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ECOLOGY, BEHAVIOR AND BIONOMICS

The Arrow Macambira (*Encholirium spectabile:* Bromeliaceae) as an Important Habitat for the Arthropod Fauna in Rocky Outcrops of the Brazilian Semi-Arid Region

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Abstract

Bromeliads play a vital role in preserving biodiversity in the Neotropical region. To understand their impact on arthropod diversity in Brazil's semi-arid region, we studied the rupicolous bromeliad *Encholirium spectabile*. From 2011 to 2018, we observed the arthropod fauna in *E. spectabile* clumps, documenting the associated taxa, their abundance, and interactions. We also investigated how seasonality affects arthropod richness and composition during the dry and rainy seasons. Over the observation period, 15 orders and 57 arthropod families were recorded in association with *E. spectabile*. Insecta dominated, followed by predatory chelicerates. Eight usage categories were identified, with Shelter being the most prevalent, followed by Predators, Nesters, and Nectarivores. Significant differences in taxonomic richness were noted between rainy and dry seasons, with the rainy season exhibiting higher diversity. Seasonal variation was also observed in species composition. Clumps of *E. spectabile* emerged as crucial habitats for surrounding arthropod fauna. This research underscores the importance of non-phylotelm bromeliads, particularly in high abiotic stress environments like semi-arid regions. The taxonomic diversity observed aligns with findings from diverse environments, shedding light on the relevance of *E. spectabile* for associated arthropod fauna. These results prompt further exploration of non-phylotelm bromeliads in semi-arid settings, providing a fresh perspective on their significance in shaping arthropod communities.

Keywords Arthropods on bromeliads · Macambiras · Invertebrates, animal-plant interaction

Introduction

Understanding the patterns of diversity is an important goal in ecological studies, with significant implications for biodiversity conservation (Wilson 1988). Bromeliads serve as a prime example of ecosystem engineers (Jones et al. 1994; Srivastava 2006; Srivastava et al. 2004) and play a crucial role in maintaining biodiversity in the Neotropical region, serving as a model for the study of biodiversity patterns (Picado 1913; Benzing 2000; Lounibos and Frank 2009; Jorge et al. 2021a). These plants not only act as resources for other species but also physically alter the environment and provide refuge and optimal conditions for many organisms, often in a mutually beneficial relationship (Frank and Lounibos 1983; Benzing 2000; Laviski et al. 2021).

The water accumulation in a structure called phytotelmata is a biodiversity-enhancing feature in some Bromeliaceae species (Gonçalves-Souza et al. 2010). The phytotelmata is formed by the rosette-shaped foliage architecture that creates a cistern-like structure, collecting rainwater and organic debris and providing a habitat for a diverse array of plants and animals (Richardson 1999; Benzing 2000; Jocque et al. 2013; Rogy et al. 2020). Invertebrates have been found in various parts of bromeliads, including phytotelmata (Frank and Lounibos 1983; Kitching 2000), inflorescences (Monteiro and Macedo 2014; Jorge et al. 2018), foliage (Richardson 1999), and roots (Fragoso and Rojas-Fernández 1996).

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Bromeliads serve as water sources and provide shelter, food, and breeding sites for various animals (Queiroz et al. 2016; Rocha 2022). They also attract predators and support diverse animal species for thermoregulation and breeding (Ramalho et al. 2004; Jorge et al. 2021a, b). Invertebrates, particularly aquatic insect larvae, dominate the animal diversity in bromeliad phytotelmata, and incoming debris provides nutrients for the phytotelma food chain (Srivastava 2006; Srivastava et al. 2004; Ngai and Srivastava 2006; Dézerald et al. 2017). Predatory invertebrates form complex food webs in bromeliads due to the abundance of invertebrates (Petermann et al. 2015; Romero et al. 2020).

Most of the research on bromeliads has primarily focused on interactions between invertebrates and phytotelmata. However, there has been limited attention given to interactions with other parts of the plants and different types of bromeliads. There is little knowledge about the arthropod groups that utilize non-phytotelmata bromeliads, despite many arthropod/animal species associated with different parts of these plants. Among these bromeliads, the rupicolous bromeliads of the *Encholirium* genus hold significant importance for the arthropod fauna in the semi-arid region of Brazil (Ramalho et al. 2004; Zanella and Silva 2010; Queiroz et al. 2016; Jorge et al. 2018, 2021a, b).

Some species of *Encholirium* (commonly known as arrow macambiras) are characterized by strongly aculeate, rigid foliage, the growth pattern of which forms dense clumps on rocky outcrops (Forzza et al. 2003; Forzza and Zappi 2011). In the Brazilian semi-arid region, with its wide temperature fluctuations and water deficit, the environment created by these bromeliads serves as an oasis. These clumps can be viewed as mesic refuges that resemble islands amid the barren rocky outcrops and provide an environment conducive to colonization by local fauna (Jorge et al. 2020). Thus, these bromeliads function as ecosystem engineers, mitigating the harsh abiotic conditions (Jorge et al. 2021a). Ecosystem engineers play a crucial role in arid and semi-arid environments by alleviating the effects of climate and will become even more important, particularly for arthropods, in the face of climate change (Romero et al. 2022; Lindner et al. 2010). In recent years, research has focused on the numerous mechanisms that underlie the association of fauna and *Encholirium spectabile* Mart.ex Schult. and Schult. F. (Pitcairnioideae) (Jorge et al. 2018, 2020, 2021a, b, 2023).

Given the limited information available regarding the patterns and potential mechanisms of the association between arthropod fauna and bromeliads of the genus *Encholirium*, this study aims to (a) provide information on the diversity of the arthropod fauna associated with *E. spectabile* clumps in the Brazilian semi-arid region, (b) examine and catalog the interactions between the fauna and host bromeliads, and (c) evaluate the potential effects of seasonality on the arthropod fauna associated with these bromeliads and the implications of these interactions for the conservation of the involved groups.

Methods

Study area

This study was conducted at Fazenda Tanques (5.853°S; 35.701°W; datum WGS84, 137 m asl.), in the municipality of Santa Maria in Rio Grande do Norte state, Brazil (Fig. 1), a region included in the "Depressão Sertaneja Setentrional" ecoregion of the Caatinga (Velloso et al. 2002). This ecoregion is characterized by irregular rainfall and a dry season from July to December. The climate is semi-arid, hot, and dry, with an average annual precipitation of 500–800 mm/year (Velloso et al. 2002). The municipality of Santa Maria is located in the "Agreste" region, a transition zone between the Caatinga and the Atlantic Forest, with characteristics of both environments (Rizzini 1997). The rainy season in the "Agreste" usually extends from January to June (Velloso et al. 2002). The minimum monthly temperatures in Santa Maria range from 22 to 24°C, and the maximum monthly temperatures range from 28 to 32°C, with an average annual rainfall of 781 mm (Jorge et al. 2020). There is a common presence of rocky outcrops with a large abundance of *E. spectabile* bromeliads in the study area.

The surroundings of the study area are covered by arboreal-shrubby vegetation, with the occurrence of Caatinga trees such as "juremas" (*Mimosa* spp.), "imburanas" (*Commiphora leptophloeos* (Mart.) J.B. Gillett), "cajueiros" (Anacardium occidentale L.), and "barrigudas" (*Ceiba glaziovii* (Kuntze) K.Schum.). *Encholirium spectabile* clumps in this rock outcrop occupy a large part of its extension (60%). Aside from the bromeliads in the rocky outcrop, the presence of "xique-xique" cactus (*Pilosocereus gounellei*) is also common (Jorge et al. 2020, 2023).

Methodological procedures

This study is part of a project that surveyed the fauna associated with *E. spectabile* clumps in the Brazilian semi-arid region, involving approximately 5500 h of sampling effort and 10 years of monitoring the associated fauna and the implications of these associations (Jorge et al. 2020, 2021a, 2023). The search for plants and data collection occurred throughout three parallel transects of 12 m in width and about 1500 m in length, situated on the north border, the center, and the south border of the outcrop (Jorge et al. 2020). All three transects were explored once per day during three consecutive days in each month by a

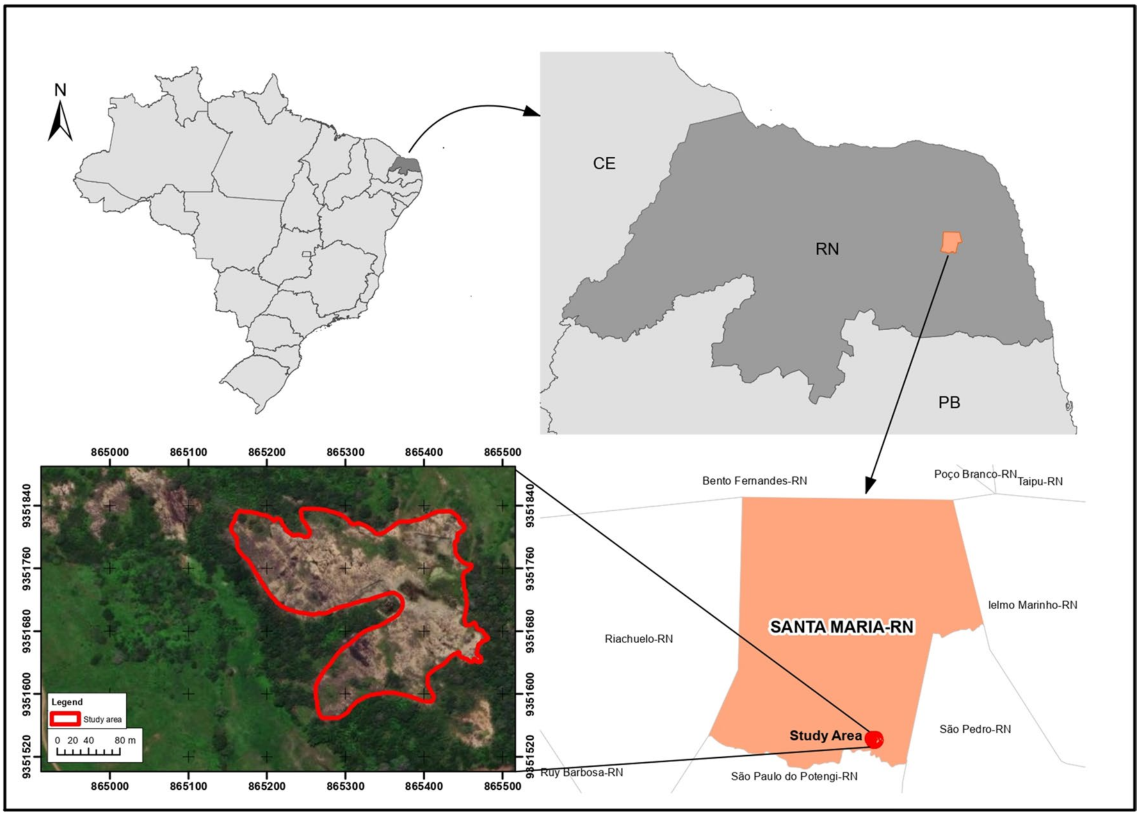

Fig. 1 Location of the rocky outcrop where this study was conducted in Brazil, highlighting the Rio Grande do Norte state and the study area (Tanques Farm) in Santa Maria municipality. Transects are visible in Jorge et al. (2020), Fig. 1

single observer (JSJ) in the morning, afternoon, and night at different times. Thus, each transect was surveyed once during each time of the day each month, reducing the problem of recounting individuals.

About 60 clumps were present on each edge, and 80 clumps in the center. Each clump had an average of 16 bromeliad individuals, totaling 1400 bromeliads. All clumps along the transect were inspected by visual active search during the 3 days of surveying, with the observer registering all taxa of arthropods occupying the bromeliad clumps in a field notebook. Each survey in the transects lasted about 2 h and surveyed different clumps along the time of the day. To avoid potential statistical errors related to the repeated counting of the same individuals in our analyses, we opted to use the "number of records" rather than the "number of individuals." This choice assumes that individuals may be counted multiple times.

The fieldwork comprised at least 12 h of observation during the day and 4 h at night during the years in which the study was conducted. Daytime observations started at 7:00 am and continued until 6:00 pm; nighttime observations resumed at 7:00 pm and continued until 11:59 pm. In the first year, individuals of each taxon were collected and deposited in the UFRN invertebrate collection for confirmation and correct identification of each group.

Each taxon observed in association with *E. spectabile* was assigned to a usage category based on their habits according to Jorge et al. (2021a, b). The usage categories were defined based on observations through the focal animal method and correlated with data present in the literature regarding the biology of the taxon in question. We utilized both general and specific bibliography to establish the type of interaction between the taxa and bromeliads. Arthropod observations were authorized by the Biodiversity Information and Authorization System of Chico Mendes Institute for Biodiversity Conservation (SISBIO–ICMBio, Authorization No. 71469–1). Additionally, an observation time by focal animal (ten individuals of each taxon) of 20 to 30 min was established to understand what type of interaction each taxon performed in the bromeliads. The recorded observations were compared with the relationships already recorded in the literature so that we could assign which type of guild each taxon established.

Data analyses

To explore whether and how arthropod family richness associated with clumps of *E. spectabile* differed between dry and wet seasons, we calculated the nonparametric 95% confidence intervals (CIs) for arthropod family richness from each season (based on 999 resamples with the BCa method) using the boot function and package (Davison and Hinkley 1997; Canty and Ripley 2021). To achieve this, data of arthropod richness were resampled within each climatic season independently from clumps, transects, days, months, and years they were sampled. In addition to providing information about data variability/dispersion, CIs can express the statistical significance of tests regarding comparisons of means (Wood 2005). This technique avoids meeting the assumptions for parametric models (for example, normal distribution, homogeneity of variance, and independency among samples) and facilitates interpretation (Carpenter and Bithell 2000; Wood 2005). Therefore, we employed this method because, in addition to being robust and straightforward to interpret, it is suitable for the analysis of data that are collected in the same places (i.e., clumps and transects) repeatedly along the time (days, months, and years), with the rainy period being considered from January to June and the dry period from July to December (Ab'Saber 1974; Velloso et al. 2002). Next, we conducted a non-metric multidimensional scaling (NMDS) using the Bray–Curtis index as a measure of distance (calculated based on the frequencies of each species) and an analysis of similarities (ANOSIM) using the Past Programs (Hammer et al. 2001). A significance level of alpha = 0.05 was considered in all analyses. The statistical analyses were performed using STATISTICA software, version 10.

Results

We recorded about 15 orders and 57 families of arthropods in association with *E. spectabile* during the years of observation. The richness of arthropods taxa recorded in association on *E. spectabile* in the study area is presented in Table 1 (Fig. 2). Insecta was the most abundant group, while the predatory chelicerates ranked second.

Regarding the use of *E. spectabile* by arthropods, we recognized eight usage categories: Nesters (Nest Builders), Herbivores, Detritivores, Nectarivores, Predators, Parasitoids, Hematophagous, and Shelter (Figs. 3, 5). Most taxa used *E. spectabile* as a Shelter ($N = 54$), followed by Predators ($N = 22$), Nesters ($N = 21$), and Nectarivores ($N = 17$). As for the parts used, most use "both" parts ($N = 26$), followed by clumps (leaves) ($N = 23$), and flower stems ($N = 11$) (Fig. 2).

Regarding the richness of registered taxa (family level) between the seasons, there were significant differences between the rainy and dry seasons (rainy season: average = 4.343096, upper limit = 4.45, lower limit = 4.25; dry season: average 4.108787, upper limit = 4.2, lower limit = 4.01, Fig. 3). Regarding species composition, it differed significantly between seasons (ANOSIM; $R = 0{,}08442$, $p = 0.0004$, Fig. 4). The taxa with most individuals recorded in the rainy season was Apidae family ($N = 9.426$), followed by Blattodea ($N = 7.320$), and Formicidae ($N = 3.767$). The most common taxa in the dry season were Apidae ($N = 6.705$), followed by Blattodea ($N = 7.320$) and Formicidae ($N = 1.955$) (Table 1, Fig. 4).

Discussion

The clumps of *E. spectabile* serve as important habitats for the surrounding arthropod fauna. Our study found a high diversity of taxa distributed among eight different usage categories that utilize the bromeliads in various ways. These results emphasize the importance of studying non-phytotelmata bromeliads, especially in environments with high abiotic stress like semi-arid regions. The taxonomic composition of the sample at the ordinal and family levels is similar in some points to the fauna documented in association with bromeliads in previous studies (Picado 1913; Laessle 1961; Cotgreave 1993; Richardson 1999; Kitching 2000; Júnior et al. 2017), despite being from different environments, with records of many terrestrial groups. The results found in present study brings a new perspective on the importance of non-phytotelmata bromeliads in relation to associated arthropod fauna, opening space for new studies on associated fauna in semi-arid environments.

The rocky outcrops where *E. spectabile* grows are fully exposed to the elements (Porembski 2007; Jorge et al. 2020), and the bromeliad clumps offer shelter from direct exposure to sunlight. In addition to providing shade, the interior of the bromeliads also has higher relative humidity compared to the exterior (Jorge et al. 2020, 2021a). In environments with water scarcity and high daily temperatures, such as in semi-arid regions, especially in rocky outcrops (Porembski 2007; Hmeljevski et al. 2015), a shelter with mild temperature and higher humidity becomes a valuable resource. The clumps can be seen as "islands" on the rocky outcrops that attract a diverse range of taxa and serve as shelter and "wildlife restaurants" (Rocha 2022; Jorge et al. 2023) for the species that make up the local community, as demonstrated by the results of this study. Rocha (2022) proposed the term "wildlife restaurants" because bromeliads, such as epiphytic and terrestrial forms, provide a varied "menu" for birds throughout the year, including nectar, flower tissues, water, fruits, seeds, and invertebrates. Based on this fact, the term can

Table 1 Taxa recorded in association with *Encholirium spectabile*, during the years 2011–2018, at municipality of Santa Maria, Rio Grande do Norte, Brazil. *Nec* Nectarivores, *Her* Herbivores, *Det* Detritivores, *Nid* Nester, *Pre* Predator, *Par* Parasitoid, *Hem* Hematophagous, *Sher* Shelter. Numbers represent abundance

Order/family	Dry season	Rainy season	Total	Usage categories
Hymenoptera				
Apidae	6705	9426	16,131	Nec, Nid, Sher
Vespidae	855	1355	2210	Nid, Det, Nec, Pre
Sphecidae	8	28	35	Nid, Sher
Evaniidae	5	12	17	Par
Ichneumonidae	5	17	22	Par, Pre
Formicidae	1955	3767	5722	Pre, Nec, Nid, Det
Coleoptera				
Elateridae	57	20	77	Det, Sher
Curculionidae	33	45	78	Her, Det
Scarabaeidae	5	31	36	Det
Cerambycidae	12	41	63	Her
Carabeidae	13	115	128	Det
Hemiptera				
Reduviidae	50	334	384	Nec, Nid
Cicadellidae	139	580	719	Nec, Sher
Scutelleridae	25	265	290	Her, Sher
Pentatomidae	12	83	95	Her, Sher
Coreidae	16	95	111	Her, Sher
Aphidoidea	490	210	700	Her
Blattodea	7320	2416	9736	Det, Nec, Sher
Lepidoptera				
Sphingidae	50	105	155	Her, Sher
Castniidae	10	203	213	Her, Sher
Geometridae	80	133	213	Her, Sher
Lycaenidae	99	115	214	Her, Sher
Odonata				
Anisoptera	17	98	115	Pre
Zygoptera	54	9	63	Pre
Orthoptera				
Acrididae	151	116	267	Her, Sher
Gryllidae	43	13	56	Her, Sher
Proscopiidae	146	0	146	Her, Sher,
Tettigonidae	67	12	79	Her, Sher
Romaleidae	173	36	209	Her, Sher
Phaneropteridae	24	0	24	Her, Sher
Mantidae				
Photinainae	23	13	36	Pre, Nid
Stagmatopterinae	9	3	12	Pre, Nid
Vatinae	12	4	16	Pre, Nid
Neuroptera				
Ascalaphidae	58	85	143	Pre, Nid, Sher
Diptera				
Culicidae	600	0	600	Hem
Psychodidae	10	0	10	Nec
Ulidiidae	73	110	183	Nec
Tabanidae	92	0	92	Hem
Arachnida				
Araneidae	896	209	1105	Pre, Nid, Sher
Pholcidae	62	17	79	Pre, Sher
Theridiidae	234	118	352	Pre, Nid, Sher

Table 1 (continued)

Order/family	Dry season	Rainy season	Total	Usage categories
Pisauridae	8	0	8	Pre, Nid, Sher
Salticidae	437	184	621	Pre, Nid, Sher
Selenopidae	4	0	4	Pre, Nid, Sher
Erithrognathidae	92	7	99	Pre, Sher
Lycosidae	19	1	20	Pre, Nid, Sher
Theraphosidae	18	3	21	Pre, Sher
Scorpiones				
Buthidae	18	7	25	Pre, Sher
Bothriuridae	15	2	17	Pre, Sher
Opiliones				
Gonyleptoidea	79	0	79	Pre, Sher
Diplopoda				
Julidae	0	695	695	Det, Sher
Polydesmidae	0	375	375	Det, Sher
Total	**21.358**	**12.314**	**33.672**	**–**

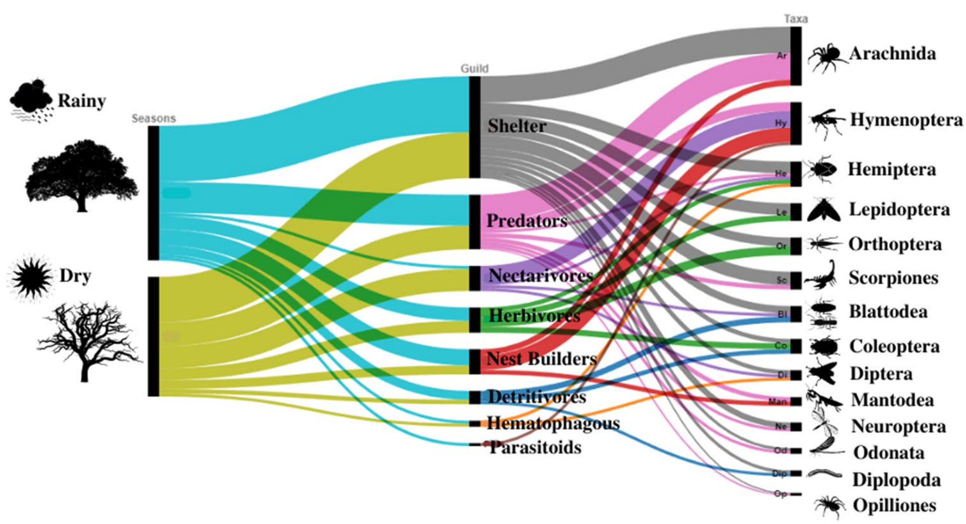

Fig. 2 Alluvial diagram summarizing the usage categories (guilds) and the relationship of uses between seasons (dry and rainy), of the arthropds taxa associated to the *Encholirium spectabile*. The set of the taxa contained in each taxonomic group is shown on the right side; on the left, the seasons dry and rainy; in the center, the usage categories. The width of the bar corresponds to the number of records registered in each usage category by season for each taxa

be expanded to other groups, such as amphibians and reptiles, and to invertebrates themselves, which are part of the "menu" for other groups and also act as "clients."

The use of *E. spectabile* clumps for foraging is a common activity among the invertebrates recorded in this study and others involving invertebrates associated with bromeliads (Benzing 1980; Benzing 2000; Júnior et al. 2017; Rogy et al. 2020). This foraging behavior includes herbivory on the bromeliad's leaf tissue, nectar and pollen collection, predation on other species, and detritivory. The most common herbivorous insects observed in the clumps were from the Orthoptera, Coleoptera, Hymenoptera, Blattodea, Lepidoptera, and Hemiptera groups, known for their potential to cause damage to bromeliad tissue (Canela and Sazima 2003; Fischer et al. 2003, 2008; Schmid et al. 2010). However, herbivorous arthropods associated with *E. spectabile* do not solely feed on the plant tissue but also on the resources available during its flowering period. Among these groups, cockroaches are among the invertebrates that feed on the tissues and resources available, such as nectar and pollen, in addition to taking advantage of the remains of other animals, showing a generalist and opportunistic diet.

Bees (Hymenoptera) are the most frequent visitors to the flowers of *E. spectabile* (Queiroz et al. 2016; Jorge et al. 2018); the European bee (*Apis mellifera* Linnaeus) and the native meliponine arapuá (*Trigona spinipes* (Fabricius)) are the most abundant. Other groups also use *E. spectabile* blooms as a place to feed, such as Diptera, Lepidoptera, and Hemiptera (Jorge et al. 2018). The blooms in the dry period function as "wildlife restaurants" (Rocha 2022; Jorge et al. 2023) for the taxa that feed on nectar, pollen, and the floral tissues themselves, as well as for their potential predators, which search for their prey in the blooms. Many bromeliad-inhabiting predators, such as spiders, scorpions, praying

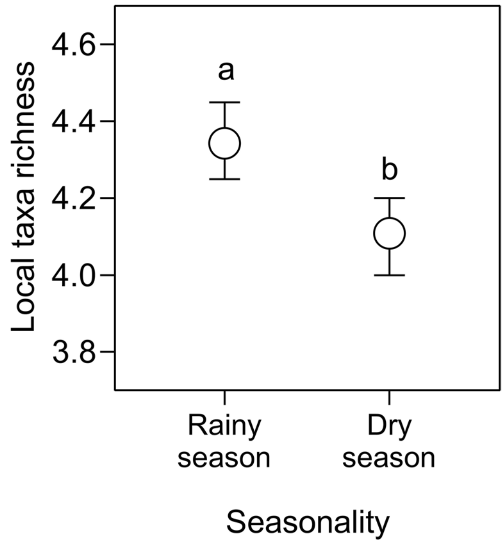

Fig. 3 Local arthropod richness observed in *Encholirium spectabile* clumps during rainy and dry seasons. The circles are the means, and the vertical lines denote the upper and lower limits of 95% confidence intervals calculated through bootstrapping with 999 iterations. Different letters indicate statistically significant differences

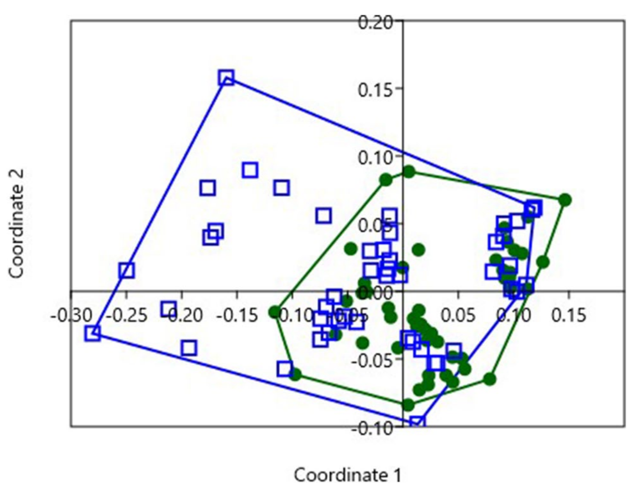

Fig. 4 Results of non-metric multidimensional scaling (NMDS) showing the differences in arthropods composition between seasons in association on *Encholirium spectabile* in Santa Maria, Rio Grande do Norte, Brazil (2011–2018). Green dots: species recorded in rainy season; Blue squares: species recorded in dry season

mantises, and dragonflies, generate debris (carcasses, exuvia, and web remains), which attracts detritivores seeking available organic material. The most common detritivores found in *E. spectabile* clumps include cockroaches, some coleopterans, isopterans, and diplopods. Termites and cockroaches (Blattodea) are abundant throughout the year, while myriapods, which rely on high humidity, are only available in the rainy season. These groups are often found in bromeliads (Picado 1913; Domingues et al. 1989; Oliveira et al. 1994; Richardson 1999; Lounibos and Frank 2009), but the relationships between these organisms and bromeliads are not well understood.

In addition to serving as a source of food and shelter, the clumps of *E. spectabile* also provide a breeding ground for local wildlife. Wasps (Hymenoptera) are among the animals that frequently build nests in *E. spectabile* (Benzing 2000). Specifically, wasps in the Vespidae family are commonly found in association with *E. spectabile*, constructing nests on its leaves as well as in its blooms, where they often forage during the day. Additionally, the solitary bees *Xylocopa abbreviata* Hurd & Moure and *X. macambirae* Zanella & Silva use the stems of *E. spectabile's* inflorescences to build their nests (Ramalho et al. 2004; Zanella and Silva 2010). These bee species (Fig. 5) are completely dependent on flowering stems to build their nests, and the disappearance of these stems can result in the decline of these solitary bee species.

Termites and ants (eusocial insects) are commonly found in bromeliads and have been documented in association with *Encholirium* sp. bromeliads (Benzing 2000; Jorge et al. 2021b). Benzing (2000) notes that termites and ants have a mutually beneficial relationship with bromeliads, where the host plant provides a suitable place for nest building and the termites and ants contribute to soil aeration and nutrient release. Both groups play a significant role in tropical ecosystems, from open habitats like the Cerrado to humid tropical forests, serving as primary consumers and decomposers and as prey for various predators (Brandão and Cancello 1999). The relationship between termites and ants with *E. spectabile* in the study area merits attention and requires further investigation, as they are abundant groups that form the foundation of trophic relationships.

Seasonality effects

The effects of seasonality on the invertebrate fauna associated with *E. spectabile* have significance in taxa richness and composition between seasons. This result is similar to other studies of invertebrates in the semi-arid region of Brazil, which found effects on species richness and composition (Vasconcellos et al. 2010; Bento et al. 2016). In this region, the concentration of rainfall in a specific period has a significant impact on the biology and ecology of the taxa, and invertebrates are particularly affected, impacting the entire food chain (Sales et al. 2011; Ribeiro et al. 2012). This is due to the concentration of available resources during this period, such as flowers, fruits, and water, increasing the abundance of arthropods during the rainy months (Vasconcellos et al. 2010).

The flowering of these bromeliads during the dry season (Queiroz et al. 2016; Jorge et al. 2018) provides a vital resource (nectar, pollen, and flower tissues) to various

Fig. 5 Record of nests of some species which use macambiras's (*Encholirium spectabile*) clumps as a nesting site in the municipality of Santa Maria, Rio Grande do Norte, Brazil. **A** Wasp (*Polibia* sp.); **B** praying mantis (Mantodea); **C** wasp (Sphecidae); **D** ant (*Crematogaster* sp.). Photos: JSJ

organisms such as bees, cockroaches, and wasps (Jorge et al. 2018). This allows the bromeliads to attract and support these taxa during times of scarcity. Research on the invertebrate assemblage associated with *Aechmea bromeliifolia* in a semi-arid region by Islair et al. (2014) found differences in abundance but not in species richness. The authors attributed this to the presence of phytotelmata, which store water and serve as a source of resources during the dry season. *E. spectabile* provides food and shelter for the fauna in both the dry and rainy seasons. Making these resources available during times of scarcity reduces the differences between seasons.

Encholirium spectabile plays a crucial role in the colonization of arthropods in rocky outcrops in the semi-arid region of Brazil, as demonstrated by the results. These resilient bromeliads create a microenvironment with their leaves arranged in a rosette, retaining moisture and offering refuge and food for arthropods in a hostile habitat. These effects can be even more exacerbated in periods of drought, where resources are even more limiting. A similar role is played by cushion plants in the Arctic region, acting as facilitators, promoting the establishment of plant and arthropod communities in the region, contributing to the establishment of these communities in a hostile environment (Liczner and Lortie 2014), and bird's nest fern epiphytes also facilitate arthropod communities in forest canopies (Phillips et al. 2020). This interdependence highlights the adaptive strategies that enable life in challenging environments, emphasizing the importance of these bromeliads in the ecological balance of semi-arid ecosystems.

Therefore, based on the results presented here, a new perspective on the significance of *E. spectabile* clumps in rocky outcrops for maintaining arthropod diversity in the semi-arid region is proposed. Recognizing the myriad ecosystem services provided by invertebrate taxa, including organic matter recycling, biological control, and plant pollination (Noriega et al. 2018), and considering the alarming loss of species diversity among invertebrates (Eisenhauer et al. 2019; Sánchez-Bayo and Wyckhuys 2019), where habitat loss is identified as a primary cause of this crisis (van Klink et al. 2020), the conservation of bromeliads becomes essential.

Bromeliads serve as significant habitats for various invertebrate species. Thus, their preservation is crucial in mitigating the decline of these groups in the Neotropical region. It is suggested to recognize non-phytotelmata bromeliads (*Encholirium* genera) as important components in semi-arid ecosystems. Given their role as keystone species in conserving biodiversity in the Brazilian semi-arid (Jorge et al. 2021a), further studies on *E. spectabile* and other *Encholirium* species, with a focus on the diversity and interactions of their associated biota, are encouraged.

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Data availability The data will be made available upon request to the authors of the work.

Declarations

Conflict of interest The authors declare no competing interests.

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