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Exotic and native medicinal plants used by Quilombola Communities in the Atlantic Forest: Popularity, versatility and exclusivity as proxies for medicinal keystone species

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ABSTRACT

Native species used in the traditional medicine of Indigenous Peoples and Local Communities undeniably require conservation efforts. Some theoretical models suggest that exotic species may reduce the pressure on native species by sharing their functions and increasing redundancy within medicinal plant use. As a result, native species would no longer be exclusive. Exclusivity in use, along with versatility and popularity, are indicators of more frequent use, potentially leading to overexploitation. These characteristics are also used to define cultural keystone species. Our study investigated these three attributes in medicinal plants used by three afro-descendants quilombola communities within the Atlantic Forest to identify the local importance of exotic and native species and to determine possible keystone species in the local medical system, in parallel with the cultural keystone species model. We conducted semi-structured interviews with local specialists and guided tours for data collection. We compared the values of popularity, exclusivity, and versatility between exotic and native species, and further identified the species with the highest values for each attribute, using as cutoff the probability of citation occurrence of each plant under a null scenario. We found no significant differences between exotic and native species in the tested attributes, suggesting that species from both origins share similar use pressures. However, when setting a threshold for the most critical attributes, we observed that, in the resulting list, most species appearing in at least two attribute lists are native. We highlight the need for conservation actions for the species present in all three lists compiled in this study and propose that these attributes be incorporated into the classification of species that form the structural core of a local medical system.

Keywords: Ethnobotany, Indigenous Peoples and Local Communities, Conservation efforts.

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SIGNIFICANCE STATEMENT

This study contributes to the understanding of how exotic and native medicinal plants are integrated into traditional medical systems of quilombola communities in the Atlantic Forest. By examining versatility, popularity, and exclusivity—key attributes linked to cultural keystone species and overexploitation risk—we provide empirical data that challenge the assumption that exotic species alleviate pressure on native flora. Our findings show that both native and exotic species are similarly valued, but native plants are more prominent among those with high levels of cultural importance. These results underscore the need to prioritize useful native species in conservation strategies and suggest that identifying species with multiple critical attributes can enhance the classification of culturally significant plants. This approach offers a valuable framework for ethnobotanical studies and conservation planning that respect and incorporate local knowledge systems.

INTRODUCTION

Several ethnobotanical studies have highlighted the local extinction threats faced by medicinal species used by Indigenous Peoples and Local Communities (IPLC) based on different conservation priority indices (Campos and Albuquerque 2021; Conde et al. 2017; Souza et al. 2017). These indices aim to guide conservation efforts toward native medicinal species essential to traditional communities, generally overlooking the role of exotic species in these medical systems. Evidently, non-cultivated native species face a greater risk of local extinction than exotic and/or cultivated species due to the ongoing environmental degradation of various natural habitats (Campos and Albuquerque 2021; Santoro et al. 2023; Souza et al. 2017). Moreover, these species experience higher levels of use pressure, as they are frequently collected to meet medicinal, fuel, and food demands (Medeiros et al. 2020; Santoro et al. 2023). It is indisputable that conservation efforts should be focused on these species, which typically exhibit low local abundance and high cultural salience. However, some theoretical studies suggest that exotic species may play a fundamental role in the local preservation of such native plants (Alencar et al. 2014; Medeiros et al. 2017; Medeiros et al. 2020).

For instance, the work of Medeiros et al. (2017) proposes that when exotic species are used for the same medicinal purposes as native species, the population may reduce its reliance on native species by diversifying medicinal use with cultivated (often exotic) species. This scenario, based on the utilitarian redundancy model, would aid in the conservation of native species. The utilitarian redundancy model was inspired by functional redundancy in ecology (Walker 1992) and predicts that local communities possess a repertoire of redundant utilitarian plants (Albuquerque and Oliveira 2007; Nascimento et al. 2015). According to the model, native species with highly redundant medicinal functions experience lower usage pressure and extraction rates, making them less threatened by local extinction than those exclusively used for specific functions (Nascimento et al. 2015).

Santoro et al. (2023) specifically relied on the exclusivity of use to infer the potential overexploitation of native species in Patagonia, Argentina, despite the high prevalence of exotic species in the region. They concluded that, although exotic species were predominant across the different uses analyzed, native species tended to be more exclusive in their uses, with limited potential for substitution by exotic species, and could therefore be more extensively exploited in certain cases. To reach this conclusion, the authors applied an index combining redundancy (the number of other species that could perform the same function) and versatility (the number of functions each plant performs) to assess the overuse of native Patagonian species.

Exclusivity in performing certain functions can also indicate a plant's cultural importance, serving as a criterion for defining a cultural keystone species — a model proposed by Garibaldi and Turner (2004) based on ecological keystone species (Power et al. 1996). Cultural keystone species are those without which a human population would be fundamentally different (Cristancho and Vining 2004; Garibaldi and Turner 2004). In other words, they are irreplaceable in a cultural group or nearly so (Coe and Goue 2020), which reinforces the importance of exclusivity in the characterization of a cultural keystone species.

In addition to exclusivity, the cultural keystone species model proposed by Garibaldi and Turner (2004) incorporates other elements - such as popularity, versatility of use, use in ceremonies, the existence of a local nomenclature, persistence in memory despite changes, and the acquisition of the species from outside the community (Garibaldi and Turner 2004) - several of which are challenging to access and quantify (Coe and Goue 2020). Bringing the concept of cultural keystone species (which clearly encompasses species with multiple uses, including religious ones) into the scope of native medicinal plant conservation, it is possible to narrow the focus to the study of keystone species within a local medical system, namely medicinal keystone species.

In the Atlantic Forest, ethnobotanical studies have emphasized the importance of some native species in the functioning of traditional medical systems.

(Begossi et al. 2002; Conde et al. 2017; Ramos et al. 2024). Many of these studies have been conducted with quilombola populations (Beltreschi et al. 2019; Conde et al. 2017), which comprise Afro-Brazilian descendants with a historical trajectory of resistance to oppression dating back to the colonial slavery period (Brasil 2003). The oppression faced by these populations in past centuries persists today in the form of structural racism. Due to marginalization, geographic isolation, and cultural misunderstanding, quilombola communities exhibit remarkably deficient health indicators and high levels of social vulnerability, making them highly dependent on medicinal plants (Azeredo and Mota 2021).

In these communities, exotic species play a fundamental role, as many were inherited from the African continent and remain cultivated to this day (Voeks 1990). However, after prolonged residence in the Atlantic Forest, with a history of constant escape from enslavement, these populations adapted to the American environment and acquired extensive knowledge of native species. Therefore, quilombola populations provide an interesting case for understanding the dynamics of native and exotic species use and identifying key native species of medicinal importance. This study aims to assess the importance of both exotic and native species for the traditional medicine of three quilombola communities located in one of the largest and most preserved remnants of the Atlantic Forest in northern Rio de Janeiro, Brazil, the Quilombos ABC.

We will use three of the six parameters defined by Garibaldi and Turner (2004) to classify cultural keystone species—specifically those that are more easily quantifiable, such as exclusivity, popularity, and versatility—to identify potential medicinal keystone species. We will identify species that simultaneously are widely known by the population (popularity), perform multiple functions (versatility), and are used in non-redundant or minimally redundant functions, making them less likely to be substituted (exclusivity). Based on these quantifiable parameters of cultural keystone species, we will also consider qualitative aspects that may characterize them as keystone species within local medical systems. Framed within a conservationist perspective, our approach further examines their biogeographical origin and extinction risk." knowledge.

MATERIAL AND METHODS

Study Area

The quilombola communities of Aleluia, Cambucá, and Batatal (Quilombos ABC) are located in the region called "Imbé," in the district of Morangaba, the 9th District of the municipality of Campos dos Goytacazes, Rio de Janeiro, Brazil (Azeredo and Mota 2021). The three Quilombos ABC received the certificate from the Palmares Foundation in 2012, ensuring their recognition as a traditional Brazilian population of African origin and certifying their territorial rights (Henriques 2010). However, the history of these populations with the territory dates back to the 18th century (Henriques 2010). It is worth noting that during the slavery period, the municipality of Campos dos Goytacazes had a majority of enslaved Black people, who made up 60% of its population, being the region with the largest contingent of enslaved individuals in the province of Rio de Janeiro (Henriques 2010).

The Imbé region is one of the few remaining areas of the Atlantic Forest in the municipality of Campos dos Goytacazes, located between Lagoa de Cima and the Desengano State Park (PED), both considered environmental preservation areas (Azeredo and Mota 2021). Its forests are among the richest and most diverse in arboreal species of the Atlantic Forest (Moreno et al. 2003). Currently, the population of the three communities consists of a total of three hundred families, who face significant social inequality, limited access to the public health system, high school dropout rates, and low household income (Azeredo and Mota 2021). The predominant religions in the communities are of Christian origin, and there are currently two evangelical churches attended by the population. The use of medicinal plants is widely practiced, being one of the main ways to deal with illnesses. However, according to residents' reports, knowledge about the local flora is concentrated among the older population, who use medicinal plants to produce teas and syrups, while younger generations show little interest. The residents' reports were collected directly by the authors during fieldwork.

Data Collection

To select the participants for the research, we used the snowball sampling technique (Albuquerque et al. 2014), starting with the community leader, who was himself an expert in local medicine. The snowball sampling ended with the recommendation of 30 participants, when no further recommendations were made. Out of the 30 participants, 5 declined to take part in the research, and our data were collected with the help of 25 local experts.

We conducted semi-structured interviews (Albuquerque et al. 2014), starting with the free-listing technique, asking the participant to list all the medicinal plants they knew. Subsequently, we asked which diseases those plants treated, their methods of use, the parts of the plant used, and the collection location (whether they were cultivated or wild-harvested).

Guided tours (Albuquerque et al. 2014) were conducted with local experts to collect and identify plants in the field by their vernacular names. To confirm the identity of the plants, at least two informants were consulted after the collection of each plant. If there was any discrepancy in the identifications, additional informants were consulted. The plants were collected for botanical identification and deposited at the Herbarium of the Center for Biosciences and Biotechnology (CBB) at the Universidade Estadual do Norte Fluminense Darcy Ribeiro (HUENF).

Data Analysis

To identify the species most important to local medicine, we used three indicators based on the popularity of the species and some quantifiable parameters outlined by Garibaldi and Turner (2004). Thus, the importance of a species in a medical system was analyzed here according to: 1. Popularity, measured by the salience index (Smith and Borgatti 1997), which considers both the frequency of citation and the order in which it was cited in each free list; 2. Versatility, measured by the number of therapeutic targets for which each plant was recommended; 3. Exclusivity, measured by the number of other plants that can be used to treat the same therapeutic targets (i.e., redundancy – the smaller this number, the greater the exclusivity).

To identify which species could be classified as the most popular and versatile (the first two measured parameters) within the list of species, we used a mathematical analysis proposed by Chaves et al. (2019). This analysis aims to find a more objective cutoff point to identify the most important species from the free lists, using the probability of occurrence of citation of each plant in a null scenario. The analysis assumes that when we claim certain elements mentioned are more important than others, we are assuming that some of these elements are cited with higher frequencies than expected by chance. The method was initially proposed to determine a cutoff point for the salience index (Chaves et al. 2019), and here we have adapted it to also investigate which plants exhibit greater versatility. Thus, the cutoff point for the list of the most versatile species identifies those that have a higher number of functions than expected by chance.

Thus, we created a list that included the names of participants and the species in the order they were cited, and another list that included the therapeutic targets and the species assigned to each target. For each of these lists, we randomly generated other lists from 300 simulated populations (populations of people and of plants, for each list) using Monte Carlo Techniques (Robert and Casella 2010). Each simulated population had the same number of items as the actual one, although the frequency with which the items appeared was completely random. Thus, the number of randomizations was equal to 300, multiplied by the number of participants and the number of therapeutic targets (for each analysis). Then, based on the real data, we calculated the salience and versatility of each cited item, followed by the probability of occurrence of these values in a null scenario (p-value). We accepted as significant all medicinal plants that presented values equal or lower than the 5% probability threshold set ($p \leq 0.05$).

This same analysis also served to establish the cutoff point for species with insignificant cultural importance: those species that showed lower salience than expected (also with $p < 0.05$), having appeared only at the end of the free lists and cited by only one individual. The citations of these species were excluded from the exclusivity analyses.

To assess the exclusivity of the plant, we used the unique species index in its function (SU), as applied by Santoro et al. (2023).

$$SU = \sum \frac{nSif}{nfSi}$$

In this formula, *nSif* is the number of species that, along with species i, perform a given function f (the redundancy of plants in each function executed by species i), and *nfSi* is the total number of functions performed by species i (versatility). By dividing the sum of the redundancy of each function performed by the medicinal plant by its versatility, we obtain an average redundancy of the therapeutic targets that each plant is indicated for. If the plant is involved in low-redundancy therapeutic targets, the value of SU will be low, and the plant will be exclusive (or nearly exclusive) for certain functions. We selected the first quartile of the lowest SU values from the species list to form the list of the most exclusive species.

The species cited and collected were classified as native or exotic according to the Flora do Brasil project (2022). A t-test was performed after the data were normalized using the Box-Cox transformation to compare the popularity value (number of citations), versatility (number of therapeutic functions), and SU (uniqueness value) between all native and exotic species, as well as between the groups selected as the most important within each category.

RESULTS

A total of 138 medicinal plants were cited - see Supplementary Information (SI). We collected and deposited 102 of these plants in HUENF, of which 45 are native and 57 are exotic. Some plants could not be collected due to the height of their canopy or the limited availability of material. These plants were identified by field experts, with the help of their popular names and characteristics dictated by the informants. Other plants were identified only with the help of their popular name. These plants are highlighted in the supplementary material, as we are not sure of their scientific names. Only five plants could not be identified by their popular name (see SI). Considering the total number of plants (including those identified by their popular name), 74 are exotic and 59 are native.

There was no significant difference between exotic and native species regarding their popularity (mean of natives = 3.30; mean of exotics = 3.11; p = 0.073), versatility (mean of natives = 2.94; mean of exotics = 2.16; p = 0.061), or exclusivity (mean SU of natives = 17.63; mean of exotics = 19.09; p = 0.633). The comparative analysis of the mean values of the tested indices was conducted exclusively for the plant specimens that were deposited in the herbarium.

Among the 13 plants that showed salience higher than expected by chance ($p \leq 0.05$), seven are native, and six were exotic (Table 1). Furthermore, 24 plants were attributed to idiosyncratic information (which includes 12 species that were not found in the region and could not be collected), having such low cultural importance that they were excluded from our analyses.

Among the 11 plants that showed versatility higher than expected by chance ($p \leq 0.05$), nine are native (Table 2).

Only four plants are present in both the lists of the most popular and most versatile species, with two native - *Adenostemma* sp. (Arnica), *Schinus terebinthifolia* (Aroeira) and *Varronia curassavica* (Erva baleeira) and one exotic - *Persea americana* (Abacate). Regarding the exclusivity of uses, excluding the idiosyncrasies, we found 28 plants listed in the first quartile, of which 14 are exotic and 14 are native (Table 3).

None of the species are present in all three lists simultaneously, but one species is in the intersection zone between the most salient and the most exclusive - *Echinodorus grandifloras* (Chapéu de couro). In addition, 3 species are in the intersection zone between the most versatile and most exclusive, all native - *Miconia albicans* (Canela de velho), *Pereskia grandifolia* (Ora-pro-nobis), and *Platycyamus regnellii* (Pau pereira) - and 4 are in the intersection zone between the most versatile and most salient - *Adenostemma* sp. (Arnica), *Persea americana* (Abacate), *Schinus terebinthifolia* (Aroeira), and *Varronia curassavica* (erva baleeira). Figure 1 shows the species in the intersection zone of at least two of the parameters analyzed.

DISCUSSION

Our results show that the proportion of exotic and native plants used by the populations of Quilombos ABC are similar. Exotic and native species also hold the same importance in local medicine according to criteria that indicate usage pressure and cultural importance—whether popularity, versatility, or exclusivity. This result is favorable from the standpoint of conserving native vegetation, as it demonstrates that the use of medicinal plants is not solely concentrated on native species, which could lead to over-exploitation (Alencar et al. 2014; Medeiros et al. 2020).

The diversification hypothesis, initially developed by Alencar et al. (2010) and refined by Medeiros et al. (2017), highlights the exotics species' conservation role in diversifying a medical system that could have originally been based on native species, as these are the first available. Although some studies show the massive replacement of African native species by Brazilian native species in the ethnomedical systems of African-descended peoples over time, exotic species remain particularly important to these populations (Medeiros et al. 2012; Voeks 1990). Specifically, in the case of quilombola populations in the Atlantic Forest, many studies emphasize the great relevance of exotic species in local medicine, without disregarding the cultural value of native species (Beltreschi et al. 2019; Ramos et al. 2024; Tostes and Senna-Valle 2022).

In other words, apparently, based on our initial results and previous studies, exotic species are just as important as native species for quilombola populations. On one hand, this is interesting from an adaptive standpoint, as these populations incorporate local flora into their cultural practices. On the other hand, simply sharing roles with exotic species may not be enough to ensure that native species are not overexploited to meet the demands of local medical systems, especially since they are, in most cases, not cultivated species (Campos and Albuquerque 2021). As we have discussed here, according to the utilitarian redundancy model (Albuquerque and Oliveira 2007; Nascimento et al. 2015), species involved in functions with low or no redundancy are more at risk of overexploitation than those that share the same function with other plants. Alencar et al. (2014) also brought the utilitarian redundancy model into the diversification hypothesis in order to better understand how exotic species may increase redundancy in medicinal functions and help reduce pressure on native species. According to the authors, greater attention should be given to native species involved in functions with little or no redundancy (here referred to as exclusive species).

In our study, two of the native species listed among the most exclusive are categorized as threatened with extinction according to IUCN criteria in the Official List of Threatened Species of the Brazilian Flora (MMA 2022). One of them could not even be collected, but its popular name (jequitibá) would hardly refer to any species other than *Cariniana legalis* (Mart.) Kuntze, categorized as endangered (EN). We were un-

Table 1. Species from the Quilombola communities of Aleluia, Cambucá, and Batatal (Quilombos ABC), Imbé region, Campos dos Goytacazes, RJ, Brazil, listed as the most salient according to the cutoff point of Chaves et al. (2019).

Popular name	Species	Origin	Salience	p.value
Aroeira	*Schinus terebinthifolia* Raddi	Native	0.4541	≤0.0001
Assa peixe	*Vernonanthura polyanthes* (Sprengel) Vega & Dematteis	Native	0.4347	≤0.0001
Arnica	*Adenostemma* sp.	Native	0.4189	≤0.0001
Boldo	*Plectranthus barbatus* Andr.	Exotic	0.3517	≤0.0001
Acerola	*Malpighia glabra* L.	Exotic	0.3169	0.0001
Erva cidreira	*Lippia alba* (Mill.) N.E.Br. ex Britton & P.Wilson	Native	0.2951	0.0001
Abacate	*Persea americana* Mill.	Exotic	0.28	0.0013
Capim limao	*Cymbopogon citratus* (DC.) Stapf	Exotic	0.2752	0.0013
Erva baleeira	*Varronia curassavica* Jacq.	Native	0.2215	0.0013
Alho	*Allium sativum* L.	Exotic	0.1879	0.0013
Cana de macaco	*Costus sprucei* Maas	Native	0.1751	0.0057
Chapeu de couro	*Echinodorus grandiflorus* (Cham. & Schltr.) Micheli	Native	0.1712	0.0057
Erva macae	*Leonurus japonicus* Houtt.	Exotic	0.1412	0.0057

Table 2. Species from the Quilombola communities of Aleluia, Cambucá, and Batatal (Quilombos ABC), Imbé region, Campos dos Goytacazes, RJ, Brazil, listed as the most versatile according to the cutoff point of Chaves et al. 2019.

Popular name	Species	Origin	Vers.	p.value
Aroeira	*Schinus terebinthifolia* Raddi	Native	13	≤0.0001
Ora-pro-nobis	*Pereskia grandifolia* Haw.	Native	11	0.0001
Arnica	*Adenostemma* sp.	Native	8	0.0037
Cura-tudo	*Justicia calycina* (Nees) V.A.W.Graham	Native	8	0.0037
Erva baleeira	*Varronia curassavica* Jacq.	Native	8	0.0037
Abacate	*Persea americana* Mill.	Exotic	7	0.0129
Casca doce	*Pradosia huberi* (Ducke) Ducke	Native	6	0.0392
Canela de velho	*Miconia albicans* (Sw.) Steud.	Native	6	0.0392
Panaceia	*Solanum cernuum* Vell.	Native	6	0.0392
Pau pereira	*Platycyamus regnellii* Benth.	Native	6	0.0392
Saiao	*Kalanchoe crenata (*Andrews) Haw.	Exotic	6	0.0392

able to collect it because the very informant who cited it said it was found in a very remote area that we could not access, but it is clearly a very rare species in the region. Jaborandi (*Pilocarpus microphyllus* Stapf ex Wardlew.), also listed among the most exclusive plants, is categorized as vulnerable (VU) according to IUCN criteria. These species were indicated for the treatment of bronchitis and for its analgesic effect, respectively.

Other native species listed among the lists also

Table 3. Species from the Quilombola communities of Aleluia, Cambucá, and Batatal (Quilombos ABC), Imbé region, Campos dos Goytacazes, RJ, Brazil, listed as the most exclusive according to the first quartile of the uniqueness index (SU) value.

Popular names	Species	SU	Origin
Arruda	*Ruta graveolens* L.	1	Exotic
Eucalipto liso	*Eucalyptus* sp.	1	Exotic
Bambu	*Bambusa* sp.	2	Exotic
Hortelã folha grande	*Coleus amboinicus* Lour.	2	Exotic
Jaborandi	*Pilocarpus microphyllus* Stapf ex Wardlew.	2	Native
Jequitibá	*Cariniana legalis* (Mart.) Kuntze	2	Native
Eucalipto cheiroso	*Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson	2.5	Exotic
Alecrim do mato	*Baccharis dracunculifolia* DC.	3	Native
Aranto	*Kalanchoe* sp.	3	Exotic
Babosa	*Aloe vera* (L.) Burm.f.	3	Exotic
Guandum	*Cajanus cajan* (L.) Huth	3	Exotic
Cordão de frade	*Leonotis nepetifolia* (L.) R.Br.	4	Exotic
Erva cinco folhas	*Sparattosperma leucanthum* (Vell.) K.Schum	4	Native
Jatobá	*Hymenaea courbaril* L.	4.75	Native
Boldo do Chile	*Peumus boldus* Molina	5	Exotic
Capim de galinha	*Eleusine indica* (L.) Gaertn.	5	Exotic
Carobinha	*Jacaranda puberula* Cham.	5	Native
Carqueja	*Baccharis crispa* Spreng.	5	Native
Mertiolate	*Jatropha multifida* L.	5	Native
Ora-pro-nobis	*Pereskia grandifolia* Haw.	5.45	Native
Pau pereira	*Platycyamus regnellii* Benth.	6	Native
Canela de velho	*Miconia albicans* (Sw.) Steud.	6.5	Native
Pico preto	*Bidens pilosa* L.	6.5	Exotic
Chapéu de couro	*Echinodorus grandiflorus* (Cham. & Schltr.) Micheli	6.8	Native
Cipó cravo	*Tynanthus fasciculatus* (Vell.) Miers	7	Native
Coco	*Cocos nucifera* L.	7	Exotic
Gervão	*Stachytarpheta cayennensis* (Rich.) Vahl	7	Native
Louro	*Laurus nobilis* L.	7	Exotic

showed low availability in the region, making collection difficult — such as *casca doce*, of which we found only a single individual. It could not be collected due to the height of its leaves and absence of reproductive parts, but it apparently corresponds to the native species *Pradosia huberi* (Ducke) Ducke. *Casca doce* is among the most versatile species. *Jatobá* — a popular name that most likely refers to *Hymenaea courbaril* L. — is among the most exclusive plants and holds significant relevance for several quilombola communities

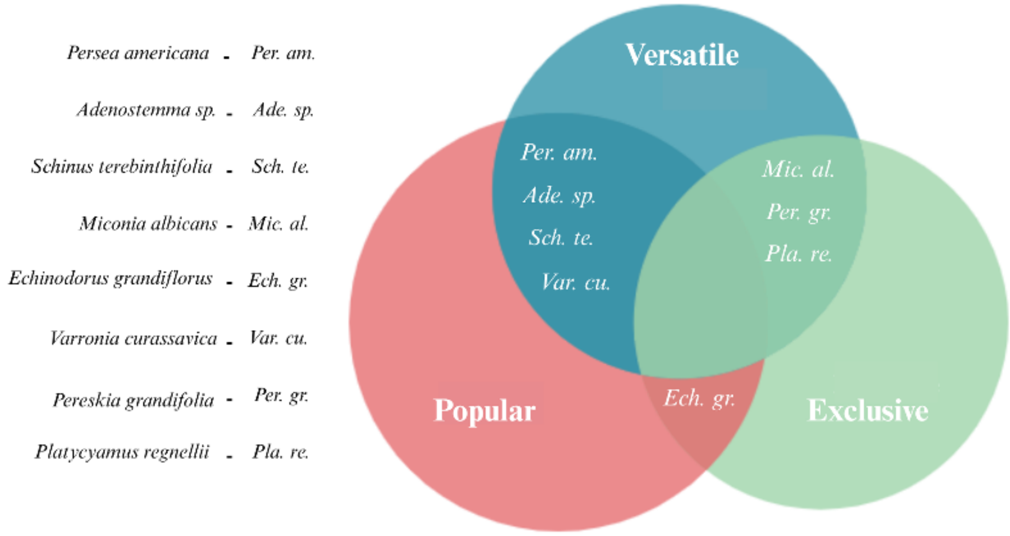

Figure 1. Diagram showing species cited by the Quilombola communities of Aleluia, Cambucá, and Batatal (Quilombos ABC), located in the Imbé region, Campos dos Goytacazes, RJ, Brazil. The diagram highlights the intersection zone among the lists of popularity, versatility, and exclusivity, indicating which species share two of these attributes and may represent key elements of the local medical system.

(Ramos et al. 2024). The species could not be found in the region. As we mentioned earlier, at first glance, our results suggest that exotic and native species contribute equally to local medicine. However, a more detailed analysis reveals that native species may subtly hold greater significance for the population: native species make up the vast majority of the most versatile species. Species versatility is classically considered by some ethnobiologists to be the strongest indicator of use value (Phillips and Gentry 1993a,b). Indeed, the ability to serve multiple medicinal functions increases the likelihood that a species will be more widely used — and thus more likely to face greater harvesting pressure.

Additionally, only native species were found in the intersection zone between the most exclusive and most versatile species. Appearing in at least two of the categories analyzed places these species as potential cultural keystone species in the local medicinal system. The cultural keystone species model goes far beyond medicine and includes other factors beyond those quantified here, such as the existence of local names, participation in ceremonies (which were absent in the study sites), and persistence across generations (Coe and Goue 2020; Garibaldi and Turner 2004). Since we were unable to quantify such factors, we identified as potential keystone species within the local medicinal system the eight species present in at least two of the selected lists (species located in what we refer to as intersection zones): Abacate (*Persea americana*), Arnica (*Adenostemma* sp.), Aroeira (*Schinus terebinthifolia*), Canela de velho (*Miconia albicans*), Chapéu de couro (*Echinodorus grandiflorus*), Erva baleeira (*Varronia curassavica*), Ora-pro-nobis (*Pereskia grandifolia*), and Pau pereira (*Platycyamus regnellii*). We noted that seven of eight plants are native.

We aim to emphasize the importance of conserving these species not only because of their relevance to the ecological processes of the Atlantic Forest, but also for what they represent to the culture of traditional populations in Brazil, such as quilombola communities. The species conservation is directly linked to the preservation of the knowledge associated with them (Molnár et al. 2023). Numerous parallels between cultural and ecological systems are increasingly being highlighted in efforts to help define conservation priorities and provide a platform for deeper understanding of the meaningful roles that cultural keystone species can play within socio-ecological systems (Coe and Goue 2020). Cultural keystone species have a profound impact on culture, being irreplaceable (Garibaldi and Turner 2004). Thus, the loss of these species would likely cause considerable disruption to cultural cohesion and balance, in contrast to other species whose loss tends to have minimal or no effect (Coe and Goue 2020). In this context, the removal or extinction of cultural keystone species can lead to significant disruptions among traditional peoples (Coe and Goue 2020).

Bringing this definition into the context of local medical systems, we can infer that a similar process would occur within a local medical system following the disappearance of a medicinal keystone species.

None of the species identified as potential medicinal keystone species—based on their presence in at least two of the studied factors—are currently listed in the Official List of Threatened Species of the Brazilian Flora (Annex 1 of Ordinance No. 443, MMA, BRAZIL). However, we have already emphasized that some of them, such as *casca doce*, have low local availability, according to the study participants. Their disappearance from nature would not only result in ecological loss but could also create cultural gaps and affect the sovereignty of traditional populations' medical systems. Among the plants identified in the intersection zone, at least five are also used by many other quilombola communities in Brazil, including Abacate (*Persea americana*), Aroeira (*Schinus terebinthifolia*), Chapéu de couro (*Echinodorus grandiflorus*), Erva baleeira (*Varronia curassavica*), and Ora-pro-nobis (*Pereskia grandifolia*) (see the review by Ramos et al. 2024).

We emphasize that, although we may identify these species as potential medicinal keystone species—since they are present in at least two of the parameters proposed by Garibaldi and Turner (2004)—none of the studied species simultaneously appeared on the primary list for all three parameters. This raises the question of whether a true medicinal keystone species exists within the local medicinal system of the Quilombos ABC, as suggested by Coe and Gaoue (2020). We may not have sufficient data to definitively identify a single or a few keystone species within the local medical system. However, the eight species identified in the intersection zone exhibit characteristics consistent with the cultural keystone species syndrome, a syndrome that would designate these species as potential cultural keystone species (see Sousa *et al.* 2024), which already underscores their relevance for conservation efforts.

Alternatively, beyond the concept of cultural keystone species, these 11 selected species may also be considered part of what Ferreira Junior and Albuquerque (2015) define as the "structural core"— that is, a set of medicinal plants with adaptive characteristics responsible for maintaining the structure and function of medical systems.

The concept of the structural core originated from the notion of *consensus within diversity*, aiming to identify the most commonly cited or culturally salient plant species—those that represent the foundational elements of a local medical system (Ferreira Junior and Albuquerque 2015). The core concept behind the structural core is that highly popular medicinal plants possess adaptive traits that meet the therapeutic demands of a medical system, such as availability and efficacy (Ferreira Junior and Albuquerque 2015; Sousa *et al.* 2022). In this study, we did not test ecological parameters of the cited plants that would classify them within the structural core. Here, we propose that in addition to popularity measured by salience, efficacy, and availability, factors such as versatility and exclusivity may also be important in identifying the structural core of a local medical system. We believe that there are relevant ecological factors that have contributed to the cultural importance of the eight species identified in the intersection zones, and we suspect that these species may constitute a structural core. This structural core represents the backbone of a medical system, and their knowledge is unlikely to be lost (Albuquerque et al. 2019).

LIMITATIONS

Our study lacks an emic perspective on what constitutes a key medicinal species—an important point well highlighted in the work of Sousa *et al.* (2024). The inclusion of an emic perspective could certainly enrich our understanding of which of these species are truly key to the functioning of the local medical system. However, we consider that the three parameters analyzed are fundamentally important for identifying species of high local relevance (such as key species) especially regarding exclusivity of use and popularity. It is unlikely that a species identified as key from an emic perspective would not be among the eight species highlighted in this study. We want to emphasize that, although we used quantitative data, we were careful to address the concern raised by Garibaldi and Turner (2004) regarding data collection, by relying on information that came directly from the interviews rather than our own ethical interpretation of each parameter studied.

From a conservation perspective, we also acknowledge that an analysis of the cultivation of the species listed here would be essential, especially in the case of native species. We suggest that future studies applying the idea that exotic species may potentially buffer the use of native ones should consider the cultivation status of these species in their analyses.

CONCLUSION

At first glance, our data show that exotic and native species hold the same local importance, whether in terms of citation frequency, popularity, versatility, or exclusivity (the ability to be irreplaceable). However, when we establish a threshold to identify the most important species within each of these indices, we begin to observe that native species take on greater importance. When we isolate species that appear in at least two of the examined attributes—those which contribute to defining a keystone species—we find that native species are the majority.

We wish to highlight the need for conservation of species identified as exclusive, as the utilitarian redundancy model suggests they are more susceptible to overexploitation. We observed that two of these exclusive (or irreplaceable) species are listed in the national list of threatened species: *Cariniana legalis* and *Pilocarpus microphyllu.* We also emphasize the importance of the most popular and most versatile native species, as both attributes are indicators of higher use intensity.

While we cannot definitively conclude that the species listed here are true medicinal keystone species, we can confidently state that they are the fundamental for the functioning of the ABC quilombos medical system. We suggest that the factors analyzed in this study should also be considered in the characterization of the *structural core*, a concept developed to identify the most significant species within a local medical system.

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HUMAN ETHICS AND CONSENT TO PARTICIPATE DECLARATIONS

This study was conducted according to the ethics guidelines of the ISE Code of Ethics and Nagoya Protocol. The work was approved by the Brazilian Research Ethics Committee (Plataforma Brasil) under the number CAAE: 64292922.8.0000.5244 and is registered in the National System for the Management of Genetic Heritage and Associated Traditional Knowledge - SisGen (Decree No. 8,772, of May 11, 2016) with the code A31B96F.

The proposal was initially presented to the community leader, Mr. Paulo Honorato, who agreed and signed a letter of consent for the work to be carried out. In accordance with the requirements of current Brazilian legislation (Resolution No. 466 of December 12, 2012, from the National Health Council), all individuals who agreed to participate in the research signed the Free and Informed Consent Form (TCLE), authorizing the collection, use, and publication of the data obtained in this study.

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DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The author has no conflicts of interest to declare.

CONTRIBUTION STATEMENT

Conceived of the presented idea: FRS, MTN.
Collected the data: FRS, JGP, LGH, MLH, MCN.
Carried out the data analysis: FRS.
Wrote the first draft of the manuscript: FRS.
Review: JGP, LGH, MLH, MCN, MTN.
Final write of the manuscript: FRS.
Supervision: MTN.

DISCLOSURE OF AI USE

The authors used ChatGPT to assist in formatting the reference list according to the journal's guidelines. The content was reviewed and edited by the authors to ensure accuracy and appropriateness.

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