



Apis mellifera in Mexico: honey production, melliferous flora and pollination aspects. Review



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Abstract:

The honeybee, *Apis mellifera*, is a species that, since its introduction to Mexico, has had great social, cultural and economic importance, representing an important source of income for thousands of families who are engaged in beekeeping. However, in the context of the so-called “pollinator crisis”, it is considered that we do not know how this phenomenon affects *A. mellifera* in Mexico. In review, it is analyzed and discussed the information about *A. mellifera* in Mexico related to the phenomena that affect its distribution, honey production and its ecology, including interactions with the local flora. In general, it is considered that there is a need for an integration of data on beekeeping at the national level, and that there are few studies on the ecology of *A. mellifera* in Mexico, from the flora they visit, their efficiency as a pollinator and competition with other native bee species. It is believed that increasing studies on *A. mellifera* will help to predict changes in honey production as well as understand and address threats to these pollinators, contributing to

generate better management practices and establish better pollinator conservation strategies that include the presence of *A. mellifera*.

Key words: *Apis mellifera*, Beekeeping, Pollination, Honey, Hives.

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Introduction

From the identification of the so-called “pollinator crisis”^(1,2), which identifies the collapse of different groups of pollinators in various parts of the world, especially in North America and Europe, much interest has arisen to understand the role of the honeybee, *Apis mellifera*, in the different ecosystems where it lives. This interest results from the fact that *A. mellifera* is a species of great importance for humans for providing goods such as honey, wax, pollen, propolis and other derivatives of the colony^(3,4), as well as for its role as a crop pollinator⁽⁵⁾. Currently, the commercial, cultural, nutritious and medicinal value of honey has caused that, of the eleven species existing in the genus *Apis*, the species *A. mellifera* (Apidae: Apini), known as honeybee or in some localities as swarms or European bee, due to its origin, is the most valued worldwide⁽⁶⁾. In Mexico, *A. mellifera*, despite being an introduced species, has a great cultural and commercial value, heir to the importance that the Mesoamerican peoples gave to bees because they were part of their traditional activities⁽⁷⁾.

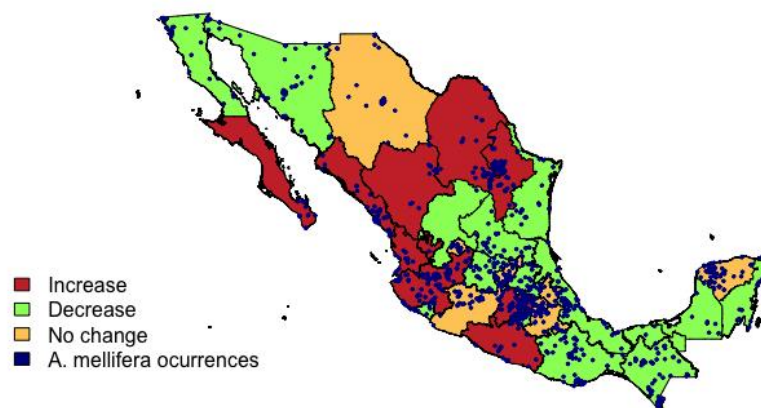
Given the environmental crisis of pollinators, the phenomenon of collapse in Latin American countries seems less accentuated, and the effects on bee populations respond to processes related to the type of beekeeping management, land use change and the type of agricultural practices⁽⁸⁾. In this context, it is necessary to review the current state of knowledge about this species in our country, in order to know its role in the productive aspects, its insertion in ecosystems, and analyze the threats to which they are subject. Likewise, identify the information gaps that exist and should be reviewed in the context of the “pollinator crisis” and climate change, as phenomena that represent threats to natural and managed populations of pollinators. Identifying these points would help establish better management and action strategies at the national level to support this important activity. This paper aims to assess what is known about *A. mellifera* in Mexico from an ecological and socioeconomic perspective from a review of the literature and official government data.

A bit of history

The presence of the honeybee, *A. mellifera*, in Mexico, and its importance as an ecological and social element within the country is the result of different processes that take to back to Mesoamerican cultures and the time of the Spanish colony, when, around 1760 and 1770, *A. mellifera* was introduced^(9,10). The management of meliponines or stingless bees (Apidae: Meliponini) represented an activity of important cultural value in different Mesoamerican peoples (e.g., Mayans, Nahuas and Totonacs;⁽⁹⁻¹¹⁾). This biocultural relationship with stingless bees was also transferred to *A. mellifera*, replacing the products obtained from the colonies of stingless bees, although it did not completely displace them⁽¹²⁾.

Despite its presence since colonial times, beekeeping began as an activity of economic relevance until the mid-twentieth century⁽¹³⁾. Since then, different varieties of *A. mellifera* have inhabit practically the entire continent, and, in the warm areas, they are almost all Africanized, a process that has happened over more than half a century since their arrival on the continent in 1956⁽¹⁴⁾. Due to the above and due to the use of the different floral resources where beekeepers move or keep their bees, *A. mellifera* is currently established in most of the ecosystems of this country⁽¹⁵⁾ (Figure 1).

Figure 1: Records of the presence of *Apis mellifera* in Mexico from data obtained in the Global Biodiversity Information Facility, GBIF (without duplicate data) and changes in beehives per state



The colors of each state indicate whether in the period from 2009 to 2018 (SIAP) there has been a decrease (red), increase (green) or no change (yellow) in the number of hives recorded (negative binomial analysis)

Abundance and distribution of colonies

The success in the introduction of *Apis* in most of the world is because it is a generalist or polylectic species, that is, it can visit a great diversity of flowering plants to collect nectar, pollen and resins, and produces large amounts of honey that can be used by people. Considering that *A. mellifera* is an exotic species and of great economic importance in Mexico, its geographical distribution and abundance in the different ecosystems, both managed and wild colonies, still lacks precise information to analyze its spatiotemporal distribution.

A review of the official records obtained from the database of the National Commission for the Use and Knowledge of Biodiversity (CONABIO, for its acronym in Spanish) and the GBIF (Global Biodiversity Information Facility), shows us that, for Mexico, there are only 1900 records of *A. mellifera* (without duplicate data; Figure 1). This contrasts with the data from beekeepers' associations and SAGARPA data, which, up to 2016, estimated around 45 thousand beekeepers who manage around 1.9 million hives throughout the country^(6,13), and 2018 censuses estimate around 2.172 million hives⁽¹⁶⁾. This discrepancy highlights the need to integrate productive information with biological information to have a better understanding of the situation of *A. mellifera* in Mexico, not only of its distribution in apiaries but also of those colonies that have escaped management.

In a review of the national agricultural survey developed by INEGI in 2016, was found that there are 7,080 apiaries with at least one hive, and they estimate an area of approximately 613,090.22 ha of land with apiaries, however, they do not report the number of hives that are kept per apiary, nor is the foraging area of bees clear. Despite having data on the number of hives and an approximation of the number of apiaries, it is still necessary to integrate the geographical information of the location of apiaries, both those that are moved to take advantage of the different flowerings and those with sedentary management. If the estimated area is divided by the number of hives reported by SAGARPA and SIAP (1.9 or 2.17 M), the information suggests that there are between 3 and 3.5 hives per hectare nationwide, which represents a low number. However, it is known that there are five main beekeeping regions in Mexico (Altiplano, Pacific Coast, North, Gulf and Yucatán Peninsula), and that they do not have the same national representation in honey production, so it is necessary to better integrate the data on the number of hives by territory (region, state, municipality) as well as the foraging area of bees. Likewise, the saturation of hives is influenced by the types of flowering, whether natural or from crops, for example, orange or orange blossom honey that is produced in citrus-growing areas or butter honey from the Mexican plateau and have a greater number of associated colonies⁽⁶⁾. Therefore, the nonhomogeneous spatial distribution of hives, as well as the interest of beekeepers in

seeking certain flowerings to increase the value of honey, results in regions with a higher density of bees and others that are underutilized.

In the context of land use change and high levels of deforestation in the national territory⁽¹⁷⁾, it is of vital importance to have information on the ecological quality of the foraging territories that support bee populations, both *A. mellifera* and native bees. This information could be very valuable to inform the policy that regulates beekeeping by knowing which territories are more favorable to locate apiaries and manage the movement of hives, while promoting better coordination between the associations of the different beekeeping areas of the country. This is particularly for those beekeepers who seek organic certification, which is increasingly demanded by the market, and therefore has been increasing and requires particular environmental conditions for the foraging of bees. On the other hand, very little is known about the wild colonies of *A. mellifera*, and it is not known if CONABIO records include this type of colonies, which in general belong to Africanized colonies that have escaped human management and have become feral^(18,19).

The loss of hives due to different factors such as diseases, pesticides, climatic phenomena such as frosts, hurricanes, lack of food due to alterations in flowering, as well as absconding (when bees leave the nest and migrate elsewhere) and swarming (when the colony divides and a large part of the bees leave the nest to form a new one) processes, is a problem little studied in Mexico, despite being commonly mentioned, mainly in the media. A study conducted by Medina-Flores⁽²⁰⁾, who interviewed 196 beekeepers from 14 states of the republic, revealed that during the winter of 2015-2016, of the total of 41,907 hives they managed, about 33 % were lost. The reasons for this loss were attributed to bad weather, diseases, pesticide use, absconding and swarming. On the other hand, this paper analyzes the official data on the number of hives by state from 2009 to 2018⁽¹⁶⁾ (negative binomial model: number of hives by state ~ year) in order to know if there is evidence of a significant reduction in hives. The result of the analysis revealed that, on the contrary, for 16 states there is a significant increase in the number of hives (Figure 1), while a significant decrease was observed only in 9 states and no change is observed in 7 states. The states with the highest number of hives coincide with the states with the highest honey production (Yucatán, Campeche, Quintana Roo; Table 1). Although beekeeping has grown in some regions and has remained stable in others, this does not necessarily mean that there have been no decreases in the number of colonies, but rather that these could have been replaced or that there is an increase in the number of beekeepers.

Table 1: Results from negative binomial analyses per state evaluating the increase or decrease of beehives in ten years (2009, 2018; SIAP)

SATE	Deviance # Hives~Year	P (Chi-square)
Aguascalientes	0.08456	0.000212 ***
Baja_California	7.8445	0.005097 **
Baja_California_Sur	11.114	0.0008569 ***
Campeche	5.9368	0.01483 *
Coahuila	12.716	0.0003626 ***
Colima	24.87	6.13E-07 ***
Chiapas	36.623	1.43E-09 ***
Chihuahua	0.85191	0.356
CDMX	0.59024	0.4423
Durango	12.886	0.000331 ***
Guanajuato	19.71	9.01E-06 ***
Guerrero	15.982	6.39E-05 ***
Hidalgo	15.921	6.60E-05 ***
Jalisco	5.5714	0.01826 *
México	12.899	0.0003287 ***
Michoacán	0.44123	0.5065
Morelos	111.34	2.20E-16 ***
Nayarit	5.887	0.01525 *
Nuevo_León	13.428	0.0002478 ***
Oaxaca	49.825	1.68E-12 ***
Puebla	3.509	0.06104
Querétaro	0.029103	0.8645
Quintana_Roo	83.473	2.20E-16 ***
San_Luis_Potosí	143.68	2.20E-16 ***
Sinaloa	64.141	1.16E-15 ***
Sonora	38.018	7.01E-10 ***
Tabasco	88.249	2.20E-16 ***
Tamaulipas	25.088	5.48E-07 ***
Tlaxcala	0.26805	0.6046
Veracruz	20.788	5.13E-06 ***
Yucatán	0.090502	0.7635
Zacatecas	26.363	2.83E-07 ***

Analyses were performed in R 3.5 (R Development Core Team, 2011) with MASS package (Venables and Ripley; 2002⁺). Asterisks indicate significant effect of year over the number of beehives.
⁺Venables WN, Ripley BD (2002). *Modern Applied Statistics with S*, Fourth edition. Springer, New York. ISBN 0-387-95457-0,

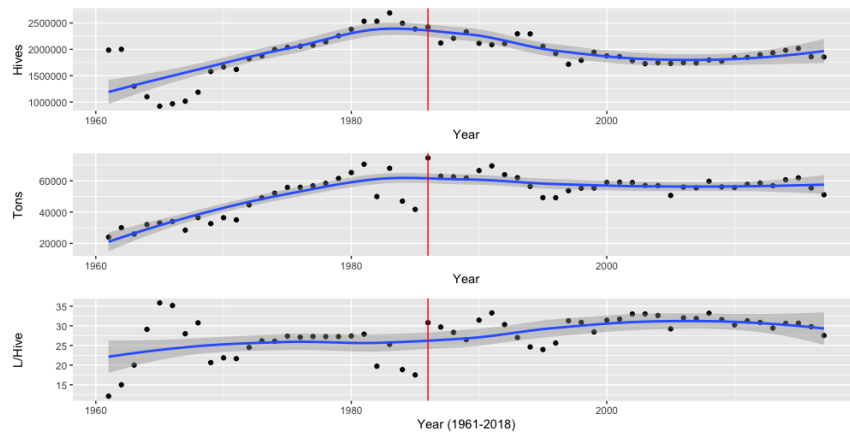
Honey production in Mexico

Current beekeeping is present to a greater or lesser degree in the 32 states that Mexico comprises, according to data from the Secretariat of Agricultural, Rural Development and Fisheries⁽¹⁵⁾. The benign climate in much of Mexico makes it possible for the colonies of *A. mellifera* remain active throughout the year⁽¹⁴⁾, as well as the great diversity of plants and ecosystems that allow a great variation in the quantity and quality of the honey that is produced, which sometimes gives an added value to this product⁽²¹⁾. Due to the diversity of these ecosystems and the socioeconomic characteristics of beekeepers, the activity is carried out under two schemes 1) Fixed or sedentary beekeeping, where the apiaries that contain the hives are kept in the same place throughout the year, and 2) Transhumance or mobile beekeeping. In this, the apiaries are moved to different sites throughout the year, according to the flowerings of interest of the beekeeper⁽²²⁾. Fixed beekeeping is favored in places where floral resources remain more or less constant throughout the year or in cases where beekeepers decide to make fewer annual harvests, of a smaller scale. Transhumance is favored in places with greater seasonality or fewer floral resources and is a strategy used to increase the number of annual harvests⁽²²⁾. In any of its two forms of use of nectar-polliniferous resources, the beekeeper learns to know the behavior of the flowering seasons and schedules the harvest times, so that, depending on the place and management techniques used, one, two or even three or more annual harvests can be achieved⁽²³⁾. Thus, the amount of honey produced per hive depends in part on the nectar-polliniferous resources present in the different beekeeping areas of the country, although there are other factors such as the time of year, the ecosystem, diseases, as well as the investment capital of beekeepers⁽²⁴⁾.

For approximately 30 years, the management of the *Apis* colonies has led to Mexico being among the ten most important countries in honey production worldwide⁽²⁵⁾. Among the most important regions in terms of honey production are the Yucatán Peninsula (Campeche, Yucatán and Quintana Roo), Jalisco and Veracruz⁽¹⁶⁾.

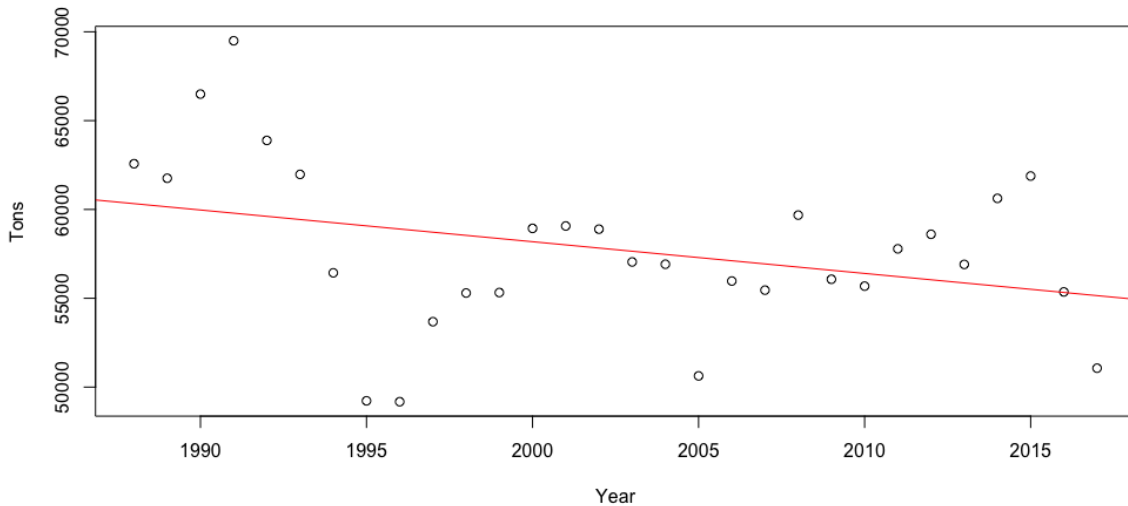
Historical data on honey production indicate that the number of hives and total honey production increased substantially from the 60s and were on the rise before 1986, when the Africanized bee was first recorded in the south of our country (a hybrid of European varieties with African varieties;^(26,27); (Figure 2). Nevertheless, Mexico ranked third worldwide in 1991, with 63,886 t⁽²⁶⁾. However, honey production has been decreasing since 1986 and Mexico ranked ninth in honey production in 2017, with 51,066 t⁽²⁵⁾ (Figure 3).

Figure 2: Historical data on the number of hives, total honey production per year (tons) and honey production per hive (kg) in Mexico from 1961 to 2018 (FAOSTAT, 2020)

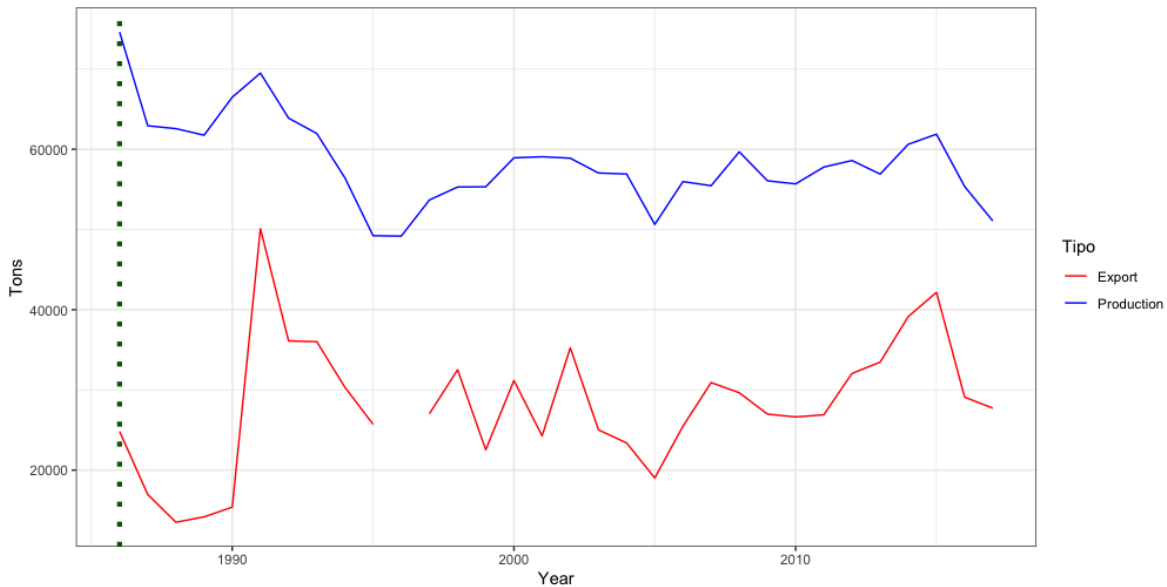


The red line indicates the year that was recorded as the beginning of the process of Africanization of the European bee in Mexico.

Figure 3: Honey production in Mexico in the last 31 years (1986-2017). Data from (FAOSTAT, 2020)



On the other hand, honey exports before 1990 represented a very low percentage of total production (between 21-33 %). However, as of 1990, the average export of honey increased to 52.5 %, with around 30,333 t per year between 1991 and 2017⁽²⁵⁾ (Figure 4). Thus, in some years, exports represented around 40 % of total production, while 2015, which was one of the best years for export, represented 68.1 % of total production⁽²⁵⁾.

Figure 4: Honey production and export from 1986 to 2017 (FAOSTAT, 2020)

The dotted line indicates the year in which the record of Africanization began in Mexico

This despite the increase in restrictions and demands of the international market, and the market fluctuations that are affected by different aspects, both internal and external⁽²⁸⁾. The main importing countries of Mexican honey have been Germany, the United States and the United Kingdom, countries with a long tradition of consumption. In contrast, domestic consumption of honey is very low⁽²⁸⁾, and the percentage of losses for beekeepers from production that is not exported and not consumed locally is unknown.

In summary, despite Africanization, Mexico has positioned itself as one of the largest producers of honey and its production has increased compared to decades prior to the entry of African bees. However, the decrease in hives and the declines in honey production in recent decades have been attributed to multiple reasons that together have affected beekeeping activity^(6,13). One of the main reasons was the arrival of Africanized bees, which produce less honey, swarm easily, and having a more defensive behavior have generated economic losses due to damage caused, which caused many beekeepers to abandon the activity⁽²⁷⁾. Despite this, Africanization has not had the same effects in all regions and, in some, it could even have benefited beekeeping, because they are better adapted to tropical environments and because they became a source of colonies (collected from the field) for beekeepers⁽²⁹⁾. Since the Africanization process began in the country, in the 1980s, the National Program for the Control of the African Bee was developed to counteract these negative effects and integrate its presence into management⁽³⁰⁾.

On the other hand, the decrease in production in the mid-90s coincides with the presence of the mite *Varroa destructor*, first reported in Mexican territory⁽³¹⁾. This parasite

infests the hives and feeds on the hemolymph of the bees, promoting the entry of other diseases associated with different viruses⁽³²⁾, affecting the reproduction and population of the colony, which means a lower production of honey and, in extreme cases, its death⁽³³⁾. This disease is currently controlled with the application of drugs based on components such as thymol, oxalic acid and formic acid, among others⁽³⁴⁾. However, there are controversies regarding their use and abuse, and even organic certification measures limit the type of drugs that can be used^(23,35). Another recent problem has been the proliferation of the small hive beetle (SHB) *Aethina tumida* Murray 1867, since it was first reported in Mexico in 2007⁽³⁶⁾ or the case of fungi of the genus *Nosema*, which have been found in the country since 1965⁽³⁷⁾. The consequences of such diseases should not only be measured in the context of the loss of colonies of *A. mellifera*, but they could have ecological consequences when transmitted to other pollinating insects.

Another aspect that may be relevant in honey production in Mexico is the frequent presence of natural phenomena, such as hurricanes and storms, which can be further altered by the effects of climate change^(38,39). Changes in flowering times, resulting from drought events or alterations in rainfall patterns, are another destabilizing factor for beekeeping⁽⁴⁰⁾; because beekeepers need to coordinate and anticipate the flowering time to ensure that hives are ready for honey harvest time⁽²³⁾. Among the regions with the highest incidence of these phenomena, the Yucatán Peninsula and Veracruz stand out, which together represented 45 % of the total honey production in 2018, and the Pacific coasts, especially the states of Jalisco, Guerrero, Michoacán, Chiapas and Oaxaca, that represented 26 % of production. Future analyses should try to consider how these climatic phenomena alter beekeeping activity in the country.

Finally, the availability of resources for honey production depends on the vegetation cover in the different ecosystems. The change of land use towards agricultural uses with intensive and industrial management and the consequent loss of floral diversity mean fewer floral resources for bees⁽⁴¹⁾. In addition to the problems with the use of toxic agricultural chemicals and even the use of genetically modified organisms that affect the health of bees⁽⁴²⁾. However, the interaction of forest cover loss or change and its effects on both native and introduced bees is another situation that has been little studied in Mexico^(43,44).

All these factors contribute to the fluctuations in production and number of hives reported in this study. In addition, the variation in the quality of honey, its floral origin, associated with the variation in honey production, are directly related to its commercialization, since the standards in the regulation of honey for export must be met (see NOM-004-SAG/GAN-2018). According to Soto-Muciño and collaborators⁽⁶⁾, in Mexico, beekeepers with high commercial power have decreased and beekeepers with small and medium production have increased. This could represent a window of opportunity to promote beekeeping in regions where the management of *Apis mellifera* is a complementary activity within the agricultural

and livestock practice, as is already the case in the north of the country, as well as to promote beekeeping, especially under agroecological management, and that it is a source of income and family employment.

An important part to promote the care of bee colonies is to improve production conditions and have a better assessment of the state of beekeeping in Mexico and have better data on the number of hives, the socioeconomic characteristics of beekeepers in different regions, management statistics, and identify their threats in different contexts. Likewise, knowledge about apiary distribution areas, flowering calendars, and coordination between beekeepers to avoid oversaturation of foraging areas are required.

Characterization of honeys and botanical origin

Despite the commercial value of Mexican honey, which is recognized in the Official Mexican Standard (NOM-004-SAG/GAN-2018), and that there is a general characterization of some honeys at the regional level (e.g., multifloral honeys from coffee plantations, or monofloral such as that of orange blossom from citrus flowering (*Citrus* sp.)), there are relatively few studies that evaluate the organoleptic characteristics of honeys (color, taste, smell, etc.)⁽⁴⁵⁾, as well as the botanical composition of honeys^(46,47) (Table 1). These studies are important not only to provide commercial added value to honey in each of the regions, but also to know the interactions of *A. mellifera* with the plants it visits and its possible role in ecosystems.

From a non-exhaustive review of the literature on the melliferous and polliniferous floras of *A. mellifera*, considering papers, book chapters, theses and publications in congresses, about 30 studies that characterize the diversity of plants visited by honeybees were found for Mexico (Table 2). Many of these studies are based on melissopalynological studies, that is, the analysis of pollen grains contained in honey to determine the species used by bees. However, some works are based on literature and direct observations of visits and interviews with beekeepers to learn about the plants in the region that bees visit to obtain nectar and pollen. From this review, it can be said that *A. mellifera* visits an average of 43 plant species per locality, for which the diversity of plant families varies in a range of 16-60 families. Although the number of species visited seems to be high, still not known what percentage it represents of the total native flora in each region and whether honeybees provide them with an effective pollination service. Only for the Yucatán Peninsula, it is estimated that *Apis* visits 40 % of the total flora⁽⁴⁸⁾. Another important aspect is that *A. mellifera* does not always collect pollen from the plants visited and only goes for nectar, so nectariferous plants may be underrepresented in melissopalynological studies⁽⁴⁹⁾.

Table 2: Records of studies on melliferous floras in different states of Mexico for *Apis mellifera* from 1994 to 2019

State	Method	Local (n)	Sample (n)	Family (n)	Species /types (n)	Ref.
QR	Palynological analysis of nectar	1	44 (22 and 22)	-	148	(49)
QR	Analysis of pollen taken from the hive	2	206	41	168	(50)
CAM	Interviews with beekeepers and field observations	1	-	35	146	(51)
TAM	It does not describe methodology (the whole state)	1	-	-	50	(52)
COL	Literature review and observations of visit	1	-	45	140	(53)
VDM	Melissopalynological	2	2	15	19	(54)
MOR	Melissopalynological	3	3	23	41	(55)
YUC, CAM, QR	Melissopalynological	40 (total)	78	15	250	(56)
YUC, CAM, QR	Melissopalynological	17 (total)	168	36	238	(57)
		10 (YUC)	56	26	92	
		5 (CAM)	56	19	66	
		2 (QR)	55	36	80	
YUC, CAM, QR, OAX	Melissopalynological	4	39	29	64	(58)
TAB	Melissopalynological	4	40	36	129	(59)
TAB	Melissopalynological	3	12	32	63	(60)
GUER	Literature review and observations of visit	-	-	53	143	(61)
GUER	Melissopalynological	2	12	27	43	(62)
DUR	Melissopalynological	3	3	16	22	(63)
BC	Melissopalynological	13	52	33	150	(64)
TAM	Melissopalynological	11	27	60	215	(65)
Páztcuaro, MICH	Direct observation of visits and interviews	1	4	33	93	(66)
Hopelchén, CAM	Interview and Herbarium review	1	40 produces	26	56	(67)

Local= municipality, region, state.

The role of *A. mellifera* as a pollinator

Although *A. mellifera* is very productive in terms of its establishment and honey production, it turns out that, from the perspective of plants, it is not necessarily the most efficient pollinator^(1,68). This means that, despite transporting pollen from one flower to another, the amount and place where it deposits it is not necessarily the most suitable for the plant to maximize seed production, and they can even be nectar robbers, that is, they take the nectar without making contact with the androecium and gynoecium of the flower. Despite this, it has been shown that *A. mellifera* is one of the most important crop pollinators so that millions of bees are managed for this purpose globally⁽⁶⁹⁾. Perhaps one of the best-known examples is that of almond cultivation in California⁽⁶⁸⁾, where *Apis* is used as the main pollinator. It is for this reason that the importance of studying and knowing the efficiency of *A. mellifera* as a pollinator of both the local flora and the crops is highlighted. In Mexico, the Beekeeping Pollination Manual⁽⁷⁰⁾ includes recommendations for the use of *Apis* for pollination of different crops (citrus, cucurbits, cotton, etc.). Despite being a species widely used in crops, its efficiency as a pollinator compared to other pollinators is unknown.

In Mexico, studies on the efficiency of pollination by *A. mellifera* in crops are still limited⁽⁷¹⁻⁷⁷⁾. Some studies have even excluded the *Apis* data because it is very abundant, to focus on native bees, so its role in pollination is not known⁽⁷⁸⁾. The studies reviewed reveal that, for some crops, *A. mellifera* is not the most effective pollinator, as in the case of tomatoes and habanero peppers⁽⁷³⁾ or as in coffee⁽⁷⁹⁾. In the case of the squash species *Cucurbita moschata* (Cucurbitaceae), although *Apis* is not the best pollinator (at each visit), its effectiveness is compensated by being very abundant⁽⁷¹⁾. In addition, it was found to be a very important pollinator during the time of year where the main pollinator is absent⁽⁷¹⁾. However, another study on pollination networks in other Cucurbitaceae species (melon, squash, cucumber and watermelon) did not report any visits by *Apis*⁽⁸⁰⁾, indicating that the role of *Apis* as a pollinator is variable. In some cases, *Apis* turns out to be a pollinator as efficient as other native bee species⁽⁸¹⁾, and in others a very important one, as in avocado⁽⁷²⁾, or even more efficient than other pollinators⁽⁷⁷⁾; while in other crops it is irrelevant, as is the case of rambutan, where no visits by *Apis* were observed⁽⁷⁴⁾. In addition, little is known about the effect of *A. mellifera* on species of economic importance that are not cultivated. For example, in different species of *Agave*, it was found that *A. mellifera* is a nectar stealer, that is, it consumes the nectar of the flower but does not pollinate, and in other species it turns out to be a secondary pollinator during the hours of the day when there is less production of pollen and nectar⁽⁸²⁾. Finally, it can be said that the efficiency of *Apis* as an effective pollinator in native species of no commercial importance has been evaluated very little. An example is the work on *Kallstroemia grandiflora*, where it was found that *Apis* is as efficient as native pollinators⁽⁸³⁾. Although there is information in the literature about the

visit of *Apis* to non-cultivated plants, particularly studies on plant reproductive biology, this information deserves to be reviewed to complement the knowledge about the interaction of *Apis* with native plants, but it has not been the subject of this review.

Studies at the landscape level and its effects on pollination indicate that *Apis mellifera* can take advantage of landscapes modified for agricultural or urban uses. A study that compared the effect of shade and sun coffee plantations on bee diversity found that shade coffee plantations harbor greater diversity of bee species, including *A. mellifera*, but that it substantially preferred sun coffee plantations, which have less plant diversity and where the diversity of native bees was lower⁽⁸⁴⁾. In European and South American landscapes, studies suggest that, due to its characteristics, *Apis* seems to adapt and is abundant in highly transformed landscapes, including urban areas and semi-natural forests or with little plant diversity⁽⁸⁵⁻⁸⁷⁾.

Finally, studies on pollination networks are important because they help to understand more comprehensively the role of *A. mellifera* as a floral visitor of different species and its possible interaction with other pollinators. Nevertheless, in Mexico, studies on pollination networks are very few^(80,88-92). These studies reveal that *A. mellifera* is a very abundant species and that it has a large number of connections within the network⁽⁹¹⁾. Given this evidence, there is a need for more studies to evaluate the role of *A. mellifera* in the different ecosystems of Mexico, in its role as a pollinator and in that of its interactions.

Competition with native bees

One aspect that should not be forgotten is that *Apis* is an introduced species and can therefore have negative effects on local fauna, particularly on other bees with which it might be competing for resources. This competence can occur in different ways, and at least seven have been described⁽⁹³⁾. Of these, the most studied are the reduction of pollen and nectar in a community due to the presence of *Apis*; the exclusion of native bees due to prolonged foraging times in floral patches, forcing native bees to travel further in search for resources; the active movement of native bees, mainly in the case of Africanized bees and the transmission of parasites of *Apis* to native bees⁽⁹³⁾. In Mexico, there are still relatively few studies on the matter^(12,79,83,94,95) and of which the work of Villanueva-Gutiérrez *et al*⁽¹²⁾ in Quintana Roo stands out, which showed that *A. mellifera* and the native bee *Melipona beecheii*, in a context of abundant floral resources, avoided competition by diversifying resources, that is, they avoided visiting the same plants. A similar result was found in studies of competition between *Apis* and three other native bees, among them *Partamona bilineata* (a stingless bee), in squash and watermelon crops in Yucatán⁽⁹⁵⁾. Another study suggests

that *Apis* displaces native pollinators in coffee plantations because it was found that the greater the presence of *A. mellifera*, the lower the richness of other bee species⁽⁷⁹⁾.

Several studies in other parts of the world have shown that *Apis mellifera* is capable of displacing native bees; however, critics of these studies argue that competition has not been demonstrated because these studies have not explored the effects on the adequacy of native bees⁽⁹³⁾. However, evaluating the success of native bees against interaction with *Apis* is very complicated if one considers that for most native bee species is know practically nothing about their natural history, even for most species only females have been described [personal communication from experts in the area⁽⁹⁶⁾].

Finally, the arrival of the Africanized variety of *Apis mellifera* could have altered the relationship with other native bees, since these varieties are more aggressive when it comes to defending their hive and floral resources, in addition to the fact that the Africanized bee is more adapted to become feral than European varieties^(13,20). Future studies should evaluate the role of feral colonies of *A. mellifera* on pollination and on other native bees and insects.

Competition with other species is mainly for floral resources, although it is not dismissed that they also compete for nesting sites. Studies on this subject are needed. Considering the transformation of the landscape and the reduction of the floral supply in transformed or impoverished landscapes, and the high densities of European bees in some areas of Mexico, it wonders if there would be greater competition between native bees and *A. mellifera* for plant resources, or if in landscapes with greater floral diversity the competition is less. This point is relevant to the regulations regarding the management of *A. mellifera*, as well as to the conservation of native fauna and of which there is no evidence.

Conclusions

The evidence presented indicates that although *A. mellifera* is an extremely important species both culturally and economically for thousands of Mexican families, and that, compared to native bees, it has been much more studied, there is still a need for studies that address both productive aspects from the generation of better databases on production, management, diseases, etc., and ecological aspects, such as its interaction with local fauna. On the other hand, and under the current scenario of global change, including climate change, land use changes and pollution, among other aspects, there is a need to have more ecological studies on *A. mellifera* in Mexico. These studies will help to predict changes in honey production as well as understand and address threats to these pollinators, contributing to the generation of better management practices. On the other hand, it will help to

understand more about its interactions with other bee and plant species, and to be able to have better conservation strategies that include the presence of *A. mellifera*. Likewise, it will provide valuable information that contributes to the management of other native bees in order to improve agricultural practices by considering the pollination efficiency of different pollinators, including *A. mellifera*.

Based on this review, it is concluded that studies of pollination ecology that integrate the role of *A. mellifera* not only in species of economic importance but in other groups of plants are very relevant. Likewise, more studies on the various threats to pollinators in general are needed. Although there are global patterns of the role of changes in the landscape on the loss of pollinators and the service of pollination, which can be extrapolated to the country, the ecological, orographic, and cultural complexity of Mexico demand a better characterization of the current state of pollinators and particularly of *A. mellifera*, due to its economic and biocultural importance.

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