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Cosmos sulphureus: environmental bioindicator of diversity of bees

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ABSTRACT. Among the flowers most visited by bees in Brazil, those belonging to the Asteraceae family stand out, and one of them is the cosmos (*Cosmos sulphureus*). This study aimed to evaluate the frequency, profile of visits and the type of collection of bees in the flowers of the cosmos during the year. The relationship between bees and cosmos flowers was observed by counting the frequency of visits and of material (nectar and / or pollen) to be collected. The foraging behavior of different bee species was also evaluated. The visits of the most frequent bees took place between 7:00 am and 12:00 pm. Among the main species of bees that made visits to the cosmos, those of the Halictidade family were noticeable: *Pseudaugochloropsis graminea* and *Augochlora* sp., *Megachile rotundata* solitary bees and, to a lesser extent, *Plebeia remota* stingless bees, *Trigona spinipes* stingless bees and *Xylocopa frontalis* and *X. griscenses* carpenter bees. Sporadic visits by stingless bees *Melipona scutellaris, M. subnida*, *Partamona helleri*, *Scaptotrigona* sp., *Nannotrigona testaceicornes* and africanized honeybees *Apis mellifera.* The cosmos should be planted close to apiaries and meliponaries as a source of food for Africanized honey bees, stingless bees and solitary bees.

Keywords: cosmos; insects; forage behavior; pollination.

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Introduction

Is estimated that there are more than 20 thousand species of bees in the world and more than 3,000 of them in Brazil (Barbosa et al., 2017). About 85% of the bee species described are solitary with many of these species belonging to the Apidae family. Representatives of this family can fly long distances in tropical forests in search of preferred plant species promoting cross-pollination. On the other hand, there are about 250,000 species of angiosperms and a large portion of them depend on insects for the pollination of their flowers and for their reproduction (Taura & Laroca, 2004).

Bees can be specialists in certain flowers or botanical families collecting them with maximum efficiency and operate as specialized pollinators, or generalists, that is, they visit many botanical species and pollinate them with less efficiency than specialists, but they do not depend exclusively on them for their survival. Thus, the relationship of bees with certain groups of plants may indicate not only the importance of plants in the diet and maintenance of the populations of such visitors but also show the importance of visitors in the process of pollination of plants. In this way, the fate of many native plants depends on the preservation of their mutualistic relations with the pollinators and vice versa (Kearns & Inouye, 1997).

Pollinators provide ecosystem services vital to wild plant cultures and communities (Klein et al., 2007). The primary pollinators of most plants are mainly bees. Land use change with the loss of floral and nesting resources are generally considered to be the most important contributors to various disturbances in the abundance and richness of species in wild bees (Potts et al., 2010).

To meet their food needs, bees visit the flowers of a wide variety of plants in order to collect pollen and nectar. Pollen, in addition to being the main source of proteins, is also the main source of lipids, minerals and vitamins, while nectar is responsible for providing carbohydrates and energy (Roberto et al., 2015). In other words, in this process three actors gain: the bees through food from flowers; the plants for continuing

reproduction; and the farmer as well, because through the pollination of the cultivars fruits larger, heavier, and better quality, and consequently, of greater value are produced (Villas-Bôas, 2012).

There is great importance of bees in different areas, whether environmental, economic or social. However, there is an accelerated increase in environmental destruction, putting several species at risk of extinction in Brazil and around the world (Silveira et al., 2002). Agricultural advances, deforestation, urban development and other human actions are highlighted as threats to biodiversity. Consequently, bee populations are reduced, as they cannot find the necessary resources for food and nesting (Barbosa et al., 2017).

Therefore, the maintenance of bees is of such importance for the conservation of the different habitats. It is noteworthy that the loss of just one species of pollinating bee can result in the reduction or even extinction of some plant species. Without pollination, it would not be possible for plants to reproduce and guarantee both the growth and survival of native vegetation. Consequently, they would not produce seeds and fruits, and ultimately, they would affect food production and the food security of populations (Villas-Bôas, 2012).

To enable environmental monitoring, which is the continuous and functional reassessment of the system, with regard to available resources, species diversity and biological variability, is necessary to study indicator groups. As bees are the main pollinators in most angiosperms, participating in the maintenance of floristic diversity, this taxonomic group shows potential to be used as an environmental indicator (Oliveira et al., 2014). Solitary wasps and bees are important because of the interactions they have with other groups of organisms (parasitism, predation, pollination, dispersion) and also because the spatial and temporal variations in their abundance and wealth have demonstrated important correlations with changes in the structure of the environment and with the diversity of other organisms (Barbieri Junior & Dias, 2012).

Bees play an even more important role in ecosystems. Due to the dependence on floral resources, bees have many adaptations to the location and collection of these resources, and when visiting flowers, they end up involuntarily promoting pollination. As a key ecological service for the maintenance and conservation of ecosystems, they can act as bioindicators of environmental quality. It is believed that bees and angiosperms coevolved mutually over evolutionary time, in a process that benefited both groups involved. Foraging is carried out by many individuals from the same colony, usually on similar plants (Dafni, 1992).

In several regions of the world, the cosmos (*Cosmos sulphureus* Cav. Synonymy: *Bidens sulphurea* Sch. Bip.) belonging to the genus *Bidens*, family Asteraceae, stands out for its easiness of dispersion and adaptation. It has already been found that this plant has an allelopathic inhibitory effect on other weeds, being the subject of several recent studies to assess its importance for species control in rural environments The cosmos is an annual herbaceous plant, originating in North America, also known as Yellow Cosmos, Big Bite and Mexico Aster, and was introduced in Brazil as an ornamental plant. It is characterized by being very branched and floriferous, reaching up to two meters in height. propagating only by seeds. Cosmos flowers can take on a yellow, orange and purplish color, with capitulum-type inflorescences (small flowers arranged in a spiral on the base / receptacle). They have structures like the petals, but they are structures that make up the ligated corolla which attracts pollinators in general, especially bees (Araujo et al., 2021).

However, *C. sulphureus* is considered a weed, due to its ability to occur spontaneously, its high potential for invasion, vigor of dissemination and growth, which provided the infestation of vacant lots, roadsides, gardens and pastures. Thus, the presence of *C. sulphureus* is very common in urban areas and also in agricultural areas (Lorenzi, 2015). Malerbo-Souza et al. (2022) studied the cosmos among the flowers of the yellow passion fruit, to successfully attract the africanized honeybees *Apis mellifera*. In this case, *A. mellifera* competes with pollinating solitary bees *Xylocopa* spp (bumblebees) for pollen, damaging the pollination of this crop.

Given the above, the objective of this study was to evaluate the frequency, constancy, profile of visits and the type of collection of the different species of bees in *C. sulphureus* flowers.

Material and methods

This experiment was conducted in the Beekeeping and Meliponiculture Sector, of the Department of Animal Science, of the University Federal Rural of Pernambuco (UFRPE), Dois Irmãos campus, located in Recife, PE, Brazil. It has an altitude of 4 m with the following geographic coordinates: 8º04'03'' S and 34º55'00'' W, with a humid tropical climate (type As' in the Köppen-Geiger climate classification), typical of the northeastern east coast. The annual average maximum temperature was 31°C, and the minimum average was 23°C.

For two years (2019 and 2020), an area containing several cosmos plants (*C. sulphureus*) (Figure 1) was monitored in relation to insect species, mainly bees, that visited these flowers. The frequency of visits and

the type (nectar and/or pollen) of bee collection from cosmos flowers were evaluated throughout the day in different months of 2019 and 2020. This data was obtained by counting in the first 10 minutes at each time, between 6:00 am and 5:00 pm with three repetitions, during three different days, in each month observed. The count was carried out with manual counters going around the plant and noting the bees present in the flowers and what they collected (nectar or pollen).

Figure 1. Area with cosmos plants (*C. sulphureus*), in Recife, PE, Brazil.

The pollen grains were collected from fully opened flowers, and subsequently, they were photographed under a Zeiss microscope with a camera attached, at the Meliponiculture Sector at UFRPE.

The foraging behavior of each bee species was evaluated through visual observations, during the day in the experimental period.

The constancy (C) of these insects was obtained using the formula: C = (P x 100) / N, where P is the number of collections containing the species studied and N is the total number of collections made (Silveira Neto et al., 1976).

The design used was the Entirely Randomized Design (DIC), and the statistical analyzes were processed using the BioStat software using the Tukey test to compare treatment averages, at the level of 5% significance, and polynomial regression analyzes in the time to assess the frequency of insects throughout the day.

Results and discussion

The cosmos flourished all year round, that is, in all months of the year 2019 and 2020, both in the dry and rainy seasons, showing vigorous flowering. Figures 2 and 3 show the phases of the cosmos flowers and the appearance of the pollen grain of this species, which has an equine ornamentation, with radial, isopolar symmetry, subtrianguarous scope, colporo opening, short colon, elongated pore, tricolporate opening, with prolate-spheroid shape, and also has a medium size (Rcpol, 2021).

Figure 2. Phases of the formation of capitulum containing cosmos flowers (*C. sulphureus*) from bud to seed formation, in Recife, PE, Brazil, in 2019.

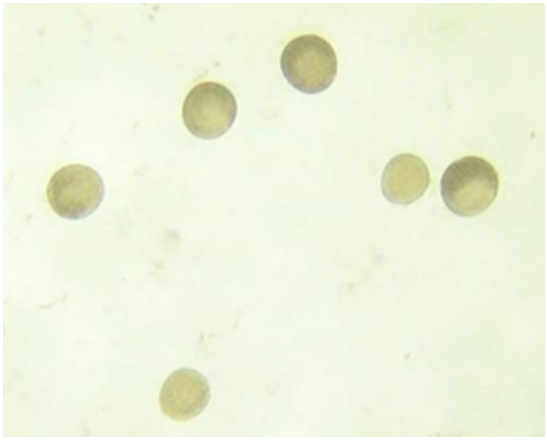

Figure 3. Cosmos pollen grain (*C. sulphureus*), in Recife, PE, Brazil, in 2019.

The release of pollen in the flowers occurred from the periphery to the central part of the capitulum. The dehiscence of the anther started at the loose button stage. The pollen was supplied exclusively by flowers of the capitulum whose anthers were fused in a tube. After dehiscence of the anther, the released mature pollen grains were accumulated inside this tube (Figure 4), in agreement with Wróblewska et al. (2016).

Figure 4. Phases of pollen release from flowers in cosmos capitulum (*C. sulphureus*), in Recife, PE, Brazil, in 2019.

Like some species of the genus Bidens, *C. sulphureus* has a high capacity to form dense and dominant populations. It is probable that the high aggressiveness inherent to *C. sulphureus*, which allows the invasion of the species in the most diverse areas is provided by its allelopathic potential as one of the strategies in the establishment of these populations. In some cases, the aggressiveness of a weed is due to its high biomass production which is not the case for the species *C. sulphureus*. So far, most studies carried out with the species have aimed to determine potential medicinal effects of the plant (Araujo et al., 2021).

Due to its extraordinary power of environmental adaptation, the Asteraceae family can be found in the most diverse habitats and in varied climatic conditions, from tropical, subtropical and temperate regions. It has great capacity of dispersion due to the presence of seeds with feathery papules, appendages, adhesion structures and secondary metabolites (Cancelli et al., 2007).

In the years of 2019 and 2020, several species of insects were observed collecting nectar and pollen, the majority of which were bees in the cosmos flowers, however, there was a lot of variation in species throughout the experiment. Among them, two species of bees from the Halictidade Family were seen: *Pseudaugochloropsis graminea* and *Augochlora* sp.; solitary bees *Megachile rotundata* and, in smaller numbers, stingless bees *Plebeia remota*. *Trigona spinipes* (irapuá) and solitary bees *Xylocopa frontalis* and *X. griscenses* (bumblebees), in addition to the Africanized honeybees *A. mellifera*, *Melipona scutellaris* (uruçu nordestina), *M. fasciculata* (tiúba or gray uruçu) collecting both nectar and/or pollen. The bee *Ceratina* sp. was also observed in flowers, however, in reduced numbers. Bees of the genus *Scaptotrigona* sp., *Nannotrigona testceicornis* (iraí) and *Partamona helleri* (frog mouth) were observed collecting pollen as well (Table 1).

Despite being close to the Institution's meliponary with several colonies of stingless bees *Frisiomellita doerdeleini* (White girl) were not observed in the cosmos flowers.

No dominance of any species over the other species was observed, but some species visited the cosmos flowers for a few days and were then no longer observed, returning to visit at other times. No species constantly visited the flowers of the cosmos during the year and in some observations few bees were recorded.

Some species of Lepidoptera, Diptera and vespids also used cosmos flowers as a food resource, however, these species used nectar for their food.

The bees visited the cosmos flowers from 7:00 am to 5:00 pm, however, they were more frequent between 7:00 am and 12:00 pm, to collect pollen, decreasing or ceasing their visitation afterwards, depending on the bee species (Figure 5). *P. helleri*, *Scaptotrigona* and *P. remota* stingless bees preferred to collect pollen in the afternoon.

Table 1. Bees visiting cosmos flowers (*Cosmos sulphureus*) in Recife, PE, Brazil, in 2019 and 2020.

Family	Bee	Common name	Resource collected
Halictidae	*Pseudaugochloropsis graminea*	Halictídeo	Pollen
Halictidae	*Augochlora* sp.	Halictídeo	Pollen
Megachilidae	*Megachile rotundata*	Abelha cortadeira	Pollen
Apidae	*Plebeia remota*	Mirim ou mosquito	Pollen
Apidae	*Trigona spinipes*	Irapuá	Pollen
Apidae	*Xylocopa frontalis*	Mamangava	Nectar
Apidae	*X. griscenses*	Mamangava	Nectar
Apidae	*Apis mellifera*	Abelha africanizada	Nectar e pollen
Apidae	*Melipona scutellaris*	Uruçu nordestina	Nectar e pollen
Apidae	*M. fasciculata*	Uruçu cinzenta ou tiúba	Nectar e pollen
Apidae	*Scaptotrigona sp.*	Canudo	Pollen
Apidae	*Partamona helleri*	Boca de sapo	Pollen
Apidae	*Nannotrigona testaceicornis*	Iraí	Pollen

P. graminea followed the same frequency pattern, bees increased the frequency of visits until 8:00 am then decreased ($Y = 0.0839x^2 - 2.2979x + 14.0180$, $R^2 = 0.6293$), where Y is the number visits and X is the time of day. According to Silveira et al. (2002), the Halictidae family is one of the most diversified in Brazil. Bees of this family have green, blue, reddish or even black metallic luster. They have different levels of sociability ranging from the lonely to the sub-social. The Augochlorini tribe is well represented in tropical rainforest areas. Examples of Halictidae species that are quite common and well distributed in Brazil are Pseudaugochloropsis graminea (Figure 5) and Augochlora spp. (Figure 6).

Figure 5. *Pseudachloropsis graminea* solitary bee collecting pollen using abdominal blades, on cosmos flowers (*C. sulphureus*) in Recife, PE, Brazil, in 2019 and 2020.

Figure 6. Solitary bee *Augochlora* sp. collecting pollen, in cosmos flowers (*C. sulphureus*) in Recife, PE, Brazil in 2019 and 2020.

It was observed that the solitary bee *M. rotundata* (Figure 7) increased the number of visits until 8:00 am then decreased (Y = 0.0571x2 - 0.0692x + 6.7697, R2 = 0.8368). Called a leaf-cutting bee, *M. rotundata* is a European bee that was introduced in several regions of the world. Because it is a solitary bee species, it does not build colonies or store honey, but is a very efficient pollinator of alfalfa, carrots, other vegetables and some fruits. Because of this, farmers often use *M. rotundata* as a pollination aid, distributing them around their crops. Each female will build her own nest, in old trees or in tunnels in wooden logs. Being a leaf-cutting bee, these nests are lined with cut leaves. Bees of the Megachilidae family use pre-existing cavities with high frequency. The easiness to obtain the nest in traps allowed to extend the knowledge of the biology of several species of Megachilidae and the mastery of the technique of creation and production in large scale (Richards, 1993).

Figure 7. Solitary bee *Megachile rotundata* collecting pollen in *C. sulphureus*) Flowers in Recife, PE, Brazil in 2019 and 2020.

The *Plebeia remota* (mosquito or mirim-guaçu) stingless bee (Figure 8) visited the cosmos flowers to collect pollen. This bee belongs to the group of meliponines that can be used commercially. Its honey has medicinal properties according to popular culture. Is a small, shy and non-aggressive bee. This bee produces propolis of a very gooey consistency, accumulated in mounds, and used emergencies, when threatened, to immobilize and jam the invaders. Can be used to pollinate cucumbers inside greenhouses (A. Evangelista-Rodrigues, personal communication, May 10, 2024)

Figure 8. Stingless bee *Plebeia remota* collecting pollen in *C. sulphureus* flowers, in Recife, PE, Brazil in 2019 and 2020.

The stingless bees *T. spinipes* (Figure 9) were observed collecting pollen from the flowers of the cosmos. This bee belongs to the group of meliponines, however, their products (honey, pollen, geopropolis) are not used due to their habit of collecting feces and putrefying materials for the construction of their nests. However, these bees are very common in the flowers of several plants, being generalist, and are considered pollinator of the chayote (Malerbo-Souza et al., 2022).

Africanized honeybees *A. mellifera* (Figure 10) were frequently seen collecting both nectar and pollen in the flowers of the cosmos every other month. There were probably other competitive sources more attractive than the cosmos. However, it is very common to see them visiting the flowers of the cosmos throughout the years (2019 and 2020).

Figure 9. Stingless bee *T. spinipes* collecting pollen in *C. sulphureus* flowers in Recife, PE, Brazil in 2019 and 2020.

Figure 10. Africanized honeybee *A. mellifera* collecting pollen in *C. sulphureus* flowers in Recife, PE, Brazil in 2019 and 2020.

The stingless bee *M. scutellaris* (Figure 11) also called 'uruçu' or 'uruçu-real' is one of the Eusocial stingless bee species of the order Hymenoptera and of the genus *Melipona*. It is considered the species of *Melipona* created by man with the greatest distribution in the North and Northeast regions of Brazil, with records from Rio Grande do Norte to Bahia. Its common name comes from the Tupi language 'eiru su', which in the indigenous language means 'great Bee'. Its honey has a pleasant taste, less sweet than the honey of Africanized honeybees and very valuable. Is a very docile bee, easy to raise. Other species of *Melipona* is *M. fasciculata* (Figure 12), known as gray uruçu, has also been observed in cosmos flowers. These two species of melipops collected nectar from the flowers of the cosmos.

Figure 11. Stingless bee *M. scutellaris* collecting nectar in *C. sulphureus* flowers in Recife, PE, Brazil in 2019 and 2020.

Figure 12. Stingless bee *M. fasciculata* collecting nectar in *C. sulphureus* flowers in Recife, PE, Brazil in 2019 and 2020.

M. scutellaris was observed only at certain times of the year, visiting the flowers of the cosmos, even with a meliponary containing nests of these bees very close. They probably were in other more attractive sources around the experiment site, such as the jurubeba (*Solanum paniculatum*), for instance. Other species such as the calabura (*Muntingia calabura*) and the lovebird (*Antigonon leptopus*) were also visited by many species of bees, including *M. scutellaris*, and flourished all year round, around the meliponary. The stingless bee *M. fasciculata* (gray uruçu or tiúba) were observed collecting nectar in the flowers of the cosmos, in some periods of the year, just as it occurred with *M. scutellaris*.

The bumblebees *Xylocopa frontalis* and *X. griscenses* (Figure 13) were observed collecting nectar in the flowers of the cosmos but in lesser number compared with the other species.

Figure 13. Bumblebee *Xylocopa griscenses* collecting nectar in *C. sulphureus* flowers in Recife, PE, Brazil in 2019 and 2020.

Ceratina sp. (Apidae: Xylocopinae: Ceratinini) (Figure 14) are small and solitary bees that, despite their size and are widely distributed around the world (Silveira et al., 2002). Recently, a new species of keratin (*Ceratina fioreseana*) was identified on a farm in Goiás (Oliveira et al. 2020).

Figure 14. Solitary bee *Ceratina* sp. collecting pollen in *C. sulphureus* Flowers in Recife, PE, Brazil in 2019 and 2020.

Regarding the Constancy index, it was observed that *M. rotundata*, *P. gramínea*, *Augochlora* sp., *T. spinipes* and butterflies were constant species in the flowers of the cosmos (81.8, 54.54, 54.54, 54, 54 and 54.54%, respectively). The bumblebees *X. frontalis* and *X. griscenses* and stingless bees *P. remota* were considered accessory species (27.27, 27.27 and 36.36%, respectively). Solitary bee *Ceratina* sp., wasps and diptera were accidental species in cosmos flowers, with less than 25% of the visits observed.

When bee species are abundant in a given plant species it indicates it is a preserved environment. This study was developed in an urban area, where the University is located, but close to the remaining preserved area of the Atlantic Forest (Dois Irmãos State Park), in Recife, Pernambuco, Brazil. Studies have shown that cities could be pollinator reservoirs with greater insect biodiversity compared to the countryside (Jędrzejewska-Szmek & Zych, 2013). High diversity of plant species is characteristic of several urban areas. Plant species richness generally increases in cities compared to natural areas (Grimm et al., 2008). Therefore, urban areas are favorable to wild pollinators. The increase in plant wealth in cities occurs using native and foreign ornamental plant species, in landscaping and gardening (Stelzer et al., 2010).

One of the families of plants well represented in urban ecosystems is Asteraceae. Asteraceae present massive flowering, showy inflorescences, type of capitulum and floral resources that attract different and abundant pollinators. Due to these characteristics, asteraceae species are often used to compose flower beds in avenues, gardens, squares and parks (Denisow et al., 2014). Numerous representatives of the Asteraceae family are described as good honey plants, providing nectar and pollen for insects. Although there is a deficit in research covering *C. sulphureus* and its relationship with bees, some studies that evaluated the pollen load in bees in Brazil pointed out that among the most visited plants, were those of the Asteraceae family, family to which the cosmos belongs (Milet-Pinheiro & Schlindwein, 2008).

In addition, more floral resources for urban bees can be achieved by encouraging the growth of ornamental bee plants in gardening, landscaping, and for sustainability. Ornamental plants are not always thought to be good for bees because pollen or nectar resources are not always visible. However, many are suitable for bees that visit them intensively. Ornamental plants that flower in different periods, if managed intensively, produce flowers and resources (nectar and pollen) that will be more consistently available to insect visitors, even in times of drought (Steiner et al., 2010).

There are several characteristics presented by the plants on order to stimulate the approach of pollinators and thus allow cross-pollination, promoting the evolutionary development of plants. When analyzing the differences between the rural and urban landscape, it is observed that the rural area is characterized by being a little transformed environment when compared to the high biodiversity of plant species in the urban environment, while the species of the rural landscape are commonly associated with the agriculture, forestry and livestock (Evert & Eichhorn, 2016).

Generalist bee species are benefitted in urban areas (Banaszak-Cibicka & Żmihorski, 2012). According to Antonini et al. (2006), pollen from the cosmos was intensely collected by the stingless bee *M. quadrifasciata*.

In Brazil, stingless bees are responsible for 40 to 90% of the pollination of wild species in tropical environments (Kerr et al., 2001). Meliponines can present premises of floral preference, which aim to optimize the cost and benefit of foraging thus avoiding the energy cost used in the collection of the resources be greater than the trophic benefits. In the reconstitution of tropical forests and conservation of the remnants, such bees can be of fundamental importance. Still, these can act as bioindicators of environmental quality (Yamamoto et al., 2010).

The mutually beneficial interaction between pollinating and dispersing animals and plants is an important factor in the generation of biodiversity on Earth. Such mutualism involves a large number of species that form complex networks of interdependence. Its structure has important implications for the coexistence and stability of species, as well as for the understanding of co-evolutionary processes, being able to portray the architecture of biodiversity (Bascompte & Jordano, 2007).

The interaction networks are very heterogeneous, where most species have few interactions (Montoya & Solé, 2002). However, certain systems may be more connected than expected; nested, forming cohesive networks or a more complex hierarchy, worlds within the world' (Newman et al., 2006).

Olesen et al. (2006) pointed out several peculiarities in pollination networks, bringing ecological approaches to this mutualistic relationship that would characterize it as being 'the smallest of the world' (e.g., high cohesion, short paths, level of dependence and size of the network).

Ollerton et al. (2011) found, among flowering plants, that 87.5% of these are pollinated by animals. This percentage increases even more in tropical ecosystems, where 94% showed a dependency relationship with pollination vectors. Costa and Oliveira (2013) pointed out that a significantly expressive number of plants

need pollinators for their reproduction, mainly in tropical forests, where biodiversity is greater, not only in species richness, but also in the diversity of specific pollination mechanisms. And they pointed out the mutualistic interactions between plants and pollinators as an important ecological mechanism in view of the enormous environmental services they provide. These ecosystem services are the basis for the survival of organisms on the planet and fundamental to human well-being (Constanza et al., 1997), with biotic pollination being the key mechanism in maintaining and balancing ecosystems (Klein et al., 2007).

Conclusion

Therefore, in this 'smallest of the world's, the cosmos can be used as an ornamental species and must be planted close to meliponaries and apiaries, being an important source of food resources for bees. It is considered a good indicator of preservation of the environment and the diversity of bees, both for Africanized bees, for meliponines and for solitary bees, in Recife, PE, throughout the year in the forest zone of Pernambuco.

Data availability

Not applicable.

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