Revista Ciência Agronômica, v. 56, e202392319, 2025
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Global review of zucchini (*Cucurbita pepo*) pollination: research approaches, distribution of pollinators and knowledge gaps[1]

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ABSTRACT - Crop pollination is indispensable for global food security. Studies that summarize the knowledge about pollination of specific crops are relevant because they identify the distribution of pollinators, guide pollinator management and conservation policies, and highlight knowledge gaps. Zucchini is cultivated in several countries, and its production is essentially dependent on pollinators. We aimed to integrate global data on zucchini pollination and answer the following questions: (1) What are the topics addressed and what are the trends of the results? (2) Which organisms pollinate zucchini, and how are they globally distributed? (3) What are the knowledge gaps? We performed a systematic literature review, built a network of countries and pollinators, and compared data on the efficiency of specific pollinators. Studies were conducted in 16 countries. Most studies investigated the frequency and diversity of floral visitors. Other approaches were discussed. Zucchini flowers fed 116 species of pollinators, especially bees. Six countries had almost exclusive groups of native pollinators. *Apis*, *Bombus*, and *Peponapis* were the most frequently recorded bees. Areas with high habitat diversity improve pollination. There was a significant difference in productivity when pollination was carried out by bees compared with pollination by Syrphidae. The main knowledge gaps are (1) the determination of which native, manageable pollinators are efficient for maximum zucchini production, (2) the investigation of how pollination influence fruit nutritional composition and seed quality, and (3) the identification of pollinators to the species level.

Key words: Apidae. Bees. Ecosystem Services. Food Security. Pollinators' Decline.

DOI: 10.5935/1806-6690.20250031
Editor-in-Chief: Prof. Alek Sandro Dutra - ccarev@ufc.br
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Received for publication 12/10/2023; approved on 16/02/2024
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INTRODUCTION

Vegetables and fruits are largely pollinator-dependent crops that represent the most important sources of micronutrients in human diet (Garibaldi *et al*., 2022; Porto *et al*., 2021; Smith *et al*., 2015). Due to the global decline in pollinators (Potts *et al*., 2010), there has been an evident decrease in agricultural production throughout the world over the last decades (Ellis; Myers; Ricketts, 2015; Smith *et al*., 2015), threatening global nutritional security (Chaplin Kramer *et al*., 2014; IPBES, 2016; Peixoto *et al*., 2022). Therefore, many studies on crop pollination seek to understand the influence of pollinators on the quantitative and qualitative aspects of production as well as their economic value, and to estimate the contribution of agricultural crops to the resilience of pollination services (IPBES, 2018; Klein *et al*., 2018). However, there has been limited effort to synthesize global data on the pollination of specific crops. These studies are relevant because they identify the distribution of pollinators, guide pollinator management and conservation policies, and highlight knowledge gaps.

Zucchini (*Cucurbita pepo* L., Cucurbitaceae) is an example of a vegetable crop with great economic importance, whose production is essentially dependent on pollinators (Giannini *et al*., 2015), and whose data on pollination have not yet been compiled. Like other Cucurbitaceae species, each zucchini has staminate (male) and pistillate (female) flowers (i.e., monoecy; García *et al*., 2020; Hoehn *et al*., 2008). Therefore, fruit and seed production rely on animal pollinators that transport the large and heavy pollen grains to the sticky pistil of the female flowers (Rech *et al*., 2014). The global production of zucchini together with other cucurbits is around 35 million tons, and plantations occupy approximately 2 million hectares (FAOSTAT, 2022). Although cross-pollination is mandatory for zucchini, the economic value of pollinators is still unknown (Wolowski *et al*., 2019).

Because flowers are large and produce abundant and easily accessible nectar and pollen (Nicodemo *et al*., 2009), they are visited by a great diversity of insects; however, bees are the main pollinators (Giannini *et al*., 2015). The bees of the Apini tribe are especially important, due to their high floral visitation rate (Giannini *et al*., 2015). The presence of Apini bees improves several commercially important characteristics of fruits and seeds, mainly size and weight, ensuring greater market value (Gemmill-Herren, 2016; Klein *et al*., 2007).

Considering the high dependence of zucchini production on pollinators, its economic relevance, and the absence of studies that have synthesized the data on zucchini pollination, in this review we aim to integrate global data on zucchini pollination to answer the following questions: (1) How are studies on zucchini pollination distributed in time and space? (2) What are the topics addressed in the studies, and what are the trends of the results? (3) Which organisms pollinate zucchini, and how are they distributed? (4) What are the knowledge gaps?

MATERIAL AND METHODS

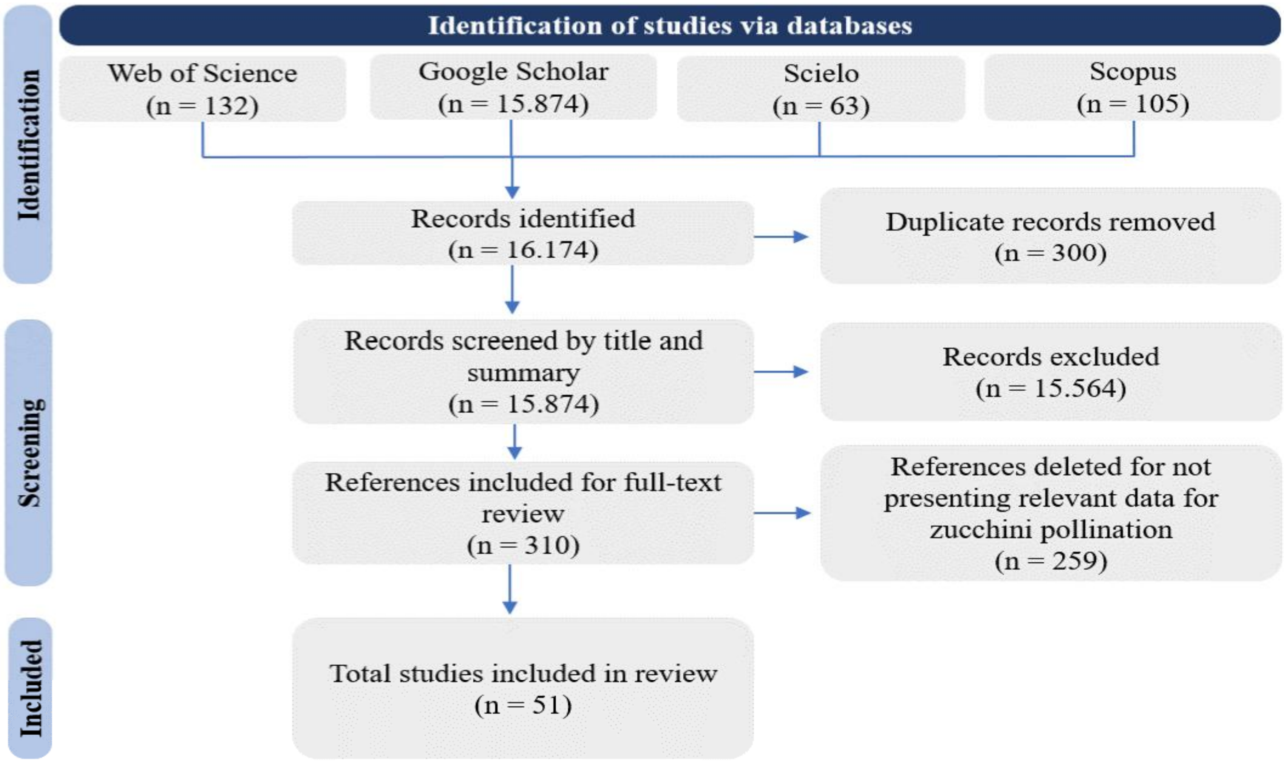
To obtain data on zucchini pollination, we conducted a systematic literature review (for articles published from 1970 to 2021) using the Web of Science (www.webofknowledge.com), Google Scholar (www.scholar.google.com), Scielo (www.scielo. org), and Scopus (www.scopus.com) repositories with the following search terms: ((“zucchini” OR “Cucurbita pepo”) AND (“pollination” OR “pollinator” OR “floral visitor” OR “floral biology” OR “breeding system”). The inclusion criteria for the articles was a clear indication that the species behaved as a pollinator, identification to the species level, and written in English. This initial search returned 16,000 studies, but only 51 met the inclusion criteria (Fig. 1).

For each study, we extracted the year of publication, the country of data collection, the main questions, the type of study area (open field or greenhouse), the pollinator species, and the main results. We verified the scientific names of the floral visitors based on Moure’s Bee Catalog (moure.cria.org.br/) and the Global Names Resolver (resolver.globalnames.org/).

We used one-way (comparing the levels of one only variable) *post hoc* pairwise chi-square analysis to check for significant differences in the frequencies of decade (≥ 2010, < 2010), regions (tropical, temperate), environments (open, closed, both), and study categories (pollinator diversity and frequency of visits, reproductive experiments, influence of landscape on pollination and tests of pollinator efficiency). We performed the *post hoc* pairwise comparisons by using the function *pairwise Nominal Independence* of the *r companion* package (Mangiafico, 2022).

To analyze the geographical distribution of the pollinators, we created a network from a weighted matrix, with countries in rows and pollinators in columns. We filled the cells with the number of studies that recorded the occurrence of a pollinator species in each country. The thickness of the edges in the net indicates the weight (the number of studies). To assess the role of the nodes in the network structure, we calculated the following centrality metrics: degree, which indicates how much a node is connected to other nodes in the network (Rodrigues, 2019); and betweenness, which describes the importance of a node as a connector between different parts of the network (Freeman, 1977). We designed the network by using the Fruchterman–Reingold algorithm (Fruchterman; Reingold, 1991) in the Igraph package of the R software (R Core Team, 2023).

Figure 1 - Flowchart of selection of pollination studies on zucchini (*Cucurbita pepo* L., Cucurbitaceae) adapted from PRISMA 2020



RESULTS AND DISCUSSION

A total of 51 studies met the inclusion criteria; they were published from 1981 to 2021. The number of studies published annually increased significantly after the 2000s (38 studies or 74.50%), with the 1980s to 2000 having the fewest studies (13 studies or 25.49%; $\chi^2 = 12.255$, degrees of freedom [df] = 1, $p < 0.01$; Fig. 2). Our review showed that 90% of the studies on zucchini pollination were carried out from the 2000s onwards, probably due to the growing concern about the global pollinator crisis that has resulted in a significant reduction in the diversity, density, and distribution of pollinators around the world, compromising human food security (Aizen *et al*., 2022; Bartomeus *et al*., 2018; Novais *et al*., 2016). Crops more dependent on pollinators tend to be more affected by the pollinator crisis (Garibaldi *et al*., 2011; Klein *et al*., 2007) due to an insufficient quantity and quality of pollen delivered to the stigmas of cultivated plants, or pollen limitation (Freitas *et al*., 2016; Vaissière; Freitas; Gemmill-Herren, 2011). For this reason, studies are being carried out with the aim of mitigating this crisis (IPBES, 2016; Shivanna; Tandon; Kou, 2020).

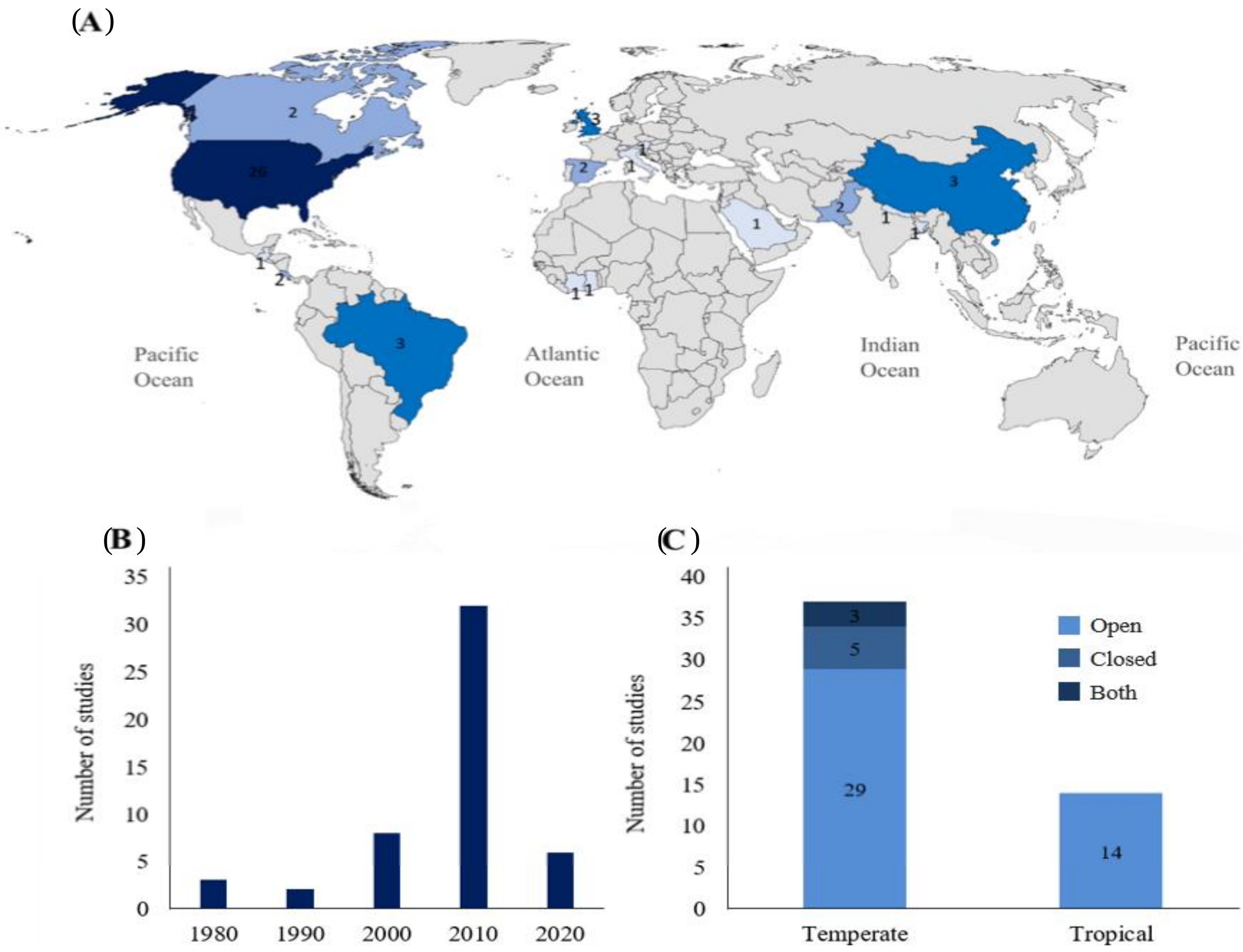
Data were collected in 16 countries (Austria, Bangladesh, Brazil, Canada, China, Costa Rica, Côte d'Ivoire, Ghana, Guatemala, Italy, Nepal, Pakistan, Saudi Arabia, Spain, the United Kingdom, and the United States), with the largest number in the United States (26 studies or 50.98%; Fig. 2). There is strong evidence of pollinator declines in the United States since 1947, with a loss of 59% of bee colonies (Stokstad, 2007), and in Europe since 1985 with a loss of about 25% (Potts *et al*., 2010). This fact may explain the predominance of studies originating from North America, especially in the United States, and in Europe. The high number of studies observed in the United States is not explained by its zucchini production, because it has the fifth highest gross production in the world (FAOSTAT, 2022). It is important to note that zucchini is native to North America, where there is strong evidence that it was domesticated at least twice, in Mexico more than 10,000 years ago and in the United States more than 4,000 years ago, and later domesticated in various locations on the North American continent (Paris, 2016).

The predominance of studies from the United States clearly influenced the higher proportion of studies in temperate regions compared with tropical ones. It is important to note that the climate of temperate regions allows the maximum production of the harvest, and produces higher quality fruits (Salehi *et al*., 2019).

The proportion of studies was significantly higher in temperate regions (37 studies or 72.54%), conducted especially on open plantations, followed by closed environments and both situations. The studies from tropical regions (14 studies or 27.45%; $\chi^2 = 10.373$, df = 1, $p < 0.01$; Fig. 2) were all conducted on open plantations ($\chi^2 = 59.765$, df = 2, $p < 0.01$). The predominance of studies conducted on open plantations may be explained by the fact that this system allows for up to a 70% increase in zucchini yield due to free access of a higher diversity and frequency of pollinators to flowers (Waters; Taylor, 2006) compared with indoor cultivation, which tends to have insufficient pollination, causing a loss in productivity (Cruz; Campos, 2009; Formisano *et al*., 2020). Pollination of crops in open fields is strongly favored by the landscape, which provides a variety of floral resources (pollen, nectar, and oil sources) and nesting sites for pollinators (Fijen *et al*., 2019; Garibaldi *et al*., 2013, 2016; Parra-Tabla; Campos-Navarrete; Arceo-Gómez, 2017). It is important to note that agricultural cultivation carried out indoors is gaining prominence worldwide, allowing the production of high-quality fruits throughout the year, in addition to reducing pest attacks and, consequently, reducing the use of pesticides (Campeche *et al*., 2017; Shamshiri *et al*., 2018).

Regarding the main approaches of the studies, most of them evaluated the frequency and diversity of pollinators (41 studies or 80.39%), the reproductive requirements by comparing production between natural and hand pollinations (11 studies or 21.56%), the influence of the landscape on pollination on open plantations (8 studies or 15.68%), and the influence of a specific pollinator on production (4 studies or 7.84%; $\chi^2 = 53.625$, df = 3, $p < 0.01$). The main results are presented below.

Figure 2 - Distribution of pollination studies in zucchini (*Cucurbita pepo* L., Cucurbitaceae) and its influence on production. (A) Study sites sampled worldwide. (B) Number of studies conducted over the decades. (C) Number of studies in tropical and temperate areas carried out in different environments. Open: plantations in the field; Closed: greenhouses; Both: both situations



Most studies that investigated the frequency and diversity of floral visitors associated the visitation rate with various aspects of foraging behavior, such as the visit time, pollen collection versus nectar or nectar theft (31 studies or 75.60%), and the abundance and density of pollen grains on the stigma after different numbers of visits (1, 2, 4, 8, and 12; 19 studies or 46.34%). A total of 38 studies (74.50%) recorded *Apis* species and, among them, 34 recorded *Apis mellifera*, three recorded *A. cerana*, and two *A. dorsata*. A smaller number of studies addressed other bee species, including *Bombus* spp. (24 studies or 47.05%), with *Bombus impatiens* being the most recorded (11 studies), followed by *Bombus terrestris* (four studies). Species of *Peponapis* species (22 studies or 43.13%) included *P. pruinosa* (17 studies), *P. apiculata*, *P. fervens* and *P. utahensis* (two studies each); and *P. limitaris* (one study).

Several studies evaluated the reproductive requirements (11 studies or 21.56%). Among them, nine focused on natural pollination and observed that bee pollination improved production in terms of the quantity (number) and quality (weight, length, and diameter) of fruits and seeds. Two studies that compared fruit set between manual cross-pollination and natural pollination did not find differences.

The studies that evaluated the influence of landscape on zucchini pollination and production tested for different distances from areas with a high diversity of habitats (i.e., natural and seminatural vegetation cover). Most of them (7 studies or 63.63%) observed that plantations located 300–2000 m from those areas had a higher frequency of visits by *B. impatiens*, *A. mellifera*, and *Peponapis* spp., but they did not test for the impact of this increased frequency on production. One study investigated the effects of the use of chemicals (insecticides and fungicides) on pollen and bees in areas 2 km away from the plantations, and observed high concentrations of chemicals in pollen grains. The authors also noted that insecticides were approximately 100 times more dangerous for bees than fungicides, exponentially decreasing the visitation of native bees.

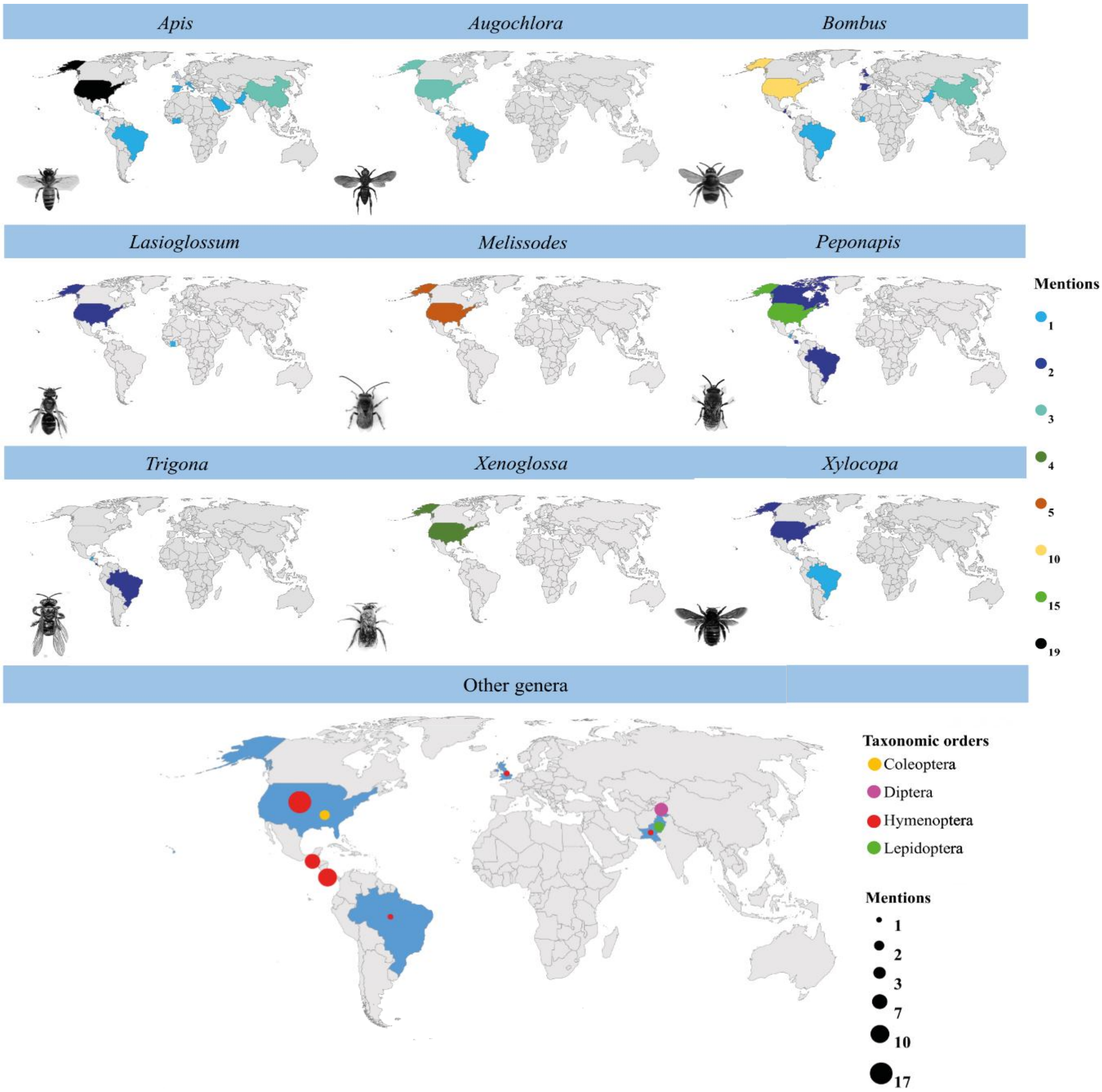
The four studies that investigated the efficiency of specific pollinators on production included Apidae (bees), Halictidae (bees), and/or Syrphidae (flies). Three studies investigated *Apis* spp. in an open environment. One of them compared *A. dorsata* (which is considered the best pollinator of zucchini in Pakistan, with 23.33% of fruit set) with *Eristalinus laetus* (6.66%), *EristalinusE. aeneus* (6.66%), *Lasioglossum* sp1 (10%), *Lasioglossum* sp2 (13.33%), *Halictus* sp. (20%), and *Nomia* sp. (36.66%). The last one was considered the best pollinator, followed by *Halictus* sp., while the other pollinator species were not statistically significant. The second study compared *A. mellifera* with *B. impatiens* and *P. pruinosa* and observed that *B. impatiens* deposited three times more pollen grains onto stigmas in a single visit compared with the other two species, reaching 64.7%, while *A mellifera* reached around 18% and *P. pruinosa* 10%. The third study compared *A. mellifera* with *P. pruinosa* and found that although the fruit set after pollination by *A. mellifera* was higher than other species, most flowers required more than one visit to reach 30%–50% of fruit set. Although *P. pruinosa* is a cucurbit bee, a single visit is rarely sufficient to produce fruit, especially when there is another competing pollinator in the growing area.

Considering all the studies that tested the efficiency of a specific pollinator, there was a significant difference in productivity when pollination was carried out by bees compared with production by Syrphidae ($\chi^2 = 35.095$, df = 9, $p < 0.01$). Among the most efficient species, *P. pruinosa* (52.63%) and *B. impatiens* (41.46%) stand out. *Bombus impatiens* was more efficient than *E. aeneus* ($p = 0.0221$) and *Eristalinus megacephalus* ($p = 0.0221$) for fruit set. Similarly, the efficiency of *P. pruinosa* was significantly higher than *E. aeneus* ($p = 0.0104$), *E. megacephalus* ($p = 0.0104$), and *Lasioglossum* sp1 ($p = 0.0432$). No study compared the influence of pollination on chemical aspects of fruits and in seed germination. A total of 116 pollinator species were recorded (Appendix 1), distributed in four orders (Coleoptera, Diptera, Hymenoptera, and Lepidoptera; Fig. 3), eight families, and 37 genera (Fig. 3).

Most species are included in the Hymenoptera genera (106 or 91.37%), exclusively bees, and distributed in North, Central, and South America; Europe; Africa; and Asia (Fig. 3). Diptera species have been recorded in Asia and Europe, Coleoptera only in North America, and Lepidoptera only in Asia. The most representative families were Apidae (bees, 64 species or 55.17%), followed by Halictidae (bees, 39 species or 33.62%). The genus *Apis* had the widest geographical distribution of records from studies in North America, Europe, and Asia. *Bombus* records were also broadly distributed, mainly in North America and Europe, and less frequently in South America. *Peponapis* was recorded mainly in North America. Other less frequent genera were widely distributed in North and Central America (Fig. 3).

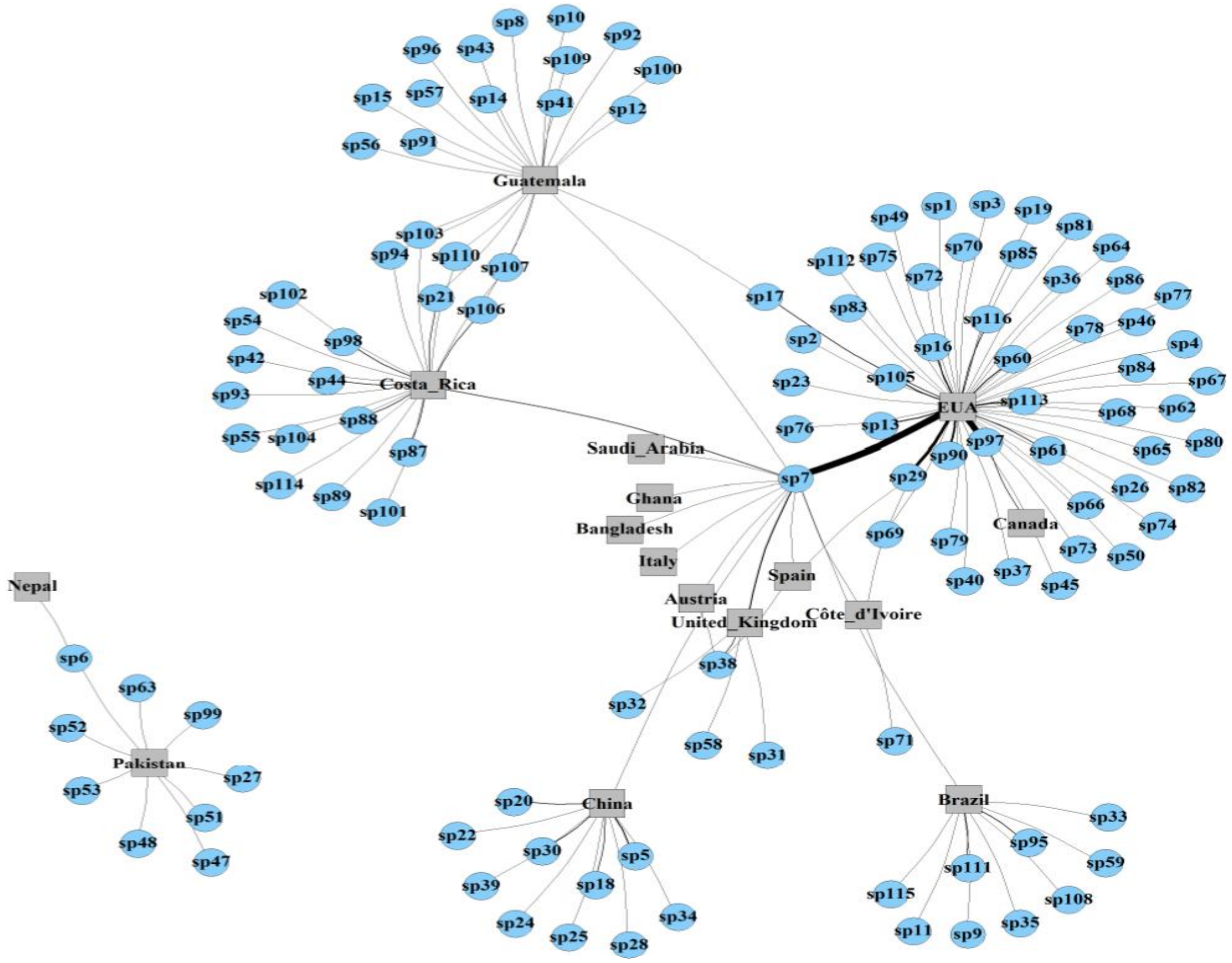
Among the countries that presented the largest number of connections in the network (Fig. 4) are the United States (betweenness = 0.825), with 8% of its species recorded in 14 other countries, and the United Kingdom (betweenness = 0.174), with 40% of the species also observed in 12 countries. *Apis mellifera* presented the widest geographic distribution of records—it was registered in 13 countries—and, consequently, obtained the highest connection value (betweenness = 0.822), followed by the bees *Augochloropsis metallica* (0.122, two countries) and *B. impatiens* (0.012, three countries).

Figure 3 - Distribution of the global literature on zucchinni (*Cucurbita pepo* L., Cucurbitaceae) floral visitors divided into taxonomic groups for the nine main genera and the four main orders. The number of studies performed with each genus is indicated by the fill color in the countries. The "other genera" consist of 28 genera, with the taxonomic orders indicated by fill color, consistent in the panel. The point size represents the frequency of mentioned studies



The network (Fig. 4) revealed that the United States had the highest number of pollinator species (50 species or 43.10%, degree = 50), with most of them (46) being exclusive. The four species shared with other countries are *A. mellifera*, *P. pruinosa*, *B. impatiens*, and *A. metallica*; the first three were the most recorded in 19, 15, and 9 studies, respectively. In Guatemala, 22 species (degree = 22) were observed in only one study, and, in Costa Rica, there were 20 species (degree = 20), seven of which were recorded in two studies, and six shared with Guatemala. China (11 species; degree = 11) and Brazil (10 species, degree = 10) presented nine exclusive species each, sharing only *A. mellifera* with other countries. Pakistan recorded nine unique species (degree = 9).

Figure 4 - Interaction network between pollinators of zucchini (*Cucurbita pepo* L., Cucurbitaceae) and geographical distribution of studies. Circles represent pollinators and squares countries. The thickness of the line is proportional to the number of studies carried out with pollinators in each country



Five species were identified in the United Kingdom (degree = 5), with three exclusive species, and *A. mellifera* (three studies) and *B. terrestris* (two studies) being the most recorded. Côte d'Ivoire (one exclusive species) and Spain recorded three species (degree = 3), with similar records for *A. mellifera* and *B. impatiens* (one study each). In Austria, two species (*A. mellifera* and *B. terrestris*; degree = 2) were observed in only one study. The other countries recorded only one species (degree = 1): *A. mellifera* in Bangladesh, Ghana, Italy, and Saudi Arabia; *P. pruinosa* in Canada; and *A. dorsata* in Nepal.

The fact that the global distribution of zucchini pollination studies is heavily concentrated on *Apis* and *Bombus* species in North America is explained by the fact that those bees constitute the main group of managed pollinators for this continent (Ghazoul, 2015; Goulson, 2003; Klein *et al*., 2007; Millard; Freeman; Newbold, 2020). *Apis* and *Bombus* are known to guarantee the production of a large quantity of high-quality zucchini fruit and seeds (Krug; Alves-dos-Santos; Cane, 2010; Nicodemo *et al*., 2009; Roubik, 2018; Vidal *et al*., 2010). It is interesting to note that the increase in studies with *Apis* spp. occurred after infestations by the parasite *Varroa destructor* in the United States in the 1980s (IPBES, 2016; Oldroyd, 1999). The rapid increase in studies with the genus *Bombus* occurred in the late 1980s with the first commercialization of species for pollination of crops (Velthuis; van Doorn, 2006). From that period on, other genera of pollinators were studied frequently (Millard; Freeman; Newbold, 2020).

The most frequent bee species in the studies (*A. mellifera*, *B. impatiens*, and *P. pruinosa*) were recorded in tropical and temperate regions (Koné *et al*., 2019; Malerbo-Souza *et al*., 2019; Phillips; Gardiner, 2015). The high frequency of *A. mellifera* is closely related to the fact that it is a generalist species that is widely managed for bee products and crop pollination and has considerable economic value (Delaplane; Mayer, 2000; Kevan, 1997; Wolowski *et al*., 2019). It is considered an efficient pollinator for zucchini flowers, from which it collects nectar and pollen and increases fruit production, reaching almost 100% after 12 visits (Artz; Hsu; Nault, 2011; Petersen; Reiners; Nault, 2013; Vidal *et al*., 2010). However, the presence of this species causes several negative impacts on the ecosystem, interfering with the relationships between plants and native pollinators, causing a reduction in their diversity, making the vast plant–pollinator interactions impossible and, consequently, causing the failure of the reproductive system of the plants that depend on these animals (Valido; Rodríguez-Rodríguez; Jordano, 2019).

Although global agricultural production depends on pollination by *Apis*, it is highly recommended that countries seek pollinators that can replace it even partially, giving preference to native, manageable, and efficient species (IPBES, 2016). The network revealed that several countries have exclusive native pollinators that could met those criteria, such as *Agapostemon*, *Euglossa*, *Eulaema*, *Exomalopsis*, *Caenaugochlora*, *Halictus*, *Megalopta*, *Melipona*, *Nannotrigona*, *Tetragona*, and *Thygater*. Some genera have already been managed in agriculture, such as *Melipona* (Mascena *et al*., 2018), *Nannotrigona* (Silva; Gimenes, 2014), and *Tetragona* (Oliveira-Junior *et al*., 2022). The large number of pollinator species recorded in several countries reinforces the importance of maintaining the diversity of these animals for the maintenance of agricultural production. Thus, in addition to seeking native and manageable pollinators through pollinator efficiency studies, it is essential to conserve environments with a high diversity of habitats, which are known to maintain pollinator populations throughout the world.

Despite having a lower frequency, *B. impatiens* is considered to be a highly efficient pollinator in zucchini (Artz; Hsu; Nault, 2011; Artz; Nault, 2011; Petersen; Huseth; Nault, 2014). The efficiency of this species is directly related to its body size (ranging from 1 to 4 cm in length) and the dense coat that carries a large amount of pollen during a visit (Goulson, 2010; Herrmann; Haddad; Levey, 2018), ensuring similar fruit set in the context of open pollination when flowers are visited four to eight times (Artz; Nault, 2011).

The bee *P. pruinosa* is a specialist pollinator of Cucurbitaceae crops, mainly squash (Artz; Hsu; Nault, 2011; Skidmore *et al*., 2019). It is one of the most abundant native bees for *Cucurbita* crops in the United States (Sampson *et al*., 2007; Shuler; Roulston; Farris, 2005): It was mentioned in 93% of the studies carried out in the region. Although is considered an efficient pollinator, capable of sustaining most of the zucchini production when the flowers are visited seven times (Cane; Sampson; Miller, 2011), pollination by this species may be less efficient compared with other species because the frequency of visits to pistillate flowers is much lower, consequently reducing fruit weight and seed formation (Artz; Nault, 2011; Petersen; Huseth; Nault, 2014).

The fact that the highest proportion of studies investigated the frequency and diversity of floral visitors is justified by the importance of this topic as a basis for understanding how much the crop depends on pollinators, how many visits are necessary for desirable production, as well as to guide pollinator management. The assessment of pollination deficits in production through natural and cross-pollination experiments has not been well addressed in studies involving zucchini. Nevertheless, there has been increased attention on this approach in the literature because it provides an estimate of pollination needs for pollinator-dependent crops (Petersen; Huseth; Nault; 2014). In addition, such studies contribute to the identification of other factors that can influence production in addition to the lack of pollen (Vidal *et al*., 2010), promoting an increase in agricultural resilience and bringing economic returns (Knapp; Osborne, 2017).

There have been very studies testing the efficiency of different species of pollinators in zucchini production, even though researchers have accepted that this knowledge helps to identify alternative pollinators (Artz; Nault, 2011) and to determine the ideal number of visits for maximum crop yield (Sihag, 2018). Despite the importance of native bees for zucchini productivity (Enríquez *et al*., 2015), only a few studies have documented the performance of these pollinators. Thus, new studies are needed to conserve and develop management strategies for native pollinators (Ali *et al*., 2014; Malerbo-Souza *et al*., 2019). Moreover, there have been few studies that evaluate the landscape around zucchini plantations, but this topic has received increased research attention for agricultural crops, because it directly influences production, as mentioned above. In addition, it has been proven that the amount and proximity of native vegetation, for example, are determining factors to increase bee populations and the effectiveness of pollination services of zucchini crops (Petersen; Nault, 2014).

Although zucchini fruit has antioxidants that benefit human health (Boschi, 2015), it is worth noting that none of the included studies evaluated the influence of pollinators on the chemical characteristics of zucchini fruit. Pollinators may alter the chemical composition of fruits (Baronio *et al*., 2021; Cruz; Campos, 2009; Klatt *et al*., 2014; Vergara; Fonseca-Buendía, 2012). Moreover, none of the studies investigated the influence of pollinators in seed germination. This is especially important for crops that are cultivated through seeds, such as zucchini. Pollinators maximize seed production in more than 40 crops throughout the world (Garibaldi *et al*., 2013)—and in at least 10 Brazilian crops (Giannini *et al*., 2015)—and may also positively influence seed germination (Kevan; Eisikowitch, 1990).

CONCLUSIONS

We reviewed studies related to the influence of pollinators on zucchini crops, how they are distributed, which organisms pollinate zucchini, and what are the main knowledge gaps. These data will help in the development and improvement of strategies for the management and conservation of pollinators. Most studies were conducted from the 2000s onwards, mainly in temperate regions and in open environments. The study approaches include evaluation of the frequency and diversity of pollinators in zucchini production, comparison of natural and manual pollination on production, evaluation of the influence of the landscape on pollination on open plantations, and evaluation of the influence of a specific pollinator in production. Bees behaved as the main pollinators, followed by other insects such as flies, beetles, and butterflies. The predominance of studies with *Apis*, *Bombus*, and *Peponapis* is probably related to their economic importance. Studies that evaluate reproductive requirements in different regions by using controlled crosses are needed to help maximize yield. In addition, studies that assess the efficiency of different pollinator species in production would help to elaborate management and conservation practices. There is still a need to assess the influence of pollinators on the chemical aspects of the zucchini fruit and in seed germination. Zucchini flowers are fed on by 116 species of pollinators, especially bees, followed by flies, beetles, and butterflies. Six countries had almost exclusive groups of pollinators. *Apis* species was recorded in all countries and, together with *Bombus* and *Peponapis*, formed the most frequently recorded bees. Studies that investigated the influence of the landscape on pollination found that areas with high habitat diversity improve pollination. Considering all the studies that tested the efficiency of a specific pollinator, there was a significant difference in productivity when pollination was carried out by bees compared with production by Syrphidae. The main knowledge gaps we found are: (1) the determination of which native, manageable pollinators are efficient for maximum zucchini production, (2) the investigation of how pollination influence fruit nutritional composition and seed quality, and (3) the identification of pollinators to the species level.

ACKNOWLEDGMENTS

We thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior for (Financing Code 001) and Fundação de Amparo à Ciência e Tecnologia de Pernambuco and Conselho Nacional de Desenvolvimento Científico e Tecnológico (research grant: 428303/2018-8, fellowship: 312372/2021-3) for financial support, and the Programa de Pós-Graduação em Biodiversidade of the Universidade Federal Rural de Pernambuco and the Universidade Federal do Agreste de Pernambuco for institutional support.

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