Pollination by bees as an economically important factor for tropical beekeeping

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Introduction

Bees are important pollinators of many crops. In the tropics, where a very diverse offer of fruits and vegetables is grown, pollination by honeybees and many species of native bees is vital for their production (Biesmeijer, 1992; Roubik, 1995). Often the importance of native bees for the pollination of tropical crops is not understood until a crop is grown outside the natural habitat of its pollinator. A good example of that is Vanilla, which is originally from Mexico and Central America, and pollinated by Orchid bees (*Euglossini*) *Eulema* sp. In regions where these bees do not occur, for instance Madagascar and Tahiti, the Vanilla orchids have to be pollinated by hand in order to produce the vanilla beans, which is less effective and more costly. Of many crops in the tropics it is still not known which bees or other insects are their pollinators, or in case it is known what their contribution is in the production.

Photo 1. Beehives on melon in Guanacaste, Costa Rica (photo by author).

In Africa it is considered (Elisante et al., 2017), that although some good studies concerning crop pollination are available, the majority of communities have not benefited yet, because beekeepers do not have the basic knowledge about pollination services and its importance for crop production.

Many of the studies are limited to the pollination of export crops, such as coffee, mangoes, cashew nut and sunflower (Roubik, 1995). Although it is estimated that the economic value of bee pollination of crops be € 153 billion, the value of pollination services in the tropics is poorly understood, and not known by the vas majority of neither beekeepers nor farmers (Elisante et al., 2017). For Asia the situation is not much different, and the specific pollination requirements of many crops, for instance Citrus remain only partly understood (Roubik, 1995). It is important to note that beekeeping

and agricultural productivity are as clearly interwoven in the tropics as they are in the temperate regions of the world.

Honeybees are generally used in the tropics for pollination of crops grown at a large scale, such as melon, watermelon, kiwifruit, cashew, papaya, oranges, cucumber, cotton, apples, and mangoes, among others.

Photo 2. Hives used for the pollination of Avocado in San Marcos, Tarrazú, Costa Rica (photo by author).

Honeybee colonies are readily available, populous, and hive management is relatively well known. For beekeepers it is often economically attractive to rent their hives for pollination of a crop. It provides them with extra income next to honey production. Especially now that climate variability makes honey production less predictable, many beekeepers look for ways of how to diversify their apicultural production. For instance in Costa Rica many beekeepers suffered from low honey productions during the severe "Niño" droughts of 2015 and 2016.

In Costa Rica tens of species of social stingless bees occur that live in colonies. However little is known about their contribution to the pollination of fruits and crops. Typically tropical crops such as Chayote (*Sechium edule*), a *Cucurbitaceae* native to Costa Rica, which is grown for export to the USA, and Macadamia (*Macadamia integrifolia*), native to Australia, are known to be pollinated by stingless bees, *Trigona sp*. (Heard, 1999; Slaa et al., 2006). Other tropical crops known to be pollinated by stingless bees are Annato or Achiote (*Bixa orellana*), Carambola (*Averrhoa carambola*), Mango (*Mangifera indica*), Coffee (*Coffea arabica*), Avocado (*Persea americana*) and Rambutan (*Nephelium lappaceum*).

Honeybees were first introduced in Costa Rica at the end of the nineteenth century, likely by German coffee growers. Many hives were kept in the backyards in rectangular rustic wooden boxes without frames. According to registers from the Central Bank, Costa Rica started exporting honey in 1918, interrupted only during World War Two. In the seventies modern beekeeping was introduced, resulting in an increase in the export of honey to the United States and Europe. In 1984, a census by the Ministry of Agriculture, reports the existence of 1500 beekeepers with 45731 hives, producing a total of 1376 tons of honey (30.1 kg / hive), of which 560 tons were exported. In December 1983 the first swarm of Africanized honeybees was captured, and due to the tremendous impact only four years later, in 1987, Costa Rica became a honey importing

country, with a first import of 195 tons. Honey production had diminished more than 50%! The latest estimate from 2016 indicates a total of 982 registered beekeepers, with a total of 45000 hives, producing about 950 tons per year (20 kg / hive). Africanized honeybees established in the wild, forming for the first time a feral honeybee population in Costa Rica.
This created a unique situation with introduced Africanized honeybees next to native bees in the wild. Next to those, hundreds of species of solitary bees and tens of species with different levels of sociality, which do not live in permanent colonies, such as bumblebees (*Bombus* sp.) and carpenter bees (*Xylocopa*), live in Costa Rica. Very little is known about their contribution to the pollination of crops.

Economical importance of beekeeping for crop pollination
In Costa Rica and neighboring Central American countries, honeybees are used for the pollination of crops that are grown at a large scale. The most important crops are melon (*Cucumis melo*), watermelon (*Citrullus lanatus*) and avocado (*Persea americana*). Beekeepers receive a rental fee for the hives, which is calculated, either based on the whole production season of the crop, or based on each time a hive is introduced into a crop field. The fee can be as much as $120 per hive for the whole season. For this the beekeeper has to bring his hives during the night in the crop field at previously selected locations, protect his hives during the pollination service in case the crop grower has to apply some pesticide, and remove the hives once the agreed upon period of pollination has finished. Beekeepers are rarely compensated for the loss of hives during pollination. In Costa Rica between five thousand and eight thousand hives are used annually for the pollination of melon and watermelon and several hundreds for avocado. The total export value of these three crops is about $50 million. Other crops where honeybees contribute in the production are coffee, citrus (oranges and lemons), mango and papaya. The values of these crops are in table 1. The values differ greatly form year to year, because of differences in price on the international markets and because of the weather conditions (excessive rainfall and droughts), which influence significantly in the production.

Crops	**Export value in million $**
Coffee	> 300,0
Oranges and lemons	67,6
Melon and watermelon	34,5
Mango	30,0
Papaya	17,5
Avocado	16,1

Table 1. Export value of crops pollinated by honeybees in Costa Rica.

Many Costa Rica beekeepers bring their hives to the Central Valley for the blooming of the coffee at the end of the dry season for an additional honey harvest. The honey

produced on this crop is of excellent quality; good taste, low in humidity and has a beautiful yellow golden color. Because of this coffee growers do not pay the beekeepers a rental fee for their hives, even though research has demonstrated that pollination by honeybees can increase the production of this coffee crop with 15% to 20%.

Research by the Research Institute for Tropical Beekeeping (CINAT)

Because of the lack of knowledge concerning on how beehives can be used for the pollination of different crops in the tropics and because of the varying circumstances between countries, and sometimes even within a country, CINAT conducted research into the pollination needs of several crops: coffee, melon, avocado, tomato and Vanilla.

Melon (*Cucumis melo*)

On one hand because of the economical importance of the export of Cantaloupe and Honeydew melons, and on the other hand because thousands of beehives are being used every year for its pollination, CINAT started its research with this crop. Beekeepers used to bring four to six hives per hectare for proper pollination, because that's what the literature cites for melon in the USA (photo 1). Flowers are receptive only for a few hours during the morning, and during that period pollination must occur. Specific crop and hive management factors, such as irrigation, the spreading of the hives on the crop, and the presence of a feral (Africanized) honeybee population were not taken into account.

The research was carried out in Guanacaste province in a Cantaloupe producing farm, where we had access to a 25-hectare plot, surrounded by not blooming crop and natural forest. During a week every hour bee presence on the flowers was observed for ten minutes, at 10m, 75m and 100m from the hives (2 per hectare) by three observers. The bee counts were performed with the hives opened and closed to estimate the visitation by honeybees from the feral population. No significant difference was found in the number of visits of the flowers between the two distances nearest to the hives. Only at 100m from the hives significantly less bees were observed. The conclusion of this field study was that with a proper distribution of beehives on Cantaloupe in Costa Rica, two hives per hectare is enough for pollination purposes, because Africanized honeybees contribute with about thirty percent in its pollination. In another study we compared the number of honeybee visits observed on hermaphroditic flowers with the resulting fruit size and quality. We found that ten to twelve visits to the flowers produced well-formed round melons with more than 600 seeds and an average weight of 1.2 kg, which is very similar to the results of Mussen and Thorp (2017) for Cantaloupe and honeydew melons in California.

Avocado (*Persea Americana*)

Our student Rosa Maria Jiménez, supervised by Luis Alejandro Sánchez, pollination expert at CINAT, studied the importance of bee pollination for the production of avocados, variety Hass. The impact of pollination was compared in three experimental conditions of branches with flowers every time on the same tree; (a) branches with flowers subject to open pollination, (b) branches with flowers that were confined with

fine mesh to prevent insect pollination, and (c) branches with flowers that were subject to open pollination after the introduction of honeybee hives (photo 2, 3).

Photo 3. Honeybee on flower of Avocado in San Marcos, Tarrazú, Costa Rica (photo by author).

The branches where no insect pollination was possible did not produce fruits at all. Where open pollination occurred (but before honey bees were introduced at the field), the flowers were visited by flies, beetles and several species of native bees, which resulted after one month in very small avocados, with an average weight of only 15 gram. When four beehives were introduced at a short distance (on average less than 50 m from the trees), to promote an intensive pollination, twelve times more avocados were produced, with an average weight after one month of 181 gram. This clearly indicates the importance of honeybees for the pollination of avocados. Even though avocados are native to Mexico, and native Meliponinae and Vespidae pollinators should be present, generally spoken only intensive pollination by honeybees gives a good production. In Australia organic avocado producer Michael Hogan uses 80 hives of native stingless bees successfully for pollination of his four hectare avocado orchard.

Coffee (*Coffea arabica*)

It is well known that this species of coffee has hermaphrodite flowers, which are largely self-pollinated, a process improved by wind and (rain) water. However several authors mention that honeybees and other bees can contribute to its pollination (Roubik, 1995; Slaa et al., 2006). CINAT staff was involved in two studies performed by students and researchers of CATIE, the Tropical Agricultural Research and Higher Education Centre. The results demonstrated that in coffee farms close to forested areas a much bigger diversity and quantity of bees could be found than in coffee fields in agricultural areas without nearby forests (Florez Fernández, 2001; Solís Rodríguez, 2014). The effect on the productivity of the coffee crop was on one hand a larger percentage of seed set in presence of bees visiting the fields from the nearby forests in comparison with a lower percentage of seed set when bee presence was lower due to the far distance of the crop fields to forested areas. On the other hand the size and weight of the fruits was on average 15% more when pollinated by honeybees. The larger the distance between the coffee fields and the forest, the smaller the number of bees and bee species that were observed on the coffee flowers during blooming, and a diminished effect on the productivity of the crop was measured. Next to *Apis mellifera* twenty species of stingless

bees (Meliponini) and other bees such as Halictidae and Antophoridae were identified (Solís Rodríguez, 2014).

Tomato (*Lycopersicon esculentum*)

In a study performed by CINAT student Laura Méndez and researcher Luis Sánchez (2013), the efficiency of the stingless bee *Nannotrigona perilampoides* for the pollination of tomatoes in greenhouses was studied in Guanacaste, Costa Rica.

Photo 4. *Nannotrigona perilampoides* on flower of tomato in greenhouse in Guanacaste, Costa Rica
(photo courtesy of Luis Alejandro Sánchez Chaves).

The researchers installed three cages inside the greenhouse measuring 4(L) x4 (W) x3 (H) m, in each of which 45 tomato plants were grown. During two months, daily observations were performed on flower visitation by this stingless bee (photo 4) in one of the cages, and compared with the results of hand pollination with the use of a hand air blower in one of the other cages and without any pollination activity in the third cage. They found that in the cage where N. perilampoides had been present, fruits were of significantly better quality: bigger diameter, heavier, well formed, and contained more seeds. No difference was found in the number of fruits between treatments or the fruit set.

Pollination of Vanilla (*Vanilla planifolia*)

A CINAT master's student, Mario Gallardo, studied pollination of *Vanilla pompona* in a small farm near Guápiles during blooming season from February to April 2013. Some 500 plants of the Vanilla orchid were grown in an area of about 7000m^2. He introduced 2 hives of the stingless bee *Melipona costarricensis* in order to study the behavior of this species on the flowers and observe if pollen packets or pollinia would be transported by it. Historically it was suggested in Mexico (Dressler, 1981) that Melipona bees are pollinators of Vanilla, which is more recently considered doubtful by others (Gigant et al., 2011; Lubinsky et al., 2006; Roubik, 1995). Gallardo found that *Euglossa flammea, Euglossa ignita* and *Eulaema cingulata* bees were the most frequent visitors on the flowers of Vanilla. He never observed any *Melipona costarricensis* on the flowers despite having two colonies within the crop field. The only bees that after visiting the flowers of the Vanilla flowers were observed carrying pollinia in their thorax were a few of the male *Eulaema cingulata* bees. Even though Melipona is reported to be an occasional

visitor of *Vanilla planifolia* and *Vanilla pompona* (Lubinsky et al., 2006), no pollen movement was observed by them neither in Peru nor Mexico. Several *Eulema* species are mentioned as pollinators for *Vanilla planifolia* and *Vanilla pompona* (Lubinsky et al., 2006). Gallardo's results are in accordance with these observations by Lubinsky (et al., 2006).
Since flowers of *Vanilla* do not seem to produce nectar, the rewards that may be collected by males of Euglossine bees are oil, floral fragrances, and occasionally pollen. The collection of fragrances by male *Euglossa*, known as "male euglossine syndrome" or "perfume flower syndrome" is not known for males of *Melipona*.

Pollination of the Brazil Nut (*Bertholletia excelsa*)

A good example of the economic value of native bees for the pollination of crops in the tropics is the Brazil Nut tree. This tree grows in tropical South America, especially in the Amazon basin. It can grow 50 m high and live for hundreds of years. The nut is an important export product of the amazon rainforest. Yearly, in Brazil only, the local people, who live in the forest, harvest more than 40,000 tons. It is their most important economic income from non-timber forest products. The nuts are praised for being a healthy food, rich in minerals, vitamin E, fats and proteins. Studies concerning the pollination biology of the tree demonstrated that an orchid bee, *Eulema mocsaryi*, is one of the most common visitors of its flowers and the most important pollinator. The bees are attracted to the Nut trees by an orchid, *Cattleya eldorado*, with which they have a symbiotic relationship. In the forest these orchids occur naturally on the Nut trees. The males collect etheric oil on the flowers of the orchid, which makes them more attractive for the female bees so that their chance for mating improves. Only where the orchids grow in the Brazil Nut, the tree is pollinated efficiently by *E. mocsaryi*, and produces abundant nuts. In areas where the tree is planted and *Cattleya eldorado* does not occur, only few *Eulema* bees visit the tree, resulting in a poor pollination and a small nuts harvest. Since honeybees cannot pollinate the flowers of the Brazil Nut tree, it is not an important crop for beekeepers.

Concluding remarks

Many tropical crops depend on bees for pollination or are known to benefit greatly from pollination by bees. In many tropical countries beekeeping is an important income generating activity, often limited to honey, pollen and wax production, but in growing numbers also through the rental of hives for pollination services of crops grown at a large scale for export. The pollination requirements for few crops, such as melon, watermelon, tomato and papaya are fairly well understood, but for many others crops, especially for those that are not pollinated by honeybees, much research is needed. There is a great potential for beekeepers offering pollination services, and also for the use of native (stingless) bees as pollinators for some crops.

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