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The Hidden Diptera Diversity in *Aristolochia* Trap-Flowers: Revealing the Identity of Pollinators Through Taxonomic Knowledge

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ABSTRACT

Although Diptera is one of the most diverse insect orders with a high potential for pollinating plants, it remains poorly studied and neglected. This is partly due to limited taxonomic efforts in species identification. For instance, despite being primary pollinators of trap flowers, species-level identification in these systems remains scarce. To highlight this taxonomic impediment, we reviewed the diversity of Diptera pollinators found on trap flowers of *Aristolochia* (Aristolochiaceae), a genus exclusively pollinated by flies. We recorded the number of morphospecies identified at the order, family, genus, and species levels across *Aristolochia* populations and calculated the percentage of species-level identification for each population. To propose a solution to the taxonomic impediment, we used data from an *Aristolochia esperanzae* population, comparing the taxonomic refinement without and with taxonomist collaboration. Our review yielded 531 Diptera records from 40 populations across 23 *Aristolochia* species. Of these, 1.9% were identified at the order, 41% at the family, 35.8% at the genus, and only 21.3% at the species levels. The mean percentage of species-level identification for the populations was 34.11%, with 40% of populations showing $<5\%$ of species identified. Overall, 43 families, 109 genera, and 61 species of Diptera were recorded as potential pollinators of *Aristolochia*. Our case study demonstrated that collaboration with taxonomists improved taxonomic refinement, particularly at the genus and species levels, with this latter rising from 0% to 38.8%. This collaboration also enabled the identification of main pollinators of *A. esperanzae*, which belong to Ulidiidae, a little-known pollinator

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family. This study highlights a substantial taxonomic impediment in Diptera pollinators of *Aristolochia*, which may limit our understanding of their role in plant pollination. Additionally, we demonstrate the importance of interdisciplinary collaboration with insect taxonomists to improve our comprehension of biological and ecological patterns involving the highly diverse yet less-known dipteran pollinators.

1 | Introduction

Most angiosperms are pollinated by animals, which play a crucial role in ecosystems and agricultural production (Klein et al. 2006; Ollerton et al. 2011; Tong et al. 2023). Despite their importance, some groups of animals are studied more extensively than others, leaving certain pollinators neglected (Ollerton 2017). This may be associated with several factors, including methodological challenges of studying nocturnal pollinators (Walton et al. 2020; Macgregor and Scott-Brown 2020; Martínez-Martínez et al. 2021), difficulties in accessing remote areas (Archer et al. 2014; Valadão-Mendes et al. 2024), and lack of funding and research in certain regions of the world (Mayer et al. 2011; Archer et al. 2014; Ollerton 2017; Millard et al. 2020; Valadão-Mendes et al. 2024). This is particularly relevant in tropical regions, where information is scarce and lesser-known pollinators have been reported (e.g., Gomes et al. 2014; Matallana-Puerto and Cardoso 2022; de-Oliveira-Nogueira et al. 2023; Bezerra-Silva et al. 2024; Domingos-Melo and Milet-Pinheiro 2024; Lai et al. 2024; Ollerton 2024). Additionally, taxonomic impediment can also be an important factor since many studies do not delve into the refinement of the identity of certain pollinator groups due to a lack of knowledge, research funding, or the inherent taxonomic complexity of certain organisms (Mayer et al. 2011; Archer et al. 2014; Millard et al. 2020). This is particularly the case for insects, the most diverse group of pollinators (Ollerton 2017). Complete identification at the species level is commonly not achieved because the community is often diverse and taxonomic treatment is time-consuming; there are no available taxonomic keys, or species identification may require morphological and even genetic approaches (Kim 2009; Meier et al. 2024).

Diptera is a megadiverse order of insects comprising over 160,000 described species in ca. 180 families (Bertone and Wiegmann 2009; Mlynarek 2022). It is estimated that ca. 70,000 Diptera species are potential pollinators, making them one of the main groups of pollinators (Wardhaugh 2015; Ollerton 2017). They can pollinate both generalist and specialist plants, including at least 100 crop plant species, being also crucial for the pollination of plants in extreme ecosystems such as the Arctic and high-altitude environments where other groups of pollinators are scarce (Ssymank et al. 2008; Inouye et al. 2015; Mlynarek 2022). Despite their importance, due to the taxonomic challenges of the order, there are still many knowledge gaps regarding their taxonomy and role in pollination (Larson et al. 2021; Mlynarek 2022). This places Diptera among the most neglected groups of pollinators (Kearns 2001; Ssymank et al. 2008), meaning that basic data such as the identity and biology of most species are still unknown. Therefore, to improve the knowledge and conservation of Diptera pollinators, recent studies have highlighted the importance of collaboration with taxonomists for identification (Ssymank et al. 2008; Mayer et al. 2011; Orford et al. 2015; Ren et al. 2018; Raguso 2020; Suárez-Mariño et al. 2025). Taxonomic work by specialists, even if not conducted at the species level, provides less biased information, which can be used to assess pollinator richness and infer pollination systems based on the natural history of the identified groups.

For instance, dipterans are the main groups of pollinators of trap flowers, including species from different families with convergent evolution, such as Apocynaceae, Araceae, Orchidaceae, and Aristolochiaceae (Berjano et al. 2009; Bröderbauer et al. 2012; Pemberton 2013; Ollerton et al. 2017). These trap flowers employ deceptive pollination systems that temporarily capture their pollinators (Berjano et al. 2009; Bröderbauer et al. 2012; Pemberton 2013; Ollerton et al. 2017; Cardoso et al. 2023; Matallana-Puerto, Brito, et al. 2024). Thus, collecting pollinators for research in trap flowers is not an issue because the pollinators can be found inside the floral chambers. However, due to the taxonomic complexity of Diptera, studies likely involve a taxonomic impediment with incomplete identifications (Berjano et al. 2009; Ollerton et al. 2017). Interestingly, studies that conducted more detailed taxonomic work on Diptera in trap flowers have led to the discovery of new species (e.g., Sakai 2002; Blagoderov et al. 2023) and previously unknown pollination systems (e.g., Sakai 2002; Heiduk et al. 2015; Oelschlägel et al. 2015; Rupp et al. 2024). This highlights the importance of taxonomic refinement not only for biodiversity knowledge but also for a deeper understanding of pollination systems and their ecological and evolutionary patterns (Mayer et al. 2011; Ollerton et al. 2017; Raposo et al. 2020; Engel et al. 2021).

To demonstrate the existing taxonomic impediment concerning Diptera pollinators, we reviewed the diversity of these pollinators found on trap flowers of the genus *Aristolochia* (Aristolochiaceae). We selected this plant genus as an example because it is a relatively well-studied group, exclusively pollinated by Diptera and that entrap their pollinators, enabling easy specimen collection (Berjano et al. 2009; Matallana-Puerto, Brito, et al. 2024). We assessed the level of identification of pollinators, that is, at the order, family, genus, and species level, across *Aristolochia* populations and calculated the percentage of species-level identification for each population. To address the taxonomic impediment of Diptera pollinators, we propose interdisciplinary collaboration with specialist taxonomists. As a case study, we selected a tropical *Aristolochia esperanzae* Kunth population with one of the highest numbers of recorded pollinator morphospecies (Matallana-Puerto, Duarte, et al. 2024). We compared the number of morphospecies and the level of taxonomic refinement without and with taxonomists collaboration. We aim to underscore the value of interdisciplinary cooperation, where botanists and ecologists can work with insect taxonomists to uncover the hidden diversity of lesser-known dipteran pollinators.

2 | Materials and Methods

2.1 | Systematic Review

To build the database on pollinators of *Aristolochia* species and populations, we searched articles in Google Scholar (scholar.google.com), with the last search on 29 October 2024. We used the search strings: 'Aristolochia' AND 'Pollination'. Then, we followed the PRISMA guidelines to screen the references (Preferred Reporting Items for Systematic Reviews & Meta-Analyses in Ecology and Evolutionary Biology, O'Dea et al. 2021).

The search returned 2850 results, which were screened by a single person. The order of the eligibility criteria was: (1) the title, abstract, or keywords included the search terms; (2) the study provided clear information on the collection and identification of dipteran pollinators of any *Aristolochia* population; and (3) the study reported the taxonomy of dipteran pollinators (e.g., order, family, genus, species).

For each *Aristolochia* population, we extracted the identification of the dipteran pollinators found inside the trap flowers considering the most refined taxonomic level, that is, up to order, family, genus, or species. We only included dipterans in our review since they are considered the exclusive pollinators of *Aristolochia* species so far (Berjano et al. 2009). We also extracted the geographic coordinates of the studied population and used the coordinates of the city's centroid through Google Earth (earth.google.com) when the authors did not provide the exact location. To reduce bias and simplify the many potential taxonomic levels, we considered the family for morphospecies identified up to subfamily and the genus for morphospecies identified up to subgenus or species group. The validity and spelling of scientific names of the final list were checked using the scientific names matching tool of the GBIF organisation (Global Biodiversity Information Facility; gbif.org/tools/species-lookup).

2.2 | Data Processing

To demonstrate the lack of taxonomic refinement, we quantified the number of dipteran records identified only at the order, family, genus, and species levels. Additionally, we created a metanetwork using the R-software package bipartite version 2.19 (Dormann et al. 2008) to visually represent the interactions between dipterans identified at the distinct levels of refinement and the *Aristolochia* populations. To identify general patterns, we used presence-absence data (i.e., binary) because abundances were not available for all records, and studies have different sampling efforts. To demonstrate the taxonomic impediment in relation to the most refined taxonomic potential (i.e., species level), we calculated the percentage of identifications at the species level (Number of identified species/Total number of Diptera taxa identified $\times 100$).

2.3 | Study Case

To highlight the importance of taxonomists in identifying and unrevealing Diptera groups as pollinators, we used the published data from a Brazilian population of the South American *Aristolochia esperanzae* (Figure 3a; see Matallana-Puerto, Duarte, et al. 2024). We selected this species because it is one of those with the highest number of morphospecies recorded in *Aristolochia* so far. The dipterans were collected at the end of the first day of anthesis from 81 flowers when these were in the female phase. The dipterans were identified as morphospecies in a less in-depth screening work by a few Diptera taxonomists (see Matallana-Puerto, Duarte, et al. 2024). For the current study, the same Diptera individuals were identified by more taxonomists, covering a wider range of specialists in each Diptera subgroup. Then, the results of taxonomic refinement were compared in these two conditions: without and with the presence of taxonomists specialised in each Diptera family.

3 | Results

We selected 25 studies that met the eligibility criteria and were published between 1981 and 2024 (Table S1). From these, we gathered data from 23 species and 40 populations of *Aristolochia* (Table S1). These were distributed across Europe (8 species and 7 populations), South America (6 and 9), North America (6 and 7), and Asia (3 and 3) (Figure 1a). We extracted a total of 531 distinct records of dipteran pollinators. Of these, 1.9% were identified at the order level, 41% at the family level, 35.8% at the genus level, and only 21.3% at the species level (Figure 1b). The percentage of identification up to the species level across *Aristolochia* populations ranged from 0% (35% of populations) to 100% (12.5% of populations) (Figure 1a,c). Although the mean percentage of identification up to the species level was 34.11%, most populations (40%) exhibited $<5\%$ of this maximum taxonomic refinement (Figure 1a,c).

The pollinator metacommunity of the *Aristolochia* genus included 43 families, 109 genera, and 61 species of Diptera order (Table S1). The most common Diptera families interacting with *Aristolochia* were Phoridae (found in 65.2% of species and 57.5% of populations), Drosophilidae (52.2% and 42.5%), and Sciaridae (47.8% and 45%; Figure 2; Table S1). The most common Diptera genera interacting with *Aristolochia* were *Megaselia* (Phoridae; 39.1% species and 25% of populations), *Drosophila* (Drosophilidae; 26.1% and 20%), and *Scaptomyza* (Drosophilidae; 13% and 10%) (Figure 2; Table S1). Regarding species, some were more common and interacted with multiple *Aristolochia* species and populations, including *Megaselia scalaris* (Phoridae; 3 and 3, respectively), *Aphanotrigonum femorellum* (Chloropidae; 2 and 4), *Drosophila simulans* (Drosophilidae; 2 and 3), and *Zaprionus indianus* (Drosophilidae; 2 and 3) (Figure 2; Table S1).

Considering our study case using dipterans trapped in *A. esperanzae* (Figure 3a), we found that when specialist taxonomists were involved, the number of records identified as morphospecies increased from 37 to 80, the number of families identified increased from 14 to 21, the number of genera identified increased from 0 to 42, and the number of species identified increased from 0 to 31 (Figure 3b; Table S2). The percentage of identification at the species level increased from 0% to 38.8%. Additionally, it was possible to identify the main pollinators of

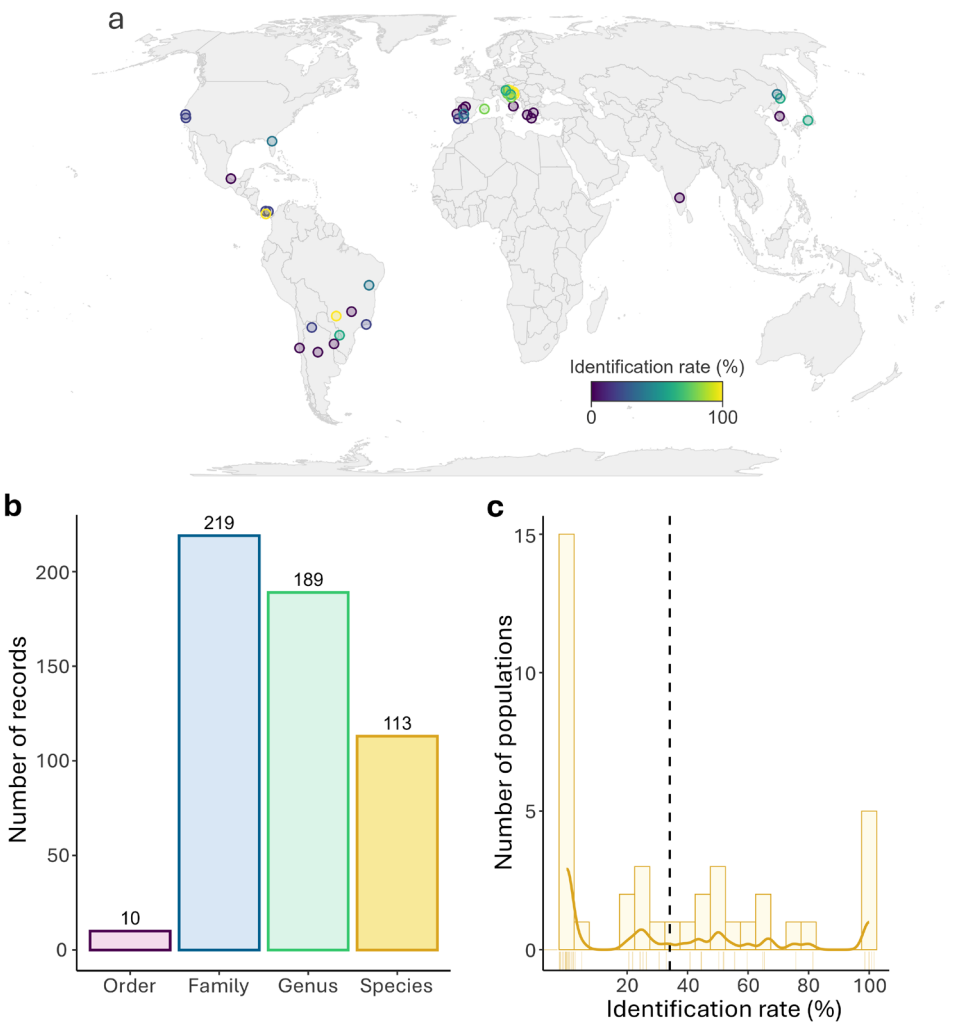


FIGURE 1 | (a) Percentage of Diptera pollinators identified to species level (identification rate) in populations of *Aristolochia* spp. trap flowers worldwide. (b) Number of records of Diptera pollinators found in *Aristolochia* spp. populations identified at different levels of taxonomic refinement. (c) Histogram showing the identification rate of Diptera pollinators at the species level found in *Aristolochia* spp. populations. The dotted line represents the mean value, the continuous line represents the density trend, and the rugs on the *x*-axis represent raw data for each population, with a jitter of 2.5 applied horizontally to improve visualisation. [Colour figure can be viewed at wileyonlinelibrary.com]

the *A. esperanzae* population, which belong to Ulidiidae and were distributed across four genera, being two morphospecies of *Acrosticta*, five species of *Euxesta*, one species of *Notogramma*, and one species of *Physiphora* (Table S2).

4 | Discussion

4.1 | Overview

By synthesising information on the taxonomic refinement of dipteran pollinators of *Aristolochia* populations, we demonstrated that the level of taxonomic refinement is low since most records were identified to family and genus levels. Alternatively, there were few records identified at the species level, which would be the ideal conditions for a complete understanding of the biodiversity of Diptera pollinators. As a solution to this problem, we showed that collaborating with taxonomists led to increased taxonomic refinement, with more distinguished morphospecies and more precise identifications at the genus and species levels. This underscores the importance of interdisciplinary research in advancing our understanding of lesser-known dipteran pollinator groups. We discuss our findings below.

4.2 | Why So Much Neglect?

Despite the wide range of lifestyles and ecological roles exhibited by dipterans, such as decomposers, phytophagous, parasitoids, predators, and pollinators (Skevington and Dang 2002; Wiegmann and Yeates 2017), studies suggest that their neglect in various ecological roles is common due to the high diversity of the order, as well as the limited research on their taxonomy and natural history (Skevington and Dang 2002; Ssymank et al. 2008; Mlynarek 2022). For instance, in pollination studies, although some Diptera families, such as Bombyliidae, Calliphoridae, Drosophilidae, Muscidae, Nemestrinidae, Tabanidae, Tachinidae, and Syrphidae, are popularly known to act as pollinators, this order remains less studied than more charismatic taxa (Symank et al. 2008; Inouye et al. 2015; Orford et al. 2015; Ollerton 2017). Even in recent years, lesser-known Diptera families, such as Anthomyiidae, Mycetophilidae,

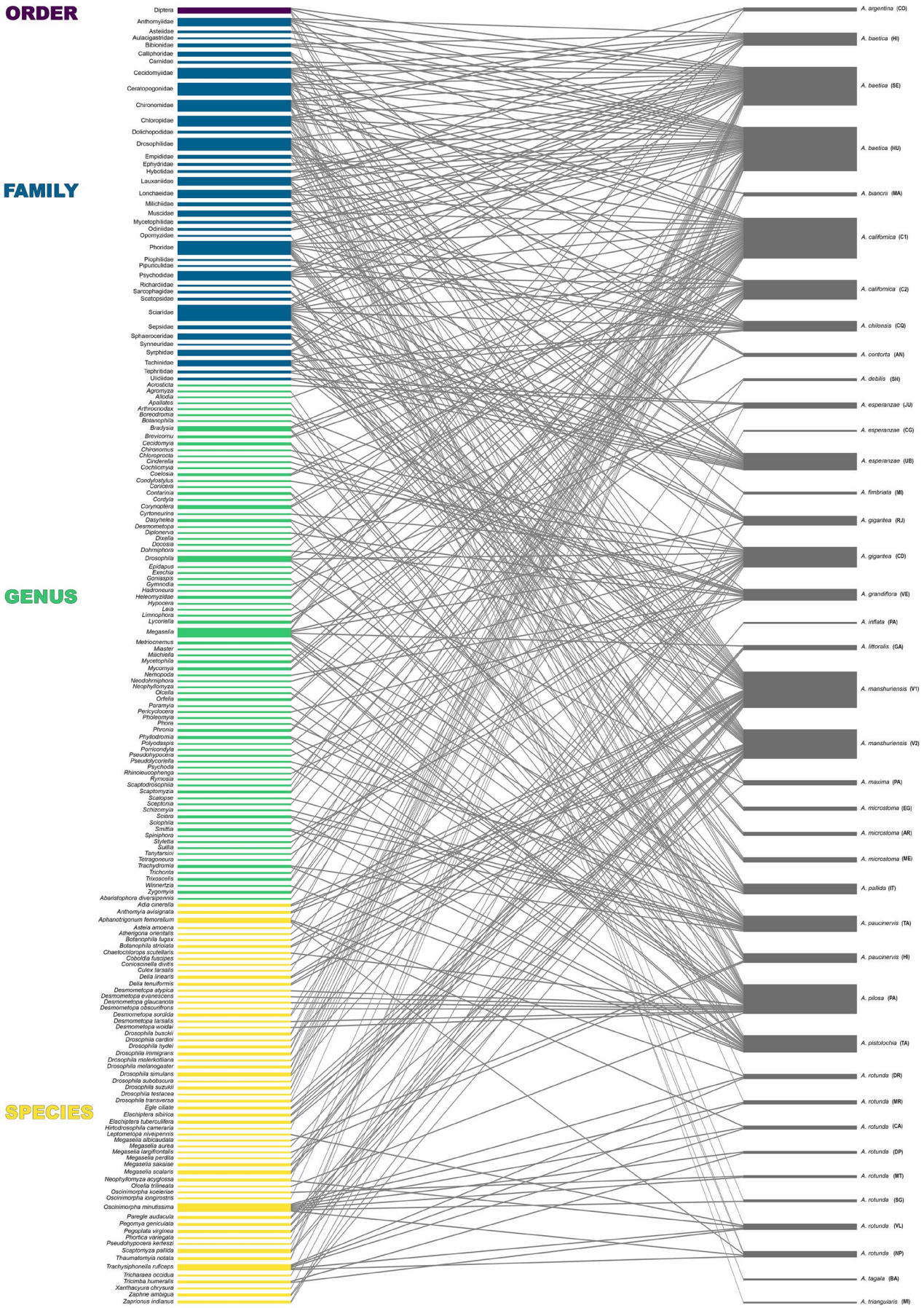


FIGURE 2 | Legend on next page.

FIGURE 2 | Metanetwork between the most refined taxonomic level to which the dipterans were identified (left) and the populations of *Aristolochia* spp. (right), with the study site indicated alongside the species name in parentheses. Abbreviations indicate the name of the city or study site, followed by the respective country: CO: Cordoba, Argentina; HI: Hinojos, Spain; SE: Sevilla, Spain; HU: Huelva, Spain; MA: Mallorca, Spain; C1 and C2: Contra Costa, United States; CQ: Coquimbo, Chile; AN: Anyang, South Korea; SH: Shiojiri, Japan; JU: Jujuy, Argentina; CG: Campo Grande, Brazil; UB: Uberlândia, Brazil; MI: Misiones, Argentina; RJ: Rio de Janeiro, Brazil; CD: Chapada Diamantina, Brazil; VE: Veracruz, Mexico; PA: Panama, Panama; GA: Gainesville, United States; V1 and V2: Vladivostok, Russia; EG: Egaleo, Greece; AR: Arachneo, Greece; ME: Methana, Greece; IT: Italy; TA: Tarrubias, Spain; DR: Dragonja, Croatia; MR: Most Raša, Croatia; CA: Caska, Croatia; DP: Dinjisko polje, Croatia; MT: Mt. Sveti Vid, Croatia; SG: Stari grad, Croatia; VL: Vlašići, Croatia; NP: Northwestern part of Croatia, Croatia; and BA: Bangakire, India. [Colour figure can be viewed at wileyonlinelibrary.com]

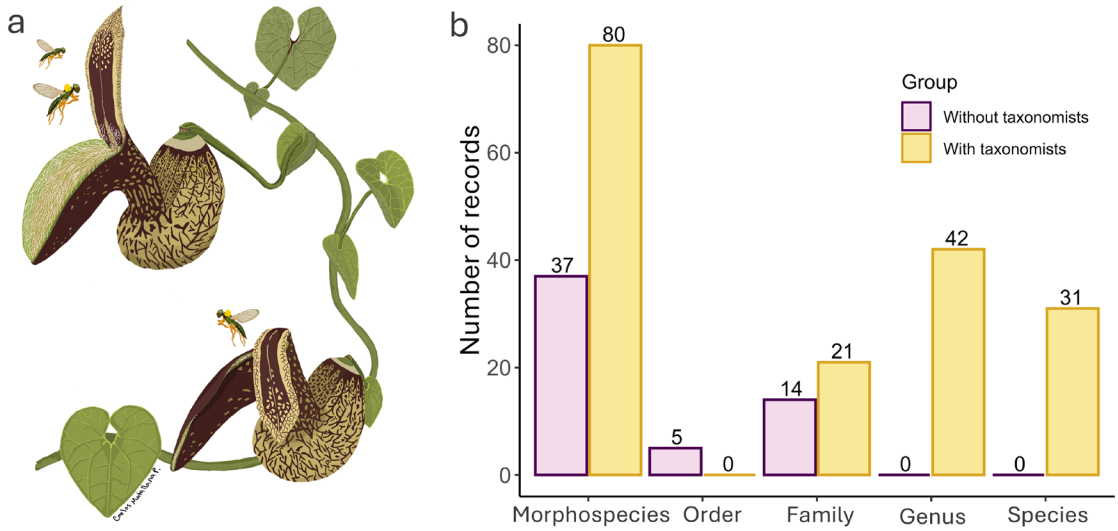


FIGURE 3 | (a) Illustration of *Aristolochia esperanzae* and their pollinating *Physiphora clausa*. (b) Number of morphospecies and identifications at different levels of taxonomic refinement without and with collaborating taxonomists. Illustration by C. A. Matallana-Puerto. [Colour figure can be viewed at wileyonlinelibrary.com]

Sciaridae, Tephritidae, and Chloropidae, have been reported as potential pollinators, highlighting the limited taxonomic knowledge of Diptera pollinators and how much we have to discover (Raguso 2020). In this context, while the taxonomic impediment of the order and the limited ecological research may explain the limited taxonomic knowledge of dipteran pollinators (Orford et al. 2015), this may also be related to the lack of collaboration with taxonomists. Additionally, the ongoing global taxonomist crisis, characterised by a decline in the training of new professionals and the evasion of the existing ones, may further exacerbate this issue (Orford et al. 2015; Löbl et al. 2023).

Our results corroborate the taxonomic impediment associated with dipteran pollinators since few records of these in *Aristolochia* spp. flowers were identified at the species level (21.3%), while most were identified at the family or genus levels (41% and 35.8%, respectively). Furthermore, the mean percentage of species identification across *Aristolochia* populations was 34.11%, with most populations having < 5% of this maximum identification. Although it is known that other dipteran-pollinated plants, whether with similar or distinct pollination systems, also exhibit limited taxonomic refinement, with many flies identified only at the family or genus level (Freitas and Sazima 2006; Berjano et al. 2009; Bashir et al. 2013; Ollerton et al. 2017; Cook et al. 2020; Ren et al. 2023). Since our results refer to the pollinators of a single genus, caution should be taken when extrapolating our findings to avoid excessive generalisation.

4.3 | Dipterans and Aristolochia

Based on the data obtained through the review of dipterans associated with *Aristolochia*, this section summarises our findings and discusses their biological significance, highlighting how taxonomic refinement of pollinators can be used to understand pollination mechanisms based on the natural history of specific Diptera groups. We found that the trap flowers of 40 populations of 23 *Aristolochia* species interact with 61 species, 109 genera, and 43 families of Diptera. Comparatively, the trap flowers of 69 taxa of *Ceropegia* interacted with only 25 Diptera families (Ollerton et al. 2017), highlighting the high diversity of potential pollinating Diptera species that may be hidden within the trap flowers of *Aristolochia*. The Diptera families interacting with *Aristolochia* represent 35% of the 180 Diptera families (Bertone and Wiegmann 2009; Mlynarek 2022). Some *Aristolochia* species show specialised interactions with a single pollinator species (e.g., *A. inflata*; Sakai 2002) or with multiple species from the same genus or family (e.g., *A. littoralis*, *A. bianorii*; Hall and Brown 1993; Alpuente et al. 2023). On the other hand, other species interact with multiple taxa involving different Diptera families (e.g., *A. baetica*, *A. manshuriensis*, *A. esperanzae*; Nakonechnaya et al. 2021; Matallana-Puerto, Duarte,

et al. 2024; Rupp et al. 2024). This specialisation-generalisation range suggests that *Aristolochia* species vary in deceptive strategies employed to attract their pollinators, as well as their ecological conditions.

On the other hand, the high and taxonomically underestimated diversity of Diptera underscores the relationship between different pollinator taxa and *Aristolochia*, which seemingly exploit diverse ecological behaviours of dipterans through distinct deceptive strategies involving scents and/or colours (Oelschlägel et al. 2015; Martin et al. 2017; Rupp et al. 2021, 2024; Alpuente et al. 2023). In agreement, most Diptera families interacting with *Aristolochia* exhibit diverse habits (Skevington and Dang 2002). For instance, Culicidae and Drosophilidae are known as nectar feeders, Empididae and Ceratopogonidae can be pollen feeders, while Syrphidae can consume both resources (Skevington and Dang 2002). However, *Aristolochia* trap flowers seemingly do not indicate the presence of such resources, suggesting that representatives of these families are deceived through mimicry mechanisms (Johnson and Schiestl 2016; Lunau and Wester 2017). In fact, most Diptera families trapped within *Aristolochia* spp. are associated with decaying organic matter, either for adults to feed on or as an oviposition site (Skevington and Dang 2002). This may include decaying plant material like wood, flowers, and fruits; decaying animal material like faeces and carrion; and fungi (Skevington and Dang 2002). Some of these families can also have species acting as parasitoids and/or predators of larvae and small invertebrate insects (Skevington and Dang 2002). Interestingly, the families that interacted with the greatest number of *Aristolochia* species and populations (Phoridae, Drosophilidae, and Sciaridae) are also associated with a wide diversity of decaying organic matter (Disney 2012; Skevington and Dang 2002). Even, some Phoridae and Drosophilidae species can also be parasitoids or predators of other insects (Skevington and Dang 2002). This suggests a high diversity of floral traits of *Aristolochia* species that can exploit the behaviour of several Diptera lineages. Specifically, this may be related to the high diversity of volatile compounds emitted by *Aristolochia* trap flowers, which may mimic yeast-fermented fruits, vertebrate and invertebrate carrion, animal faeces, or even insect semiochemicals that can attract kleptoparasitic flies (Johnson and Jürgens 2010; Oelschlägel et al. 2015; Martin et al. 2017; Rupp et al. 2021, 2024; Alpuente et al. 2023).

Diptera-mediated deceptive pollination systems are also prevalent in other unrelated trap flowers, such as *Arum* (Araceae), *Arisaema* (Araceae), and *Ceropegia* (Apocynaceae) (Gibernau et al. 2004; Vogel and Martens 2000; Ollerton et al. 2017). Although dipterans are obligate pollinators in these specialised pollination systems, recent studies with these plants continue to discover pollinating flies belonging to rarely known groups as pollinators (Raguso et al. 2020). Such is the case of Chloropidae, known for containing some kleptoparasite groups (e.g., *Trachysiphonella, Conioscinella, Tricimba*), which were recently recognised as pollinators of trap flowers belonging to the unrelated genera *Aristolochia* and *Ceropegia* (Heiduk et al. 2015; Oelschlägel et al. 2015). Interestingly, the trap flowers of these unrelated genera produce volatile compounds associated with insects being preyed upon. This taxonomic recognition, coupled with ecological data, enabled experiments that led to the discovery of a new pollination system known as kleptomyophily (Heiduk et al. 2015; Oelschlägel et al. 2015). This highlights how much we still must discover about lesser-known dipteran pollinator groups and the importance of their refined identification, even in understanding fascinating cases of evolutionary convergence.

4.4 | What Can We Do?

In our case study with *A. esperanzae*, we demonstrated that collaborating with taxonomists specialised in different Diptera subgroups can enhance the refinement of pollinator identification, uncovering new biological information, as well as new records that will potentially reveal new species (Costa et al., in prep.). In this case, the number of morphospecies increased by 53.75% (from 37 to 80) and identification at the family level by 33.3% (from 14 to 21). Furthermore, we achieved the identification of 42 genera and 31 species that had not been previously identified. The insights gained through the taxonomic work with specialist taxonomists place *A. esperanzae* as the population interacting with the highest number of Diptera morphospecies and species worldwide to date (80 morphospecies and 31 species), followed by *A. manshuriensis* (36 and 16; Nakonechnaya et al. 2021) and *A. baetica* L. (39 and 15; Rupp et al. 2024). Our results reveal the hidden biodiversity within the community of Diptera pollinators and demonstrate how collaboration with taxonomists enhances taxonomic refinement, as the final number of identified morphospecies and species was higher when taxonomists were involved.

Furthermore, taxonomic refinement allowed us to identify the primary fly pollinators of the Brazilian population of *A. esperanzae*, which belong to Ulidiidae (Matallana-Puerto, Duarte, et al. 2024). This family is widely known for being a maize crops pest, developing in decomposing plant organic matter and animal faeces (Cruz et al. 2011; Goyal et al. 2012; Ebejer and Nicolosi 2022), but rarely recognised as pollinators. To date, only a few studies have reported some Ulidiidae morphospecies as potential pollinators of fetid flowers. Examples include species of the genus *Acrosticta*, recorded as potential pollinators of *Acianthera aphthosa* (Orchidaceae; Pansarin et al. 2016) and *A. esperanzae* in Argentina (Aristolochiaceae; Aliscioni et al. 2017), a species of *Idana* reported in another population of *A. aphthosa* in Brazil (Ribeiro et al. 2006), and a species of *Timia* considered the pollinator of *Pilostyles haussknechtii* in Iran (Apodanthaceae; Bellot and Renner 2013). In our study, which also involved fetid flowers from the *A. esperanzae* population in Brazil, the Ulidiidae were among the main pollinators (Matallana-Puerto, Duarte, et al. 2024). We recorded two morphospecies of *Acrosticta* and identified species of *Euxesta* (5 spp.), *Notogramma* (1 spp.), and *Physiphora* (1 spp.) as pollinators (Table S2). These findings underscore the importance of taxonomists in revealing the identity of lesser-known pollinators, such as Ulidiidae. Moreover, our findings suggest that pollination by species of this family may be more frequent than previously thought, particularly in flowers emitting volatile compounds associated with decomposing organic matter or animal faeces, such as in the understudied tropical *Aristolochia* species.

Notably, we were far from achieving 100% of morphospecies identification, even after collaborating with specialist taxonomists. This can be related to various general and group-specific taxonomic challenges. The first issue is that most specimens

trapped by these flowers belong to dipteran families considered 'open-ended taxa', meaning they are highly speciose and widely distributed while their true diversity remains largely unknown (sensu Bickel 2010). This can be the case of some families commonly found in *A. esperanzae*, such as Tachinidae (1477 genera and 8592 species), Cecidomyiidae (736 and 6203), Syrphidae (209 and 6107), Muscidae (187 and 5200), Phoridae (300 and 4500), and Drosophilidae (74 and 4000) (Bickel 2010; Courtney et al. 2017). Furthermore, the lack of funding for studying certain animal groups and the reduced number of employed taxonomists hinder species identification (Marques and Lamas 2006; Haseyama et al. 2024). Consequently, the availability of taxonomic keys for dipteran families and genera is limited. Even in less diverse groups that were trapped by *A. esperanzae* trap flowers, such as Piophilidae (14 genera and 83 species) and Richardidae (34 and 74), there is a lack of taxonomic information sufficient to identify their species (Haseyama et al. 2024). A third issue is that species-level identification often requires males (Sinclair et al. 2013), whereas *A. esperanzae* captured predominantly females (Matallana-Puerto, Duarte, et al. 2024), further complicating species identification. Some genetic techniques, such as DNA barcoding, are effective in delimiting species and have gained increased use in recent years (Kranzfelder et al. 2017; Meier et al. 2024; Riccardi and Hartop 2024). However, the absence of reference libraries for diverse insect groups such as Diptera can lead to biased data, particularly in less funded tropical regions where a considerable portion of the biodiversity remains unknown (Meier et al. 2006, 2022, 2024; Virgilio et al. 2012; Kranzfelder et al. 2017; Kjærandsen 2022; Riccardi and Hartop 2024). Therefore, as highlighted by other studies, we believe that the first step to improving the recognition of the role of Diptera in ecological processes, including pollination, is to increase interdisciplinary collaboration with taxonomists (Kim and Byrne 2006; Granjou et al. 2014; Orford et al. 2015). In the future, with more specialist taxonomists, greater investment, and the broader application of genetic tools, we hope to improve the species identification of dipteran pollinators of *A. esperanzae*, as well as those of other plant species.

5 | Conclusion

Using a genus of trap flowers exclusively pollinated by Diptera, we demonstrated that although pollinator diversity is high, most of their taxonomy remains unresolved, contributing to their neglect. Despite the inherent taxonomic challenges associated with Diptera identification, through our case study we also demonstrated that interdisciplinary collaboration with specialist taxonomists is a key alternative to enhancing the taxonomic refinement of lesser-known pollinators, such as Ulidiidae. We hope that future studies on Diptera or others less studied pollinator groups will foster collaborative research with taxonomists, contributing to the knowledge of their diversity and advancing our understanding of the eco-evolutionary processes underlying plant-pollinator interactions.

Author Contributions

Carlos A. Matallana-Puerto: conceptualisation (lead); methodology (lead); data curation (lead); methodology (lead); investigation (equal); formal analysis (lead); writing – original draft preparation (lead); writing – review and editing (equal). **Sávio Cunha Costa:** investigation (equal); writing – review and editing (supporting). **Alexandre S. Araujo:** investigation (equal). **Carolina Poloni Guilherme:** investigation (equal). **Danilo César Ament:** investigation (equal). **Diego Aguilar Fachin:** investigation (equal); writing – review and editing (supporting). **Marcoandre Savaris:** investigation (equal). **Paula Raile Riccardi:** investigation (equal). **Rodrigo de Vilhena Perez Dios:** investigation (equal). **Taís Madeira-Ott:** investigation (equal). **Vera C. Silva:** investigation (equal). **Paulo E. Oliveira:** funding acquisition (lead); writing – review and editing (supporting). **João C. F. Cardoso:** conceptualisation (equal); methodology (equal); investigation (equal); formal analysis (equal); writing – review and editing (equal); supervision (lead).

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available in Figshare at https://figshare.com/s/e64d976d9adc068499a7, reference number 28112345.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.