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The melliferous flora of Veracruz, Mexico

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ABSTRACT

Objective: To contribute to the knowledge of the situation of the melliferous flora in Veracruz for pollinators and to communicate it for the benefit of beekeepers and stingless beekeepers, as well as to develop comprehensive strategies with these activities.

Design/Methodology/Approach: The information was obtained through a bibliographic review in reference databases such as Scopus, Web of Science Group, Academic Google, Elsevier and Springer Link, using the following keywords: flora, bees, pollinators, honey, pollen.

Results: 63 families were recorded, with 176 genera and 216 species of melliferous flora, finding that the largest number of species are found in the Fabaceae family (20%) and Asteraceae (16.55%). There were also 44 crops with 22 families.

Study Limitations/Implications: There were no limitations in conducting this study.

Findings/Conclusions: The greatest diversity of melliferous flora species is related to wild plants, and strategies need to be implemented for their protection and multiplication. For these actions, various actors must be involved at different levels of government, educational and private institutions, civil society, farmers, beekeepers, and stingless beekeeping. Conservation actions include the use of melliferous plants in gardens and their protection in crops, sites surrounding crops and on edges. It is necessary to preserve natural landscapes and restore damaged ones, as well as to lead favorable practices in pollinator-dependent crops.

Keywords: flora, bees, pollinators, honey, pollen.

INTRODUCTION

Bees maintain a close relationship with melliferous flora, since they depend on them for their food, when consuming nectar and pollen obteined from the flowers. Likewise, they also collect resinous material that they use for the construction of their nest and for the elaboration of propolis, which serve as protection against pathogens and predators (Bonet and Vergara, 2016).

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Melliferous flora or honey flora is made up of plants that produce resins or whose flowers produce nectar and/or pollen; it is classified into polliniferous, nectariferous or pollen-nectariferous (Montoya-Bonilla *et al*., 2017). In exchange for food or resins that the bees receive from wild and cultivated plants, they pollinize their flowers thus favoring the formation of fruits that serve as food for human beings and other animals, contributing with this to food security and ecological equilibrium of ecosystems (Alquisira-Ramírez, 2019).

The availability of flower resources for the development and reproduction of bee colonies is required during the whole year. This is achieved through short flowering periods that most agricultural crops have, as well as native plants of the Asteraceae and Fabaceae families, which are important to feed the populations of bees and other pollinators because they are the most visited (González-Suárez *et al*., 2020).

The conservation and multiplication of melliferous flora is of huge interest for beekeepers and meliponiculture producers, because they ensure the production and quality of honey from their bee colonies (Araujo-Mondragón and Redonda-Martínez, 2019). In order to achieve this, the following strategies have been applied: use of melliferous plants in agroecologic gardens, or else interspersed in the crops or on the edges of the paths (Kremen and M'Gonigle, 2015; Landaverde-González *et al*., 2017).

The implementation of conservation strategies for both melliferous flora and pollinators is vital, since the absence or decline of the populations of any of them can impact their survival, in addition to reducing the production of fruits and seeds, which will have an environmental, social and economic impact globally (Hipólito *et al*., 2016; Wilson *et al*., 2017).

Therefore, the objective of this study was to understand the situation of the melliferous flora of the state of Veracruz, Mexico, through a bibliographic review with the aim of broadening knowledge about the available flower resources for pollinators, in addition to contributing with this information to beekeepers and meliponiculture producers to develop integral strategies in these activities.

MATERIALS AND METHODS

The information of melliferous flora of the state of Veracruz, Mexico, was obtained through the bibliographic review of the reference databases Scopus, Web of Science Group, Academic Google, Elsevier and Springer Link, using the following keywords: flora, bees, pollinators, honey, pollen. The information was systematized assigning categories of use, phenology, taxonomy and biology, in the following way: family, scientific name, resource that bees are supplied with —nectar or pollen—, flowering period, status —whether native, exotic or naturalized—, and life form; in the case of crops pollinated by bees, the common name was added.

RESULTS AND DISCUSSION

Flora in Mexico

In Mexico there is a record of 23,314 species of vascular plants, among which 2,854 genera, 297 families and 73 orders were included; in this flora there are 149 gymnosperms and 22,126 angiosperms (Ulloa *et al*., 2017; Villaseñor, 2016). The state of Veracruz occupies the third place in floristic richness of the country (Martínez-Adriano *et al*., 2016), divided into 271 families, 1,956 genera and 8,497 species (Villaseñor, 2016).

Despite the great floristic richness of Veracruz, it is primarily threatened by deforestation, as shown in a study carried out by Von *et al*. (2021), in three regions of the state of Veracruz from 2003 to 2013, in the region of the Tuxtlas, with a loss of natural plant coverage of 4.6% (3,516 ha), the old Antigua with 2% (1,634 ha) and Sierra de Otontepec with 1.4% (618 ha). This deforestation also causes fragmentation of habitats, loss of soil fertility, loss of biodiversity, and reduction of environmental services (Ramírez-Bravo and Hernández-Santin, 2016).

Additionally, erosion and genetic loss were caused by the loss of biodiversity, since angiosperms present reduced germination and progeny of lower quality (Aguilar *et al*., 2019), because of the loss of biological corridors for their pollinators (Gómez-Pompa *et al*., 2010), which has the consequence of smaller, scarce and isolated populations at the local scale, landscape and regional, with which their probability of extinction increases (Auffret *et al*., 2017).

Bee-Plant Ecological Interactions

Bees have evolved with plants and present a complex network of inter-specific interactions where sight, smell, moisture detection, contact and weak electrostatic field between a flower and a bee are involved; through these

interactions flowers use bees as vehicles for the transport of pollen for fertilization (Thakur and Nanda, 2020), and the bees benefit from nectar and pollen as sources of food that plants provide, thus establishing an ecological relationship between them known as mutualism. Therefore, bees are attracted by the nectar which is an aqueous substance, rich in sugars, which contributes carbohydrates as main source of energy for the bees. During nectar collection, bees transport pollen from the anthers to the stigma of the plants, thus benefiting a large number of species of angiosperms (Castellanos-Potenciano *et al*., 2012).

Bees, in addition to nectar, use the pollen that they find in the anthers (apical part) of the stamens, both in angiosperms and in gymnosperms; during their visits, foraging bees attract these grains of pollen through the generation of a weak electrostatic field generated between the flower (with negative charge) and the bee's body (positive charge) (Clarke *et al*., 2017).

The way in which the bees harvest pollen from the flowers is by scraping or licking the anther and then sticking it on the carbuncle (cavity that is found in the tibia of the third pair of legs), using nectar to stick the pollen and thus transport it, accumulating it in form of granules; then, they take it to their nest and, generally, they deposit it around the breeding area where the larvae are developing, since it is the protein source for larvae and adults, containing between 10 and 40% of protein (Leonhardt *et al*., 2007; Vossler, 2015).

Pollen is an indicator that allows understanding the botanical and geographic characteristics of beekeeping products such as honey (Stephen, 2014; Thakur and Nanda, 2020). In addition, bees collect resins from some plants for the production of propolis, which they use as building material and defensive substance (Bankova *et al*., 2018).

The interactions that happen between plant and pollinator play an important role in the structure of communities, in addition to determining the diversity, wealth and persistence of species in a specific locality (Martínez-Adriano *et al*., 2018). Entomopalynology studies pollen found in the body or in the intestine of insects and provides information about the migration routes and their feeding, in addition to defining the pollination mechanisms and the foraging resources. Another important research area is Melissopalynology, which studies the botanical and geographic origin of honey, through the analysis of pollen in honey (Stephen, 2014). In palynological studies, there are records that bees, particularly *Apis mellifera*, visit approximately 2,000 plant species (Cadena *et al*., 2019).

Melliferous Plant Species in Veracruz, Mexico

Based on the information gathered through scientific search engines, an inventory of 63 families were obtained, with 176 genera and 216 species of melliferous flora in the state of Veracruz, Mexico. The families that present the highest number of genera are Fabaceae with 20%, and Asteraceae with 16.55%, the same as the highest number of species (Fabaceae 22.58% and Asteraceae 15.59%) (Table 1, Annex 1), as mentioned by González-Suárez *et al*. (2020).

Most of the species of melliferous flora reported for the state of Veracruz are native (85.65%), exotic species contribute 10.19% and naturalized 4.17%. Concerning their life form, 37.04% are trees, 33.80% are herbaceous, 24.07% shrubs, 2.31% arborescent, 2.31% vines, and 0.46% liana. Most of the species of melliferous flora are nectar-producing (37.96%), followed by pollen-producing (32.87%) and, in lower numbers, there are pollen-nectariferous (29.17%) (Figure 1).

The Asteraceae family is one of the most diverse plant families in Mexico, with around 392 genera and approximately 3,005 species; several of its species are of interest to beekeepers (Cadena *et al*., 2019), so they are considered as a nectar-polliniferous family. The

Table 1. The most representative melliferous flora families of Veracruz, Mexico.

Family	Genus	%	Species	%
Asteraceae	24	16.55	29	15.59
Combretaceae	4	2.76	4	2.15
Commelinaceae	4	2.76	4	2.15
Convolvulaceae	3	2.07	6	3.23
Euphorbiaceae	6	4.14	7	3.76
Fabaceae	29	20	42	22.58
Lamiaceae	6	4.14	9	4.84
Malvaceae	8	5.52	10	5.38
Myrtaceae	4	2.76	5	2.69
Poaceae	4	2.76	5	2.69
Rubiaceae	4	2.76	4	2.15
Sapindaceae	7	4.83	8	4.30
Verbenaceae	4	2.76	4	2.15

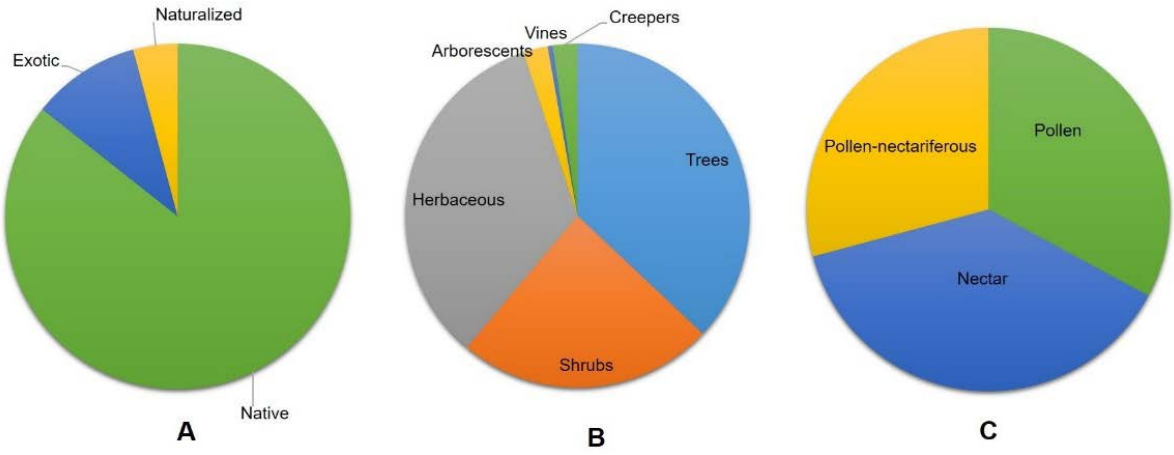

Figure 1. Main characteristics of melliferous flora: A) Status, B) Life form and C) Resource offered to pollinators.

Fabaceae family is also one of the most important in Mexico, since it presents 139 genera and 1,850 species (Ramírez-Arriaga *et al*., 2016).

On the other hand, there is a record of 44 plant species that are cultivated and visited by bees to obtain their food; these crops belong to 23 botanical families, of which 43.18% are nectariferous and the same percentage are also pollen-nectariferous, and only 9.09% are polliniferous (Annex 2, Figure 2).

The crops that depend on pollination are soybean, coffee, tomato and orange; the importance of pollinators in agricultural crops is that they improve the yield and quality of the seeds and fruits, so this service presents a social and economic impact (Giannini *et al*., 2020); however, some of the crops only provide food to pollinators during a few weeks, that is, during a short period, and then they must survive a long scarcity, and although some may migrate, social pollinators require accessible floral resources throughout the year for survival of the colony. For that, wild melliferous flora can provide food and nesting sites, so changes must be made in agricultural practices to foster biodiversity and restore, at least to a certain degree, the complexity of the ecosystem, as well as its functionality and sustainability (Kevan and Silva, 2020).

On the other hand, regional and local crops could depend on more

Figure 2. Crops pollinated by bees: A) *Persea americana* Mill., B) *Citrus limon* (L.) Osbeck, C) *Macadamia integrifolia* Maiden & Betche D) *Byrsonima crassifolia* (L.) Kunth, E) *Capsicum annuum* L. y F) *Zea mays* L. Photographs: Diana Caballero Alvarado.

specialized pollinators, although more research in this regard is required, particularly in small-scale agriculture, since this benefits the local and regional economy, in addition to this knowledge being important in local communities (Giannini *et al*., 2020).

Beekeeping and meliponiculture are important activities thanks to the pollination service that they provide, in addition to the products that bees provide to human beings, such as honey, pollen, wax and propolis, which arise directly or indirectly from the melliferous flora from which working bees feed (Kevan and Silva, 2020).

CONCLUSIONS

In Veracruz there is a great richness of melliferous flora represented by 215 wild plant species, the vast majority of species belong to Fabaceae (20%) and Asteraceae (16.55%). There were also 44 crops detected that provide pollen and nectar to the bees.

The bibliographic references analyzed in this study report that melliferous flora is represented essentially by wild plants, which tend to be eliminated because they are considered weeds. Due to the importance of this type of plants in the life of bees, it is necessary to implement strategies for their protection and reproduction. These actions involve various actors at different levels of government, educational and private institutions, as well as in civil society, although especially farmers, beekeepers and meliponiculture producers. Among the actions for conservation of melliferous flora, the use of melliferous plants in garden design stands out, both in urban and in rural zones in places next to the crops or edges, whether of crops, paths, forests, etc. It is necessary to conserve natural landscapes and restore those damaged by agriculture and livestock activities, as well as using favorable practices for bees in agriculture, primarily for the crops on which these pollinators depend.

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Appendix 1. Melliferous flora in Veracruz state, Mexico

Family	Plant species	Pollen	Nectar	Flowering	Status	Life-form	Reference
Acanthaceae	*Avicennia germinans* (L.) L.	X	X	April-July	Native	Tree	Castellanos-Potenciano *et al.* (2012);Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Bravaisia integerrima (Spreng.) Standl.		X	January-April	Native	Tree	Villegas *et al.* (2000)
Altingiaceae	*Liquidambar* sp.	X		January-March	Native	Tree	Niembro-Rocas *et al.* (2015); Ramírez-Arriaga *et al.* (2018)
Amaranthaceae	*Chamissoa altissima* (Jacq.) Kunth		X	February-April	Native	Shrub	Villegas *et al.* (2000)
	Dysphania ambrosioides (L.) Mosyakin & Clemants	X		April-December	Native	Herbaceous	Contreras-Oliva *et al.* (2018)
	Iresine diffusa Humb. & Bonpl. ex Willd.	X			Native	Herb	Bonet y Vergara (2016)
Anacardiaceae	*Spondias mombin* L.	X		April-May	Native	Tree	Castellanos-Potenciano *et al.* (2012); Contreras-Oliva *et al.* (2018); Niembro-Rocas *et al.* (2010)
Apocynaceae	*Asclepias curassavica* L.		X	May-August	Native	Herbaceous	Villegas *et al.* (2000)
	Plumeria rubra L.	X	X	March-September	Native	Tree	Villegas *et al.* (2000)
	Tabernaemontana citrifolia L.		X	February-April	Native	Shrub	Villegas *et al.* (2000)
Araliaceae	*Dendropanax arboreus* (L.) Decne. & Planch.	X	X	December-August	Native	Tree	Contreras-Oliva *et al.* (2018); Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Oreopanax sp.	X		September-December	Native	Tree	Ramírez-Arriaga *et al.* (2018)
Arecaceae	*Acrocomia aculeata* (Jacq.) Lodd. ex Mart.		X	March-September	Native	Arborescent	Villegas *et al.* (2000)
	Attalea butyracea (Mutis ex L. f.) Wess. Boer		X	January-May	Native	Arborescent	Villegas *et al.* (2000)
	Sabal mexicana Mart.	X	X	December-April	Native	Arborescent	Villegas *et al.* (2000)
Asparagaceae	*Echeandia albiflora* (Schltdl. & Cham.) M. Martens & Galeotti	X		March-June	Native	Herbaceous	Bonet y Vergara (2016); López-Ferrari y Espejo (1995)
	Nolina parviflora (Kunth) Hemsl.		X	January-March	Native	Arborescent	Villegas *et al.* (2000)
	Yucca gigantea Lem.		X	January-April	Native	Arborescent	Villegas *et al.* (2000)
Asteraceae	*Achillea millefolium* L.	X		May-November	Native	Herbaceous	Villegas *et al.* (2000)
	Ageratum houstonianum Mill.	X		All year	Native	Herbaceous	Villegas *et al.* (2000)
	Ambrosia peruviana Willd.	X	X	May-July	Native	Herbaceous	Villegas *et al.* (2000)
	Baccharis conferta Kunth		X	January-March	Native	Shrub	Villegas *et al.* (2000)
	Baccharis trinervis (Cham.) Pers.	X	X	January-March	Native	Shrub	Villegas *et al.* (2000)
	Baltimora recta L.	X	X	July-September	Native	Herbaceous	Villegas *et al.* (2000)
	Barkleyanthus salicifolius (Kunth) H. Rob & Brettell	X	X	January-March	Native	Shrub	Villegas *et al.* (2000)
	Bidens pilosa L.	X	X	September-January	Native	Herbaceous	Contreras-Oliva *et al.* (2018); Parra-Tabla *et al.* (2019); Villegas *et al.* (2000)
	Bidens reptans (L.) G. Don		X	All year	Native	Herbaceous	Villegas *et al.* (2000)

Family	Plant species	Pollen	Nectar	Flowering	Status	Life-form	Reference
Asteraceae	*Bidens triplinervia* Kunth	X	X	December-March	Native	Herbaceous	Villegas *et al.* (2000)
	Chromolaena odorata (L.) R.M. King & H. Rob.		X	September-December	Native	Shrub	Villegas *et al.* (2000)
	Elephantopus mollis Kunth	X			Native	Herbaceous	Bonet y Vergara (2016)
	Helianthus sp.	X			Native	Herbaceous	Contreras-Oliva *et al.* (2018)
	Heliopsis buphthalmoides (Jacq.) Dunal	X			Native	Herbaceous	Bonet y Vergara (2016)
	Melampodium divaricatum (Rich.) DC.	X	X	August-December	Native	Herbaceous	Villegas *et al.* (2000)
	Montanoa grandiflora Alamán ex DC.	X	X	January-March	Native	Shrub	Villegas *et al.* (2000)
	Parthenium fruticosum Less.	X			Native	Shrub	Contreras-Oliva *et al.* (2018)
	Pluchea odorata (L.) Cass		X	September-December	Native	Shrub	Villegas *et al.* (2000)
	Sanvitalia procumbens Lam.	X		August- January	Native	Herbaceous	Villegas *et al.* (2000)
	Simsia amplexicaulis (Cav.) Pers.	X	X	September-December	Native	Herbaceous	Hernández-Villa *et al.* (2020) Villegas *et al.* (2000)
	Simsia eurylepis S. F. Blake	X	X	October-December	Native	Herbaceous	Villegas *et al.* (2000)
	Smallanthus maculatus (Cav.) H. Rob.	X		August-October	Native	Herbaceous	Bonet y Vergara (2016)
	Tithonia tubiformis (Jacq.) Cass.	X	X	December-March	Native	Herbaceous	Hernández-Villa *et al.* (2020) Villegas *et al.* (2000)
	Tridax procumbens L.	X	X	December-March	Native	Herbaceous	Villegas *et al.* (2000)
	Verbesina sp.	X			Native	Shrub	Contreras-Oliva *et al.* (2018)
	Vernonia sp.	X			Native	Herbaceous	Contreras-Oliva *et al.* (2018)
	Vernonanthura patens (Kunth) H. Rob.		X	January-April	Native	Shrub	Villegas *et al.* (2000)
	Viguiera dentata (Cav.) Spreng.	X	X	August-December	Native	Herbaceous	Gónzalez(2014) Villegas *et al.* (2000)
	Viguiera grammatoglossa D. C.		X	August-February	Native	Shrub	Villegas *et al.* (2000)
Balsaminaceae	*Impatiens walleriana* Hook. f.	X		January-June	Naturalized	Herbaceous	Bonet y Vergara(2016)
Berberidaceae	*Berberis trifolia* Schult. & Schult. f.		X	January-March	Native	Shrub	Villegas *et al.* (2000)
Bignoniaceae	*Handroanthus chrysanthus* (Jacq.) S. O. Grose	X	X	January-March	Native	Tree	Villegas *et al.* (2000)
	Tabebuia rosea (Bertol.) DC.	X	X	February-April	Native	Tree	Niembro-Rocas *et al.* (2010; Villegas *et al.* (2000)
	Tecoma stans (L.) Juss. ex Kunth		X	All year	Native	Shrub	Canto *et al.* (2017) Villegas *et al.* (2000)
Bixaceae	*Cochlospermum vitifolium* (Willd.) Spreng.		X	December-May	Native	Tree	Niembro-Rocas *et al.*, (2010; Villegas *et al.* (2000)
Boraginaceae	*Cordia alliodora* (Ruiz & Pav.) Oken	X	X	August-April	Native	Tree	Contreras-Oliva *et al.* (2018); Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Cordia dentata Poir.		X	All year	Native	Tree	Villegas *et al.* (2000)
	Cordia megalantha S.F. Blake	X		February-May	Native	Tree	Villegas *et al.* (2000)

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Brassicaceae	*Brassica rapa* L.	X	X	May-December	Naturalized	Herbaceous	Villegas *et al.* (2000)
	Brassica nigra (L.) W.D.J. Koch	X		December-February	Naturalized	Herbaceous	Villegas *et al.* (2000)
	Raphanus raphanistrum L.	X	X	September-May	Exotic	Herbaceous	Villegas *et al.* (2000)
Burseraceae	*Bursera simaruba* (L.) Sarg.	X	X	February-August	Native	Tree	Contreras-Oliva *et al.* (2018); Herrera-López *et al.* (2019); Villegas *et al.* (2000)
Cactaceae	*Cilindropuntia imbricata* (Haw.) F.M. Knuth	X	X	January-April	Native	Shrub	Villegas *et al.* (2000)
	Opuntia huajuapensis Bravo	X	X	February-May	Native	Shrub	Villegas *et al.* (2000)
	Opuntia stricta (Haw.) Haw.	X	X	February-April	Native	Shrub	Villegas *et al.* (2000)
Campanulaceae	*Lobelia xalapensis* Kunth	X		January-April	Native	Herbaceous	Bonet y Vergara (2016)
Cannabaceae	*Trema micrantha* (L.) Blume		X	February-April	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
Chloranthaceae	*Hedyosmum mexicanum* C. Cordem.	X			Native	Shrub	Ramírez-Arriaga *et al.* (2018)
Combretaceae	*Combretum farinosum* Kunth		X	December-March	Native	Vine	Villegas *et al.* (2000)
	Conocarpus erectus L.	X	X	April-June	Native	Tree	Parra-Tabla *et al.* (2019) Villegas *et al.* (2000)
	Laguncularia racemosa (L.) C.F. Gaertn.		X	February-May	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Terminalia catappa L.		X	February-March	Naturalized	Tree	Villegas *et al.* (2000)
Commelinaceae	*Commelina diffusa* Burm. f.	X		All year	Native	Herbaceous	Bonet y Vergara (2016); López-Ferrari *et al.* (2014)
	Gibasis pellucida (M. Martens & Galeotti) D.R. Hunt	X		All year	Native	Herbaceous	Bonet y Vergara (2016); López-Ferrari *et al.* (2014)
	Tinantia erecta (Jacq.) Schltdl.	X		August-November	Native	Herbaceous	Bonet y Vergara, 2016; Hernández-Villa *et al.*, 2020
	Tripogandra serrulata (Vahl) Handlos	X		All year	Native	Herbaceous	Bonet y Vergara (2016); López-Ferrari *et al.* (2014)
Convolvulaceae	*Convolvulus nodiflorus* Desv.	X	X	May-December	Native	Herbaceous	Villegas *et al.* (2000)
	Ipomoea arborescens (Humb. & Bonpl. ex Willd.) G. Don		X	December-March	Native	Tree	Villegas *et al.* (2000)
	Ipomoea carnea subsp. fistulosa (Mart. ex Choisy) D.F. Austin		X	November-May	Native	Shrub	Villegas *et al.* (2000)
	Ipomoea indica (Burm.) Merr.	X		All year	Native	Vine	Bonet y Vergara (2016)
	Ipomoea triloba L.		X	October-February	Native	Herbaceous	Canto *et al.* (2017) Villegas *et al.* (2000)
	Merremia dissecta (Jacq.) Hallier f.	X	X	All year	Native	Vine	Canto *et al.* 2017) Villegas *et al.* (2000)
Crassulaceae	*Sedum praealtum* A. DC.		X	January-February	Native	Herbaceous	Villegas *et al.* (2000)

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Cucurbitaceae	*Luffa aegyptiaca* Mill.		X	All year	Exotic	Vine	Villegas *et al.* (2000)
	Momordica charantia L.	X	X	All year	Exotic	Vine	Villegas *et al.* (2000)
	Sicyos microphyllus Kunth		X	September-December	Native	Herbaceous	Villegas *et al.* (2000)
Cyperaceae	*Rhynchospora radicans* (Schltdl. & Cham.) H. Pfeiff.	X			Native	Herbaceous	Bonet y Vergara (2016)
Ehretiaceae	*Ehretia anacua* (Terán & Berland.) I.M. Johnst.		X	April-December	Native	Tree	Villegas *et al.* (2000)
	Ehretia tinifolia M. Martens & Galeotti		X	February-July	Native	Tree	Villegas *et al.* (2000)
Euphorbiaceae	*Alchornea latifolia* Sw.	X		December-April	Native	Tree	Niembro-Rocas *et al.* (2010); Ramírez-Arriaga *et al.* (2018)
	Cnidoscolus multilobus (Pax) I.M. Johnst.	X	X	December-March	Native	Shrub	Villegas *et al.* (2000)
	Croton draco Schltdl. & Cham.		X	October-February	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Croton reflexifolius Kunth		X	February-April	Native	Shrub	Villegas *et al.* (2000)
	Euphorbia heterophylla L.	X			Native	Herbaceous	Bonet y Vergara (2016)
	Euphorbia schlechtendalii Boiss.		X	March-June	Native	Tree	Villegas *et al.* (2000)
	Ricinus communis L.	X	X	All year	Exotic	Shrub	Villegas *et al.* (2000)
Fabaceae	*Acacia* sp.	X			Native	Shrub	Ramírez-Arriaga *et al.* (2018)
	Vachellia cornigera (L.) Seigler & Ebinger	X	X	February-April	Native	Shrub	Villegas *et al.* (2000)
	Vachellia farnesiana (L.) Wight & Arn.	X	X	December-May	Native	Shrub	Villegas *et al.* (2000)
	Vachellia pennatula (Schltdl. & Cham.) Seigler & Ebinger	X	X	April-June	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Bauhinia divaricata L.	X	X	All year	Native	Shrub	Villegas *et al.* (2000)
	Caesalpinia cacalaco Bonpl.	X	X	November-February	Native	Tree	Villegas *et al.* (2000)
	Cajanus cajan (L.) Huth	X		September-February	Exotic	Shrub	Villegas *et al.* (2000)
	Cassia fistula L.	X		February-April	Exotic	Tree	Villegas *et al.* (2000)
	Cassia grandis L. f.	X		February-May	Native	Tree	Villegas *et al.* (2000)
	Chamaecrista sp.	X			Exotic	Shrub	Contreras-Oliva *et al.* (2018)
	Cojoba arborea (L.) Britton & Rose		X	January-March	Native	Tree	Villegas *et al.* (2000)
	Dalbergia brownei (Jacq.) Schinz		X	February-April	Native	Shrub	Villegas *et al.* (2000)
	Dalea botterii (Rydb.) Barneby		X	September-December	Native	Herbaceous	Villegas *et al.* (2000)
	Delonix regia (Bojer ex Hook.) Raf.		X	April-July	Naturalized	Tree	Villegas *et al.* (2000)
	Desmodium adscendens (Sw.) DC.	X			Native	Herbaceous	Contreras-Oliva *et al.* (2018)

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Fabaceae	*Desmodium canescens* (L.) DC.	X		April-July	Exotic	Herbaceous	Bonet y Vergara (2016)
	Desmodium tortuosum (Sw.) DC.	X			Native	Herbaceous	Contreras-Oliva *et al.* (2018)
	Enterolobium cyclocarpum (Jacq.) Griseb.	X	X	March-May	Native	Tree	Niembro-Rocas *et al.*, (2010); Villegas *et al.* (2000)
	Eysenhardtia polystachya (Ortega) Sarg.	X	X	September-October	Native	Tree	Villegas *et al.* (2000)
	Gliricidia sepium (Jacq.) Kunth ex Walp.	X	X	December-April	Native	Tree	Niembro-Rocas *et al.* 2010: Villegas *et al.* (2000)
	Haematoxylum brasiletto H. Karst.	X	X	February-March	Native	Tree	Villegas *et al.* (2000)
	Haematoxylum campechianum L.	X	X	September-April	Native	Tree	Gónzalez, (2014) Villegas *et al.* (2000)
	Inga inicuil Schltdl. & Cham. ex G. Don	X	X	February-April	Native	Tree	Niembro-Rocas *et al.*(2010); Villegas *et al.* (2000)
	Inga vera Willd.	X	X	April-May	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Leucaena diversifolia (Schltdl.) Benth.	X		August-December	Native	Tree	Villegas *et al.* (2000)
	Leucaena lanceolata S. Watson	X			Native	Shrub	Villegas *et al.* (2000)
	Leucaena sp.	X			Native	Tree	Ramírez-Arriaga *et al.* (2018)
	Lonchocarpus guatemalensis Benth.		X	February-May	Native	Tree	Villegas *et al.* (2000)
	Lonchocarpus sp.	X			Native	Tree	Ramírez-Arriaga *et al.* 2018)
	Lysiloma acapulcense (Kunth) Benth.	X	X	March-May	Native	Tree	Villegas *et al.* (2000)
	Mimosa albida Humb. & Bonpl. ex Willd.	X		August-November	Native	Shrub	Villegas *et al.* (2000)
	Mimosa pigra L.		X	March-July	Native	Shrub	Villegas *et al.* (2000)
	Mimosa pudica L.	X		September-November	Native	Herbaceous	Bonet y Vergara (2016)
	Mimosa scabrella Benth.	X		December-January	Exotic	Shrub	Villegas *et al.* (2000)
	Piscidia piscipula (L.) Sarg.	X	X	May-July	Native	Tree	Niembro-Rocas *et al.* (2010); Canto *et al.* (2017); Villegas *et al.* (2000)
	Pithecellobium dulce (Roxb.) Benth.	X	X	November-May	Native	Shrub	Niembro-Rocas *et al.* (2010); Contreras-Oliva *et al.* (2018); Villegas *et al.* (2000)
	Pithecellobium insigne Micheli ex Donn. Sm.	X	X	January-March	Native	Tree	Villegas *et al.* (2000)
	Prosopis juliflora (Sw.) DC.	X	X	January-April	Native	Tree	Villegas *et al.* (2000)
	Trifolium repens L.	X	X	All year	Naturalized	Herbaceous	Villegas *et al.* (2000)
	Vachellia pringlei (Rose) Seigler & Ebinger	X	X	February-may	Native	Tree	Villegas *et al.* (2000)
	Verbesina turbacensis Kunth	X	X	November-January	Native	Shrub	Villegas *et al.* (2000)
	Vicia sativa L.		X	January-March	Native	Herbaceous	Villegas *et al.* (2000)

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Fagaceae	*Quercus* sp.	X		June	Native	Tree	Ramírez-Arriaga *et al.* (2018)
Hypoxidaceae	*Hypoxis decumbens* L.	X			Native	Herbaceous	Bonet y Vergara(2016)
Juglandaceae	*Juglans pyriformis* Liebm.	X		February-March	Native	Tree	Villegas *et al.* (2000)
Lamiaceae	*Hyptis mutabilis* (Rich.) Briq.		X	August-December	Exotic	Herbaceous	Villegas *et al.* (2000)
	Hyptis suaveolens (L.) Poit.		X	August-October	Native	Herbaceous	Villegas *et al.* (2000)
	Marrubium vulgare L.		X	February-May	Naturalized	Herbaceous	Villegas *et al.* (2000)
	Marsypianthes chamaedrys (Vahl) Kuntze	X			Native	Herbaceous	Bonet y Vergara (2016)
	Mentha × *piperita* L.		X	June-October	Exotic	Herbaceous	Villegas *et al.* (2000)
	Ocimum sp.	X			Native	Herbaceous	Ramírez-Arriaga *et al.* (2018)
	Salvia albiflora M. Martens & Galeotti	X			Native	Herbaceous	Bonet y Vergara (2016)
	Salvia purpurea Cav.		X	September-January	Native	Herbaceous	Villegas *et al.* (2000)
	Salvia rubiginosa Benth.		X	September-January	Native	Shrub	Villegas *et al.* (2000)
Lauraceae	*Nectandra ambigens* (S.F. Blake) C.K. Allen		X	February-May	Native	Tree	Villegas *et al.* (2000)
Lythraceae	*Ginoria nudiflora* (Hemsl.) Koehne	X	X	November-May	Native	Tree	Villegas *et al.* (2000)
Malvaceae	*Ceiba aesculifolia* (Kunth) Britten & Baker f.		X	November-May	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Dombeya wallichii (Lindl.) Baill.		X	November-February	Exotic	Tree	Villegas *et al.* (2000)
	Hampea nutricia Fryxell		X	September-November	Native	Shrub	Villegas *et al.* (2000)
	Heliocarpus pallidus Rose	X		October-February	Native	Tree	Contreras-Oliva *et al.* (2018); Villegas *et al.* (2000)
	Heliocarpus appendiculatus Turcz.	X		December-March	Native	Tree	Ramírez-Arriaga *et al.* (2018)
	Malvaviscus arboreus Cav.	X	X	All year	Native	Shrub	Canto *et al.* (2017); Parra-Tabla *et al.* (2019) Villegas *et al.* (2000)
	Pachira aquatica Aubl.		X	All year	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Pseudobombax ellipticum (Kunth) Dugand	X	X	January-June	Native	Tree	Villegas *et al.* (2000)
	Sida acuta Burm. f.	X			Exotic	Shrub	Bonet y Vergara (2016)
	Sida rhombifolia L.	X		All year	Native	Herbaceous	Bonet y Vergara (2016)
Meliaceae	*Trichilia havanensis* Jacq.		X	December-April	Native	Tree	Niembro-Rocas *et al.*(2010); Villegas *et al.* (2000)
	Trichilia hirta L.		X		Native	Tree	Villegas *et al.* (2000)
Melastomataceae	*Miconia* sp.	X			Native	Herbaceous	Ramírez-Arriaga *et al.* (2018)

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Muntingiaceae	*Muntingia calabura* L.		X	All year	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
Myrtaceae	*Callistemon citrinus* (Curtis) Skeels		X	December-April	Exotic	Shrub	Villegas *et al.* (2000)
	Eucalyptus globulus Labill.		X	May-July	Exotic	Tree	Villegas *et al.* (2000)
	Eugenia capuli (Schltdl. & Cham.) Hook. & Arn.	X			Native	Shrub	Contreras-Oliva *et al.* (2018)
	Eugenia mexicana Steud.	X	X	May-August	Native	Shrub	Villegas *et al.* (2000)
	Syzygium jambos (L.) Alston		X	February-July	Naturalized	Tree	Villegas *et al.* (2000)
Nyctaginaceae	*Pisonia aculeata* L.		X	January-April	Exotic	Shrub	Villegas *et al.* (2000))
Oleaceae	*Ligustrum lucidum* W. T. Aiton	X	X	March-June	Exotic	Tree	Villegas *et al.* (2000)
Onagraceae	*Lopezia hirsuta* Jacq.		X	November-January	Native	Herbaceous	Villegas *et al.* (2000)
Papaveraceae	*Argemone mexicana* L.	X	X	January-April	Native	Herbaceous	Villegas *et al.* (2000)
	Argemone platyceras Link & Otto	X	X	All year	Native	Herbaceous	Villegas *et al.* (2000)
Piperaceae	*Piper* sp.	X			Native	Shrub	Ramírez-Arriaga *et al.* (2018)
Platanaceae	*Platanus mexicana* Moric.	X		January-May	Native	Tree	Ramírez-Arriaga *et al.* (2018)
Poaceae	*Brachiaria plantaginea* (Link) Hitchc.	X		May-November	Native	Herbaceous	Bonet y Vergara (2016)
	Panicum sp.	X			Native	Herbaceous	Bonet y Vergara (2016)
	Paspalum conjugatum P.J. Bergius	X		All year	Native	Herbaceous	Bonet y Vergara (2016)
	Paspalum virgatum L.	X			Native	Herbaceous	Bonet y Vergara (2016)
	Pseudechinolaena polystachya (Kunth) Stapf	X			Native	Herbaceous	Bonet y Vergara (2016)
Polygonaceae	*Antigonon leptopus* Hook. & Arn		X	August-December	Native	Vine	Villegas *et al.* (2000)
	Coccoloba uvifera (L.) L.	X	X	February-April	Native	Shrub	Contreras-Oliva *et al.* (2018); Villegas *et al.* (2000)
Pontederiaceae	*Pontederia sagittata* C. Presl		X	January-March	Native	Herbaceous	Villegas *et al.* (2000)
Proteaceae	*Grevillea robusta* A. Cunn. ex R. Br.	X	X	March-April	Exotic	Tree	Villegas *et al.* (2000)
Resedaceae	*Reseda odorata* L.		X	September-December	Exotic	Herbaceous	Villegas *et al.* (2000)
Rhamnaceae	*Gouania lupuloides* (L.) Urb.		X	September-November	Native	Shrub	Villegas *et al.* (2000)
	Ziziphus sp.	X		June	Native	Shrub	Ramírez-Arriaga *et al.* (2018)
Rhizophoraceae	*Rhizophora mangle* L.		X	All year	Native	Tree	Villegas *et al.* (2000)
Rosaceae	*Prunus serotina* Ehrh.		X	January-March	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
Rubiaceae	*Calycophyllum candidissimum* (Vahl) DC.		X	October- January	Native	Tree	Villegas *et al.* (2000)
	Ixora coccinea L.		X	November-January	Exotic	Shrub	Villegas *et al.* (2000)

Family	Plant species	Pollen	Nectar	Flowering	Status	Life-form	Reference
Rubiaceae	*Murraya paniculata* (L.) Jack		X	April-June	Exotic	Tree	Villegas *et al.* (2000)
	Spermacoce confusa Rendle		X	September-December	Native	Herbaceous	Villegas *et al.* (2000)
Sapindaceae	*Acer negundo* L.	X		February-March	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Cupania sp.	X		August	Native	Tree	Ramírez-Arriaga *et al.* (2018)
	Sapindus saponaria L.		X	August-March	Native	Tree	Villegas *et al.* (2000)
	Serjania sp.	X			Native	Shrub	Contreras-Oliva *et al.* (2018)
	Serjania racemosa Schumach.		X	November-January	Native	Shrub	Villegas *et al.* (2000)
	Talisia oliviformis (Kunth) Radlk.		X	February-May	Native	Tree	Villegas *et al.* (2000)
	Thouinia paucidentata Radlk.	X			Native	Tree	Ramírez-Arriaga *et al.* (2018)
	Thouinidium decandrum (Bonpl.) Radlk.		X	February-April	Native	Tree	Villegas *et al.*, (2000)
Sapotaceae	*Manilkara zapota* (L.) P. Royen		X	June-October	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
	Pouteria sp.	X		May	Native	Tree	Contreras-Oliva *et al.* (2018); Niembro-Rocas *et al.* (2010)
Scrophulariaceae	*Buddleja cordata* Kunth	X	X	March-October	Native	Tree	Niembro-Rocas *et al.* (2010); Villegas *et al.* (2000)
Solanaceae	*Solanum rostratum* Dunal		X	May-September	Native	Herbaceous	Villegas *et al.* (2000)
	Solanum sp.	X			Native	Herbaceous	Contreras-Oliva *et al.* (2018)
Malvaceae	*Waltheria indica* L.		X	January-March	Native	Herbaceous	Villegas *et al.* (2000)
Urticaceae	*Cecropia peltata* L.		X	All year	Native	Tree	Villegas *et al.* (2000)
	Cecropia obtusifolia Bertol.	X		All year	Native	Tree	Ramírez-Arriaga *et al.* (2018)
Verbenaceae	*Aloysia virgata* (Ruiz & Pav.) Pers.		X	All year	Exotic	Shrub	Villegas *et al.* (2000)
	Lantana camara L.		X	All year	Native	Shrub	Villegas *et al.* (2000)
	Lippia myriocephala Schltdl. & Cham.		X	September-January	Native	Tree	Villegas *et al.* (2000)
	Phyla fruticosa (Mill.) K. Kenn. ex Wunderlin & B.F. Hansen		X	All year	Native	Herbaceous	Villegas *et al.* (2000)
Zygophyllaceae	*Tribulus cistoides* L.	X	X	September-March	Native	Herbaceous	Parra-Tabla *et al.* (2019) Villegas *et al.* (2000)
	Tribulus terrestris L.		X	January-April	Naturalized	Herbaceous	Villegas *et al.* (2000)

Appendix 2. Crops pollinated by bees in Mexico.

Family	Crop	Common name	Pollen	Nectar	Flowering	Status	Reference
Anacardiaceae	*Mangifera indica* L.	"mango"	X	X	November-March	Naturalized	Meléndez *et al.* (2018); Villegas *et al.* (2000)
	Spondias mombin L.	"jobo"		X	March-May	Native	Villegas *et al.* (2000)
	Spondias purpurea L.	"ciruelo"	X	X	December-March	Native	Villegas *et al.* (2000)
Arecaceae	*Cocos nucifera* L.	"cocotero"	X	X	All year	Naturalized	Castellanos-Potenciano *et al.* (2012); Meléndez *et al.* (2018); Ramírez-Arriaga *et al.* (2018); Villegas *et al.* (2000)
Asteraceae	*Helianthus annuus* L.	"girasol"	X	X	March-July	Native	Villegas *et al.* (2000)
Brassicaceae	*Brassica napus* L.	"canola"	X	X	September-December	Exotic	Villegas *et al.* (2000)
Caricaceae	*Carica papaya* L.	"papaya"	X	X	All year	Native	Badillo-Montaño *et al.* (2019) Villegas *et al.* (2000)
Convolvulaceae	*Ipomoea batatas* (L.) Lam.	"camote"	X	X	July-April	Native	Villegas *et al.* (2000)
Cucurbitaceae	*Citrullus lanatus* (Thunb.) Matsum. & Nakai	"sandía"		X	All year	Exotic	Villegas *et al.* (2000)
	Cucurbita ficifolia Bouché	"calabaza"		X	May-August	Native	Villegas *et al.* (2000)
	Cucurbita maxima Duchesne	"calabaza"	X	X	May-August	Exotic	Villegas *et al.* (2000)
	Cucumis melo L.	"melón"		X	January-June	Exotic	Villegas *et al.* (2000)
	Cucurbita moschata Duchesne	"calabaza"	X			Native	(eléndez *et al.* (2018)
	Cucumis sativus L.	"pepino"	X	X	January-June	Exotic	Villegas *et al.* (2000)
	Sechium edule (Jacq.) Sw.	"chayote"		X	All year	Native	Villegas *et al.* (2000)
Ebenaceae	*Diospyros digyna* Jacq.	"zapote negro"		X	March-June	Naturalized	Villegas *et al.* (2000)
Euphorbiaceae	*Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg.	"hule"		X	February-April	Exotic	Villegas *et al.* (2000)
Fabaceae	*Medicago sativa* L.	"alfalfa"		X	All year	Exotic	Villegas *et al.* (2000)
	Phaseolus coccineus L.	"ayocote" "frijol colorado"		X	September-October	Native	Villegas *et al.* (2000)
	Tamarindus indica L.	"tamarindo"		X	May-November	Naturalized	Villegas *et al.* (2000)
Lauraceae	*Persea americana* Mill.	"aguacate"		X	February-May	Native	Meléndez *et al.* (2018); Villegas *et al.* (2000)
Malpighiaceae	*Byrsonima crassifolia* (L.) Kunth	"nanche"	X	X	March-June	Native	Villegas *et al.* (2000)
Malvaceae	*Gossypium hirsutum* L.	"algodón"	X	X	August, February, May	Native	Canto *et al.* (2017)
Musaceae	*Musa paradisiaca* L.	"plátano"	X	X	All year	Naturalized	Villegas *et al.* (2000)
Myrtaceae	*Psidium guajava* L.	"guayaba"	X	X	April-June	Native	Villegas *et al.* (2000)
Poaceae	*Zea mays* L.	"maíz"	X	X	February-March, July-August	Native	Villegas *et al.* (2000)
Proteaceae	*Macadamia integrifolia* Maiden & Betche	"macadamia"		X	January-March	Exotic	Villegas *et al.* (2000)

Family	Crop	Common name	Pollen	Nectar	Flowering	Status	Reference
Rosaceae	*Crataegus mexicana* DC.	"tejocote"	X	X	March-May	Native	Villegas *et al.* (2000)
	Eriobotrya japonica (Thunb.) Lindl.	"níspero"		X	December-February	Naturalized	Villegas *et al.* (2000)
	Malus pumila Mill.	"manzana"	X	X	February-March	Exotic	Villegas *et al.* (2000)
	Prunus domestica L.	"ciruelo"	X	X	February-April	Exotic	Villegas *et al.* (2000)
	Prunus persica (L.) Batsch	"durazno"		X	February-April	Exotic	Villegas *et al.* (2000)
	Pyrus communis L.	"pera"		X	February-March	Exotic	Villegas *et al.* (2000)
	Rubus eriocarpus Liebm.	"zarzamora", "mora"		X	January-March	Native	Villegas *et al.* (2000)
Rubiaceae	*Coffea arabica* L.	"café"		X	April-June	Exotic	Ramírez-Arriaga *et al.* (2018); Villegas *et al.* (2000)
Rutaceae	*Casimiroa edulis* La Llave	"zapote blanco"		X	January-February	Native	Villegas *et al.* (2000)
	Citrus × *aurantiifolia* (Christm.) Swingle	"limón agrio"	X	X	All year	Exotic	Villegas *et al.* (2000)
	Citrus maxima (Burm.) Merr.	"toronja"	X	X	December-February	Exotic	Villegas *et al.* (2000)
	Citrus reticulata Blanco	"mandarina"		X	June-February	Exotic	Villegas *et al.* (2000)
	Citrus × *sinensis* (L.) Osbeck	"naranja"		X	June-February	Exotic	Villegas *et al.* (2000)
Sapindaceae	*Litchi chinensis* Sonn.	"lichi"	X	X	January-March	Exotic	Villegas *et al.* (2000)
	Nephelium lappaceum L.	"rambután"	X			Exotic	Meléndez *et al.* (2018)
Solanaceae	*Capsicum annuum* L.	"chile"	X		All year	Native	Meléndez *et al.* (2018); Villegas *et al.* (2000)
	Solanum lycopersicum L.	"jitomate"	X			Native	Meléndez *et al.* (2018)