Bibliometric Analysis of Ornithophilous Species of Bromeliaceae in the Atlantic Forest

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This bibliometric analysis quantified the articles published on ornithophilous species of Bromeliaceae in the Atlantic Forest biome, demonstrating the scarcity of studies and the need for work to reduce the knowledge of this plant-animal relationship in the state of Bahia (Brazil). The bibliometric analysis of ornithophilous species of Bromeliaceae in the Atlantic Forest in the time cut from 1996 to 2024, with the first filter of the expressions "ornithophilia, Bromeliaceae, Atlantic Forest", selected 251 articles from 819 authors in 96 journals from 23 countries, with Brazil highlighted by 111 articles (44%). The second filter with the term "pollination" generated 40 (15.9%) articles listed by national institutions. In Brazil, most of the surveys on ornithological pollination in Bromeliaceae were carried out in the Atlantic Forest (96%). The third filter for the final selection of articles published by authors of Brazilian institutions grouped only 8 (3%) articles from the initial total. The method is effective and limited, excluding articles published in the middle of the dissemination books in modest or low-cost journals. A non-factor of impact phase can also devalue research of regional or local relevance, leading to a distorted vision of the relevance of endemism.

Keywords: R Studio. Hummingbirds. Pollination. Citations. Brazilian Authors.

The Atlantic Forest is a biome rich in biodiversity of fauna and flora. The great diversity of the biome makes it possible for thousands of species that inhabit this environment to survive [1]. Ecological relationships maintain the trophic network and thus ensure the community's survival, development, and evolution. Ornithophilous plant species in the Atlantic Forest biome are abundant and sustain pollination syndromes in various plants and animals from different vegetation strata. The varied morphologies usually indicate the type of pollinator [2]. In this biome, Bromeliaceae predominates in the composition of families with ornithophilous species [3].

Among pollinators, insects and birds are important, with adaptations to plant species. About 10 to 15% of the angiosperms in a forest are ornithophilous plants with specific bird pollination characteristics, especially hummingbirds that use floral nectar as a food resource. Hummingbirds (Trochilidae family) make up the most significant pollinators among the vertebrates of the Neotropical belt and may be the primary pollinators of plant species with specific adaptations [2]. Species of the subfamily Phaethornithinae feed in the understory, and those of Trochilinae act in the canopy with less richness of ornithophilous plants [4-6].

The plants' characteristics, such as size, color, shape, and floral features, will indicate the pollinator type. For example, plant species pollinated by birds have tubular shapes, striking colors, no odor, relatively dilute abundant nectar, diurnal anthesis, and spatial separation of the nectariferous chamber about the stigmas and anthers [7].

This bibliometric analysis aimed to quantify the articles published on ornithophilous species of Bromeliaceae in the Atlantic Forest biome, demonstrating the scarcity of studies and the need for studies to reduce this knowledge gap.

Bromeliaceae: Adaptations and Ecosystem Services

The family Bromeliaceae Juss is a group of monocots that is extremely successful in

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neotropical environments. It is characterized by great diversity in terms of habits, modes of reproduction, and a significant role in the trophic web. About 3,547 species of 76 genera are described, in addition to another 550 infraspecific variations found from the south of the United States to Chile [8].

Bromeliads are perennial plants, usually with a short stem, forming a rosette that can be conspicuous or inconspicuous. They range in size from a few centimeters (*Tillandsia usneoides*) to more than 10 meters (*Puya raimondii*). Most species are epiphytic, but there are also terrestrial and saxicolous (growth on rock). The stem has short internodes, with leaves arranged in a spiral and dilated sheath. The inflorescences are terminal or pseudolateral, sympodial growth, and usually showy, playing an important role in attracting pollinators [5].

They also have an excellent adaptation to colonize new niches and environments, expanding their ecological possibilities. This is thanks to the most notable characteristic of the group, the trichomes modified into peltate scales that absorb water directly from the atmosphere, combined with the photosynthetic mechanism of the CAM (crassulacean acid metabolism) type [9].

Although most genera of Bromeliaceae are present in Brazil, with more than 85% being endemic [9,10], little is known about their reproduction, especially in relation to issues involving speciation and reproductive strategies. Recent research on pollination in the family indicates that bromeliads play a crucial role in the networks of plant-animal interactions [11].

Other intriguing aspect investigated in Bromeliaceae species is the quality of the nectar produced and its relationship with different types of pollinators. Recent research on nectar concentration in Bromeliaceae has drawn attention, as the sugar levels are consistently higher than in other families [2,12]. This underscores the family's importance as one of the main sources of resources for the pollinator community.

Among the pollination syndromes, the Bromeliaceae family includes ornithophilous species (birds), especially troquilophiles (hummingbirds), mesophiles (bees), chiropterophiles (bats), psychrophiles (butterflies), sphingophiles (moths), and even species pollinated by rodents, conferring a wide adaptive irradiation to the family [11].

The Bromeliaceae are recognized as one of the most important sources of resources for hummingbirds in the Atlantic Forest.

Hummingbirds are the main pollinators of the family, both in Brazil and in other Neotropical regions. To date, 51 species of hummingbirds have been recorded pollinating bromeliads, which includes the 34 (66.7%) species of the smaller, beautiful, and showy birds that occur in Brazil [2,11].

The importance of this work lies in presenting the current state of scientific production on plant-animal interaction between bromeliads and birds in the gap of this knowledge and its greater diffusion.

Materials and Methods

The method adopted was the bibliometric analysis of articles published in the Scopus, Web of Science, and Scielo databases over 28 years (1996 to 2024), using filters with terms ("ornithophilia, Bromeliaceae, Atlantic Forest, pollination") and search criteria (Brazilian authors) using the R algorithm.

Literature review is a method characterized by the use and analysis of scientific works published as articles, dissertations, theses, and books. This research uses secondary data to identify and describe results obtained by other authors on a given topic.

Bibliometric analysis is a quantitative and statistical technique for measuring indices of the production and dissemination of scientific knowledge [13]. On the other hand, systematic reviews are a comprehensive and detailed search method for identifying more comprehensive studies and significant gaps in published theoretical and methodological studies [14, 15].

The selection of articles was made using 3 filters of specific search terms and criteria: (1) identification of ornithophilous species of Bromeliaceae in Atlantic Forest by the expressions "ornitholyphilia, Bromeliaceae, Atlantic Forest" in the R Core Team for statistical analysis and generation of graphs and tables by the Bibliometrix package of the R 4.0.1 software; (2) refinement by titles or abstracts with the search term "pollination"; and (3) selection of articles published by authors from Brazilian institutions.

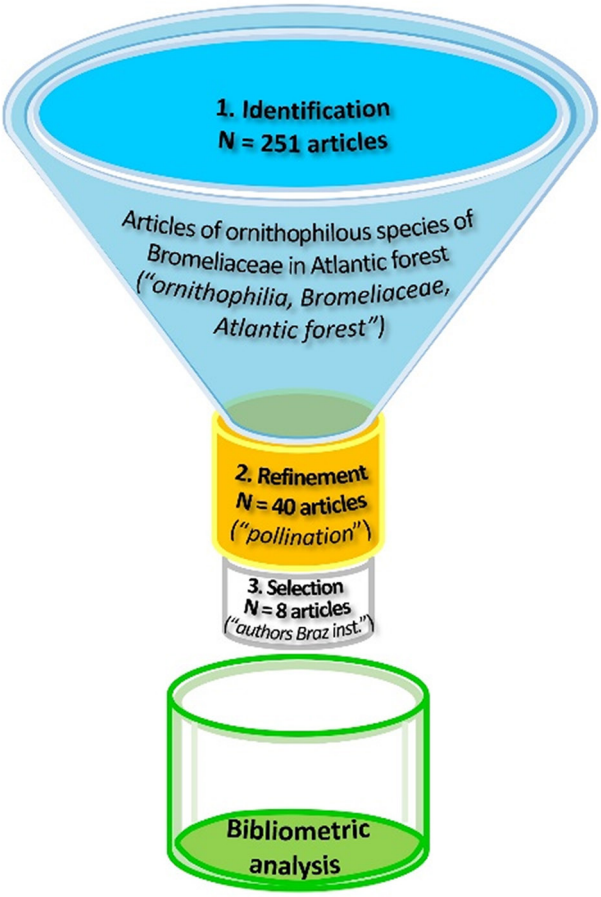
This use of successive filters (requirements) was recorded as a history of the research, following guidelines from a qualified quorum. This allowed clear visualization of why studies were excluded at different stages of the review and under which specific criteria. The qualified quorum is the minimum number of articles necessary for systematic review research to take place [16].

Results and Discussion

The bibliometric analysis of articles on ornithophilous species of Bromeliaceae in the Atlantic Forest, published from 1996 to 2024, used three search filters. The first one, with 3 initial expressions "ornithophilia, Bromeliaceae, Atlantic Forest", selected 251 (100%) articles from 819 authors in 96 journals in 23 countries. The second filter, with the term "pollination", generated 40 (15.9%) articles related to ornithophilia and Bromeliaceae. The third and final filter got only 8 (3%) articles published by authors from Brazilian institutions (Figure 1).

In the first level, the highlight was Brazil (N=111, 44.0%), followed by Germany (N=31, 12.3%), the United States (N=29, 11.5%), the United Kingdom (N=17, 6.8%), Switzerland (N=12, 4.8%), Mexico (N=11, 4.4%), Argentina, Austria and Colombia (N=6, 2.4%), Spain and Sweden (N=4, 1.6%), Belgium, Chile and Italy (N=3, 1.2%), Panama, Peru and Uruguay (N=2, 0.8%), Australia, Canada, Costa Rica, Czech Republic, Guatemala and the Netherlands (N=1, 0.4%) (Figure 2).

Figure 1. Filter method for selecting articles on ornithophilous species of Bromeliaceae in the Atlantic Forest, published from 1996 to 2024.



Nine of the selected articles had more than 60 citations, indicating greater scientific dissemination on the theme of interactions between bromeliads and birds as pollinators (Figure 3).

The analyzed articles have, on average, 5 authors, with two papers written by only 1 author. About 60 papers have international co-authors (24%). The average annual production was 8.94%. The journals with the highest h-index were the Botanical Journal of the Linnean Society, Biota Neotropica, and Rodriguésia. This index is an important metric that quantifies the productivity and impact of individual or group research based on the authors of the most cited articles (Table 1).

On the other hand, most of the articles were published in the journals Phytotaxa (N=24),

Figure 2. Scientific production by country of articles on ornithophilous species of Bromeliaceae in the Atlantic Forest, published from 1996 to 2024.

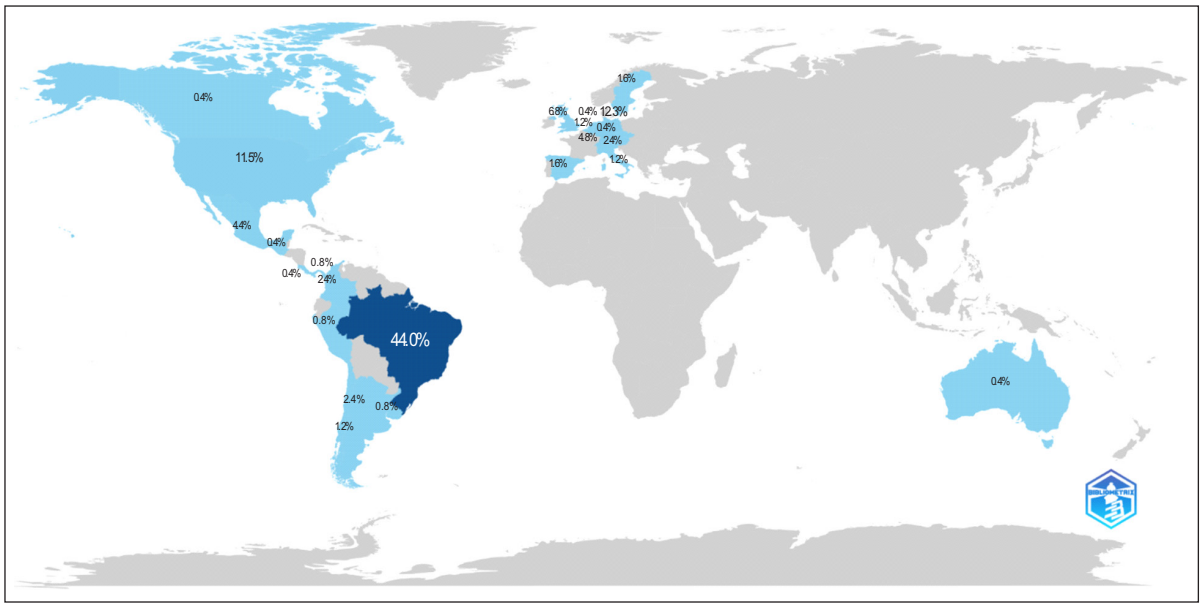
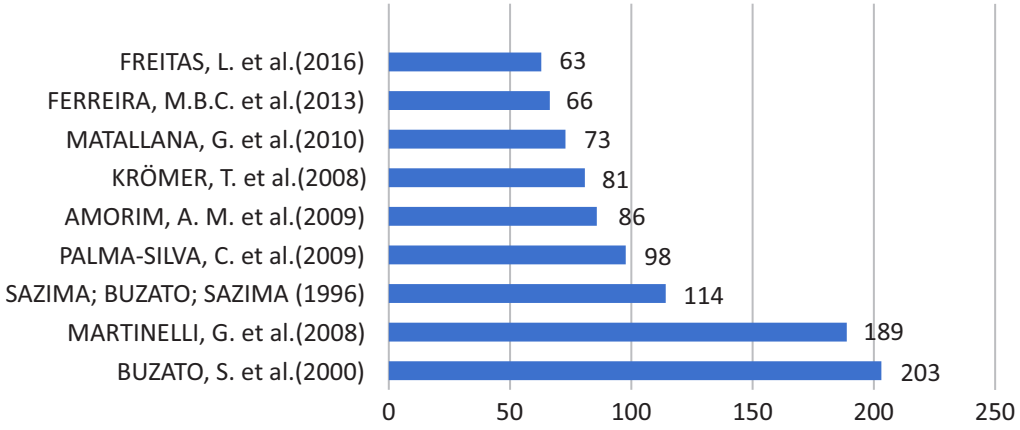


Figure 3. Nine articles with more than 60 citations were extracted from Bibliometrix.



Botanical Journal of the Linnean Society (N=22), and Rodriguésia (N=21), concentrating mainly on botany and plant systematics. This reflects the scientific production and the interest of the academic community in topics such as taxonomy, ecology, morphology, and evolution of plants (Table 1).

Phytotaxa is a journal focused on plant taxonomy, nomenclature, and phylogeny. Its high number of articles indicates a strong research production in the description and classification of new plant species, a fundamental field for the registration of biodiversity and the consequent need for conservation. The Botanical Journal of the Linnean Society is one of the most respected journals in botanical research. Rodriguésia is a Brazilian journal focused on botany, standing out as one of the most relevant journals for scholars

of neotropical flora, reflecting the rich biodiversity of Brazil and its importance for disseminating this knowledge.

The second filter with the expression "pollination" generated 40 (15.9%) articles listed by national institutions with scientific production in areas related to ornithophilia and Bromeliaceae. In Brazil, most research on pollination in Bromeliaceae was carried out in the Atlantic Forest (96%) [2,10,11,17-27], followed by 3 articles in the Amazon [28] and 1 article in the Pantanal [9]. No detailed studies were found on the pollination of Bromeliaceae by birds in Cerrado and Caatinga.

The survey of articles with more than 10 affiliated national authors showed 13 Brazilian public institutions, 12 universities (9 federal and 3 states), and 1 research institute, demonstrating the importance of development and investment agencies in guaranteeing teaching, research, and extension activities (Table 2).

The Federal University of Rio de Janeiro (UFRJ) led with 74 affiliated authors, evidencing its most significant contribution to research on ecological interactions between birds and bromeliads, driven by its botany and ecology programs. The Botanical Garden of Rio de Janeiro (JBRJ), associated with UFRJ, had 23 authors, being a reference in the research of Brazilian flora, especially with the great diversity of species and ecological interactions of birds that depend on bromeliads for food or nesting in the Atlantic Forest. Still, on the theme of bromeliad pollination by birds, other institutions also stood out, such as the Federal Universities of Rio Grande do Sul (UFRGS) with 41 authors, Juiz de Fora (UFJF) with 37 authors, and the Recôncavo da Bahia (UFRB) with 25 authors, in studies of biodiversity and landscape ecology (Table 2).

The other Federal Universities of Santa Catarina (UFSC), Espírito Santo (UFES), Alagoas (UFAL), Pernambuco (UFPE), and the Regional University of Blumenau (FURB) also appeared on the list with a relevant production, indicating a wide geographical coverage. This suggests that research on ornithophilia in bromeliads is spread across several regions of Brazil, reflecting the biogeographic distribution of the botanical family in different biomes and the birds that interact with them (Table 2).

State Universities, such as São Paulo (USP), Santa Cruz (UESC), and Campinas (UNICAMP), on the other hand, showed a few publications

Table 1. Selected journals with the most relevant articles by year and their h≥5) factor of impact.

Journal	N = 114 (article)	Year	h Index (h≥5)
Acta Botanica Brasilica	7	2001	5
Plant Biology	6	2003	6
American Journal of Botany	5	2005	5
Rodriguésia	21	2007	8
Botanical Journal of Linnean Society	22	2008	12
Biota Neotropica	13	2009	8
Systematic Botany	8	2010	6
Flora Morphology, Distribution, Functional Ecology of Plants	8	2011	5
Phytotaxa	24	2013	6

Table 2. Brazilian institutions with affiliated national authors (N≥10) of articles published from 1996 to 2024.

Brazilian Institution of Affiliation	Number of Authors (N ≥ 10)
Universidade Federal do Rio de Janeiro (UFRJ)	74
Universidade Federal do Rio Grande do Sul (UFRGS)	41
Universidade Federal de Juiz de Fora (UFJF)	37
Universidade Federal do Recôncavo da Bahia (UFRB)	25
Jardim Botânico do Rio de Janeiro (JBRJ)	23
Universidade Federal de Santa Catarina (UFSC)	21
Universidade Federal do Espírito Santo (UFES)	20
Universidade Federal de Alagoas (UFAL)	19
Universidade de São Paulo (USP)	17
Universidade Estadual de Santa Cruz (UESC)	16
Universidade Federal de Pernambuco (UFPE)	13
Universidade Estadual de Campinas (UNICAMP)	12
Universidade Regional de Blumenau (FURB)	11

above the metric established as a cut-off parameter, probably by environmental research. The UESC, located in Bahia, a state rich in biodiversity, had studies focused on the interactions of local flora and avifauna (Table 2).

The third filter for the final selection of articles published by authors from Brazilian institutions grouped 8 (3%) articles, presented a brief description of the main aspects dealing with the relationship between ornithophilous species of Bromeliaceae and their trochylophilic pollinators (hummingbirds) (Table 3).

Sazima, Buzato, and Sazima (1996), pioneers in this theme, observed native species of Bromeliaceae pollinated by hummingbirds in the Atlantic Forest in the Mantiqueira mountain. The predominant tubular flowers result in different pollen deposition sites on visiting hummingbirds' bodies, although mainly deposited in the beak. Four of the six species of hummingbirds are common and differ in beak size, body mass, and foraging preferences, reflecting on the preferred flower clusters. A hermit hummingbird and a trochylid hummingbird were the primary pollinators and shared the most flower species [12].

Schmid and colleagues (2011) and Magalhães and colleagues (2018) evaluated the floral biology and pollination syndrome of the bromeliad Aechmea nudicaulis in the Atlantic Forest in southern Brazil. The obligatory xenogamy reproductive system relies on pollinators. Most of the floral traits are characteristic of ornithophilia, and nectar production is adapted to the energy demands of hummingbirds. The pollination system involves birds and bees, ensuring a high probability of reproductive success [29,30]. Magalhães and colleagues (2018) compared the breeding systems between the generalist *A. nudicaulis* and the specialized *Vriesea neoglutinosa*. Single-visit experiments have shown that hummingbirds are

Table 3. Final selection of 8 (3%) articles by Brazilian authors affiliated with Brazilian institutions from 1996 to 2024.

Brazilian Institution	Authors (year)	Journal	Title
Universidade Estadual de Campinas (UNICAMP)	Sazima, Buzato and Sazima (1996)	Botanica Acta	An Assemblage of hummingbird-pollinated flowers in a montane forest in Southeastern Brazil.
	Nunes and colleagues (2018)	Acta Botanica Brasilica	Nectar ecology of the endemic epiphytic hummingbird-pollinated bromeliad *Vriesea altodaserrae*: secretion dynamics and pollinator visitation pattern.
	Zambonand colleagues (2019)	Botanical Journal of the Linnean Society	Nectar as manipulator: how nectar traits influence changes in *Aechmea vanhoutteana's* pollinator groups, a Brazilian Atlantic Forest bromeliad.
Universidade Federal do Rio de Janeiro (UFRJ)	Magalhães and colleagues (2018)	Botanical Journal of the Linnean Society	The relative importance of hummingbirds as pollinators in two bromeliads with contrasting floral specializations and breeding systems.
Universidade Federal de Santa Catarina (UFSC)	Schmid and colleagues (2011)	Plant Biology	Bimodal pollination system of the bromeliad *Aechmea nudicaulis* involving hummingbirds and bees.
	Kamke and colleagues (2011)	Flora	The importance of bees as pollinators in southern Brazil's short corolla bromeliad *Aechmea caudata*.
Universidade do Estado do Rio de Janeiro (UERJ)	Missagia and Alves (2015)	Zoologia	The rate of visitation by *Amazilia fimbriata* (Apodiformes: Trochilidae) influences seed production in *Tillandsia stricta* (Bromeliaceae).
Universidade de São Paulo (USP)	Pansarin and Pedro (2016)	Plant Biology (Stuttg)	Reproductive biology of a hummingbird-pollinated Billbergia: light influence on pollinator behavior and specificity in a Brazilian semi-deciduous forest.

more efficient than ants at pollinating *A. nudicaulis* and as efficient as bees and ants at *V. neoglutinosa* [30].

Kamke and colleagues (2011) stated that most bromeliad species are pollinated by vertebrates, especially hummingbirds and bats, which are important for the success of pollination in *Aechmea caudata* (Bromeliaceae) due to the frequency and efficacy measured by the number of seeds per single visit in secondary Atlantic Forest in southern Brazil. The authors recorded 16 species visiting the flowers, with bees being the most abundant and frequent taxon (91% of 647 visits) and *Bombus morio* the most common (41%). Although *A. caudata* is associated with ornithophilia, with tubular corollas and daily

nectar secretion, the only hummingbird species *Thalurania glaucopis* was unable to pollinate the flowers, with a low frequency of visits (2.5%) that did not favor pollen flow between conspecific bromeliads [31].

Missagia and Alves (2015) conducted a study in the Atlantic Forest in Rio de Janeiro, monitoring 30 flowers, of which 5 were analyzed for spontaneous self-pollination and the other 25 exposed to floral visitors, with the hummingbird *Amazilia fimbriata* identified as the only legitimate visitor of Tillandsia stricta (Bromeliaceae), with a visitation rate of 6.6 (±3.4) visits per flower. About 22 formed fruits and seeds, and 3 produced seeds without floral visits. A positive correlation was observed between the number of floral visits and the number of seeds produced (r^2=0.58, $p<0.01$) [32].

Pansarin and Pedro (2016) explored the reproductive biology and specificity of pollinators of the species *Billbergia distachia* in a semideciduous forest in southeastern Brazil, where it is exclusively pollinated by the hermit hummingbird species *Phaethornis eurynome*, which seeks floral nectar above the placenta, regardless of air temperature and humidity, and the visit is influenced only by daylight [33].

Nunes and colleagues (2018) studied the nectar ecology of the endemic epiphytic bromeliad *Vriesea altodaserrae*, which is dependent on hummingbirds for its sexual reproduction, and the nectar composition is consistent with most hummingbird-pollinated species. The rhythm of nectar secretion did not influence the frequency of hummingbird visits, being visited by two-thirds of the hummingbird species at the study site, with emphasis on the subfamily Trochilinae, suggesting a specialization of this group and the importance of this endemic bromeliad as a keystone species in areas of the highland Atlantic Forest [34].

Zambon and colleagues (2019) recorded nectar production dynamics in Aechmea vanhoutteana and hummingbird, bee, and butterfly species. The volume of nectar and the amount of sugar also showed significant spatial and temporal variations during floral anthesis, which were related to increased bee visits. This aspect is crucial for the species' reproductive strategy, as bees can fly greater distances than hummingbirds, despite both having territorial behaviors [35].

For all the above, bibliometric analysis is an efficient tool for selecting articles from journals with a high impact factor, allowing the identification of publications that have greater influence and relevance in the researched area.

In addition, bibliometric analysis tends to prioritize the number of citations to the detriment of the quality of articles, which can lead to the undervaluation of innovative or emerging research that has not yet been widely cited [13].

However, it proved to be a limiting method by not including articles published in restricted means of dissemination, such as modest or low-cost journals. The emphasis on the impact factor (citations) can devalue research of great regional relevance or of a smaller scale that can be crucial in advancing local knowledge or specific areas of knowledge. Not considering the contribution of articles to scientific and social practice or their application in practical contexts can also lead to a distorted view of the relevance of endemic studies.

Conclusion

The bibliometric analysis of articles on ornithophilous species of Bromeliaceae in the Atlantic Forest, published from 1996 to 2024, used three search filters: (1) Three initial expressions ("ornithophilia, Bromeliaceae, Atlantic Forest") selected 251 (100%) articles from 819 authors in 96 journals of 23 countries, with emphasis on Brazil (N = 111, 44%). (2) The term "pollination" generated 40 (15.9%) articles related to ornithophilia and Bromeliaceae. (3) The filter of authors from Brazilian institutions grouped only 8 (3%) articles.

In Brazil, most of the research on pollination in Bromeliaceae was carried out in the Atlantic Forest (96%). The survey of articles with more than 10 affiliated national authors showed 13 Brazilian public institutions, 12 universities (9

federal and 3 states), and 1 research institute, demonstrating the importance of development and investment agencies in guaranteeing teaching, research, and extension activities. The Federal University of Rio de Janeiro (UFRJ) led by 74 affiliated authors, evidencing its most significant contribution to research on ecological interactions between birds and bromeliads, driven by its botany and ecology programs. Therefore, bibliometric analysis is an efficient tool but limiting as it does not include articles published in restricted means of dissemination, such as modest or low-cost journals. The emphasis on the impact factor (citations) can devalue research of great regional relevance or, on a smaller scale that can, play a crucial role in advancing local knowledge or specific areas of knowledge. Not considering the contribution of articles to scientific and social practice or their application in practical contexts can also lead to a distorted view of the relevance of endemic studies.

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