Archaeopalynological evidence of activities and relationships of pre-colonial populations with the semiarid environment, Bahia, Brazil

Evidências arqueopalinológicas de atividades e relações de populações pré-coloniais com o ambiente semiárido, Bahia, Brasil

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Abstract: This study aimed to identify palynomorphs from sediments at the Gruta da Caixa d'Água archaeological site (Caetité, Bahia, Brazil), to obtain information about plant species represented in the archaeological records. The sediment samples were chemically treated following the techniques recommended for Quaternary pollen grains at the Laboratório de Estudos Palinológicos (LAEP), Campus VII of Universidade do Estado da Bahia. Permanent slides with the sediments samples were prepared for identification/counting of palynomorphs under light microscopy. Two samples were dated based on 14C, which 5,650-5,690 Cal yr BP at the 70-80 cm level and 520-540 Cal yr BP at the 20-30 cm level. 44 pollen types were identified in seven of the ten samples analyzed and most of them were related to the families Convolvulaceae, Rubiaceae and Convolvulaceae. A greater quantity of pollen grains was recorded in the more superficial sediments samples, while they were very reduced and/or absent in the basal layers. The pollen types were related to current representatives of the local flora, with a predominance of plants of herbaceous-shrub habit, indicative of secondary vegetation resulting from possible past human interference in the vegetation. The palynological results associated with the site's archaeological remains contributed to broadening the understanding of the relationships between pre-colonial inhabitants and the Caatinga biome environment.

Keywords: Caetité. Archaeopalynology. Cave.

Resumo: Este estudo teve como objetivo a identificação de palinomorfos de sedimentos do sítio arqueológico Gruta da Caixa d'Água, no município de Caetité, Bahia, para obtenção de informações sobre espécies vegetais representadas nos registros arqueológicos. Amostras de sedimento foram processadas de acordo com as técnicas recomendadas para grãos de pólen do Quaternário. Para duas amostras foram realizadas datações através do 14C, para uma foi revelada idade calibrada de 5.650-5.690 anos AP no nível 70-80 cm e outra de 520-540 anos AP no nível 20-30 cm. Foram identificados 44 tipos polínicos em sete das dez amostras analisadas e a maioria deles foi relacionada às famílias Convolvulaceae, Rubiaceae e Asteraceae. Foi registrada maior quantidade de grãos de pólen nas amostras de sedimento mais superficiais, sendo muito reduzidos ou ausentes nas basais. Os tipos polínicos foram relacionados a representantes atuais da flora local, com grande predomínio de plantas de hábito herbáceo-arbustivo, indicativas de vegetação secundária, resultante de possíveis interferências humanas pretéritas. Os resultados palinológicos associados aos vestígios arqueológicos do sítio contribuíram para ampliar a compreensão das relações de habitantes pré-coloniais em ambiente da Caatinga.

Palavras-chave: Caetité. Arqueopalinologia. Caverna.

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INTRODUCTION

Archaeopalynological investigations are relevant toboth Archaeology and Palynology, as they provide a wide range of information that contributes to the understanding of environmental scenarios in the context of ancient human occupations and activities, including the potential uses of plants for various purposes. They can also yield specific data on deforestation, cultivation practices, and the use of plant species, thereby highlighting processes that shaped vegetation and landscapes through past anthropogenic effects (Carrión et al., 2009; C. Oliveira et al., 2015).

Numerous studies report archaeopalynological data from various parts of the world, particularly from the Old World. In Brazil, however, such studies remain scarce, with a few focusing on the Northeast region, specifically in the states of Piauí, Pernambuco and Ceará. Chaves and Renault-Miskovsky (1996) analyzed three human coprolites from an archaeological rock shelter site in Pedra Furada, Piauí, dated between 8,500 and 7,000 BP. Based on the pollen spectra obtained from their analyses, the authors inferred aspects of the paleoclimate and paleoenvironment of the study area and suggested possible plant uses for food and medicinal purposes by groups who inhabited the shelter over a span of 1,500 years.

Four years later, Chaves (2000) published a new study on the same site in Piauí, this time analyzing a larger number of human coprolites and including coprolites from various animal species, totaling 31 coprolites. The results of this study expanded the number of plant species identified as having food and medicinal uses by the human groups who inhabited the shelter, and provided further insights into paleoclimatic and paleoenvironmental changes based on the pollen spectra from the animal coprolites. Parasitological results from the coprolites were also presented and discussed. Additional possible medicinal uses of plant species recorded at the Pedra Furada site were proposed by Chaves and Reinhard (2003).

Teixeira-Santos et al. (2015) analyzed pollen grains from human coprolites collected at the Furna do Estrago rock shelter archaeological site, in the state of Pernambuco, and, through the pollen spectra, identified several species that were possibly used by pre-colonial groups for the treatment of intestinal parasitic infections between 1,860 and 1,610 BP.

Freitas et al. (2015) analyzed ceramic artifacts and sediment samples contained within them, collected in Baturité, a mountainous region in the state of Ceará, dating from 670 to 530 years ago. They identified pollen types related to various plant species potentially used for food, medicinal, or ritual purposes. More recently, Freitas et al. (2022) analyzed sediment samples adhered to human remains and from the interior of funerary urns in which they were contained, recovered from the Toca da Baixa dos Caboclos archaeological site, in the state of Piauí. The authors provided information on diet and the diverse uses of plants, their management and cultivation, and also identified three episodes of climatic and vegetation changes occurring between 510 and 140 years BP.

It is observed that the vast majority of published archaeopalynological studies have focused on open-air archaeological sites or those associated with rock shelter walls. Specific palynological data for sediments from cave archaeological sites are more limited and are mainly concentrated in the Old World, such as in Spain (Garcia-Antón & Sainz-Ollero, 1991; Carrión et al., 1995, 1999) and South Africa (Carrión & Scott, 1999). In the New World, data are scarce. One of the pioneering studies was conducted by Reinhard et al. (2008), who analyzed chloroplast DNA and pollen grains found in human coprolites from a cave in Texas, USA, revealing information about the paleodiets of Amerindian groups. In Mexico, the recent study by Pucu et al. (2020) also provided insights into the paleodiet of pre-Columbian groups based on the analysis of pollen grains, as well as micro- and macroremains in human coprolites collected from a cave.

Other studies, however, outside the archaeological context, provide palynological information from caves and show great potential for contributing to the interpretation

of pollen spectra in archaeological sites located in such environments. Navarro et al. (2002) analyzed pollen grains from surface sediment samples collected in two caves in arid regions of inland Spain. Also in Spain, Carrión et al. (2005) analyzed pollen grains from badger coprolites found in a cave and inferred information about the landscape over the past three centuries. Coles and Gilbertson (1994) analyzed and quantified modern pollen deposition in a cave in England, and Hunt and Rushworth (2005) conducted a similar study in a cave in Borneo. In the latter, the authors highlighted the importance of bats and birds in the passive transport of pollen into cave environments.

Previous studies of cave sediments in contexts of past human occupation have revealed important information regarding both the low quantities of palynomorphs in samples and the diversity of pollen types present in them. Palynological data from sediment samples in caves were reported in studies by Garcia-Antón and Sainz-Ollero (1991), Carrión et al. (1995), and Carrión et al. (1999), all focused on Spain, and by Carrión and Scott (1999) for South Africa

In the study by Garcia-Antón and Sainz-Ollero (1991), conducted in a cave environment, 58 pollen types were identified in the analyzed profiles, most of which had a pollen sum below 200 grains. Nevertheless, according to the authors, it was possible to establish five pollen zones that indicated changes in vegetation and climate in the área.

Carrión et al. (1995) conducted a study on the palynological and sedimentological sequence of the Perneras Cave, located in a semi-arid region of southeastern Spain. Among the analyzed samples, he found that many contained few or no palynomorphs. However, from a limited number of samples, it was possible to produce pollen diagrams and discuss aspects of the area's paleovegetation and paleoclimate. Possible human interventions in the vegetation or the use of plants by pre-Columbian communities were not addressed by the author.

Carrión et al. (1999) highlighted the paleoecological potential of pollen records in Mediterranean caves of Spain, based on sediments extracted from their vertical lithological sections. The author revealed that many species were represented in these sediments through pollen grains, especially entomophilous ones, and that some of them had already been detected in previous studies of the region based on lacustrine and marine sediment samples. The author also emphasized that qualitative palynology in caves without evidence of human occupation is influenced by biotic transport and can provide important findings in arid regions that elude conventional quantitative lacustrine paleopalynological methodology. According to the author, the main challenge regarding cave palynology is to determine to what extent the vegetation cover contributed to each pollen spectrum, considering local taphonomic and depositional processes. Possible human impacts on the vegetation or the use of plants by ancient cave dwellers were not addressed by the author.

Carrión and Scott (1999) analyzed palynomorphs present in sediments from different stratigraphic levels of the Sterkfontein Caves in South Africa, an important archaeological complex, and noted that it was not possible to perform statistically reliable pollen counts that would allow for accurate percentage calculations. The authors reported that many samples contained no palynomorphs, that only one sample yielded more than 200 pollen grains, and that most of them were poorly preserved. They attributed the low quantity of palynomorphs to the possible ancient aeration of the carbonate sediments prior to their cementation—processes that may have occurred repeatedly over time in cycles of dissolution and recrystallization. The oxidation associated with these processes likely destroyed the palynomorphs originally present. The authors discussed the palynological data solely in relation to environmental aspects, without making any connection to potential human occupation of the cave.

Thus, as observed in the studies cited above, reports of reduced quantities of palynomorphs in ancient cave sediments were frequent, as well as a generally low diversity of pollen types (Garcia-Antón & Sainz-Ollero, 1991;

Carrión et al., 1995; Carrión & Scott, 1999), though still representative of elements of the local and/or regional flora.

Palynological studies conducted in cave environments in Brazil are limited to those by Coelho and Marinho-Filho (2002) and Freitas et al. (2020), both unrelated to archaeological sites. Coelho and Marinho-Filho (2002) analyzed and identified pollen grains found on the body surfaces (abdomen, dorsal surface, wings, and head) of bats inhabiting caves within an environmental protection area in the Federal District, and inferred the possible plant species visited by them. Freitas et al. (2020) conducted the first records of palynomorphs in cave sediments in Brazil. The study area was the Gruta do Urso cave, located in the state of Tocantins. Analyses were performed on twenty-one collected samples, including four surface sediment samples and seventeen subsurface sediment samples from different depths. A total of 44 pollen types from angiosperms were recorded, distributed among 26 families and 36 genera, associated with shrub-tree and shrub-herbaceous taxa currently found in the Cerrado biome's plant communities. The pollen types were palynologically described, and information related to the taxonomy and ecology of the associated species was presented. The authors emphasized that the pollen data obtained in the study reflect the paleovegetation surrounding the cave during the Last Glacial Maximum and the Holocene, and constitute a reliable source for paleoecological, paleoenvironmental, and paleoclimatic investigations. However, detailed information on the pollen spectra (palynomorph quantity/diversity of pollen types) found in the different profiles from the six sampling points was not provided.

Leonor et al. (2019) published archaeobotanical data on seeds and fruits recovered from excavation sediments at the Gruta da Caixa d'Água archaeological site, located in Caetité, in the state of Bahia. This is a pioneering study for the state, and the results revealed the presence of seed and fruit remains in different levels of excavation profiles, corresponding to twelve species, seven of which were identified. These species are still present in the current local flora. The possible uses of these species by pre-colonial communities were discussed by the authors.

It is observed, therefore, that there is a lack of palynological data for sediments from archaeological sites in cave environments in Brazil. Moreover, there is also no archaeopalynological information available for Bahia, the largest state in the Northeast. Thus, with the aim of reducing these knowledge gaps, the present study focused on the investigation of palynomorphs in sediment samples from the Gruta da Caixa d'Água Archaeological Site (Caetité, Bahia), in order to understand the relationships of pre-colonial communities with the paleoenvironment and especially with the surrounding vegetation.

MATERIALS AND METHODS

ENVIRONMENTAL SETTING OF THE STUDY AREA

The Caetité region is located within the Semi-arid domain and is part of the Espinhaço geological belt, where the presence of minerals is common, enabling the establishment of industries that extract iron ore (Bahia Mineração Ltda.) and uranium (Indústrias Nucleares do Brasil — INB) (SEI, 2015). The landscape is predominantly flat, with gently undulating terrain in the higher areas (Silva-Santana, 2010), and the topography is uniform, with elevation ranging from 900 m to 1,230 m, interrupted only by drainage channels.

Arboreal Caatinga predominates in the vegetation of the Caetité region, but the occurrence of many contact zones with other biomes is frequent, such as various transitions between cerrado, arboreal cerrado, and seasonal forest. These contact areas between different vegetation types constitute ecotones (SEI, 2015).

In general, the region can be considered of medium potential for the development of natural cavities. During the study phase for the environmental impact report of the Pedra de Ferro Project, 67 caves were located and recorded. Among these caves, two were considered highly

relevant by the study. The caves are formed in ferruginous rocks, and four of them were occupied by pre-colonial populations (Silva-Santana, 2010).

The Gruta da Caixa d'Água Archaeological Site (765654 / 8410134 UTM) (Figure 1) is one of these caves and was classified as a pre-colonial site. It is located on a hillside of a small mountain range, in a sloping area. It measures 10 m × 17 m and consists of large rock walls composed of banded iron formations, which in the past served as shelter for ancient communities. The location may also have been used as a vantage point, as it offers a wide view of the surrounding landscape. The site was excavated between 2010 and 2011, resulting in the formation of a substantial collection of lithic and ceramic artifacts (Silva-Santana, 2010). At the time of the research, the area surrounding the Gruta da Caixa d'Água featured dense vegetation composed of floristic elements characteristic of the transition between the Caatinga and Cerrado biomes.

EXCAVATIONS, ARCHAEOLOGICAL FINDINGS, AND DELIMITATION OF THE STUDY AREA

The pre-excavation phase of the Gruta da Caixa d'Água archaeological site consisted of removing ground vegetation and cleaning the surface at the entrance and inside the cave, including the removal of decomposed plant matter, leaves, and other materials present on the site's surface. Subsequently, the site and excavation areas were delimited, the grid system was established, and the surface topography of the units was recorded.

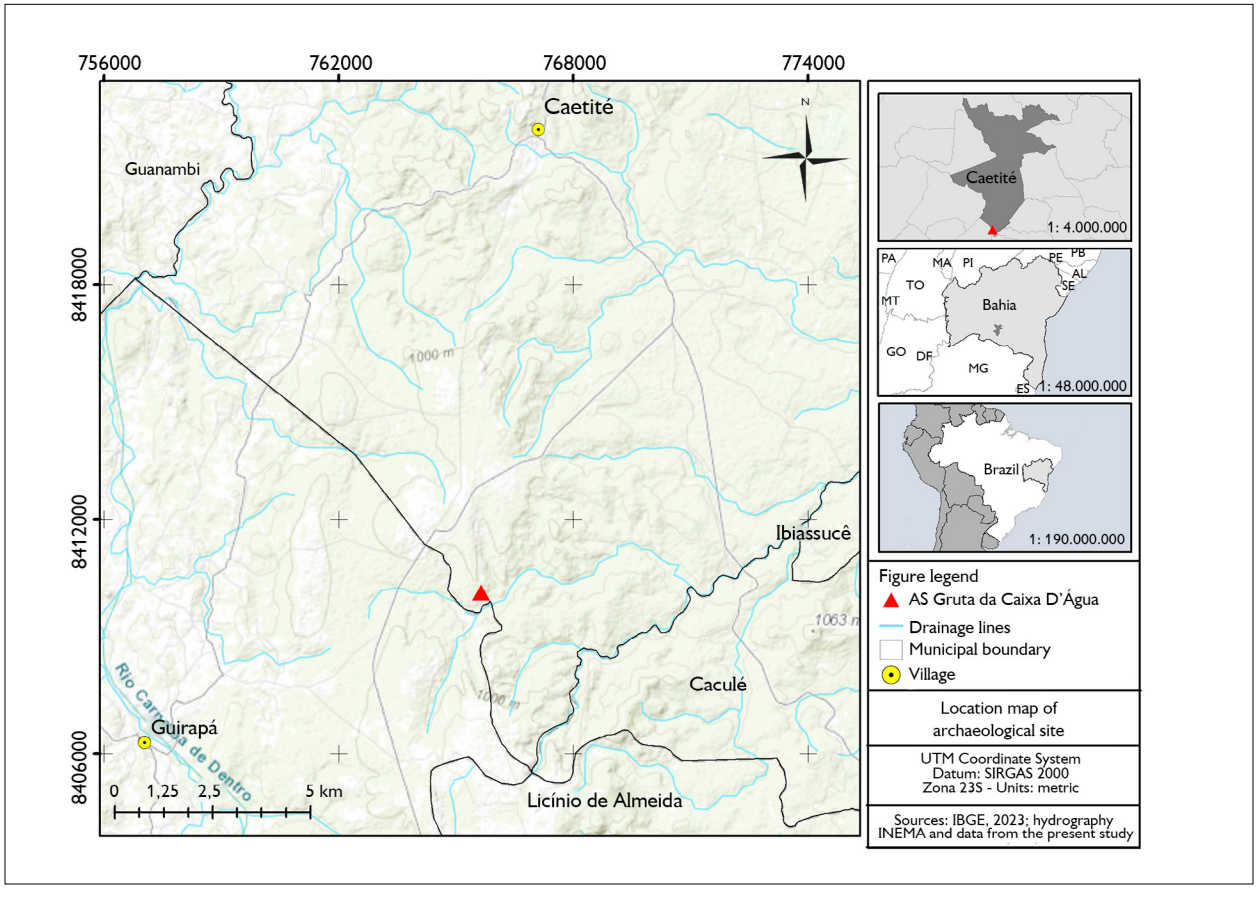

Figure 1. Location of the Archaeological Site Gruta da Caixa d'Água, in the municipality of Caetité, Bahia, Brazil. Source: IBGE (2023).

The excavation was carried out in 67 units measuring 1 m × 1 m (Figure 2), using artificial levels, and reached depths ranging from 80 cm to a maximum of 1.0 m, when the bedrock was reached. The sediment was predominantly sandy-clayey in nature, with a dark brown coloration, likely due to the high iron content and soot resulting from numerous campfires.

Archaeological remains were found down to a depth of 80 cm, and all excavation levels contained evidence of occupation, with no sterile intermediate layers. The levels with the highest concentration of remains were those between 20–30 cm and 70–80 cm.

The remains were mostly concentrated in the central area of the cave, which also showed good natural ventilation and lighting. The findings consisted mainly of lithic artifacts, some ceramic fragments distributed on the surface and down to a depth of 20 cm, as well as hearths containing charcoal and plant carpological remains.

The lithic remains from the site allowed its classification as a lithic workshop, based on two lithic assemblages whose characteristics, along with the ceramic component, suggest that there were two phases of occupation. The ceramics were associated with the more superficial levels, mostly thin and with smooth surfaces; however, some had rims with plastic ungulate decoration.

The site was characterized predominantly by flakes, debitage remains, and a few utilized or polished tools. Among the artifacts, simple and retouched flakes, scrapers, and borers were found; a single small axe was recovered at the 20 cm level.

With regard to the lithic raw materials, a predominance of quartz was observed at all levels. Chert occurred in

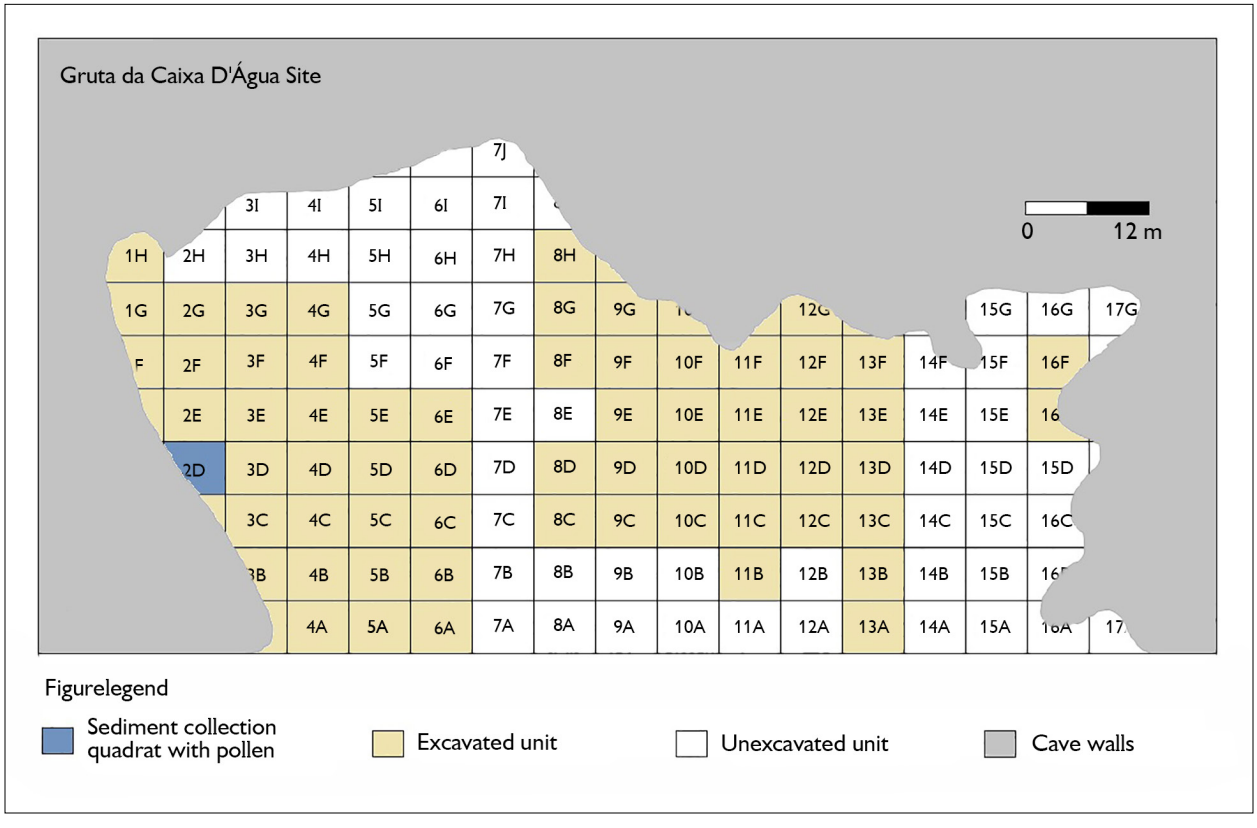

Figure 2. Excavation plan of the Gruta da Caixa d'Água, highlighting square 2D, where the samples for palynological analyses were collected. Source: Silva-Santana (2010).

smaller quantities, however it showed higher concentration in the lower (older) levels. Other raw materials used were ironstone and ochres (many ochres show scraping marks). With respect to the treatments applied to the lithic artifacts, thermal alteration was noteworthy, visible through the typical concavities in the rocks, especially in silexite.

Based on the set of archaeological evidence, it appears that there were two distinct moments of occupation at the site. The first was pre-ceramic, with intensive quartz knapping and the production of silexite flakes and artifacts obtained through direct percussion, many of which show retouch and traces of fire, potentially associated with hunter-gatherer groups. The second was ceramic, represented in the more superficial levels, with fewer silexite artifacts, characterized by simple flakes mostly without retouch, while the quartz artifacts were simpler, some showing bipolar flaking.

During the archaeological excavations, unit 2D (Figure 2), located near the inner rock wall, was selected for the collection of sediment samples to test for the presence of palynomorphs and for future palynological analyses in the event of a positive result. On the same day and in the following weeks, archaeological excavations continued uninterrupted in the other units, but without collecting samples for palynological prospecting.

SEDIMENT SAMPLE COLLECTION FOR PALYNOLOGICAL ANALYSES

Ten sediment samples were collected from grid unit 2D of the site, from a depth of one meter up to the surface, performed sequentially from bottom to top, with each sample collected individually. The samples were taken using sterile universal collectors, which, once individually opened, were immediately inserted into the pre-scraped profile of the unit to avoid contamination by recent pollen. After insertion into the profile, each collector was pressed against the sediment and rotated to maximize sediment collection, then immediately withdrawn and sealed to prevent contamination. This procedure was repeated for each of the ten samples (Silva-Santana, 2010). All collectors were labeled with the site name, code, municipality, grid unit, layer color, level, structure, origin, type of find, collector's name, and date of collection. The samples were then transported to the Palynological Studies Laboratory (LAEP) at the State University of Bahia – Campus VII, where they were kept refrigerated until the time of chemical processing, which took place after the conclusion of the cave excavations.

SEPARATION OF SAMPLES FOR CHEMICAL PROCESSING AND RADIOCARBON DATING

From each of the stored sediment samples, 2 cm^3 subsamples were separated at LAEP and placed in test tubes for chemical processing. For the 70–80 cm and 20–30 cm levels, additional subsamples were set aside for radiocarbon dating, which was conducted at Beta Analytic Inc. Laboratory in Miami, Florida, USA. Both radiocarbon dates were obtained using the C-14 method from charcoal remains found in hearths (Silva-Santana, 2010), with further details provided in Table 1.

Table 1. Radiocarbon dates for two profiles from the Gruta da Caixa d'Água Archaeological Site, Caetité, Bahia, Brazil.

Lab. nº	Depth (cm)	Dated material	Conventional age (years BP)	$\delta^{13}C$	Calibrated age 2σ upper	Calibrated age 2σ lower (years BP)
Beta 328326	20-30	Carbonized material	510 ± 30	-22.9	510-550	520-540
Beta 328327	70-80	Carbonized material	5,000 ± 30	-25.6	5,820-5,880	5,650-5,690

CHEMICAL PROCESSING, IDENTIFICATION, AND COUNTING OF POLLEN GRAINS

For the chemical processing of the sediment samples, the standard technique recommended by Ybert et al. (1992) was used. This method involves the destruction of organic matter (except sporopollenin) and inorganic content using acids (HCl and HF), a base (KOH), and an acetolysis mixture (acetic anhydride and sulfuric acid in a 1:10 ratio), applied in specific concentrations and alternated with repeated centrifugation steps to concentrate the palynomorphs. These were followed by rinsing with distilled water and subsequent mounting on microscope slides for analysis, identification, and counting under optical microscopy. Due to importation restrictions, it was not possible to acquire exotic markers for inclusion in the palynological samples. For each sediment sample, ten permanent slides were prepared using glycerin jelly, sealed with paraffin, and will be deposited in the LAEP palynotheque after the analyses are completed.

Qualitative and quantitative analyses of the slides were performed using a Zeiss Axioskop optical microscope, with 40X objective lenses for counting and 100X for more precise visualization of key details such as ornamentation, wall structure, and pollen grain apertures. Photomicrographs used to illustrate the main pollen types were obtained through an image capture system attached to the microscope, using the 100X objective.

Pollen grains were quantified following the guidelines of Salgado-Labouriau (2006), which consist of counting in vertical transects from top to bottom and from left to right, with a spacing of only one field of view between lines to avoid repeated counting of the same pollen grain. As is standard practice in archaeopalynological studies, counts aimed to reach a minimum of 150–200 pollen grains and at least 20 pollen types per sample (Dimbleby, 1985).

The identification of pollen types was conducted through comparisons with reference keys and catalogs (Roubik & Moreno, 1991; Salgado-Labouriau, 1973; Magalhães-e-Silva, 2007; Cassino & Meyer, 2011; Macedo, 2009; P. P. Oliveira, 2003) and by comparison with slides from the LAEP reference collection, which includes permanent slides of hundreds of species from biomes present in Bahia.

RESULTS

The total quantity of palynomorphs found in the samples was 456 (Table 2), being 452 pollen grains and only 4 pteridophyte spores. Of this total, only 21 palynomorphs, related to 16 pollen types, were not identified, which represents 4.6% of the total. The impossibility of identifying some pollen types occurred because the pollen grains were highly deformed and/or deposited on the slide surfaces in positions that did not allow the visualization of important characteristics, such as apertures, for example.

Palynomorphs were found in seven out of the ten analyzed samples (Table 2). They were categorized into 44 pollen types, 28 of which were identified with botanical origin (Table 3), and the most common types in the samples were illustrated (Figure 3). Regarding the quantities and percentages of palynomorphs per sample, variations were observed among them. Three samples showed no palynomorphs (50–60 cm, 80–90 cm, and 90–100 cm), most samples showed very low numbers (0–10 cm, 10–20 cm, 20–30 cm, 40–50 cm, 60–70 cm, and 70–80 cm), and only one sample (30–40 cm) presented a high number (Figure 4).

In nearly all of the samples in which palynomorphs were found, high percentages of pollen grains related to herbaceous/shrubby taxa were observed. In the 30–40 cm sample, which stood out the most due to the greater number of palynomorphs, the percentage representation of herbaceous/shrubby taxa reached 99.0%, and the most representative pollen types were *Evolvulus* (Figure 3E–3F) (259 pollen grains = 67%), *Mitracarpus/Spermacoce* (Figure 3O) (69 pollen grains = 17.89%), and *Asteraceae* 1 (Figure 3A) (39 pollen grains = 10.11%). A total of 15 pollen types were identified in this sample.

Table 2. Quantitative results of the palynological analyses from the ten sediment levels of a profile from Gruta da Caixa d'Água cave (Caetité, Bahia, Brazil), regarding the absolute and percentage numbers of palynomorphs distributed across the categories herbaceous/shrubby, arboreal, and indeterminate by sample level.

Sample level (cm)	Quantity and percentage (%) of palynomorphs in relation to the habits of the taxa assigned to the pollen types			Total
	Herbaceous/shrubby	Arboreal	Indeterminate	
0-10	22 (68.8%)	4 (12.5%)	6 (18.8%)	32
10-20	8 (66.7%)	1 (8.3%)	3 (25.0%)	12
20-30	1 (25.0%)	2 (50.0%)	1 (25.0%)	4
30-40	382 (99.0%)	1 (0.3%)	3 (0.8%)	386
40-50	7 (58.3%)	0 (0.0%)	5 (41.7%)	12
50-60	0 (0.0%)	0 (0.0%)	0 (0.0%)	0
60-70	2 (66.7%)	0 (0.0%)	1 (33.3%)	3
70-80	5 (71.4%)	0 (0.0%)	2 (28.6%)	7
80-90	0 (0.0%)	0 (0.0%)	0 (0.0%)	0
90-100	0 (0.0%)	0 (0.0%)	0 (0.0%)	0
Total	427 (93.6%)	8 (1.8%)	21 (4.6%)	456

Table 3. List of pollen types with absolute and percentage (%) values recorded in the seven sediment levels of the profile from Gruta da Caixa d'Água cave (Caetité, Bahia, Brazil), where palynomorphs were found, along with information on the ecology and distribution of the taxa related to them. (Continue)

Pollen type	Quantity and percentage of palynomorphs by levels (cm)								Ecology and distribution of the taxa related to pollen types	Source
	0-10	10-20	20-30	30-40	40-50	60-70	70-80	Sum		
Asteraceae										
1. Asteraceae 1	1 (3,1%)	0	0	39 (10,1%)	0	0	0	40	Lianas, ervas ou arbustos presente em áreas de vegetação aberta.	Marchant et al. (2002)
2. Asteraceae 2	1 (3,1%)	1 (8,3%)	0	0	0	0	0	2		
3. Asteraceae 3	0	0	0	5 (1,3%)	0	0	0	5		
Arecaceae										
4. *Syagrus* 1	0	0	0	0	0	1 (33,3%)	0	1	Trees or shrubs distributed in South America, in Mata, Cerrado, and Caatinga regions.	Felfili et al. (2007)
5. *Syagrus* 2	1 (3,1%)	1 (8,3%)	2 (50%)	1 (0,3%)	0	0	0	5		
Cactaceae										
6. *Pilosocereus*	2 (6,3%)	0	0	0	0	0	0	2	Rock-dwelling or terrestrial. Found in Cerrado and Caatinga. Indicators of anthropogenic pressure.	Calvente et al. (2005)

Table 3. (Continue)

Pollen type	Quantity and percentage of palynomorphs by levels (cm)								Ecology and distribution of the taxa related to pollen types	Source
	0-10	10-20	20-30	30-40	40-50	60-70	70-80	Sum		
Convolvulaceae										
7. *Evolvulus*	0	0	0	259 (67,1%)	1 (8,3%)	0	0	260	Herbs or shrubs present in arid areas. Indicators of anthropogenic activity.	Marchant et al. (2002)
8. *Jacquemontia*	0	0	0	1 (0,3%)	1 (8,3%)	0	0	2		
Euphorbiaceae										
9. *Croton*	1 (3,1%)	0	0	0	0	0	0	1	Herbs or shrubs present in arid areas. Indicators of anthropogenic activity.	Marchant et al. (2002)
10. *Maprounea*	0	1 (8,3%)	0	0	0	0	0	1		
Fabaceae										
11. *Aeschynomene*	7 (21,9%)	0	0	1 (0,3%)	1 (8,3%)	0	1 (14,3%)	10	Herb common in disturbed areas.	Marchant et al. (2002)
12. *Anadenanthera*	1 (3,1%)	0	0	0	0	0	0	1	Widely distributed trees in Caatinga and Cerrado.	Flora e Funga do Brasil (s.d.)
13. *Copaifera*	2 (6,3%)	0	0	0	0	0	0	2		
14. *Zornia* 1	1 (3,1%)	0	0	0	0	0	0	1	Herbs present in the Cerrado.	Marchant et al. (2002)
15. *Zornia* 2	0	0	0	1 (0,3%)	0	0	0	1		
Malpighiaceae										
16. Malpighiaceae	0	0	0	1 (0,3%)	1 (8,3%)	0	0	2	Herbs, lianas, and trees that predominate in the Cerrado.	Marchant et al. (2002)
17. *Byrsonima*	1 (3,1%)	0	0	0	0	0	0	1		
Malvaceae										
18. *Helicteres* 1	2 (6,3%)	0	0	0	0	0	1 (14,3%)	3	Herbs or shrubs common in the Caatinga, Atlantic Forest and Pantanal. They have medicinal potential.	Cristóbal (2001)
19. *Helicteres* 2	1 (3,1%)	0	0	0	0	0	0	1		Lorenzi (2002)
20. *Melochia/Walteria*	1 (3,1%)	0	0	1 (0,3%)	0	0	0	2		
Nyctaginaceae										
21. Nyctaginaceae 1	0	0	0	4 (1%)	0	0	0	4	Shrubs and trees common in dry areas. Present in the Atlantic Forest and Cerrado.	Marchant et al. (2002)

Table 3. (Continue)

Pollen type	Quantity and percentage of palynomorphs by levels (cm)								Ecology and distribution of the taxa related to pollen types	Source
	0-10	10-20	20-30	30-40	40-50	60-70	70-80	Sum		
Poaceae										
22. Poaceae	0	0	0	1 (0,3%)	0	0	0	1	Mainly herbs that survive the dry seasons in savannas and Cerrado.	Marchant et al. (2002)
Phyllanthaceae										
23. *Phyllanthus*	0	0	0	0	2 (16,7%)	0	0	2	Herbs or shrubs common in dry environments: Seasonal Forests and Cerrado.	Marchant et al. (2002)
Rhamnaceae										
24. *Ziziphus*	1 (3,1%)	0	0	0	0	0	1 (14,3%)	2	Terrestrial shrub present in the Atlantic Forest and semideciduous seasonal forest.	Lima (2000)
Sapindaceae										
25. *Serjania*	0	0	1 (25%)	0	0	0	0	1	Lianas present in floodplain areas, in the Cerrado, and in arid environments.	Marchant et al. (2002)
Rubiaceae										
26. *Mitracarpus/ Spermacoce*	2 (6,3%)	3 (25%)	0	69 (17,9%)	1 (8,3%)	1 (33,3%)	2 (28,6%)	78	Herbs from open vegetation, where there are regular disturbances.	Marchant et al. (2002)
Gleicheniaceae										
27. *Gleichenia*	0	3 (25%)	0	0	0	0	0	3	Pantropically distributed pteridophytes. Common in open áreas.	Cassino e Meyer (2011)
Selaginellaceae										
28. *Selaginella*	1 (3,1%)	0	0	0	0	0	0	1	Pteridophytes widely distributed in South America. Found in shaded areas or pastures. Common in the Cerrado.	Cassino e Meyer (2011)
Undetermined										
29. Undetermined 1	3 (9,4%)	0	0	0	0	0	0	3	—	—
30. Undetermined 2	1 (3,1%)	0	0	0	0	0	0	1	—	—

Table 3. (Conclusion)

Pollen type	Quantity and percentage of palynomorphs by levels (cm)								Ecology and distribution of the taxa related to pollen types	Source
	0-10	10-20	20-30	30-40	40-50	60-70	70-80	Sum		
31. Indeterminado 3	1 (3,1%)	0	0	0	0	0	0	1	—	—
32. Indeterminado 4	1 (3,1%)	0	0	0	0	0	0	1	—	—
33. Undetermined 5	0	1 (8,3%)	0	0	0	0	0	1	—	—
34. Undetermined 6	0	1 (8,3%)	0	0	0	0	0	1	—	—
35. Undetermined 7	0	1 (8,3%)	0	0	0	0	0	1	—	—
36. Undetermined 8	0	0	0	1 (0,3%)	0	0	0	1	—	—
37. Undetermined 9	0	0	0	1 (0,3%)	0	0	0	1	—	—
38. Undetermined 10	0	0	0	1 (0,3%)	0	0	0	1	—	—
39. Undetermined 11	0	0	0	0	1 (8,3%)	0	0	1	—	—
40. Undetermined 12	0	0	0	0	3 (25%)	0	0	3	—	—
41. Undetermined 13	0	0	1 (25%)	0	1 (8,3%)	0	0	2	—	—
42. Undetermined 14	0	0	0	0	0	1 (33,3%)	0	1	—	—
43. Undetermined 15	0	0	0	0	0	0	1 (14,3%)	1	—	—
44. Undetermined 16	0	0	0	0	0	0	1 (14,3%)	1	—	—
Totals =	32	12	4	386	12	3	7	456	—	—

The 0–10 cm sample presented the second highest number of palynomorphs, with 68.8% representation of pollen types related to herbaceous/shrubby taxa. Furthermore, it also showed the greatest diversity, totaling 20 pollen types, with sixteen identified: Asteraceae 1 (Figure 3A), Asteraceae 2, *Syagrus* 2 (Figure 3C–3D), *Aeschynomene*, *Anadenanthera* (Figure 3J–3K), *Byrsonima*, *Copaifera*, *Croton*, *Helicteres* 1 (Figure 3L), *Helicteres* 2 (Figure 3M), *Melochia/Waltheria*, *Mitracarpus/Spermacoce* (Figure 3O), *Pilosocereus*, *Ziziphus*, *Selaginella* and *Zornia* 1.

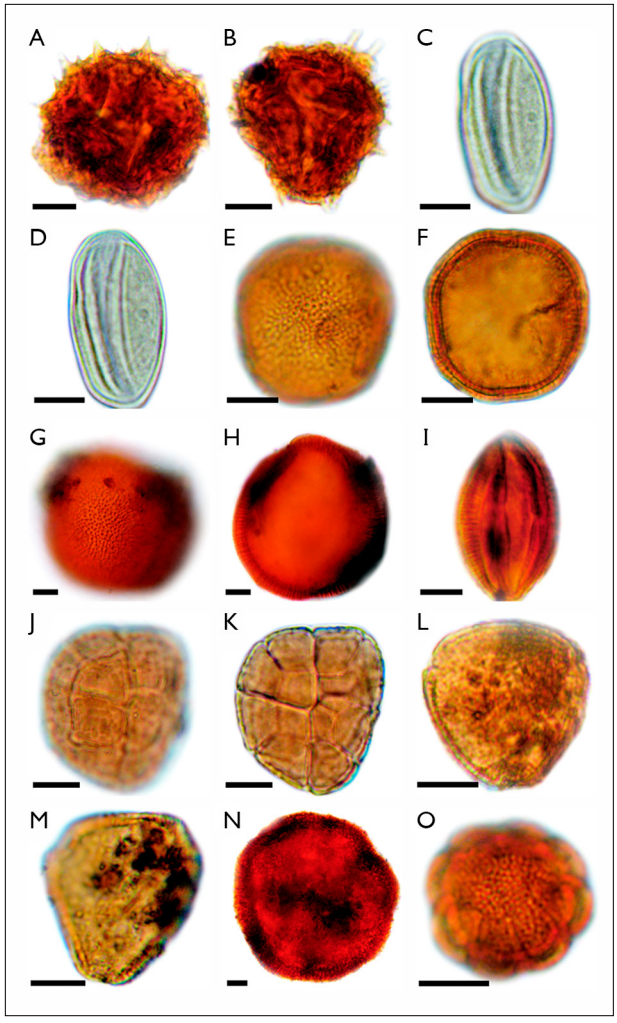

Figure 3. Main pollen types recorded in the sediments of the Archaeological Site Gruta da Caixa d'Água in the Caetité Region, Bahia: Asteraceae: A) Asteraceae 1; B) Asteraceae 3; Arecaceae: C–D) *Syagrus* 2; Convolvulaceae: E–F) *Evolvulus*; G–H) *Jacquemontia*; Euphorbiaceae: I) *Maprounea*; Fabaceae: J–K) *Anadenanthera*; Malvaceae: L) *Helicteres* 1; M) *Helicteres* 2; Nyctaginaceae: N) Nyctaginaceae; Rubiaceae: O) *Mitracarpus/Spermacoce*; Scale bar = 10 micrometers. Source: Santos (2012).

Only in the 20–30 cm sample, dated to approximately 530 years BP, did the percentage of arboreal taxa reach 50% (Table 2), with one pollen grain related to *Syagrus* 2 (Figure 3C–D), two pollen grains identified as *Serjania* type, and a fourth classified as indeterminate. However, this was one of the samples with the lowest number of palynomorphs found. In the 70–80 cm profile sample, dated to approximately 5,760 years BP, among the six pollen types identified, it was possible to relate the botanical origin of four herbaceous/shrubby taxa: *Aeschynomene*, *Helicteres* 1, *Mitracarpus/Spermacoce*, and *Ziziphus*.

A search in species databases for Caetité (SpeciesLink, n.d.) conducted in May 2023 showed that most of the pollen types identified in this study correspond to species currently recorded in the local flora. Exceptions include *Aeschynomene*, *Helicteres* 1, and *Gleichenia*, which are only represented at the family level. Using the website's simple search function, with 'plantae' entered in the kingdom field and 'Caetité' in the municipality field, 7,194 plant specimen records were found in herbaria. This data reflects a high floristic diversity in the municipality, with hundreds of species distributed among 114 angiosperm families, as well as smaller numbers in nine families of seedless vascular plants and ten bryophyte families.

DISCUSSION

ON THE DIVERSITY AND QUANTITY OF PALYNOMORPHS IN A CAVE ENVIRONMENT

As observed in the quantitative results, a total of 456 palynomorphs were recorded in the analyzed slide set. Some samples contained no palynomorphs at all, and in most of them the counts were very low, with the exception of the sample from the 30–40 cm level, which yielded 386 pollen grains, predominantly from herbaceous taxa (Asteraceae, *Evolvulus* and *Mitracarpus/Spermacoce*) (Figure 4). Regarding the qualitative results, the identification of 44 pollen types (28 with a suggested botanical origin) is considered noteworthy given the low number of palynomorphs in the vast majority of the samples.

Regarding the diversity of pollen types, it is important to emphasize that the results of this study were very similar to those found by Freitas et al. (2020) for the only study of this kind carried out in Brazil, which coincidentally also detected 44 pollen types. However, while the pollen types reported by Freitas et al. (2020) indicated their relationships

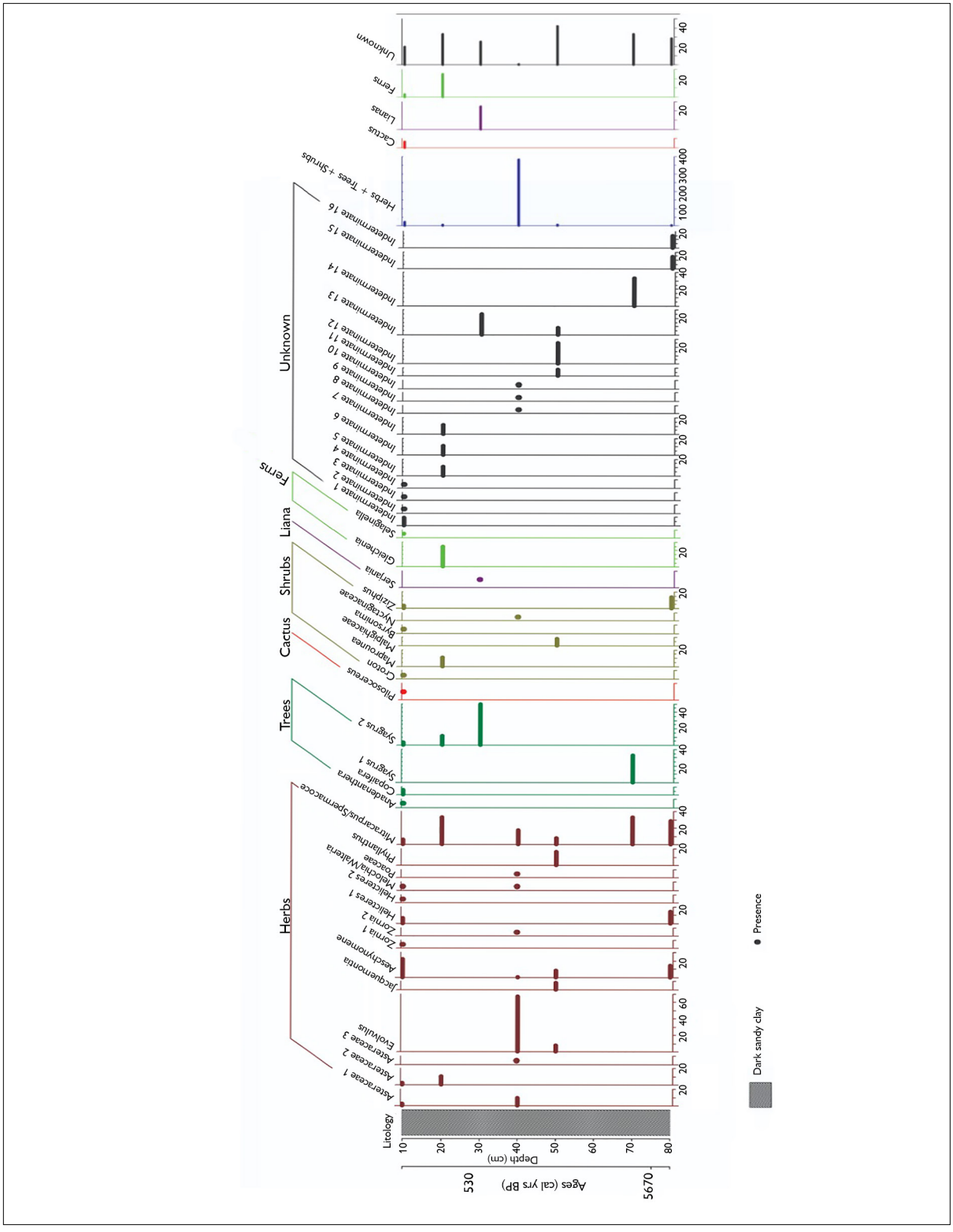

Figure 4. Pollen diagram of the Gruta da Caixa d'Água cave, in the municipality of Caetité, Bahia, Brazil. Source: Gráfico: P. E. de Oliveira e D dos S. Duarte.

with several cerrado species occurring as shrubs and subshrubs, trees from forest formations, or herbs from open fields, the pollen types in this study had a predominant relationship with herbaceous plants (e.g., Asteraceae, *Evolvulus*, *Mitracarpus/Spermacoce*), fewer shrub species, and very few tree species, which together indicate an open phytophysiognomy with small-sized plants. On the other hand, it is important to highlight that the cave sediments in this study are related to an archaeological site, unlike the cave sediments studied by Freitas et al. (2020).

In the same archaeological site of the present study, Leonor et al. (2019) found remains of fruits and/or seeds of *Qualea* sp., *Enterolobium contortisiliquum* Vell., *Eugenia dysenterica* (Mart.) DC., *Hymenaea courbaril* L., *Couepia grandiflora* Benth., and *Syagrus werdermannii* Burret. According to the authors, the fruits and/or seeds found at the Caixa D'Água site have potential medicinal uses (*Quale* sp., *E. contortisiliquum*, *E. dysenterica*, *H. courbaril* and *C. grandiflora*) and/or food uses (*E. dysenterica*, *H. courbaril* and *S. werdermannii*), and in the case of *Syagrus* sp., also for use in campfires, especially the mesocarps, which, when burned, help maintain a strong and long-lasting fire. Among these species, only *Syagrus* sp. was recorded in the pollen spectra, and was even the second most common pollen type found in the sediment levels. This prominent presence is likely due to the frequent collection of fruits in the area and their transport into the cave for food use and for combustion in campfires, favored by the probable presence of a large number of individuals and high fruit production. Unlike *Syagrus*, the other species probably had occasional collections and/or specific uses, possibly with individuals located farther from the cave, which may have contributed to the non-detection of their pollen grains in the analyzed sediments.

Regarding the presence of the *Serjania* type in the sample from the 20–30 cm level, it should be noted that species of this genus exhibit toxic effects on fish and mammals and are used by Indigenous groups from the Amazon region and central-western Brazil in fishing activities and for poisoning arrow tips (Pott & Pott, 1994; Lima & Costa, 1997; Lopes, 2012; Soentgen & Hilbert, 2016). In light of this, it can be inferred that this plant may have been used for hunting, fishing, or for poisoning lithic points, since the site was used as a lithic workshop for the production of various artifacts.

As previously reported, there are few palynological studies conducted in archaeological sites located in cave environments worldwide (Garcia-Antón & Sainz-Ollero, 1991; Carrión et al., 1995, 1999; Carrión & Scott, 1999). In these studies, the authors also highlighted the low quantities of palynomorphs and the reduced diversity of pollen types. However, only in two of them was it possible, for some samples, to obtain pollen sums that allowed the establishment of pollen zones with indications of changes in vegetation and climate (Garcia-Antón & Sainz-Ollero, 1991; Carrión et al., 1995).

It is worth noting that the number of sediment samples in the aforementioned studies was much greater than in our study. As reported in our results, only the sample from the 30–40 cm level presented a high number of palynomorphs (386 pollen grains), a fact that made it impossible to establish pollen zones in the pollen diagram. On the other hand, the sediment samples in this study were obtained from a square located near the inner left wall and in an intermediate position between the back and the entrance of the cave. Thus, we consider that if other samples from different squares had been analyzed, there might have been a greater possibility of detecting more pollen types and obtaining palynomorph count results that would allow the establishment of pollen zones. However, this possibility is merely speculative, since Carrión et al. (1995) and Carrión and Scott (1999) also pointed out that many of the samples analyzed contained few or no palynomorphs, an observation also applicable to this study, considering that we did not detect palynomorphs in three of the ten levels and that in the others, with the exception of the 30–40 cm level, the quantity of palynomorphs was low.

Carrión and Scott (1999) attributed the low quantity of palynomorphs to the possible ancient aeration of sediments, which accelerates the oxidative degradation of

sporopollenin present in the walls of these microfossils. Considering the sandy–clayey nature of the sediments from Gruta da Caixa d'Água, the low palynomorph preservation observed in this study may likewise be explained by the same process described by those authors. In such substrates, oxidative processes are enhanced due to greater aeration, especially when compared to more consolidated and less aerated sediment types.

Regarding the diversity of pollen types, Carrión et al. (1999) noted that species represented in the pollen spectra were predominantly entomophilous. A similar pattern was observed in our results. In the 30–40 cm level, for instance, more than 98% of the pollen types are associated with plant families and genera that are widely recognized as being pollinated by insects.

ON THE PALYNOMORPH INFLUX, DEPOSITION, AND THE REPRESENTATIVENESS OF FLORA IN CAVE POLLEN SPECTRA

Before addressing the potential vegetation cover surrounding the Gruta da Caixa d'Água cave in the past, as well as possible environmental interventions by pre-colonial human communities, it is first necessary to review existing literature on the processes, dynamics, and vectors governing the influx and deposition of pollen grains and spores in cave environments—both in contexts of human occupation and in their absence. Such background is essential to interpret why certain pollen types are more strongly represented in some samples than in others, and what the overall pollen assemblage reveals about the vegetation around the archaeological site. Furthermore, integrating available paleoenvironmental records for the region is crucial to reconstructing the likely environmental setting during the period encompassed by this study.

Regarding the dynamics, transport, and deposition of palynomorphs in caves, as well as their effectiveness in representing surrounding vegetation, several palynological investigations have yielded important results on the pollen spectra of recent surface sediments from cave interiors (D. Burney & L. Burney, 1993 [United States of America]; Coles & Gilbertson, 1994 [England]; Navarro et al., 2002 [Spain]; Hunt & Rushworth, 2005 [Malaysia]).

D. Burney and L. Burney (1993) investigated modern pollen deposition in cave environments in the state of New York. Results from two years of pollen-trapping experiments showed that the pollen spectra from the three studied caves were very similar to the pollen rain outside the caves. Statistical comparisons of modern pollen grains deposited in Tauber-type collectors, speleothems, bryophyte mats, and sediments from nearby ponds suggested that pollen deposition inside caves can provide reliable evidence of local and regional vegetation and is directly comparable to more conventional pollen spectra derived from lake sediments and bryophyte mats. However, the authors noted that relatively low pollen influxes inside caves may be related to specific characteristics of each cave, such as the shape and dimensions of the entrance and interior, geographical location, among other factors.

Coles and Gilbertson (1994) investigated modern pollen spectra from four caves in England over the course of a year, with monthly sampling intervals. Their analysis revealed that the spectra reflected not only the vegetation in close proximity to the cave entrances but also that of much broader areas beyond their immediate surroundings. By examining the relationships between arboreal and non-arboreal pollen corresponding to dozens of species present in the region, they found that the spectra mirrored the proportions of forests and open fields within a radius of approximately 5 km from each site. The high abundance of pteridophyte spores was associated both with the presence of these plants at the cave entrances and with the dynamics of their spore production and dispersal. In two of the four caves, the authors further observed that the number of palynomorphs accumulated per mm^2 decreased as the distance from the cave entrance increased.

Navarro et al. (2002) studied the pollen rain in two caves located in arid environments dominated by entomophilous plants in Spain. The authors emphasized the

positive effect of aridity on the preservation of pollen in cave sediments, reflected in the high concentration and taxonomic diversity found in their samples, with the occurrence of both local and regional taxa. The effect of aridity on pollen preservation was reinforced when they compared the abundance and diversity of palynomorphs in the two caves with those of non-arid regions of Spain. They highlighted that the pollen spectra of caves, although strongly influenced by biotic transport, can represent the surrounding vegetation, sometimes even more adequately than the external pollen rain, biased by the abundant production and dispersal of wind-pollinated species. Through Spearman's correlation coefficients, a negative gradient in pollen concentration was observed from the entrances to the interior of the caves. The morphology of the caves also proved to be an important factor: the cave with a long and narrow cavity and small entrances presented lower pollen concentration (155,613 grains/g) than the cave with an isodiametric cavity and a wide entrance (282,470 grains/g).

Hunt and Rushworth (2005) investigated taphonomy and pollen rain in a tropical cave in Malaysia. The sediments were predominantly biogenic in origin (bat and bird guano) and were collected from an archaeological site inside the cave. Near the entrance, in the inner section, the pollen spectra were similar to those obtained from forest soil samples outside the cave. In the interior, sedimentation was highly organic and largely composed of bat and bird excrement. The pollen assemblages from the inner part proved to be 'biased,' with an overrepresentation of mangrove and riparian forest taxa. This resulted from the selective recruitment of pollen grains by bats and swifts, which foraged mainly in these environments, about 7 and 2 km from the cave, respectively, and returned to their roosts inside it. At the cave entrance, the proportions of different palynomorph groups largely reflected the outside vegetation, as exemplified by some pteridophytes occurring at the entrance. Ferns, tropical forest/swamp taxa, and weeds showed a gradual decline in their pollen signals along the 30 m transect into the cave. Both the sediments and the pollen influx were influenced by two main factors: the proximity of external entrances and the flow of guano produced and deposited inside the cave.

Based on the aforementioned studies, some congruences were observed among them in relation to two relevant aspects: (1) the recent pollen spectra from caves faithfully reflect both local and regional vegetation (D. Burney & L. Burney, 1993; Coles & Gilbertson, 1994; Navarro et al., 2002; Hunt & Rushworth, 2005), and (2) the quantity and diversity of palynomorphs are lower at internal points farther from the cave entrance and higher at points closer to it (Coles & Gilbertson, 1994; Navarro et al., 2002).

Thus, based on this information, it is possible to support three inferences in this study: (1) that an extensive area in front of the Gruta da Caixa d'Água probably had vegetation dominated by herbaceous plants during the period of sediment deposition at the 30–40 cm level, with a strong presence of entomophilous herbs (Asteraceae, *Evolvulus*, *Mitracarpus/Spermacoce*), and (2) that the low quantity of palynomorphs detected in the other levels of the profile, in addition to possibly being related to the location of the profile—which was not among the most favorable for greater palynomorph accumulation when compared to more central points closer to the cave entrance—may also be associated with factors related to a possible decrease in the flow of human entry/exit and/or with the intensification of degradative processes of the palynomorphs, for which, in the case of this second possibility, more detailed analyses of sediment sample composition, granulometry, and the taphonomic processes of these levels would be necessary. (3) The greater input of pollen grains into the sediments may have been unintentionally increased by their ancient human occupants, through transport on their bodies and on the materials they brought into the cave, from which pollen grains could have fallen inside. The fact that herbs are of lower stature may have favored greater physical contact and consequent adherence of pollen grains, especially to the feet and legs of humans moving between the outside and inside of the cave, resulting in an over-representation

of these plants in the pollen spectra relative to the trees and shrubs in the area, which were under-represented.

Considering that archaeological remains were present in all levels, it could be expected that the samples with the highest concentrations of such remains, for instance the 20–30 cm and 70–80 cm levels, would be those presenting the largest quantities and diversity of pollen grains. However, this was not the case; on the contrary, these two levels revealed very low quantities and diversity of palynomorphs. On the other hand, the 30–40 cm level, which did not stand out for the amount of remains, showed the highest quantity and diversity of palynomorphs in the sediment sample. In this context, which factors could have resulted in the low representativeness of the local flora in the pollen spectra of the great majority of the levels?

A possible answer to the question above is difficult to reach. However, based on information available in previous studies, it is possible to raise some possibilities. It is known, for instance, that the ideal conditions for pollen grain preservation occur in permanently waterlogged (and therefore anoxic) environments of low energy, which inhibit the degradation of sporopollenin (Twiddle & Bunting, 2010). In this sense, it would indeed be expected that the preservation of palynomorphs in the Gruta da Caixa d'Água cave would be low.

Post-depositional damage to pollen grains is generally divided into two types: oxidative and mechanical. In samples from contexts with good oxygen availability, the most susceptible taxa are usually those with thinner exines (Havinga, 1964, 1967). However, the susceptibility of pollen grains to damage is more related to the percentage of sporopollenin within the wall than to its thickness. Brooks (1971) found that the sporopollenin content varies not only among taxa but also among pollen grains of the same taxon. Consequently, some pollen grains will be more resistant than others. In this sense, the pollen grains related to the pollen types *Evolvulus*, Asteraceae 1, and *Mitracarpus/Spermacoce* should present a significant amount of sporopollenin in their walls, especially *Mitracarpus/Spermacoce*, which was not detected in only one of the sediment samples containing palynomorphs, that of the 20–30 cm level.

Beyond the resistance of the walls of palynomorphs, the spectrum of damage is directly related to taphonomic processes, which should be the most relevant in the context of this study. Corrosive processes occur more intensely in environments with high biological activity, whereas mechanical damage processes primarily affect pollen grains that are transported and deposited in minerogenic environments (Twiddle & Bunting, 2010). Thus, the palynomorphs from the Gruta da Caixa d'Água site in most levels were likely destroyed both by oxidative and mechanical damage, considering the predominantly sandy nature of the sediments, which favors aeration and frequent abrasion with sand grains. According to Twiddle and Bunting (2010), the intensity of destruction by mechanical damage is significantly higher in substrates richer in sand, and if larger mineral particles are present in the substrate, there is an even greater tendency toward mechanical damage, which will be reflected in the percentages of broken and heavily deformed pollen grains. In this regard, a possible mineralogical and granulometric analysis of the sediment samples could have contributed to elucidating this issue, especially with respect to the sediment sample from the 30–40 cm level, the only one that stood out in terms of the quantity and diversity of palynomorphs.

EVIDENCE ON CLIMATE AND POSSIBLE ANTHROPOGENIC EFFECTS ON VEGETATION DURING THE PERIOD OF FORMATION OF THE CAVE'S SEDIMENT DEPOSITS

Paleoenvironmental studies covering periods up to 6,000 years BP do not provide evidence of significant climatic variations that could have resulted in relevant changes in the vegetation of areas under the Caatinga and Cerrado domains in the Northeast and Midwest of Brazil, respectively (Parizzi et al., 1998; P. E. Oliveira et al., 1999;

Barberi et al., 2000; Medeiros et al., 2018; Horák-Terra et al., 2020). The main taxa representative of Caatinga species, for example, continue to be present in the current pollen rain in natural pollen deposits (Gomes et al., 2014; Santos et al., 2015; Magalhães-e-Silva & Santos, 2024).

In this context, considering the great diversity of species present in the study area, with hundreds of angiosperm species, as reported in the results, a much greater diversity of pollen types related to species with various habits (e.g., herbs, shrubs, trees) would naturally be expected in the sediments of the studied cave, which did not occur. Instead, the results summarized in Table 2 and Figure 4 revealed a predominance both in diversity and in the quantity of pollen grains related to herbaceous and shrubby species, which contrasts with the current vegetation and with literature information indicating that no climatic changes occurred that could have significantly altered the vegetation in the last six thousand years. Thus, it is possible that the pre-colonial occupants of the cave and its surroundings made constant use of secondary woody vegetation and necromass (dead wood) from the area under anthropogenic influence for the production of fires. Herbaceous plants naturally persisted in the area with a large number of individuals, characteristic of secondary vegetation areas. The results of studies by Scheel-Ybert et al. (2016), based on anthracological analyses in sites of different cultural traditions that occupied Brazilian territory in the South, Southeast, and Central Amazon regions, demonstrated that groups interacted with the natural vegetation and transformed the landscape in many ways, particularly by creating areas of secondary vegetation within forests. According to the authors, due to their proximity, structure, and/or social significance, domesticated secondary vegetation spaces around settlements were possibly preferred for firewood collection.

In a recent article, Silva and Souza (2022) revealed that the spatial structure of the woody flora of the Caatinga over time was significantly influenced by certain environmental factors, particularly during the Pleistocene, and even by the activities of pre-colonial peoples who inhabited its domain. However, the authors emphasize the need for advances in archaeological studies combined with biological indicators to improve the understanding of how pre-colonial populations impacted the biodiversity and structure of Caatinga vegetation.

In some levels, especially the more basal ones in this study, it was not possible to make inferences about the vegetation, since they presented a very small or even absent amount of palynomorphs. Leonor et al. (2019) reported a decrease in macrobotanical remains of seeds and fruits in these levels. The sediments of these levels showed a yellowish coloration, which indicates a low amount of organic matter and consequently disfavors the preservation of palynomorphs. According to Salgado-Labouriau (2006), substrates poor in organic matter are much less efficient in preserving palynomorphs than substrates with abundant organic content.

On the other hand, an increase in organic matter is not necessarily an indicator of a greater amount of palynomorphs in the substrate. The remains of plant parts found by Leonor et al. (2019) in the Gruta da Caixa d'Água showed greater quantity and diversity at the 40–50 cm and 60–70 cm levels, and in these levels very low amounts of palynomorphs were found.

Both plant part remains and charcoal were found in greater quantities above the most basal levels. Macrofossils of *Syagrus* were the only types found in all levels by Leonor et al. (2019) at the site. As highlighted in the results, the *Syagrus* pollen type was the second most frequent in the levels where palynomorphs were detected. This result therefore corroborates the findings of Leonor et al. (2019) and places the taxon in a prominent position for paleoenvironmental inferences in the area of this study.

CONCLUSION

The prospecting of palynomorphs in sediments from the archaeological site of the Gruta da Caixa d'Água cave revealed a low diversity of pollen types and an irregular distribution of palynomorphs along the studied

profile levels, predominantly related to herbaceous and subshrub taxa. Both the reduced diversity and the irregular quantities of palynomorphs have been reported by other authors for cave environments in archaeological contexts worldwide. Previous studies indicate that no significant climatic changes have occurred in the last 6,000 years in the current Caatinga areas, so the composition and structure of the vegetation should not have undergone substantial natural alterations during this period. In this sense, the pollen spectra found in the Gruta da Caixa d'Água did not reflect the characteristic vegetation of the Caatinga or ecotone areas, common in the study area, which are represented by high floristic diversity, including hundreds of arboreal and shrubby species. Instead, they revealed an overrepresentation of palynomorphs related to herbaceous and subshrub taxa, characteristic of secondary vegetation formed through anthropogenic actions.

This overrepresentation is most likely a consequence of the persistence of these plants in the area and the continuous transport of their pollen grains into the cave, primarily by its occupants. Given that these are small-sized plants, usually represented by numerous individuals in their natural habitats, pollen grains are more likely to come into contact with and adhere to the lower parts of the body (such as feet and legs). As a result, herbaceous and subshrub species tend to be more strongly represented inside the cave, due to the gradual release of pollen from the occupants' bodies over time. Although present in smaller quantities, the *Syagrus* pollen type was the second most frequent in the levels where palynomorphs were detected. This finding corroborates evidence from a recent paleobotanical study that confirmed the presence of individuals in the study area, whose uses are consistently reported in archaeological research conducted in regions where these species occur, including the Brazilian semi-arid region.

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J. O. B. Santos contributed to conceptualization, data curation, investigation, validation, and writing (original draft, review, and editing); C. C. Silva-Santana contributed to conceptualization, formal analysis, methodology, and writing (review, and editing); and F. H. Magalhães-e-Silva contributed to conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, and writing (original draft, review, and editing).

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