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Research Letters

# Contrasting nation-wide citizen science and expert collected data on hummingbird–plant interactions

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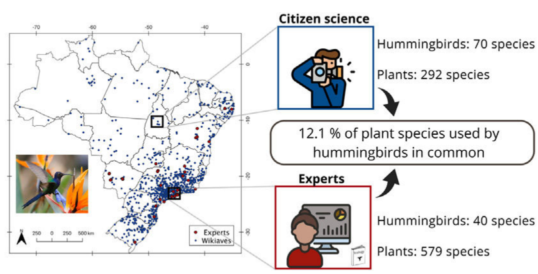
## HIGHLIGHTS

- We extracted hummingbird-plant data from an online photograph platform.
- Data were compared with expert collected data, available in the literature.
- There were some similarities between citizen and expert data.
- For the hummingbirds, overlap in plant species interacting was generally low.
- Unstructured citizen science data can be a rich source of interaction information.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Citizen science has the potential to increase the efficiency of scientific data collection. However, such initiatives often focus on unique taxa for each record, not necessarily involving interspecific interactions. Moreover, whether openly available unstructured citizen science data can contribute to better understand ecological patterns is still not well understood. Here, we identify hummingbird-plant interactions recorded by amateur birdwatchers in the most popular online platform in Brazil, Wikiaves. Then, we evaluated how this information can benefit our understanding of interactions in a large Tropical country by comparing with data generated by experts. We also constructed a nation-wide meta-network to identify the structural roles of hummingbirds and plants. In total, 3210 interactions were compiled, with better hummingbirds and geographic coverage of citizen data in relation to expert data. The interaction network showed a modular pattern, and some plant species found as most frequently interacting here were similar to those found by experts. Nevertheless, when comparing the plant partners for hummingbirds featured in both expert and citizen data, the proportion of plants in common were generally low (usually less than 40%), indicating that amateur birdwatchers are mostly recording interactions not captured by scientists. Finally, as in other cases of compilation of interaction data, we found that sampling intensity (here, number of photographs) is a strong driver of interaction records, highlighting the unique challenge of separating biologically meaningful patterns from sampling artifacts in citizen science data. Our study illustrates the richness of citizen-gathered biodiversity data available in a megadiverse country, which show great potential to complement expert collected data.



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## Introduction

Citizen science has gained popularity in recent decades, helping to advance scientific knowledge (Bonney et al., 2009). It consists of the participation of the general public in the construction of knowledge through the collection of information, including photographic records, and interpretation of results (Miller-Rushing et al., 2012). Research projects in ecology use citizen science data mainly to obtain large amounts of information, allowing expansion of data coverage (Silvertown, 2009). The partnership between experts and non-professionals has the potential to increase the efficiency of scientific data collection by providing more complex and comprehensive data (Roy et al., 2016). In addition, it allows the population to actively engage in science, improving scientific literacy and society's interest in the subject being investigated (Cohn, 2008; Stafford et al., 2010). The involvement of society in citizen science projects generally happens in two ways: (1) the public participating in a scientific project by producing specific and structured information for scientists; (2) the public can contribute through crowdsourcing, usually involving a large number of people, with an undefined audience providing data across wide geographic regions by using e.g., social media platforms (McKinley et al., 2017; Muñoz et al., 2020). In this context, the development of tools and internet platforms that assist in the dissemination of information obtained by the general public is one of the factors responsible for the growing amount of data collected by citizen scientists. Such platforms allow interactions among users through comments, discussions, and photo sharing, expanding social groups by facilitating the contribution of the population to science (Stafford et al., 2010; Tubelis, 2023).

A practice that is very popular worldwide and presents a great potential to contribute to citizen science is birdwatching, which is the act of observing and identifying birds in their native habitats (Sekercioglu, 2002). Birdwatching is among the most popular type of ecotourism, and by collecting photographic and audio records of birds, identifying different species, and analyzing behavior, vocalizations, habits, migrations, and their interactions with other organisms, birdwatchers can also contribute with new scientific knowledge (Sekercioglu, 2002). Owing to their popularity, there are several different platforms that include information on occurrence and biology of birds such as the Cornell Lab of Ornithology's eBird (https://ebird.org) or broader initiatives such as iNaturalist (https://www.inaturalist.org/), which includes many different organisms. Such citizen science initiatives usually focus on single taxa in each record, and not necessarily on specific records of two or more organisms associated in ecological interactions, for which data generation can be more challenging (Groom et al., 2021, but see Marín-Gómez et al., 2022; Tubelis, 2023).

Pollination is a major interaction between plant and animals, which supports ecosystem functions across terrestrial ecosystems and also provides relevant ecosystem services (Ollerton et al., 2011). In this context, a previous study by Kremen et al. (2011) assessed the floral visitor abundance data collected by citizen scientists with data collected by professional scientists in an agricultural landscape in California-USA. Their results showed that citizen scientists collected observational data similar to that collected by professional scientists and equally useful for science. However, there are still few studies comparing citizen and expert generated interaction data (Kremen et al., 2011). Such projects may be especially relevant in the tropics, where there is a higher diversity of pollinators and plants, but which has been comparatively less studied (e.g., Maruyama et al., 2022). Brazil is considered one of the most biodiverse tropical countries in the world (Lewinsohn and Prado, 2005). This includes birds, with more than 1900 species cataloged in the country (Pacheco et al., 2021). Although not a formal citizen science initiative, in the sense that it was conceived to support a specific science project, the Wikiaves website (www.wikiaves.com.br) is a popular platform in Brazil that receives more than 1000 bird media files daily, consisting in a large database with an important role in gathering information on Brazilian birds. The website encompasses information on behavioral records, distribution, reproduction, natural history, and migration (Cunha and Fontenelle, 2014; Tubelis, 2023). The easy access of scientists to this information has allowed them to carry out research projects to gather distribution and breeding biology data, records of rare species and even to evaluate ecological interactions (Cunha and Fontenelle, 2014; Tubelis and Sazima, 2021; Turella et al., 2022). As English literacy is generally low in Brazil, this Portuguese language platform is widely used by amateur birdwatches, more so than other international platforms (Barbosa et al., 2021; Tubelis, 2023). We took advantage of this platform to investigate the usefulness of unstructured citizen science data on understanding plant-bird interactions. Birds provide essential ecosystem functions including pollination (Whelan et al., 2008), and among them hummingbirds are the most speciose and specialized group (Fleming and Muchhala, 2008; Zanata et al., 2017). Moreover, there are several compilations in hummingbird–plant community-wide interaction data already published in the literature, which include data from Brazil (Araujo et al., 2018; Dalsgaard et al., 2021; Maruyama et al., 2019). Therefore, we were able to effectively compare the data collected by scientists and non-scientists regarding these interactions in Brazil, as a biodiverse model country.

Here, we aim to identify patterns of hummingbird-plant interactions with data that have not been collected by scientists and evaluate how this information can benefit our understanding of these interactions. Specifically, we asked: (1) which species of hummingbirds and plants were most frequently recorded interacting?; (2) were legitimate interactions, with potential for pollination, recorded more often than illegitimate interactions (i.e., robbing and thieving)?; (3) what are the network roles played by different hummingbird and plant species in the nationwide modular meta-network?; (4) how overlapping are the interactions of hummingbirds with plants recorded by non-scientists and previously reported data in the literature?; and finally (5) how sampling intensity, i.e., total number of photographic records for each hummingbird species, influences the characterization of interaction patterns? We hope that by answering these questions, we are able to highlight the strengths and challenges associated with the large amount of unstructured and seldom used citizen generated data to better understand species interactions and tropical biodiversity.

## Materials and methods

### *Data collection: citizen science platforms*

Eighty-nine species of hummingbirds are found in Brazil (Pacheco et al., 2021), and are among many of the records included in the Wikiaves platform (www.wikiaves.com.br), which is a Brazilian website created in 2008 with the objective of promoting birdwatching. Through the collaboration of users, it has become an online database with photographic and audio records and other information about Brazilian bird species. The site brings together the largest online community of birdwatchers in Brazil and allows the interaction of collaborators, which makes it an important tool for the amateur birdwatchers in the country (Dias, 2011; Tubelis, 2023).

We surveyed for the interaction events on the Wikiaves platform, entered between January 2008 (date of creation of the platform) until May 9, 2021, the day of the last access. We analyzed the photos of all hummingbird species recorded in Brazil (Pacheco et al., 2021). We considered as one record of interaction when the image showed an individual hummingbird and a flower. Only records made in Brazil were considered, and photos that referred to the same event (i.e., images made in the same location, date and by the same author) were counted only once. We sought to identify the plant species associated with hummingbirds to the lowest taxonomic level possible, using keys and illustrated books. Plant species were classified as native or non-native and according to their habit (herbaceous, shrubby or arboreal) using the Flora e Funga do Brasil (2022) website and were identified to the lowest taxonomic level possible. Some plants were only classified at the level of genus, and in a few cases at the level of family. For simplicity, we refer to each recorded morphospecies as "species" henceforth. For example, the plants from the genus *Inga* could not be identified at the species level from the photographs due to the similarity in their flower morphology, so we probably lumped together several distinct species in our data. Additional information such as sex, age of the hummingbird (young, adult or undefined), author, locality where the interaction was observed, type of visit (legitimate or illegitimate), the date the photo was taken and date of publication in the platform were also compiled. We also classified hummingbird species according to red list status (IUCN, 2022).

The compiled hummingbird-plant interaction data were then compared with the interaction datasets previously reported by Araujo et al. (2018); Dalsgaard et al. (2021) and Maruyama et al. (2019), which compiled information of plant–hummingbird interactions at different localities in Brazil. Dalsgaard et al. (2021) also included localities from other countries, which were not considered here. The experts' data covered different Brazilian ecosystems, totaling 72 localities/communities (Atlantic Forest $n = 36$, Cerrado $n = 18$, Caatinga $n = 8$, Pampa $n = 4$, Pantanal $n = 3$, Campos Rupestres $n = 3$; Fig. 1, Table S2).

### *Hummingbird-plant interaction networks*

From the analyzed images, two matrices of quantitative interactions were constructed, considering the number of photos a specific hummingbird-plant combination was represented as a measure of the strength of the interactions. In the first matrix (Total Matrix), we considered all records of a hummingbird interacting with a flower (irrespective of legitimate or illegitimate), while in the second matrix (Pollination Matrix), the criterion was refined to consider only the records of hummingbirds accessing the flowers legitimately, i.e., touching the reproductive structures of the flower in the photos, with potential for pollination interactions.

### *Data analysis*

To characterize the hummingbird-plant meta-network structure and species role, we calculated modularity, which was calculated with the DIRTLPAwb + algorithm (Beckett, 2016). This algorithm identifies modules in weighted networks. Significances of metrics at the network level were assessed by comparing observed values with those generated by null models (n = 1000). Here we used the *r2dtable* null model, which constraints the network size and the marginal totals in the simulations (Dormann et al., 2008). The roles of the species in the modular network were identified using the čänd žšcores. Among-module-connectivity (c) indicates the role of species as connectors of different modules, while the within-module degree (z) indicates the relevance of each species within its module (Olesen et al., 2007). Species can then be categorized according to their role in the modular network by crossing the values of these two indices, as: connectors (high c and low z values), peripherals (low values of c and z), network hubs (high values of c and z) or module hubs (high z and low c values). Following Dormann and Strauss (2014), we used threshold values determined by using 95% quantiles from the null networks, with z = 2.8 and c = 0.62 as critical values to define species roles. In meta-networks spanning wide areas such as ours, interactions are expected to reflect both the geographic distribution and ecological attribute of species that determine interactions locally when species co-occur (Araujo et al., 2018). Thus, spatial co-occurrence is an essential first template for species to interact, determining the potential interactions that may or may not be realized according to other attributes, such as traits and abundances of species (Bartomeus et al., 2016). All network analyses were performed in the R package 'bipartite' (Dormann et al., 2008).

To evaluate the overlap in plant partners interacting with hummingbirds between citizen and expert collected data, we estimated the proportion of plant species in common between the two sources in relation to the total number of plant species and hummingbirds which were found interacting in Wikiaves. Thus, if a hummingbird species *A* interacted with *n* number of plants in the Wikiaves platform, we estimated the proportion of these *n* plants that also appeared interacting with hummingbird *A* in the expert data. Finally, we adjusted two simple linear regressions taking the total number of records for a hummingbird (i.e., number of photographs in Wikiaves) as the predictor variable: (1) with the number of observed plant species visited in the citizen data as the response variable, to evaluate sampling effects; and (2) with the richness of plants visited in the expert data, to evaluate the correspondence between the two datasets. The data were log transformed to improve the fit after checking the residuals. All analyses were conducted in R (R Core Team, 2020).

## Results

In total, 3210 interactions were compiled from the Wikiaves platform (of which 634 interactions were nectar robbery and theft, 19.75%), distributed across all Brazilian states and biomes, in contrast to expert collected data (Fig. 1, Table S1). Of the 89 hummingbird species observed in Brazil, the online platform included records for 70 species. The species most frequently found interacting with flowers was *Phaethornis pretrei* (Fig. 2A), with 412 records, representing 12.83% of the images analyzed. The second and third most recorded species were *Chlorostilbon lucidus* with 322 records (10.03%) and *Florisuga fusca* with 207 records (6.44%). Two species were classified as threatened (*Phaethornis margarettae*, *Thalurania watertonii*) and one as vulnerable (*Phaethornis aethopygus*) by the IUCN Red List (IUCN, 2022). As for the plants, a total of 292 different morphospecies were identified, 161 at the species level (55.2%), 124 at the genus level (42.6%) and 7 at the family level (2.39%). Of the plants identified at the species level, 49.6% were classified as native, 40.3% as non-native, and for 9.93% we had no information. Within the native plants, 22 species were classified as endemic to Brazil. The plants presented predominantly shrubby habit (34.7%), followed by herbs (24.8%) and trees (20.4%).

*C. lucidus* was the hummingbird species that interacted with the highest number of plants (98 species), which represents 34.5% of the total plant morphospecies identified. It was followed by *Eupetomena macroura* (85 species, Fig. 2B) and *P. pretrei* (79 species). From the plant perspective, the species recorded interacting with the highest number of hummingbirds (36 species, 51.42%) was *Inga* sp., which could not be identified at the species level from the photographs owed to similarity in flower morphology within the genus. The second and third species that interacted most with hummingbird species were the non-native *Grevillea banksii* (30 hummingbird species, 42.85%) and the native *Lantana camara* (26 hummingbird species, 37.14%).

When comparing the geographical distribution of the data, although there seems to be a concentration of data towards the Atlantic coast, which parallels the countrys demography, the citizen data covered 889 cities in Brazil, including many localities in the

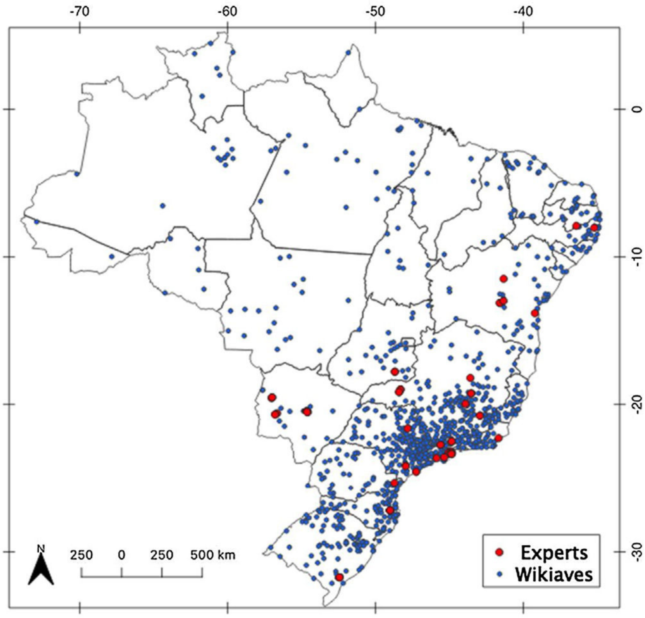


**Fig. 1.** Distribution of hummingbird-plant photographic records extracted from the online platform Wikiaves (in blue), in contrast to localities where expert data were collected (in red) in Brazil.

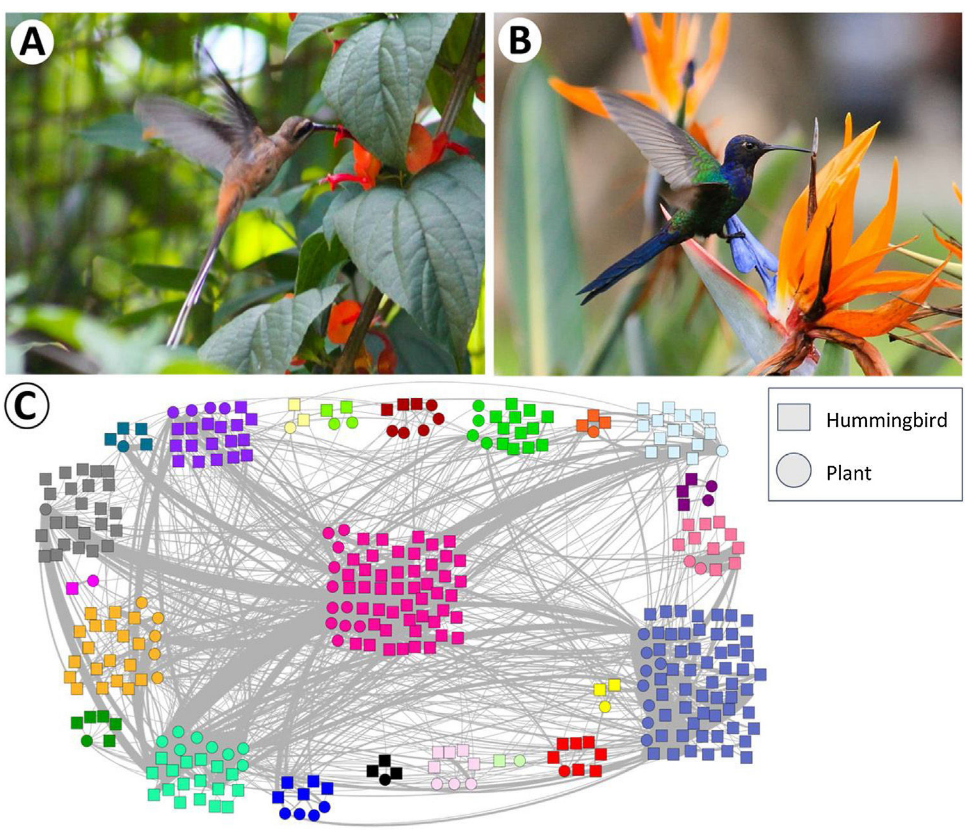


**Fig. 2.** Photographs illustrating interactions that were extracted from Wikiaves platform and the resulting interaction meta-network. Planalto Hermit, *Phaethornis pretrei* (A) interacting with *Holmskioldia sanguinea* (Lamiaceae). Swallow-tailed Hummingbird, *Eupetomena macroura* (B) interacting with *Strelitzia reginae* (Strelitziaceae). Hummingbird-plant interaction network from citizen science data (Total Matrix), different colors represent different modules, squares are hummingbirds and circles are plants (C).

Brazilian Amazon not covered by expert data (Fig. 1). The experts' data covered only 36 cities.

The two interaction networks compiled showed a modular pattern with higher observed values than expected by the null model that incorporates species richness and marginal totals. The total interaction network (including legitimate and illegitimate interactions) had a modularity of $Q = 0.383$ ($p < 0.001$), with 15 modules (Fig. 2C). In this modular network, all hummingbird species acted as peripherals. When considering the plants, seven species were classified as module hubs (*Calliandra* sp., *Dioclea* sp., *Inga* sp., *Iser-*

*tia* sp., *Ixora coccinea*, *L. camara, Vismia* sp.). The other 97.6% of the species were classified as peripherals, no species was identified as a network hub or connectors.

In the pollination network, modularity was slightly higher $Q = 0.413$ ($p < 0.001$), with 23 modules, all hummingbird species were classified as peripherals. For the plants side, eight species acted as module hubs (*Heliconia* sp., *Inga* sp., *I. coccinea*, *Ixora* sp., *L. camara*, *Odontonema* sp., *Prunus* sp., *Stifftia chrysantha*). The other 96.9% of the plants were classified as peripherals, no species was identified as network hubs or connectors.

From the 70 hummingbird species with records of interactions in the citizen science data, 40 species also had data on interactions in the expert data. In contrast, only one hummingbird species, *Chrysuronia brevirostris* had data collected by experts but not in the online platform. Moreover, 92 plant species (identified at the species level) with record in the online platform were not present in the expert data. Regarding the comparison of the plants that hummingbird species interacted with between expert and citizen data, only 36 species of hummingbirds had plants in common between the two sources (Fig. 3). The hummingbird that presented the highest proportion of plants in common was *Phaethornis squalidus* with 66.6% of the plants in common (from the total of 3 plants it interacted with in the citizen data). The other species showed values below 40%. *E. macroura* was the species that presented the highest number of plants in common (16 species). However, this hummingbird interacted with 85 species of plants in Wikiaves data, reflecting in a proportion of 18.8% of plants in common with the experts.

Finally, there was a strong positive relationship between the total number of hummingbird photographic records in the online platform and the richness of plant species visited by hummingbirds ($R^2 = 0.92$; $p < 0.001$, Fig. 4A). In addition, there was a positive but less strong relationship between the photographic records by the citizen scientists and the number of plant species hummingbirds interacted with as recorded by the experts ($R^2 = 0.45$; $p < 0.001$, Fig. 4B).

## Discussion

Here, by contrasting hummingbird-plant interaction data collected by amateur birdwatchers and trained scientists, we illustrate the richness of data available in online platforms. Importantly, the citizen science data showed higher hummingbird and geographic coverage of interaction records, even including records from the Amazon Rainforest, where scientific information in plant-pollinator interactions, including hummingbirds, is comparatively scarce (Nascimento et al., 2020). Some plants found acting as module hubs are those also found as important for hummingbirds when considering expert data, e.g., *Inga* sp. (Araujo et al., 2018).

On a global scale, there is a gap in data collected by citizen scientists for different taxonomic groups in South America (Chandler et al., 2017). Furthermore, citizen science studies evaluating interactions are relatively rare, because there are often limitations in data collections involving more than one organism groups (Groom et al., 2021; but see e.g., Marín-Gómez et al., 2022; Heilmann-Clausen et al., 2016). The use of photographs can, however, mitigate some of these limitations (Groom et al., 2021), and the large amount of information we have compiled seems to confirm this potential. Some studies in the past had pointed out the importance of photographs in social media and science platforms (Pitman et al., 2021), which even allow for more detailed analyses, for example with studies on specific bird behaviors (Schunck et al., 2022; Tubelis and Sazima, 2021), and interaction network analysis as we did in the current study. One recent study from Mexico also evaluated hummingbird-plant interactions from photographic platforms (iNaturalist and eBirds) across urban areas in the Mexico City, and quantified the use of native and non-native plants by these birds, among other patterns (Marín-Gómez et al., 2022). Such studies further illustrate how these platforms may contribute to answer relevant ecological questions at different spatial scales.

Our method, like other uses of unstructured data, can suffer from biases such as lack of standardization in data collection (Bayraktarov et al., 2019), or over-sampling of more common species in less natural areas, such as urban areas, since potentially these environments are the most commonly photographed due to the easier access for amateurs. Even so, when we compared our database with that of the experts, we observed many hummingbirds only recorded in the online database, including species classified as endangered (*P. margarettae*, *T. watertonii*) and vulnerable (*P. aethopygus*) by the IUCN Red List (IUCN, 2022). The presence of these species in the online platform data indicates that even though there are possible biases in the citizen data, there are potential benefits for covering a larger number of species in comparison to expert data, even including endangered species. Especially considering that many vertebrate pollinator species, including some hummingbirds, show a tendency of decline and worsening in endangered status (Regan et al., 2015), information on their food plants is highly valuable.

As shown for the country wide Brazilian meta-network based on expert data (Araujo et al., 2018) we also found that the citizen science meta-network showed a modular pattern. But when species were classified into their modules, all hummingbird species were classified as peripherals in both citizen data networks. The hummingbird *P. pretrei*, however, had a z-score value of 2.74, slightly lower than the critical value of 2.8 determined by the null model, making this species almost a module-hub. This species has a wide distribution occurring in five Brazilian biomes and was the species that recorded the highest number of interactions with plants, interacting with 79 plant species. Interestingly, this species is also one of the most frequently interacting hummingbirds in Brazil based on expert data (Araujo et al., 2018), indicating that citizen science data capture both geographical and ecological information about species interactions (see Araujo et al., 2018).

A good part of the plants for which species identity was recovered was classified as non-native (40.3%), potentially reflecting the fact that a large part of birdwatchers are concentrated mostly in transformed/urbanized areas (Barbosa et al., 2021). Such places often show a high number of ornamental and non-native species attractive to the fauna and pollinators (Aronson et al., 2014; Nascimento et al., 2020; Silva et al., 2023, but see Vitorino et al., 2021). Of the seven species from the Total network and the 8 species from the Pollination network that acted as module hubs, most species or genera are plants that are commonly found as ornamental plants across the urban landscape in Brazil (Nascimento et al., 2020). This reinforces the notion that a considerable proportion of the photographs in Wikiaves may be coming from more altered habitats. Moreover, this high proportion of non-native plants may represent future research opportunities with this unique dataset for factors facilitating the incorporation of novel food resources by hummingbirds.

It should be noted that the number of plants that a given hummingbird interacted with was strongly related to the number of photos a species had, indicating a sampling effect (see also Marín-Gómez et al., 2022). Nevertheless, such result may also have a biological meaning, if we reasonably assume that the most photographed species are possibly abundant species that interacted with more plant species (Simmons et al., 2019). Previous studies using compilation of interaction information over large geographic extent have shown that sampling intensity affected interaction data (Nascimento et al., 2020), but such tendencies also reflect the geographic range sizes of species, which can be an important determinant of interaction diversity in country-wide networks (Araujo

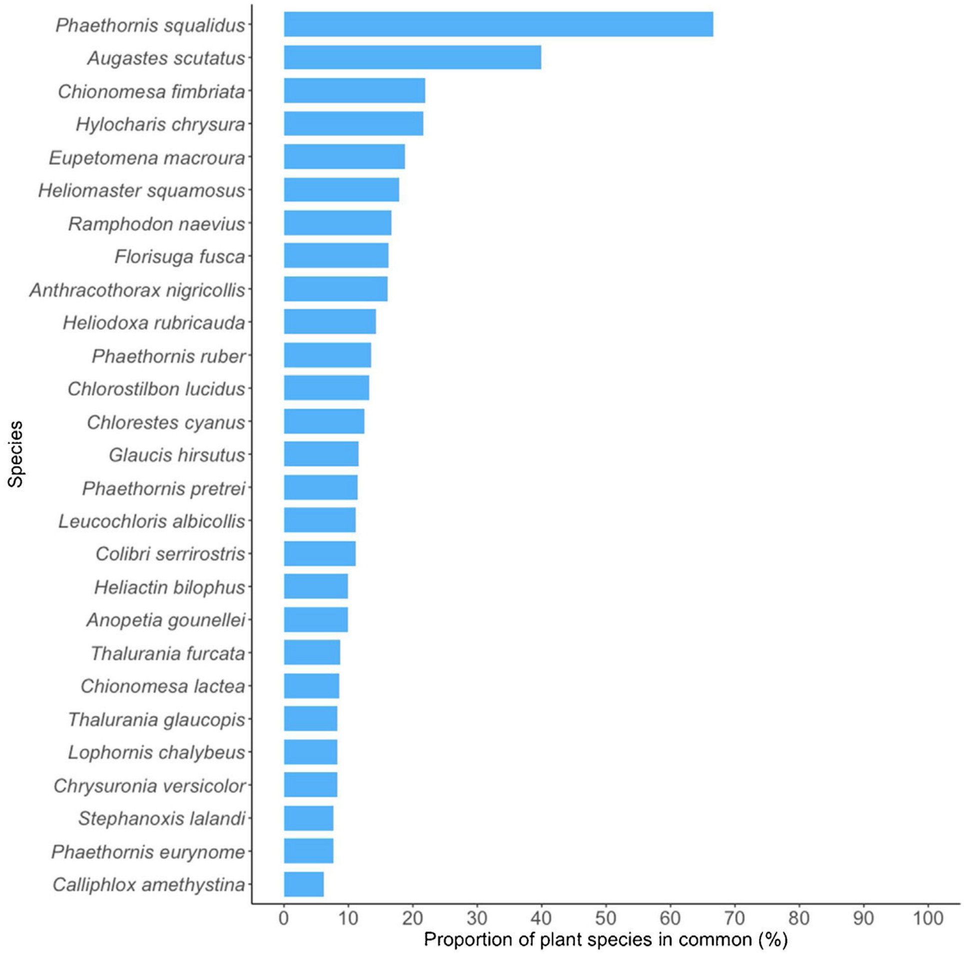


**Fig. 3.** Proportion of plants in common for the hummingbirds that showed some overlap in the identity of plants they interacted with between expert and citizen data. These proportions denote the ratio between plants in common divided by the total number of plants hummingbirds were found interacting with in the Wikiaves online platform.

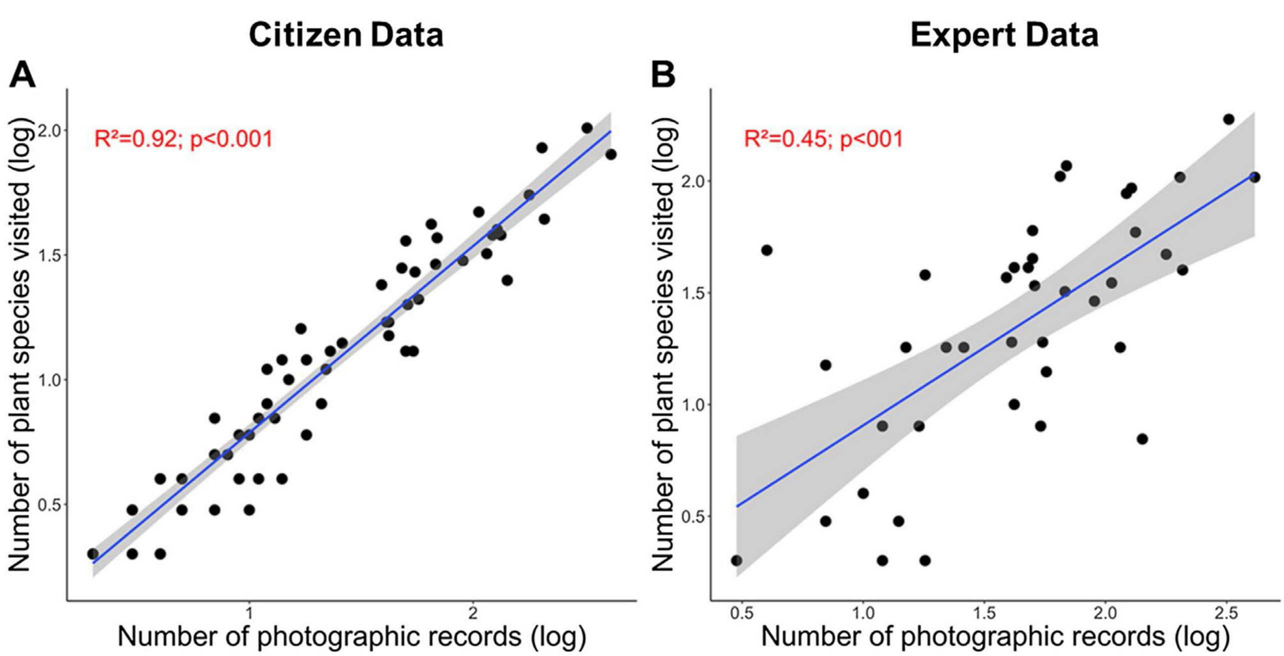


**Fig. 4.** **(A)** Relationship between number of plant species visited by hummingbirds and the number of photographic records in the Wikiaves platform (B) Relationship between the number of plant species visited by hummingbirds recorded by experts and the number of photographic records in Wikiaves.

et al., 2018). That the number of photographic records in the citizen science platform was less strongly related to the number of plant species experts found interacting with hummingbirds, underscores both the similarities and uniqueness of each dataset.

Citizen science data are not yet fully incorporated into mainstream science, but show strong promises because the availability of these data can provide broad access to information about biodiversity patterns (Theobald et al., 2015). Moreover, professional scientists alone are not always able to provide data at the speed that policy decisions are made (Theobald et al., 2015). Hence, citizen science offers complementarity of data to scientists, since amateurs can contribute with information and build huge databases, helping to solve conservation issues (Fontaine et al., 2021). As shown here, these efforts may even cover species of conservation concern, which are often little known owed to their rarity and difficulty in recording their natural history, including interactions (Regan et al., 2015). In addition, citizen science can help modern science in broadening its epistemological worldviews, bringing scientists closer to non-scientists and providing close-to-nature experience for society (Fontaine et al., 2021). In this regard, it is noteworthy that birdwatchers express their satisfaction for participating in activities that add knowledge, enhance their skills, bring personal well-being and also contribute to science (Greenwood, 2007). This is probably true also in a megadiverse and in development country such as Brazil.

## Conclusion

We hope that our study will serve as an additional step for furthering research making use of citizen science platforms, as they present considerable wealth of data. In the specific case of Wikiaves, it is a platform that includes a large amount of data, presenting records of wide distribution, and is being fed daily as a source of new data for one of the most biodiverse countries in the world. Furthermore, the extensive database of interactions between plants and hummingbirds presented here contains relevant information that can be used with the purpose of expanding the knowledge of the interactions between pollinators and plants in Brazil. The findings here could potentially also be extended to other relevant bird groups associated with other ecosystem functions, such as frugivorous seed dispersers. Finally, we hope that the results found here will encourage data collection practices by non-scientists and implementation of specific citizen science projects, in order to better bridge society and science produced in academia in countries such as Brazil, where such initiatives are only beginning to take shape.

## Declaration of Competing Interest

The authors report no declarations of interest.

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## Appendix A. Supplementary data

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