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Research article

Dendroenergetic species used for *mezcal* production in the *Región Norte* of the state of *Guerrero*

Especies dendroenergéticas empleadas para la producción de mezcal en la Región Norte de Guerrero

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Resumen

La producción artesanal de mezcal en el norte de Guerrero, México representa una práctica biocultural de gran arraigo, en el cual la leña desempeña un papel clave como fuente de energía para el proceso. Este estudio etnobotánico se realizó en cuatro comunidades con fuerte tradición mezcalera (El Calvario, Apetlanca, Temalac y Mezquitlán), con el objetivo de identificar y analizar las especies dendroenergéticas empleadas. Para ello, se llevaron a cabo 80 entrevistas semiestructuradas a productores, que corresponden a 50 % del total en el área de estudio. Se aplicaron los índices de Valor de Uso (*IVU*), Nivel de Uso Significativo (*UST*) y Clasificación Matricial Directa (*CMD*). Los resultados documentan 15 taxones maderables, con predominancia de la familia Fabaceae por su densidad y poder calorífico. Especies como *Lysiloma acapulcense* y *Leucaena esculenta* presentaron los mayores niveles de consenso cultural (*UST*>50 %). El análisis inferencial mostró diferencias altamente significativas en el conocimiento y consumo de dendrocombustible entre localidades (p<0.0001). Se identificó que 90 % de los productores emplean leña verde al menos en alguno de sus procesos, práctica que compromete la eficiencia energética y eleva la presión sobre la selva baja caducifolia. Se concluye que la sostenibilidad del sistema mezcalero exige integrar la gestión forestal comunitaria y la trazabilidad de la leña en marcos normativos como la NOM-070-SCFI-2016, así como el reconocimiento al recurso dendroenergético como un insumo tan crítico para la identidad y permanencia de la industria, como el propio agave.

Palabras clave: Artesanal, combustibles, dendroenergía, energía, etnobotánica, leña.

Abstract

Artisanal *mezcal* production in Northern state of *Guerrero*, Mexico, is a deeply rooted biocultural practice, where firewood plays a key role as the primary energy source. This ethnobotanical study was conducted in four communities with a strong *mezcal* tradition (*El Calvario*, *Apetlanca*, *Temalac* and *Mezquitlán*) to identify and analyze the dendroenergetic species that are used as fuel for cooking and distillation for *mezcal* production. Eighty semi-structured interviews were carried out with producers, representing 50 % of the total population in the study area. The Use Value (*UV*), Significant Use Level (*SUL*) and Direct Matrix Ranking (*DMR*) indices were applied. Results documented 15 timber species, with the Fabaceae family predominating due to its high density and calorific value. Species such as *Lysiloma acapulcense* and *Leucaena esculenta* showed the highest levels of cultural *consensus* (*SUL*>50 %). Inferential analysis showed highly significant differences in ethnobotanical knowledge and fuel consumption among locations (p<0.0001). It was identified that 90 % of producers use green firewood in at least one of their processes, a practice that compromises energy efficiency and increases pressure on the low deciduous forest. It is concluded that the sustainability of the *mezcal* system requires integrating community forest management and firewood traceability into regulatory frameworks such as NOM-070-SCFI-2016, recognizing dendroenergetic resources as an input as critical to the industry's identity and permanence as the *agave* itself.

Keywords: Artisanal, fuels, dendroenergy, energy, ethnobotany, firewood.

Introduction

In Mexico, firewood is a fundamental energy source for the rural population, both for domestic use and for traditional productive activities (Libert-Amico et al., 2024). Among these, the artisanal production of *mezcal* stands out, a process that demands considerable amounts of biomass and represents a key component of the economy and culture in various regions of the country. However, in the current debate on the sustainability of the *mezcal* industry, attention is often focused almost exclusively on the management and conservation of the *Agave* genus, without considering the critical role that wood energy plays as a fundamental input in the distillation process.

Under this premise, the present research is situated within a conceptual framework of holistic sustainability, recognizing that the long-term viability of these biocultural systems depends on integrated forest management. This approach considers firewood not only as an extractable resource but also as an essential ecosystem service for rural energy security. Therefore, the analysis of natural resources needed for *mezcal* distillation must necessarily extend beyond *agave* plants (Torres-García & Delgado-Lemus, 2019).

Previous studies in states such as *Michoacán*, *Oaxaca* and *Puebla* have documented the preferential use of species from *Quercus*, *Lysiloma* and *Prosopis* genera, valued for their high calorific value and their ability to impart distinctive organoleptic characteristics to *mezcal* (Torres-García & Delgado-Lemus, 2019; Jiménez-Mendoza et al., 2023). The use of these taxa is integrated into traditional knowledge systems in which forest resources have multiple uses (timber, fodder or medicine), increasing their socio-ecological value and justifying their technical selection by producers (García-Maceda, 2024).

However, the unregulated use of these resources carries risks of overexploitation and ecosystem degradation (López-Santiago et al., 2019). Despite the importance of the *mezcal* industry in other regions of the country, a lack of systematic information persists regarding the dendroenergetic species used, specifically in northern *Guerrero*, as well as the technical and cultural criteria that guide their use. Therefore, the objective of this study was to identify the main woody species used in *mezcal* production in four localities in this region, characterize their uses, and evaluate their cultural importance, in order to propose a basis for sustainable forest management that harmonizes traditional production with the conservation of local biodiversity.

Materials and Methods

Study area

The study was conducted in the northen region of the state of *Guerrero*, Mexico. Four sites were intentionally selected due to their *mezcal*-making tradition and distinct socioecological characteristics (Figure 1): *El Calvario*, *Apetlanca*, *Temalac* and *Mezquitlán*. The region presents high levels of marginalization and a diversity of climates and vegetation types (Instituto Nacional de Geografía y Estadística [Inegi], 2020; Consejo Nacional de Población [Conapo], 2021), as detailed in Table 1.

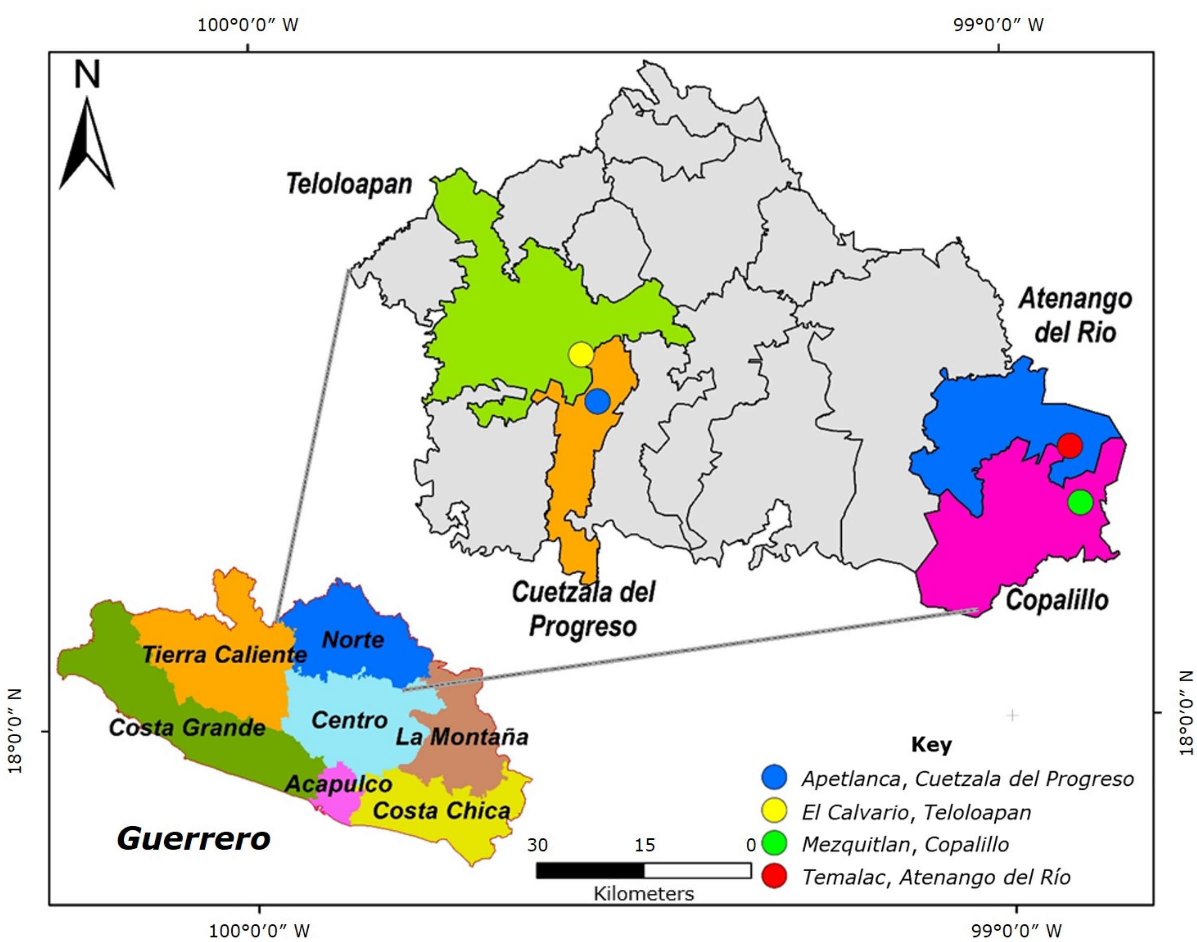

Figure 1. Location of the study sites in the northern region of *Guerrero*, Mexico.

Table 1. Biophysical and sociocultural context and population coverage of *mezcal* producers by site.

Municipality	Locality	Ethnicity	*Gm*	Altitude	Geographical coordinates	Climate	Tv	*Tpm*	*Tpme*
Atenango del Río	*Temalac*	Indigenous	Medium	968	18°7'4.8" N 98°57'10.0" W	Semidry very warm	Sbc	35	20
Copalillo	*Mezquitlán*	Indigenous	High	642	18°1'16.3" N 98°56'7.0" W	Subhumid warm	Sbc and thorny	22	15
Cuetzala del Progreso	*Apetlanca*	Mestizo	Medium	1 720	18°12'29.9" N 99°47'16.2" W	Subhumid temperate	Sbc	50	20
Teloloapan	*El Calvario*	Mestizo	High	1 753	18°17'21.2" N 99°48'59.6" W	Subhumid temperate	Sbc and ecotone cedar forest	53	25

Gm = Degree of marginalization; Tv = Type of vegetation; *Tpm* = Total number of *mezcal* producers; *Tpme* = Total number of *mezcal* producers interviewed; Sbc = Tropical deciduous forest. Source: Conapo (2021); Inegi (2020).

Population and sample

The target population consisted of 160 active *mezcal* producers in the four selected locations. A non-probability sampling method was used, achieving 50 % coverage (80 informants). The sample size was justified based on the theoretical saturation criterion, the point at which collecting additional data did not generate new categories of analysis or records of species other than those already documented (Hernández-Sampieri, 2014). The representativeness achieved, which ranged from 40 to 68 % per location, allowed for robust inferences regarding dendroenergetic management practices in the region. Limitations of the study include the inherent bias of voluntary participation and the exclusion of producers who, due to seasonality or temporary migration, were not active during the data collection period.

Data collection and seasonal justification

Information was obtained through semi-structured interviews (46 items) validated by ethnobotanical specialists and a pretest with five producers not included in the final sample. The study was timed to coincide with the dry season (January-April), the only period of artisanal *mezcal* production in northern *Guerrero*, due to the need for thermal control in pit ovens and stability in fermentation (Jiménez-Mendoza et al., 2023).

This design allowed for the real-time capture of technical data and minimized recall bias. Following the framework of Romero-Carazas et al. (2024), the variables included: (1) Sociodemographic (ethnicity, marginalization, access to resources); (2) Technical processes (details of pineapple cooking and distillation); (3) Ethnobotanical (preferences, perceived caloric value, and influence on flavor/quality); (4) Selection and sourcing (traditional identification and sources of supply); and (5) Management and additional uses (extraction, forage, construction, among others).

Botanical collection and identification

To ensure accurate taxonomic identification that included the phenological variations of the species, the collection phase of the biological material was carried out from June 2024 to December 2025. During this period, 16 field trips (four per locality) were conducted, accompanied by local guides, to collect samples at different phenological stages (flowering, fruiting, and vegetative state).

Three biological samples were obtained from each taxon, which were processed using the herbarium technique of Sánchez-González and González-Ledesma (2007) and deposited in the Herbarium of the *Universidad Autónoma de Guerrero* (*UAGC*) (Autonomous University of *Guerrero*). Taxonomic determination was performed using specialized keys (Pennington & Sarukhán, 2005) and comparison with reference specimens. This confirmed the identity of the species mentioned by the producers during the interviews.

Data analysis

Quantitative data were processed using SPSS statistical software version 25 (International Business Machines (IBM), 2022) to obtain descriptive statistics (frequencies, means, and standard deviations), while qualitative data underwent content analysis and thematic categorization. The study of biocultural importance and pressure on the resource was based on the following indices:

Use Value Index (*UVI*). This index determines the versatility of species according to the diversity of uses and their frequency of mention (Olea-Reséndiz et al., 2022). It was calculated using the following formula:

$$UVI_{is} = \frac{\Sigma\ U_{is}}{n_{is}} \qquad (1)$$

Where:

ΣU_{is} = Total sum of the number of uses mentioned by each informant (*i*), for each species (*s*)

n_{is} = Number of interviewed informants

***TRAMIL* Significant Use Level (*UST*).** This evaluates the social consensus on the use of a specific category. The methodology proposed by Boulogne et al. (2011) was used for its calculation.

$$UST = \frac{Use\ of\ species\ (s)}{n_{is}} \times 100 \qquad (2)$$

Where:

Use of species = Number of mentions for each species

n_{is} = Number of informants surveyed

Species with $UST \geq 20$ % were considered significant (Zambrano-Intriago et al., 2015).

Use Value (*UV*). This allows for the quantification and comparison of the importance of plant species based on informant consensus, which is fundamental for prioritizing taxa in management and conservation programs. To prevent the total number of specific uses from biasing the results, a method is proposed in which each use category has a maximum value of one (1); if a species has several uses within a single category, the unit is divided equally among them. In this way, the maximum importance value of a taxon is determined by the number of categories analyzed and not by the number of different uses, ensuring a balanced assessment of its functional relevance and facilitating the design of sustainable use strategies (Marín-Corba et al., 2005).

Direct Matrix Classification (*DMC*). A participatory technique for ranking resources according to yield, availability, and quality. A scale of 1 to 4 was used to generate an index of importance or scarcity (Martin, 2004).

$$DMC = \sum\{i = 1\}^{\{n\}\,V\,\{ij\}} \qquad (3)$$

Where:

DMC = Direct matrix classification for species *j*

$\Sigma=\{i=1\}^{\{n\}}$ = Sum from informant 1 to informant *n*

$^{V\{ij\}}$ = Value assigned by informant *i* to species *j*

Inferential analysis

All statistical analyses were performed using IBM SPSS statistical software version 25 (IBM, 2022). Prior to the analysis, the distribution of the variables was verified using the Shapiro-Wilk test, which determined the use of non-parametric methods due to the lack of normality. The Kruskal-Wallis test was applied to compare ethnobotanical knowledge and fuel consumption among localities, as well as to compare the scale of annual production among preferred species. Additionally, Pearson's chi-squared test was used to evaluate the association between species preference and community of origin. Finally, the Mann-Whitney test was used to determine variations in biomass consumption according to the distillery's ownership status (owned or leased). All analyses were performed with a 95 % confidence level.

Results and Discussion

Socio-productive characterization of *mezcal* producers

The 80 producers interviewed ranged in age from 20 to 77 years, with an average age of 43 to 56 years, and limited participation from young people. Their production experience varied from 10 to 18 years on average by location. Only 34 % (n=27) owned their factories, while 66 % (n=53) operated them under a lease (Table 2).

Table 2. Socio-productive profile and scale of *mezcal* production by locality.

Locality	Total number of *mezcal* producers interviewed	Average age (years)	Average expertise (years)	Ownerss (%)	Average *mezcal* production volume per producer (L cycle^{-1})
El Calvario	25	48.5	18.0	36.00	250-360
Apetlanca	20	54.9	18.0	35.00	800-1 000
Temalac	20	56.1	14.7	45.00	350-400
Mezquitlán	15	43.0	10.7	20.00	60-80
Global	80	51.0	15.8	34.00	60-1 000

Production is concentrated between February and May, with average volumes per producer ranging from 60 to 1 000 L (Table 2). The most commonly used *agave* species were *Agave angustifolia* Haw. and *Agave cupreata* Trel. & A. Berger, and to a lesser extent *Agave rhodacantha* Trel., *Agave salmiana* Otto *ex* Salm-Dyck and *Agave americana* var. *oaxacensis* Gentry. *Mezcal* is sold informally in bulk for between MXN $150.00 and $250.00 per liter. These variations in the scale of production are due to differences in access to raw materials, capital, and marketing channels; factors that also influence the pressure on wood resources (Toribio-Solis et al., 2024).

In the cultural context, producers perform rituals to bless the ovens, thus integrating the production process into the local biocultural heritage. This practice is carried out with the purpose of obtaining divine assistance to achieve an adequate quantity and high-quality *mezcal* production. *Mezcal* production is an economic activity that complements subsistence agriculture (corn), and is also fundamental to the family and local economy (Sánchez-Jiménez, 2024).

Identification and distribution of dendroenergetic species

Fifteen tree species used as firewood in the cooking and distillation processes of *mezcal* were identified (Table 3). The distribution of taxa varied considerably among localities. *Lysiloma acapulcense* (Kunth) Benth. (*tepeguaje*) and *Leucaena esculenta* (Moc. & Sessé *ex* DC.) Benth. (*guaje rojo*) were present in two and three localities, respectively, demonstrating broad ecological adaptation and cultural acceptance. In contrast, species such as *Haematoxylum brasiletto* H. Karst. (*palo de Brasil*) y *Ziziphus mexicana* Rose (*tepemezquite*) was only recorded in *Mezquitlán*, associated with specific ecological conditions of a warm subhumid climate and low thorny forest vegetation (Table 1), suggesting a localized preference or restricted availability due to specific ecological conditions (Flores-Villela & Gerez, 1994).

Table 3. Dendroenergetic species identified in four localities of the northern region of *Guerrero*, Mexico.

Famiiy	Common name Scientific name	UAGC Herbarioum folio number	*EC*	*AP*	*TM*	*MZ*	Total
Fabaceae	*Tepeguaje* *Lysiloma acapulcense* (Kunth) Benth.	15112, 115113	X	X			2
Fabaceae	*Guaje rojo* *Leucaena esculenta* (Moc. & Sessé *ex* DC.) Benth.	15117, 15115	X	X	X		3
Fabaceae	*Mezquite* *Lysiloma aff. microphyllum* Benth.	15097, 15118	X	X			2
Burseraceae	*Copal* *Bursera bipinnata* (Moc. & Sessé *ex* DC.) Engl.	15102, 15119	X				1
Convolvulaceae	*Cazahuate* *Ipomoea arborescens* (Humb. & Bonpl. *ex* Willd.) G. Don	115096	X				1
Fabaceae	*Palo dulce* *Eysenhardtia aff. polystachya* (Ortega) Sarg.	15108		X			1
Moraceae	*Amate* *Ficus aff. insipida* Willd.	15106	X				1
Malvaceae	*Coahuilote* *Guazuma ulmifolia* Lam.	15100		X			1
Fagaceae	*Encino blanco* *Quercus glaucoides* M. Martens & Galeotti	15107			X		1
Fabaceae	*Pata de cabra* *Lysiloma tergeminum* Benth.	15104, 15105			X	X	2
Fabaceae	*Borrego* *Senegalia acatlensis* (Benth.) Britton & Rose	15098, 15099			X	X	2
Fabaceae	*Tehuiztle* *Vachellia bilimekii* (J. F. Macbr.) Seigler & Ebinger	15109			X	X	2
Fabaceae	*Guamúchil* *Pithecellobium dulce* (Roxb.) Benth.	15116			X	X	2

Rhamnaceae	*Tepemezquite* *Ziziphus mexicana* Rose	15101	X	1
Fabaceae	*Palo de Brasil* *Haematoxylum brasiletto* H. Karst.	15103	X	1

EC = El Calvario; *AP = Apetlanca*; *TM = Temalac*; *MZ = Mezquitlán*.

The prevalence of the Fabaceae family in Northern *Guerrero* (10 of the 15 recorded species) confirms a forest management pattern that exhibits a marked functional convergence with other mezcal-producing regions of the country. When these results are compared with those reported for *Michoacán* and *Oaxac*a, where the use of legumes from the genera *Lysiloma* and *Prosopis*, as well as *Quercus* spp., predominates (Torres-García & Delgado-Lemus, 2019), it becomes evident that the producer's selection responds to an ethnobotanical selectivity aimed at optimizing the energy efficiency of the distillation process. This preference is based on key technical attributes such as the high wood density, high calorific value, and remarkable resprouting capacity of the taxa used (Jiménez-Mendoza et al., 2023).

Under this approach, the research transcends the regional inventory to propose a model in which the quality of artisanal *mezcal* and the sustainability of the industry depend directly on the technical management of biomass, a critical link to mitigate anthropogenic pressure on the ecosystems of low deciduous forest.

Cultural importance and use patterns

The applied ethnobotanical indices revealed a gradient of cultural importance among the species (Table 4). *Lysiloma acapulcense* obtained the highest Use value index (*UVI*=4.11) and *TRAMIL* Significant Use Level (*UST*=58.75 %), followed by *Leucaena esculenta* (*UVI*=3.37, *UST*=56.25 %). These values reflect its frequent and multifunctional use, as up to eight different uses were recorded per species (fuel, fodder, timber, living fences, posts, food, ritual, and organic fertilizer).

Table 4. Uses of the species used as firewood, Use Value Index (*UVI*), Significant Use Level (*UST*), Use Value (*UV*) and Direct Matrix Classification (*DMC*).

Common name Scientific name	Uses	Mentions	*UVI*	*UST* (%)	*UV*	*DMC*
Tepeguaje *Lysiloma acapulcense* (Kunth) Benth.	C, MA, CV, P, AO, F, CB	47	4.11	58.75	7	2
Guaje rojo *Leucaena esculenta* (Moc. & Sessé *ex* DC.) Benth.	C, MA, CV, P, F, CB	45	3.37	56.25	6	2
Mezquite *Lysiloma aff. microphyllum* Benth.	M, MA, CV, P, CB	20	1.25	25.00	5	3
Copal Bursera bipinnata (Moc. & Sessé *ex* DC.) Engl.	MA, CV, P, RI, CB	20	1.25	25.00	5	3
Cazahuate Ipomoea arborescens (Humb. & Bonpl. *ex* Willd.) G. Don	MA, CV, P, C, CB	17	1.06	21.25	5	3
Palo dulce *Eysenhardtia aff. polystachya* (Ortega) Sarg.	MA, CV, P, F, CB	17	1.06	21.25	5	1
Amate *Ficus aff. insipida* Willd.	MA, CV, P, F, CB	15	0.93	18.75	5	4
Coahuilote *Guazuma ulmifolia* Lam.	MA, CV, P, AO, CB	14	0.87	17.50	5	5
Encino blanco *Quercus glaucoides* M. Martens & Galeotti	MA, CV, P, AO, CB	11	0.87	13.75	5	9
Pata de cabra *Lysiloma tergeminum* Benth.	MA, CV, P, F, CB	10	0.87	12.50	5	1
Borrego *Senegalia acatlensis* (Benth.) Britton & Rose	MA, CV, P, CB	9	0.31	11.25	4	2
Tehuiztle Vachellia bilimekii (J. F. Macbr.) Seigler & Ebinger	MA, CV, P, CB	8	0.31	10.00	4	7

Guamúchil *Pithecellobium dulce* (Roxb.) Benth.	MA, CV, P, CB	8	0.31	10.00	4	8
Tepemezquite *Ziziphus mexicana* Rose	MA, CV, P, CB	7	0.31	8.75	4	6
Palo de Brasil *Haematoxylum brasiletto* H. Karst.	MA, CV, P, CB	6	0.31	7.50	4	1

C = Edible; MA = Timber; CV = Live fences; P = Posts; AO = Organic fertilizer; F = Fodder; CB = Fuel; RI = Ritual.

The multifunctionality of these species is a finding consistent with ethnobotanical studies in other rural regions of Mexico. Rodríguez-Hernández et al. (2024) and López-Santiago et al. (2019) also documented that woody taxa valued as fuel often have complementary uses in traditional medicine, construction, and food. This versatility increases their cultural and economic value, but can intensify harvesting pressure, requiring integrated management strategies.

The Use Value (*UV*) ranged from 7 (*tepeguaje*) to 4 (species such as *palo de Brasil*). High *UV* values indicate a concentration of use on a few species, which, if not followed by management practices, could lead to local overexploitation. Andrade-Limas et al. (2025) have documented forest cover losses associated with the intensive use of oak in *Tamaulipas*, a warning applicable to *tepeguaje* in *Guerrero* if its extraction is not regulated.

Heterogeneity in ethnobotanical selectivity

The use of dendroenergetic resources in northern *Guerrero* is not uniform, as there is marked heterogeneity in both traditional knowledge and intensity of use. The Kruskal-Wallis test confirmed highly significant differences in the richness of known species among localities (H=79.00; p<0.0001). While *El Calvario* and *Temalac* recorded an average of 6.0 species, knowledge in *Apetlanca* was limited to 4.0. This disparity suggests selectivity conditioned by the availability of taxa in the immediate environment (Torres-García & Delgado-Lemus, 2019).

When comparing the results with other *mezcal*-producing regions, the number of species recorded in this study (15) is lower than the 24 cited for *Michoacán* or the more than 30 documented in the *Valles Centrales de Oaxaca* (Torres-García & Delgado-Lemus, 2019; Jiménez-Mendoza et al., 2023). However, there is a functional convergence in the preference for the Fabaceae family (*Lysiloma* spp., *Leucaena* spp. and *Prosopis* spp.). This preference is based on shared technical criteria: high basic wood density and a calorific value greater than 19 MJ kg^{-1} (Jiménez-Mendoza et al., 2023), attributes that guarantee the thermal stability necessary for the hydrolysis of *agave* fructans.

Consumption dynamics, production scale and energy efficiency

Energy demand showed critical variations among communities (H=62.72; p<0.0001), ranging from 620.8 kg (*El Calvario*) to 1 290.6 kg (*Mezquitlán*) per cycle. Inferential analysis demonstrated that the annual production scale is the determining factor in the pressure on the resource (H=14.15; p<0.001), since larger-volume producers opt for taxa with denser wood, such as *Quercus* spp. and *Lysiloma tergeminum* Benth. (*pata de cabra*), which exerts selective pressure on their populations.

A critical finding is the predominant use of green firewood in at least one of the *mezcal* production stages (90 %) compared to dry firewood (10 %; Figure 2). Although green firewood is culturally valued for the slow release of steam, necessary for baking the *agave* stalks; from a forest thermodynamics perspective, this practice implies a severe loss of efficiency. Much of the energy released during combustion is consumed as latent heat of vaporization of the water contained in the fresh wood, reducing the net calorific value and doubling the amount of biomass required compared to using dry wood (Barrientos-Rivera et al., 2020). Furthermore, the incomplete combustion of green wood increases the emission of particulate matter and volatile organic compounds, which affects the carbon footprint of artisanal *mezcal*.

A and B = Green oak firewood and dry firewood of various species in *Temalac*; C = Preparing the kiln with *tepeguaje* wood and rocks in *Temalac*; D = Distillation in *El Calvario*.

Figure 2. Representation of wood types and their use in the cooking and distillation processes of *mezcal*.

Governance, certification and sustainable markets

The lack of correlation between factory ownership (owned or rented) and consumption (p=0.98) confirms that pressure on resources is a structural challenge that transcends the producer's socioeconomic status. Currently, frameworks such as NOM-

070-SCFI-2016 (Secretaría de Economía [SE], 2017) focus traceability exclusively on the *Agave* genus and omit the management of dendroenergetic resources, which constitute the forgotten link in the production chain (SE, 2017; Torres-García & Delgado-Lemus, 2019).

Starting from the growing demand from specialized markets for sustainability certifications, the Use value index (*UVI*) and Significant use level (*UST*) documented here provide a replicable technical basis for the design of community forest management plans. The transition to sustainable markets requires that *mezcal* certification include the legal origin of firewood and the adoption of more efficient technologies (such as improved kilns) that allow the use of dry wood. This would not only align production with national energy transition goals but also allow producers in *Guerrero* to access higher value-added market niches based on the comprehensive socio-environmental traceability of the product (Corona-Terán & Rutiaga-Quiñones, 2025; Jiménez-Mendoza et al., 2023).

Conclusions

The characterization of the dendroenergetic flora in northern *Guerrero* reveals robust ethnobotanical knowledge, with the identification of 15 timber species and a predominance of the Fabaceae family, due to the high density and calorific value of the species used. However, the research demonstrates that this knowledge is not homogeneous; the spatial heterogeneity identified through the Kruskal-Wallis test confirms that traditional knowledge and the intensity of use are conditioned by the microregion and the scale of production in each locality. The coverage of 50 % of the total producer population gives these results high representativeness and consolidates a solid baseline for forest resource management in the state.

From an energy efficiency perspective, the predominant use of green firewood (90 %) represents a critical challenge for the sustainability of the production chain. This practice, common in various *mezcal*-producing regions of the country, generates a significant energy loss due to latent heat of evaporation, increasing human pressure on the tropical dry forest by demanding larger volumes of biomass to compensate for thermal inefficiency. This finding underscores the fact that the sustainability of *mezcal* should not be limited solely to the management of the *Agave* genus, but rather requires the mandatory integration of traceability and management of the dendroenergetic resource.

Finally, in the national context, the results demonstrate the urgent need to update regulatory frameworks, such as NOM-070-SCFI-2016, to incorporate clean or sustainable energy certification criteria. The high dependence on leased factories (66 %) suggests that conservation policies should focus on community forest management schemes and local nurseries of native species (such as *tepeguaje* and *guaje rojo*), to ensure that the global boom in *mezcal* does not result in irreversible degradation of the forest ecosystems that sustain its biocultural identity.

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Conflict of Interest

The authors declare that there is no conflict of interest in their contributions, such that the published data will not provide them with any professional, employment, or financial benefit.

Contribution by author

Viridiana Álvarez González: fieldwork, data collection and main drafting of the manuscript; Héctor Ramón Segura Pacheco: study conception, general supervision of the work and statistical analysis; Elías Hernández Castro: review of the manuscript and fieldwork; Natividad D. Herrera Castro: methodological validation, taxonomic support, processing, handling, and identification of plant specimens; Eduardo Sánchez Jiménez: initial design and final revision of the manuscript; Jorge Huerta Zavala: study concept, fieldwork, and writing of the manuscript.

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