07	12.567