Pollination efficiency of *Apis mellifera* Linnaeus, 1758 (Hymenoptera, Apidae) on the monoecious plants *Jatropha mollissima* (Pohl) Baill. and *Jatropha mutabilis* (Pohl) Baill. (Euphorbiaceae) in a semi-arid Caatinga area, northeastern Brazil

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Abstract

Previous studies have shown the superior competitive ability of honeybees compared with native bees in the exploitation of floral resources and nesting sites besides their low efficiency in pollinating native plant species. However, there is little evidence of the effect of this invading species on autochthonous plant populations in natural environments. Thus experiments were performed to test the pollination efficiency of honeybees in two species of *Jatropha* (Euphorbiaceae), *J. mollissima* (Pohl) Baill. and *J. mutabilis* (Pohl) Baill., after a single flower visitation. Samplings were carried out between March and April 2006 in a hyperxerophilous shrub-arboreal Caatinga at Estação Biológica de Canudos, Bahia (9º 56´ 34" S, 38º 59´ 17" W), the property of Fundação Biodiversitas. *Apis mellifera* was efficient at pollinating *J. mollissima* (100%) and *J. mutabilis* (85%). This high efficiency may be explained by 1) the simple floral characteristics of both plant species, which facilitate access to the sexual organs of the plant; and 2) the body size of *A. mellifera* that fits the flower's dimensions.

Keywords: bees, exotic species, pollination, semi-arid, reproductive success.

Eficiência de *Apis mellifera* Linnaeus, 1758 (Hymenoptera: Apidae) na polinização das espécies monoicas *Jatropha mollissima* (Pohl) Baill. e *Jatropha mutabilis* (Pohl) Baill. (Euphorbiaceae) em uma área de Caatinga, nordeste do Brasil

Resumo

Estudos sugerem que *Apis mellifera* é altamente generalista e oportunista, interfere nas populações de abelhas nativas através da competição por recursos florais e por sítios de nidificação, além de ser pouco eficiente na polinização de espécies nativas. Entretanto, há poucas evidências que comprovem o efeito de *Apis mellifera* sobre populações autóctones em ambientes naturais. O presente estudo testou experimentalmente a eficiência de *A. mellifera* na polinização das espécies *Jatropha mollissima* e *J. mutabilis* em apenas uma visita e observou o seu comportamento de visitação. As amostragens foram feitas entre março e abril de 2006 em uma área de caatinga hiperxerófila arbustiva-arbórea na Estação Biológica de Canudos, Bahia (9º56´34"S, 38º59´17"W), pertencente à Fundação Biodiversitas. *Apis mellifera* foi eficiente na polinização de *J. mollissima* (100%) e *J. mutabilis* (85%). Essa alta eficiência deve-se: 1) às características florais simples das duas espécies, que facilitam o acesso aos órgãos sexuais da planta; e 2) ao ajustamento entre o tamanho corporal da abelha e as dimensões das flores.

Palavras-chave: abelhas, espécie exótica, polinização, semiárido, sucesso reprodutivo.

1. Introduction

The diversity of plant species in tropical environments is remarkably high when compared to other areas of the globe (Wilson, 1997). Nevertheless, the speed-up of environmental degradation through the increase of agricultural areas, destruction of natural ecosystems, and predatory human activities has been causing a drastic reduction of this biodiversity. Following habitat loss, the introduction of exotic species represents the biggest threat to global biodiversity (Pimm et al., 1995), since it affects the structure and functioning of ecosystems (Vitousek, 1990), altering their evolutionary dynamics (Traveset and Richardson, 2006), and may lead native species to extinction (Gurevitch and Padilla, 2004).

Exotic species may benefit or damage the sites in which they settle (Sax et al., 2007). For a long time, exotic bees aroused little concern due to their economic importance for honey production and their flower-visiting behaviour that was associated with pollination, usually considered positive in the sense of increasing agricultural productivity (Goulson, 2003). However, many studies argue that not all flower visitors are effective pollinators (e.g. Roubik, 1989; Endress, 1994; Proctor et al., 1996), which highlights the need for knowing the real role of exotic bees in the pollination of native plants.

According to a review carried out by Traveset and Richardson (2006), an exotic pollinator may affect a plant community in three ways: 1) negative effect, when it reduces the amount and/or quality of the pollen transferred among plants, which decreases the reproductive success of the plant, 2) positive effect, when it increases the reproductive success of the plant, 3) no relevant effect, when the visitation rate is low and does not affect the reproductive success of the plant. The negative effect may occur due to: 1) competition with native pollinators, which decreases the number of flower visits by effective pollinators; 2) removal of pollen grains previously deposited on the stigma; 3) low fidelity and pollen loss due to deposition on other species; 4) differences in flower visit rates on male and female flowers, resulting in a low transferred pollen rate; 5) pollen and nectar stealing behaviour without accomplishing pollination; 6) rise of high geitonogamy rates; and 7) deposits of heterospecific pollen, which competes on the stigma for co-specific pollen.

Though the introduction of some exotic species has been accidental in some cases, in others, it has been deliberate through human activities such as, for instance, agroforestry (Paini, 2004). Among the introduced species that succeed in South America, the Africanised honey bee *Apis mellifera* Linnaeus, 1758 stands out. These bees are poly-hybrids resulting from breeding of European races (*Apis mellifera mellifera*, *Apis mellifera ligustica*, *Apis mellifera carnica*) introduced in colonial times (Brand, 1988), plus the African race *Apis mellifera scutellata* Lepeletier, 1836, accidentally introduced in Rio Claro, São Paulo state, southeastern Brazil (Stort and Gonçalves, 1994). After becoming Africanised, these bees dispersed to almost all Brazilian biomes (Minussi and Alves-dos-Santos, 2007) and settled as wild species. The only area in the Brazilian territory where Africanised bees are not found is inside the Amazon (Oliveira and Cunha, 2005).

Although *A. mellifera* have long-term colonies, their workers have a short lifespan. Therefore, individuals must have flexibility in collecting behaviour, which makes floral specialisation unfeasible (Westerkamp, 1991; Goulson, 2003; Paini, 2004). For this reason, some authors (e.g. Westerkamp, 1991; Klein et al., 2003; Celebrezze and Paton, 2004) suggest that *A. mellifera* is an inefficient pollinator.

This species is also considered the most important competitor of native bees and is responsible for removing them from flowers (e.g. Roubik, 1980; Waser et al., 1996; Kato et al., 1999; Steffan-Dewenter and Tscharntke, 2000) and/or destabilising the pollination services in natural and agroforest environments (e.g. Björkman and Pearson, 1995; Gross and Mackay, 1998; Dupont et al., 2004). Nevertheless, some authors declare that there is no evidence of the negative effect of *A. mellifera* on the biota (e.g. Manning, 1997), and other authors even highlight experimental evidence that testifies the efficiency of this species on pollination (e.g. Sampson and Cane, 2000; Gross, 2001; Roubik, 2002).

In Brazil, few studies on the effect of *A. mellifera* on the pollination of native plants have been carried out, and some of them pointed out the negative effects of *A. mellifera* (e.g. Carmo and Franceschinelli, 2002; Carmo et al., 2004; Jacobi and del Sarto, 2007). However, no experimental study has been developed so far aiming to test the effect of this species on the pollination of native species in the Caatinga.

Considering the relevance of the topic and the lack of information about it, the present study intends to contribute to this discussion by bringing information on the influence of *A. mellifera* on fruit production of native species of the Caatinga, a dry forest in the semi-arid region of northeastern Brazil. Two monoecious species of the genus *Jatropha* L., members of the family Euphorbiaceae, were selected.

2. Material and Methods

2.1. Study area

The present study was carried out in the Ecoregion Raso da Catarina (Velloso et al., 2002), a priority area for the conservation of the invertebrates fauna and flora of Caatinga , in accordance with the report of the Ministério do Meio Ambiente (2002). The climate of the region is tropical semi-arid, with average annual temperatures varying between 27 °C and 29 °C and average rainfall below 800 mm. Samplings were carried out from March to April 2006 in an area of hyperxerophilous shrub-arboreal Caatinga at Estação Biológica de Canudos (9° 56´ 34" S, 38° 59´ 17" W), the property of the Fundação Biodiversitas.

2.2. Plant species

The studied plants were the monoecious species *Jatropha mollissima* (Pohl) Baill. and *Jatropha mutabilis*

(Pohl) Baill., both members of the family Euphorbiaceae. These plants are resident shrubs of the Caatinga. They have a dichasium inflorescence, dish-shaped pentamerous flowers (Figure 1), dichlamydeous, and superior trilocular ovary with one ovule per loculus. Both pistillate and staminate flowers produce nectar. The anthers are yellow with longitudinal dehiscence. The fruits are schizocarp type with explosive dehiscence, green when immature and grayish-brown when ripe (Neves, 2008).

Monoecy is a fairly common sexual system among plants of the Euphorbiaceae family, in particular the genera *Euphorbia*, *Cnidosculus*, *Croton* and *Jatropha* (Bullock, 1985). Monoecious plants usually need vectors in order to transfer pollen from staminate to pistillate flowers, on the same individual or between individuals. Studies on *Jatropha* pollination evince that these plants are preferentially pollinated by insects (Raju and Ezradanam, 2002; Bhattacharya et al., 2005; Santos et al., 2005) and show that the most abundant flower visitors and would-be pollinators are eusocial bees, especially *A. mellifera*.

2.3. Behaviour on flowers

The visiting behaviour of *A. mellifera* was observed in the field, when we recorded its way of accessing flowers, the duration of visits to flowers and its way of contacting the flower's sexual organs.

2.4. Assessment of pollination efficiency

In order to test the pollination efficiency of *A. mellifera*, we followed the procedures described by Sampson and Cane (2000), Gross (2001) and Klein et al. (2003). Results were calculated based on the total amount of fruits produced by flowers that received a single visit.

Figure 1. Visiting behaviour on *Jatropha mutabilis* (a - c) and *Jatropha mollissima* (d, e) flowers by *Apis mellifera* at Estação Biológica de Canudos, Canudos, Bahia state, northeastern Brazil. a) arrival on branch with staminate flowers; b, e) on pistillate flowers; and c, d) on staminate flowers.

We carried out the following procedures: 1) for each plant species five individuals were selected; 2) 20 pistillate flower buds were bagged the day before the experiment; 3) on the day of the experiment, virgin flowers at anthesis had the bag removed, allowing the visit of a single individual of *A. mellifera*; 4) after the visit, the flowers were labelled and re-bagged and remained that way until the production, or not, of ripe fruits; 5) 20 other pistillate flowers not visited remained bagged to measure bagging efficiency in keeping unwanted visitors away from flowers; and 6) 20 flowers were labelled and left open to visitors.

The experiments were carried out from 6:00 to 9:00 AM, a period when the flowers had 100% viable pollen grains and 100% stigmatic receptivity (Neves, 2008).

We also measured the height of *A. mellifera* on the thorax and the height of the stigma lobes on pistillate flowers, from the ovary base in order to evaluate if the body size of *A. mellifera* fits the flower's dimensions.

3. Results

3.1. Pollination efficiency

In accordance with the data presented in Table 1, *A. mellifera* proved to be an efficient pollinator of *J. mollissima* and *J. mutabilis*, considering a single visit.

3.2. Behaviour on flowers

During the sampling period, we observed that worker bees foraged, indistinctively, on staminate and pistillate flowers during each foraging bout, remaining from 3 to 15 seconds on each flower, and visiting several flowers of the same individual plant. We also observed that when workers changed plants, they went to the nearest neighbour. At sites where there were specimens of the two species next to each other, the worker bees indistinctively visited flowers of the two species.

When *A. mellifera* visited pistillate flowers of both species, it landed on petals and started gathering nectar, and, after a few seconds it surrounded the ovary, searching for areas with a higher amount of nectar. On this action, the bee contacted the stigma lobes with the superior part of its thorax. On *J. mollissima* flowers, this contact was favoured because the flowers of this species are usually cup-shaped (Figure 1e). Besides, the height of the stigma lobes from the ovary base is lower and the lobes are closer to each other, whereas the stigma lobes of *J. mutabilis* are more distant from each other (Figure 1b).

The average height of *A. mellifera* on the thorax region was 6.2 ± 0.4 mm (n=10). The height of the stigma lobes of *J. mollissima* had an average measurement of 5.8 ± 0.4 mm (n=10) and the height of the stigma lobes of *J. mutabilis* had an average measurement of 6.4 ± 0.5 mm (n=10).

While collecting nectar on staminate flowers, *A. mellifera* showed two distinct behaviours: 1) when the flower exhibited opened and flattered petals, the bee landed on the petal and collected nectar beneath the stamens, touching them with the upper part of its thorax where the pollen grains were attached, 2) when the flower was cup-shaped, *A. mellifera* introduced its body inside the flower, between the stamens, remaining upside down, and by doing so, had its body covered up with pollen grains. However, when *A. mellifera* collected pollen, it landed directly on the anthers' top, removed pollen grains with its anterior legs and thereafter, transferred them into the corbicula, without allowing them to attach to its body. Agonistic behaviour towards individuals of other species was not observed.

4. Discussion

Because *A. mellifera* is a generalist, its incorporation as an exotic species into native interaction webs is favoured and, therefore, its colonisation and dispersion in the new environment are also favoured (Olesen et al., 2002). Recent studies show assemblages composed of native and exotic species occur for which in spite of coexisting for a short time, (as could be supposed because exotic species do not have an evolutionary history of coadaptation to the local flora) evolutionary adjustments might have occurred in a shorter time scale (Sax et al., 2007).

In Canudos, B.F. Viana and C.M. Pigozzo (personal communication) analysed the interaction web established between bees and flowers of the region and distinguished the presence of the *A. mellifera* at the core of the system, assuming a central position in the interactions. These authors also observed that some plant species, such as *Lippia pohliana* Schauer (Verbenaceae), *Ipomoea rosea* Choisy (Convolvulaceae), *Aspilia bonplandiana* (Gardner) S.F. Blake (Acanthaceae) and *Piptadenia stipulacea* (Benth.) Ducke (Fabaceae), exhibited exclusive interactions with *A. mellifera*. Because these interactions are very recent in Brazil, there was probably not enough time for the action of evolutionary adjustments to take place between this bee species and the native plants. In this case we should question: which bees interacted with these plants before the introduction of *A. mellifera*?

According to Westerkamp (1991), no flower was able to adapt to the unpredictable behaviour of *A. mellifera*, since the evolution of eusociality would be incompatible with floral specialisation, as this species needs a huge amount of food throughout the year. Thus, the match between the body dimensions of *A. mellifera* and the floral morphology and dimensions of the plant may be a more determinant

Table 1. Results of tests for the efficiency of the exotic bee *Apis mellifera* in pollinating *Jatropha mollissima* and *Jatropha mutabilis* in Canudos, Bahia state, northeastern Brazil, from March to April 2006.

Treatment	***J. mollissima***	Success (%)	***J. mutabilis***	Success (%)
	Flowers/fruits		**Flowers/fruits**	
Pollination by *Apis mellifera*	20/20	100	20/17	85
Natural pollination (control)	20/18	90	20/19	95

fact for the reproductive success of certain plant species than its historical relations with native visitors.

The flower visitors' ability to pollinate plant species seems to be exclusively related to flower morphology. Flowers that do not exhibit structures to restrain access to the resources and that keep their reproductive organs exposed to visitors are more easily pollinated by *A. mellifera*, as observed in the present study. However, species with more specialised attributes, such as poricidal anthers, are hardly pollinated by *A. mellifera*, since this bee is not able to vibrate its wing muscles hard enough to promote the release of the grains from anthers. *Apis mellifera* was the most frequent flower visitor on *J. mollissima* and *J. mutabilis* flowers and showed to be efficient at pollinating these species. Similar results were related by Santos et al. (2005) for *J. mollissima* in a study on the pollination biology of this species in a Caatinga area in Pernambuco.

The efficiency of *A. mellifera* in pollinating *J. mollissima* and *J. mutabilis* on a single visit suggests that, even though it is exotic, it may have an important role in pollination and therefore on the subsequent fruit production of native and agroforestry species. Results pointing out the efficiency of this bee as pollinator were recorded for other taxa (e.g. Sampson and Cane (2000) for *Vaccinium ashei* Reade (Ericaceae); Gross (2001) for *Dillwynia juniperina* Lodd. (Fabaceae); Roubik (2002) for *Coffea arabica* L. (Rubiaceae); Bhattacharya et al. (2005) for *Jatropha curcas* L. (Euphorbiaceae); Machado and Sazima (2008) for *Melochia tomentosa* L. (Sterculiaceae).

The simple floral characteristics of *J. mollissima* and *J. mutabilis* suggest that these plants can be pollinated by several groups of flower visitors, featuring as generalists concerning pollinator attraction. Neves (2008) suggest that before the introduction of *A. mellifera,* it is likely that other visitors may have efficiently developed this role, distinct among them the hummingbirds *Chlorostilbon lucidus* (Schaw, 1812), *Anopetia gounellei* (Boucard, 1891), *Chrysolampis mosquitus* (Linnaeus, 1758), solitary bees such as *Xylocopa grisescens* Lepeletier, 1841 and *Xylocopa frontalis* (Oliver, 1789) and the eusocial native bees like *Melipona mandacaia* Smith, 1863, observed visiting flowers of these species in the study area. These *Jatropha* species, hence, would be less affected by the impacts (negative or positive) of an exotic pollinator species because they are visited by several native visitors.

In the studied monoecious species of *Jatropha*, there is no restriction on pollination by *A. mellifera.* The staminate flowers exhibit longitudinal dehiscence, which completely expose the pollen, making it available to visitors. Because pollen grains become extremely exposed, it increases the chances of an involuntary deposit of pollen on the bee's body, which can be transferred into the stigma of a pistillate flower.

However, pistillate flowers exhibit morphological differences that may explain the variation on the pollination efficiency of *A. mellifera* on these species. The flower of both species are dish-shaped, though on *J. mollissima,* the petals do not deflect completely, conferring to the flower an aspect similar to a cup, favouring the contact between its reproductive organs and the bee's thorax, which arrives on the flower by its side, searching the nectar that is located on the ovary base. These morphological characteristics give the flower a greater likelihood of pollination by *A. mellifera*.

Otherwise, the smaller amount of fruits produced by *J. mutabilis* in the experiments of pollination by *A. mellifera* may result from two prominent differences on the pistillate flowers of this species in comparison with *J. mollissima* flowers: first, the petals deflect completely conferring to the flower a dish shape that disfavours the contact of the reproductive organs with the bee's thorax; second, the three stigma lobes exhibit a distinct spatial partition, compelling the visitor to surround the flower in order to deposit the proper amount of pollen grains. Therefore, for some flowers of this species, more than one visit might be needed to provide a successful pollination.

Studies carried out in areas of occurrence of *A. mellifera* evinced that this bee visits several flowers of a same individual favouring geitonogamy (e.g. Richardson et al., 2000; Goulson, 2003; Celebrezze and Paton, 2004). In Raso da Catarina Ecoregion, *A. mellifera* must have stimulated the rise of the geitonogamy rate on *J. mollissima* and *J. mutabilis* populations.

In the same way, the visiting behaviour of *A. mellifera* on flowers of these two *Jatropha* plants, indistinctively, and the overlapping flowering period of these two species observed in the study area (Neves, 2008), revealed that this bee is favouring the cross breeding between the two species in this region.

Another negative effect of the foraging behaviour of *A. mellifera* on the reproductive success of plants is the excessive pollen gathering before dawn, leaving behind anthers with a extremely low amount of pollen even before other visitors start their activity period (see review in Goulson, 2003). Carmo et al. (2004) recorded that on *Clusia arrudae* Planchon and Triana (Clusiaceae) less than 10% of the total amount of pollen grains remained available during the period of activity of effective pollinators, due to the excessive gathering of *A. mellifera,* which caused a decrease in fruit production in natural conditions. Jacobi and del Sarto (2007) observed that *A. mellifera*, in spite of being one of the most frequent visitors and being able to pollinate the species *Vellozia epidendroides* Mart. ex Schult. and *Vellozia leptopetala* Goeth. et Henr. (Velloziaceae), restricted the reproductive success of these species due to its behaviour of collecting efficiently and actively a lot of pollen and afterwards depositing only a few grains on the stigma.

Besides collecting a large amount of pollen, *A. mellifera* exhibits low floral fidelity (Westerkamp, 1991), which is an extremely interesting strategy for social bee populations, but that may impair the pollination of the visited plant species: it is possible that *A. mellifera* deposits on stigmas heterospecific grains that can obstruct the style, preventing conspecific grains from germinating.

Evidence presented here reinforces evidence from other studies that the exotic bee *A. mellifera* was efficient at pollinating native species, as previously mentioned. Nevertheless, these results should be taken with caution, since this positive effect was evinced for individuals for a restricted time scale. Long-term genetic studies at the population level should be conducted to identify possible deleterious effects on the population, as a result of the foraging behaviour of this species, as previously discussed.

Moreover, we should not exclude the hypothesis that, because *A. mellifera* has perennial colonies and needs huge amounts of food, these bees forage in a high number of flowers, hence this behaviour may lead to a decrease in populations of native pollinators due to the depletion of floral resources (Roubik, 1980; Waser et al., 1996; Kato et al., 1999; Steffan-Dewenter and Tscharntke, 2000). As a consequence, this bee will also indirectly affect the reproductive success of specialist plant species that depend on native pollinators.

At first, though there might be a high endogamy rate in these plant populations due to the intense movement of *A. mellifera* among flowers of a single plant, or among neighbouring plants, the efficiency of this bee as a pollinator of these plants with a simple morphology might have contributed to a positive selection and consequent dominance of these plant species in the environment, since they achieve reproductive success in terms of fruit production. In case this hypothesis may be corroborated, the plants favoured by *A. mellifera* through an increased fruit production, might constitute larger populations and have wider distributions. In this way, these plants would make available higher amount of flowers in the environment, increasing their competitive potential to attract native pollinators and would compete as well with other local plant species for water and nutrients in the soil.

Otherwise, the plant species of native flora with a more complex floral morphology (e.g. keel and bilobed flowers) might be impaired not only by the impossibility of pollination by *A. mellifera*, which usually are the most abundant visitors, but also by the likely competition between *A. mellifera* and native pollinators that may have their populations depleted on account of a reduced offer of resources.

It is also important to consider that species with simplified morphologies are frequently r-strategists, with a quantitative investment in their offspring, usually without autogamy barriers and easy germination, featuring coloniser species that rapidly establish themselves in a new environment. Empirical evidence is presented by some authors (e.g. Barthell et al., 2001), which shows that *A. mellifera* is an efficient pollinator of ruderal and exotic plants. In this way, in the medium and long-term, *A. mellifera* might cause the reduction of the biodiversity of the native flora and fauna as well as the genetic diversity of the remaining population. Hence, it is likely that a selection of more generalistic systems is on course, because of the presence of *A. mellifera* in these environments. It is recommended, therefore, long-term monitoring in order to evaluate all the possible impacts caused by the introduction of exotic species, such as *A. mellifera*.

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