ECOLOGICAL ATTRIBUTES OF WEEDS AS INDICATORS OF SUSTAINABILITY IN AGROECOSYSTEMS OF THE SOUTHEASTERN REGION OF MEXICO CITY †

[ATRIBUTOS ECOLÓGICOS DE LAS ARVENSES COMO INDICADORES DE LA SUSTENTABILIDAD EN AGROECOSISTEMAS DE LA REGIÓN SUROESTE DE LA CIUDAD DE MÉXICO]

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SUMMARY

Background: Pre-Hispanic agroecosystems in Mexico City have changed the kind of crops, management practices, tools, and inputs, seriously impacting their biocultural value and sustainability. Previous studies have demonstrated these changes' economic, cultural, and political consequences. However, their effects on biodiversity have not been considered. The present study characterized the management carried out in three agroecosystems in the southeastern area of Mexico City and its possible relationship with agrobiodiversity. **Objective**: To evaluate the contribution of diversity, abundance, and composition of weeds as components of the sustainability of agroecosystems in Milpa Alta, Tláhuac, and Xochimilco municipalities. **Methodology:** 179 interviews were conducted with campesinos. Weeds sampling in 30 plots, recording the abundance and frequency of each species. These data were used to estimate different ecological parameters. Information on management practices was transformed to develop an "agroecosystem sustainability index." A multivariate analysis was applied to compare weed attributes between agroecosystems and spaces and to detect possible relationships between the index and ecological parameters. **Results:** 156 species were recorded. The *slope* had the highest diversity, and *ciénega* had the lowest. More than half of the weeds were native, and the *slope* exhibited the highest number. The Importance Value indicated no dominant species on the *slope*, opposite to *chinampa and ciénega*. Species composition also differed between the three agroecosystems. *Chinampa* was impacted the most, whereas the *slope* was least affected. **Implications:** The displacement of traditional crops and agricultural practices and the incorporation of technological practices have modified the ecological attributes of weeds, like their abundance and composition. **Conclusion:** Starting from the argument that ecological attributes of weeds can be used as an indicator of sustainability, the *slope* resulted in the agroecosystem being most sustainable and should be used as a model to recover the agrobiodiversity of *ciénegas* and *chinampas*.

Key words: weed; agrochemicals; agroecosystem sustainability; traditional agroecosystem; urban agriculture.

RESUMEN

Antecedentes: Los agroecosistemas prehispánicos en la Ciudad de México han cambiado en tipos de culitvo, prácticas de manejo, herramientas e insumos, con graves consecuencias sobre su valor biocultural y su sostenibilidad. Diferentes estudios han demostrado las consecuencias económicas, culturales y políticas de estos cambios. Sin embargo, no se han considerado sus efectos sobre la biodiversidad. En el presente estudio se caracterizó el manejo realizado en tres agroecosistemas de la zona suroeste de la Ciudad de México y su posible relación con la agrobiodiversidad. **Objetivo**: Evaluar la contribución de la diversidad, abundancia y composición de las arvenses como componentes de la sostenibilidad de estos agroecosistemas en los municipios de Milpa Alta, Tláhuac y Xochimilco. **Metodología**: Aplicación de 179 entrevistas a campesinos. Muestreos de arvenses en 30 parcelas, registrando la abundancia y frecuencia de cada especie. Con estos datos se estimaron diferentes parámetros ecológicos. La información de las entrevistas se analizó con estadística descriptiva. La información

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sobre las prácticas de manejo se transformó para desarrollar un "índice de sustenibilidad del agroecosistema". El análisis multivariado permitió comparar atributos de malezas entre agroecosistemas y espacios y detectar posibles relaciones entre el índice y los parámetros ecológicos. **Resultados**: Se registraron156 especies arvenses. La *ladera* tuvo la mayor diversidad y la *ciénega* la más baja. Más de la mitad de las malezas fueron nativas y la *ladera* presentó el mayor número. El valor de importancia ecológica indicó que no existen especies dominantes en la *ladera*, lo opuesto a la *chinampa* y la *ciénega*. La composición de especies también difirió entre los tres agroecosistemas. La *chinampa* fue la más afectada, mientras que la *ladera* fue la menos afectada. **Implicaciones:** El desplazamiento de cultivos y prácticas agrícolas tradicionales y la incorporación de prácticas tecnológicas han modificado atributos ecológicos de las malezas, como su abundancia y composición. **Conclusión:** Partiendo del argumento de que los atributos ecológicos de las malezas pueden usarse como indicador de sustentabilidad, la *ladera* resultó en el agroecosistema más sustentable y debe usarse como modelo para recuperar la agrobiodiversidad de *ciénegas* y *chinampas*.
Palabras clave: Agroecosistema tradicional; agroquímicos; arvense; ecología urbana; sustentabilidad del agroecosistemas.

INTRODUCTION

The current existence of agricultural areas in Mexico City (CDMX) is linked to a pre-Hispanic heritage characterized by the development of agricultural systems to supply approximately 20 million inhabitants prior to the Spanish conquest (Brooks, 1993; Losada *et al.*, 1998). These agroecosystems (AES), denominated as *chinampas*, *terraces*, *slash-and-burn*, and *backyards,* exhibit ecological, technological, and socio-cultural characteristics that are developed according to the environmental and topographic characteristics of the land (Hernández-Xolocotzi and Ramos, 1977; Cruz-León, 2003; Zuria and Gates, 2006; Toledo and Barrera-Bassols, 2008; Casanova-Pérez *et al*., 2015).

Until the first third of the 20th century, these systems operated similarly to those of the pre-Hispanic times. Then, they shifted from traditional agriculture to technician agriculture due to urbanization and industrialization processes that exerted pressure on them. Currently, 87,291 ha of the 1,494.3 km^2 that corresponds to CDMX are classified as "Conservation Land of Mexico City" (SCCDMX for their Spanish acronym) (SEDEMA, 2013), where agricultural activities, wooded areas, natural grasslands, and recreation areas are designated. Ten municipalities (CONABIO-SEDEMA, 2016) share 20% of the land used for agriculture. Milpa Alta, Tláhuac, Xochimilco, and Tlalpan (Table 1) have the most conservation and agricultural production land (Castelán-Crespo, 2016). Agriculture is not only an economic activity but also an element of resistance to the changes brought about by urbanization and modernization. Various studies have addressed the phenomenon of agriculture in CDMX from archeological, historical, anthropological, economic, and socio-environmental perspectives (Calderón-Contreras and Quiroz-Rosas, 2017; Rojas-Rabiela, 1985, 1988, 1991; Losada *et al*., 1996; Losada *et al*., 1998; Torres-Lima and Burns, 2002; Torres-Lima and Rodríguez-Sánchez, 2008; Torres-Lima *et al*., 2010; Dieleman, 2017; Torres-Lima and Cruz-Castillo, 2018; Torres-Lima *et al*., 2018). However, agriculture has not been systematically recorded from a biological point of view even when an important diversity of crops is used for different purposes and different tolerated weeds and wild species, conform this landscape (Rendón-Aguilar and Rocha-Munive, 2018; Rivera-Ramírez *et al.*, 2021; Rendón-Aguilar *et al.*, 2021).

Floristic records about weed richness and composition in these agroecosystems and their possible relationship with some agricultural practices and socioeconomic factors are absent. Previous general floristic studies have followed the Valley of Mexico, including the urban area of CDMX (Espinosa-García and Sarukhán, 1997; Vibrans, 1997, 1998; Vieyra-Odilon and Vibrans, 2001; Sánchez-Blanco and Guevara-Ferrer, 2013). No study has been developed to analyze the agrobiodiversity of weeds in these agroecosystems or to compare possible differences in ecological attributes like weed richness, abundance, and composition.

In this scenario, it is expected that agroecosystems that stick to more traditional farming methods will have more useful weeds, a more diverse composition, and a higher percentage of native species. The study's goals are: 1) to characterize the management carried out in three agroecosystems in the southeastern area of Mexico City; 2) to compare some ecological and floristic aspects between three agroecosystems; and 3) to evaluate the contribution of the ecological and floristic parameters of weeds as components of sustainability.

MATERIALS AND METHODS

Study area

The study was conducted in Milpa Alta, Tláhuac, and Xochimilco (Fig 1), located in the southeastern region of Mexico City (CDMX). Based on the classification of CDMX in three spaces: urban, suburban, and peri-urban, by Losada *et al.* (1998), Torres-Lima and Burns (2002), Torres-Lima *et al.* (2010), and Dieleman (2017), the last two were considered:

Suburban space (SUB). In physiographic terms, these are lands below 2400 m a.s.l., with a slope between 0 and 20%, and rainfed agriculture supplemented by irrigated water from water treatment systems. There are ejidal areas, although most of the land is privately owned. Large, paved boulevards surround them. The presence of *chinampa*, *ciénega*, and *backyard* AES distinguishes SUB.

ii. Peri-urban space (PERI). In physiographic terms, these are lands above 2400 m a.s.l., with a slope of at least 20% suited for rainfed agriculture. The land is located far from the home and near forested regions. Regarding agroecosystems, previous research has documented the presence of *slash-and-burn*, *terraces*, and *backyards*. Field trips revealed that pre-Hispanic *terraces*, as reported by Rojas-Rabiela (1985, 1988, 1991), are nearly extinct and no longer functional. The CDMX government promoted the construction of contemporary *terraces* during the 1990s to grow nopal; collaborators did not refer to them as terraces but as nopaleras. To prevent unbridled fire, the practice of *slash-and-burn* has been eliminated. Crops such as maize (*Zea mays* L.), ebo (*Vicia sativum* L.), and oat (*Avena sativa* L.) are planted on the *slope*, not the *terrace*, hence the usage of this term.

Field work

To characterize the management carried out in the three agroecosystems, 179 collaborators, hereafter referred to as campesinos, were subjected to interviews (Table 1) using two methods:

a) through the collaboration of those who had participated in the CDMX transgenic maize sequence monitoring project (Rendón-Aguilar and Rocha-Munive, 2018).

b) using the snowball method (Albuquerque *et al.*, 2014), which was used in the offices of the Coordinación Regional de Recursos Naturales (CORENA) in the different city halls and in the offices of the different ejidal or communal areas. The coordinators and representatives were briefed on the objectives of this study and asked to reach out to potential collaborators, which they agreed to do in every instance. This same approach was occasionally used to contact other collaborators who were also campesinos.

In both instances, interviews were conducted primarily in the collaborators' residences or on their plots and occasionally in the CORENA offices or local markets where the collaborators sell their goods. The interview format utilized was structured and printed. The average duration of the interview was 1:40 hours ± 20 minutes. They were asked for their authorization to record the dialogue generated in this process and take photographs.

The structure of the interviews was based on Rendón-Aguilar and Rocha-Munive (2018). It included questions related to management, like farming practices, kinds of crops cultivated, and preservation/changes in the structure or functioning of the agroecosystem.

To evaluate agrobiodiversity, we analyzed different ecological and floristic parameters of weeds: diversity, abundance, and composition in 30 plots from the various agroecosystems: thirteen plots of *slope* were sampled in the three municipalities, and two zones; seven plots of *ciénega* were sampled in the SUB zone in Tláhuac; and ten plots of *chinampa* were in the SUB zone in Xochimilco (Table 1).

Using the "W" method (Caamal and Castillo, 2011), weeds were sampled by drawing an imaginary diagonal line within each plot, where 50 x 50 cm squares were collocated every 20 meters, following the silhouette of an imaginary letter W. The number of individuals belonging to each specimen was counted. We considered the collaborators' perception of them. When we asked them, "What plants grow alone, or spontaneously, without being sown, in your plot?" They did mention weeds, but they also mentioned seedlings of potatoes, beans, squash, or even maize since it is possible to find them "growing spontaneously" and they are dispersed irregularly throughout the plot; during weeding, they are also eliminated, so they were recorded as weed species. However, the number of registered individuals was generally low. Campesinos refer to weeds as “herbs” or *quelites* and, to a lesser extent, “weeds”. During sampling, two or three voucher specimens of each species were collected, pressed, and dried according to standard methods (Lot and Chiang, 1986).

Table 1. Socioeconomic data for the study area. The kind and number of agroecosystems sampled in each municipality and space (PERI or SUB) are indicated. (S= *slope*; C= *ciénega*; CH= *chinampa*). Based on [1]INEGI (2021) and [2]Torres Lima *et al.* (2008).

MUNICIPALITY	POPULATION (1)	AREA (km^2) (1)	ECONOMICALLY ACTIVE POPULATION (EAP)(1)	ECONOMICALLY ACTIVE POPULATION IN PRIMARY ACTIVITES (EAPPA) (2)	NUMBER OF INTERVIEWS	SUB (Under 2400 m a.s.l.)	PERI (Above 2400 m a.s.l.)	PLOTS SAMPLED
Milpa Alta	152 685	298.2	102 298	5 074	70		4 S	4 S
Tláhuac	392 313	85.9	247 941	2 427	40	3 CH, 7 C, 3 S		3 CH, 7 C, 3 S
Xochimilco	442 178	114.1	279 456	4 485	69	10 CH	3 S	10 CH, 3 S
TOTAL	988 176	500.83	696.360	11 986	179	23	7	30

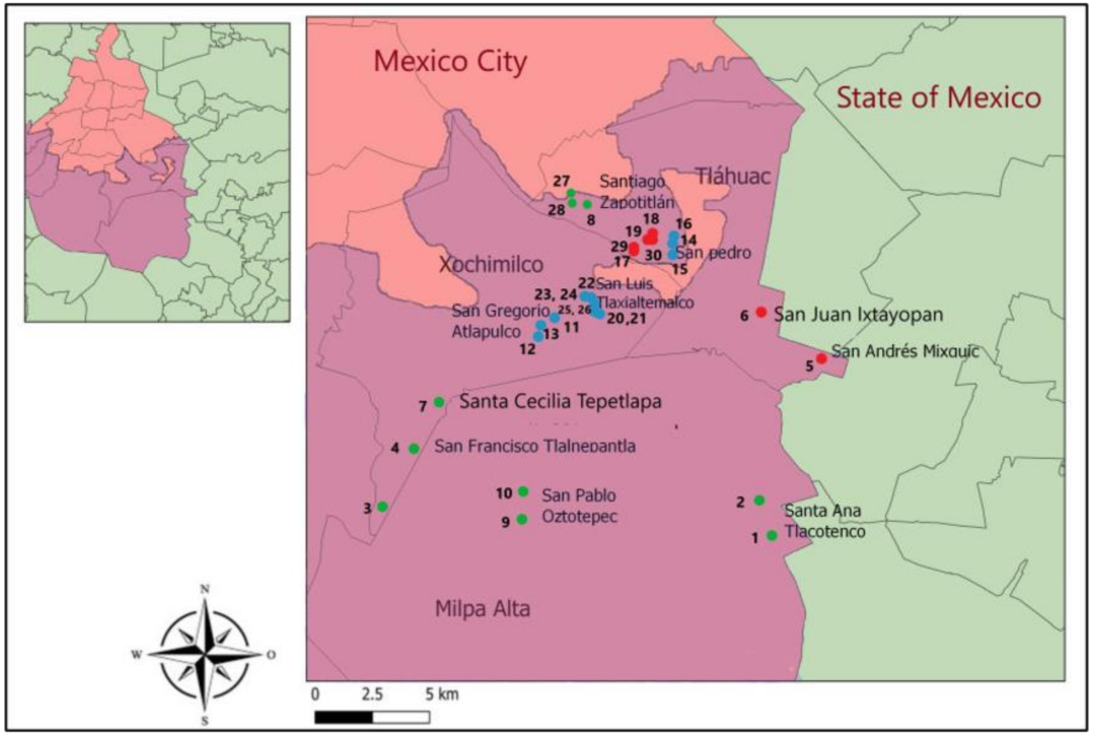

Figure 1. Study area. The 30 plots sampled in the three municipalities are indicated: (Blue, CH = *chinampa*; red, C =*ciénega*; green, S= *slope*). The area designated for agriculture, livestock, and forestall management, denominated the Conservation Land of Mexico City is indicated in lilac (Elaborated: Ismael Rivera-Ramírez).

Data analysis

From the interviews, we applied descriptive statistics to analyze socioeconomic aspects. Data related to management were transformed into quantitative values to obtain an "agroecosystem sustainable index"
that allowed us to compare changes between AES:

a) main crop: 2= maize, squash, oats, or ebo, 1= ornamentals, aromatics, or greens

b) substrate: 2= soil, 1= pot, greenhouse

c) origin of water: 2= rain; 1= irrigation

d) land preparation: 2= yunta, 1= tractor/motocultor

e) kind of fertilizer: 2= organic, 1= chemical

f) weeding: 2= manual, 1= chemical

g) pest control: 2= nothing, 1= insecticide + fungicide, 0.5= insecticide or fungicide

Weed diversity, abundance, and composition were quantified from a database that included all the records of the species registered in the 30 samplings in *chinampa*, *ciénega*, and *slope*. The database included the AE, the botanical family, the scientific name of each species, its abundance, and its frequency (recorded as the number of squares where they appear). Some species were not completely identified; in these cases, they were numbered depending on the taxonomic level recognized (e.g., Poaceae1, Poaceae2; *Chenopodium1*, *Chenopodium2*). In the case of the specimens identified up to species, the migratory status (native, introduced) was indicated according to the International Plant Names Index (IPNI, 2024) as well as the World Plant Database (POWO, 2024). Its risk category was reviewed in the IUCN Red List (IUCN, 2022), SEMARNAT NOM059 (SEMARNAT, 2010), and the CITES list (CITES, 2021). Voucher specimens were deposited in the herbarium of the Universidad Autónoma Metropolitana Iztapalapa (UAMIZ) and the Faculty of Sciences (María Agustina Batalla Herbarium) of the Universidad Nacional Autónoma de México (UNAM).

The richness, similarity, and exclusivity of weeds in the three annual agroecosystems were visualized using a Venn diagram. Native and introduced species present in each AE were also accounted for.

The abundance and frequency of the species were converted to relative values using the following formulas:

Relative Abundance (RA) = Amount of a species x divided by the total amount of all species

and

Relative Frequency (RF) = Number of squares with the presence of species x/total number of squares

Using these data, the significance of each weed was determined as follows:

IV species= RA + RF,

where values close to 2 indicate a greater dominance of certain species.

The specific richness and Shannon diversity index were obtained at the plot and AE levels. Based on the main crops cultivated by the 179 campesinos in their respective agroecosystems, a PCoA using the Jaccard index was applied to evaluate the possible differentiation between the three AES.

A PCoA was followed by a presence/absence matrix of species found in the sampling to examine how similar the weed composition was between AES and the two spaces. A PCA was applied using IV values to analyze the possible dominance of some weeds in some AES (e.g., *chinampa*). A PCA was applied with the "agroecosystem sustainable index" and IV to detect possible differences between AES and associated variables. All analyses were done using the PAST4 (2022) software.

RESULTS

Characterization of the management carried out in the three agroecosystems and the two spaces

The 179 collaborators represented 1.5% of the economically active population of the agricultural sector in the three municipalities studied. Most of the collaborators (86.59%) were men. However, in Milpa Alta, the highest number of women were interviewed (18) (Table 2). Most collaborators (160, 89.38%) were born in CDMX and remained in the same localities where they were born. Only 17% immigrated from other states of the Mexican Republic. Collaborators aged 20 to 92 years, but less than half (45.2%) are over 60. From them, a young sector with a maximum age of 30 (6.7%) is determined to be campesinos and expresses their desire for it (Table 2). Most of them mixed their agricultural activity with other occupations like traditional healers, bricklayers, and electricians; those who carried out higher studies (8.9%) were biologists, metallurgical engineers, elementary or secondary school teachers, public accountants, and veterinarians. The income received from agriculture allowed them to cover various expenses, including those generated by agriculture; just (17.8%) considered themselves full-time campesinos.

Table 2. Socioeconomic information of the collaborators (*They were born in the same municipality but in another town.)

	SEX		BORN IN THE MUNICIPALITY			SPOKEN OF ETHNIC LANGUAGE		AGE		
MUNICIPALITY	MEN	WOMEN	YES	NO	HALF*	YES	NO	20-39 YEARS	40-59 YEARS	OLDER THAN 59 YEARS
Milpa Alta	52	18	64	4	2	15	55	12	31	27
Tláhuac	37	3	32	5	3	4	36	4	13	23
Xochimilco	66	3	61	8	0	7	62	12	24	33
Total	**155**	**24**	**160**	**17**	**2**	**26**	**153**	**24**	**42**	**57**

The largest number of collaborators was found in the PERI (107), compared to the SUB (72); more women participated in the PERI (16.8%), compared to the 8.3% recorded in the SUB; a higher participation of young people was found in the PERI (94.4% vs 90.0%); however, the greatest contrasts were found in the mother language. The collaborators of the SUB did not understand or speak any language, and only 25% of their parents did. Conversely, 22.3% of the collaborators in the PERI speak or understand a language; a little more than 45% of their parents spoke it and 78.5% of their grandparents spoke or understood an indigenous language. Paradoxically, in the SUB were the largest number of collaborators dedicated exclusively to the field (52.8% *vs* 26.2%).

According to the collaborators' data, most plots (148, 82.7%) have been worked continuously for more than ten years, although spatial or seasonal crop rotation is common. Slightly more than half of the land is considered owned. It is common for people to have their own land, which is generally inherited from their parents, grandparents, or in-laws, and they also rent or borrow from others, indicating that these people have an important role in agricultural production.

Chinampa

This AE is located in the SUB zone. Agricultural practices in *chinampas* have deeply changed. Campesinos used to build them with mud from the channels of the Xochimilco and Chalco lakes, mixed with the remains of plants and roots. However, three decades ago, the collapse of several *chinampas* due to the extraction of water from the groundwater and the earthquakes obliged campesinos to fill and level them with gravel fills. However, they maintain their original shape, are surrounded by channels and *apantles* (narrow water channels) and are delimited by *ahuejotes* (*Salix bonplandiana* Kunth). During the dry season, the water level is very low and insufficient to moisten the *chinampa*. Due to this, there is an increasing dependence on treated water from the water treatment system coming from Cerro de la Estrella (Iztapalapa). Another change corresponds to the main crops that are cultivated. Vegetables, flowers, condiments, and medicinal plants have displaced the traditional ones, like native maize, beans, squash, or even weeds, like *quelites*. This crop displacement came hand in hand with the incorporation of agrochemicals. Campesinos mentioned at least 10 different pesticides, herbicides, and fertilizers. Each crop has its own pesticide necessities, so this agroecosystem contains these products. Most of the 107 cultivated species recorded in this agroecosystem are cultivated in plastic bags placed outdoors or seed starter grays in greenhouses, which include annual vegetables, ornamental flowers, aromatic and medicinal plants, and fruit trees. Of the 38 collaborators who farm in *chinampa*, only nine cultivate maize and beans following the traditional technique, in addition to vegetables.

Ciénega

Plots grouped in this agroecosystem are in the basins of the Xochimilco and Chalco in the SUB. They were historically *chinampa*, but water extraction in these areas caused their collapse and intense flooding variation. Consequently, the original structure of the *chinampa* disappeared, and only some of the most important canals remained, as well as *ahuejote* trees that are still used to delimit plots. Due to these flood problems, which are unpredictable since they depend on rainfall, agriculture in *ciénega* is fluctuating. The number of plots increases as the lake water level decreases, but irrigation water is necessary when rain is scarce. However, with high rainfall, some plots are flooded and completely disappear. Remains of colonial agriculture exist. Campesinos use a yunta or tractor depending on the crop or divide their plots into small subplots or *pancles*. This is done for planting different vegetables during the same season, so each *pancle* is cultivated with a different species, or the same species can be cultivated three or four times in the same year. All the plots are irrigated with treated water. The use of agrochemicals is very frequent. Campesinos mentioned 51 cultivated species. The most mentioned were creole or hybrid white maize planted by 75% of the collaborators, followed by broccoli (*Brassica oleracea* L.), and Mexican rosemary (*Suaeda torreyana* S. Watson), which are planted by around 50% of the collaborators. The use of greenhouses for planting potted ornamental flowers is increasing; however, some campesinos still elaborate *chapines* (seedbeds elaborated with lakebottom mud) to cultivate chili (*Capsicum annuum* L.), or purslane (*Portulaca oleracea* L.).

Slope

This agroecosystem corresponds to lands with irregular topography and a variable slope greater than 20% that depends on rainwater. Traditionally, this form of agriculture corresponded to shifting cultivation; however, since burning is now practically prohibited, people practice only slash-grave or just slash. Annual crops like maize, beans, pumpkin, oats, or ebo are grown in this agroecosystem. In this landscape, some campesinos have modified their plots, so we can see two variants of *slope*:

A) *Pantles***.** Campesinos cut the pronounced slope at a certain distance, between 15 and 20 m, as a stairway. On edge, wild or domesticated perennial species are planted, such as tepozán (*Buddleja cordata* Kunth), or cultivated, such as capulín (*Prunus serotina* L.), tejocote (*Crataegus mexicana* DC), or maguey (*Agave* spp.), which function as a barrier to prevent soil loss.

B) *Terraces***.** As previously stated, these "terraces" were constructed in the 1990s to cultivate *nopal*. 48 collaborators are advocated exclusively for this perennial crop. There are remnants of pre-Columbian and colonial practices. Some people still cultivate with *coa*, while others use *yunta* or tractor. However, intensive cultivation of *nopal* has been accompanied by many pests, such as insects or fungi.

In the *slope* AE, campesinos mentioned 159 cultivated species in the three municipalities. Of these, 122 species are annual or perennial cultivated seedlings sold annually. *Nopal* is the most important perennial crop. The species cultivated by more than 40 collaborators were: maize (60 % of the collaborators); squash or ground (*Cucurbita moschata* (Duchesne ex Lam.) Duchesne ex Poir., and *C. pepo* L., respectively) (37%); beans and broad beans (*Phaseolus* spp.) (28%). *Nopal*, coriander (*Coriandrum sativum* L.), *cempasuchil* (*Tagetes erecta* L.), and spinach (*Spinacea oleracea* L.) were cultivated by 21-25% of the collaborators. The Cluster analysis based on the absence - presence of crop species cultivated in each AE shows that *chinampa* is separated from the other two because most cultivated species are ornamental, medicinal, and aromatic, representing an important economic input for campesinos (Fig 2).

Different agricultural practices are followed by campesinos, most of them in the three agroecosystems. The most common were:

Barbecho (land cleaning). – It is carried out in the three AES. The grass is removed with a machete and hoe and the remains of the crop are collected or burned; the team gets in to loosen the earth. Occasionally the land is fertilized with manure, whether horse, sheep, cow or pig.

Fallow. – It is carried out in the three AES, except for the *chinampa* that do not occupy the land for planting. It is the first step when starting a new agricultural cycle of any crop, and it is conditioned to be carried out when the soil is moist. While the tractor or yunta passes through the land, the soil is stirred and turned, and the weeds are crushed, which will serve as organic fertilizer and help retain soil moisture.

Irrigation. – It is applied in the *chinampa* and *ciénega* AES, which have access to water from the natural channels of the Xochimilco and Chalco lakes to the constructed channels that distribute water from the Cerro de la Estrella treatment plants and, to a lesser extent proportion, by the purchase of water from pipes or the construction of water stores in their cultivation areas. Fuel pumps extract water from the channels and spread it with hoses or sprinklers; only one collaborator transports water and irrigates with buckets.

Dredge. – It occurs in *ciénega* and *chinampa*. It is carried out with a harrow, a tool that is placed on the yunta or tractor, which breaks up lumps in the soil so that the land is as “even” and porous as possible, helping the retained moisture to escape and promoting the germination of crops, as well as eliminating weed shoots.

Furrowed. – It occurs in the three AES, except for the *chinampas* that do not occupy the land to plant. Tracing the furrows occurs when the first rains begin in March and April and can be done five or six days after tracing. Most of the farmers plant at the same time as furrowing. While the tractor or team makes the furrows, one or two people follow behind sowing. In the case of swamps where vegetables are planted, furrowing is done manually with the help of a hoe.

Camellonado for *melga*. – It occurs in the *ciénega*. For the cultivation of various vegetables such as lettuce, broccoli, purslane, huauzontle, onion, and garlic, among others, the furrows are not marked, but rather, with the help of the hoe, small quadrants or beds of crop that are delimited by slightly raised edges for better use of irrigation, called *melgas*.

Seedbed and enchapinado. – It occurs in the *chinampa* and *ciénega*. With mud, a 5-10 m bed is made, which is subdivided into small squares or chapines, where the seeds are placed; when seedlings appear, they are ready for transplanting. Sometimes the seeds are spread on the bed, depending on the crop.

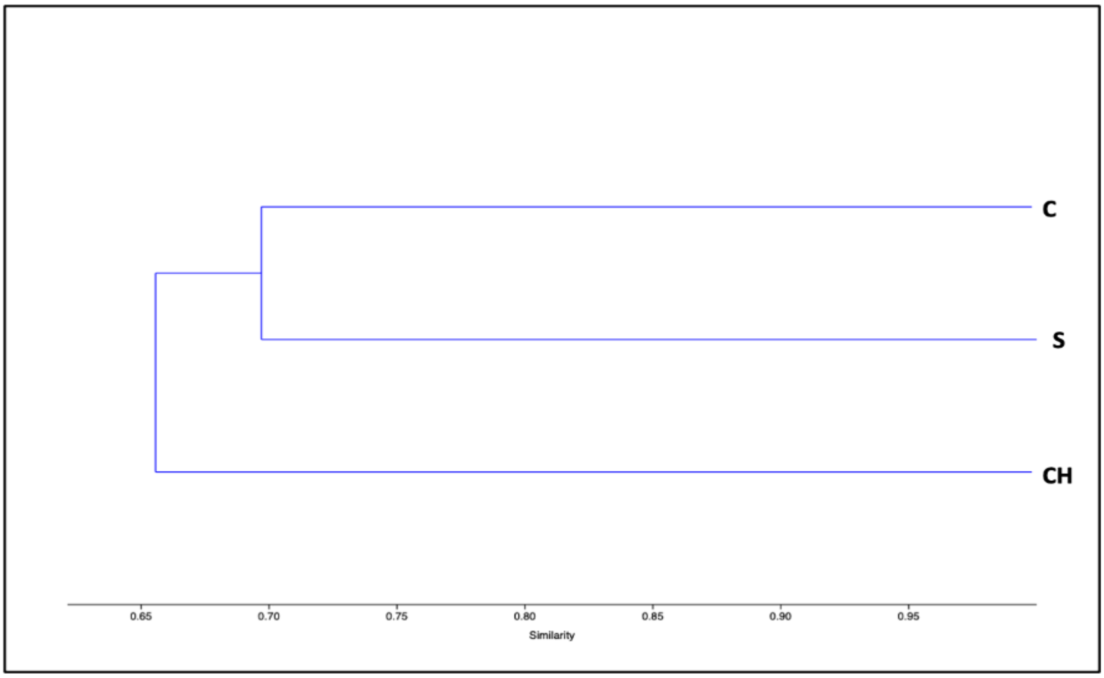

Figure 2. Cluster analysis based on the absence-presence of cultivated crops in each agroecosystem. (CH = *chinampa*; C =*ciénega*; S= *slope*).

Padded. – It occurs in the *chinampa*. A plastic sheet with holes is laid over the furrow where the seedlings will be transplanted. This plastic prevents the growth of weeds and retains moisture.

Sowing. – Occurs in all AES. It is carried out manually, using a shovel to open the holes and put the seeds. The distance they leave between sown seeds ranges from 20 cm to a normal human step. This process is usually carried out by family members. Most crops are planted in the first semester. If the crop is sown not evenly on the land, it is replanted to fill in those spaces where germination failed.

Transplant. – It occurs in all AES when the plants have been propagated in a seedbed or the seedlings are acquired in a tray, like vegetables.

Escardas. – They are applied in all AES. They consist of adding soil to the bases of the plants to provide them with protection from high temperatures and wind, promoting aeration, and this also helps to prevent weeds from proliferating. It is carried out with different tools such as shovels, rakes, teams (animal or human), or with the motocultor or tractor. Some farmers apply for a second escarda sometime later if they consider it necessary.

Weeding. – They are applied in all AES and are focused on weed control and labor facilitation. Traditional methods, such as using the hoe, a machete, or simply by hand, or chemical methods applying herbicides, are followed. The method, as well as the number of weedings, depends on the farmer´s decision and the kind of crop.

Fertilization. – It occurs in all AES. Fertilizers of animal or chemical origin are administered to provide crops with the nutrients necessary for better production. It is important to note that the majority use organic fertilizers of animal origin. It is applied in two ways: before fallow, it is dispersed on the land and incorporated during it; matted, when the plants are grown.

Pile/drawer. – It occurs in the *slope*. It is applied only to corn; it consists of bringing soil closer to the base of the plants when they are at the maximum point of maturity, when they jitter, to give the plant a strong base so that it does not fall with the winds. This practice is done manually, by hand, or with simple tools such as a hoe, a team, or a tractor. The period for the heap is from June to August, depending on the date they planted and the weather.

Harvest. – It occurs in all AES. Harvesting is a highly variable activity throughout the year and depends on the crop. Some species, such as corn, beans, and squash, are only harvested once; others are harvested almost all year round, like the nopal. Others are harvested three or four times, as is the case with vegetables. Regardless of the crop, it is completely manual. The sweet corn or cob are cut and placed in bundles. In the case of ebo and oats are kneaded, cut, and packaged. The remaining crops, such as vegetables, are cut and placed in plastic containers.

Throw cañuela and Mogotada/Amogotar. – It occurs in the *slope* and *ciénega* and only applies to maize cultivation. The plants are thrown away and allowed to dry to later harvest the cob. When the cob has matured, the leaves are removed, the stalks are cut, and stacked in a structure known as a *mogote*. The ears remain there to finish drying, and little by little, the campesinos collect them. In the case of forage, they are cut completely.

The "agroecosystem sustainable index" (ASI) average of agricultural practices by AE shows that in all cases, the *slope* AE presented the highest values and the *chinampa* the lowest, indicating that *slope* still retains more traditional, sustainable practices (Table 3).

The PCA showed a clear separation between the plots of the three AES depending on the type of agricultural practices (Fig 3). To the right side of the first component, *slope*, *and ciénega* plots are separated from most of the *chinampas*. The variables with the greatest weight corresponding to the *slope* were mostly traditional practices such as cultivating annual plants, manual weeding, and fertilizing with animal manure. On the left, the variable with the greatest weight were the principal crop (PC), including ornamental and aromatic plants. The second component groups, in the lower coordinate, *ciénega* and *chinampa* plots that cultivate maize, or greens, respectively, in the ground.

Weed diversity, abundance, and composition in the three agroecosystems, in the two spaces

Weeds mentioned by collaborators

From the 179 interviews, 1,750 records of 219 different weeds were obtained. Over 60% of the weeds are considered part of the agroecosystem, with no benefits or prejudices; 34.6% of the records were considered exclusively harmful, and only 1% were classified as truly beneficial for crops. Edible plants *quelites* (green, red, white, and wild), *quintonil*, rosemary, were the most mentioned; different types of grass, some of them considered aggressive (*pajasín*, *zacatón-pelillo-güero*, wild, common, Chinese, wheelbarrow, patio, fine, thick, *pipiloli*, crow's foot, guide, grass, grass fat); *acahual* or *alcahuali* (white and yellow), and some weeds that are considered annoying but not aggressive and even used mainly as fodder: *chayotillo, chocaca* or *xocaca* (Table 4). The main uses are edible (21%), medicinal (15%) and fodder (17%). Of the 179 collaborators interviewed, 146 recognized the importance and usefulness of these plants. Collaborators mentioned one to six uses of weeds: food, medicine, fodder, fertilizer, ecological, and economic (Fig 4).

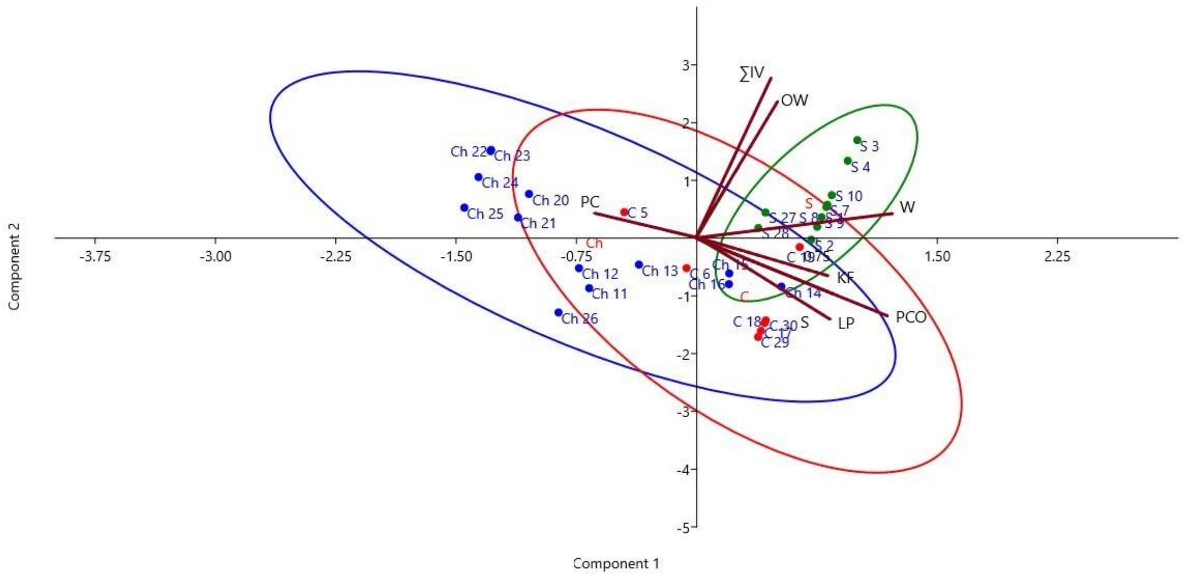

Figure 3. Principal Component Analysis of 30 plots based on correlation analysis of the eight variables related with management practices (component$_1$= 83.67%, component$_2$= 16.32%). (Blue, CH = *chinampa*; red, C =*ciénega*; green, S= *slope*). PC= principal crop; S= substrate; SW= water source; LP= land preparation; KF= kind of fertilizer; W= weeding; PCo= pest control.

Table 3. Agroecosystem sustainable index (ASI) obtained for the 30 plots: main crop: 1= ornamentals, aromatics, or greens, 2= maize, squash, oats, or ebo; substrate: 2= soil, 1= pot; origin of water: 2= rain, 1= rain + irrigation; land preparation: 2= yunta, 1= tractor/motocultor; fertilizer: 2= organic, 1= chemical; weeding: 2=manual, 1= chemical; pest control: 2= nothing, 1= insecticide + fungicide, 0.5= insecticide or fungicide. IV= Importance Value. * Significant differences between agroecosystems.

Agroecosystem	Main Crop	Substrate	Origin of water	Land Preparation	Kind of Fertilizer	Weeding	Pest Control	∑ASI*	∑IV	Number of individuals	Number of species	Specific Richness	Shannon Diversity
Chinampa 11	2	2	1	2	1	1	1	10.0	4,410	639	20	2.941	0.629
Chinampa 12	2	2	1	2	1	1	0.5	9.5	5,200	547	16	2.379	0.771
Chinampa 13	2	2	1	2	1	1	2	11.0	6,600	216	12	2.046	0.493
Chinampa 14	1	2	1	2	2	2	2	12.0	6,400	557	15	2.214	0.631
Chinampa 15	1	2	1	2	2	2	0.5	10.5	5,997	149	13	2.398	0.807
Chinampa 16	1	2	1	2	1	2	2	11.0	5,773	243	18	3.095	0.808
Chinampa 20	2	1	1	1	1	1	2	9.0	6,900	758	22	3.167	1.084
Chinampa 21	2	1	1	1	1	1	2	9.0	5,500	692	16	2.294	0.943
Chinampa 22	2	1	1	1	1	1	0.5	7.5	8,255	894	28	3.973	0.840
Chinampa 23	2	1	1	1	1	1	0.5	7.5	8,324	1498	33	4.376	0.811
Chinampa 24	2	1	1	1	1	1	0.5	7.5	6,714	185	14	2.490	0.921
Chinampa 25	2	1	1	1	1	1	0.5	7.5	4,900	247	24	4.175	0.954
Chinampa 26	2	2	1	2	1	1	0.5	9.5	2,572	123	7	1.247	0.515
Ciénega 17	1	2	1	2	2	2	2	12.0	4,250	217	8	1.301	0.395
Ciénega 18	1	2	1	2	2	2	2	12.0	3,781	602	11	1.562	0.451
Ciénega 19	1	2	1	2	2	2	2	12.0	8,745	363	15	2.375	0.674
Ciénega 29	1	2	1	2	2	2	2	12.0	3,415	733	8	1.061	0.501
Ciénega 30	1	2	1	2	2	2	2	12.0	4,400	74	11	2.323	0.321
Ciénega 5	2	2	1	2	1	1	1	10.0	8,919	682	21	3.065	1.002
Ciénega 6	1	2	1	2	2	1	0.5	9.5	6,680	1750	24	3.080	0.889
Slope 1	1	2	2	2	2	2	2	13.0	7,432	1332	24	3.197	0.960
Slope 10	1	2	2	2	2	2	2	13.0	8,135	1017	26	3.610	0.685
Slope 2	1	2	2	2	2	2	2	13.0	5,491	653	26	3.857	1.026
Slope 27	1	2	2	2	2	2	0.5	11.5	5,918	242	22	3.826	0.887
Slope 28	1	2	2	2	2	2	0.5	11.5	5	195	14	2.464	0.862
Slope 3	1	2	2	2	2	2	2	13.0	11,400	1823	16	1.998	0.886
Slope 4	1	2	2	2	2	2	2	13.0	10,175	1059	16	2.154	0.979
Slope 7	1	2	2	2	2	2	2	13.0	7,563	352	15	2.388	0.959
Slope 8	1	2	2	2	2	2	2	13.0	6,259	847	16	2.225	0.631
Slope 9	1	2	2	2	2	2	2	13.0	6,825	764	27	3.917	0.849
Chinampa mean	1.76	1.53	1	1.54	1.15	1.23	1.11	9.35	5.97	519.07	18.31	2.83	0.785
s.e.	(0.121)	(0.144)	(0)	(0.144)	(0.104)	(0.122)	(0.205)	(0.425)*	(0.429)	(108.89)	(1.95)	(0.25)	(0.05)
Ciénega mean	1.14	2	1	2	1.86	1.71	1.64	11.36	5.741	631.57	14	2.11	0.605
s.e.	(0.142)	(0)	(0)	(0)	(0.142)	(0.184)	(0.237)	(0.419)	(0.890)	(208.14)	(2.39)	(0.31)	(0.09)
Slope mean	1	2	2	2	2	2	1.7	12.7	7.420	828.4	20.2	2.96	0.872
s.e.	(0)	(0)	(0)	(0)	(0)	(0)	(0.2)	(0.2)	(0.645)	(161.21)	(1.67)	(0.25)	(0.04)

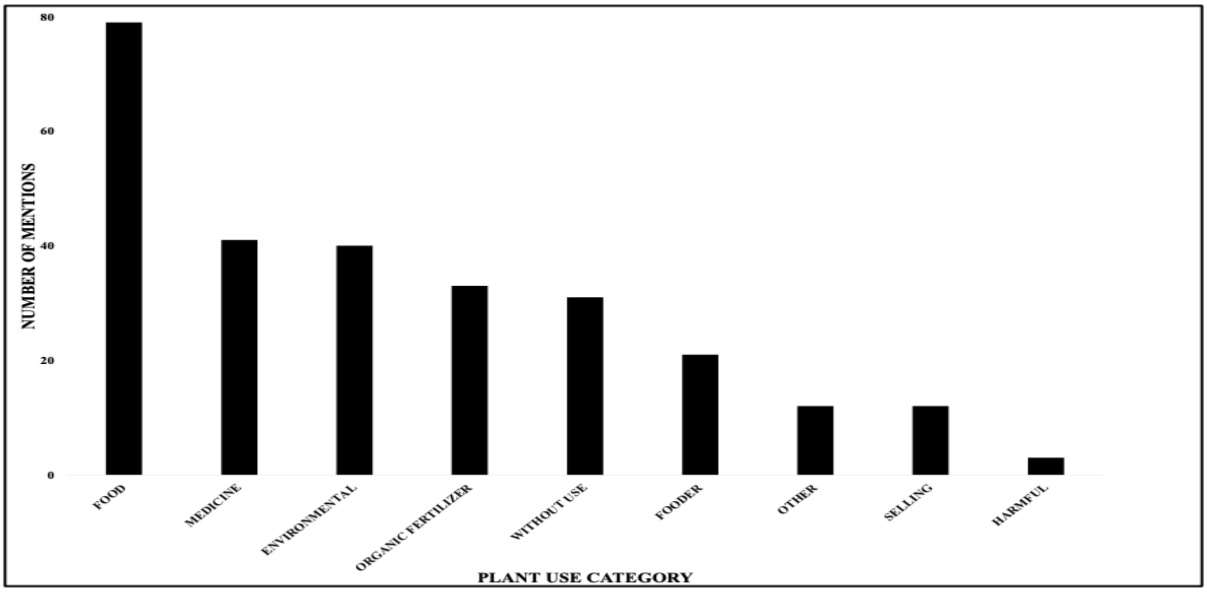

Figure 4. Number of species mentioned in each use category of weeds.

Table 4. Local names and scientific names of the weed species that were mentioned by at least 25 collaborators. (F= food; FO= fodder; M= medicine; T= tool).

LOCAL NAME	MENTION FREQUENCY	SCIENTIFIC NAME	USES
Quelite verde, cenizo, rojo, blanco, cimarrón	169	*Chenopodium album, Chenopodium berlandieri, Chenopodium cf. desiccatum, Chenopodium fremontii, Chenopodiastrum murale*	*F, FO*
Different kinds of grasses	160	*Avena sativa, Bromus diandrus, Bromus carinatus, Bromus catharticus, Bromus dolichocarpus, Cynodon dactylon, Cynodon plectostachyus, Cyperus esculentus, Disakisperma dubium, Echinochloa crus-galli, Eleusine indica, Eleusine multiflora, Eragrostis mexicana, Hordeum jubatum, Lolium multiflorum, Melinis repens, Poa annua, Poa pratensis, Polypogon interruptus, Setaria adhaerens*	*FO*
Quintonil	113	*Amaranthus hybridus, Amaranthus retroflexus*	*F, FO*
Romero	77	*Suaeda nigra*	*F, M*
Verdolaga	73	*Portulaca oleracea*	*F*
lengua de vaca o vinagrera, vinagreta, tipo 1, 2, 3, lagrimera	69	*Persicaria amphibia, Rumex crispus, Rumex obtusifolius*	*F*
Malva	63	*Fuertesimalva jacens, Fuertesimalva limensis, Malva parviflora, Kearnemalvastrum lacteum*	*F*
Acahual o alcahuali blanco y amarillo, pixoxihuitl	62	*Bidens pilosa, Chamaecereus silvestrii, Galinsoga parviflora, Phaseolus coccineus, Simsia amplexicaulis, Tithonia cf. rotundifolia*	*F*
Mortanza, nabo amarillo y blanco	55	*Brassica rapa, Eruca vesicaria, Eruca vesicaria subsp. sativa, Sisymbrium irio, Raphanus raphanistrum*	*F, FO*
Chayotillo, chocaca, xocaca	48	*Sicyos microphyllus*	*F*
Lechuguilla	42	*Sonchus oleraceus, Helminthotheca echioides*	*F*
Chivatitos o Chivitos	36	----	*F*
Estafiate	29	*Artemisia ludoviciana, Artemisia cf. annua*	*M*
Ortiga	28	*Urtica chamaedryoides, Urtica dioica, Urtica dioica var. holosericea*	*M*
Árnica	27	*Heterotheca inuloides*	*M*
Diente de león	26	*Taraxacum campylodes, Taraxacum sect. taraxacum*	*M*
Jarilla, jarilla blanca	26	*Baccharis salicifolia*	*M, H*
xocoyol o xocoyol agrio, amarillo, blanco, morado	25	*Oxalis corniculata, Oxalis hernandesii, Oxalis latifolia, Oxalis lunulata, Oxalis pes-caprae*	*F, FO*
Maíz cimarrón o azizi, asese, maíz del diablo, cizaña	22	*Zea mays ssp. mexicana*	*FO*
Chichicaxtle/espina blanca/espino	21	*Chchicaste grandis*	*M*

Weed diversity, abundance, and composition

In the 30 samplings, 31 botanical families and 355 species were recorded. Of these, 156 were identified at the species level, 6 up to a subspecies or variety, 68 to genera, and 65 to family; 57 specimens remained unidentified. Poaceae, Asteraceae, Amaranthaceae, and Brassicaceae, were the botanical families most represented in the three AES, with more than 20 species (Fig 5). The highest richness was found in *slope*, with 30 botanical families, while *chinampa* presented 26 families and *ciénega* only 15. Unique species recorded in each AE also indicated that *slope* shared the highest value (54), while *ciénega* shared the lowest (7). Venn diagram shows that 32 species were common to the three agroecosystems; between pairs of agroecosystems, *chinampa-slope* shared the highest number of weeds (16), while *slope-ciénega*, the lowest (5) (Fig. 6).

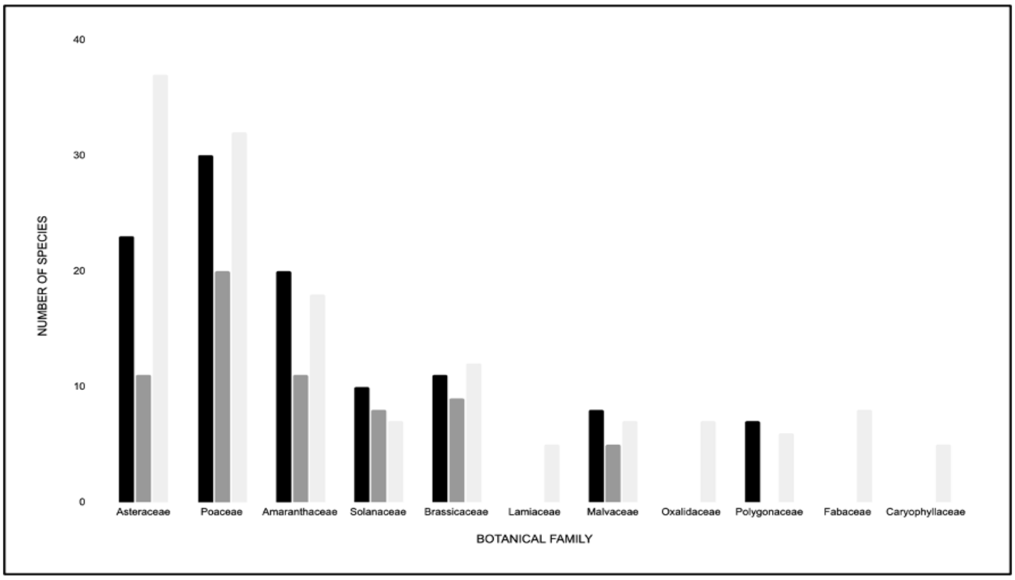

Figure 5. Number of species recorded in the 11 most abundant families recorded in the 30 plots of three agroecosystems: black = *chinampa*; gray =*ciénega*; white= *slope*.

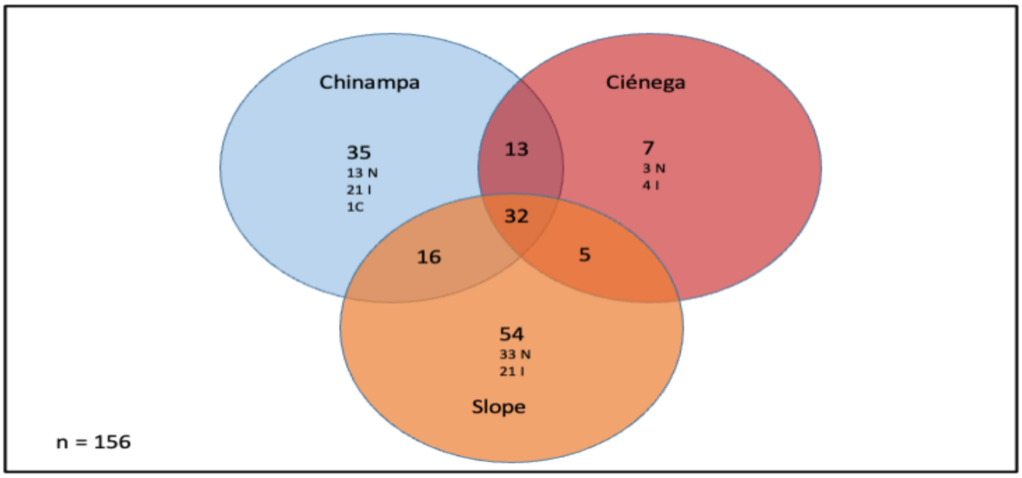

Figure 6. Venn diagram indicating the number of weeds that are common to the three agroecosystems, to *chinampa-ciénega*, *chinampa-slope*, and *ciénega-slope*, and that unique to each agroecosystem. (N=native; I= introduced; C= cosmopolitan).

According to the IUCN, 43 species are in a category of minor concern or with insufficient information, including *Marrubium vulgare* L., which is classified as near-decreasing danger.

Concerning their migratory status, it was determined that of the 162 identified species, 87 are native, 73 are introduced, and 2 are cosmopolitan. A comparison between AE revealed that the *slope* shared more native species (Fig 6).

Importance Value (IV) and Variation Coefficient (VC) in the three agroecosystems

Differences are observed in the species with higher IV (above 0.1). In the *slope* plots, the highest IV did not exceed 0.25. Although the two species with the highest IV corresponded to two grasses (Poaceae), only three grasses presented values above 0.1. In the case of *chinampa* and *ciénega*, the species with the highest IV correspond to a Poaceae (*Poa pratensis*) and one Asteraceae (*Sonchus oleraceus*) with values that double those registered in *slope*. Most of the species with the highest IV values in *chinampa* and *ciénega* were exotic (Table 5).

Multivariate analyses grouped the plots in their agroecosystem, indicating differences in weeds' composition (*PCoA*) and dominance (*PCA*). In the case of PCoA (Fig 7), the first coordinate separated *slope* plots (right side) from *ciénega* and some *chinampa* plots, while the second coordinate separated most of the *chinampa* plots. However total variance explained is low (coordinate$_1$= 9.02%, coordinate$_2$= 6.81%).

Table 5. Relative abundance (RA), Relative Frequency (RF), and Importance Value (IV) of species with IV values > 0.1 in the three agroecosystems: CH = *chinampa*; C =*ciénega*; S= *slope*. (*introduced species).

	CH				C				S		
WEED	***RA.***	***RF***	***IV***	***WEED***	***RA.***	***RF***	***IV***	***WEED***	***RA.***	***RF***	***IV***
*Sonchus oleraceus**	0.5041	0.04936	0.5534	*Setaria adhaerens**	0.1867	0.3797	0.5664	*Bromus carinatus**	0.0547	0.1953	0.2500
Poa pratensis	0.3008	0.2524	0.5532	*Cynodon dactylon**	0.155	0.2278	0.3828	*Poaceae 1*	0.0038	0.2344	0.2381
Oxalis corniculata	0.2195	0.0888	0.3083	*Chenopodium album**	0.0213	0.3038	0.3251	*Oxalis lunulata*	0.00013	0.2188	0.2189
*Helminthotheca echioides**	0.2440	0.0288	0.2727	*Malva parviflora**	0.0106	0.3038	0.3144	*Oxalis corniculata*	0.0051	0.1953	0.2004
Portulaca oleracea	0.2114	0.0309	0.2423	*Amaranthus hybridus*	0.0605	0.1899	0.2504	*SIN IDENTIFICAR 32*	0.0083	0.1797	0.1879
Asteraceae 13	0.1545	0.0392	0.1936	*Chenopodium cf. fremontii*	0.0222	0.2152	0.2374	*Fuertesimalva limensis*	0.0034	0.1797	0.1831
*Setaria adhaerens**	0.1301	0.0214	0.1515	*Poaceae 12*	0.1142	0.1013	0.2155	*Chenopodium fremontii*	0.0060	0.1563	0.1623
*Bromus carinatus**	0.1219	0.02630	0.1483	*Sisymbrium irio**	0.0168	0.1646	0.1813	*Disakisperma dubium*	0.0005	0.1563	0.1568
*Poa annua**	0.1138	0.02749	0.1413	*Chenopodium sp. 3*	0.0338	0.1266	0.1603	*SIN IDENTIFICAR 3*	0.0009	0.1484	0.1493
*Chenopodium album**	0.12195	0.0161	0.1381	*Portulaca oleracea*	0.0159	0.1392	0.1551	*Phaseolus coccineus*	0.0001	0.1484	0.1486
*Malva parviflora**	0.1138	0.0093	0.1231	*Setaria sp. 3*	0.04055	0.1139	0.1545	*Caryophyllaceae 2*	0.0070	0.1328	0.1398
Setaria sp.5	0.1057	0.0117	0.1174	*Chenopodium berlandieri*	0.0054	0.1392	0.1447	*Sclerocarpus sp1*	0.0001	0.125	0.1251
Solanum americanum	0.1057	0.0112	0.1169	*Poaceae 11*	0.04100	0.1013	0.1423	*Eruca vesicaria**	0.0884	0.03123	0.1197
Chenopodium berlandieri	0.1057	0.0095	0.1151	*Solanum angustifolium*	0.0066	0.1266	0.1332	*Poaceae 15*	0.0491	0.0703	0.1194
*Lepidium didymum**	0.1057	0.0087	0.1144	*Setaria sp. 2*	0.0374	0.089	0.1260	*Chenopodium sp. 13*	0.0113	0.1012	0.1128
				*Sonchus oleraceus**	0.0041	0.1140	0.1180	*Erodium moschatum**	0.0260	0.0859	0.1119
				*Brassica oleracea**	0.0032	0.1140	0.1171	*SIN IDENTIFICAR 21*	0.0001	0.1016	0.1017
				Flaveria trinervia	0.0057	0.1013	0.1069	*SIN IDENTIFICAR 4*	0.0149	0.0859	0.1008

Similarly, PCA analysis based on IV values separated plots by IV of some weeds. The total variance explained was high (component$_1$= 62.59%, component$_2$= 37.41%), and the separation of plots by AE is too much clear. The first component separated the *slope* plots on the right side of the figure, while the *chinampa* and most of the *ciénega* plots are separated on the left side (Table 5). The second component separated all the *slope* and most of the *chinampa* plots in the upper side. Grouping of the plots belonging to different spaces (PERI or SUB) is implicit only in the case of *ciénega* and *chinampa* plots.

DISCUSSION

Agricultural activity in Mexico City develops in three annual agroecosystems: *chinampa*, *ciénega*, and *slope*, representing an important source of economic income, along with other satisfactions. Based on the interviews, this activity is carried out mainly by people over 40. There is a sector of young people (between 20 and 39) who expressed their interest in this activity. Campesinos identified weeds as components of the main crops and as useful species for different purposes. Differences were found in the weed diversity, composition, and abundance at the family and species level between the tree agroecosystems, with the highest values in *slope*. Alpha diversity values were similar, but dominance was higher in *chinampa*, and *ciénega*, suggesting a decrease in agrobiodiversity. In this context, ecological attributes of weeds represented reliable indicators of sustainability.

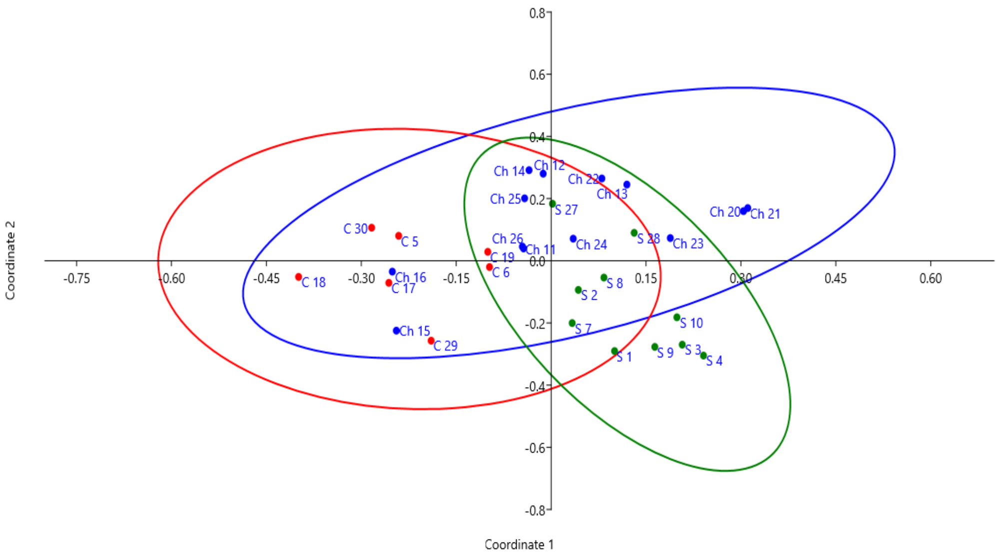

Figure 7. Principal Coordinate Analysis of 30 plots based on the absence-presence of weeds. (coordinate$_1$= 9.02%, coordinate$_2$= 6.81%). (Blue, CH = *chinampa*; red, C =*ciénega*; green, S= *slope*).

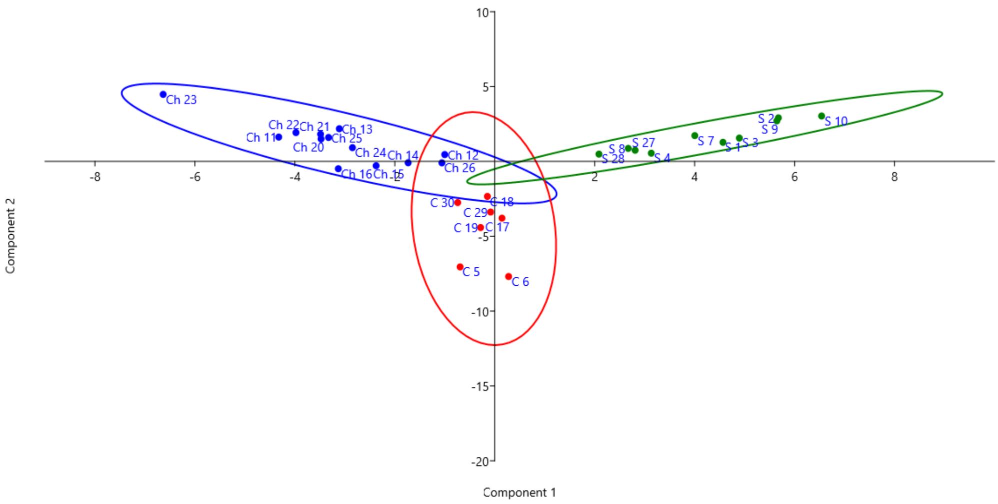

Figure 8. Principal Component Analysis of 30 plots based on the IV of weeds. (component$_1$= 62.59%, component$_2$= 37.41%). (Blue, CH = *chinampa*; red, C =*ciénega*; green, S= *slope*).

Differences between the three agroecosystems are explained by different factors: the environmental characteristics of each agroecosystem, the similarity in the agricultural practices, and their location in the PERI and SUB areas.

Despite the high rate of migration that occurs in CDMX, most of the collaborators are native to the localities where they were interviewed, so this activity is linked to strong ancestral ties of land ownership, identity with their local roots, the permanence of certain traditions, and even to their ethnic roots -mainly Nahua roots-. Different reasons explain why they are campesinos in this megapolis: Some turned back to agricultural activity after they retired or became ill; others do not want to lose or abandon their lands inherited from their parents or grandparents. These reasons have been mentioned before (Torres-Lima and Burns, 2002). With COVID-19 pandemic, many students and professionals retreated to their homes because of a lack of employment or the impossibility of going to school. This isolation was the spearhead for promoting local organizations in different localities. An interesting case was observed in San Pedro Atocpan, where during the two years of the pandemic, a collective was formed, *Colectivo Rural Atocpan*, to preserve native maize seeds, promote their exchange, and even experiment with new varieties. The new generation, consisting of young people with at least bachelor's degree, actively and methodically adopted this group after one of the collaborators over 60 years old created it (Daniel Vázquez, Pers. Comm.). Thus, agricultural activity has the potential to continue even when, in each generation, there is an increase in the percentage of people with higher education, which has been a trigger for the rapid change from agricultural activity to other productive activities. However, a strong local organization is necessary to avoid external factors affecting land tenure (urbanization, criminal groups, invasions).

According to Hernández-Xolocotzi and Ramos (1977) *slope*, *chinampa*, and *ciénega* are agroecosystems because they have their characteristics that differentiate one from other: the characteristics of the landscape where these are inserted, the temporality of crops, labor division, the tools and inputs used, the forms of social organization, the level of insertion in the market (v.g., local, regional) and (Martínez-Alfaro, 2001; Casanova-Pérez *et al.*, 2015). The historical component indicating its pre-Hispanic presence is also added (Table 8). However, we observed changes that arise from the campesinos' own initiatives, given the changing demands of local, national, or even international crop markets, fluctuations in the sale price of different agricultural products, pest and disease problems that reduce production and cause campesinos to look for new options, and, more recently, the decrease in the amount of rainwater and the increasingly erratic changes in the rainy season.

Changes in crop cultivation occur concurrently with the introduction of new technologies, such as agrochemicals, or infrastructure, such as the excessive use of plastic bags or greenhouses. A negative pressure corresponds to the use of different agrochemicals, with the argument that, without their application, crop production is almost impossible. In the *slope*, *nopal* has the highest demand for pesticides, but maize requires more chemical fertilizer. Some authors suggest that the tendency to convert maize fields on *nopal* fields is related to "the best strategy that the collaborators have adopted to deal with the field, located at the urban-rural interface, the dependence on rain, the reduced use of machinery, and, therefore, the greater use of rudimentary procedures in its planting and harvesting, which allow them to take better advantage of the precarious production conditions" (Bonilla-Rodriguez, 2014). Our findings suggest that this strategy is not sufficiently regulated, and it is expanding with numerous management issues and serious market problems due to the expansion of the cultivation area of this species not only in CDMX but also in Morelos, which has created a very competitive market in recent years.

However, the results demonstrated that dependence on agrochemicals is more pronounced in *chinampa* and *ciénega*. This perception has already been reported (FAO, 2015; González-Pozo *et al.*, 2016; Dieleman, 2017; Losada *et al.*, 2017), as the negative impact of its use was detected in an increase in the concentration of nitrates in the water channels near greenhouses (Méndez, 2006) or the presence of ammonium, among others, in Lake Xochimilco-Chalco (Zambrano *et al.*, 2009).

Along with the large amounts of trash generated in *chinampas*, the level of contamination in the channels of Xochimilco, the inadequacy of water purification, and the precipitous decline in water levels is remarkable. During 2021 field trips, we observed the level of dirt in the water and the foul odors it emitted. The accumulation of significant amounts of organic matter reduces dissolved oxygen concentrations in the water channels and *apantles* (Mazari-Hiriart *et al.*, 2008).

These changes in agricultural practices have resulted in substantial shifts in weed diversity, abundance, and composition. Vibrans (1998) recorded 42 families and 256 ruderal species in the urban zone of the city, in areas below 2300 m a.s.l. A recent study to quantify knowledgeable and beneficial weed diversity and composition from the Cuajimalpa municipality (Rivera- Ramírez *et al.* 2021) reported 42 species and 19 botanical families. Additionally, Vieyra-Odilon and Vibrans (2001) and Sánchez-

Reyes (2016) reported comparable data for maize fields in the Estado de Mexico.

In the case of flooded agricultural lands, such as *ciénega* AE, Sánchez-Blanco and Guevara-Ferrero (2013) reported a higher number of families (34) and species (133). This study examines the geographical phenomenon of the lake's desiccation and eutrophication, which has resulted in the exposure of salt-impregnated agricultural soils. Intermittent inundation and soil salinization were two issues the collaborators mentioned. In the present study, *ciénega* presented the lowest species and family diversity and the greatest number of Poaceae species with a dominance index (IV) greater than 0.1. This suggests that certain species are becoming dominant.

Few studies examine the effect of herbicides on weed diversity, composition, and abundance. Sánchez-Reyes (2016) compared these parameters in maize fields with and without herbicide application in Ixtlahuaca, Estado of Mexico. She recorded 43 species belonging to 17 botanical families. Although richness values were comparable whether herbicides were used or not, the composition did change, with a significant decrease in dicot dry weight and an increase in monocot dry weight in fields where herbicides were frequently applied. A similar phenomenon was observed in the plots corresponding to *ciénega* and *chinampa*. In these AES, farmers cultivate the greatest diversity of crops dependent on various pesticides, such as ornamental and aromatic plants and greens. As a result, the highest proportion of Poaceae species with IV greater than 0.1 were recorded, indicating this family's dominance.

Concerning the *slope* AE, the relatively high percentage of some native species and their low IV suggest that some traditional management practices still exist and are associated with Mesoamerican agriculture (Molina-Freaner *et al.*, 2008). Despite the high use of chemical fertilizers, our findings indicate that only a small proportion of pesticides are used. According to Sánchez-Reyes (2016) and Rivera- Ramírez *et al.* (2021), the fertilizer has no direct negative effects on weed diversity or composition. Molina-Freaner *et al.* (2008) discuss the role that certain agricultural practices (e.g., polyculture, rotation, intercropping, mechanized cultivation) can play in the weed richness and abundance, in the low values of dominance of some species, and in the presence of certain weeds that have adapted in some way to these agricultural practices.

Thus, the decrease or loss of traditional crops in *chinampa* and *ciénega* because of their substitution for commercial crops, the indiscriminate use of agrochemicals, and the possible effect of treated water used for irrigation has resulted in the loss of numerous native weed species and the increase of introduced species. Our findings reveal a trend in the number of native species versus alien species. According to Bye (1998) and Molina-Freaner *et al.* (2008), in cultivated fields that utilize traditional management techniques, there will always be an increased presence of native weed species adapted to specific agricultural practices.

The comparison of weed diversity and composition between agroecosystems by zones (SUB, PERI) reinforces their differences, where *slope* plots of the PERI zone are differentiated from *chinampa*, *ciénega*, and *slope* sections located in the SUB zone.

It is assumed that regardless of their suburban or peri-urban location, agroecosystems that preserve more traditional agricultural practices will have a greater intra- and interspecific diversity of weeds. This is partially supported by the fact that the *slope* agroecosystem, located in the PERI zone, has considerably more traditional agricultural practices and a greater proportion of traditional crops (corn, broad bean, and bean) primarily cultivated for subsistence. In the SUB zone, *slope*, *ciénega*, and *chinampa* plots will be used to cultivate crops for sale, including *nopal*, squash, *cempasuchil*, broccoli, and tomato. Losada *et al.* (1996, 1998), Torres-Lima *et al.* (1994), Torres-Lima and Burns (2002), and Torres-Lima and Rodríguez-Sánchez (2008) have conducted a comprehensive analysis of the dynamics of agriculture from a historical perspective and the implications of being a campesino in a region with high urban growth in terms of the productive processes that occur between these zones. A duality of campesino-worker, campesino-employee, and educator-campesino has evolved.

Even though these changes have affected weed richness and composition between AES, traditional knowledge and use of weeds persist because a) Campesinos classify this group of plants separately from the main crops and conceive them as plants that grow spontaneously in cultivated fields, much like Espinosa-García and Sarukhán (1997), or Bye (1998) do. Consequently, the list includes perennial species such as *tepozán*, *ahuehuete*, and *tabaquillo*, which are species that sprout during the agricultural cycle and are then eliminated with weeding practices (manual or chemical); b) there is an important group of plants mentioned by almost all campesinos, which is similar to those reported in other studies, otherwise the study area and stand still through the years (Sánchez-Blanco and Guevara-Ferrer, 2013; Linares-Mazari and Bye-Boettler, 2015). The most significant number was associated with edible plants, followed by fodder and medicine. c) there is a group of species that maintains the náhuatl designation and reflects specialized knowledge based on their own experiences (Luna-José and Rendón-Aguilar, 2012): *xahuilisca*, *yolochichi*, *ocoxochil*, *pitzitlalcual*, *chilacaxtle*, and *chinantlaco*. An ethnobotanical investigation aiming at collecting and documenting these species systematically would be fascinating, given that many were not collected. It is important to note that, of the 216 registered species, we were only able to collect 111, so this information remains incomplete.

CONCLUSIONS

This study provided insight into differences in ecological and floristic parameters among three agroecosystems extant in CDMX, *ciénega*, *chinampa*, and *slope*. It also enabled us to comprehend the relationship between these attributes of weeds and agricultural practices and the potential for using weeds parameters as sustainable indicators for agroecosystems. *Slope* is the most sustainable in terms of weed diversity and composition and native/introduced composition. It is also sustainable because of the prevalence of some traditional agricultural practices, despite the introduction of technician practices; however, using herbicides and displacing traditional crops will exacerbate soil issues and the presence of pests and diseases.

There is a loss of intraspecific agrobiodiversity in native annual crops because campesinos are planting fewer maize, bean, or squash landraces and more improved varieties or hybrids. They are also focused on propagating medicinal or ornamental plants via clonal production. This is because campesinos are constrained by market demand, the ease of planting certain varieties, or the limited time they can devote to crops due to their primary occupations. Milpa prevails in the sense that maize continues to be cultivated, whereas the concept of polyculture is fading away.

However, small producers in the SUB and PERI zones of CDMX provide the city's residents with a vast array of basic foods, retaining the knowledge of ancestral sustainable agricultural practices and combining them with modern techniques. This is a form of resistance and prevalence despite the strong external pressures contributing to their gradual extinction.

The agrobiodiversity of CDMX is not just high and useful, it also reflects resistance processes in the territories. It continues to be a way of life for the campesinos and can be for the rest of the inhabitants of CDMX. The loss of knowledge and use of agrobiodiversity can be reversed, as the agricultural areas of CDMX can remain as sites for collecting food for themselves and the rest of the city. This is a hopeful prospect, as seen in other countries where weeds are becoming an important food source for people of varying social conditions. Finally, the study suggests that the ecological attributes of weeds can be used as a sustainability indicator, further adding to the potential for positive change.

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Conflict of interest. All authors declare that there is no competing interest.

Compliance with ethical standards. To comply with the code of ethics for ethnobiological research in Latin America (Cano-Contreras *et al.*, 2016), we immersed ourselves in the cultural context of the communities, solicited project approval from all three municipal administrations, and highlighted the significance of ethnobiological research to continue fieldwork. During the fieldwork, we understood and respected that the collaborators could hide special information about their experience, history, cosmovision, and other aspects of their lifestyle. Collaborators sign a printed document acknowledging their participation in the study, including their consent to participate in the interview, take photographs, and collect voucher specimens from the plots. These documents are available if needed.

Data Availability. Data are available with B. Rendón-Aguilar, bra@xanum.uam.mx upon reasonable request.

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