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Review article

Crop pollinators in Brazil: a review of reported interactions

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Abstract – Pollinators are important to maintain ecosystem services, being part of the reproduction and seed formation process of plant species. In this study, we reviewed the literature and developed a database of interactions between pollinators and agricultural crops for Brazil. We classified the pollinators as effective, occasional, or potential, and also identified those species quoted simply as "visitors" (without reference to pollination). We found 250 crop pollinators pertaining to the three categories quoted, with 168 effective ones. Besides, we identified the effective pollinators of 75 agricultural crops. Bees pertaining to the family Apidae, mainly those from the genera *Melipona* , *Xylocopa* , *Centris* , and *Bombus* , were reportedly the most effective pollinators of agricultural crops. We also found that the exotic managed species *Apis mellifera* and the stingless bee *Trigona spinipes* are effective pollinators of some crops. In spite of some data having been originated from gray literature and the taxonomic impediment, this effort is a crucial step to clarify the gaps and bias on data. This study is the first to attempt to build, analyze, and make available a comprehensive data set about pollinators of agricultural crops in a country level, aiming to contribute to protective measures and to enhance the sustainable use of native pollinators in agriculture.

ecosystem services / pollination / agriculture / bees / Apoidea

1. INTRODUCTION

Plant-pollinator interactions are mutualistic relationships that involve mutual gains by both groups: The animals (pollinators) collect food resources (mainly pollen and nectar), and their activities facilitate the reproduction of the plants. These interactions are important because the action of pollinators plays a role in the formation of fruits and seeds. Approximately 300,000 plant species (almost 90 % of all flowering plants) require animal pollination to reproduce (Ollerton et al. 2011). In addition, approximately 75 % of agricultural food crops have shown increased production as a result of animal pollination (Klein et al. 2007).

Some studies have reported declines in pollinator species in different regions of the globe. For example, in the USA and Europe, declines in *Apis mellifera* Linnaeus bees, an important managed social bee species (Becher et al. 2013), have been reported. Other cases of reductions in native bee species have also been reported (Lennartsson 2002; Biesmeijer et al. 2006; Girão et al. 2007;

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Cameron et al. 2011; Dupont et al. 2011). The causes of decline seem to involve multiple factors, including pathogens, habitat reduction and loss, competition for resources with invasive species, aggressive agricultural practices (including inappropriate use of pesticides), and global climate change (Potts et al. 2010). Monitoring programs are currently being implemented on a global scale to examine the decline of pollinator species (LeBuhn et al. 2013).

The evidence of pollinator declines has raised discussion about the possible impacts of these declines on the pollination of agricultural crops and, consequently, on food production. The importance of pollination for global human feeding was emphasized in a study that showed one scenario of pollinator loss resulting in a decrease in production of at least three classes of foods (stimulant crops, fruits, and vegetables) below the level of current consumption (Gallai et al. 2009). In developing countries, scenarios involving the loss of pollinators are even more worrisome because they may involve a more severe decrease in crop production (Aizen et al. 2009). A study using global data from the Food and Agriculture Organization (FAO) showed that, in recent years, the crops that are most dependent on pollinators have displayed lower growth rates and lower production stability (Garibaldi et al. 2011). Producer prices also increased in the most dependent crops (Lautenbach et al. 2012). Deficits in pollinator populations have already been reported in agricultural crop systems (Morandin and Winston 2005). These results show that there is an urgent need to establish effective measures for the protection of pollinators and their habitats.

However, for such measures to be adequate, the first step is to identify the most important pollinator species for each agricultural species and examine the variation in the composition of pollinators among regions and agricultural species. There does not appear to be an available database on interactions between pollinators and agricultural crops. These interactions were described in a pioneering review on the subject (Free 1993) but are not available in the form of a database. Additional information on plant-pollinator interactions is available on the Food and Agriculture Organization of the United Nations Global Action on Pollination Services for Sustainable Agriculture website, but a database is not available either.

Thus, this study is the first attempt to build, analyze, and make available a database containing a reviewed data on pollinators of species of agricultural interest. This database would be useful not only for studies on basic species biology and the sustainable use of native pollinators in agriculture but also for predictive studies on the impacts of climate change (Giannini et al. 2012; Giannini et al. 2013a; Polce et al. 2013). Therefore, a list of pollinators by agricultural crop could be an important tool for policy makers who wish to develop strategies for the protection and management of pollinator species.

2. MATERIALS AND METHODS

To build the database of pollinator and crop plant interactions reported in Brazil, we used Biodiversity Data Digitizer (BDD) (Cartolano et al. 2007; Saraiva et al., 2011) that is a computational tool based on Darwin Core (DwC), a data standard for information about biodiversity (Wieczorek et al. 2012).

We collected information on pollination and pollinators from various databases, such as international and Brazilian providers of scientific literature (Web of Knowledge, Google Scholar, and Scielo). Also, we searched specific data sets that provide information about tropical agriculture (such as the Campinas Agronomic Institute and the Brazilian Agricultural Research Corporation) and pollinators (Encontro sobre Abelhas [Meeting on Bees] in Ribeirão Preto, among others) (see Supplementary Material A for details). The scientific names of bees were retrieved, corrected, and updated using Moure's Bee Catalogue (http://moure.cria.org.br/). The scientific names of other pollinators were found in the Integrated Taxonomic Information System (ITIS) (http://www.itis.gov/). When necessary, synonymies were also corrected. The scientific names of plant species were compiled and updated using the Missouri Botanical Garden's Tropicos website (http://www.tropicos.org/). As we used the literature to build the database, we included all the crops that were investigated considering pollinators or pollination by the scientific community. We do not have a national list of crop plants to Brazil. The website of the Brazilian Institute of Geography and

Statistics (IBGE) provides a list that includes only the most economically important ones, but that website includes a series of crops that are known as being independent of pollinators and are highly produced in Brazil such as rice, maize, wheat, and others.

Types of plant-pollinator interactions were categorized into two categories: "pollinates" and "visits." The category named pollinates included cases in which (1) the researcher observed the behavior of the visiting animal and reported that it touched the reproductive floral parts of the plant, or (2) the researcher conducted a pollination test and found that fruit and/or seed production increased in the presence of a particular animal species. Pollination efficiency was not considered, because few studies included a measure of pollinator efficiency. The visits category included cases in which the researcher noted a particular flower visit but failed to note the flower visitor's behavior or perform any pollination experiments.

The category named pollinates was subdivided into three classes of pollination events: (1) effective, (2) occasional, and (3) potential. "Effective" referred to cases in which the researcher reported that the animal always pollinated the flower by touching the floral reproductive organs. The "occasional" category was used for cases where there was only occasional contact between the animal and the reproductive parts of the flower. "Potential" pollination events referred to accounts of plant-pollinator interactions in which accurate observations were not possible. In addition, the latter category included the cases in which the researcher tested whether uncovered flowers produced more seeds and/or fruits compared to a control group of covered flowers. If the results of this type of test were positive and all visiting animals were captured and listed without discriminating among their roles, all of them were classified as potential pollinator.

The visits category was also subdivided into three classes: (1) robber, (2) damages, and (3) no comment on pollination. The subclass "robber" included cases in which the researcher specifically mentioned that the animal collected resources from the flower but did not touch the reproductive organs. In the subclass "damages," the animal caused some kind of damage to flower, for example, piercing the corolla to rob nectar and/or pollen, but did not touch the reproductive organs of the flower. The subclass "no comment on pollination" referred to cases in which the researcher did not make any comments about the behavior of the animal with regards to the flower.

3. RESULTS

The complete database used in this study is available at http://www.biocomp.org.br/bdd/interactions under password request. A summarized result, describing the main pollinator groups of each crop, can be found on Table I.

A total of 249 references were found, of which 34 % were published in Brazilian journals, 35 % at national meetings, and only 4 % in international journals (Figure 1a). Thirty-nine percent of the total publications found were published by only two sources: the Encontro sobre Abelhas [Meeting on Bees] in Ribeirão Preto and the Brazilian Agricultural Research Corporation (EMBRAPA) (Figure 1a). Seventy-one percent of the total was not indexed in any scientific database (Figure 1b).

A total of 2,545 plant-pollinator interactions were cited in these references, but only 1,470 actually referred to pollinators, with the remaining interactions (1,075) referring to floral visitors. In 594 interactions (23 % of the total number of interactions recorded), the animal species were not identified. Effective pollinators of crop species were identified in 801 interactions (Figure 2).

Of the animals cited as either pollinators or visitors, a total of 321 species were identified. Most of the citations (99.8 %) were about insects, and the remainder referred to birds. Among the bird species, only *Anthracothorax nigricollis* Vieillot and *Thalurania glaucopis* Gmelin (occasional pollinators of passion fruit) were cited as pollinators.

Hymenoptera was the dominant order (89 %), followed by Coleoptera (5 %), Diptera (4 %), and Lepidoptera (2 %). The family Apidae accounted for 74 % of the total cases of plant-pollinator interaction, followed by Halictidae (10 %). Both families are members of the superfamily Apoidea (Figure 3a1). The most cited genera were bees from the genus *Centris* (12 %) and *Trigona* (11 %), followed by *Xylocopa* (9 %), *A. mellifera* (an exotic species in Brazil and the only representative of the genus *Apis*) (8 %), and *Melipona* (5 %), all members of the family Apidae (Figure 3a2). The species most often cited in the entire data set were *A. mellifera* (8 %), *Trigona spinipes* Fabricius (a social stingless bee, 6 %), and *Xylocopa frontalis* Olivier (3 %).

Table I. Main group of effective, occasional, and potential pollinators reported for each agricultural crop.

Crops[a] (English and Portuguese vernacular names)	*Bombus* spp.	*Centris* spp.	*Xylocopa* spp.	Meliponini tribe	Other native species	*A. mellifera*
Avocado/abacate				x		x
Squash/abóbora	x		x	x	x	x
Zucchini/abobrinha				x		x
Açai tree/açaizeiro				x		
/Acapú				x	x	x
/Acerola		x		x	x	
/Adesmia		x			x	
Cotton/algodão			x	x	x	x
Mulberry/amora				x	x	x
Araticum/araticum					x	
Atemoya/atemóia					x	
Oily bacaba/bacaba de azeite				x	x	
Bacaba tree/bacabizeiro				x	x	
Eggplant/beringela	x	x	x	x	x	x
Coffee/café	x	x	x	x	x	x
Caja tree/cajazeira		x	x	x	x	x
Cashew tree/cajueiro		x				x
Camu-camu/camu-camu				x	x	x
/Canola				x	x	x
Persimmon/caqui		x	x		x	x
Star fruit/carambola					x	x
Brazil nut tree/castanheira do brasil	x	x	x	x	x	x
Onion/cebola	x		x	x	x	x
Carrot/cenoura				x	x	
Chayote/chuchu				x		
Coconut tree/coqueiro				x	x	x
/Cumaru	x		x		x	
Cupuassu/cupuaçu				x	x	
African oil palm/dendezeiro					x	
Bean/feijão	x		x		x	
Cowpea/feijão caupi			x			
/Gabiroba	x				x	
Sunflower/girassol	x		x	x	x	x
/Gliricídia			x		x	
Guava/goiaba	x	x	x	x	x	x
Soursop/graviola					x	
Red jambo/jambo vermelho				x	x	
/Juazeiro					x	x
/Jurubeba	x	x	x		x	
Orange tree/laranjeira				x		x
/Macadamia				x		x

Table I. (continued)

Crops[a] (English and Portuguese vernacular names)	*Bombus* spp.	*Centris* spp.	*Xylocopa* spp.	Meliponini tribe	Other native species	*A. mellifera*
Castor beans/mamona						x
Cassava/mandioca			x	x	x	x
Mango/manga				x	x	x
/Mangaba	x	x	x		x	
Passion fruit/maracujá	x	x	x		x	
Sweet passion fruit/maracujá doce	x	x	x		x	
Watermelon/melancia				x		x
Melon/melão			x	x		x
São caetano melon /melão de são caetano	x				x	
Pumpkin/moranga				x		x
Strawberry/morango				x	x	x
/Murici		x		x	x	
/Murici pitanga		x	x	x	x	
Tucumã palm/palmeira tucumã					x	
/Pedra-ume caá					x	x
Cucumber/pepino				x		x
Peach tree/pessegueiro			x	x		x
Phalsa/phalsa			x	x	x	x
Sweet pepper/pimenta doce				x		
Chili pepper/pimenta malagueta				x		
Wild chili pepper/pimenta malagueta silvestre				x		x
Bell pepper/pimentão				x	x	x
Jatropha/pinhão-manso				x		x
/Pitanga					x	x
/Pitangatuba					x	x
/Pitomba				x	x	x
Okra tree/quiabeiro				x		x
Pomegranate/romã				x		
Soybean/soja						x
Tangerine/tangerina				x		x
Tomato/tomate	x	x	x	x	x	x
/Tucumã					x	
/Umbu			x	x	x	x
Annatto/urucum	x	x	x	x	x	x

[a] Scientific names can be found on Supplementary Material B

When a filter was applied to show only those species observed to be pollinators (effective, occasional, or potential), a total of 250 species were identified. Taxonomic representation in this pollinator-only group was similar to that of the comprehensive pollinator/visitor data set, i.e.,

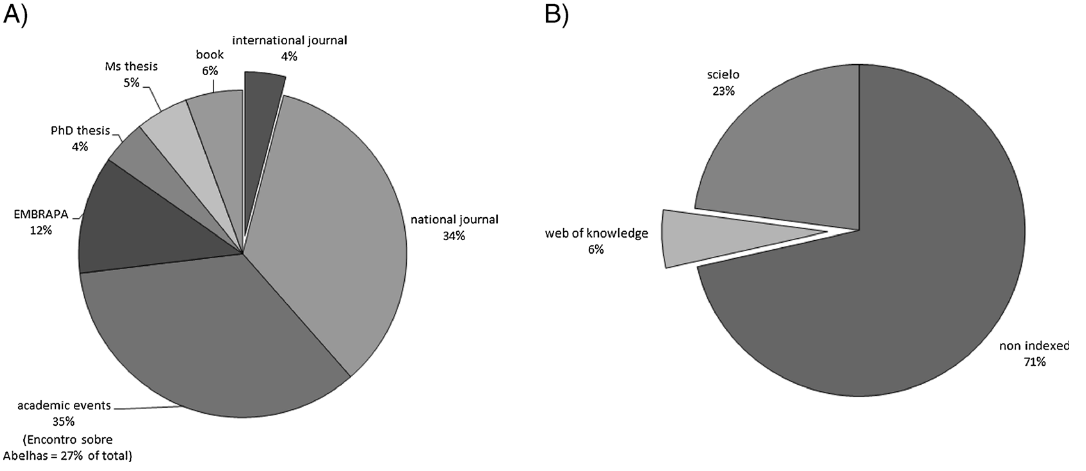

Figure 1. References compiled for the database. **a** Type of reference; **b** index (total=249). *EMBRAPA* Brazilian Agricultural Research Corporation, *Scielo* Scientific Electronic Library Online, *Web of Knowledge* Web of Science Citation Index–ISI Web of Knowledge.

Hymenoptera (89 %), Coleoptera (4 %), Diptera (4 %), and Lepidoptera (1 %). With regard to families, Apidae accounted for 77 % of the pollinator-only cases, and Halictidae accounted for 8 % (Figure 3b1). As seen in the pollinator/visitor data set, the most frequently cited genus in

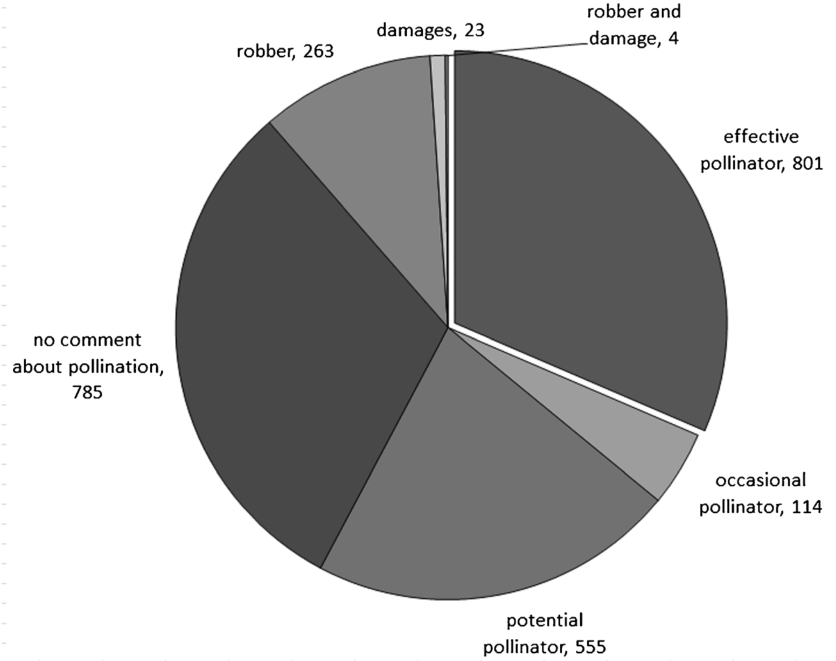

Figure 2. Number of interactions between animals and agricultural plants, classified into the following categories: (1) pollinator (effective, occasional, or potential) and (2) visitor (no comment on pollination; robber; damage or robber and damage) (total=2545) (see Sect. 2 for details).

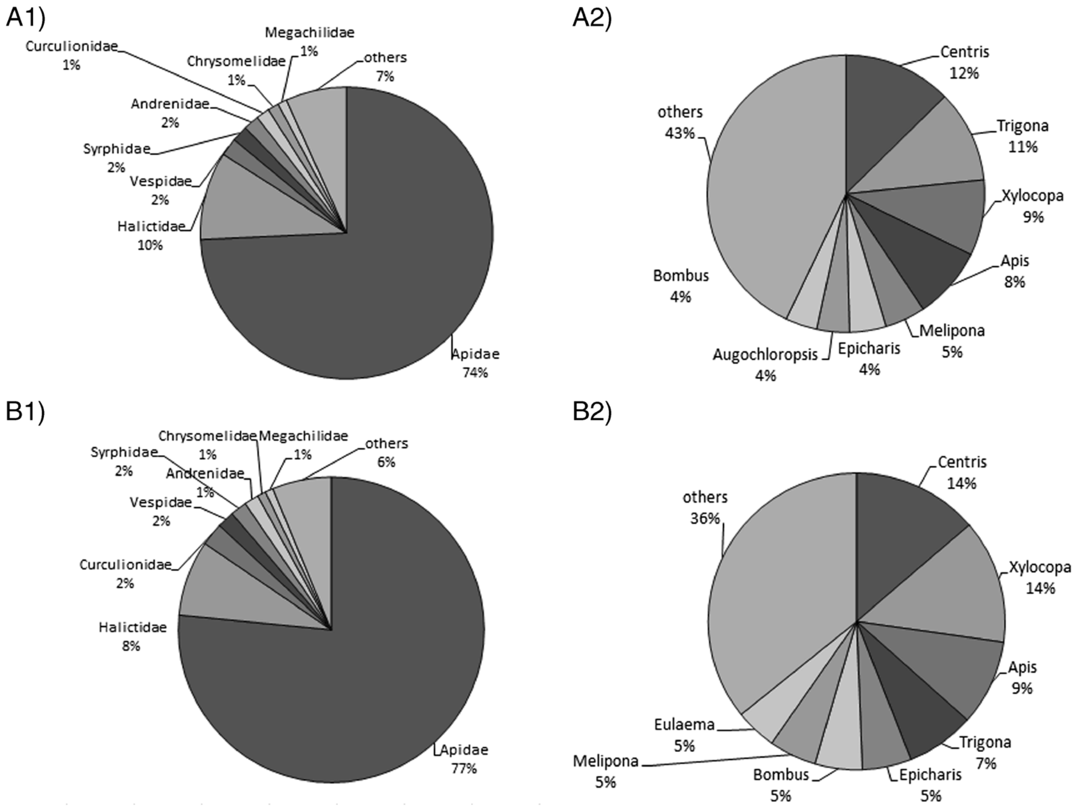

Figure 3. Taxonomic groups most frequently cited in interactions with agricultural crops: **a1** families (visitors or pollinators) and **a2** genera (visitors or pollinators), and **b1** families (pollinators only) and **b2** genera (pollinators only).

the pollinator-only group was *Centris* (13.7 %), followed by *Xylocopa* (13.5 %); *Apis* (9 %); *Trigona* (7 %); and *Bombus*, *Melipona*, and *Epicharis* (5 %) (Figure 3b2). The species most often cited as pollinators were *A. mellifera* (9 %), *X. frontalis* (5 %), and *T. spinipes* (4 %).

Despite being the second most frequently cited family in Apoidea, the family Halictidae presented many taxonomic identification problems. Of the 115 citations for this family, only 45 citations were identified to the species level. Halictidae species were considered effective pollinators of nine crops (bell pepper, tomato, jurubeba, eggplant, strawberry, camu-camu, acapu, and cotton) (complete taxonomic identification of plant species may be found in Supplementary Material B).

Among the Coleoptera, *Elaeidobius subvittatus* Faust and *Elaeidobius kamerunicus* Faust were the most frequently cited species. Species of this order were considered effective pollinators of seven crops (araticum, atemoya, cupuassu, African oil palm, soursop, and tucumã palm). Among the Diptera, the most frequently cited species were *Ornidia obesa* Fabricius, *Palpada vinetorum* Fabricius, and *Belvosia bicincta* Robineau-Desvoidy, and species in this order were considered effective pollinators of eight crops (mango, caja trees, acapu, carrot, pedra hume caa, bell pepper, pitanga, and pitangatuba).

References to 85 crops were found. Of these, 10 did not cite pollinators (only floral visitors). Thus, in total, pollinators were identified for 75 crops (Table I). Crops with a high number of pollinators included passion fruit, acerola, bell pepper, sweet passion fruit, and Brazil nut trees (Table II).

In terms of the number of crop species per pollinator (effective, potential, or occasional), the most frequently cited pollinator genera were *A. mellifera* (44 crops), *Trigona* (36), *Melipona*,

Table II. Agricultural crops with the highest number of effective pollinators.

Crop	Species quoted as effective pollinator
Passion fruit	*Acanthopus excellens* ; *Bombus morio* ; *B. pauloensis* ; *C. denudans* ; *C. flavifrons* ; *C. longimana* ; *C. lutea* ; *C. scopipes* ; *C. sponsa* ; *Epicharis analis* ; *E. bicolor* ; *E. fasciata* ; *E. flava* ; *E. nigrita* ; *Eufriesea surinamensis* ; *Eulaema bombiformis* ; *E. cingulata* ; *E. nigrita* ; *Hopliphora velutina* ; *Oxaea austera* ; *O. flavescens* ; *Xylocopa brasilianorum* ; *X. cearensis* ; *X. frontalis* ; *X. grisescens* ; *X. hirsutissima* ; *X. nigrocincta* ; *X. ordinaria* ; *X. suspecta*
Acerola	*Centris aenea* ; *C. caxiensis* ; *C. denudans* ; *C. flavifrons* ; *C. fuscata* ; *C. longimana* ; *C. maranhensis* ; *C. mocsaryi* ; *C. nitens* ; *C. obsoleta* ; *C. rhodoprocta* ; *C. scopipes* ; *C. spilopoda* ; *C. sponsa* ; *C. tarsata* ; *C. trigonoides* ; *C. varia* ; *C. vittata* ; *Epicharis affinis* ; *E. albofasciata* ; *E. analis* ; *E. bicolor* ; *E. cockerelli* ; *E. flava* ; *E. xanthogastra* ; *Nannotrigona testaceicornis* ; *Partamona cupira* ; *Trigona spinipes*
Bell pepper	*Apis mellifera* ; *Augochlora morrae* ; *A. thalia* ; *Augochlorella acarinata* ; *Augochloropsis aurifluens* ; *A. cleopatra* ; *A. heterochroa* ; *A. laeta* ; *A. wallacei* ; *Ceratalictus theius* ; *Dialictus picadensis* ; *D. ypirangensis* ; *Exomalopsis analis* ; *E. auropilosa* ; *E. fulvofasciata* ; *Frieseomelitta varia* ; *Halictus lanei* ; *Hylaeus tricolor* ; *Melipona fasciculata* ; *M. quadrifasciata anthidioides* ; *M. scutellaris* ; *M. subnitida* ; *Pereirapis rhizophila* ; *Tetragonisca angustula* ; *Trigona spinipes*
Sweet passion	*Acanthopus excellens* ; *Bombus brasiliensis* ; *B. morio* ; *B.pauloensis* ; *Centris collaris* ; *C. decipiens* ; *C.denudans* ; *C.derasa* ; *C.flavifrons* ; *C.longimana* ; *C.lutea* ; *C.scopipes* ; *C.similis* ; *C.sponsa* ; *Epicharis affinis* ; *E. bicolor* ; *E.fasciata* ; *E.flava* ; *Eulaema cingulata* ; *E.nigrita* ; *E.seabrai* ; *Xylocopa brasilianorum* ; *X. frontalis* ; *X.ordinaria* ; *X.suspecta*
Brazil nut tree	*Bombus brevivillus* ; *B. transversalis* ; *Centris americana* ; *C. carrikeri* ; *C.denudans* ; *C.ferruginea* ; *C.similis* ; *Epicharis affinis* ; *E. conica* ; *E.flava* ; *E.rustica* ; *E.umbraculata* ; *E.zonata* ; *Eufriesea flaviventris* ; *E.purpurata* ; *Eulaema cingulata* ; *E.meriana* ; *E.mocsaryi* ; *E.nigrita; Xylocopa aurulenta; X. frontalis*

Complete taxonomic identification of each crop can be found in Supplementary Material B

and *Xylocopa* (26) (Figure 4a). Effective pollinators included species from the genera *A. mellifera* (28 crops), *Trigona* (17), *Melipona* and *Xylocopa* (15), *Centris* (12), and *Bombus* (11) (Figure 4b and Table III).

Species that were considered effective pollinators for the highest number of crops included *A. mellifera* (28 crops), *X. frontalis* (11), *T. spinipes* (10), and *Melipona fasciculata* Smith (8) (Table IV).

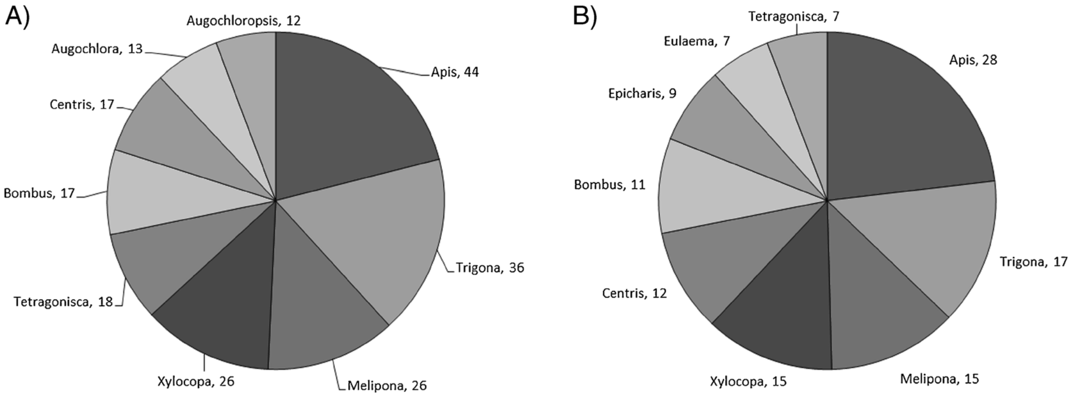

Figure 4. Genera cited as **a** effective, potential, or occasional pollinators, and **b** effective pollinators of agricultural crops. *Numbers* correspond to the number of crops pollinated by members of each genus.

Table III. Genera containing species that are considered effective pollinators of a large number of crops.

Bee genus	Pollinated crop
Apis mellifera	Squash, acapú, cotton, mulberry, coffee, caja tree, cashew tree, camu-camu, canola, onion, sunflower, guava, juazeiro, orange tree, cassava, mango, melon, strawberry, pedra hume caa, cucumber, wild chili pepper, bell pepper, jatropha, pitanga, pitangatuba, soybean, tomato, umbu
Trigona	Squash, açai tree, acapu, acerola, caja tree, camu-camu, carrot, chayote, cupuassu, sunflower, orange tree, mango, strawberry, cherry murici, bell pepper, pomegranate, umbu
Melipona	Squash, murici, pitanga, eggplant, coffee, guava, tomato, annatto, açai tree, caja tree, camu-camu, bell pepper, red jambo, sweet pepper, chili pepper, wild chili pepper
Xylocopa	Squash, murici, pitanga, umbu, eggplant, coffee, brazil nut tree, cumaru, cowpea, gliricidia, guava, jurubeba, passion fruit, sweet passion, tomato, annatto
Centris	Cherry murici, eggplant, guava, tomato, brazil nut tree, jurubeba, passion fruit, sweet passion, acerola, adesmia, cashew tree, murici
Bombus	Eggplant, guava, tomato, brazil nut tree, jurubeba, passion fruit, sweet passion, squash, urucum, cumaru, gabiroba

Complete taxonomic identification of each crop can be found in Supplementary Material B

Two species had interactions that were classified into the subclass damages: *Diabrotica speciosa* (Coleoptera), which was associated with pumpkin and bell pepper, and *T. spinipes*, which was associated with acerola, cashew trees, catauba, coconut trees, guava, soursop, mango, passion fruit, sweet passion fruit, and red passion fruit. Although *T. spinipes* was reported to have damaged the flowers of mango and acerola, it was also considered an effective pollinator of these two crops (Table IV).

The database included citations of plant-pollinator interactions from a total of 123 locations in Brazil, most of which were in the northeastern (42 locations), southeastern (40), southern (18), and northern (16) regions of the country (Figure 5). Locations in the midwestern region of Brazil (7) were rarely cited.

4. DISCUSSION

This study showed that a considerable number of publications on crop pollination in Brazil are difficult to access, especially for the international community, which hinders large-scale analyses, making crucial the issue of data access. However, it is important to emphasize the role of the national meeting called the Encontro sobre Abelhas [Meeting on Bees] in Ribeirão Preto. The meeting is a traditional event that brings

Table IV. Bee species considered to be effective pollinators of a large number of agricultural species.

Bee species	Effectively pollinated crops
Apis mellifera	Acapu, cotton, mulberry, coffee, caja tree, cashew tree, camu-camu, canola, onion, sunflower, guava, juazeiro, orange tree, cassava, mango, melon, strawberry, pedra hume caa, cucumber, wild chili pepper, bell pepper, jatropha, pitanga, pitangatuba, soybean, squash, tomato, umbu
Xylocopa frontalis	Brazil nut tree, cumaru, cowpea, gliricidia, guava, jurubeba, passion fruit, sweet passion, cherry murici, umbu, annatto
Trigona spinipes	Acerola, carrot, chayote, sunflower, orange tree, mango, strawberry, squash, bell pepper, pomegranate
Melipona fasciculata	Açai tree, eggplant, caja tree, camu-camu, chili pepper, bell pepper, tomato, annatto

Complete taxonomic identification of each crop can be found in Supplementary Material B

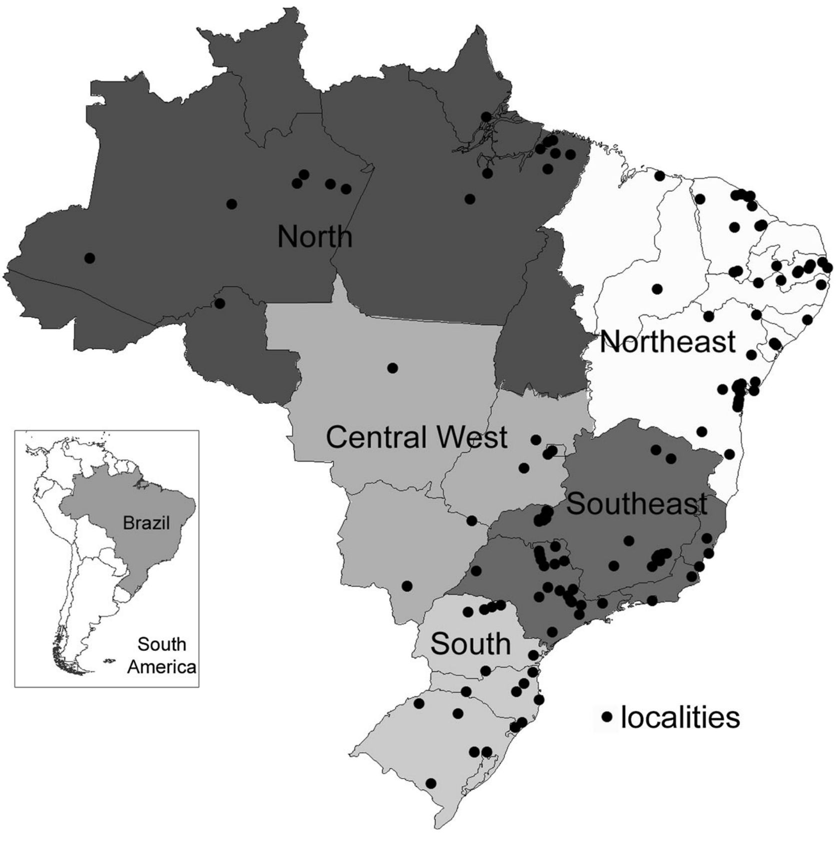

Figure 5. Locations of interactions between pollinators and agricultural crops.

together the majority of Brazilian researchers and many international ones on the topic, and it has been taking place every 2 years since 1994 in the city of Ribeirão Preto in the state of São Paulo. This meeting is organized by a committee of professors and researchers, which are traditionally involved in studies about bees and pollinators in Brazil. Also noteworthy is the work of the Brazilian Agricultural Research Corporation (EMBRAPA), containing top scientific researchers involved with many topics in tropical agriculture, which has contributed substantially to pollinator research in Brazil. EMBRAPA researchers have their own publish vehicles where they publish their scientific results (see Supplementary Material A for details).

In addition to data access, another important challenge is the correct identification of species. The urgent need for a greater number of taxonomists in Brazil has been previously noted (Silveira et al. 2002). However, the identification of species is also a global problem that is considered a bottleneck for ecological studies (Gotelli 2004; Kim and Byrne 2006; Agnarsson and Kuntner 2007). Alternative species identification techniques have been proposed and applied, including the barcoding of DNA using a standardized DNA region (Valentini et al. 2009; Magnacca and Brown 2012) and morphometry techniques, most notably geometric morphometry, which involves measuring certain traits of the bodies of organisms and comparing these measurements among different groups (Rohlf and Marcus 1993; Adams et al. 2004). For example, the venation pattern of the wings of bees has been used successfully in the identification of Brazilian bee species (Francisco et al. 2008; Francoy et al. 2009 and 2011).

Moreover, the difficulty in determining whether or not a species is an effective pollinator of a plant species of interest is also a significant challenge. In this study, almost 40 % of reported interactions were only visits, i.e., there was no information about the role of the species as a pollinator or not. Many of the species observed may be important pollinators. The method cited in this paper of observing the behavior of visitors to verify their contact with the reproductive parts of flowers (anthers and stigma) may be applied to identify effective pollinators. Subsequently, the efficiency of each pollinator can be estimated by counting the number of pollen grains transferred to the stigma during a single visit (Dafni et al. 2005; Delaplane et al. 2013).

Aside from the issues mentioned above, studies on biodiversity of crop pollinators are vital if we want to develop adequate conservation strategies. Thus, the review presented here has a twofold importance: It presents a first evaluation of previous studies that have already been done and published in this area and highlights the data problems that need to be addressed. The data set presented here clarifies which are the main groups of pollinators of studied Brazilian agricultural crops. It also aims to contribute to increase the awareness about the topic and encourage the continuity of this type of research.

Among the most important groups of pollinators is the family Apidae, which includes numerous bee species found in Brazil. Many of these species are eusocial and form colonies with thousands of individuals, as is the case for some of the genera mentioned in this study (e.g., *Trigona* and *Melipona*). Apidae species have broad trophic niches and are well adapted to different environmental characteristics (Michener 2007). The family Halictidae is also large and shows a wide variation in sociality, with species that exhibit a range of solitary to social behavior.

Among the genera cited in the references compiled in this study, the stingless bees (Meliponini tribe) are especially noteworthy. These bees have been previously reported as important for pollination of agricultural crops (Heard 1999; Imperatriz-Fonseca et al. 2006; Slaa et al. 2006) because of their perennial colonies, large number of individuals, non-aggressive behavior, and recruiting of nest mates to the most important floral sources. Additionally, this group of bees exhibits a behavioral pattern known as flower constancy, in which individuals specialize in feeding on a single floral source for a period of time, making pollination more efficient (Slaa et al. 2006). However, it is important to note that some species of stingless bees, such as *T. spinipes*, are not suitable for crop management because of their aggressive behavior.

Centris is a genus of solitary bees that was emphasized in this study. Species from this genus usually build their nests on the ground or in pre-existing cavities. The genus is considered an important pollinator of plants that produce floral oil because species from this genus use the oil for nest building, and many species provide this resource as food to their larvae (Vogel 1974). Thus, plant species from the family Malpighiaceae, among other oil producers, present a close relationship to *Centris* bees (Giannini et al. 2013b). The role of this genus as pollinators of various agricultural crops was demonstrated for the first time in this study. Similarly, *Xylocopa* and *Bombus* species (carpenter bees and bumblebees, respectively) were also cited in the study.

Two species that were widely cited in the database, *A. mellifera* and *T. spinipes*, are important species in Brazil because they play a central role in networks of interactions with plants (Kleinert and Giannini 2012). The species are considered to be similar with respect to their ecological role and resource exploitation behavior (Cortopassi-Laurino and Ramalho 1988). Specimens of *A. mellifera* were introduced in Brazil in the 1950s from Africa and underwent a rapid process of hybridization with European breeds that were already present in South America (Schneider et al. 2004). Currently, Africanized honeybees are dispersed throughout the country and are extensively managed by beekeepers. Doubts have been raised about *A. mellifera*'s true role as an effective pollinator because native species are assumed to be better adapted to the local flora (Ollerton et al. 2012). Recent global studies have also demonstrated that native insects pollinate agricultural crops more efficiently than *A. mellifera* (Garibaldi et al. 2013). Moreover, the role of *A. mellifera* as a major competitor that could deplete floral resources and harm native pollinators has also been discussed (Dupont et al. 2004; Thomson 2004; Roubik 1980; Roubik and Villanueva-Gutierrez 2009). In contrast, *T. spinipes* is a native species of stingless bee. This species also forms colonies with thousands of individuals and is not dependent on specific habitats to build its nests. *T. spinipes* is also highly generalist in terms of resource collection and occurs throughout almost all of Brazil. The importance of *T. spinipes* as an effective pollinator has been questioned, given that this species has been reported to damage flowers by piercing the corolla to rob resources (Sazima and Sazima 1989; Boiça Jr. et al. 2004). However, the data analyzed in this study suggest that these two species are effective pollinators of certain agricultural crops, providing pollination services.

This study showed that there is still a high diversity of species acting as pollinators of agricultural crops in Brazil and that these species should be a priority for conservation. The decline of *A. mellifera* in the Northern Hemisphere supports the idea that conservation efforts should aim to preserve a rich fauna of pollinators (Aebi et al. 2012) than relying on only a few species for pollination. Because pollinator species are affected by landscape-level factors, especially in agricultural landscapes (Kennedy et al. 2013), it is also crucial to protect and properly manage their habitats to ensure the continuity of pollination services. Furthermore, the development of management techniques that allow native species to pollinate agricultural crops is important for food production. *Bombus* species, for example, are used in Europe during the flowering season for crop pollination (Velthuis and Doorn 2006). In Colombia, *Bombus* was successfully raised for pollination in greenhouses (Aldana et al. 2007). In Brazil, management techniques involving *Melipona* (Nunes-Silva et al. 2013), *Tetragonisca* (Malagodi-Braga and Kleinert 2004), *Centris* (Oliveira and Schlindwein 2009; Magalhães and Freitas 2013; Alonso et al. 2012), and *Xylocopa* (Freitas and Oliveira Filho 2001, 2003; Pereira and Garófalo 2010) species have been used.

5. CONCLUSION

The rich diversity of pollinator species in Brazil and their role in agriculture are important issues that should be investigated using robust data analysis techniques, including techniques facilitated by technology. Understanding the role of bees is particularly important because this group of pollinators contributes to the pollination of many crop species. Additional research is required to understand the total diversity and individual roles of pollinator species in Brazil. A database on pollinator-plant interaction can be of high value to increase our understanding and can contribute to the development of public policies to protect species and their habitats. Such database can grow faster and be more robust if it is developed collaboratively. For example, the Global Pollination Project, under the guidance of Food and Agriculture Organization (FAO), United Nations Environment Programme (UNEP), and Global Environment Facilities (GEF), is already collecting pollinator interaction data from the literature and field surveys for agricultural crops. This support could be crucial to global initiatives such as The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) that has established a task force to develop a first global assessment on pollinators. Thus, the compilation of data on crop pollinators, as suggested here, could provide a snapshot of the current situation of data on this subject of critical importance.

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Pollinisateurs des cultures au Brésil: synthèse des intéractions observées

service écosystémique / pollinisation / agriculture / abeilles / Apoidea

Bestäuber von Kulturpflanzen in Brasilien: Ein Review über dokumentierte Interaktionen

Ökosystem Service / Bestäubung / Landwirtschaft / Bienen / Apoidea

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