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Essays and Perspectives

Large-scale patterns of useful native plants based on a systematic review of ethnobotanical studies in Argentina

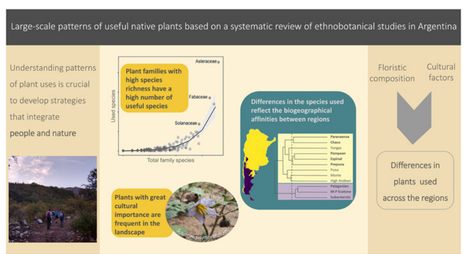
María Virginia Palchetti[a,*], Fernando Zamudio[b], Sebastián Zeballos[a], Agustín Davies[c], Gloria E. Barboza[b], Melisa A. Giorgis[a,c]

[a] Instituto Multidisciplinario de Biología Vegetal (CONICET-UNC), Vélez Sarsfield 1611, CC 495, 5000, Córdoba, Argentina
[b] Instituto Multidisciplinario de Biología Vegetal (CONICET-UNC), Vélez Sarsfield 299, CC 495, 5000, Córdoba, Argentina
[c] Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, Vélez Sarsfield 299, CC 495, 5000, Córdoba, Argentina

HIGHLIGHTS

- A country-level database of useful native plants is provided.
- Plant families with high species richness have a high number of useful species.
- Plant species with great cultural importance are frequent in the landscape.
- 70% of useful native plant species are used exclusively in one region.
- Differences in the plants used reflect the biogeographical affinities between regions.

GRAPHICAL ABSTRACT



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ABSTRACT

Plants are essential for our lives because they provide food, medicine, fuel, shelter, and immaterial resources. Understanding patterns of plant uses through large-scale plant use analysis may contribute to the development of a biocultural conservation approach. We conducted a systematic review to assess current knowledge of the ethnoflora of Argentina, as well as to identify taxonomic and geographic patterns of ethnobotanical uses of native plants at the large scale. We analyzed 124 articles reporting the use of 1706 species. We found that the most widely studied region and use category were Chaco and medicine, respectively. The number of useful native species within a family was positively related to the total native species in each family at the country level. In general, species of greatest cultural importance at the country level had a wide distribution. Almost 70% of native plants used in one phytogeographic province were exclusive to it, and species with the highest importance were characteristic elements of its vegetation. We found that southern Argentina has an exclusive ethnoflora that differs from that in a large area of central and northern Argentina. Our review highlights that plants used by people are intimately associated with the local environment, and that species with great cultural importance across phytogeographic provinces are frequent in the landscape. We provide the first analysis of ethnobotanical studies and a database of useful native plants across Argentina. This information highlights strengths and gaps in knowledge of useful native species, which is crucial for conservation, sustainability and human well-being.

* Corresponding author.
E-mail address: vpalchetti@imbiv.unc.edu.ar (M.V. Palchetti).

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Introduction

Plants are the basis for terrestrial ecosystems and support diversity of life on Earth. They are crucial for human survival and well-being, providing food, medicines, fuel, clothing, shelter, among other consumptive uses, and are an important element of many cultures (Knapp, 2019; Schaal, 2019). In this context, ethnobotany, the study of relationships between people, plants and their environment, has received growing attention from researchers, institutions, and governments in the last decades (Benítez et al., 2016), due to its relevance to global issues such as food security, climate change, biodiversity conservation and human health (Quave and Pieroni, 2015).

In the last decades, the focus of conservation and ecosystem management has shifted from species and protected areas to the shared human-nature environment in an attempt to allow the development of sustainable and resilient relationships between societies and the natural environment (Mace, 2014). At the same time, ethnobiology has moved towards a more interdisciplinary framework to address human-environmental issues (Wolverton, 2013). Large-scale systematic reviews of plant uses allow us to understand their patterns (Medeiros et al., 2013; Díaz-Forestier et al., 2019). This knowledge is essential for biocultural conservation and the development of management strategies that integrate people and nature. However, the ethnobotanical uses have been scarcely studied at the large scale (e.g., de la Torre et al., 2012; Díaz-Forestier et al., 2019).

Plant use patterns have been analyzed in many ethnobotanical studies. Thus, rich taxonomic groups and regions have been positively linked to the number of plants used. Accordingly, plant families with great species richness (e.g., Asteraceae) are likely to have a high number of useful plants (Díaz-Forestier et al., 2019; Zhuang et al., 2021); the same pattern was found in areas with a great number of species (e.g., de la Torre et al., 2012). However, certain plant taxa tend to be over or underrepresented, depending on different environmental and cultural factors (Leonti et al., 2020). For instance, some studies have found that the most accessible or locally abundant plant species are the most useful to local people (Albuquerque, 2006; Arias Toledo et al., 2009; Gaoue et al., 2017; Kujawska et al., 2018). The use of plants may also be associated with species identity. In this line, species within a family may contain similar bioactive molecules useful for a specific use category (Leso et al., 2017), as occurs in the Solanaceae family, which has high alkaloid content and many medicinal species (Díaz-Forestier et al., 2019). Plant use patterns are commonly evaluated at a rather small scale and the analyses include only one or few categories of uses; therefore, broader analyses are still necessary.

Argentina is one of the four countries in Latin America with the highest number of scientific publications in ethnobiology; in addition, several consolidated research groups are specialized in ethnobiology (Albuquerque et al., 2013), and different ethnic groups and regions have been studied (Alvarez, 2019). Argentina is a large country, covering 3694 km from north to south (IGN, 2022). The country supports a diverse flora, with high species richness (more than 10,000 species; Zuloaga et al., 2019). Climate varies strongly along the country geographic gradients, with the consequent important changes in floristic composition and physiognomy (Ribichich, 2002). Thus, the northern extreme is characterized by species-rich subtropical forests or savannas, whereas the southern extreme holds temperate Patagonian steppes and forests. Additionally, from east to west, Argentina holds contrasting environments: the Pampas, one of the richest grasslands in the world, and a cold mountain desert in the Andes (Oyarzabal et al., 2018). An increasing number and multiplicity of ethnobotanical studies have addressed a significant part of the biological and cultural diversity in Argentina, including a checklist of the native medicinal species (Barboza et al., 2009); however, no quantitative review of the ethnoflora that considers most categories of uses at the country level has been conducted.

We performed a systematic review of ethnobotanical uses reported for Argentina with the aim to characterize the current knowledge of the native ethnoflora, as well as to identify taxonomic and geographic patterns of ethnobotanical uses of plants at the large scale. To that purpose, we (1) recorded the number of published articles, the study sites, use categories and taxa reported; (2) evaluated the relationship between the number of useful plant species per family and the family species richness at the country level; (3) calculated the cultural importance indices of each species at the country and regional levels; and (4) explored the relationship among phytogeographic provinces in terms of their useful species. We predict that (1) families with the highest species richness are likely to have a high number of useful species; (2) species with great cultural importance will have a wide distribution; and (3) regions with biogeographic affinities will share a great number of species with ethnobotanical uses. This large-scale analysis may be an important tool to safeguard different ecosystems because it allows us to measure the multiple nature's contributions to people (Díaz et al., 2018).

Methods

Information sources and literature search

We conducted an extensive literature search in three online databases, Google Scholar, Scopus and Scielo, for peer-reviewed publications of ethnobotanical studies in Argentina published between 1964 (see below) and July 2021. We used the following search string: ((ethnob*) OR (etnob*) OR (ethnoecol*) OR (etnoecol*) OR (ethnophar*) OR (etnof*) OR (ethnof) OR (ethnomed*) OR (etnomed*) OR (ethnovet*) OR (etnovet*)) AND (Argentina). This combination of keywords allowed us to cover publications of ethnobotanical research on the ethnoflora of Argentina. Additionally, we performed a manual search in the reference list of two reviews, Barboza et al. (2009) and Alvarez (2019). Since R. Martínez Crovetto was the first Argentine researcher that introduced the term ethnobotany in his articles (Alvarez, 2019), we took as starting point the year 1964, when he published "Estudios Etnobotánicos I". Therefore, we excluded ethnoarchaeological and ethnohistorical works, except for research on R. Martínez Crovetto data.

Study selection

We summarized the study selection following the PRISMA guidelines (O'Dea et al., 2021). The specific criteria used for including or excluding studies are detailed in PRISMA diagram (Supplementary Material—Diagram S1).

The search produced 9075 records. We screened their titles and abstracts, and retained 314 publications. Then we assessed the full texts of 314 potentially relevant studies and excluded 96 studies.

We retained 218 relevant studies, of which only 124 were included in the analysis (list of references in Supplementary Material—Table S1). The remaining articles were excluded because of their high risk of bias due to underrepresentation of the studied taxonomic groups, habitat, distribution or therapeutic indications.

Data extraction and compilation

We extracted the following data from the 124 articles: publication date, study site, scientific and vernacular species names, and uses reported for each native species. Non-native plants were excluded from this review, since many ethnobotanical studies did not clearly indicate the inclusion or not of non-native species.

The extracted information on plant uses was compiled in a database and grouped into use categories based on the Level 1 states of plant uses from the Economic Botany Data Collection Standard (Cook, 1995 ; see Table 1). Additionally, we classified the articles into one or more use categories according to the reported uses for their study species.

We used the online database Flora Argentina (http://www.floraargentina.edu.ar/) to assign the currently accepted scientific name and native status of the species. We georeferenced each locality reported in the studies and assigned it to a phytogeographic province according to Oyarzabal et al. (2018), who described 11 phytogeographic provinces and one ecotone between Monte and Patagonian provinces. Here, the Monte-Patagonian (M-P) Ecotone was analyzed as another phytogeographic province. For the analysis of phytogeographic provinces, we excluded articles in which the use of plants was reported for more than one province, without distinction between them.

Data analysis

To evaluate the relationship between the number of useful plant species per family and the family species richness at the country level (taken from Zuloaga et al., 2019), we used generalized linear models with a negative binomial distribution and a log link function. We assessed the validity of the model assumptions using graphical residual analysis (Inchausti, 2023; Supplementary Material—Fig. S1). Analyses were performed using MASS (https://CRAN.R-project.org/package=MASS) and DHARMa (https://CRAN.R-project.org/package=DHARMa) R-packages.

To estimate the cultural importance of each species at the country and regional levels, we calculated the relative importance (RI) index using the following formula proposed by Tardío and Pardo-de-Santayana (2008):

$$RI_S = RFC_{s(max)} + RNU_{s(max)}/2 \quad (1)$$

where $RFC_{s(max)}$ is the relative frequency of citation for the species "*s*" over the maximum value for all the species of the survey. In our assessment, RFC represents the number of articles that mention the use of each species by the total number of analyzed articles in each phytogeographic province, and $RNU_{s(max)}$ is the relative number of use categories for the species "*s*" over the maximum value of all the species of the survey (i.e., in each phytogeographic province). The RI index ranges from 0, when no one mentions any use of a given plant species, to 1 when the species is the most frequently mentioned as useful and in the maximum number of use categories.

The RI index was calculated for each phytogeographic province. At the country level, RI was weighted by phytogeographic province, due to the differences in the number of studies conducted in each one.

$$RIs = \frac{\sum_{p=p1}^{pN} RIsp(max)}{N} \quad (2)$$

where $RI_{sp(max)}$ is the RI index for the species "s" over the maximum value in all the species of each phytogeographic province "p", and N is the total number of phytogeographic provinces.

To analyze the relationship among phytogeographic provinces in terms of useful species, we conducted a cluster analysis using the unweighted pair group method using arithmetic averages (UPGMA) and the Bray-Curtis distance applied to the presence-absence data (matrix of 1592 useful species × 12 phytogeographic provinces). We used the average silhouette width to select the optimal number of clusters. It measures the degree of membership of an object to its cluster compared to its closest neighboring cluster. Silhouette widths range from −1 to 1, higher values indicate optimal number of clusters, negative values suggest that the objects were misclassified and placed in the wrong cluster (Borcard et al., 2018).

For this analysis we used vegan (https://CRAN.R-project.org/package=vegan) and cluster (https://CRAN.R-project.org/package=cluster) R-packages.

All analyses were performed in R version 4.1.3 (R Core Team, 2022).

Results

Current knowledge of the ethnoflora of Argentina

The ethnobotanical articles published about Argentina increased between 1964 and 2021. Medicines was the most widely reported use category (60% of total articles), followed by food (34%), materials and social uses (32%), food additives (27%) and fuels (22%) (Fig. 1a). The study sites of the articles included in our review were conducted throughout all phytogeographic provinces. Most of them were located in the northeastern, southwestern and central regions of Argentina, mostly in the Chaco phytogeographic province, followed by Paranaense and Patagonian, whereas the large provinces, High Andean, Espinal, and Puna, were poorly studied (Fig. 1b).

The studies included a total of 1706 native vascular plant species, of which 24 are endemic to Argentina, distributed among 774 genera and 156 families with ethnobotanical uses (database of useful native species in Supplementary Material—Table S2).

Large-scale taxonomic and geographic patterns

The number of useful native species within a family was positively related to the total number of native species in each family (the model explained 85% of the total deviance with $p < 2.2e\text{-}16$; Fig. 2). Therefore, families with a large number of species are likely to have a large number of useful species. However, some relatively large families, such as Cyperaceae and Brassicaceae, showed values below the predicted number of useful species, whereas Myrtaceae, Solanaceae, Fabaceae and Asteraceae showed the opposite pattern. We found the same positive relationship when we evaluated the four most important use categories individually (Supplementary Material—Fig. S2). The families with higher numbers of useful species than predicted are different across categories: for medicines, Asteraceae, Fabaceae, and Solanaceae; for food, Myrtaceae, Cactaceae, and Fabaceae; for animal food, Poaceae and Fabaceae; and finally, for materials, Fabaceae and Bignoniaceae (Supplementary Material—Fig. S2).

At the country level, the species with the greatest weighted RI was *Dysphania ambrosioides*, which was reported in almost all phytogeographic provinces (except in Puna) for food, animal food, non-vertebrate poisons and medicines. The species ranking second in weighted RI was *Schinus* group (*Schinus areira* and *Schinus molle*), which was reported in almost all domains (except in Subantarctic), for food, food additives, materials, fuels, social uses, medicines and environmental uses. These species were followed by *Aloysia citrodora*, *Solanum sisymbriifolium*, *Aloysia polystachya*, *Ilex paraguariensis*, *Geoffroea decorticans*, *Fabiana imbricata*, *Xanthium spinosum*, and *Equisetum giganteum*, which were used in at least half of the phytogeographic provinces (Fig. 3). Several uses were reported for all these species, with the medicinal one being cited in all cases. *Geoffroea decorticans* stands out for its multiple use categories, i.e., food, animal food, materials, fuel, social uses, medicines and environmental uses. Notably, seven out of

Table 1
Number of native species included in each use category. Use categories and description based on the Level 1 states of plant uses of the Economic Botany Data Collection Standard (Cook, 1995).

Use Category	Description (Cook, 1995)	N° of native species
Medicines	Both human and veterinary	1182
Animal Food	Forage and fodder for vertebrate animals only	470
Materials	Woods, fibres, cork, cane, tannins, latex, resins, gums, waxes, oils, lipids etc. and their derived products	379
Food	Food, including beverages, for humans only	328
Social uses	Plants used for social purposes, which are not definable as food or medicines, for instance masticatories, smoking materials, narcotics, hallucinogens and psychoactive drugs, contraceptives and abortifacients and plants with ritual or religious significance	271
Fuels	Wood, charcoal, petroleum substitutes, fuel alcohols etc.	221
Environmental uses	Examples include intercrops and nurse crops, ornamentals, barrier hedges, shade plants, windbreaks, soil improvers, plants for revegetation and erosion control, waste water purifiers, indicators of the presence of metals, pollution, or underground water	171
Vertebrate Poisons	Plants which are poisonous to vertebrates, both accidentally and usefully, e.g., for hunting and fishing	81
Food Additives	Processing agents and other additive ingredients which are used in food preparation	64
Non-Vertebrate Poisons	Both accidental and useful poisons (e.g., molluscicides, herbicides, insecticides) to non-vertebrate animals, plants, bacteria and fungi	20
Invertebrate Food	Only plants eaten by invertebrates useful to humans, such as silkworms, lac insects and edible grubs	5
Bee Plants	Pollen or nectar sources for honey production	3
Gene Sources	Wild relatives of major crops which may possess traits or qualities, such as disease resistance, cold hardiness etc., of value in breeding programmes	0

the 24 endemic species, *Schinus johnstonii*, *Atriplex lampa*, *Condalia microphylla*, *Minthostachys verticillata*, *Acantholippia seriphioides*, *Neltuma denudans*, and *Diposis patagonica*, showed high weighted RI values (values for each species are indicated in Supplementary Material—Table S3).

Regarding specific uses, medicines represented 69% of the species used in Argentina, followed by species used for animal food (28%), materials (22%), and food (19%) (Table 1). The families Asteraceae, Fabaceae, and Solanaceae stand out for their medicinal use, comprising 28% of the total national medicinal species. Regarding animal food, Poaceae, Asteraceae, and Fabaceae involve 40% of animal food species. Similarly, these three families represent 33% of materials species at the country level. For food, Cactaceae, Myrtaceae, and Fabaceae appeared as the important families in Argentina, representing 27% of the national food species (number of species for each use category and family are indicated in Supplementary Material—Table S4). The highest weighted RFC values for medicinal uses in Argentina were those of *Dysphania ambrosioides*, *Aloysia citrodora,* and *Equisetum giganteum* (values for each medicinal species are indicated in Supplementary Material—Table S5), while the highest values for food uses corresponded to *Berberis microphylla*, *Arjona tuberosa*, and *Ephedra ochreata* (values for each food species are indicated in Supplementary Material—Table S6).

Considering the phytogeographic provinces, the highest number of useful species was reported for Chaco (724), followed by Paranaense (621), Yungas (205), Patagonian (168), Monte (149), Espinal (132), Pampean (124), Subantarctic (106), High Andean (97), Prepuna (83), M-P Ecotone (71), and Puna (41) provinces. Most species (68%) are used exclusively in one phytogeographic province; in this sense, Puna and Paranaense provinces had the highest proportion of exclusive species, whereas M-P Ecotone and Espinal provinces had the lowest values. Similarly, the species with the highest RI varied across phytogeographic provinces and are, in general, characteristic of each province (Supplementary Material—Fig. S3, values for each species and phytogeographic province are indicated in Supplementary Material—Table S7).

UPGMA cluster analysis based on plants used across phytogeographic provinces is presented in Fig. 4. Silhouette widths analysis showed similar values for three to seven clusters (from 0.14 to 0.16), being higher at three (Supplementary Material—Fig. S4a). We considered three main clusters and the rest as sub-clusters. The silhouette plot of the final seven-group partition validated these groups, with no negative values for any provinces (Supplementary Material—Fig. S4b). Puna phytogeographic province was split first from the other main groups. Cluster 2 was divided into three sub-clusters, separating Yungas from the group composed of Paranaense and Chaco, and the group including Pampean, Espinal and Prepuna provinces. Cluster 3 was divided into three sub-clusters, splitting the three southern provinces (Subantarctic, Patagonian, and M-P Ecotone) from High Andean and Monte.

Discussion

This is the first systematic review assessing ethnobotanical uses of native plants across Argentina. Our findings show that most of the studies are geographically concentrated in a few areas and are mainly concentrated on medicinal uses. Additionally, we found that the richest plant families concentrate most of the useful plant species; however, families with specific characteristics (e.g., chemical substances or fleshy fruits) and abundant in the Neotropics are overrepresented (e.g., Solanaceae, Cactaceae). The great biogeographic variability of Argentina was associated with changes in the cultural importance of native plant species; however, the most important useful plants were always locally abundant. These results are in line with the availability hypothesis in ethnobotany, which states that most accessible or locally abundant plant species are most useful to local people (Albuquerque, 2006; Gaoue et al., 2017; Kujawska et al., 2018). We present the first database of useful native plants, covering all types of uses and phytogeographic provinces of Argentina, which may serve as baseline information for future research and conservation strategies.

Our review revealed that Argentine people use a high number of native plant species, but in a lower proportion than in other Latin American countries. The number of species with ethnobotanical uses represents 18% of the total native flora of Argentina. This percentage is slightly lower than values reported in Chile and Mexico (23%, Díaz-Forestier et al., 2019), and Ecuador (30%, de la Torre et al., 2008). These differences may be associated with the strict criteria followed in this review, as well as with a more diverse ethnicity in Chile, Ecuador and Mexico (The World Factbook, 2021) and a more diverse flora in Ecuador and Mexico (Ulloa Ulloa et al., 2017). The percentage of medicinal species (~13%) was similar to the value reported in the checklist of native medicinal species from Argentina (i.e., 14% in Barboza et al., 2009), suggesting that our database is reliable and robust. Another possible source of bias is the non-homogeneous geographic distribution of studies. In fact, the highly diverse phytogeographic province of Yungas was little studied. Besides, the number of useful species will likely increase

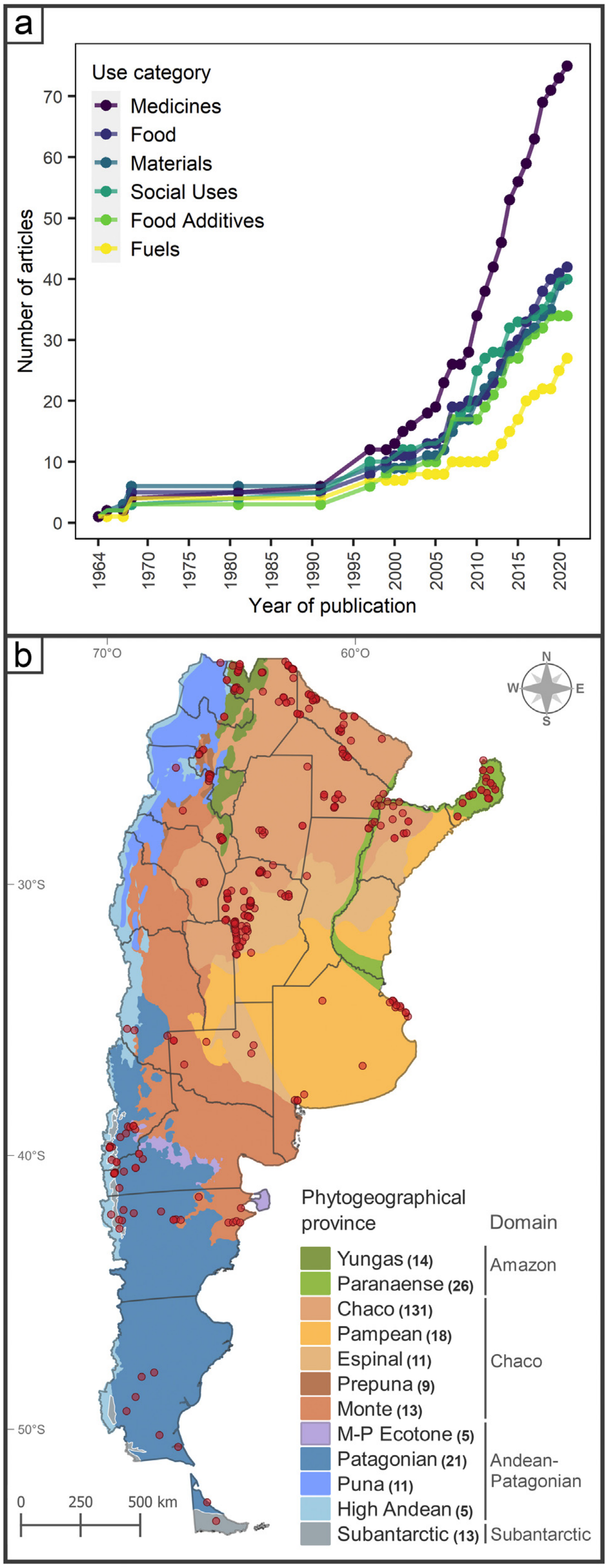

Fig. 1. (a) Cumulative number of articles over time for the six most reported use categories (b) Distribution of the study sites (red circles) analyzed in the articles across the different phytogeographic provinces. The number of study sites in each province is shown in brackets. Different colors indicate the phytogeographic provinces based on Oyarzabal et al. (2018).

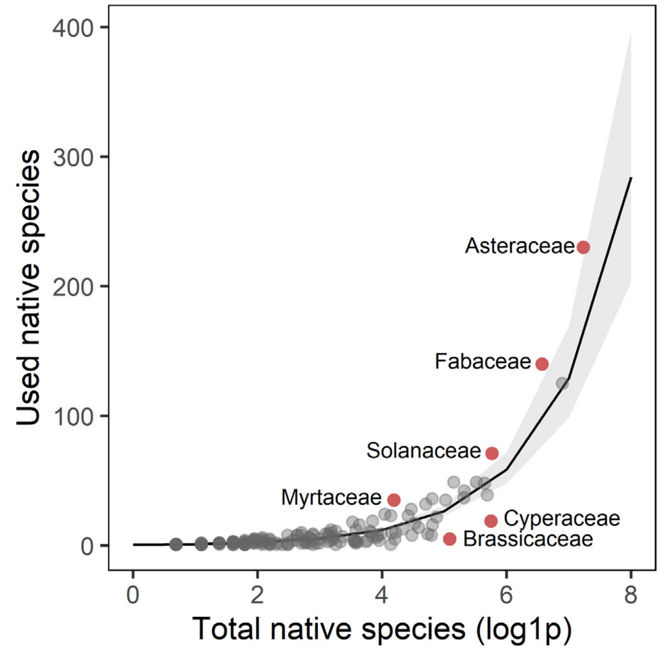

Fig. 2. Relationship between the number of useful species within a family and the total number of native species (log1p) of each family in Argentina (n = 156). The solid line represents the fitted negative binomial model and grey shaded areas represent the 95% confidence intervals.

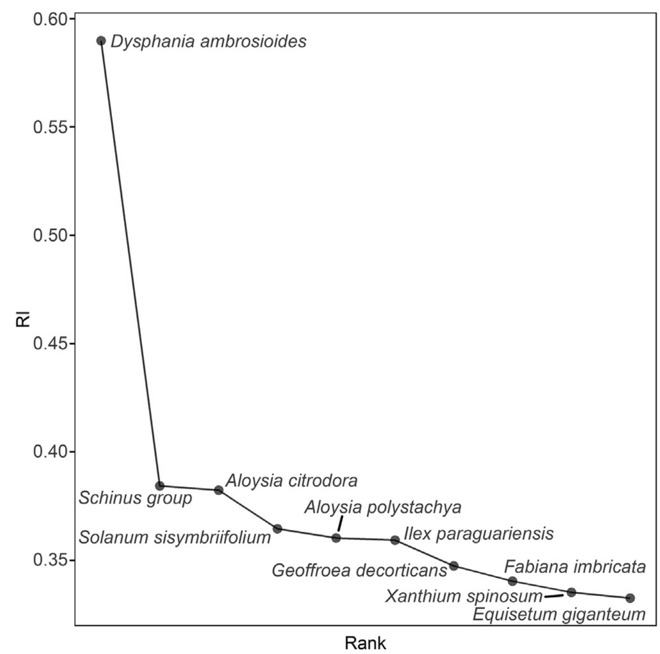

Fig. 3. Rank-RI curves of the 10 species with the highest weighted relative importance (RI) values in Argentina. Due to the complex taxonomic history of some species of the genus *Schinus*, we decided to group the species *Schinus areira* and *Schinus molle* into the "*Schinus* group".

when more indigenous groups are included, especially Andean indigenous people, the second most populous indigenous group in Argentina (INDEC, 2010). In addition, the increasing substitution of useful native species for non-native equivalents (Medeiros, 2013) might reduce the number of native species used in Argentina. Additionally, the use of non-native plants may become important for both indigenous and non-indigenous groups. This pattern is more noticeable among non-indigenous; for example, among the Polish migrants and their descendants in Misiones (Kujawska et al., 2017).

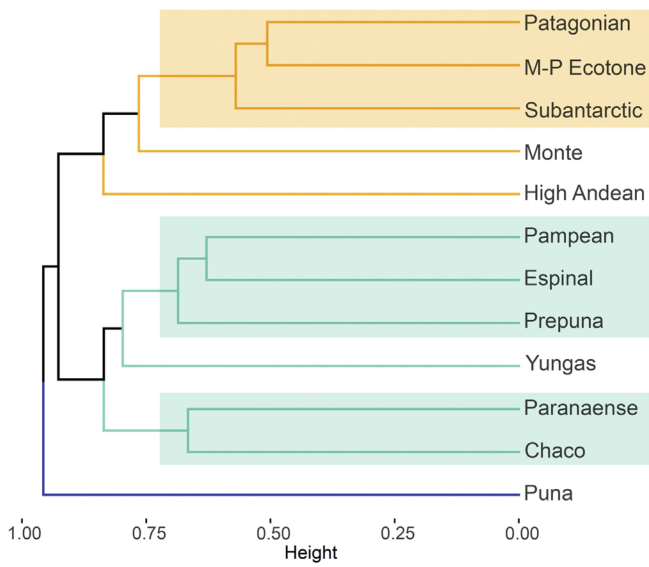

Fig. 4. UPGMA cluster dendrogram of phytogeographic provinces of Argentina according to the useful species. Different colors represent three main clusters. Rectangles represent sub-clusters (see methods for more details).

However, since many ethnobotanical studies did not clearly report the inclusion or not of non-native species, we were not able to test reliable patterns of useful non-native species.

Our results of taxonomic patterns of ethnobotanical uses of native plants confirm the prediction that families with the highest species richness are likely to have a high number of useful species. Therefore, the fourth largest vascular plant families in Argentina have the highest number of useful species, i.e., Asteraceae (17% of its total species, sensu Zuloaga et al. (2019)), Poaceae (13%), Fabaceae (20%), and Solanaceae (22%). However, we found that some families are used in a higher (e.g., Myrtaceae, Solanaceae, Fabaceae, and Asteraceae) or lower proportion (e.g., Cyperaceae and Brassicaceae) than the predicted value, suggesting that other factors are also conditioning the number of used species in each family. Previous studies have found that useful plant species are not always randomly distributed among botanical families (Medeiros and Albuquerque, 2015; León-Lobos et al., 2022). It has also been suggested that the drivers of plant uses are multiple and could be related not only to abundance, but also to accessibility, taste, prior knowledge or experience (Ray et al., 2020), or even to the similarity of attributes between species (Pedrosa et al., 2021). Certainly, the database provided in this review can help to select key useful native species throughout the region to test those drivers.

The overrepresentation of certain families can be related to the content of biologically active compounds that are effective as medicines (Gaoue et al., 2017), such as alkaloids in Solanaceae (Eich, 2008) or triterpenes and flavonoids in Asteraceae (Sülsen et al., 2017). On the other hand, some families are underrepresented. This is the case of Poaceae species, which have low content of biologically active compounds because they often do not depend on chemical defenses (Gaoue et al., 2017). However, this low toxicity and the herbaceous habit make grasses appropriate forage (Díaz-Forestier et al., 2019). Another example is Myrtaceae, which is overrepresented in the food use category due to the high proportion of species with edible fleshy fruits (Díaz-Forestier et al., 2019).

Overrepresented plant families in Argentina vary among use categories, but Fabaceae stands out as a consistently overused family both for general uses and for medicinal, food, fodder, and firewood uses. Within this family and in agreement with Velazco et al. (2022), *Prosopis* (recently, the American species were segregated into the genera *Neltuma* and *Strombocarpa*; Hughes et al., 2022) had the largest number of species with uses. The use of *Prosopis* in Argentina dates back to thousands of years (Capparelli et al., 2015) and their edible pods have been associated with the origins and identity of native communities, which use them to prepare different foods and a fermented alcoholic beverage (Sciammaro et al., 2016). In addition, the dominance of *Prosopis* species in several vegetation units in arid and semiarid regions of Argentina (Oyarzabal et al., 2018) may explain the essential role they play in rural economies. Due to the significant ecological and cultural importance of these species, policies based on local and scientific ecological knowledge are necessary to guarantee the conservation and restoration of this key genus.

Another pattern of use of native plants could be related to the distribution of species in Argentina. Thus, the most important native species in Argentina, i.e., that with the highest weighted RI value, was *Dysphania ambrosioides*, commonly named "*Paico*". This aromatic herb is native to Mexico, and Central and South America, but is considered a cosmopolitan invasive species (CABI, 2022). It occurs almost all throughout Argentina and grows in highly modified environments (e.g., on roadsides, urban areas, farmlands) and along rivers and lakes (Flora Argentina, 2018). Thus, in line with the above mentioned pattern, the species with greatest cultural importance in Argentina has a wide distribution and a range of potential environments. The other species with the highest importance in Argentina, i.e., *Geoffroea decorticans*, *Solanum sisymbriifolium*, *Xanthium spinosum*, *Schinus* group, and *Aloysia polystachya*, are also widespread plants and are even considered invasive species in other countries (CABI, 2022). In contrast, *Ilex paraguariensis*, known as "*Yerba mate*", is the sixth species with highest weighted RI but has a restricted natural distribution in the subtropical *Araucaria* forest in northeastern Argentina and southern Brazil. In this particular case, almost all the "*Yerba mate*" consumed is commercially cultivated and purchased for preparing the traditional infusion "*mate*", which has a social and almost ritualistic role in several South American societies (Bracesco et al., 2011).

Considering the species used in different regions of Argentina, Chaco and Paranaense were the phytogeographic provinces with the highest number of records of useful species. The number of study sites in Chaco was much higher than in the remaining phytogeographic provinces, which could explain the great number of useful species in that province. On the other hand, the local diversity of plants in Paranaense province could be an important driver of the number of plant species used, since the Atlantic Forest (belonging to Paranaense province) is one of the regions with the greatest total vascular plant species richness in Argentina (Zuloaga and Belgrano, 2015). Socio-cultural aspects could also be responsible for the diversity of species used. Most of Paranaense province is located in Misiones, where the multi-ethnic character or ethnic mosaic (Bartolomé, 1975) likely promotes the use of a wide variety of species. However, the use patterns reported here should be used to generate questions and hypotheses about the socio-ecological mechanisms that gave rise to them, rather than explanations.

The cluster analysis based on useful species separated Puna from the other phytogeographic provinces. This may be because of the highest proportion of exclusive useful species, and also because only two articles were considered. On the other hand, some clusters reflect biogeographic affinities (Oyarzabal et al., 2018; Arana et al., 2021). Thus, the southern Subantarctic, Patagonian and the M-P Ecotone, which extend from nearly 35 °S to 55 °S, are characterized by cold weather typical of the Andean-Patagonian and Subantarctic domains. Taking into account the biogeographic affinities, we would expect a strong relationship between Yungas and Paranaense provinces; however, Paranaense was closely related to Chaco. This weak consistency between phytogeographic affinities and useful species may be due to cultural factors underlying the relationships between phytogeographic provinces; for example, the geographic proximity and the absence of topographic barriers between Chaco and Paranaense may facilitate knowledge exchange about plant uses (Diamond, 2002). Moreover, across the Chaco domain, we would expect the phytogeographic provinces to be related from east to west, since they change along this geographic gradient associated with changes in annual precipitation (Cabido et al., 1993). However, the heterogeneous distribution of ethnobotanical studies in Argentina and the high exclusivity of useful species in each region did not allow us to fully understand the relationship between phytogeographic provinces based on useful plants.

The species with the highest regional ethnobotanical importance were in general dominant or frequent elements of the vegetation of each phytogeographic province, for example *Geoffroea decorticans* and *Sarcomphalus mistol* in Chaco, *Larrea nitida* in M-P Ecotone, *Vachellia caven* and *Geoffroea decorticans* in Espinal province, *Condalia microphylla* and *Neltuma flexuosa* in Monte province, *Celtis* spp. in Pampean province, *Aristotelia chilensis* in Subantarctic province, and *Juglans australis* and *Eugenia uniflora* in Yungas province (Oyarzabal et al., 2018). This association could be also related to the availability hypothesis in ethnobotany (Albuquerque, 2006; Arias Toledo et al., 2009; Gaoue et al., 2017; Kujawska et al., 2018). However, cultural factors also undoubtedly influence the complex selection process of useful plants. Thus, some species do not grow spontaneously in certain regions but have high RI, such as *Aloysia citrodora*, which is used as medicinal plant in Espinal and Pampean provinces, and *Ilex paraguariensis*, which is used as food, medicine and pigment in Yungas.

To sum up, the unique relationships between people and plant species vary between cultures and regions in Argentina. Based on our results, we conclude that differences in the plant species used may be associated with differences in the floristic composition and cultural factors across the regions. This ecological and cultural heterogeneity supports the need for biocultural approaches to conservation spanning different regions to address the loss of biological and cultural diversity (Gavin et al., 2015).

Future perspectives

1 The first database of useful native plants across Argentina, based on a systematic review of ethnobotanical studies, represents a starting point to identify different gaps. Although the studies are concentrated on some regions, all the phytogeographic provinces were represented. However, some regions of Argentina where numerous indigenous people live remain poorly studied, highlighting the need to target a broader range of regions and people communities (e.g., the northwestern region).
2 Medicinal and food categories were the most widely reported uses. At the moment these are the only suitable categories to study different patterns of plant use across Argentina, such as the role of protected areas for useful species or the uses of threatened species. The other use categories were underrepresented in studies in all the territory; therefore, it is necessary to increase the number of studies focused on varied uses.
3 Since the spread of invasive species may threaten the diversity of native ethnospecies of each region (e.g., Martínez and Manzano-García, 2019), studies dealing with uses of non-native or invasive species should be a priority in the coming years. In some ethnobotanical studies, the native/non-native status, ecological environment, and way of obtaining the useful species are not clearly defined aspects; therefore, we strongly suggest incorporating this important information in future assessments of the representativeness of non-native species in the ethnoflora of Argentina.
4 Several phytogeographic provinces with high numbers of useful species are threatened by land use change, especially in the Chaco region (de la Sancha et al., 2021), where it is crucial to prioritize conservation actions.
5 Given the huge diversity of plant uses, vegetation, and cultures in the different regions of Argentina, conservation actions should be designed for each region, and should consider not only the conservation and sustainable use of biodiversity and ecosystems but also long-term human well-being (Díaz et al., 2015; Hill et al., 2020). Therefore, local ecological knowledge should not be neglected in conservation and restoration policies (Albuquerque et al., 2019).

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Author contributions

MVP, FZ, SZ and MAG contributed to the study conception and design. Material preparation and data collection were performed by MVP, FZ, SZ, AD and MAG. Data analysis was performed by MVP. The first draft of the manuscript was written by MVP and MAG. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.pecon.2023.04.001.

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