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Research article

Árboles asociados a los cafetales en comunidades de la Montaña de Guerrero

Associated trees to coffee plantations in communities of the Montaña de Guerrero region

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Abstract

The coffee (*Coffea arabica*) plantations of the *Montaña de Guerrero* region preserve the characteristics of a forest and also contribute to the generation of economic resources that help a large number of families to meet some of their basic needs. The objective of this work was to identify the structure and uses of shade species in coffee plantations in two *Me'phaa* communities in the *Montaña de Guerrero* region. Twelve plots in *Tres Cruces* (TC), *Acatepec* and *La Ciénega* (LC), *Malinaltepec*, were sampled using the point-center-square method; trees were measured for distance, height, crown cover and normal diameter. The alpha diversity was estimated based on species richness (*S*), Simpson's Index, Shannon-Wiener's Index, and the effective number of species (*N0*, *N1* and *N2*); similarity was calculated with the Jaccard index (J_I), and the Importance Value Index (*IVI*) was determined. In order to identify the uses of the trees, structured interviews (50 in TC and 10 in LC) were carried out with coffee growers. Thirty-five species were recorded —16 in *Tres Cruces* and 22 in *La Ciénega*—, of which 83.3 % were native; therefore, the region is classified as under traditional management. *Alnus acuminata* in LC and *Myrsine juergensenii* in TC had the highest *IVI*. Coffee growers reported 24 species in TC and 14 in LC that provide shade, generate organic matter, fruits, flowers, and fuel. The most commonly used species are *Clethra mexicana* and *A. acuminata*.

Key words: Agroecosystems, *Alnus acuminata* Kunth, composition, diversity, native species, *Myrsine juergensenii* (Mez) Ricketson & Pipoly.

Resumen

Los cafetales (*Coffea arabica*) de la región de la Montaña de Guerrero mantienen las características de un bosque, además contribuyen a la generación de recursos económicos que ayudan a un gran número de familias a mitigar parte de sus necesidades básicas. El objetivo de este trabajo fue identificar la estructura y los usos de las especies de sombra de los cafetales en dos comunidades *Me'phaa* de la Montaña de Guerrero. Se muestrearon 12 parcelas en Tres Cruces (TC), Acatepec y La Ciénega (LC), Malinaltepec; se utilizó el método de punto-centro-cuadrado; a los árboles se les midió la distancia, altura, cobertura de copa y diámetro normal. Se estimó la diversidad alfa basada en la riqueza de especies (*S*), el Índice de *Simpson*, *Shannon-Wiener* y el número efectivo de especies (*N0*, *N1* y *N2*), la similitud se calculó con el Coeficiente *Jaccard* (I_J) y se determinó el Índice de Valor de Importancia (*IVI*). Para reconocer los usos de los árboles se aplicaron entrevistas (50 en TC y 10 en LC) estructuradas a los cafeticultores. Se registraron 35 especies, 16 en Tres Cruces y 22 en La Ciénega, de las cuales 83.3 % fueron nativas, por lo que se clasifica como manejo tradicional. *Alnus acuminata* en LC y *Myrsine juergensenii* en TC fueron las de mayor *IVI*. Los cafeticultores señalaron a 24 especies en TC y 14 en LC que proporcionan sombra, generan materia orgánica, frutos, flores y combustibles; las especies más empleadas son *Clethra mexicana* y *A. acuminata*.

Palabras clave: Agroecosistemas, *Alnus acuminata* Kunth, composición, diversidad, especies nativas, *Myrsine juergensenii* (Mez) Ricketson & Pipoly.

Introduction

Coffee growing systems in Mexico are mostly developed under the shade of the original vegetation canopy, which allows the native diversity of each region to be maintained (Moguel and Toledo, 1996, 1999; Anta, 2006; Manson *et al.*, 2008). Trees in these agroecosystems also provide services that help regulate water availability and mitigate the negative effects of long dry periods (from November to May and from June to August during the dry summer months), which affect crop production. In addition, they contribute to keep soil fertility, recycling nutrients, providing a large amount of organic matter, and reducing erosion (Espinoza-Guzmán *et al.*, 2020; Farfán, 2020).

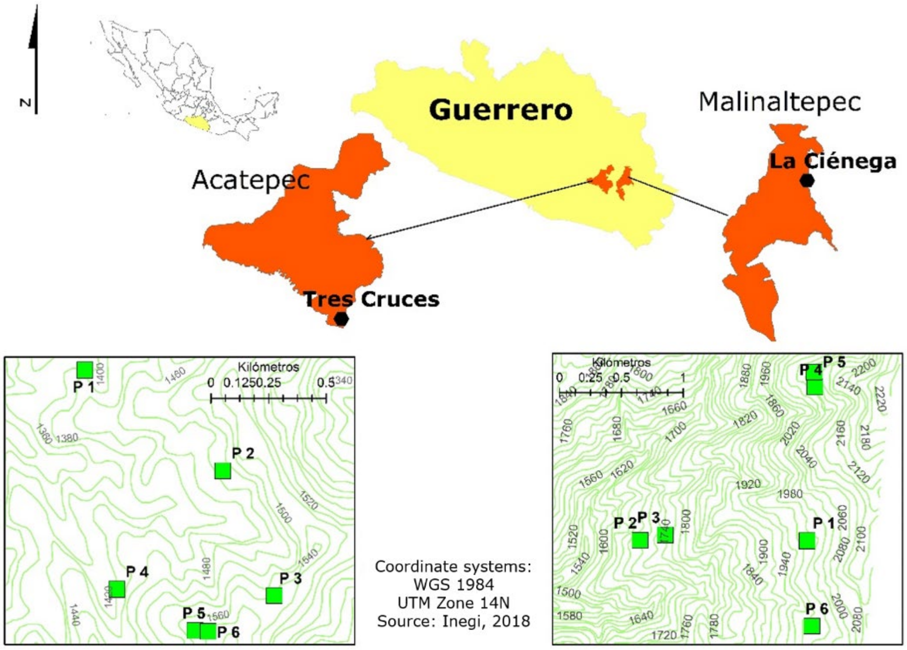
The diversity of trees recorded in the different coffee growing regions of Mexico, according to Moguel and Toledo (1996), includes between 13 and 60 species per hectare. However, this richness is determined by the management of each coffee plantation; *i. e.*, it reflects the producer's decisions in the face of environmental, social and economic opportunities and constraints; therefore, these production systems vary in their structure, botanical composition and agronomic practices (Escalante and Somarriba, 2001). In some cases, the original canopy is replaced by fruit and timber trees, which is known as a coffee garden (Moguel and Toledo, 1999), or the recommendation to establish monospecific shade with species of the *Inga* Mill. genus is followed (Reyes-Reyes and López-Upton, 2003; Reyes *et al.*, 2022). Thus, coffee plantations keep a tree structure similar to that of a forest or areas with introduced taxa (Ibarra-Isassi *et al.*, 2021).

In the *Montaña de Guerrero* region, the municipalities that are dedicated to this activity are *Metlatonoc*, *Ilitenco*, *Tlacoapa*, *Malinaltepec* and *Acatepec* (SIAP, 2022); the crop is grown under shade, and the population obtains economic income from their commercialization, in addition to other benefits that come from the utilized trees; however, their management includes the replacement of species; therefore, the canopy presents variations. The objective of this study was to identify the alpha and beta diversity, as well as the structure and uses of tree taxa in coffee plantations in two *Me'phaa* communities (*Tres Cruces* [TC], Acatepec, and *La Ciénega* [LC], *Malinaltepec*) located in the *Montaña de Guerrero* region; they are expected to be different due to the difference in environmental conditions between TC and LC.

Materials and Methods

Study area

The study area included coffee plantations in the communities of *La Ciénega* (LC), belonging to the *Malinaltepec* municipality, and in *Tres Cruces* (TC), located in the *Acatepec* municipality (Figure 1). The climate in LC is temperate sub humid A(C)m, while in TC it is semi-warm sub humid (A)C(w_1) (INEGI, 2008).



Guerrero = State of *Guerrero*; *Acatepec* = *Acatepec* municipality; *Malinaltepec* = *Malinaltepec* municipality; *Tres Cruces* = *Tres Cruces* community; *La Ciénega* = *La Ciénega* community; *Kilómetros* = Kilometers.

Figure 1. Geographical location of plots in the study communities.

Sampling. Six coffee plots at different altitudes and with different exposures were selected in each of the communities (Figure 1; Table 1). The sampling method that was utilized was the point-center-square (Mostacedo and Fredericksen, 2000) and it was adjusted to the size (average 0.5 ha) and irregular shape of the plots (Silva-Aparicio *et al.*, 2021); this type of sampling consists of marking five points along each plot, 50 m apart from each other. At each point, the four nearest trees were located, and the distance to the center point, crown cover (both measured with a TFC-30ME Truper® tape), height (with a PM-5 Suunto® clinometer), and normal diameter at 1.30 m (with a 308WP/10M Qualitäs-bandmanß® diameter tape) were recorded.

Table 1. Physical-environmental characteristics of the sampled plots (P).

Community	P	Altitude (m)	Coordinates in UTM	Exposure	Slope (%)
Tres Cruces	1	1 398	507784-1881106	North	65
	1	1 474	508381-1880669	Southeast	16
	3	1 540	508605-1880118	Northeast	51
	4	1 451	507913-1880155	East	44
	5	1 553	508161-1879976	Southeast	43
	6	1 563	508319-1879971	Northeast	11
La Ciénega	1	1 968	537187-1905857	West	13
	1	1 654	537187-1905857	North	10
	3	1 713	537490-1905901	Northwest	33
	4	1 044	538701-1907098	Northwest	31
	5	1 064	538696-1907118	North	40
	6	1 973	538677-1905164	East	16

Botanical specimens of all the registered shade trees were collected following the method of Lot and Chiang (1986) and taxonomically determined with dichotomous keys and specialized guides (Valencia *et al.*, 2002). The nomenclature revision was performed in The World Flora Online database (WFO, World Flora Online, 2023), and the specimens were deposited in the collection of the Plant Laboratory of the Intercultural University of the State of *Guerrero*.

Tree species management. Data on shade tree use were collected through the application of questionnaires to cooperating producers in TC (50) and LC (20); questions included information on the composition, uses, and management of the shade species.

Tree structure analysis. The alpha diversity was estimated with the Shannon-Wiener Index (H'), Simpson's dominance (λ), and the effective number of species ($N0$=Total number of species [S], $N1$=Number of abundant species [$e^{H'}$] and $N2$=Number of very abundant species [$1/\lambda$]) (Moreno *et al.*, 2011), beta diversity with the Jaccard similarity coefficient (J_I) (Moreno, 2001), and a dendrogram was made with the data from the plots of each community, using the aforementioned Coefficient in the Past software, v. 4.03 (Hammer *et al.*, 2001).

$$H' = -\sum pinlpi \qquad (1)$$

$$\lambda = \sum pi^2 \qquad (2)$$

$$I_J = \frac{c}{a + b - c} \qquad (3)$$

Where:

H' = Shannon-Wiener Diversity Index

Pi = Number of individuals of each species divided by the total number of individuals of all species recorded

nl = Natural logarithm

λ = Simpson's Dominance Index

J_I = Jaccard Index

a = Total number of species present at site A

b = Number of species present at site B

c = Number of species present at sites A and B

The attributes of the tree community were calculated using the following indexes (Mostacedo and Fredericksen, 2000):

$$Relative\ dominance = \frac{Absolute\ dominance\ per\ species}{Absolute\ dominance\ of\ all\ the\ species} X100 \qquad (4)$$

For density, the formula suggested for the point-center-square method was used:

$$Dh = \frac{10\ 000}{(D^2)} \qquad (5)$$

Where:

Dh = Density per hectare

D = Average distance

Basimetric area as follows:

$$BA = \pi\ (ND^2/4) \qquad (6)$$

Relative abundance:

$$RA = \frac{Absolute\ abundance\ per\ species}{Absolute\ abundance\ of\ all\ the\ species} X100 \qquad (7)$$

Relative frequency:

$$RF = \frac{Absolute\ frequency\ per\ species}{Absolute\ frequency\ of\ all\ the\ species} X100 \qquad (8)$$

Importance Value Index (*IVI*):

$$IVI = \left(\frac{1}{3}\right) Relative\ dominance + Relative\ density + Relative\ frequency \qquad (9)$$

Data analysis. The species accumulation curve was developed to determine the representativeness of sampling, for which the non-parametric estimator *ICE* (López-Gómez and Williams-Linera, 2006) was used. Likewise, for the purpose of determining the existence of significant differences between diversity (*H'*) and dominance (λ) among the plots of the study communities, Hutcheson's method was applied to calculate the modified *t* value (Magurran, 2004) in the Past v. 4.03 software (Hammer *et al.*, 2001). In addition, mean comparison tests (Student's *t*-test) (Molina, 2022) for density, height, normal diameter, and canopy cover were performed with the R 4.3.1 software (Contento, 2019).

In addition, the species' Use Value Index (*SUVI*), which expresses the importance or cultural value of a given species for all the informers interviewed, was calculated with the following formula (Zambrano-Intriago *et al.*, 2015):

$$SUVI = \frac{\Sigma iVUis}{Ns} \qquad (10)$$

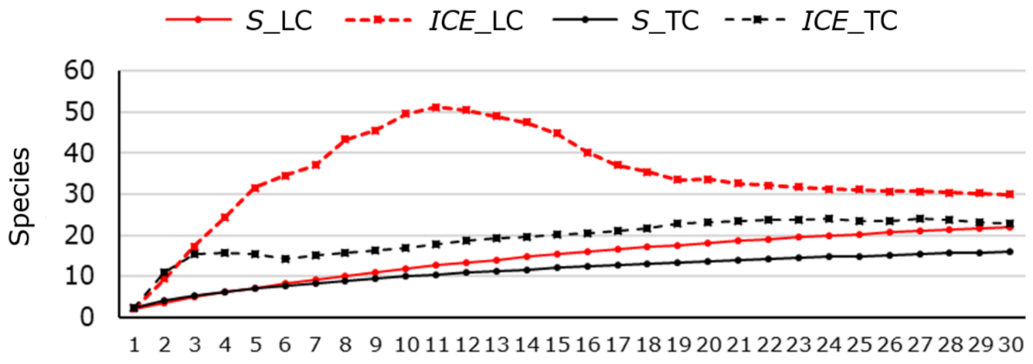
Where:

SUVI = Value of use of the species by each informant

Ns = Number of informers for each species

Results

Tree species richness associated with coffee cultivation. According to the *ICE* estimator, the sampling effort registered 73 % of shade tree species for TC and 70 % for LC (Figure 2).



Observed = *S*_LC and *S*_TC; Estimated = *ICE*_LC and *ICE*_TC.

Figure 2. Species accumulation curve.

Thirty-five species were recorded, 22 in *La Ciénega* (LC) and 16 in *Tres Cruces* (TC), belonging to 13 families, of which the richest was Fagaceae with five species, followed by Fabaceae with four, and Solanaceae with three; the rest of the families recorded less than two species (Figure 3) (Table 2). Likewise, 83.3 % of the trees within the coffee plantations were native, among which are those belonging to the genera *Quercus* L., *Clethra* L., *Myrsine* L., and *Alnus* Mill.; the introduced species were *Eriobotrya japonica* (Thunb.) Lindl., *Citrus aurantium* L., *C. limon* (L.) Osbeck, *C. medica* L., *Hesperocyparis benthamii* (Endl.) Bertel, *Mangifera indica* L. y *Psidium guajava* L.

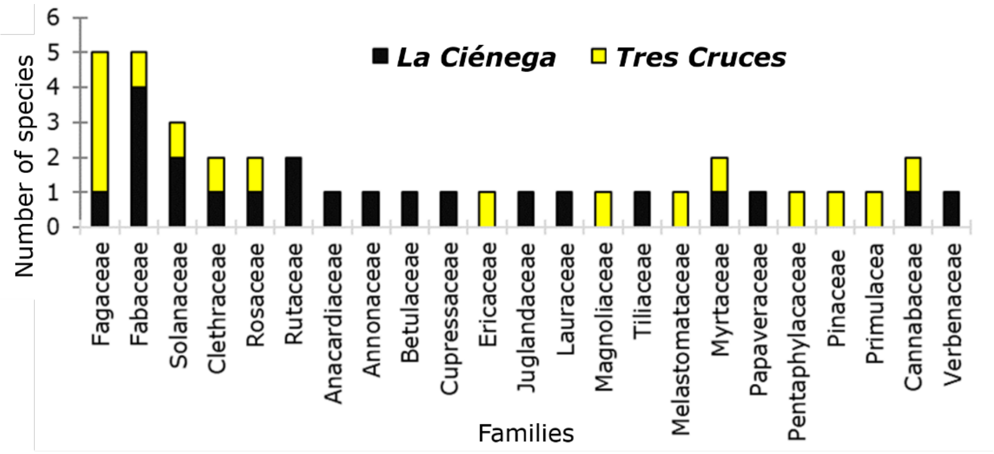


Figure 3. Number of species per family recorded in the coffee plantations of the studied communities.

Table 2. Tree species recorded in the coffee plantations of the study communities.

Family	**Species**	***La Ciénega***						***Tres Cruces***					
		1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
Fabaceae	*Acaciella lemmonii* (Rose) Britton & Rose	0	0	0	1	0	0	0	0	0	0	0	0
Betulaceae	*Alnus acuminata* Kunth	1	1	1	1	1	1	0	0	0	0	0	0
Annonaceae	*Annona cherimola* Mill.	0	0	1	1	0	0	0	0	0	0	0	0
Papaveraceae	*Bocconia arborea* S. Watson	0	0	0	0	1	0	0	0	0	0	0	0
Juglandaceae	*Carya myristiciformis* (F. Michx.) Nutt *ex* Elliott	0	0	1	0	0	1	0	0	0	0	0	0
Rutaceae	*Citrus medica* L.	0	1	1	0	0	0	0	0	0	0	0	0
Rutaceae	*Citrus aurantium* L.	0	0	1	0	0	0	0	0	0	0	0	0
Clethraceae	*Clethra lanata* M. Maertens & Galeotti	0	0	0	0	0	0	1	1	1	1	1	1
Clethraceae	*Clethra rosei* Britton	1	0	0	0	0	1	0	0	0	0	0	0
Pentaphylacaceae	*Cleyera pachyphylla* Chun *ex* Hung T. Chang	0	0	0	0	0	0	0	1	0	0	0	1
Cupressaceae	*Hesperocyparis lusitanica* (Mill.) Bartel	0	1	0	0	0	0	0	0	0	0	0	0
Rosaceae	*Eriobotrya japonica* (Thunb.) Lindl.	0	0	0	0	0	0	0	0	1	0	0	0
Fabaceae	*Erythrina americana* Mill.	0	1	0	0	0	0	0	0	0	0	0	0
Malvaceae	*Heliocarpus appendiculatus* Turcz.	0	0	0	0	1	0	0	0	0	0	0	0
Fabaceae	*Inga edulis* Mart.	1	1	0	0	0	0	1	0	0	1	0	0
Verbenaceae	*Lippia umbellata* Cav.	0	0	0	1	0	0	0	0	0	0	0	0
Magnoliaceae	*Magnolia krusei* J. Jiménez Ram. & Cruz Durán	0	0	0	0	0	0	1	0	0	0	0	1
Anacardiaceae	*Mangifera indica* L.	0	1	0	0	0	0	0	0	0	0	0	0
Melastomataceae	*Miconia mirabilis* (Aubl.) L. O. Williams	0	0	0	0	0	0	0	0	1	0	0	0

Fabaceae	*Mimosa lacerata* Rose	1	0	0	1	0	0	0	0	0	0	0	0
Primulaceae	*Myrsine juergensenii* (Mez) Ricketson & Pipoly	0	0	0	0	0	0	1	1	1	1	1	1
Lauraceae	*Persea americana* Mill.	0	1	0	0	0	1	0	0	0	0	0	0
Pinaceae	*Pinus pseudostrobus* Lindl.	0	0	0	0	0	0	1	0	0	1	0	0
Rosaceae	*Prunus virginiana* L.	0	0	1	0	0	1	0	0	0	0	0	0
Myrtaceae	*Psidium guajava* L.	0	1	0	0	0	0	0	1	0	0	0	0
Fagaceae	*Quercus candicans* Née	0	0	0	0	0	0	1	0	1	0	0	0
Fagaceae	*Quercus glaucoides* M. Martens & Galeotti	0	0	0	0	0	0	0	0	0	0	0	1
Fagaceae	*Quercus liebmannii* Oerst. *ex* Trel.	0	0	0	0	0	0	0	1	1	0	0	0
Fagaceae	*Quercus peduncularis* Née	0	0	0	0	1	0	0	0	0	0	0	0
Fagaceae	*Quercus scytophylla* Liebm.	0	0	0	0	0	0	0	0	1	1	1	1
Solanaceae	*Solanum aligerum* Schltdl.	1	0	0	0	0	0	0	0	0	0	0	0
Solanaceae	*Solanum pubigerum* Dunal	1	0	0	0	0	0	0	0	0	0	0	0
Solanaceae	*Solanum* sp.	0	0	0	0	0	0	1	0	0	0	0	0
Cannabaceae	*Trema micranthum* (L.) Blume	0	1	0	0	0	0	0	0	0	0	0	1
Ericaceae	*Vaccinium leucanthum* Schltdl.	0	0	0	0	0	0	0	0	0	0	1	0
Number of species		6	9	6	5	4	5	7	5	7	5	4	7

Species richness ($N0$) was higher for the *La Ciénega* community (22 species), but lower in the number of abundant and very abundant species ($N1$: LC=8.7, and TC=9; $N2$: LC=4, and TC=7); Hutcheson's t-test did not show significant differences (P=0.57) for diversity (H') between the coffee plantations of the study communities (H'=2.16 for LC and 2.25 for TC), but it did for dominance (λ) (LC=0.23, TC=0.13, P=0.021). As for the species shared among the plots, the average was 1.1 (LC=1.5±0.6 *d. s.*; TC=1.8±0.56 *d. s.*), and the similarity (J_I) was 0.13 (LC=0.15, TC=0.31) (Figure 4).

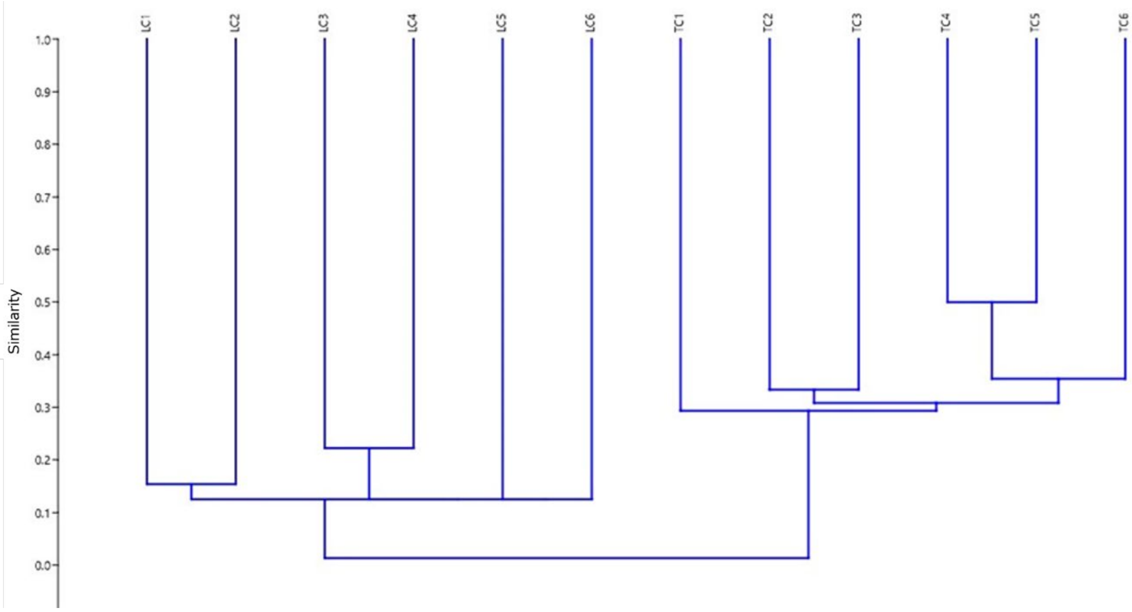
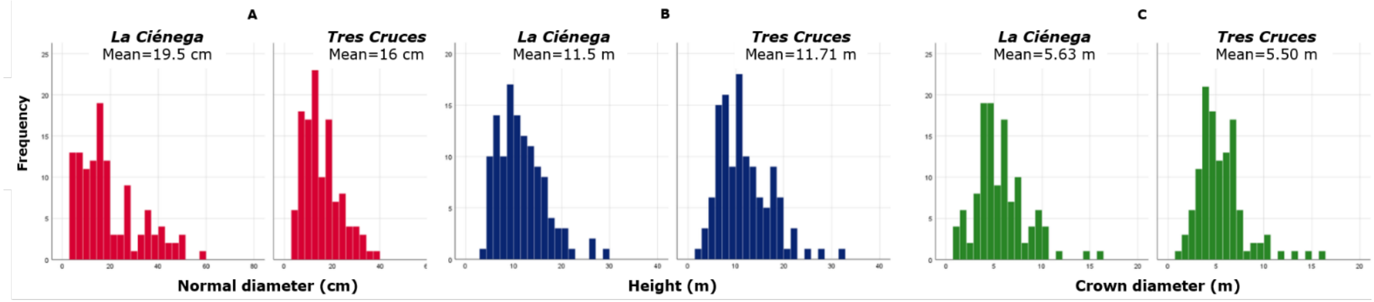


Figure 4. Dendrogram of species similarity recorded in the coffee plantations of the plots in *Tres Cruces* (TC) and *La Ciénega* (LC).

The most abundant species were *Alnus acuminata* Kunth with 55 individuals in LC, and *Myrsine juergensenii* (Mez) Ricketson & Pipoly with 18 individuals in TC. The average density for LC was 1 703.6 ind. ha^{-1}, and 1 874.7 ind. ha^{-1} for TC —values without significant differences (P=0.64, t df, 68=-0.111).

The average tree height recorded in LC coffee plantations was 11.5 m, and in TC it was 11.71 m, these values also showed no differences (P=1.01, t df, 138=1.46). The species with the highest average heights were *Hesperocyparis benthamii* in LC and *Pinus pseudostrobus* Lindl. in TC. Regarding crown diameter, the averages by community were 5.63 in LC and 5.50 m in TC, with no differences (P=0.36, t df, 138=4.0). However, for normal diameter, the averages of 19.56 for LC and 16.03 cm for TC did show significant differences (P=0.01, t df, 138=1.46) (Figure 5).



A = Normal diameter; B = Height; C = Crown diameter.

Figure 5. Frequency histograms by community.

Importance value of tree species. The species with the highest *IVI* were *Myrsine juergensenii* in TC with 19 %, and *Alnus acuminata* in LC with 9 % (Figure 6), both species being native.

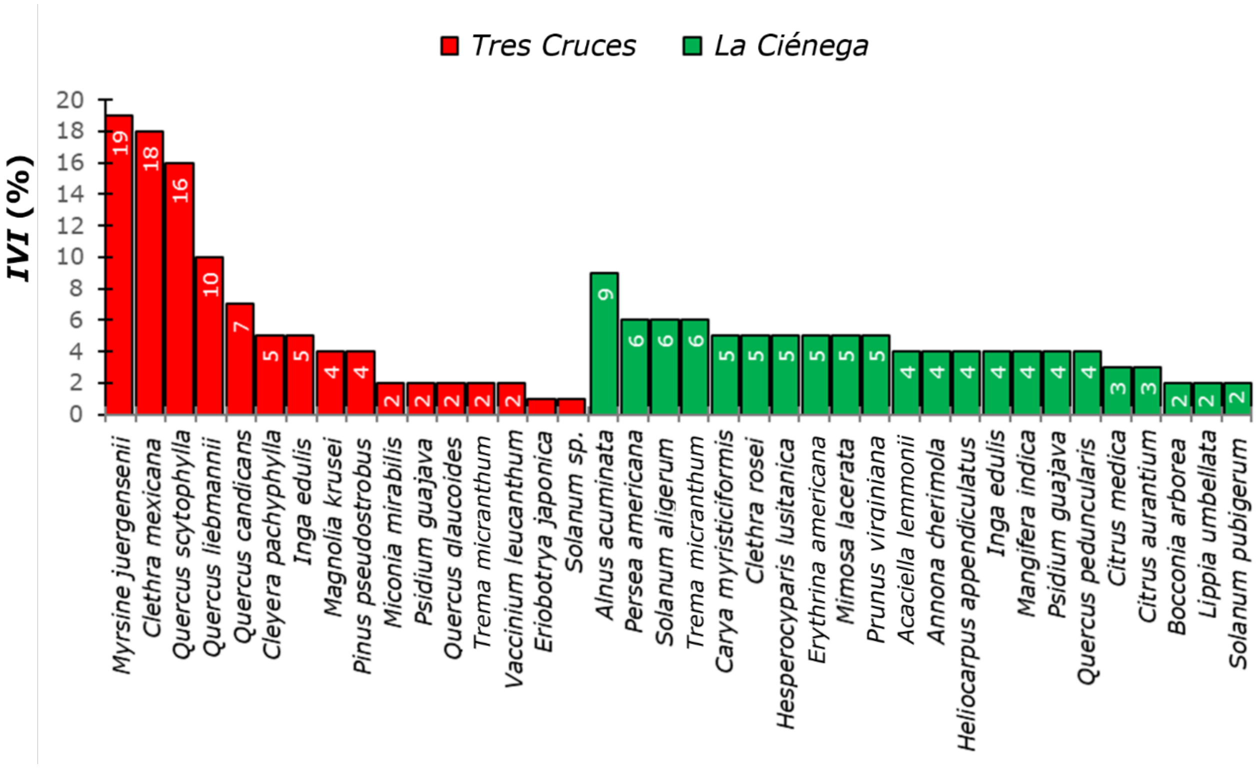


Figure 6. Importance value index (*IVI*) of tree species in the coffee plantations of the study communities.

Local management of coffee plots. Coffee growers in the communities under study indicated that coffee cultivation began approximately 30 years ago in LC and 10 years ago in TC, due to the economic benefits and the ease of establishment; nevertheless, it was necessary to invest family work and some economic resources. In TC 100 % of the farmers interviewed indicated that the vegetation on their land, before establishing the crop, was coniferous forest (56 % oak forest and 44 % pine-oak forest); in LC 60 % indicated that there was pine-oak forest, 35 % that there was cultivated land (corn, beans, and squash) and only 5 % stated that there was no vegetation (induced pasture). Coffee growers in TC mentioned 24 species of trees that they use as shade, in LC they only mentioned 14 (Table 3).

Table 3. Tree species (common and *Me'phaa* names) mentioned by producers and Use Value Index (*UVI*) by species and community.

Community	**Common name**	**Name in the *Me´phaa* language**	**Scientific name**	**S**	**M**	**Fr**	**Fl**	**F**	***UVI***
Tres Cruces	*Cuajinicuil*	*Ixé grian*	*Inga* sp.	X	X				0.09
	Molinillo	*Ixé xta'majá*	*Clethra mexicana* DC.	X	X			X	0.13
	White oak	*Ixé xánúu*	*Quercus candicans* Née	X	X			X	0.13
	Red oak	*Ixé xtámañá*	*Quercus scytophylla* Liebm.	X	X			X	0.13
	Reddish oak	*Ixé xíxó*	*Quercus liebmannii* Oerst. *ex* Trel.	X	X			X	0.13
	Yellow oak	*Ixé txàbun*	*Quercus* sp.	X	X			X	0.13
	Tepehuaje	*Ixé xíxtá*	*Lysiloma acapulcense* (Kunth) Benth.	X	X				0.09
	Guava tree	*Ixé ndíjia'*	*Psidium guajava* L.	X		X		X	0.13
	Heart flower	*Ixé xda'kún*	*Magnolia krusei* J. Jiménez Ram. & Cruz Durán	X	X		X		0.13
	Jamaican nettletree	*Ixé rúmá*	*Trema micranthum* (L.) Blume	X	X				0.09
	Pine	*Ixé xti'ka*	*Pinus pseudostrobus* Lindl.	X	X				0.09

	Capulín	*Ixé rúgu'*	*Cleyera pachyphylla* Chun *ex* Hung T. Chang	X	X		X		0.13
	Árbol de tizne	*Ixé kidí*	*Solanum* sp.	X	X				0.09
	White *marangola*	*Ixé xto'gojó*	*Saurauia pedunculata* Hook.	X	X				0.09
	Capulín de mayo	*Ixé xká*	*Myrsine juergensenii* (Mez) Ricketson & Pipoly	X		X			0.09
	Umbrellawort	*Ixé lañù*	*Miconia mirabilis* (Aubl.) L. O. Williams	X		X			0.09
	Lime	*Ixé limú*	*Citrus limon* (L.) Osbeck	X					0.04
	Orange tree	*Ixé láxa*	*Citrus sinensis* (L.) Osbeck	X		X			0.09
	Loquat	*Xdu'ga*	*Eriobotrya japonica* (Thunb.) Lindl.	X		X			0.09
	Avocado	*Ixé dúdii*	*Persea americana* Mill.	X		X			0.09
	Locustberry (*Nanche*)	*Ixé luxó*	*Byrsonima cinerea* DC.	X			X		0.09
	Izote	*Ixé béxó*	*Yucca* sp.	X		X			0.09
	Mango tree	*Ixé mángo'*	*Mangifera indica* L.	X		X			0.09
	Grapefruit	*Láxa bu'rru*	*Citrus aurantium* L.	X		X			0.09
La Ciénega	Andean alder	*Íxe gro ' on*	*Alnus acuminata* Kunth	X	X			X	0.19
	Cherimoya	*Íxe ra'gó*	*Annona cherimola* Mill.	X		X			0.13
	Sangre de Cristo	*Íxe íg'dí*	*Bocconia arbórea* S. Watson	X	X				0.13
	Nutmeg hickory	*Tsida'*	*Carya myristiciformis* (F. Michx.) Nutt *ex* Elliott	X	X	X		X	0.15
	Citron	*Íxe limo'*	*Citrus medica* L.	X		X			0.13
	Grapefruit	*Íxe láxa*	*Citrus aurantium* L.	X		X			0.13
	Molinillo	*Íxe xá*	*Clethra rosei* Britton	X	X			X	0.19
	Cuaniquil	*Íxe drian*	*Inga edulis* Mart.	X	X			X	0.19
	Árbol de comal	*Íxe ì'fuíí*	*Lippia umbellata* Cav.	X	X			X	0.19
	Mango tree	*Íxe xkodee*	*Mangifera indica* L.	X		X			0.13
	Sensitive plant	*Íxe tsu´wuá*	*Mimosa lacerata* Rose	X	X				0.13
	Avocado	*Íxe xdúdiin*	*Persea americana* Mill.	X		X		X	0.19
	Chokecherry	*Íxe pulí*	*Prunus virginiana* L.	X	X			X	0.19
	Oak	*Íxe xtamaña*	*Quercus peduncularis* Née	X				X	0.13
	Cypress	*Xtíkha*	*Hesperocyparis benthamii* (Endl.) Bartel		X			X	0.13
	Guava	*Íxe díin*	*Psidium guajava* L.			X			0.06

S = Shade; M = Organic matter; Fr = Fruit; Fl = Flowers; F = Fuel.

Use of tree species. The tree species recognized by coffee growers in the study communities, in addition to being used for shade, are also appreciated for generating organic matter, fruits, flowers (edible and medicinal), timber, and fuel (firewood); those with the highest use value are mostly native species. In LC, the Andean alder (*Alnus acuminata*) was the one with the highest value (0.19), while in TC the highest values were for eight species (0.13), including oak species (*Quercus* spp.) and *molinillo* (*Clethra mexicana* DC.) (Table 3).

Discussion

All the coffee plantations of the study communities include the presence of representative families for the vegetation type —among them, the Fagaceae (Sánchez and Schwentesius, 2015; Silva *et al*., 2021), as well as the most species-rich Fabaceae, recorded by López-Gómez and Williams-Linera (2006) in *Veracruz* state and by García *et al.* (2015) in the *Sierra de Atoyac* in *Veracruz*. The richness of shade trees in the coffee plantations of the study communities, which included 35 species, is similar to that recorded by other authors (Ramos *et al.*, 2020; Ruiz-García *et al.*, 2020); also, 83.3 % of the species are native, bespeaking traditional management (Moguel and Toledo, 1999), which contributes to their conservation. On the other hand, the presence of taxa of the *Quercus*, *Alnus*, and *Myrsine* genera is due to their qualities for shade and to their being part of the original forests, in addition to their multiple uses (as fuels and producers of organic matter) and their rapid establishment (Moguel and Toledo, 1999; Silva-Aparicio *et al.*, 2021; Mozo and Silva, 2022).

The structure of the shade tree community in the coffee plantations of the study communities exhibited differences in terms of normal diameter that can be related to the composition of species, which depends to a great extent on the management of the plots, where the producer decides what to plant or eliminate according to the environmental, economic, and cultural characteristics of his community. They design their coffee plantation with certain species and define the density, diameter, height, and canopy cover required for the good development of the coffee trees (Cruz, 2004; Martínez *et al.*, 2004).

In this sense, the abundance and density of *Myrsine juergensenii* and *Clethra mexicana* was higher in TC, and that of *Alnus acuminata* and *Solanum pubigerum* Dunal in LC. This differs from what has been recorded by various authors (Silva-Aparicio *et al.*, 2021; Reyes *et al.*, 2022), who report taxa such as *Musa paradisiaca* L. and *Inga* spp. as the most abundant. The average heights recorded were 11.71 m in TC and 11.48 m in LC, unlike the values documented by Reyes *et al.* (2022) of 10 m. This is due to the type of species used, the management of the plots, and the type of vegetation. In this regard, Silva *et al.* (2013) indicate that, in cocoa plantations in Nicaragua, a shade tree averages in height 15-25 m and has an open crown that does not lose foliage in the dry season and the best rapid growth rate. However, the manuals of projects like Maximizing Opportunities in Coffee and Cocoa in the Americas (MOCCA, 2022) cite that the appropriate height is 4 to 5 m above the height of the coffee plant, which also depends on the management, the variety grown, and the species used as shade (Anacafé, 2019).

The average diameter of the species associated with coffee was 16.03 cm in TC and 19.53 cm in LC, which may be related to the composition, since in TC there were species that reach large diameters, such as *Pinus pseudostrobus*. Authors such as Sánchez-Clavijo *et al.* (2007) indicate an average diameter of 10 cm, and Silva-

Aparicio *et al.* (2021) an average of 10.83 cm, which is related to the management; that is, the producer makes use of trees with larger diameters for the purpose of limiting the space to establish the largest number of coffee plants, in addition to monitoring the shade, as, according to Sánchez *et al.* (2017), it should be slight, with a continuous supply of easily degradable leaf litter (with a decomposition rate of k=0.415, depending on environmental conditions) (Munguía, 2007).

In the present study, the average canopy cover in TC was 5.5 m, and 5.73 m in LC, consistently with the above; however, there is a lack of information on the rate of degradation of the taxa associated with coffee plantations, from those with thin consistencies such as *Inga* spp. to coriaceous taxa like *Quercus* spp.

According to the Shannon-Wiener Index, the average diversity was 2.16 for LC and 2.25 for TC, values close to those recorded by Ramos *et al.* (2020) of 3.04, and by Silva-Aparicio *et al.* (2021) of 2.05. However, they are high in comparison with the values for the coffee growing areas of *Soconusco* estimated by Reyes *et al.* (2022) of 1.1, due to the tendency to the establishment of species of the *Inga* genus. As for the dominance (λ) per community (0.23 for LC and 0.14 for TC) and the effective number of species (abundant and very abundant, $N1$: LC=8.7, TC=9; $N2$: LC=4, TC=7), the values differ, as in relation to other works, such as the study by Silva-Aparicio *et al.* (2021), who report an average dominance of 0.14 and a number of species rated abundant ($N1$, 7.7) and very abundant ($N2$, 4.1). Variation in the richness and abundance of established species in each plot depends on both the environmental characteristics and the management (Manson *et al.*, 2018). This last aspect could reflect a similar diversity (H') in the coffee plantations of the study communities, as the test of means did not exhibit significant differences; however, the environmental difference is evident in the composition of species.

The above also reflects the beta diversity values, since the average similarity (J_i) between the plots was only 0.31, that is only 31 % of the species are shared. In this sense, certain authors such as Ramos *et al.* (2020) indicate that the species composition of different coffee plantations is linked to the original vegetation, without neglecting the management as a determining factor, given that the producers decide which trees to leave and which to fell, depending on the needs of the coffee trees and their own economic needs.

Notably, in the two studied communities, the species with the highest *IVI* were native (*Alnus acuminata* in LC and *Myrsine juergensenii* in TC), consistently with Moreno-Guerrero *et al.* (2020), who also cites species that are part of the original vegetation, such as *Cedrela odorata* L., *Quercus crispifolia* Trel., *Tabebuia rosea* (Bertol.) DC., and *Guarea glabra* Vahl. Likewise, Reyes *et al.* (2022) mention *Inga micheliana* Harms (synonym of *Inga flexuosa* Schltdl.), *Tabebuia donnell-smithii* Rose (synonym of *Roseodendron donnell-smithii* (Rose) Miranda), *Cedrela odorata*, and *Tabebuia rosea* as the species with the highest *IVI*. The presence of native species is due to their adaptation to the environmental characteristics; likewise, their permanence is also an indicator of the preference of the producers for these trees, since they generate additional benefits such as timber, fruit and flowers, and they fixate nitrogen, in addition to providing environmental services, among others (Sánchez *et al.*, 2017).

The uses of registered tree species refer to the needs of producers; in this regard, Sánchez and Schwentesius (2015), Sánchez *et al.* (2017), and Ramos *et al.* (2019) point out that tree taxa, in addition to providing shade for the coffee trees, are also used as firewood, as well as for timber, fruit, and organic matter. In the studied communities, coffee growers agree in recognizing that the trees in their plots have at least one function (shade, organic matter, fruits, flowers, and fuel); also, native species (such as pines, oaks, Andean alders) are used for shade, wood, and fuel; on the other hand, introduced species are used to obtain fruits (such as citrus fruits, annonas and bananas) that complement the family diet and in some cases are marketed. In LC, the species with the highest *IVI* and *UVI* was the same (*Alnus acuminata*), which reinforces its importance, while in the case of TC, it is not similar. However, *Quercus* species with high importance values are those with the highest use value, which may indicate the importance of native species for the inhabitants of the study communities and reinforces the relevance of these agroecosystems for the conservation of plant diversity.

Conclusions

The composition of species associated as providers of shade in the coffee plantations of the study communities includes 83.3 % of native taxa, the best-represented families being Fagaceae and Fabaceae. The diversity of species estimated in the study communities is within the range recorded in other regions. Species similarity between LC and TC coffee plantations is low. The structure of the shade tree community differs only in diameter between the two studied communities, and the species with the highest Importance Value Index, including *Myrsine juergensenii*, *Clethra mexicana* and *Quercus scytophylla* Liebm., are native. The use categories registered for the species associated with coffee plantations refer to the function fulfilled by the trees within the coffee system (providing shade and organic matter) and within the family (providing food and raw materials), in addition to the provision of environmental services. The structure of the shade tree community in the coffee plantations of the *Montaña de Guerrero* Region exhibits variations due to environmental conditions (especially altitude) and management conditions. Likewise, the species with the highest *IVI* and *UVI* are native and relevant for the agroecosystem and the conservation of vegetation diversity.

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Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

Marisa Silva Aparicio: conceptualization of the research, revision and analysis of the information, drafting and editing of the manuscript; Carmelo Francisco Olguín: field data collection, drafting and revision of the manuscript; Severino Jesús Cruz: field data collection, drafting and revision of the manuscript.

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