

Uncharted territory: flora of the *Campos Rupestres* of Serra do Frazão - new records, geographic distribution, and conservation highlights

Vitor Araújo da Silva^{1,2,5}, Luciano Gonçalves Pedrosa^{1,3} & Livia Echternacht^{1,4}

Key words:

- biodiversity
- collection bias
- conservation
- flora survey
- Quadrilátero Aquífero-Ferrífero

Palavras-chave:

- biodiversidade
- viés de coleta
- conservação
- levantamento florístico
- Quadrilátero Aquífero-Ferrífero

Abstract

The Brazilian *Campos Rupestres* are highly biodiverse, yet many areas remain unexplored, even those near research centers. We present the first floristic survey of 291 hectares of *Campos Rupestres* in Serra do Frazão, a previously under-sampled area in the eastern Quadrilátero Aquífero-Ferrífero (QAF), in Minas Gerais (MG). Botanical specimens were collected from 2022 to 2024 and deposited in herbarium collections. We compared our findings with those from Itacolomi State Park and RPPN Santuário do Caraça, identifying patterns of geographic distribution and species threat status. 410 tracheophyte species across 97 families and 261 genera were identified. Among these, 335 are new records for Frazão, 18 for Ouro Preto municipality, and two for MG. Fifty-one species are endemic to MG, eleven of which are exclusive to the QAF. We expanded the known distribution of seven of these species and proposed two new endemics: *Aristolochia marianensis* and *Pleroma decemcostatum*. Two microendemic species from Serra do Frazão, *Barbacenia beauverdii* and *Paepalanthus atrovaginatus*, are critically endangered. In total, thirty-three threatened species were recorded. Frazão's flora is unique, with 21.2% of species exclusive to the area, showing greater floristic similarity with Caraça. Our findings underscore the urgency of establishing Frazão as a conservation unit.

Resumo

Os *Campos Rupestres* brasileiros são altamente biodiversos, mas muitas áreas ainda permanecem inexploradas, mesmo próximas a centro de pesquisas. Apresentamos o primeiro levantamento florístico de 291 hectares na Serra do Frazão, uma área anteriormente pouco amostrada no leste do Quadrilátero Aquífero-Ferrífero (QAF), em Minas Gerais (MG). Espécimes botânicos foram coletados entre 2022 e 2024 e depositados em herbário. Comparamos nossos resultados com os do Parque Estadual do Itacolomi e da RPPN Santuário do Caraça, identificamos os padrões de distribuição geográfica e o estado de ameaça das espécies. Foram identificadas 410 espécies de traqueófitas, distribuídas em 97 famílias e 261 gêneros. Dessas, 335 são registros novos para o Frazão, 18 para o município de Ouro Preto e dois para MG. Cinquenta e uma espécies são endêmicas de MG, sendo onze exclusivas do QAF. Ampliamos a distribuição conhecida de sete delas e propusemos duas

¹ Universidade Federal de Ouro Preto, Campus Morro do Cruzeiro - ICEB III, Ouro Preto, MG, Brazil.

² ORCID: 0000-0002-8763-1141

³ ORCID: 0009-0003-2613-076X

⁴ ORCID: 0000-0003-1534-7181

⁵ Author for correspondence: vitoraraujosilva.va@gmail.com

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novas endêmicas: *Aristolochia marianensis* e *Pleroma decemcostatum*. Duas espécies microendêmicas do Frazão, *Barbacenia beauverdii* e *Paepalanthus atrovaginatus*, estão criticamente ameaçadas. Ao todo, registramos 33 espécies ameaçadas. A flora do Frazão é única, com 21,2% de espécies exclusivas da área, apresentando maior similaridade florística com o Caraça. Os dados reforçam a urgência de sua proteção como Unidade de Conservação.

Introduction

Species inventories are a key objective for biodiversity identification and conservation (CBD 2012, 2016). However, species distributions remain poorly understood (Wallacean deficit) (Hortal *et al.* 2008), and many species may become extinct before they are even known to science (Linnaean deficit) (Costello 2013; Brown *et al.* 2023), especially in megadiverse countries such as Brazil (Gallagher *et al.* 2023). These gaps have been associated with historical collection biases, including ease of access, proximity to urban areas, research centers, rivers, and previously visited locations, regions, and biomes (Kadmon *et al.* 2004; Hopkins 2007; Hortal *et al.* 2008; Madeira *et al.* 2008; Sousa-Baena *et al.* 2013; Oliveira *et al.* 2016; Hughes *et al.* 2021). Consequently, sampling bias compromises studies in biogeography, conservation, ecology, and evolution, as it limits understanding of population dynamics, phylogenetic relationships, functional traits, adaptive responses, and ecological interactions (Hortal *et al.* 2015). Addressing these deficits requires prioritizing under-sampled areas in biodiversity research (Sobral & Stehmann 2009; Oliveira *et al.* 2016; Bachman *et al.* 2023), mainly through floristic surveys, which provide the primary data that support all fields of biological science (Funk 2006; Rapini *et al.* 2008; Sobral & Stehmann 2009; Ulloa-Ulloa *et al.* 2017).

The Brazilian *Campos Rupestres*, due to their unique flora, stand out as one of the most important and biodiverse mountain ecosystems. They are characterized by mountainous azonal vegetation, predominantly herbaceous to shrubby, prone to fire, with the presence of mainly quartzitic and ferruginous rocky outcrops (Jacobi *et al.* 2007; Silveira *et al.* 2016; Miola *et al.* 2020). They are responsible for sheltering 15% of the total vascular plant flora in an area that occupies less than 1% of the Brazilian territory (Fernandes *et al.* 2014; Silveira *et al.* 2016), with many endemic, rare, and threatened species (Alves & Kolbek 1994; Giulietti *et al.* 1997; Rapini *et al.* 2008; Echternacht *et al.* 2011; Alves *et al.* 2014; Silveira *et al.* 2016). Due to their azonal characteristics, forming isolated islands within an adjacent vegetation matrix, and with flora influenced by climatic, edaphic, lithological, and topographic conditions on a microscale (Giulietti

et al. 1997; Benites *et al.* 2003, 2007; Schaefer *et al.* 2016; Silveira *et al.* 2016; Neves *et al.* 2017), the identity of the *Campos Rupestres* flora has intrigued botanists for a long time (*e.g.*, Silveira 1928).

It is known that the *Campos Rupestres* do not represent a single floristic group, encompassing areas of endemism at various scales and across several biomes (Echternacht *et al.* 2011; Neves *et al.* 2017). As a result, different provinces and districts are now recognized (Colli-Silva *et al.* 2019; Azevedo *et al.* 2024), and each habitat has its own specific flora and phylogenetic lineages (Zappi *et al.* 2017). This directly affects conservation efforts in *Campos Rupestres*, emphasizing the need to reassess the current limits of their protected areas and create additional conservation units to safeguard their biota and their ecosystem services (Neves *et al.* 2017; Pacheco *et al.* 2018; Fernandes *et al.* 2020). It is worth mentioning that this broader understanding of *Campos Rupestres* is a direct result of continuous efforts in taxonomic research and floristic studies, which began in the 19th century (*e.g.*, *Flora brasiliensis* [Martius 1840-1906]) and became more intensive in the late 20th century (Giulietti *et al.* 1997, 2005; Rapini *et al.* 2008; Almeida *et al.* 2023). New floristic studies covering unexplored *Campos Rupestres* areas are essential for a more comprehensive understanding of their flora and regions of endemism (Echternacht *et al.* 2011; Almeida *et al.* 2023).

The Quadrilátero Aquífero-Ferrífero (QAF; term adopted here, see Lobo & Cioni 2024), also known as the Iron Quadrangle, is located in the central part of the state of Minas Gerais (MG) and forms part of the southern portion of the Espinhaço Mountain Range (hereafter Espinhaço), although with geomorphological characteristics. The region covers an area of 7,200 km², distributed across 34 municipalities (Dorr 1969). It lies in an ecotonal zone between two biodiversity hotspots, the Atlantic Forest and Cerrado domains (Mittermeier *et al.* 2004, 2011), and encompasses both ferruginous and quartzitic *Campos Rupestres* (Dorr 1969; Jacobi & Carmo 2008; Messias *et al.* 2012). The region has been continuously impacted by historical changes in the landscape and exploratory economic activities, resulting in irreversible damage to its ecosystems (Dorr 1969; Jacobi & Carmo 2008; Jacobi *et al.* 2011; Salles *et al.* 2019; Mucida *et al.* 2019; Fernandes-Filho

et al. 2022). It is the largest iron-ore province in the world (Spier *et al.* 2003; Jacobi & Carmo 2008). Due to its high richness, endemism, and threats to its species (Jacobi *et al.* 2007, 2011; Borsali 2012; Carmo & Jacobi 2013), QAF is considered an important hotspot for the conservation of the evolutionary history and phylogenetic diversity of the *Campos Rupestres* flora (Fernandes *et al.* 2014; Pontara *et al.* 2018) and the biodiversity of the state of Minas Gerais (Drummond *et al.* 2005), where new species continue to be discovered, even in historically well-collected areas such as the Itacolomi State Park (Pessoa & Pedrosa 2022; Zavatin *et al.* 2023).

Despite the recognition and importance attributed to QAF and the objectives of biodiversity inventory, relict *Campos Rupestres* areas can still be identified within QAF, where the flora remains unexplored. One example is the Serra do Frazão, located in the eastern portion of the QAF. The area has not been submitted to botanical collections for the past two decades and is surrounded by mining activities, especially the adjacent Timbopeba Mine (Vale S.A). Therefore, this study aimed to perform the first floristic survey of the species in the *Campos Rupestres* of Frazão to fill the knowledge gap on the local flora and historically neglected areas in QAF. A species list was provided, identifying patterns of geographic distribution, endemism, and threat status, and compare their richness with two adjacent areas, the Itacolomi State Park and the Santuário do Caraça Private Natural Heritage Reserve. We hope our results help advance biodiversity inventories, reduce sampling biases, improve understanding of species distribution, and support the conservation of the *Campos Rupestres*, especially the protection of Serra do Frazão.

Materials and Methods

Study area

Serra do Frazão (20°15'40"S, 43°29'10"W) is located in the eastern portion of the QAF, in the municipality of Ouro Preto, district of Antônio Pereira, near the border with the city of Mariana, Minas Gerais (Figs. 1b; 2a). It covers an area of approximately 1,100 hectares (ha), of which 200 ha constitute a Legal Reserve area of the Vale S.A. company (Fig. 1c), where the Timbopeba mining enterprise and the Doutor Dam operate within the Mariana Complex (Fig. 1a,c,e). In 2007, it was considered a natural site by the Municipal Government of Ouro Preto (PMOP 2023) and, in 2012, recognized as an important geological area included in the proposal to create the Quadrilátero Ferrífero Geopark (Azevedo *et al.* 2012).

The vegetation is composed of Semideciduous Seasonal Forest (SSF), mainly at the base, slopes, and in valleys with soil accumulation, between 700

and 1,200 m above sea level. At the top, there are quartzitic *Campos Rupestres*, mainly above 1,200 m, up to 1,350 m at Pico do Frazão (Figs. 1d-e; 2). It is important to note that *Campos Rupestres* also occur at lower altitudes, as well as forest enclaves at higher altitudes between outcrops (Figs. 1; 2e-h). In the northern portion of Serra do Frazão, between 800 and 900 m, there are *Campo Sujo* features between quartzite outcrops (Fig. 2d). Gallery forests are associated with the Frazão and Natividade streams.

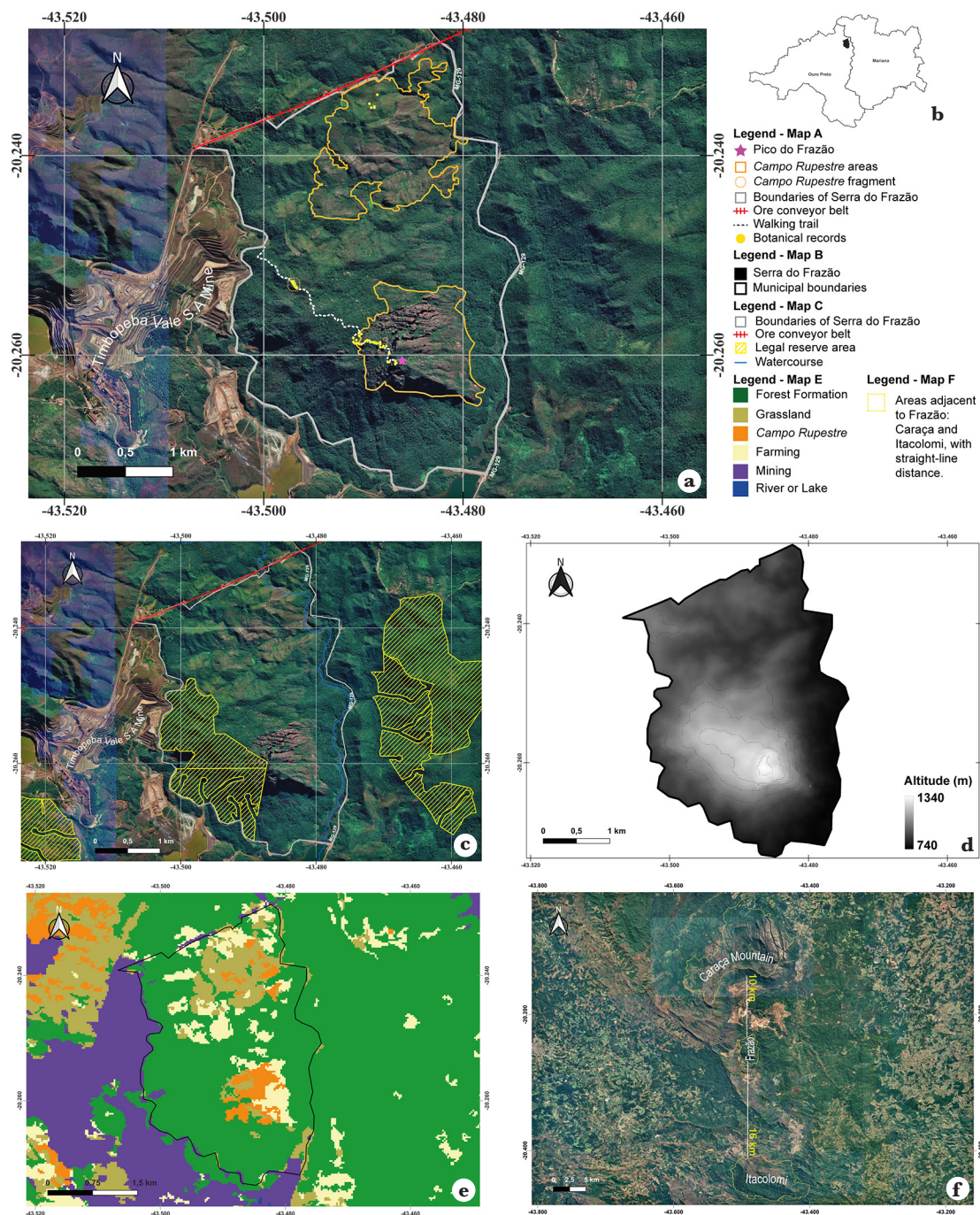
The climate is mesothermal of the Cwb type, with cold, dry winters and hot, rainy summers, according to the Köppen classification (Álvares *et al.* 2013). The hydrographic network comprises tributaries of the Rio Doce Basin, such as the Gualaxo do Norte River and the Piracicaba River. According to Dorr (1969), Serra do Frazão represents a remnant of post-Gondwanan erosion in QAF and is located between the Conta História and Alegria synclines, and south of the Santa Rita syncline, with stratigraphy composed of rocks from the Itacolomi Group. Its lithology consists of coarse to medium grains of sericitic quartzites at the top, along with vein quartz, conglomeratic quartzites, and lenses of conglomerates with itabirite, phyllite, and ferruginous quartzite pebbles (Dorr 1969; Maxwell 1972).

Campos Rupestres delimitation and accessibility

In the Pico do Frazão region, the criterion for recognizing *Campos Rupestres* is the presence of rocky outcrops. This core area is confined to the mountaintop and covers approximately 123 ha (1.23 km²) (Figs. 1a; 2b-c). In this region, the *Campos Rupestres* is composed of large, interlocking rock blocks, without the diversity of physiognomies that characterize *Campos Rupestres* in its broader sense, such as *Campos Limpos*, *Campos Sujos*, and *Turfeiras* (Fig. 2e-g). Access to this core area is via a single trail, approximately 4 km in length and 440 m of elevation gain (Fig. 1a, white dashed line). The difficulty in walking this trail and keeping it open imposed certain field planning and required a high level of effort so that it was not possible to invest in other accesses and routes. Furthermore, moving through this core area is unhealthy and dangerous, as the rock blocks form large cracks within the vegetation (Fig. 2e). These factors limited access to the area and the scope of collections.

Floristic survey

The survey was initiated by compiling records from virtual herbaria available at SpeciesLink (<<http://www.splink.org.br/>>), Re flora (<<https://reflora.jbrj.gov.br/reflora/herbarioVirtual/>>), and JBRJ (<<http://jabot.jbrj.gov.br/>>). This initial database gathered data from the following herbaria:



Geographic Coordinate System DATUM WGS 84. Maps B, C and D - scale 1: 20,000. Map E - scale 1: 34,000. Map F - scale 1:200,000. Data Source: Field Work, Google Earth, MapBiomias Brasil, IDE-Sisema, SICAR, U.S. Geological Survey. Elaborated by Vítor Araújo da Silva - July 2024.

Figure 1 – a-f. Maps of the study area – a. delimitation of the Serra do Frazão, including the collection trail, botanical records, and limits of sampled *Campos Rupestres* areas; b. location of Serra do Frazão in Ouro Preto; c. delimitation of the Serra do Frazão, highlighting the Legal Reserve area, registered according to SICAR (<<https://www.car.gov.br/#/>>), and Córrego Natividade route; d. altimetry of Serra do Frazão; e. land use and coverage according to MapBiomias (2024); f. distance from Frazão to Itacolomi State Park (Ouro Preto) and Serra do Caraça RPPN (Catás Altas/Santa Bárbara).

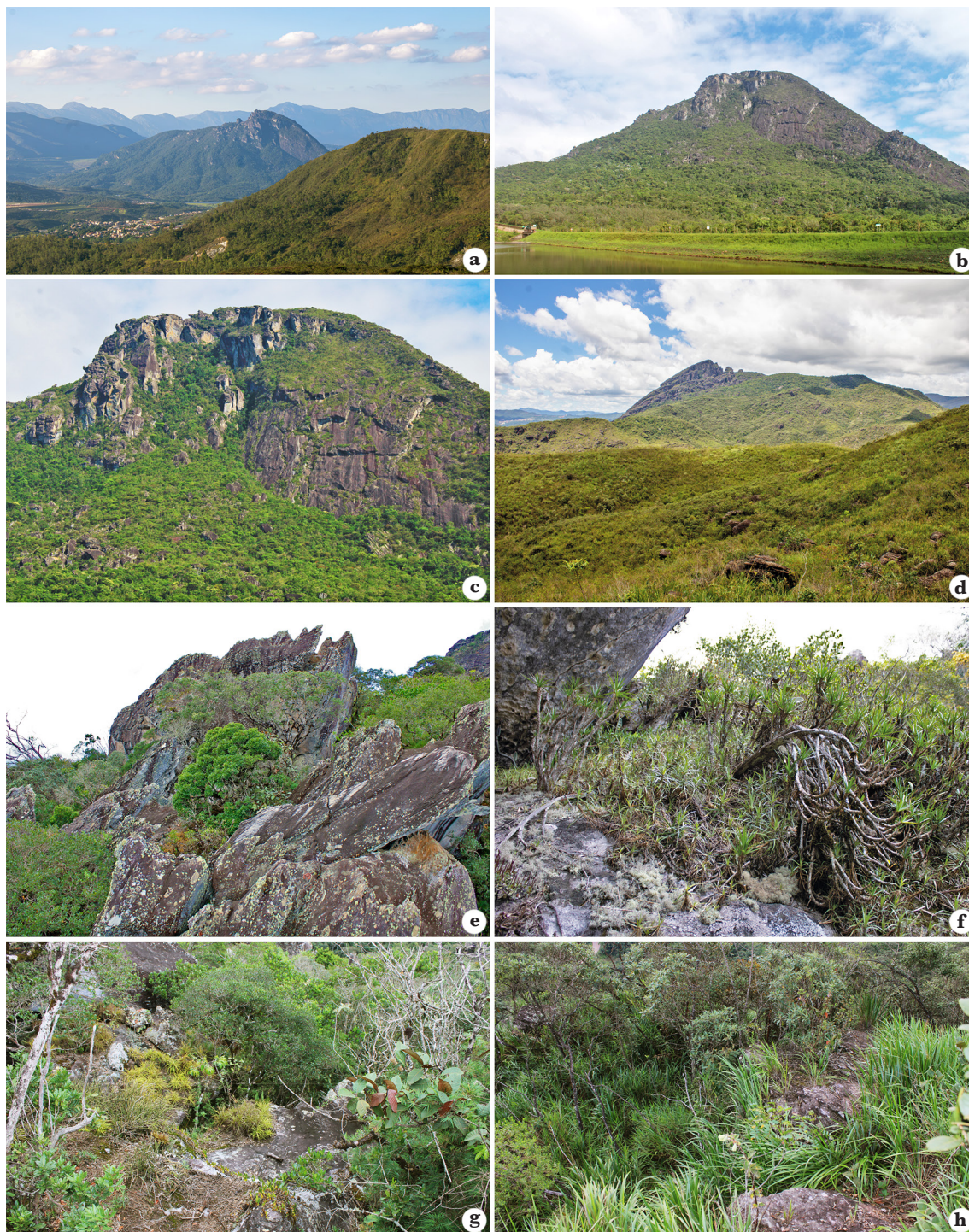


Figure 2 – a-h. Zoom into Frazão’s landscapes and *Campo Rupestre* vegetation – a. view of the eastern face of Serra do Frazão, with the district of Antônio Pereira in the foreground and Serra do Caraça in the background; b-c. views of the southern face of Pico do Frazão; d. view of the northern face of Serra do Frazão; e-g. *Campo Rupestre* vegetation in the Pico do Frazão region; h. *Campo Rupestre* fragment at the base of Frazão. (Photos by Vitor Araújo).

ALCB, B, BHCB, CESJ, ESAL, MO, NY, OUPR, P, R, RB, SPF, UFP, US, and VIC (acronyms according to Thiers, continuously updated). The collections of the OUPR and BHCB herbaria were also physically consulted.

Field expeditions were conducted from November 2022 to September 2024, covering all seasons. Botanical collections were performed using the walking method (Filgueiras *et al.* 1994). Fertile Tracheophyte individuals, occurring on or between outcrops were collected, herborized, and deposited in the OUPR herbarium. Authorization for collection was requested from the Vale S.A. company. Identifications were based on comparisons with exsiccata already determined in the herbarium, consultations with identification keys, and specialized references such as taxonomic reviews and local floras. When necessary, photos and/or duplicates were sent for identification by expert taxonomists.

The nomenclatural definitions and synonyms follow the Flora and Funga of Brazil (FFB 2024; <<http://floradobrasil.jbrj.gov.br/>>). Photos of the type specimens were consulted in Global Plants on JSTOR (<<https://plants.jstor.org/>>). The taxonomic classification system for the angiosperm families follows APG IV (2016), and for lycophytes and ferns, the PPG I (2016).

Data filtering

Considering that the *Campos Rupestres* and forest vegetation are intertwined, some filters were applied to avoid inflating the floristic list with species typical of forest environments. Herbarium records without habitat information were excluded. Species that had not been recorded for *Campos Rupestres* by FFB (2024), taxonomic reviews, descriptions, flora studies, or in herbarium records such as those that are typical elements of forest environments, were also excluded from the final list, even if they were on or among Serra do Frazão rocky outcrops.

For each listed species, data on origin, phytogeographic domains, vegetation types, and geographic distribution were compiled according to FFB (2024) (Tab. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.31872700>>). In cases where this information was unavailable, the respective fields were marked as 'not available'. Habit and substrate were categorized based on field observations and collectors' notes; missing data were supplemented with information from FFB (2024). All species with scandent or climbing habits were standardized as Lianas. Furthermore, the classification of exotic invasive species follows ICMBio Ordinance No. 510 (2025) and the Horus Institute database (2025), whereas the identification of weeds follows Lorenzi (2008).

To analyze the geographic distribution patterns, species the occurrence was categorized as widespread when present in more than five states, moderate when present in up to five states, and restricted when present in fewer than three states. Endemism levels were assessed for the state of Minas Gerais (MG), Quadrilátero Aquífero-Ferrífero (QAF), and Serra do Frazão (FZ).

Endemism at the MG level follows FFB (2024). After identifying species endemic to MG, we filtered occurrences in virtual herbaria and consulted taxonomic reviews and other reference works to classify species endemic to QAF. Specimens with *cf.* determinations or *aff.* designations were excluded. Only species recorded within municipalities of the QAF were considered exclusive to the region. We also verified whether the determination had been confirmed by a specialist and, for exceptional records, requested exsiccata photos to confirm the identification. The list was compared with Borsali (2012). Finally, we comment on the distribution and conservation status of each species listed as endemic to the QAF. The recognition of microendemic species of Serra do Frazão follows Rodrigues (2022) and Smith & Ayensu (1976), and the same analysis criteria for confirmation.

Floristic similarity

The species identified for the *Campos Rupestres* of Serra do Frazão were compared with two adjacent areas: Itacolomi State Park (IT) and the Santuário do Caraça Private Natural Heritage Reserve (SCA) (Fig. 1f), two important conservation units of the QAF with similar phytophysiognomies. Serra do Frazão is approximately 16 km and 10 km away in a straight line from IT and SCA, respectively (Fig. 1f). Messias *et al.* (2017) and Rolim & Salino (2008) were consulted as references for IT, Ferreira (2015) and Viveros (2010) for SCA. When necessary, synonyms were standardized according to FFB (2024). Results were illustrated using a Venn diagram to demonstrate the shared and exclusive species between the selected areas.

Threatened species

The threat status of species follows the National Center for Flora Conservation (CNCflora, constantly updated) and MMA Ordinance No. 148 (2022). In addition, species whose status was assessed in taxonomic review works or regional floras were also indicated. To assess the threat status of *Barbacenia beauverdii* Damazio, a microendemic species of Serra do Frazão, the Area of Occupancy (AOO) was calculated using the GeoCAT platform (<<https://geocat.iucnredlist.org/>>; Bachman *et al.* 2011), following IUCN Red List criterion B. Since this species are known from a single-occurrence

location, only AOO was used, and it is not necessary to calculate the Extent of Occurrence (EOO). Regarding *Paepalanthus atrovaginatus* Ruhland, which is also a microendemic of Serra do Frazão, its assessment was conducted by Rodrigues (2022) and more thoroughly by Amorim *et al.* (2024).

Maps

A polygon for Serra do Frazão was delimited based on satellite images from Google Earth®. The boundary of the Legal Reserve area was obtained via the Rural Environmental Registry (CAR) platform (SICAR 2024; <<https://www.car.gov.br/publico/imoveis/index>>) (Fig. 1c). Land use and land cover data were obtained from MapBiomas Collection (<<https://brasil.mapbiomas.org/>>), available in the QGIS software (<<https://qgis.org>>) (Fig. 1e). The classes and legend colors follow the 7th MapBiomas collection (2024). Based on MapBiomas land cover data, the vegetation boundaries of the rocky field were superimposed to delimit the spatial extent of Pico do Frazão and other *Campos Rupestres* areas within the Serra do Frazão (main *Campos Rupestres* areas are shown in orange in Fig. 1a). Elevation data were generated from the U.S. Geological Survey (<<https://earthexplorer.usgs.gov/>>) (Fig. 1d). Additional reference vector layers were downloaded from the IDE-Sisema database (<<https://idesisema.meioambiente.mg.gov.br/>>). Because most herbarium records lacked geographic coordinates, the botanical records primarily correspond to our field collections. All maps were generated using the QGIS 3.34.3 software. The vegetation classification follows the Brazilian Vegetation Technical Manual (IBGE 2012).

Results

We recorded 436 specimens belonging to 97 families, 261 genera, and 410 species of vascular plants in the *Campos Rupestres* of Serra do Frazão (Tab. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.31872700>>). Of these species, 335 (81.7%) are new records for Serra do Frazão, 18 for the municipality of Ouro Preto, and two for the state of Minas Gerais (see column B, “New records for Frazão”, and column H, “Geographic distribution”, in Tab. S2). Two records remained identified only at the family level, 23 at the genus level, and four species to be confirmed (*cf.*), in addition to four subspecies and two varieties (Tab. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.31872700>>).

Angiosperms are represented by 83 families, 228 genera, and 339 species (82.7% of total species), with Orchidaceae (50 spp.) and Asteraceae (37 spp.) being the richest families, followed by Melastomataceae (17 spp.), Rubiaceae,

Bromeliaceae, and Fabaceae (15 spp. each), Piperaceae (11), Myrtaceae (10), and finally Cyperaceae and Eriocaulaceae (8 spp. each) (Fig. 3a). Among genera, *Peperomia* (9 spp.), *Myrcia* (7), *Epidendrum* (6), *Cattleya*, *Paepalanthus*, *Mikania* and *Solanum* (5 spp. each) stand out. Another eight genera (*Baccharis*, *Barbacenia*, *Chamaecrista*, *Leandra*, *Bulbophyllum*, *Microlicia*, *Dioscorea*, and *Maxillaria*) are tied with four species each (Fig. 3b).

Ferns are distributed across 14 families, 33 genera, and 71 species (17.3%). Polypodiaceae (21 spp.), Aspleniaceae (12), Dryopteridaceae (11), Pteridaceae (8), and Hymenophyllaceae (6) are the richest families (Fig. 3c), while *Asplenium* (12 spp.), *Elaphoglossum* (9), and *Campyloneurum* (5) are the most species-rich genera, followed by *Serpocaulon*, *Pecluma*, *Microgramma*, and *Hymenophyllum*, with three species each (Fig. 3d).

These numbers are highly expressive; the total number of species in this inventory represents an increase of 349 taxa (85%). Before our fieldwork, only 61 species of vascular plants had been indicated for the *Campos Rupestres* of Serra do Frazão (based on the filtering of the voucher collection notes). Of these species, 75% were ferns, represented by 13 families and 26 genera, while the remaining 25% were angiosperms, represented by eight families and 12 genera. This representation is highlighted in Figure 3 (gray columns) through the comparison of species' richness, as well as their absence.

Considering the habit of the species, herbs correspond to the main life form (216 spp.), followed by shrubs (89), trees (43), lianas (31), and subshrubs (30). The palm habit was represented by only one species (Fig. 4a). Regarding the substrate, terrestrial species predominate (211 spp.), followed by rupicolous (140), epiphytes (24), and those that occupy terricolous and rupicolous habits (20) (Fig. 4b).

Six taxa, including five species and one form, have type collections from Serra do Frazão: *Barbacenia beauverdii* (L.B. Damazio 1846 [G, OUPR]), *Oleandra baetae* Damazio (A.B. Neves [OUPR 10824]; L.B. Damazio 1795 [RB]; A.B. Neves 1795 [P]), *Paepalanthus atrovaginatus* (W. Schwacke 14329 [B, LL]), *Paepalanthus damazioi* Beauverd (L.B. Damazio 1844 [G, RB]), *Paepalanthus plantagineus* f. *luxurians* Beauverd (L.B. Damazio 1844 [G]), and *Peperomia barbulpetiola* C.DC (L.B. Damazio 2041 [RB, G]).

Regarding the geographic distribution of species, 57.4% were widely distributed across Brazilian states, 23% showed moderate distribution, and 19.6% were restricted (Tab. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.31872700>>). Among species with more restricted distribution, 14 only occur at Espinhaço (MG and BA), and 51 are exclusive to the state of

Minas Gerais. Of the species endemic to Minas Gerais, 11 occur exclusively in the Quadrilátero Aquífero-Ferrífero: *Staurogyne minarum* (Nees) Kuntze (Acanthaceae); *Aristolochia marianensis* Ahumada (Aristolochiaceae); *Hoplocryptanthus ferrarius* (Leme & C.C.Paula) Leme, S.Heller & Zizka and *H. glaziovii* (Mez) Leme, S.Heller & Zizka (Bromeliaceae); *Cipocereus laniflorus* N.P.Taylor & Zappi (Cactaceae); *Paepalanthus atrovaginatus*, *P. caespititius* Mart. ex Körn. and *P. plantagineus* (Bong.) Körn. (Eriocaulaceae); *Pleroma decemcostatum* (Cogn.) P.J.F.Guim. & Michelang. (Melastomataceae); *Barbacenia beauverdii* and *B. damaziana* Beauverd (Velloziaceae) (Fig. 5). *B. damaziana* and *P. caespititius* are endemic to the municipality of Ouro Preto, whereas *B. beauverdii* and *P. atrovaginatus* are microendemic to Frazão.

Of these species, only *Staurogyne minarum*, *Hoplocryptanthus ferrarius*, *Cipocereus laniflorus*, and *Barbacenia damaziana* were previously listed as endemic to the QAF by Borsali (2012). Based on the analysis of occurrence records, we also consider *A. marianensis* and *P. decemcostatum* to be endemic to the QAF. Additionally, *A. marianensis* and *H. glaziovii* are reported here as new records for Ouro Preto. In total, the known distributions of seven of the eleven QAF-endemic species were expanded in this study (*A. marianensis*, *B. damaziana*, *H. ferrarius*, *H. glaziovii*, *Paepalanthus caespititius*, *Pleroma decemcostatum*, and *S. minarum*; see section 4.3 of the Discussion for further details).

In addition to the two species mentioned, another 16 taxa that are new records for the municipality of Ouro Preto: *Anathallis sclerophylla* (Lindl.) Pridgeon & M.W.Chase (Orchidaceae); *Barbacenia graminifolia* L.B.Sm. (Velloziaceae); *Bulbophyllum plumosum* (Barb.Rodr.) Cogn. (Orchidaceae); *B. regnellii* Rchb.f. (Orchidaceae); *Cyclopogon argyriifolius* Barb.Rodr. (Orchidaceae); *Cyrtopodium glutiniferum* Raddi (Orchidaceae); *Epidendrum filicaule* Lindl. (Orchidaceae); *Gomesa flexuosa* (Lodd.) M.W.Chase & N.H.Williams (Orchidaceae); *Hymenophyllum rufum* Fée (Hymenophyllaceae); *Maranta cristata* Nees & Mart. (Marantaceae); *Maxillaria notylioglossa* Rchb.f. (Orchidaceae); *Microlicia passerina* Naudin (Melastomataceae); *Peperomia hydrocotyloides* Miq. (Piperaceae); *Philodendron cipoense* Sakur. & Mayo (Araceae); *Schwartzia adamantium* (Cambess.) Bedell ex Gir.-Cañas (Marcgraviaceae) and *Sesamum indicum* L. (Pedaliaceae).

Two Orchidaceae species are newly recorded for the state of Minas Gerais: *Cochleanthes flabelliformis* (Sw.) R.E.Schult. & Garay and *Stanhopea guttulata* Lindl. Additionally, *Rhipsalis crispata* (Haw.) Pfeiff. (Cactaceae) and *Peperomia lanceolato-peltata* C.DC. (Piperaceae), which are not listed with distributions for Minas Gerais in Flora and Funga of Brazil (2024), had their occurrence in the state confirmed here (column H, Tab. S2, available on supplementary material <<https://doi.org/10.6084/m9.figshare.31872700>>).

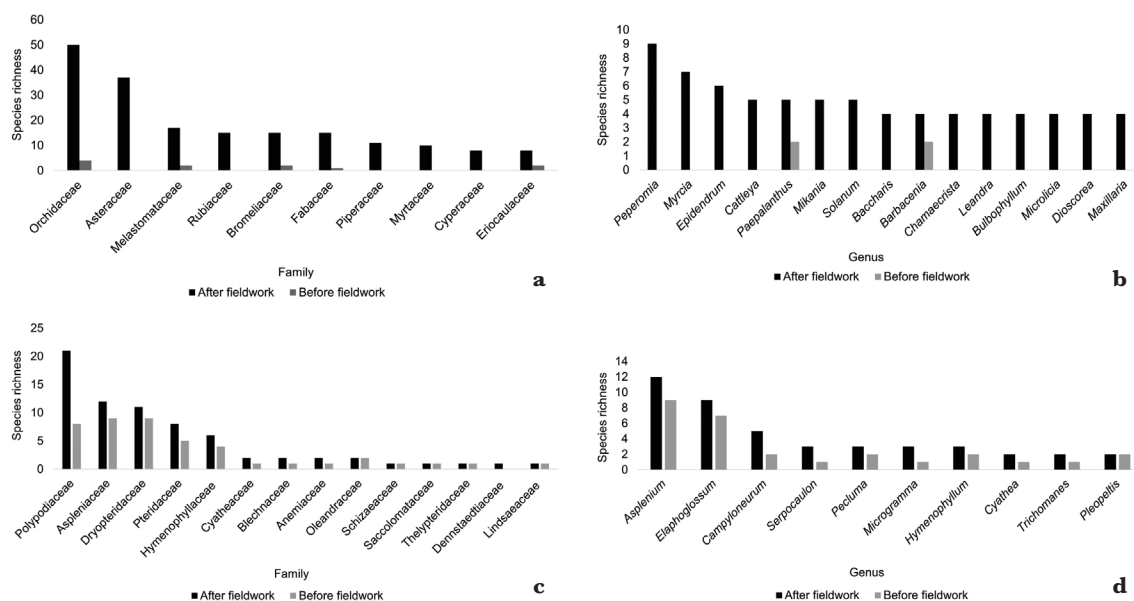


Figure 3 – a-d. Diversity of angiosperms and ferns in Frazão – a. the 15 richest Angiosperm families; b. the 10 richest Angiosperm genera; c. the richest Fern families; d. the richest Fern genera. Black columns represent species richness after our field collections, while gray columns represent richness before our collections, relying solely on previous records in herbaria.

Almost all species are native to Brazil; only *Sesamum indicum* and *Melinis minutiflora* P.Beauv. are considered invasive, exotic, and/or naturalized in the country and in Serra do Frazão. Two other weedy and invasive species were also recorded: *Triumfetta semitriloba* Jacq. and *Pteridium esculentum* subsp. *arachnoideum* (Kaulf.) Thomson. Particularly noteworthy is the first recorded occurrence of *S. indicum* (sesame) in *Campos Rupestres* of Brazil.

Regarding the floristic similarity, less than half of the species are shared among Frazão, Caraça, and Itacolomi (42.4%). In terms of species shared exclusively by each area, Serra do Caraça stands out with 26.6% similarity with Serra do Frazão, while Itacolomi has only 9.8%. The uniqueness of the flora of *Campos Rupestres* of Frazão is also noteworthy, with 21.2% of the total species exclusive to its area (Fig. 4c).

Regarding the risk of extinction, 260 (63.6%) of species were not evaluated (NE), 114 (28%) are classified as least concern (LC), 14 (3%) in the near threatened (NT) category, four (1%) vulnerable (VU): *Elaphoglossum acrocarpum* (Mart.) T.Moore (Dryopteridaceae), *Ficus laureola* Warb. ex C.C.Berg & Carauta (Moraceae), *Hippeastrum morelianum* Lem. (Amaryllidaceae), *Macropeplus schwackeanus* (Perkins) I.Santos & Peixoto (Monimiaceae). Nine species (2.2%) are classified as endangered (EN): *Cattleya wittigiana* (Barb. Rodr.) van den Berg (Orchidaceae), *Cipocereus laniflorus* (Cactaceae), *Mikania glauca* Mart. ex Baker (Asteraceae), *Paepalanthus plantagineus* (Eriocaulaceae), *Philodendron cipoense* (Araceae), *Psychotria paludosa* Müll.Arg. (Rubiaceae), *Qualea lundii* (Warm.) Warm. (Vochysiaceae), *Richtergo polyphylla* (Baker) Ferreyra (Asteraceae) and *Staurogyne minarum* (Acanthaceae); six (1.2%) are critically endangered (CR): *Barbacenia beauverdii* (Velloziaceae), *Heterocoma albida* (DC. ex Pers.) DC. (Asteraceae), *Hoplocryptanthus glaziovii* (Bromeliaceae), *Paepalanthus atrovaginatus* (Eriocaulaceae), *Paepalanthus caespititius* (Eriocaulaceae), and *Rhipsalis crispata* (Cactaceae); and two (0.5%) are classified as insufficient data (DD): *Anetanthus gracilis* Hiern (Gesneriaceae) and *Vriesea schwackeana* Mez (Bromeliaceae) (Fig. 4d; see Figs. S1 and S2 (available on supplementary material <<https://doi.org/10.6084/m9.figshare.31872700>>) for images of the species; Tab. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.31872700>>).

Among these species in the NT to CR categories, 11 are listed by the MMA (2022), 18 are recorded on the CNCFlora platform (continuously updated; Borges & Moraes 2012; Coelho & Moraes 2012; Kutschenko & Messina 2012a,b; Messina & Moraes 2012a,b; Moraes & Messina 2012a b; Moraes 2012; Pessoa & Messina 2012; Amaro &

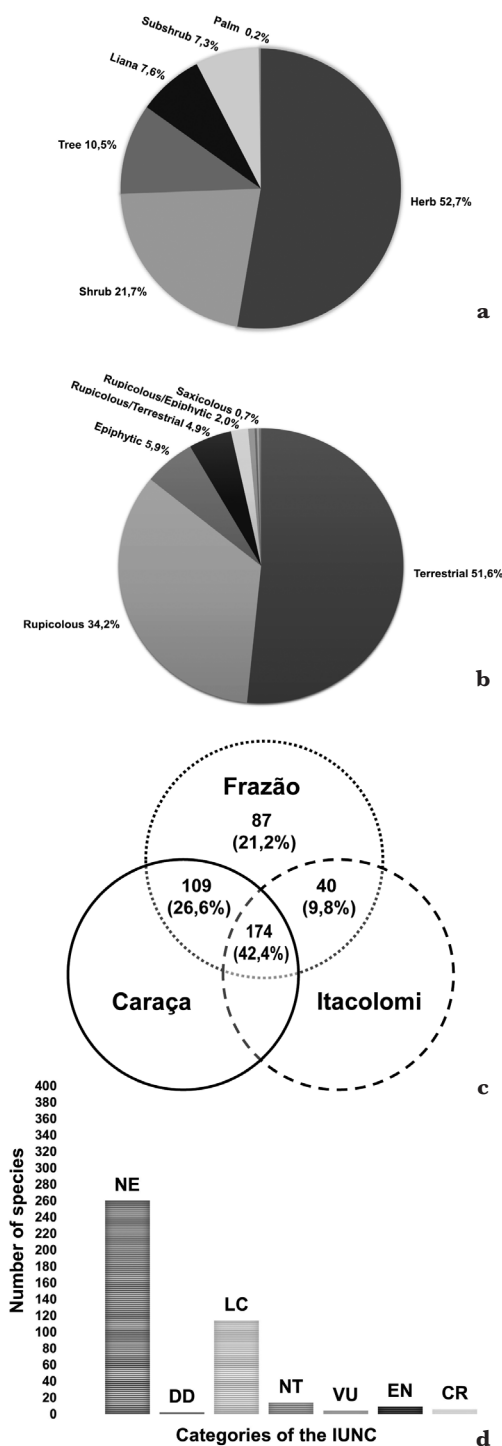


Figure 4 – a. Main life forms of vascular plants in the *Campos Rupestres* of Frazão. b. Main substrates of occurrence of vascular plants in the *Campos Rupestres* of Frazão. c. Floristic similarity of Frazão with Itacolomi and Serra do Caraça, including species exclusive to Frazão and shared with the other two areas. d. Number of species from Frazão assessed in any of the IUCN Red List categories.

Santos 2014; Araújo & Messina 2014a,b; Amorim *et al.* 2020, 2024; Moraes *et al.* 2021; Negrão *et al.* 2021; Fraga *et al.* 2023), and four were identified through independent studies (Barbosa *et al.* 2021; Rodrigues 2022), including *Barbacenia beauverdii*, which is assessed in this study. In total, 33 species are classified as threatened in the Serra do Frazão (Tab. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.31872700>>).

Discussion

Species richness of Serra do Frazão

We collected mostly within an area of approximately 4 km², and nearly 82% of the species recorded were new records for Frazão, increasing the total number of species by more than sixfold. We also expanded the geographic distribution of species previously considered more restricted and identified 18 new records for the municipality of Ouro Preto (Wallacean deficit). If the determination of *Heisteria* cf. *perianthomega* (Vell.) Sleumer (Erythrolpalaceae) is confirmed in the future, this species will also be a new occurrence for the municipality, totaling 19 new records. These findings show that even small, unexplored *Campos Rupestres* areas close to historical research centers are home to unprecedented flora richness and diversity.

The richest angiosperm families reported in Serra do Frazão were similar to what was expected for *Campos Rupestres* (Giulietti *et al.* 1987; Conceição & Giulietti 2002; Pirani *et al.* 2003; Conceição & Pirani 2005, 2007; Teixeira & Lemos-Filho 2013; Forzza *et al.* 2013; Ferreira 2015; Silveira *et al.* 2016; Messias *et al.* 2017). However, they vary in richness position, with exceptions for monocotyledons Poaceae, Cyperaceae, Eriocaulaceae, Velloziaceae, Xyridaceae, which are less represented in Frazão. This can be explained by the fact that such families occur preferentially in open *Campos Rupestres* areas, and only rarely in areas where forest physiognomies exert greater influence on *Campos Rupestres* (Zappi *et al.* 2017), as is the case of Frazão. In contrast, Piperaceae, listed in this study among the richest families, presents species richness in shaded and forested environments (Guimarães *et al.* 2024), further evidencing the influence of the Atlantic Forest on the *Campos Rupestres* of Frazão.

Other studies in Minas Gerais, although not focused exclusively on *Campos Rupestres* vegetation, have also showed great diversity of Piperaceae. In Serra do Caraça, 27 species were listed (Ferreira 2015), 25 in Itacolomi (Messias *et al.* 2017), 23 in Serra do Cipó (Carvalho-Silva *et al.* 2013), 21 in Ibitipoca Park (Medeiros & Guimarães 2007), and 16 in Serra da Canastra (Carvalho-Silva & Guimarães 2009). Although they appear more frequently as epiphytes

in the Atlantic Forest, especially the genus *Peperomia* (Menini-Neto *et al.* 2016; Moura *et al.* 2022), of the 11 species of Piperaceae recorded in Frazão, only one is epiphytic, while seven are rupicolous and the other three are terricolous. Notably, all seven species that inhabit rupicolous environments belong to the genus *Peperomia*. Moura *et al.* (2022) also note that the rupicolous habit is frequent among *Peperomia* species, sometimes being restricted to this substrate or varying between epiphytic and terrestrial habits. Furthermore, *Peperomia* stands out as one of the most species-rich angiosperm genera, presenting pantropical distribution, mainly in humid forests, and a wide variety of habits (Frodin 2004; Frenzke *et al.* 2015).

The other two Monocotyledons, Orchidaceae and Bromeliaceae, which present a significant species richness in Frazão, are remarkably diverse both in the Atlantic Forest and the *Campos Rupestres* (Giulietti *et al.* 1977; Rapini *et al.* 2008; van den Berg *et al.* 2009; Freitas *et al.* 2016). Orchidaceae is also the second most species-rich family in the Brazilian flora, surpassed only by Fabaceae. In Frazão alone, Orchidaceae accounted for 12% of the angiosperm richness. Two genera rank among the richest: *Epidendrum* (3rd place) and *Cattleya* (4th). *Epidendrum* is a species-rich genus in the Atlantic Forest domain, where they are frequently found as epiphytes and, to a lesser extent, rupicolous and /or terricolous (Pinheiro & Cozzolino 2013; Forzza *et al.* 2014; Pessoa 2024). In contrast, the genus *Cattleya* exhibits high species richness in *Campos Rupestres*, with many of them being strictly endemic to a single area (van den Berg 2018). Additionally, eight of the 50 species listed for the family represent new records for the municipality of Ouro Preto. This suggests that Frazão is a relictual refugium of orchid diversity, as the family has been overcollected in the surrounding areas for ornamental purposes.

The second richest family in species in Frazão, Asteraceae, is also one of the most diverse in Brazil and worldwide (Funk *et al.* 2009; BFG 2015). Its diversity is primarily concentrated in open vegetation areas, such as the Cerrado and the *Campos Rupestres*, but it is also found along the Atlantic Forest (Funk *et al.* 2009; Silveira *et al.* 2016; FFB 2024). In Frazão, the most species-rich genera are *Mikania* (6th) and *Baccharis* (8th), both of which are also among the most diverse in the *Campos Rupestres*, a region recognized as a center of diversity and endemism for many of its species (Campos *et al.* 2019; Heiden 2021).

Myrcia, *Paepalanthus*, and *Solanum* are among the most species-rich angiosperm genera in Brazil (BFG 2015), and *Myrcia* and *Paepalanthus* are also the richest in *Campos Rupestres* (Silveira *et al.* 2016). It is noteworthy that, of the five *Paepalanthus* species, three are restricted to the QAF, and one is endemic



Figure 5 – a-k. Endemic species of the Quadrilátero Aquífero-Ferrífero with occurrences in Frazão, including the two microendemics and those endemic to Ouro Preto – a. *Aristolochia marianensis*; b. *Barbacenia beauverdii*; c. *Barbacenia damaziana*; d. *Cipocereus laniflorus*; e. *Hoplocryptanthus ferrarius*; f. *Hoplocryptanthus glaziovii*; g. *Paepalanthus atrovaginatus*; h. *Paepalanthus caespitius*; i. *Paepalanthus plantagineus*; j-k. *Pleroma decemcostatum*. (Photos: a. João Custódio; b, c, d, e, g, i, j and k. Vitor Araújo; f. Livia Echternacht; h. Luciano Pedrosa).

to Minas Gerais state. Notably, this work expands the distribution of *Paepalanthus caespitius*, a species endemic to Ouro Preto, and highlights the record of *Paepalanthus atrovaginatus*, a species strictly restricted to Frazão (further comments are provided below). *Solanum* is also among the largest genera of angiosperms in the world (Frodin 2004), being a speciose element in the Atlantic Forest. However, some of its species also extent into *Campos Rupestres* (Kamino *et al.* 2008; FFB 2024).

Regarding ferns, Polypodiaceae, Aspleniaceae, Dryopteridaceae, Pteridaceae, and Hymenophyllaceae are also among the richest families in Itacolomi (Rolim & Salino 2008), Serra do Caraça (Viveros 2010), Espinhaço (Salino & Almeida 2008), Atlantic Forest (Salino & Almeida 2009), and Brazil (Prado *et al.* 2015). Among genera, in general, *Elaphoglossum* and *Asplenium* were commonly mentioned in terms of richness (Rolim & Salino 2008; Salino & Almeida 2008, 2009; Viveros 2010; Prado *et al.* 2015). Both stand out as the most numerous and widely distributed genera of ferns in Brazil (Prado *et al.* 2015), comprising 90 and 75 species, respectively (Matos 2024; Sylvestre *et al.* 2024). Their species are frequently found as epiphytes, rupicolous, and/or terricolous in humid areas (Tryon & Tryon 1982).

The genera *Campyloneurum*, *Serpocaulon*, and *Pecluma* have lower species richness compared to the previous two. *Campyloneurum* has 21 species, while both *Serpocaulon* and *Pecluma* comprise 20 species each in Brazil (Assis & Salino 2024; Gonzatti & Windisch 2024; Schwartsburd 2024). *Campyloneurum* has a Neotropical distribution and typically occurs in humid forests as epiphytes or terrestrials. It also grows in disturbed areas and among rocks (Tryon & Tryon 1982). *Serpocaulon* is primarily found in tropical wet forests and mountainous regions, with its species occupying habitats that range from hemiepiphytic to rupicolous (Sanín *et al.* 2023). In contrast, *Pecluma* is a tropical to subtropical genus that is predominantly epiphytic, with a smaller proportion being terrestrial (Price 1983; Assis *et al.* 2016).

In general, pteridophytes are highly diversified in the humid forests of tropical and subtropical mountains (Tryon & Tryon 1982). In Brazil, the Southeast region is considered a special center of endemism, mainly along the Serra do Mar (Tryon & Tryon 1982). This pattern is highly attributed to the influence of the Atlantic Forest domain, which harbors the largest number of pteridophyte species among all Brazilian phytogeographic domains (Prado *et al.* 2015), particularly in the Ombrophilous and Semideciduous Forest formations (Salino & Almeida 2009). Species distribution patterns are closely related to the suitability of habitats for their survival and colonization, since few individuals are

capable of colonizing typically xeric environments, where water limitation is the main restrictive factor (Salino & Almeida 2008; Santiago *et al.* 2023). In the Espinhaço, the Quadrilátero Aquífero-Ferrífero comprises the richest region in fern and lycophyte species, with emphasis on the municipality of Ouro Preto, which holds most of the endemic species (Salino & Almeida 2008).

Regarding the habit and substrate of species in Frazão, the families richest in species of angiosperms and ferns surveyed were related to the percentages of these categories, with little representation of other families. Although it was not an analysis criterion in this study, Messias *et al.* (2011) point out the consistency of hemicryptophytes and phanerophytes as the main life forms for *Campos Rupestres*. Generally, hemicryptophytes predominate in depressions of quartzite rocks and shallow sandy soils, and in areas where there is an accumulation of deeper soil and organic matter, allowing species to root, phanerophyte species predominate (Messias *et al.* 2011). Furthermore, at higher altitudes, forests are strongly influenced by atmospheric humidity and fog events, making these locations rich in epiphytes, including orchids, bromeliads, anthuriums, peperomias, ferns, and bryophytes (Giulietti *et al.* 1997).

Geographic distribution and new occurrences of endemic species of QAF

The percentages of species with broad (57.4%) and restricted (19.6%) distribution patterns in the *Campos Rupestres* of Frazão are consistent with the findings of Giulietti & Pirani (1988). With respect to Quadrilátero Aquífero-Ferrífero endemics, *Staurogyne minarum* (Acanthaceae) is mainly restricted to the mountainous regions of Serra do Caraça and Santa Bárbara, above 700 m in altitude (Braz & Monteiro 2017). However, it also occurs in Brumadinho, Mariana, Nova Lima, and Ouro Preto (Borsali 2012), and is frequently found inside Gallery Forests (Kameyama *et al.* 2009). In Frazão, the species was collected in a transition area between the Semideciduous Seasonal Forest and *Campos Rupestres*. At the same time, in Serra da Gandarela, it was also recorded in a transitional environment between Semideciduous Forest and ferruginous *Campos Rupestres* (E.T. Neto & T. Mansur 5345 [BHCB]). In Serra da Calçada, the species also occurs in quartzitic *Campos Rupestres*, near a stream (P.L. Viana 1000 [BHCB]). Although it is frequent and recognized within Semideciduous Seasonal Forests (FFB 2024), based on the records above, we consider its occurrence in *Campos Rupestres* as well. *Staurogyne minarum* was listed in the “Plantas raras do Brasil” work (Kameyama *et al.* 2009), and according to Araújo & Messina (2014b), it is classified as EN.

Aristolochia marianensis (Aristolochiaceae), whose type specimen is from the city of Mariana (Ahumada 1979), is recorded here for the first time in Ouro Preto. This species is poorly sampled in herbaria, and in addition to the record in Frazão and the type collection, there is only one historical collection for the Caraça region (H.S. Irwin 29247 [RB, NY, UEC]), in the *Campos Rupestres* area. Despite the absence of the vegetation type of occurrence of the specimen in the type material (Ahumada 1979), the species has been included within the Cerrado vegetation (*lato sensu*) (Freitas *et al.* 2024). Based on our new collections and those cited above, we emphasize the need for the species to be considered part of the *Campos Rupestres* vegetation and as an endemic species of the QAF region. Regarding the status of threat, *Aristolochia marianensis* has not yet been evaluated (NE).

Hoplocryptanthus ferrarius (Bromeliaceae) is distributed mainly in Mariana and Catas Altas, with its populations mainly associated with ferruginous *canga* areas, from which the epithet “ferrarius” originates (Leme & Paula 2009). Its record in Frazão is the second for the municipality and the first for the area, where it is found as a rupicolous plant on quartzite outcrops. In Serra de Antônio Pereira, an area adjacent to Frazão, it grows on ferruginous *Campos Rupestres* (*canga*) (E. Guarçoni & C.C. de Paula 1577, 1576 [VIC]; E. Guarçoni 1574, 1697 [VIC]). Anastacio *et al.* (2020) also recorded *H. ferrarius* in quartzitic *Campos Rupestres* in the Poço Fundo RPPN (Congonhas, MG), Córrego Seco, and Capivari II (Itabirito, MG). Thus, the authors point to *H. ferrarius* as a species that escapes the concept of endemic to the Quadrilátero Aquífero-Ferífero *cangas* (Anastacio *et al.* 2020). Although Frazão has a greater predominance of quartzitic outcrops, there are local occurrences of ferruginous quartzites (Dorr 1969; Maxwell 1972). The species has not been evaluated for threat status (NE), and Leme & Paula (2009) have already indicated that *H. ferrarius* may become locally extinct in the future due to pressures from mining in the region.

Hoplocryptanthus glaziovii (Bromeliaceae) and *Cipocereus laniflorus* (Cactaceae) were considered strictly endemic to Serra do Caraça (Versieux & Wendt 2006; Taylor & Zappi 2008; Borsali 2012; Ferreira 2015). The new record of *H. glaziovii* for Serra do Frazão is the first for the municipality of Ouro Preto. In Serra do Caraça, the species is found in *Campos Rupestres*, as a saxicolous, between 1,000 and 1,600 m above sea level (Versieux & Wendt 2006). In Frazão, it was also found occupying the same habitat, being locally frequent above 1,200 m above sea level. The distribution range of *C. laniflorus* was recently expanded. The species occurs in Catas Altas (Serra do Caraça), Ouro Preto, and Santa Bárbara (Amorim *et al.* unpublished data).

In Ouro Preto, it is recorded in Frazão, Serra de Capanema (F.F. Carmo 3451 [BHCB]) and Cachoeira das Andorinhas Environmental Protection Area (APA) (L.G. Pedrosa 437 [OUPR]), all in areas of quartzitic *Campos Rupestres*. In Frazão, *C. laniflorus* is found in outcrops above 1,200 m above sea level, but is locally rare. Young individuals were also observed in the northern portion, at about 900 m above sea level. Signs of degradation were observed in mature individuals from Frazão, such as cuts in cladodes, which may compromise their survival. Even with the expanded geographic distributions, new assessments of the threat status indicate that *C. laniflorus* maintains its previous status (EN) (Amorim *et al.* unpublished data), and *H. glaziovii* remains classified as CR (MMA 2022).

Paepalanthus atrovaginatus (Eriocaulaceae) occurs only in the *Campos Rupestres* of Serra do Frazão and until 2021 was known only from its type material. The species is found mainly above 1,200 m above sea level, as an arenicolous, saxicolous, and/or rupicolous plant in shaded and humid environments, forming small population patches (Silva 2024). *P. caespititius* is endemic to Ouro Preto; it was previously known only from the type material of Cachoeira do Campo and was recently rediscovered in the Cachoeira das Andorinhas APA (Rodrigues 2022), with the Serra do Frazão record being the second for Ouro Preto. *P. plantagineus* is restricted to the Ouro Preto and Mariana regions, being more frequently found in Serra do Itacolomi (Rodrigues 2022). According to Rodrigues (2022), *P. atrovaginatus* and *P. caespititius* can be considered CR, and *P. plantagineus* EN, following the IUCN criteria B1ab (i,ii,iii) and B2ab (i,ii,iii) (2024). After reevaluation, *P. atrovaginatus* continues to be classified as Critically Endangered (CR) (Amorim *et al.* 2024).

Pleroma decemcostatum (Melastomataceae) is cited in the type material as having “Habitat in prov. Minas Geraes” (Cogniaux 1885). After consulting virtual herbaria, it was observed that the species occurs most frequently in Serra do Caraça (JBRJ 2024; SpeciesLink 2024). In Ouro Preto, it is distributed in Antônio Pereira, Frazão, Serra do Itacolomi, and Morro do Fraga, all of which have recently been documented (SpeciesLink 2024). In Frazão, its populations are concentrated in the Pico region on rocky outcrops. Both municipalities are located in the QAF, leading us to classify this species as endemic to the region, while acknowledging that further studies are needed to support our hypothesis. We believe that recognizing this, as in the case of *Aristolochia marianensis*, can stimulate research into their distribution and improve conservation strategies for both the region and these species. Additionally, *Pleroma decemcostatum* has not yet been evaluated for its threat status (NE).

Barbacenia beauverdii (Velloziaceae) is also exclusive to the *Campos Rupestres* of Frazão (Smith & Ayensu 1976), and its first record after the type collection was made in 2021 (D. Rodrigues *et al.* 37, 42, 46 [OUPR]). It is common on rocky outcrops above 1,200 m above sea level, forming islands of vegetation as rupicolous and/or saxicolous, and more rarely occurring as terricolous. Following the IUCN (2024) criteria, the species fits the B2ab (i,ii,iii) criteria and should be categorized as CR. Finally, *B. damaziana* is endemic to the Ouro Preto region (Smith & Ayensu 1976; Borsali 2012) and is frequently found in the Cachoeira das Andorinhas APA (SpeciesLink 2024). With the records for Frazão, we expanded its range of occurrences; in the area, it grows on rocky outcrops as a rupicolous species between 1,100 and 1,340 m above sea level. The species has also not been evaluated for its threatened category (NE).

New occurrences and comments on unlisted species for Minas Gerais

In addition to the new distribution records for endemic species of the Quadrilátero Aquífero-Ferrífero and the new records for Ouro Preto, two new occurrences were identified for the state of Minas Gerais: *Cochleanthes flabelliformis* and *Stanhopea guttulata*, both from the Orchidaceae family. *C. flabelliformis* is a Neotropical species recorded in the states of Rio de Janeiro and São Paulo, Brazil, within the Atlantic Forest domain, in Ombrophilous Forest (Meneguzzo & Hall 2024). *S. guttulata* is an endemic species of Brazil, distributed in the states of Bahia, Espírito Santo, Rio de Janeiro, and São Paulo, also in Ombrophilous Forest vegetation (Meneguzzo 2024). According to the collector's notes, both species were found growing on rocks in Frazão, suggesting they may belong to the *Campos Rupestres* vegetation. Despite extensive fieldwork, we did not encounter these species in the field, and the most recent collections date to 1974. However, their identifications have been confirmed by experts. Neither *C. flabelliformis* nor *S. guttulata* have been evaluated for threat status.

Rhipsalis crispata (Cactaceae) is endemic to Brazil and have been reported only from the states of Bahia, Pernambuco, Rio de Janeiro, São Paulo, and Santa Catarina (Zappi & Taylor 2024). Barbosa *et al.* (2021), in a study of Serra da Mantiqueira, reported the first record of *Rhipsalis crispata* in Minas Gerais, occurring as an epiphyte in Semideciduous Seasonal Forest (Barbosa *et al.* 2021). However, in 2018, the species was also recorded in Parque do Itacolomi, in Ouro Preto, occurring in a *Campos Rupestres* area (L.G. Pedrosa 252 [OUPR]), as was recently observed in Serra do Frazão. Since its identification was validated by an expert taxonomist, these records represent the first indications of its occurrence in

Campos Rupestre areas, as well as new occurrences outside the Serra da Mantiqueira region in Minas Gerais. *Rhipsalis crispata* is currently classified as DD due to a lack of population data; however, Barbosa *et al.* (2021) suggest it should be considered CR within the state. Considering that IT is a State Conservation Unit of Integral Protection, this finding is important for the species' conservation, and both sites (Frazão and Itacolomi) contribute to expanding its known distribution.

Peperomia lanceolato-peltata (Piperaceae) is endemic to South America, usually found as saxicolous or epiphytic in Tropical and Montane Forests (Vergara-Rodríguez *et al.* 2017). In Brazil, it has been recorded as a rupicolous or terricolous herb in Gallery or Ombrophilous Forests, in the states of Ceará, Distrito Federal, and Goiás (Carvalho-Silva *et al.* 2024). In addition to the records for Frazão, in Minas Gerais, the species was also collected in 2021 at Rio Funil, Ouro Preto (L.G. Pedrosa 3277 [OUPR]); in 2019 on limestone outcrops in Pedro Leopoldo (V.L. Ferreira *et al.* 303 [BHCB]) - also recorded for the same municipality in Ferreira & Stehmann's 2023 study); and in 2005 on a "limestone slope" in Iguatama (P.H.A Melo & J.F. Martins 1321 [BHCB]). Therefore, the record from Serra do Frazão represents the second occurrence for the municipality of Ouro Preto and the fourth for the state of Minas Gerais.

Ruderal, exotic, and naturalized species in Frazão

In Frazão, in response to the effects of land cover change and anthropogenic pressures such as vegetation suppression and fire, exotic (*Melinis minutiflora*; *Sesamum indicum*) and weedy (*Triumfetta semitriloba*; *Pteridium esculentum* subsp. *arachnoideum*) species are found developing locally and competing with native species, or occurring side by side with microendemic species, as is the case of *P. esculentum* subsp. *arachnoideum*. In addition, *M. minutiflora* appears to occupy the spaces where *Apochloa poliophylla* occurs, a grass species endemic to Espinhaço (Dias *et al.* 2024). This situation poses serious conservation challenges, as the introduction of invasive and highly competitive species accelerates the decline of native diversity and richness to alarming levels (Davis 2003; Hejda *et al.* 2009), especially in ecosystems such as the *Campos Rupestres*, where plant communities are already rare and vulnerable to extinction (Silveira *et al.* 2016).

An exceptional case draws our attention here: the occurrence of *Sesamum indicum* (sesame, Pedaliaceae) in the area. Sesame is one of the oldest oilseed species known and used by humans (Hegde 2012). It has been cultivated for centuries, particularly in Asia and Africa, for its high content of edible oil and protein, and for its seeds, which are

used both in cooking and for medicinal purposes (Hedge 2012). It is currently widely dispersed across the globe, reaching China and Japan, which have themselves become secondary distribution centers (Hedge 2012). In Brazil, it occurs in all regions and almost all states (FFB 2024). It is possible that its cultivation in the country began in the 16th century, in the northeastern region, by the Portuguese (Arriel *et al.* 2007). However, currently, in addition to the northeastern region, it is also cultivated in São Paulo, Goiás (the largest producer), Mato Grosso, and Minas Gerais (Arriel *et al.* 2007). Its record in Frazão is the first to indicate its occurrence in *Campos Rupestres* areas in Brazil and may be related to an escape from cultivation, since the species is resistant to drought and stressful conditions and has the capacity for self-pollination (Hedge 2012). The species was collected with flowers and fruits and produced seeds. This record highlights the need for the species to be monitored locally and in other areas of the state.

Floristic similarity

High beta diversity and floristic dissimilarity are observed between *Campos Rupestres* areas (Conceição & Pirani 2005, 2007; Mourão & Stehmann 2007; Alves & Kolbek 2009; Messias *et al.* 2012; Carmo & Jacobi 2013; Carmo *et al.* 2016), even in similar lithologies with little distance between them (Conceição & Giulietti 2002; Conceição & Pirani 2005; Azevedo *et al.* 2024) or in distinct lithologies occurring side by side (Messias *et al.* 2012). This pattern is no different here, since less than half of the Frazão species were common among the three locations. Moreover, the flora of Serra do Frazão shares fewer exclusive species with Itacolomi than with Serra do Caraça.

The shorter distance in this case may favor the dispersion of species. In addition, the highest parts of Serra do Caraça present quartzitic *Campos Rupestres* interspersed with tree and nebular formations, with geomorphology similar to that found in Serra do Frazão. The sharing of microendemic species associated with these formations, in this case *Cipocereus laniflorus* and *Hoplocryptanthus glaziovii*, corroborates this hypothesis. Furthermore, Serra do Caraça and Frazão, are geographically located in an intermediate region, influenced by both the flora of the mountain ranges in the southern sector of Espinhaço to the north and by the Serra da Mantiqueira formations in the southeastern part of the country (Oliveira 2010).

Threatened Species and Serra do Frazão Conservation

Serra do Frazão is not currently included in any of the categories of the National System of Nature Conservation Units (SNUC), despite being

located in a region impacted by iron ore mining and harboring 33 threatened species, including two CR microendemics - *Paepalanthus atrovaginatatus* and *Barbacenia beauverdii* - in addition to other threatened taxa identified in this study. The area is also subject to vegetation changes, including the presence of exotic and invasive species, as well as the effects of global warming.

The Quadrilátero Aquífero-Ferrífero is considered one of the few climatically stable regions under future climate scenarios, being extremely important for the conservation of this ancient and threatened ecosystem (Fernandes *et al.* 2014, 2017). However, only a few conservation units fully protect the *Campos Rupestres* (Fernandes *et al.* 2014, 2017), including their woody plant communities (Pontara *et al.* 2018). Given this context, we recommend that Serra do Frazão be elevated from a Legal Reserve to a Conservation Unit.

In summary, our results increased the number of species listed for the *Campos Rupestres* of Serra do Frazão by more than 80%, enriching the scientific collection of the municipality with over 700 new records. Furthermore, the geographic distributions of previously restricted species were expanded, identifying new occurrences for the municipality of Ouro Preto, and the Quadrilátero Aquífero-Ferrífero, and for the state of Minas Gerais (Wallacean deficit). These are significant findings, despite the small size of the sampled area and the difficulties in access. We also cataloged endemic species and assessed the threat status of the taxa investigated, demonstrating the uniqueness of the Frazão flora, based on biogeographic analyses. We reinforce the importance and need to conduct floristic surveys in areas that have been little explored or not yet inventoried, as a source of primary data for science. Our study demonstrates here that even in areas close to research centers and collected more than a century ago, there are still important sampling gaps. The new distribution data for endemic species of QAF can support studies that assess environmental conditions and responses to habitat changes (Hutchinsonian deficit), as well as abundance patterns and population dynamics (Prestonian deficit), which are essential for conservation strategies and for the application of IUCN criteria. The list of species from Frazão also contributes to the understanding of the *Campos Rupestres* flora identity, especially in areas influenced by the Atlantic Forest domain, as well as the endemism of its species. All these aspects reinforce the importance of the Serra do Frazão as a significant refuge area for the conservation of biodiversity in Brazil, Minas Gerais, and the Quadrilátero Aquífero-Ferrífero, and reinforce the urgency of implementing legal protection measures for the area.

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Data availability statement

In accordance with Open Science communication practices, the authors inform that there is no data sharing of this manuscript.

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