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High floral trait diversity of aquatic plants in the Pantanal reveals different pollination strategies

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ABSTRACT

This research brings novel information regarding the floral traits and pollinator groups of aquatic macrophytes. Classifying functional traits and pollinator groups contributes to understanding reproductive processes, community structuring, and ecosystem functioning. Based on an extensive survey of information on 524 species of aquatic macrophyte angiosperms from the Pantanal wetland, we classified the floral traits of these species to identify their potential group of pollinators and how these traits are distributed throughout the botanical families of aquatic plants. We classified their life forms, floral traits (flower type, color, and resource), and main pollinator groups. We also investigated trends, plotting the occurrence of species throughout the phylogeny of angiosperm families, and using a network of interactions, we verified how interactions with different groups of pollinators are distributed within species traits. As a result, the species of aquatic macrophytes in the Pantanal are well distributed within the phylogeny, indicating that they may be more related to ecological than phylogenetic factors. We found a high diversity of floral traits and pollinator groups, predominating white flowers, providing nectar as a resource, and bees as their primary pollinators. Although bees were the main group of pollinators, we also found abiotic interactions linked to the species richness in Poaceae and Cyperaceae, with pollination system mainly performed by wind. Our research represents a first step towards identifying key information gaps. Future studies should focus on understanding *in loco* traits to fill this gap, besides information on ecological interactions with potential pollinators and species phenology.

1. Introduction

Species functional traits are defined as any morphological, physiological, or phenological characteristic measurable at the individual level that indirectly impacts fitness through its effects on growth, reproduction, and survival (Delalandre et al., 2023; E-Vojtkó et al., 2020; Violle et al., 2007). Therefore, the classification of floral traits of species is a very useful and complementary tool for understanding reproductive processes (Schleuning et al., 2015; E-Vojtkó et al., 2020). Nonetheless, for some plant groups in different communities, surveys of floral traits have generally been neglected (E-Vojtkó et al., 2020). In addition, floral traits may vary in response to biotic and abiotic factors that affect ecosystem functioning (E-Vojtkó et al., 2020; Song et al., 2022) by providing connections with other trophic levels, such as interactions with different groups of pollinators (Schleuning et al., 2015; Souza et al., 2018).

Ecological interactions shape ecosystem functioning and contribute to the evolutionary history of plant species and pollinators (Schleuning et al., 2015). Knowing floral traits, systems, and pollination syndromes significantly improves our understanding of the evolutionary

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mechanism and natural scenario in which organisms are inserted (Fenster et al., 2004; Rosas-Guerrero et al., 2014). Mutualistic relationships between plants and pollinators represent one of the most diverse and widely distributed interactions in terrestrial ecosystems, involving many invertebrate animals, mainly bees, flies, beetles, wasps, and other insects, and vertebrates, such as hummingbirds and mammals (Ollerton, 2017). Thus, the floral traits (resources, colors, fragrances) are fundamental for defining pollination interactions that are associated with the attraction and use of specific groups of animals (Fenster et al., 2004; Souza et al., 2016). It is also worth highlighting that the study of ecological interactions often completely ignores abiotically pollinated plant species, which in some groups or communities can be represented by a large number of species, influencing the dynamics of these interactions (Schleuning, 2015; Rech et al., 2016; E-Vojtkó et al., 2020).

The Pantanal is the largest continuous floodplain in the world and spans over 140,000 km^2 (Silva et al., 2022). Its location, surrounded by the main Brazilian vegetation domains, results in a biota with representatives of these neighboring provinces. It is influenced by the Amazon in the north, Chaco to the west, Atlantic Forest in the southeast and Cerrado (which covers the plateau surrounding the Pantanal) in its eastern portion (Silva et al., 2022). The geographical location and the interaction between soil and biogeographic factors, besides seasonal flooding, explain the mosaic of vegetation types that characterize the Pantanal (Silva et al., 2022). This heterogeneous landscape and differences in flooding regimes result in various formations such as grasslands, savannas, riparian forests, monodominant pioneer plant formations, and ponds with aquatic plants (Silva et al., 2022).

Among plant species, aquatic plants are an extremely representative group (Pott and Pott, 2000; Ali, 2007; Lesiv et al., 2020). Currently, a total of 533 species have been recorded (Pott and Pott, 2022), distributed in the most different life forms (amphibious, floating meadow, emergent, epiphyte, free-floating, free-submerged, rooted floating, rooted submerged), occupying the most diverse habitats in the Pantanal (ponds, flooded grassland, river, swamp, *vereda*). The flooded area of the Pantanal can vary monthly (Pott and Pott, 2022), expanding its aquatic habitats, where aquatic plants begin their establishment within a few days or weeks of flooding. That indicates that the distribution and occurrence of aquatic macrophytes in the Pantanal may correspond mainly to ecological factors rather than historical and phylogenetic relationships (Du et al., 2016; García-Girón et al., 2020; Zhou et al., 2023). Therefore, aquatic vegetation is of great importance because of its ability to retain suspended sediments and nutrients, besides serving as a refuge and food for fauna in aquatic environments (Pott, 2007; Pott and Pott, 2022). Although aquatic plants account for a large part of the diversity in the Pantanal, investigations into their relationships with pollinators are still incipient. Despite extensive floristic surveys and ecological research that include aquatic plant species in the Pantanal wetland (e.g., Pott and Pott, 2000; Souza et al., 2018, 2021; Simão et al., 2021), large scale studies that address and synthesize floral traits, systems, and pollination syndromes are still scarce (e.g. Souza et al., 2021; Gomes et al., 2022).

In this study, we used an extensive and updated list of aquatic plant species recorded for the Pantanal (Pott and Pott, 2022) to assess the distribution of these species throughout the phylogeny of the botanical families of angiosperms and classify their floral traits. We also identified potential pollinator groups based on floral traits. Therefore, we asked the following questions: 1) Are families widely distributed throughout the phylogeny or concentrated in a few clades? 2) What are the floral traits (floral type, color class, and potential resources), and how are they distributed among aquatic plant species? 3) What are the potential pollination modes (different groups of pollinators, pollination by wind, and water) of aquatic plants in the Pantanal? 4) How are floral traits associated with different pollinator groups? We expected a high diversity of floral traits, mainly because of the high diversity of aquatic plant species in Pantanal. Furthermore, we expected a high incidence of species potentially pollinated by the wind but also by bees, the main group of pollinators within angiosperms.

2. Material and methods

2.1. Survey of the Pantanal Wetland aquatic plant species

Information on the composition of the aquatic flora in the Pantanal was primarily obtained from the book written by Pott and Pott (2000). This book is a milestone in the knowledge of aquatic plants in the Pantanal region, as it provides complete information on the occurrence of species, habits, uses, and main aquatic environment distribution in the Pantanal. Based on Pott and Pott (2000), with 247 species of aquatic macrophytes, 227 species of angiosperms were selected here to determine the traits and pollinator group. After surveying these species, we conducted an update including the new species mentioned in Pott and Pott (2022), totaling 523 species of aquatic angiosperms included in this study. We used Flora do Brasil (2020) and Taxonomic Name Resolution Service V5.1 (Boyle et al., 2013, 2021) for the valid names of these listed species.

To classify life forms, floral traits, and potential pollinator groups, we used previously sampled data when available (e.g., Souza et al., 2018, 2021; unpublished data from the research group) and literature data. With the name of the validated species, we determined the life forms based on Pott and Pott (2000, 2022) into amphibious, floating meadow, emergent, epiphyte, free-floating, free-submerged, rooted floating, and rooted submerged. However, for synthesis purposes and better visualization of the types of life forms, we also summarize these classifications as contained in García-Girón et al. (2020): 1 - floating leaved: epiphyte, free-floating and rooted floating; 2 - submerged leaved: rooted submerged and free-submerged; and 3 - emergent leaved: amphibious, floating meadow and emergent species.

2.2. Survey and description of floral traits and groups of potential pollinators

To classify floral traits, we conducted additional searches in the literature, in addition to observing photos of exsiccates, reading descriptions, and complementary information on species traits on the platforms Flora do Brasil (2020) and Royal Botanic Gardens Kew Herbarium (Castellanos and Lewis, 2012; Pelissari et al., 2013; Stokstad, 2023). To survey these traits in scientific articles, we conducted searches using the names of the species, genera, and families. The searches were realized on Google Scholar and Web of Science using the following keywords: pollination, floral type, floral biology, reproductive biology, and the name of each species, genus, or family. A search for each term and species was conducted in Portuguese, Spanish, and English. On average, we selected 150 studies to describe floral traits and the main groups of potential pollinator (See supplemental material for details).

We classified the floral types as dish, inconspicuous (small pale flowers), tube, gullet, flag, and brush (*sensu* Machado and Lopes, 2004). The rewards offered to pollinators were classified into pollen, nectar, oil, floral tissue, and scent. We used color as seen by humans, with color classes similar to those used in previous related studies (e.g., Carvalheiro et al., 2014; Souza et al., 2018, 2021). We defined four classes of flower color: white (includes all white and very pale flowers); yellow; warm colors (including all orange, red and pink/"salmon" flowers); and cold colors (including all blue and purple flowers). Flowers with more than one color were classified according to their predominant color. To classify the pollinator groups of each aquatic plant species, a synthesis was performed using data on floral traits and literature data from articles that realized studies on pollination ecology. The groups of potential pollinators classified in this study were: **1** – bat, **2** – bee, **3** – bee + butterfly, **4** – bee + butterfly + hummingbird, **5** - bee + butterfly + moth, **6** – bee + hummingbird, **7** - bee + moth + hummingbird, **8** – bee + wind, **9** – bee + wind + fly, **10** - beetle, **11** - beetle + fly, **12** - butterfly, **13** - dsi (dsi = including diverse and small insects - Souza et al., 2021),

14 - dsi + hummingbird, **15** - fly, **16** - hummingbird, **17** - moth + hawkmoth + butterfly, **18** - wasp, **19** - water, **20** - wind, **21** - wind + dsi. The information on floral traits and pollinator groups was graphically illustrated using the count of the number of species sampled within each category.

To explore the occurrence trends of plant species in the Pantanal within angiosperm families, we first constructed a phylogeny of botanical families of angiosperms using the V.PhyloMaker2 package (Jin and Qian, 2019; 2022). In the phylogenetic tree of angiosperm families, we highlighted all families of aquatic plants surveyed in this study and the richness of genera and species sampled within each family. The resulting phylogeny was visualized and edited in R software v4.3.1 (R Core Team, 2023), using the packages tidytree (Yu, 2022), ggtree (Yu et al., 2017, 2018; Yu, 2020; Yu, 2022; Xu et al., 2022) and treeio (Wang et al., 2020; Yu, 2022). Finally, after gathering all information on potential groups of pollinators of aquatic plants, we built a network of interactions to illustrate the relationships between plant species, their groups of potential pollinators, and their floral traits (floral type, color, and resource) using the Pajek program (Batagelj and Mrvar, 1998). In this way, we created a network, including plants in the rows and groups of pollinators classified in the columns. The frequency (matrix filling) was considered as the sum of the number of plant species with a particular associated pollinator group. In the network figure, we illustrate the main resources and main color of each plant species and grouped species according to their floral type. Finally, we established interactions (lines) between different groups of pollinators.

3. Results

The 524 species of aquatic plants included in this study are within 56 botanical families, where 16 % of all species belong to Cyperaceae (86 species), followed by Poaceae (14 %; 76 species), Fabaceae (7 %; 36 species) and Plantaginaceae (7 %; 28 species). Onagraceae (5 %; 26 species) and Alismataceae (4.5 %; 24 species) were also representative families, with approximately 10 % of all species sampled. The large number of families highlights the high diversity and distribution of aquatic plants in the Pantanal (Fig. 1). Life forms also showed high variation. Some species presented different life forms, such as *Ludwigia peploides* (Onagraceae), varying from amphibious, emergent, rooted floating to rooted submerged (Table S1). Overall, within the categories of life forms summarized (*sensu* García-Girón et al., 2020), most species presented emergent leaved life forms: amphibious, floating meadow and emergent species (81 % - 424 species), followed by floating leaved: epiphyte, free-floating and rooted floating (11 % - 58 species) and

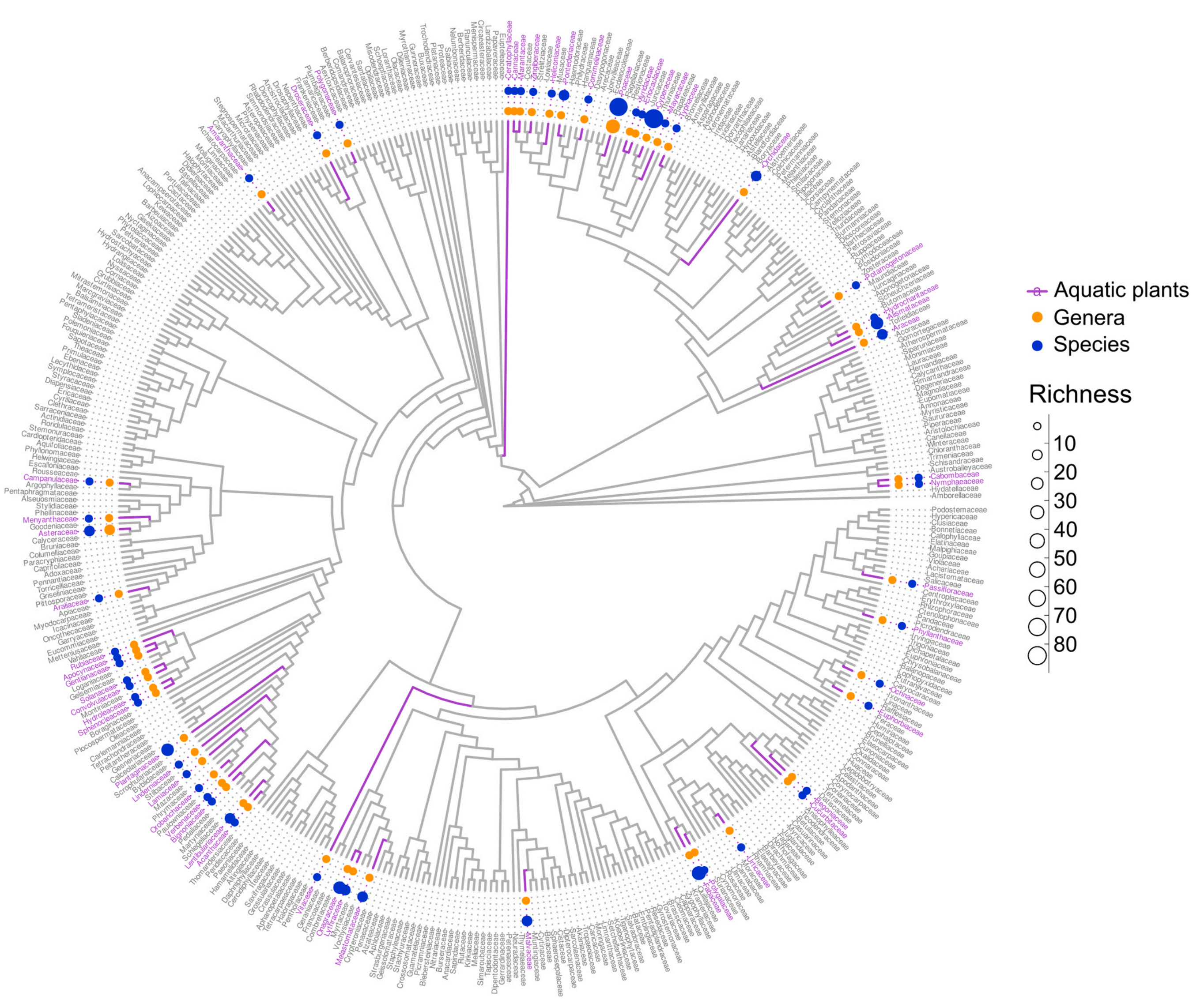

Fig. 1. Phylogeny of the botanical families of angiosperms, highlighting in purple the families with records of aquatic plants sampled in this study. The richness of genera (Orange) and species (blue) of each family that include aquatic plants was illustrated by the size of the circle present in each name.

submerged leaved: rooted submerged and free-submerged (8 % - 42 species; Fig. 2a).

Besides the extensive distribution among botanical families and high variation in life forms, floral traits were highly diverse among the species sampled (Fig. 3: a-l). Among the color classes, white/pale flowers were the most representative (56 %), followed by yellow flowers (19 %), cold colors - blue and purple flowers (18 %) and warm colors - orange, red and pink/"salmon" flowers (6 %; Fig. 2b). Regarding floral resources offered by aquatic plant species in the Pantanal, nectar was the most abundant resource (56 %), followed by pollen (39 %), nectar + scent (3 %), pollen + tissue (2 %), and oil flowers (1 %; Fig. 2c). The most abundant floral type was the inconspicuous type, mainly represented by species of Poaceae and Cyperaceae (34 %), followed by dish (27 %), tube (20 %), flag (11 %), gullet (6 %) and brush (1 %; Fig. 2d).

Among the 21 combinations found as potential pollinators of aquatic plant species in the Pantanal, bees were the most representative group as potential pollinators (43 %). In addition to species potentially pollinated exclusively by bees, records of plants potentially pollinated by bees, together with other groups of pollinators (moths, hummingbirds, butterflies, dsi, flies, and hawkmoths), and wind (ambophilia), were also frequent (18 %). Plants potentially pollinated by wind and diverse and small insects (dsi) were the second most abundant category (17 %), followed by plants potentially pollinated exclusively by wind, a category that included mainly species of Poaceae and Cyperaceae (11 %; Fig. 2e).

The network of interactions between aquatic plants and potential pollinator groups highlights the high diversity of interactions between species and different pollinator groups. Some groups, such as bees, butterflies, hummingbirds, and flies, interact with aquatic plant species with various floral traits. Furthermore, given the large number of Poaceae and Cyperaceae, wind is also an essential abiotic vector for potential pollination. However, it is worth highlighting the presence of species in these families potentially pollinated by different groups of pollinators in addition to wind (Fig. 4).

4. Discussion

In this study, we found a great diversity of floral traits and pollinator groups within the aquatic macrophytes of the Pantanal. Furthermore, we identified a high incidence of inconspicuous white flowers, which offer nectar as a resource. As expected, bees were the primary biotic pollinator group within the aquatic macrophytes. It is also worth highlighting the high variation in life forms of aquatic plant species in the Pantanal, which, driven by the flood regime or cycle, allows for high diversification of life forms, even within the same species (Pott and Pott, 2022). Thus, the different traits and groups of pollinators identified here occur randomly in these life forms, and aquatic plant species from the Pantanal are widely distributed within the angiosperm families (Fig. 1).

The distribution of aquatic macrophytes within several families that are not phylogenetically related suggests a probable association with ecological factors generated by specific characteristics of the Pantanal region (flooding, seasonal variation, and fire), which might also be attributed to the plasticity of these species in terms of life forms, depending on environmental conditions. Thus, local characteristics and temporal distribution factors can influence not only the life forms of different species, but also within the same species. (Damasceno-Junior et al., 2022; Pott and Pott, 2022). These findings underline the idea that ecological niches can often evolve independently of phylogeny, which is expected for functional traits that converge in different lineages and have high phenotypic plasticity (e.g., form of growth and mode of reproduction; Barret et al., 1993; García-Girón et al., 2020). Quantitative studies evaluating the phylogenetic hypothesis of niche conservatism in aquatic plants have found little evidence that closely related species are more similar in terms of ecological traits, than species randomly extracted from a phylogeny (Pavoine et al., 2013; García-Girón et al., 2019; García-Girón et al., 2020). In addition, there are some theoretical criticisms regarding the analyses of phylogenetic signals (Mouquet et al., 2012; García-Girón et al., 2020), and, as reviewed by Cadotte et al. (2019) and demonstrated by García-Girón et al. (2020), the methods and traits used need to be carefully evaluated, specially when evaluating groups of such plasticity in a phylogenetic context. That reinforces that not only evolutionary processes, but also ecological factors are relevant to understanding the phylogenetic background (Cadotte et al., 2019; García-Girón et al., 2020).

Within the aquatic plant species of the Pantanal, nectar is the leading resource available to different groups of pollinators. Nectar is the main resource in most tropical communities, including aquatic and other

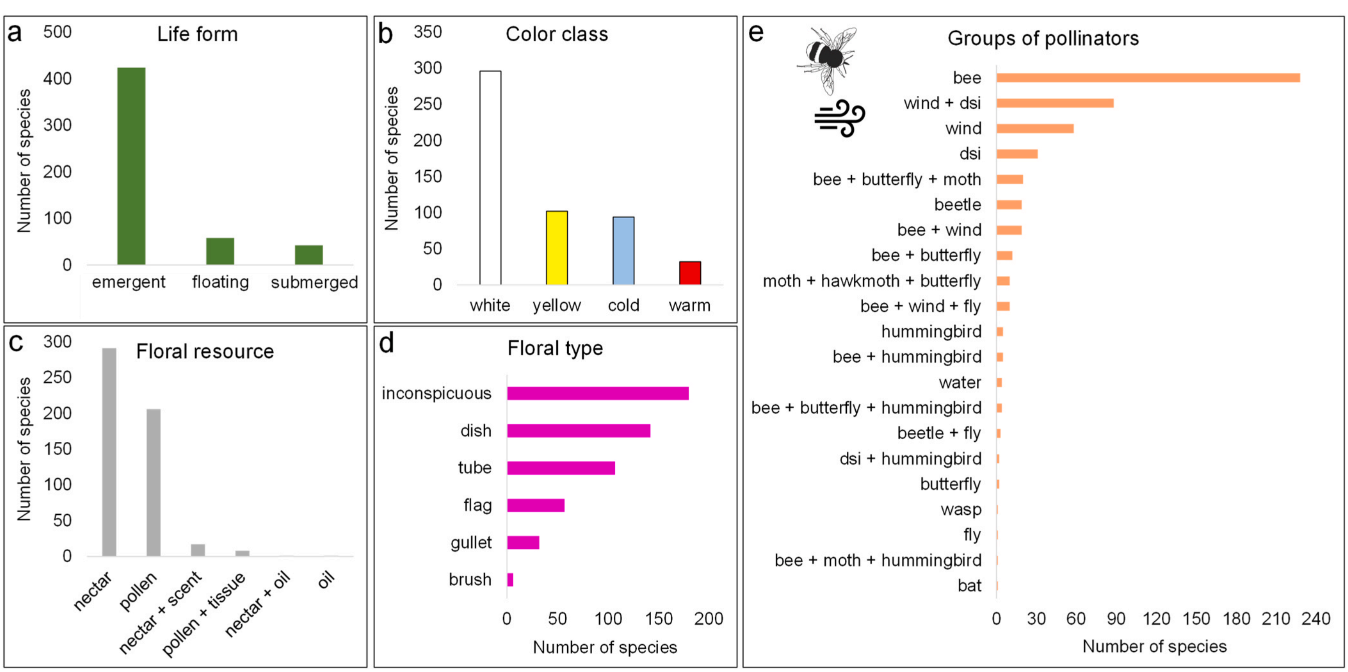

Fig. 2. Floral traits description of the aquatic plant species sampled in this study. a) life form; b) color class; c) floral resource; d) floral type; e) groups of pollinators identified.

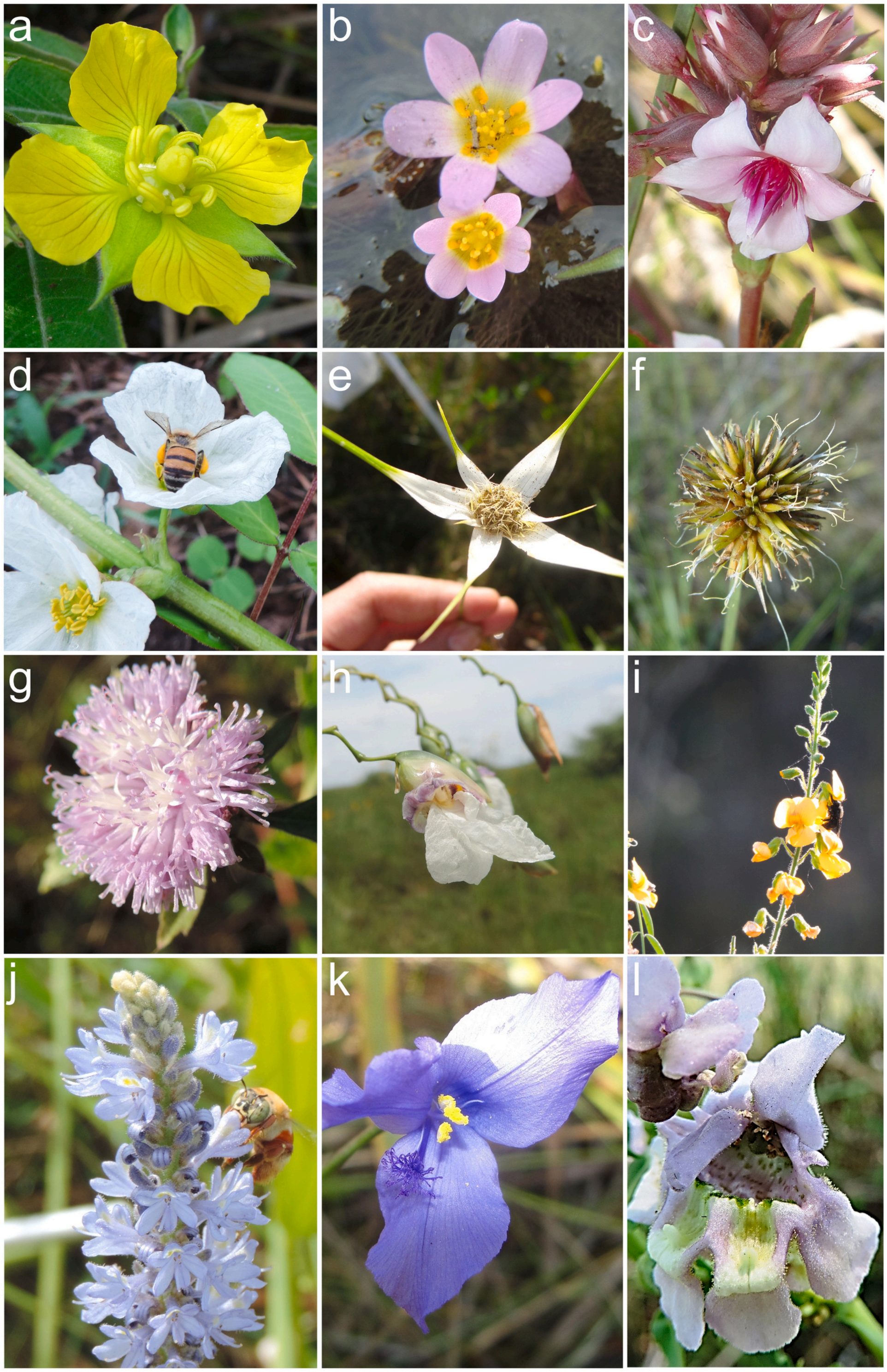

Fig. 3. Aquatic plants included in this study, highlighting the high diversity of floral traits. a) *Ludwigia nervosa* (Onagraceae): dish, yellow, nectar and bee pollination; b) *Cabomba furcata* (Cabombaceae): dish, cold color, nectar and bee pollination; c) *Sauvagesia racemosa* (Ochnaceae): dish, warm color, pollen and bee pollination; d) *Echinodorus grandiforus* (Alismataceae): dish, white, nectar and bee pollination; e) *Rhynchospora nervosa* (Cyperaceae): inconspicuous flower, white color, pollen and wind and bee pollination; f) *Rhynchospora globosa* (Cyperaceae): inconspicuous flower, pale color, pollen and wind and diverse and small insects pollination; g) *Lessingianthus rubricaulis* (Asteraceae): tube flower, cold color, nectar and bee pollination; h) *Thalia geniculata* (Marantaceae): flag flower, white, nectar and bee, butterfly and hummingbird pollination; i) *Discolobium pulchellum* (Fabaceae): flag flower, yellow, nectar and bee pollination; j) *Pontederia cordata* (Pontederiaceae): gullet flower, cold color, nectar and bee pollination; k) *Abolboda pulchella* (Xyridaceae): dish flower, cold color, nectar and bee pollination; l) *Angelonia perennis* (Plantaginaceae): gullet flower, cold color, oil as resource and bee pollination. Photos: Camila Souza.

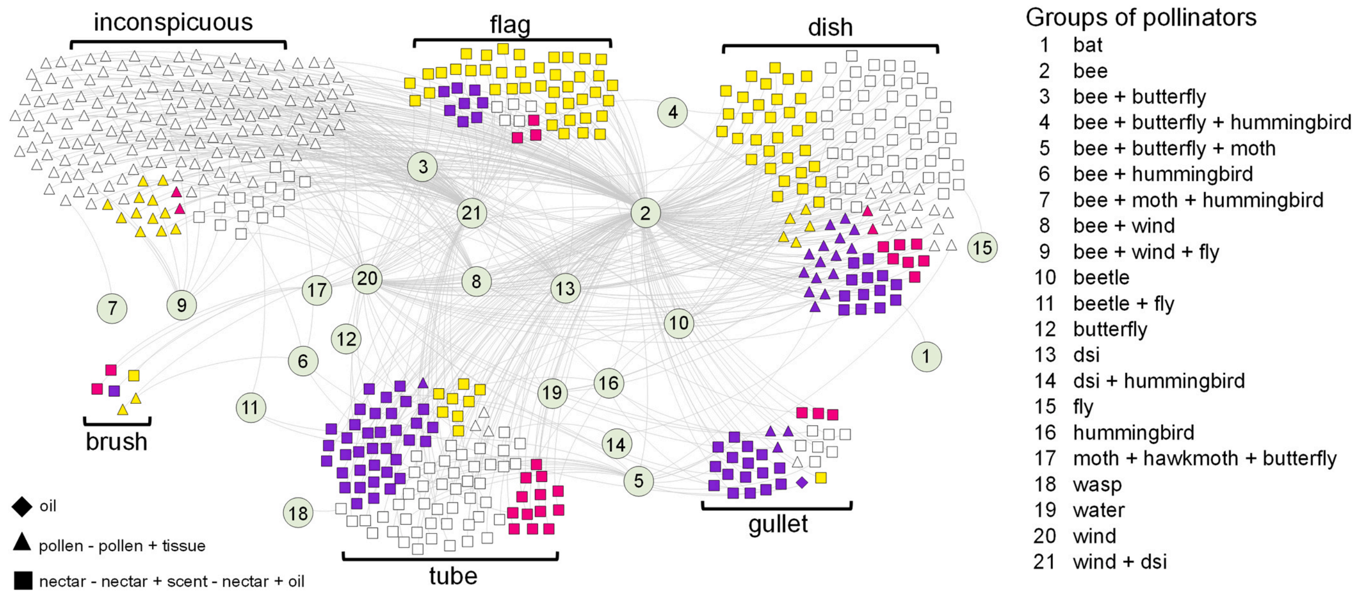

Fig. 4. Network interactions of aquatic plants (diamond, triangle and box vertices) and potential groups of pollinators (green and circular vertices), showing a high diversity of species interactions with different groups of pollinators. The network was divided into six groups represented by the floral types sampled (inconspicuous, flag, dish, brush, tube and gullet), and in each of these groups, different shapes and colors vertices represent a type of resource (diamond - oil; triangle - pollen and pollen + tissue; box - nectar, nectar + scent and nectar + oil) and color class (white/pale; yellow; cold - purple; warm - pink) respectively. The numbers on the green vertices represent the different combinations of pollinator groups (legend on the right).

species (Machado and Lopes, 2004; Souza et al., 2016; Souza et al., 2018, 2021; Luna et al., 2024), being widespread (Faegri and van der Pijl, 1979; Endress, 1994; Proctor et al., 1996). Nectar, together with pollen, is the resource most collected by pollinators, constituting the primary source of carbohydrates and proteins for pollinators, such as bees, which seek this resource to feed their offspring and provide for the nesting process (Faegri and van der Pijl, 1979; Simpson and Neff, 1981; Barbola et al., 2000; Souza et al., 2021). However, we also highlighted the presence of other types of resources within the aquatic macrophytes of the Pantanal, which are important for different groups of pollinators, such as tissue and oil. Floral tissue is used by different species of beetles, thrips, and flower bugs for food and is also an essential resource for groups of diverse and small insects (dsi) (Krenn et al., 2005; Karolyi, 2019). Floral oil is a crucial resource for solitary bees that feed the larvae with an oil and pollen mixture and is also used for nest construction (Simpson and Neff, 1981). Oil-collecting species of the genera *Centris* and *Epicharis* are the primary pollinators of neotropical oil-producing plants (Barônio et al., 2020), which include abundant species in tropical communities (for example, Malpighiaceae, Plantaginaceae and Iridaceae species; Vogel, 1990; Guimaraes et al., 2021).

White and yellow flowers also tend to prevail in tropical plant communities such as Cerrado, Caatinga and Pantanal (Machado and Lopes, 2004; Souza et al., 2016, 2018, 2021). Additionally, the dish type is the most generalist floral type and is commonly found in several communities (Machado and Lopes, 2004; Souza et al., 2016; Luna et al., 2024). However, in the present study, the predominant floral type was inconspicuous, followed by the dish-type flowers. That highlights the influence of the presence and richness of species of Poaceae and Cyperaceae, which have inconspicuous floral types (Tzvelev, 1989; Richards, 2002; Vrijdaghs et al., 2011). Many pollination studies ignore certain botanical families (Poaceae, Cyperaceae) because they mainly establish abiotic interactions. However, little is known about the influence of biotic interactions on these families. The study by Schulze-Albuquerque et al. (2020) on Poaceae showed that insects contributed directly to pollen transfer from one flower to another and or indirectly through insect-induced wind pollination. This mixed pollination system allows species to ensure pollination under different environmental conditions (Schulze-Albuquerque et al., 2020). Furthermore, Wolowski and Freitas (2015), Ruiz-Sánchez et al. (2017), and Dórea et al. (2018) concluded that a set of pollination syndromes can occur in Poaceae, with them being predominantly anemophilous. However, there also exists some secondary ambophilia mediated by insects.

Overall, the different traits of aquatic macrophytes found in this study can lead to a range of potential pollinators, as evidenced by the network of interactions between plant species and different groups of pollinators (Fig. 4). For example, dish flowers can have various resources and colors, and can be visited or potentially pollinated by bees, butterflies, beetles, hummingbirds, flies, diverse and small insects (dsi), wind, and also bats (Fig. 4). The same can be evidenced with tube flowers, for example, which can have different colors and are potentially pollinated by bees, butterflies, hummingbirds, diverse and small insects (dsi), wind and water. Thus, a given pollination syndrome or association with a specific group of pollinators does not necessarily represent exclusivity, but a high probability of frequency of visits (Faegri and van der Pijl, 1979; Rech et al., 2014), a fact that is evident in the complexity of the types and associations of potential pollinators of aquatic macrophytes in the Pantanal. These floral traits that form each of the floral syndromes or groups of specific potential pollinators can be presented as a set of convergent adaptations of flowers to the particularities of pollinators and their morphological traits (van der Pijl, 1961; Rech et al., 2014; Dellinger, 2020), or to the characteristics of the abiotic environment responsible by pollination (wind, water). However, despite the high incidence of different groups of pollinators, not all can actually be effective, that is, guarantee the reproductive success of plant species (Rech et al., 2014). Therefore, future studies should consider the effectiveness of floral visitors as pollinators on aquatic macrophytes in the Pantanal, where this apparently generalist system may reveal specialization in some cases (Waser and Ollerton, 2006; Fenster et al., 2004; King et al., 2013).

Bees are the primary group of pollinators, well distributed within the interactions that occur in the families of aquatic macrophytes in the Pantanal. The morphological and behavioral diversity of bees enables this group to explore a wide variety of floral traits (Pinheiro et al., 2014; Ollerton, 2017). Thus, most angiosperm species have flowers that are visited and pollinated, mainly, or exclusively, by bees. That explains why bees are the most representative pollinator group also within the aquatic macrophytes of the Pantanal. Furthermore, to ensure their survival, bees depend on floral resources, besides having adaptive advantages compared with other groups of pollinators, establishing close relationships with angiosperms throughout the coevolution of both groups (Pinheiro et al., 2014; Ollerton, 2017; Shrestha et al., 2024). Therefore, as we found here, interactions with bees occur in different types of flowers. However, it is worth highlighting that, despite the presence of native bee species, in Pantanal plant species, empirical studies show the high frequency of visits by the exotic bee *Apis mellifera* (Boff et al., 2011, 2013; Santos et al., 2021; Souza et al., 2018, 2021). *Apis mellifera* has high behavioral plasticity, being highly efficient at searching for and exploiting resources and presents an indiscriminate foraging behavior (Traveset and Richardson, 2006; Valido et al., 2019; Dáttilo et al., 2022). Future studies should focus on evaluating the impact of *A. mellifera* on pollination of Pantanal aquatic plant species, and its floral preferences (Hung et al., 2018) should be determined, as studies are still scarce (Hung et al., 2019).

Although abiotic pollination is present in a large number of macrophyte species, here we show that biotic pollination, which can be performed by a large number of groups of pollinators, mainly insects representing 87 % of all groups (e.g., bees: Cunha et al., 2014; Souza et al., 2018, beetles: Fava and Gomes, 2017), but also hummingbirds (e.g., *Heliconia marginata*, *Vigna longifolia, Cuphea melville* - Araújo and Sazima, 2003) and even bats (e.g., *Chelonanthus alatus* - Domingos-Melo et al., 2023), has a high representation within the aquatic macrophytes of the Pantanal. In contrast, abiotic interactions (34 % in total), such as wind pollination, occur in particular families, e.g. Poaceae and Cyperaceae, with numerous species. In this way, we draw attention to the importance of wetlands, such as the Pantanal, in protecting biodiversity. Wetlands are of global relevance for climate, hydrology, and the maintenance of species of local fauna and flora (Wantzen et al., 2024), and have extraordinary value for the conservation of biodiversity (Junk et al., 2006; Almeida-Gomes et al., 2022). However, human actions do not only impact wetland biodiversity but also their functional and ecological characteristics (Moi et al., 2022). Given the constant threats that the Pantanal is undergoing (Wantzen et al., 2024), knowing biodiversity, including processes that structure ecological communities, such as interactions, is extremely important to support and discuss conservation strategies.

5. Conclusion

This research contributes novel information regarding the floral traits and pollinator groups of aquatic macrophyte species in the Pantanal by synthesizing and connecting pre-existing information. This is because abiotic and biotic factors shape species distribution (E-Vojtkó et al., 2020). Therefore, in addition to taxonomic knowledge, listing and describing patterns of functional traits of Pantanal aquatic macrophytes represents a first step towards establishing future research strategies. We highlight here that there are few ecological studies regarding aquatic macrophyte species in the Pantanal, which makes it difficult to classify floral traits and possible groups of pollinators. There is a lack of studies addressing ecological interactions and, in general, information about the reproductive biology of these macrophytes. Our research represents a first step towards identifying the information to be studied. To fill this gap, future studies should focus on understanding *in loco* traits as well as information on ecological interactions with potential pollinators and the phenology of these species. Studies on reproductive biology and, specifically, interactions and floral traits in local communities should be prioritized, especially in environments with high species diversity (*hotspots*) of aquatic macrophytes, such as the Pantanal.

Author contributions

RTS, SNM and CSS conducted the conception and design of the work. SNM, VJP, AP and CA development support. RTS, SSMB, DMCA and CSS conducted data surveys and organization. CSS and DMCA conducted statistical analysis. RTS, DMCA and CSS conducted the first draft of the manuscript. RTS, SSMB, DMCA, SNM, VJP, AP, CA and CSS read and approved the final manuscript.

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CRediT authorship contribution statement

Arnildo Pott: Writing – review & editing, Validation. **Vali Pott:** Writing – review & editing, Validation. **Suzana Moreira:** Writing – review & editing, Conceptualization. **Camila Souza:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Camila Aoki:** Writing – review & editing, Validation, Data curation. **Daniel Alcantara:** Writing – review & editing, Methodology, Formal analysis. **Sara Sofia Benavides:** Writing – review & editing, Methodology, Data curation. **Raissa Santos:** Writing – original draft, Investigation, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data used in this article are available in the supplementary material.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.aquabot.2024.103761.

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