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Agroforestry systems of a Zapotec community in the Northern Sierra of Oaxaca, Mexico

Sistemas agroforestales de una comunidad zapoteca de la Sierra Norte de Oaxaca, México

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Abstract

Background: Agroforestry systems have cultural, economic, social, and biodiversity conservation significance and are essential for the subsistence of communities.

Questions: Is there a difference in the richness, management and use of useful plants present in the agroforestry systems (home gardens, coffee plantations, and milpa)? What is the influence of sociodemographic factors on the distribution of traditional knowledge regarding plants of these systems?

Site and years of study: Las Delicias, municipality of Juquila Vijanos, Sierra Norte of Oaxaca, Mexico, from January 2016 to May 2018.

Methods: Visits to three agroforestry systems and semistructured interviews with 30 families to learn how they use the plants and to calculate the use value (UV) for each species. The similarity of floristic composition between agroforestry systems and the influence of sociodemographic factors (age, gender, schooling, economic activity and language) in the traditional plant knowledge was evaluated. The methods used were chi squared and proportions analyses, and a generalized linear analysis with Poisson distribution.

Results: The three agroforestry systems consisted of 211 of useful plants; home gardens and coffee plantations had a greater similarity in floristic composition; the dissimilarity of the milpa agroecosystem is related to seasonality. The plants with higher UVs were those with multiple uses, and are found mainly in coffee plantations. Production in these spaces is complemented to satisfy the needs of the inhabitants. Gender and economic activity are factors that influence the distribution of traditional knowledge.

Conclusion: Agroforestry systems provide a species richness differentiated for specific purposes but complementary to each other.

Key words: coffee plantation, home gardens, milpa, use value.

Resumen

Antecedentes: Los sistemas agroforestales tradicionales tienen una importancia cultural, económica, social y en conservación de la biodiversidad; son esenciales en la subsistencia de las comunidades.

Pregunta: ¿Existe diferencia en la riqueza, manejo y uso de plantas útiles presentes en los sistemas agroforestales (huertos familiares, cafetales, milpa)? ¿Cuál es la influencia de los factores sociodemográficos en la distribución del conocimiento tradicional sobre las plantas de estos sistemas?

Sitio y años de estudio: Las Delicias, municipio de Juquila Vijanos, Sierra Norte de Oaxaca, México; de enero de 2016 a mayo de 2018.

Métodos: Recorridos por tres sistemas agroforestales y entrevistas semiestructuradas a 30 familias, para calcular el Valor de Uso de cada especie vegetal. Se evaluó la similitud de la composición florística entre los sistemas agroforestales y la influencia de factores sociodemográficos (edad, sexo, escolaridad, ocupación e idioma) en el conocimiento tradicional de plantas, mediante pruebas de Ji cuadrada, de proporciones y de un modelo lineal generalizado con distribución Poisson.

Resultados: Los sistemas agroforestales estudiados conservan 211 especies vegetales útiles; los huertos familiares y los cafetales tienen una mayor similitud florística; la disimilitud del sistema milpa se relaciona con su temporalidad. Las plantas con mayor Valor de Uso fueron las que tienen múltiples usos y presentes en los cafetales. La producción se complementa para satisfacer las necesidades de los pobladores. El sexo y la ocupación están influyendo en la distribución del conocimiento tradicional.

Conclusión: Los sistemas agroforestales proporcionan una riqueza de especies diferenciada con propósitos específicos, pero complementaria entre sí.

Palabras clave: Cafetal, huertos familiares, milpa, Valor de Uso.

Societies in the world have practiced the cultivation of arboreal species in agricultural spaces in close relation to the main purpose of food production (Steppler & Nair 1987, Nair 2011). In tropical America, farmers have traditionally simulated forest conditions in their crop fields, mimicking the structure of forests by planting species with different growth habits (Steppler & Nair 1987). Agroforestry systems "combine agricultural crops, tree crops, and forest plants and / or animals simultaneously or sequentially, and applies management practices that are compatible with the cultural patterns of the local population" (Bene *et al*. 1977). These systems are distinguished by integrating agricultural, forestry and cultural diversity (Moreno-Calles *et al*. 2016) and have been maintained over time to produce food, fiber, and fuel, among other essentials (Power 2010, Boafo *et al*. 2016), which is why they are considered the best option for food security and biodiversity conservation (Segnon *et al*. 2015).

Multi-strata agroforestry systems have shown that they can contribute to the conservation of tropical biodiversity when forests are maintained within the agricultural landscape (Harvey & González-Villalobos 2007). Among the main agroforestry systems are agroforests, home gardens, terraces, and shifting cultivation or slash-and-burn agricultural systems (Moreno-Calles *et al*. 2016); in addition, they are characterized for their plant diversity in form of polycultures and agroforestry patterns (Rosset & Altieri 2018).

In Mexico, agroforestry systems are part of a biocultural heritage (Moreno-Calles *et al*. 2013) where woody species in agricultural spaces are used as fruit trees, firewood, shade, ornaments, respect for nature and other environmental benefits (Vallejo *et al*. 2014). This cultivation system is used in the milpa in Yucatán, where the farmer selects some suitable woody species for construction, trees, fruit trees and shade (López-Forment 1998). In studies carried out in Mayan family gardens, a mosaic of stages is observed as in natural vegetation, and fulfills the function of protecting the resources of forest vegetation and the processes of the natural ecosystem of the area (De Clerck & Negreros-Castillo 2000).

Another important agroforestry system in Mexico is the traditional shaded coffee plantations produced mainly by small producers of indigenous communities and located in areas of biogeographic and ecological importance (Moguel & Toledo 1999). In the coffee plantations of the Sierra Norte de Puebla it was found that 80 % of native plants that are mainly used as medicinal and edible (Martínez *et al*. 2007). In the Sierra Sur of Mexico, the set of heterogeneous plantations of coffee plantations has proven valuable for the conservation of plant diversity (Bandeira *et al*. 2005)

At present, the conservation of areas with biodiversity is necessary, but also the satisfaction of human needs with the development of sustainable ways to use the resources that local ecosystems provide (Sarukhán *et al*. 2009). Traditional agroforestry systems can help maintain a higher level of biodiversity compared to practices that require greater transformation of ecosystems (Schroth *et al*. 2004, Bhagwat *et al*. 2008).

In this context, the importance of plant resources has been evaluated quantitatively through ethnobotanical indices, with use value (UV) being the most widely used indicator (Phillips & Gentry 1993 a,b, Ribeiro *et al*. 2014, Shaheen *et al*. 2015, Kunwar *et al*. 2016, Lopes *et al*. 2017). The use of plant resources is influenced by socioeconomic factors, with age, gender, schooling, language and economic activity being the most influential (Saynes-Vásquez *et al*. 2013, Andriamparany *et al*. 2014, Laleye *et al*. 2015, Segnon *et al*. 2015, Kunwar *et al*. 2018). In this study we define primary economic activities as those involve natural resource extraction and management, whereas tertiary activities are the providing of services.

In this study, the use value index was used to determine the importance of useful plants in three agroforestry system (home gardens, milpa and coffee plantations) in the town of Las Delicias, municipality of San Juan Juquila Vijanos, Sierra Norte. This region has great biological and cultural diversity, which is why it is recognized as part of a priority Terrestrial Region (number 130, Arriaga-Cabrera 2009) and Biocultural Region (number 17, Boege 2008), classifications that consider centers of origin, species diversification, and the presence of agroecosystems with domesticated native agrobiodiversity. Therefore, it is important to know the plant diversity in these agricultural spaces, the importance they have and how people manage them. Thus, this study aims to answer the following questions: 1) What plants of the three agroforestry systems are used in this Zapotec community, and what is the UV of these species? 2) What agroforestry system contains plants with the greatest UV? 3) What floristic similarity exists between agroforestry systems? 4) What sociodemographic factors influence the distribution of knowledge of plants in the community of Las Delicias?

Materials and methods

Study area. The locality Las Delicias is located in the communal lands of the municipality of San Juan Juquila Vijanos, Sierra Norte (Figure 1). Groups of people of Zapotec culture (INEGI 2005) settled there; therefore, the inhabitants have deep traditional knowledge about use and management of natural resources (González 2001). It occupies 62.02 km^2; 77.80 % of the vegetation corresponds to forest, 20.20 % to agriculture and 2.0 % to human settlements (INEGI 2005). Because land ownership is communal (González 2001), the inhabitants can own land in any part of the municipality.

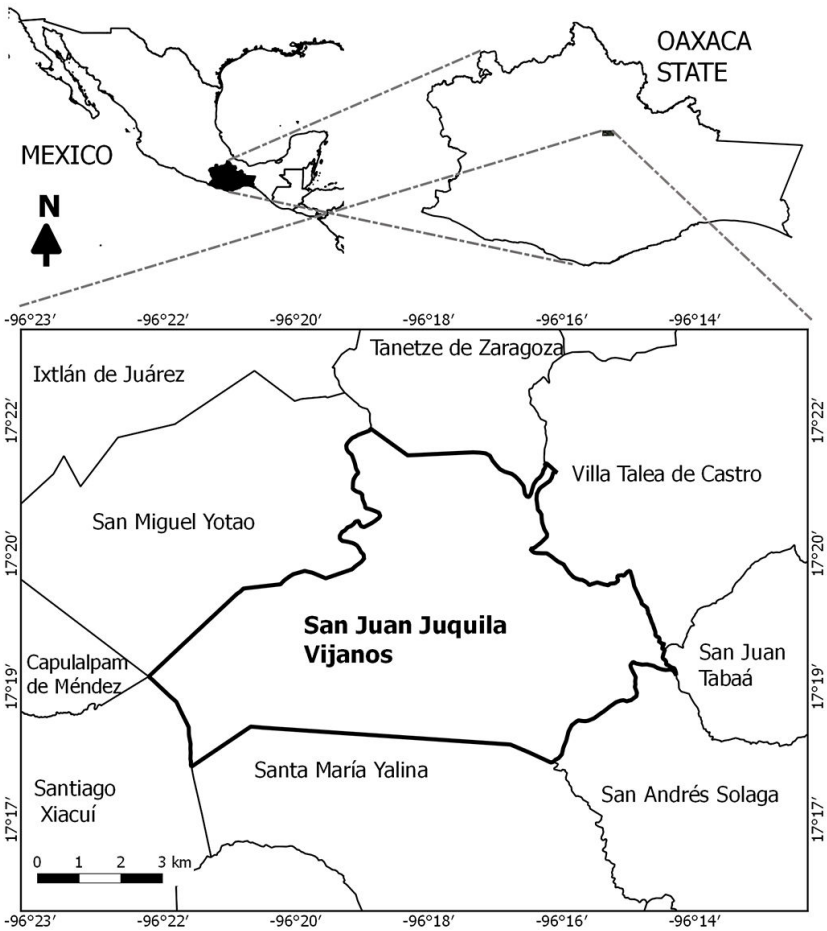

Figure 1. Location of Las Delicias, in San Juan Juquila Vijanos, Sierra Norte, Oaxaca, Mexico.

The climate is semiwarm humid and temperate wet (INEGI 2005). Precipitation ranges from 1,200 to 2,000 mm (INEGI 2005), is common throughout the year but reaches maximum levels in summer (Pérez-García & Del Castillo 2016). Middle temperature ranges from 16 to 22 °C. The altitude ranges from 900 to 2,400 meters above sea level, The landscape is composed of riparian vegetation, pine forest, pine-oak forest, cloud montane forest, secondary vegetation and cultivated areas like milpa and coffee fields, (Del Castillo & Blanco-Macías 2007, Pérez-García & Del Castillo 2016).

Of the above, shade-grown coffee represents the majority of economic income for the local farmers (Nader 1964). The mosaic of natural vegetation with interspersed cultivated areas (Figure 2) is due to slash-and-burn systems (Pérez-García & Del Castillo 2016).

Field work. The study was conducted from January 2016 to May 2018. We choose 30 families at random (Abdoellah *et al.* 2006); in 15 households, only women were interviewed, and in the other 15 households, only men were interviewed. All families had all three agroforestry systems (home gardens, coffee plantations and milpa), and each collaborator was interviewed once in each agroforestry systems. Semistructured interviews were applied to determine the useful plants in each agroforestry systems the destination (self-consumption, selling or bartering), the part used (whole plant, fruit, leaves, stem, flowers, root, seeds, and pods), the degree of management of plants (cultivated, wild, tolerated, promoted and protected) according to De Wet & Harlan (1975), and the use (food, medicinal, ornamental, live fence, firewood, shade, construction, domestic use and forage). Likewise, sociodemographic data were obtained, such as age, gender, schooling, economic activity and language (Spanish and/or Zapotec).

The ethnobotanical surveys were carried out in the three agroforestry systems of each collaborator (Albuquerque *et al.* 2014), in total there were ninety interviews. The plants were photographed, some identified in the field and others collected for identification and deposition in the herbarium of the Interdisciplinary Center for Regional Integrated Research and Development-National Polytechnical Institute

Figure 2. Vegetation surrounding the community of Las Delicias, Juquila Vijanos, Sierra Norte, Oaxaca, Mexico.

(Centro Interdisciplinario de Investigación y Desarrollo Integral Regional- Instituto Politécnico Nacional, CIIDIR-IPN), Oaxaca.

Statistical analysis. The similarity in floristic composition among agroforestry systems was performed with the Sørensen index with paired tests: SI = (2C/A + B) × 100, where A is the number of species in community A, B is the number of species in community B, and C is the number of species in both communities (Moreno 2001, Castillo *et al.* 2014).

To determine the use value (UV) of the species (Phillips & Gentry 1993 a,b, La Torre-Cuadros & Islebe 2003, Thomas *et al.* 2009), we calculated the UV by species for each collaborator *i* (UV_{is}) and then the UV for each species *s* (UV_s). The UV_{is} calculated as $UV_{is} = \Sigma U_{is}/n_{is}$, where U_{is} is the number of uses the collaborator *i* refers to the species *s* in an interview (event), and n_{is} is the number of events for species *s* with collaborator *i*. We conducted three events per collaborator. Finally, the UV for each species was calculated as $UV_s = \Sigma UV_{is}/n_s$, where n_s is the number of collaborators interviewed for a given species.

The differences in the number of species for the life-form, the origin (introduced, native) and the degree of management of the species in general and among them were analyzed with the chi-square test (χ^2), and in the cases where differences between groups were found, paired tests were conducted. The proportions test was used to analyze the overall and between-agroforestry systems differences in the categories of richness, destination, part used and use of the species (Conover 1999, Agresti 2002, Mendenhall *et al.* 2013). In the *post hoc* tests, Bonferroni correction was performed for both the chi-square and proportional tests (Agresti & Finlay 2009). These tests were performed with the R statistical environment (R Core Team 2016).

The UV data of the species of the agroforestry systems were analyzed in the program InfoStat (Di Rienzo *et al.* 2008). Due to the nature of the data, the nonparametric Kruskal-Wallis test (Mendenhall *et al.* 2013) was used to evaluate whether the differences in the UV between agroforestry systems are statistically significant. From this, a *post hoc* analysis was performed to determine between which pairs of agroforestry systems the difference resided (Conover 1999).

The sociodemographic factors related to the traditional knowledge of plants used were evaluated with a generalized linear analysis with a Poisson distribution and log link function (McCullagh & Nelder 1983) in the program IBM SPSS v.26 (IBM 2019). And the sum of squares (SS) Type III is used because Type III SS adjusts the sums of squares to estimate what they might be if the design were truly balanced (Hershberger 2005). The number of known species was used as a quantitative measure of traditional knowledge (Souto & Ticktin 2012, Beltrán-Rodríguez *et al.* 2014).

Results

Home gardens are located in the front and back of houses. Each family establishes the arrangement based on the available space and its needs; therefore, there is no distribution pattern. The farmers delimit the spaces with vegetables with mesh to protect them from breeding animals (hens and sheep), which they call 'cercos' (fences). Home gardens are mostly managed by women, who decide which species to introduce to the gardens, particularly ornamental and edible species. The men perform activities such as weeding, clearing of land for planting and irrigation.

Coffee cultivation is one of the main economic activities for the inhabitants. Each family has at least one parcel for coffee and can use it for commerce or self-consumption during that year. Coffee plantations are planted in areas with secondary vegetation and accompanied by various crops. In some cases, they are sown between pine forests (*Pinus chiapensis*), where these trees provide the main shade to the crop.

The milpa system is usually conducted along terraces. Farmers plant four types of maize based on their color: white, red, black and yellow. There are two types of milpa according to altitude: cold (*tierra fría*) and hot (*tierra caliente*) lands (*yu ziág* and *yu tza'a,* respectively), which determine the type of management given to these systems. In cold lands, the slash-and-burn system is used. These lands generally consist of permanent agriculture, in which ornamental or shade trees are maintained along the edges of the land. In hot lands, oxen are used to stir-up the earth, and the planting spaces are intermittent. According to the inhabitants, there is a greater richness of useful plants in cold zones.

Richness of species in agroforestry systems. The total richness of useful species in these spaces was 211 species and 32 varieties, distributed in 80 botanical families and 176 genera (Supplementary data 1). Asteraceae, Fabaceaeae, Solanaceae and Cucurbitaceae were the families with the greatest number of species in the three agroforestry systems. A large variety of beans (*Phaseolus*), squash (*Cucurbita*), chayote (*Sechium*), bananas (*Musa*) and chilis (*Capsicum*) were recorded. The resources are used for home-consumption, in some cases for sale and to a lesser extent bartering.

Home gardens showed the greatest species richness, followed by coffee plantations and milpa (Figure 3 and Figure 10). Relevant aspects were detected in the diversity of species in each agroforestry system (Table 1).

The proportions test showed significant differences in the richness of useful species among the three agroforestry systems (χ^2 (2,211) = 162.71, $p < 0.001$), with the richness of the home gardens and coffee plantations significantly different from that of the milpa (Supplementary data 2).

Table 1. Relevant aspects of the diversity of plant species in the agroforestry systems of Las Delicias, Oaxaca

Agroforestry systems	Diversity
Home garden	Characterized by ornamental plants such as roses (*Rosa*) and lilies (*Lilium*) and plants used in the diet: 'cebollina' white garlic (*Allium neapolitanum*), epazote (*Dysphania ambrosoides*), coriander (*Coriandum sativum*), chilis (*Capsicum* spp.), guava (*Psidium guajava*), peach (*Prunus pérsica*) and citrus. There is also a significant presence of epiphytes, some in the risk categories of the NOM-059-SEMARNAT-2010 of the SEMARNAT (Secretary of Environment and Natural Resources): orchid (*Prosthechea vitellina*), which is subject to special protection, and one bromeliad (*Tillandsia imperialis*) that is considered threatened.
Coffee plantation	The diversity associated with coffee plantations is mainly made up of trees that serve as shade for the main crop. Among the main species are 'yavito' (*Liquidambar straciflua*), 'palo de águila' (*Alnus acuminata*), 'yedou' (*Clethra mexicana*) and 'guajinicuil' *(Inga jinicuil*). When clearing land, some medicinal species such as arnica (*Tithonia diversifolia)*, 'huele de noche' (*Cestrum nocturnum*) and 'gordolobo' (*Pseudognaphalium viscosum*) remain. They also harbor one pine (*Pinus chiapensis*) subject to special protection and one threatened species of palm 'tepejilote' (*Chamaedora oreophila)* according to NOM-059-SEMARNAT-2010.
Milpa	Because it is a seasonal system, milpa mainly host herbaceous plants. The main crop of maize (*Zea mays*) is associated with varieties of squash (*Cucurbita* spp.) and bean (*Phaseolus* spp.), in addition to wild 'quelites' potherbs such as the quelite de piojito (*Galinsoga parviflora*) and the 'cuan bech' (*Phytolaca icosandra*). However, in cold land crops, trees remain, either for their edible fruits, such as mango (*Mangifera indica*), or for their ornamental value and shade, such as the *xóchitl* or *yaj zá'a* (*Magnolia macrophylla var. dealbata* (Zucc.) D. L. Johnson.).

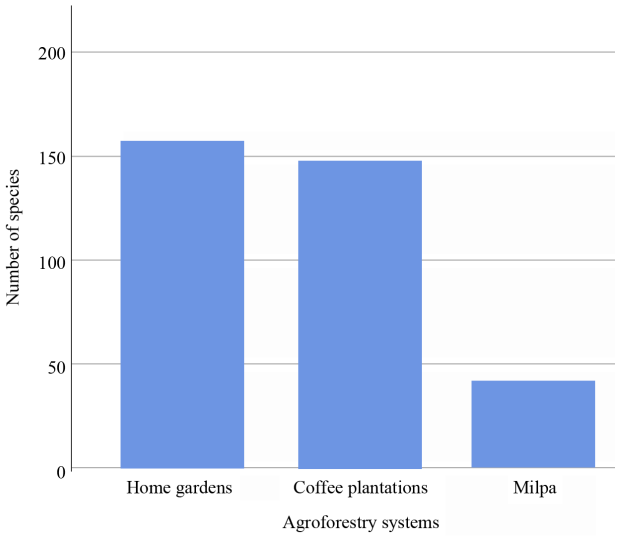

Figure 3. Richness of useful species in agroforestry systems.

The tests also showed that self-consumption is the main destination of plant species (χ^2 (2,211) = 492.11, $p < 0.001$), followed by their sale (Figure 4), mainly vegetables such as 'cebollina' (*Allium neapolitanum*), peas (*Pisum sativum*) and fava beans. Species that the inhabitants mentioned they used for bartering were beans (*Phaseolus* spp.), and squash seeds (*Cucurbita* spp.).

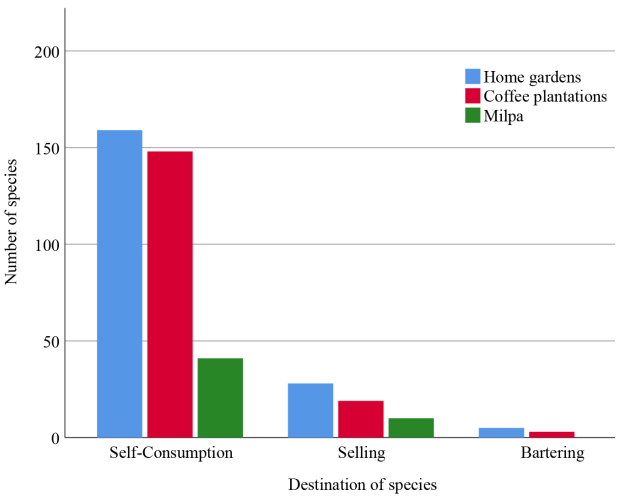

Figure 4. Destination of plant species from agroforestry systems.

In agroforestry systems in general, there is a greater amount of native plants than introduced plants (χ^2 (1,211) = 7.20, p = 0.001). When comparing agroforestry systems, a statistically significant difference was observed (χ^2 (2,211) = 45.51, p <0.001), where the highest percentage of introduced species was detected in home gardens due to ornamental species brought from the city. In contrast, coffee plantations and milpa presented higher percentages of native species (Figure 5).

The life-forms in the three agroforestry systems were herbaceous, trees, shrubs, climbing, epiphytes and ferns (Figure 6). The proportions test (χ^2 (2,119) = 63.21, $p < 0.001$) showed that the herbaceous plants are found in greater proportion in the three systems, the coffee plantations harbored more trees, shrubs are scarce in milpa, and the remaining categories, such as climbing, epiphyte and fern, showed no statistically significant differences among agroforestry systems (Supplementary data 2).

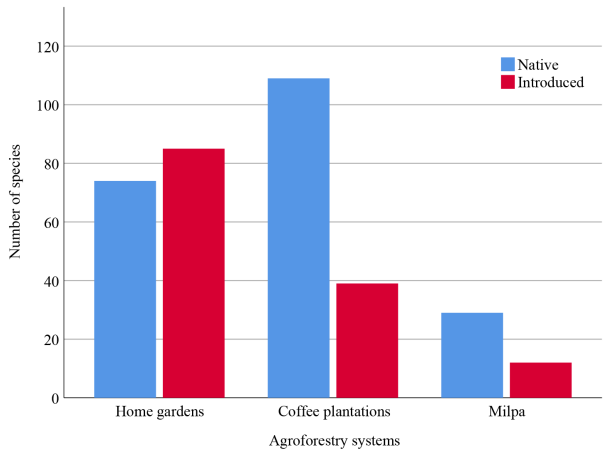

Figure 5. Origin of species from agroforestry systems.

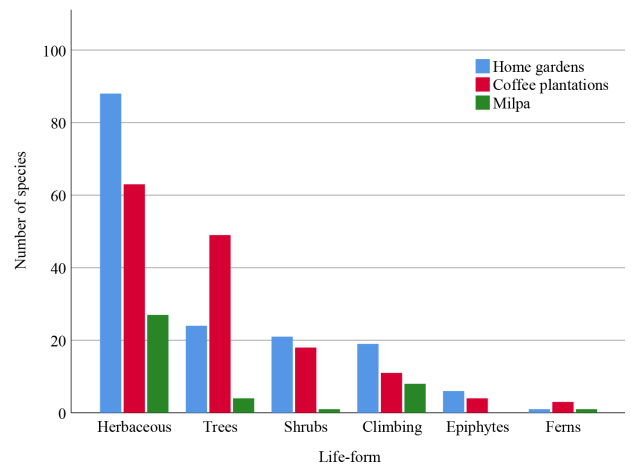

Figure 6. Life-form of species from agroforestry systems.

The whole plant is used more frequently than any of its parts alone, mainly as decoration in home gardens or to provide shade (64 %) (χ^2 (7,211) = 453.83, $p < 0.001$). The

most commonly used parts of the plants were the fruit, leaves, stem, and flower, and, to a lesser extent, the seeds, pods and roots (Figure 7).

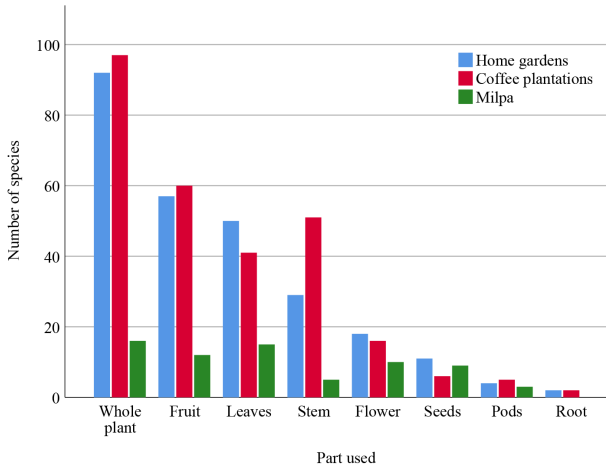

Figure 7. Part used of species from agroforestry systems.

Cultivated plants had greater representation in these agricultural spaces (χ^2 (4,211) = 314.19, p < 0.001), followed by wild plants that are used and, to a lesser extent, tolerated, promoted and protected. In the home gardens, a greater number of cultivated plants was recorded, while wild plants predominate in the coffee plantations (Figure 8).

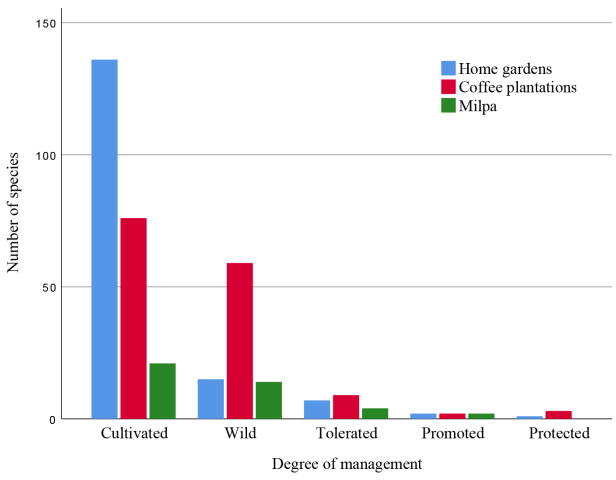

Figure 8. Degree of management of species from agroforestry systems.

The main function of agroforestry systems in the community is the provision of food; therefore, food use was the main categorie (χ^2 (8,211) = 260.83, p < 0.001), followed by ornamental, firewood, shade, medicinal, hedgerow, construction, forage and domestic use (Table 2). Although the pattern of use of plants is similar in the three agroforestry systems, home gardens had an important component of ornamental plants while woodlands had an important component of firewood, shade and construction (Figure 9).

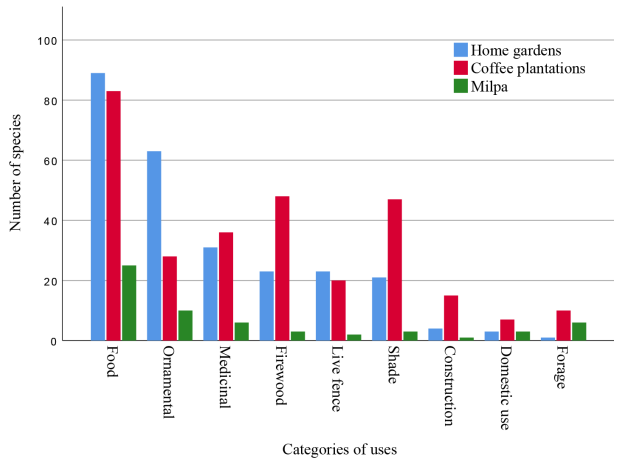

Figure 9. Use of species from agroforestry systems.

Similarity of floristic composition among agroforestry systems. There are 12 species shared among the three systems, all edible and the majority herbaceous (Table 3). They are generally short-cycle beans and squash.

The Sørensen index showed greater similarity between home gardens or coffee plantations in terms of the number of shared and exclusive species (Table 4).

A total of 69 exclusive species were recorded in home gardens, mainly ornamental and food plants. In coffee plantations, 61 exclusive species were recorded, mostly trees used as shade and wild species used for food or medicinal purposes. The milpa system presented 10 exclusive species, mostly herbaceous species, such as 'quelites', and forage for cattle.

UV of plants in agroforestry systems. The species with the highest UV are trees. For example, the flowers of 'gallito' (*Diphysa americana*) are used as food (cooked with salt or fried with eggs). This tree can also be used as a hedgerow to delimit areas of cultivation and provide shade for coffee plantations, and the stem is used as firewood or for the construction of houses (Table 5). Species with lower UVs are those with more specific uses, such as medicinal plants.

The Kruskal-Wallis test indicated that there are differences between agroforestry systems regarding the UV of species. In the *post hoc* test, coffee plantations exhibited

the highest UV (Table 6) with many uses. Home gardens and milpa presented species with more specific purposes, such as ornamental or food purposes.

Sociodemographic factors and traditional knowledge. The data obtained from the interviews are summarized in Table 7 where the factors Gender, age and economic activity are shown. The results of the generalized linear model showed that gender (χ^2 (1,30) = 12.258, $p < 0.0001$), and economic activity (χ^2 (1,30) = 7.263, $p = 0.007$), significantly influence the distribution of knowledge within the community. It was also observed that only the interactions between gender and schooling (Gender × Schooling) and between Economic Activity and Age (Economic activity × Age), were statistically significant with values of χ^2 (1.30) = 8.953, $p = 0.003$ and χ^2 (1.30) = 7.463, $p = 0.006$. (Table 8).

Figure 10. Agroforestry systems of Las Delicias in San Juan Juquila Vijanos, Sierra Norte, Oaxaca, Mexico. A, B) Home gardens, C, D) Coffee plantations E, F) Milpa, (Photos: S. Pascual-Mendoza, G. Manzanero-Medina).

Table 2. Categories of uses of plant species in agroforestry systems.

Categorie	Uses of plant species
Food	One of the main functions of tree, shrub and herbaceous species is the production of food in a short time, which guarantees food security, at least for one season of the year, primarily 'quintolines' edible greens (Amaranthus hibridus), 'chepiles' (*Crotalaria longirostrata*), 'verdolagas' (*Portulaca oleracea*), chayote (*Sechium*), squash (Cucurbita) and fruits such as oranges, guavas, peaches and bananas.
Medicinal	The medicinal use of plants is relevant, due to their rapid and economic access. Among the plants most commonly used are 'hierbabuena' spearmint (*Mentha spicata*), chamomile (*Matricaria recutita*), citrus leaves and arnica to relieve stomach discomfort.
Ornamental	This category has a large representation in home gardens, mainly introduced species. Its main function is the decoration of houses on the outside or for vases (when the flowers are cut from species in coffee plantations or milpa). Among the most frequent are 'agapandos' (*Agapanthus praecox*), gladiolas (*Gladiolus grandiflorus*) and 'alcatraces' (*Zantedeschia aethiopica*).
Firewood	Firewood is a traditional and accessible fuel for the rural population, and the inhabitants mainly source from the dry branches of the trees and bushes of the coffee plantations they collect from. Among some trees are the genus Inga, the yag yere trumpet tree (*Cecropia obtusifolia*), 'palo rojo' (*Heliocarpus donnellsmithii*) and '*palo blanco'* (*Heliocarpus appendiculatus*).
Shade	The trees with the greatest shade presence were the small-pod (*Inga jinicuil*) and the large-pod (*Inga edulis*). The frequency of this species is due to the strategies implemented by INMECAFE in the 1970s, in which the use of species of the genus Inga and fruit trees of the genus *Citrus* as a shade was promoted.
Domestic use	Species with domestic use have various purposes, For example, dried leaves of sugarcane (*Saccharum officinarum*) are used to protect panela (unrefined whole cane sugar), bule (*Lagenaria siceraria*) is used to transport water or serve food or coffee, and the yaj xúba (*Sida rhombhifolia*) is also used to sweep the courtyards or to clean the houses.
Hedgerows	Hedgerows are used to delimit, protect and create boundaries for crops and livestock, in addition to providing food, medicine, ornaments and fuel. These plants provide scenic beauty and firewood for fuel and produce edible fruits such as plantains.
Construction	The species used in construction are obtained mainly from coffee crops and are also used as shading, among which are 'yavito' (*Liquidambar straciflua*), 'palo de águila' (*Alnus acuminata*), 'guajinicuiles de vaina pequeña' (*Inga jinicuil*), 'guajinicuiles de vaina grande' (*Inga edulis*), 'gallito' (*Diphysa americana*), pine (*Pinus chiapensis*) and oak (*Quercus*).
Forage	Forage species are found mainly in milpa and coffee plantations. They are herbaceous plants that serve as food for cattle and chickens. Among them are grasses (*Cyperus esculentus* and *Setaria parviflora*).

Discussion

Traditional knowledge of plants in agroforestry systems. In the Las Delicias Zapotec community, families have different agroforestry systems. In these, 85 % of Zapotec names were recorded for different plant species, which is higher in comparison to other Zapotec communities in the Sierra Madre del Sur, where up to 67 % of names in Zapotec have been recorded (Luna-José & Rendón-Aguilar 2012). This reflects the degree of conservation and use of the indigenous language in the community. For example, squash is called *yutu*, but there are specific names that describe particular physical characteristics: *yutu uech* means thin squash and is also known as 'chilacayota' (*Cucurbita ficifolia*); *yutu chuga* means squash with solid-looking skin (*Cucurbita maxima*); *yutu bela* describes fleshy squash whose skin is thin (*Cucurbita pepo*); and *yutu nicachi* alludes to the long form of squash (*Cucurbita argyrosperma*). This classification is similar to that reported in the chinantec milpa of Oaxaca, where the determinant characteristics of four variants of squash were hardness of the skin and shape of the fruit (Mateos-Maces *et al.* 2016).

Home gardens, coffee plantations and milpa are the main agroforestry systems in this Zapotec community and provide food, supplement the economic income of families and have an important role in bartering among the inhabitants. They also represent a strategy of adaptation to the environment because they show multiple management strategies for domesticated and wild resources, thus fulfilling a conservationist, resilient and sustainable function (Altieri & Toledo 2011). In this sense, the agroecological management practiced by farmers in the communities is fundamental for food sovereignty, which is why it has been recognized as an alternative and sustainable agriculture (Sámano-Rentería 2013).

Among the different types of agroforestry sytems, Mexico recognizes that home gardens are the most important for farmers because of their role in obtaining food (Boege 2008), while coffee plantations are the most

Table 3. Species shared among the agroforestry systems of Las Delicias, Juquila Vijanos, Sierra Norte, Oaxaca.

Family	Species	Common name
Amaranthaceae	*Amaranthus hybridus* L.	Quintonil, cuan yösj
Anacardiaceae	*Mangifera indica* L.	Mango, yag mango
Apiaceae	*Eryngium foetidum* L.	Cilantro de espinas, culandr yötzi
Asteraceae	*Galinsoga parviflora* Cav.	Quelite de piojito, cuan' béchi
Cucurbitaceae	*Cucurbita ficifolia* Bouché.	Chilacayota, yutu uech
Cucurbitaceae	*Cucurbita maxima* Duchesne	Tamala, yutu chuga
Fabaceae	*Phaseolus coccineus* L.	Frijol grandote, za dupi
Fabaceae	*Phaseolus* sp.	Frijol de enredadera de milpa, za ya'a
Fabaceae	*Phaseolus* sp.	Frijol de cuarentena, za chua
Poaceae	*Zea* mays L.	Maíz, yöl
Solanaceae	*Capsicum pubescens* Ruiz & Pav.	Chile marongo, guina'marongo
Solanaceae	*Cestrum nocturnum* L.	Huele de noche, cuan xu'u

Table 4. Floristic similarity among the agroforestry systems home gardens, coffee plantations and milpa.

	Sites A-B	**Sites A-C**	**Sites B-C**
Sites	Home gardens-Coffee plantations	Home gardens-Milpa	Coffee plantations-Milpa
Sørensen index	50.81	23.00	23.28

important in terms of conservation, such as Chinantec coffee plantations (Bandeira *et al.* 2005) and those of Veracruz (Cerdán *et al.* 2012) and Chiapas (Valencia *et al.* 2014). In the Las Delicias community, coffee plantations play an important role in the economic activities of families because coffee cultivation represents an important subsistence strategy, which has been observed in other regions of Mexico, such as Los Tuxtlas in Chiapas (Castillo *et al.* 2014), and in other countries, such as El Salvador (Olson *et al.* 2012) and Puerto Rico (Borkhataria *et al.* 2012).

Particularly for milpa, the peasants of Las Delicias classify the land according to altitude and climate, in which the 'tierra fría' (cold land) is found at higher elevations with pine, oak and cloud forest and the 'tierra caliente' (hot land) is found at lower elevations. This classification is also used in other communities, such as the Zapotec and Chinantec in Oaxaca and Purépecha from Michoacan, whose classification of the territory is related to the productive cycle and soil quality (Mateos-Maces *et al.* 2016, Pérez-García & Del Castillo 2016, Pulido & Bocco 2016). As well as that of the ekuaro system in the same region (Franco-Gaona *et al.* 2016). It should be emphasized that the classification of the agroecosystem milpa of Las Delicias is very similar to that of the communities of Coyomeapan in the state of Puebla, and San Lorenzo Pápalo and Santa María Ixcatlán in the state of Oaxaca, which are inhabited by Nahuatl, Cuicatecos and ixcatecos, respectively, where this system is classified as highland cultivation of the region where the vegetation includes different types of association of pine, oak and pine-oak, and lowland commonly combining corn, beans and pumpkins with other crops (Vallejo *et al.* 2014)

Diversity of species in agroforestry systems. Species richness in Las Delicias home gardens is high (159) compared to that reported in other Mexican communities (García-Flores *et al.* 2019), in other countries such as Perú (Coomes & Ban 2004) and Argentina (Eyssartier *et al.* 2011), and in Asia (Mekonen *et al.* 2015). The majority of species in home gardens are selected by the owners for their reproduction and availability throughout the year (Manzanero-Medina *et al.* 2009). Despite the high species richness in this agroforestry, a little more than half (53 %) corresponds to introduced plants, which has been observed in other Zapotec home gardens (Gómez-Luna *et al.* 2017).

The number of useful species found in coffee plantations (148) is also considered high because it is higher than that reported for an Otomí community in Hidalgo (Acosta-Tolentino 2009). Although the most frequent life-form in the three agroforestry systems is herbaceous plants, the presence of trees was higher in coffee plantations. The abundance of trees in coffee plantations has also been reported in the Sierra Norte de Puebla and La Chinantla in

Table 5. Species with the highest use value. AGS: Agroforestry systems: HG-Home Garden, C-Coffee plantation, M-Milpa. Uses: Ed-Edible, FW-Firewood, Sha-Shade, HR-Hedgerow, Med-Medicinal, Con-Construction, Orn-Ornamental. UV: Use Value Index.

Kindred	Common name	Name in Zapotec	AGS	Uses	UV
Diphysa americana (Mill.) M. Sousa.	Gallito	Ye'yecho	C	Ed, FW Sha, HR, Con	3.18
Prunus persica (L.) Batsch.	Durazno	Traz	HG, C	Ed, Med, FW, Sha, HR	3.05
Psidium guajava L.	Guayaba	Uyaj	HG, C	Ed, Med, FW, Sha	2.52
Persea schiedeana Nees.	Aguacate chupón	Xudu dxi	C	Ed, Med	2.11
Mangifera indica L.	Mango	Yag mango	HG, C, M	Ed, FW, Sha, Con	2.00
Alnus acuminata Kunth.	Palo de águila	Yag i'uiöl	C	FW, Sha, HR, Con	1.98
Erythrina americana Mill.	Zompancle, colorín	Cuan btu tzu	HG, C	Ed, FW, Sha, HR	1.96
Citrus medica L.	Lima	Guiy xi'x	HG, C	Ed, FW, Sha, Con	1.93
Manilkara chicle (Pittier) Gilly.	Zapote	Lau gasi Lau qul	C	Ed, FW, Sha, Con	1.92
Inga jinicuil Schltdl.	Guajinicuil	Yag yaj'tul	HG, C	Ed, FW, Sha, Con	1.91
Cestrum nocturnum L.	Huele de noche	Cuan xu'u	HG, C, M	Ed, Med, Orn, HR	1.90
Inga edulis Mart.	Guajinicuil sombra	Yag yaj'tul guixi'	C	Ed, FW, Sha, Con	1.88

Table 6. Kruskal-Wallis test for use value among Agroforestry systems, as well as the post hoc analyses.

Variable	Agroforestry systems	N	Mean	St. Dev	Median	H	P
UV	Coffee plantations	138	1.78	0.87	1.36	11.98	< 0.001
UV	Home gardens	147	1.57	0.84	1.00		
UV	Milpa	38	1.26	0.72	1.00		
Systems	Range						
Milpa	123.22	A					
Home garden	155.73	A					
Coffee plantation	179.35	B					

Means with common letters are not significantly different ($p > 0.05$).

Oaxaca, where they are used for food, medicine, firewood and construction wood (Martínez *et al.* 2007, Bandeira *et al.* 2005). Unlike home gardens, coffee plantations conserve a considerable number of wild species, which demonstrates the importance of this agroforestry system in the conservation and use of native biodiversity (Valencia *et al.* 2014).

For milpa, the number of species (41) was also high compared to a Chinantec village in the state of Oaxaca, where 26 species were recorded (Mateos-Maces *et al.* 2016).

The floristic composition of coffee plantations and milpa is approximately 70 % native plants, a characteristic that they share with this type of agroforestry system in countries such as Brazil (Souza *et al.* 2012) and Puerto Rico (Borkhataria *et al.* 2012). Based on the above, it can be suggested that the agrobiodiversity associated with agroforestry systems in the Las Delicias community is high, which is due to planting various crops for food, ornamental, and medicinal purposes, among others (Thrupp 2004).

Similarity of floristic composition among agroforestry systems. The 12 plant species that are present in the three agroforestry systems were mostly herbaceous, and the presence of those used as food, such as maize, beans and chili, is noteworthy. This not only demonstrates that these species are key components of agrobiodiversity in this community but also reflects their importance in the diet of Mexicans (Mateos-Maces *et al.* 2016, Salazar *et al.* 2016). Our results indicate that the agroforestry systems of this Zapotec community follow strategies based on the management of biodiversity. In this context, Olson *et al.* (2012) highlight the importance of agricultural matrices for the subsistence of farmers and the maintenance of different

species. Thus, in the Las Delicias community, edible and ornamental plants are obtained from home gardens, trees for firewood and construction are obtained from coffee plantations, and basic food resources such as maize, beans and squash are obtained from milpa.

Table 7. Mentioned plant species and sociodemographic data (gender, age and economic activity).

Gender	Age	Economic activity	Number of species mentioned			
			Minimum	Maximun	Mean	Standard error
Women	55.57	Primary	72	133	95.42	9.466
	42.13	Tertiary	65	109	83.87	5.745
Men	59.73	Primary	62	103	78.45	3.47
	35.25	Tertiary	63	98	88.25	8.439

Table 8. Influence of sociodemographic factors on the distribution of traditional knowledge in the community.

Source	Wald Chi-squared	df	Sig.
Intersecction	614.925	1	< 0.0001
Gender	12.258	1	< 0.0001
Economic activity	7.263	1	0.007
Age	1.684	1	0.194
Language	0.128	1	0.868
Schooling	0.506	1	0.477
Gender × Economic activity	0.014	1	0.906
Gender × Schooling	8.953	1	0.003
Economic activity × Age	7.463	1	0.006

Sum of squared Type III.

Use value of plants in agroforestry systems. Plants with higher UVs are found in coffee plantations and correspond to species with more than three categories of use, mainly plants for which the same part is used in different ways. In this regard, in the coffee plantations, a greater presence of trees was reported, for which different uses such as wood, fuel and construction were recorded. This variety of uses has been recorded in other studies, in which a high UV has been reported for woody plants (Lucena *et al.* 2007, Kwetche *et al*. 2012). Additionally, the presence of trees of different species in Las Delicias, mainly fruit and timber species, contributes to the highest UVs in this type of agroforestry system compared to home gardens and milpa (Acosta-Tolentino 2009).

Notably, quantitative approaches, such as those performed in this study, allow us to know the statistical support of the close relationship between the ecological aspect and the UV of plants (Tomazini *et al.* 2016). Thus, the UV not only allows the identification of the most well-known and utilized species in a community but also quantifies the traditional knowledge (Amusa *et al.*2012, Lucena *et al*. 2013).

Sociodemographic factors and traditional knowledge. In the Las Delicias community, gender and economic activity were the factors that had the greatest effect on the distribution of traditional knowledge that people possess in relation to plants. Manzanero-Medina *et al.* (2009) and Vásquez-Dávila & Manzanero-Medina (2015) note that activities in home gardens are carried out mainly by women. They decide which plants will be incorporated into the garden and know the edible plants used in cooking, such as condiments and vegetables, as well as those used in home medicine. Similarly, in the Zapotec families of the Isthmus and Sierra Sur, women have greater influence on decisions regarding agricultural spaces for food and economic purposes, while the rest of the family members participate to a lesser degree in the care and maintenance of agroecosystems (Velasco-Morales *et al*. 2001, Zurita-Vásquez 2012 *et al*. 2019).

However, economic activity was significantly associated with the number of plants mentioned. In the Las Delicias community, people with an economic activity other than field activities (*e.g.* masonry, merchants or teachers) were those who mentioned fewer plants, while those who carried out agricultural and gathering activities in forests or agroecosystems showed greater traditional knowledge about the use of plants and the management of ecosystems. This shows that occupational activities other than agricultural activities are negatively related to ethnobotanical knowledge, which has also been reported for the Zapotecs of the Isthmus of Tehuantepec (Saynes-Vásquez *et al.* 2013). Thus, we can suggest that the existence and permanence of agroforestry systems are directly related to traditional knowledge.

On the other hand, the interaction between gender and schooling could be interpreted as that schooling is not the same between genders. In this regard it was observed that among men there is a smaller number of people who attended primary school while in women the pattern is reversed; although among the women, none attended the baccalaureate. In the interaction between economic activity and age, it would indicate that in primary economic activity we find a greater number of people over the age of fifty, while in tertiary activity this pattern is reversed.

In addition to the benefits provided by agroforestry systems in the Las Delicias community (for example, food, medicine, and firewood, among others), they also contribute to the conservation of the associated diversity because people perform "*ex situ*" conservation of species that are

brought from the forest or "*in situ*" conservation of native, tolerant or promoted species as well as varieties of squash, chilis, beans and plantains. Even when the UV results reflect the degree of use of many plant species, this does not compromise the availability or permanence of their populations, as these are highly abundant species with a wide distribution, which is why they are not listed in any risk category (Lucena *et al*. 2007, Amusa *et al*. 2012).

Finally, agroforestry systems play an important role in the economic activities of the community and in the conservation of biodiversity. However, as communities begin to participate in the global market economy, their system of resource management tends to change, which in turn causes the loss of biodiversity in these systems (Vásquez-Dávila & Lope-Alzina 2012). Therefore, the need to incorporate traditional knowledge of indigenous communities into public policies is evident, as they are the basis for guaranteeing food sovereignty and biodiversity conservation.

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Supplemental data

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