SCIENTIFIC CULTURE

SOCIOTECHNICAL TYPOLOGIES AND WATER STRATEGIES IN THE ANCESTRAL PRODUCTION OF MEZCAL: A MULTIVARIATE ANALYSIS IN OAXACA, MEXICO

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ABSTRACT

Mezcal production in the municipality of Sola de Vega, Oaxaca, represents a key activity for territorial development and community sociocultural reproduction. However, it faces increasing pressures related to water scarcity, waste disposal, and the transition toward sustainable models. This study aims to comprehensively characterize mezcal producers by considering sociodemographic variables, production practices, traditional knowledge, and water management. A structured survey was applied to 60 producers selected through stratified sampling across three localities, representing 80% of the active producers in the region. The questionnaire was validated (a = 0.76), and statistical analyses were carried out (Chi-square, correspondence analysis, K-means clustering, and principal component analysis). Three differentiated profiles were identified: (A) punctual technification without water efficiency, (B) transition toward sustainability, and (C) traditional resilience with local knowledge. The findings reveal a high perception of water scarcity (90%) and a diversity of water and vineyard management strategies, shaped by territorial, technical, and cultural factors.

KEYWORDS: Mezcal Production, Water Management, Traditional Knowledge.

1. INTRODUCTION

"Mezcal production in Oaxaca has experienced sustained growth in the last two decades, reaching more than 8 million liters annually, with a significant contribution to local income in regions such as the Sierra Sur and Valles Centrales (DOF, 2022). In the municipality of Sola de Vega, this activity is not only an economic source, but also a key cultural and territorial component. However, it faces increasingly complex challenges, such as water scarcity, lack of infrastructure for waste treatment, and pressure to adopt more sustainable models. In this context, the following research question arises: What are the socio-technical profiles of mezcal producers in Sola de Vega in terms of production practices, access to water and use of technologies, ¿and how do these differences condition their possibilities for sustainability?

Mezcal is not only a beverage of high commercial value, but also a cultural good that articulates local identities, territorial memories and family economies. However, this productive system faces profound transformations derived from the boom of the national and international market, which has generated pressures on natural resources, especially water, and has modified the traditional logics of agave management and productive organization (Andrade et al., 2017; García, 2007).

One of the main current challenges lies in the environmental sustainability of productive processes, particularly in relation to water availability, fertilization practices and the maintenance of agave biodiversity. Despite the ecological, economic and cultural relevance of mezcal, most existing studies have focused on its value chain or its economic implications, leaving aside an integral characterization of producers that simultaneously considers socio-technical variables, traditional practices and use of natural resources. This omission limits the understanding of the productive diversity existing in the territory and hinders the design of differentiated and pertinent public policies from a territorial perspective.

On the other hand, previous research has shown that the use of multivariate methodologies, such as cluster or principal component analysis, makes it possible to identify profiles of producers with different degrees of technification, organization, access to resources and adoption of sustainable practices (Tlelo-Cuautle et al., 2022). Likewise, studies on water footprint in distilled beverages have revealed a wide variability in water use per liter of product, but there is a lack of specific data for artisanal mezcal in community contexts (Water Footprint Network, 2018; Logoche, 2020). Added to this is the scarce documentation of traditional knowledge that guides production, such as the use of lunar cycles, ritual practices, and community decision-making on water access and use.

The general objective of this study is to comprehensively characterize mezcal producers in Sola de Vega, Oaxaca, considering sociodemographic variables, production practices, water management and traditional knowledge. The specific objectives are: (1) to identify differentiated productive profiles through multivariate analysis, (2) to compare these typologies according to community of origin and territorial variables, and (3) to propose organizational and water recommendations with a focus on sustainability.

The hypothesis is:

H_0: There is no significant association between community of origin, type of water source used and socio-technical strategies of mezcal producers.

Hypothesis: H1. The community of origin is significantly associated with the type of water source and with the socio-technical strategies implemented by the producers."

2. THEORETICAL FRAMEWORK

2.1 Mezcal production as a peasant socioecological system

Traditional mezcal production in Oaxaca is deeply rooted in peasant and community ways of life. Unlike agroindustrial logics, the traditional mezcal system operates under a peasant rationality, which is oriented towards social reproduction, the diversified use of resources and the articulation of local knowledge with the natural environment (Van der Ploeg, 2010). In this framework, the maguey is not only a plant of economic interest, but also a cultural, symbolic and territorial component.

The socioecological systems perspective allows understanding mezcal production as a network of interactions between ecological (climate, water, soil), social (community organizations, customary norms) and technical (cultivation methods, artisanal distillation) factors (Toledo & Barrera-Bassols, 2008). This approach recognizes that production decisions are mediated by traditional knowledge, community norms and differential access to natural resources.

The consolidation of mezcal as a product with a denomination of origin has generated new pressures on traditional systems, including overexploitation of

wild maguey, intensive water use and transformations in productive organization (Lira et al., 2022). These tensions put the socioecological sustainability of the activity at risk if they are not accompanied by local regulation and community strengthening strategies.

2.2 Agroecology and transitions to sustainability

Agroecology constitutes a key theoretical and methodological approach to analyze the transition processes towards more sustainable production systems. Gliessman (2007) proposes five levels of agroecological transition: (1) increasing the efficiency of conventional inputs, (2) replacing external inputs with alternatives, (3) redesigning the production system, (4) reconnecting producers and consumers, and (5) transforming the global food system. This classification makes it possible to situate the processes of adopting appropriate technologies and sustainable practices within an evolutionary trajectory. The agroecological approach emphasizes the importance of peasant knowledge, biological diversity and community participation as pillars of sustainability (Altieri & Nicholls, 2020). It also raises the need to redesign production systems from a territorial perspective, considering cultural, ecological and social aspects. In the case of mezcal, this implies a reflection on the use of water, the selection of maguey species, plot rotation and the use of renewable energies. Wezel et al. (2014) complement this vision by proposing agroecological principles such as the enhancement of functional biodiversity, the reduction of external inputs and the valorization of local knowledge. These guidelines help guide technical support and the design of agricultural policies that are more consistent with local contexts.

2.3 Traditional knowledge and appropriate technologies

Traditional knowledge is a form of situated knowledge, built collectively over generations, based on empirical observation, memory and peasant experience. Toledo and Barrera-Bassols (2008) define them as expressions of "biocultural memory", in which technical, spiritual and social knowledge about the use of the territory is interwoven. In mezcal production, this knowledge is expressed in the selection of magueys, cooking times, identification of fermentation points and distillation in a still or clay pot. This knowledge coexists and is transformed in relation to technological innovations, such as the use of biodigesters or rainwater harvesting systems. The incorporation of appropriate technologies implies the development of technical solutions that are economically, environmentally and culturally viable in local contexts (Leff, 2004). These technologies should be adapted to the ecological conditions and organizational capacities of the communities, avoiding the imposition of external models that generate technological dependence or environmental deterioration.

2.4 Community water governance and commons

Water is a fundamental resource for maguey cultivation and mezcal production, and its community management has been a historical practice in many regions of Oaxaca. The commons theory, formulated by Elinor Ostrom (1990), provides a conceptual basis for understanding the institutional arrangements that enable collective management of natural resources. Ostrom identified eight design principles for effective governance of the commons, including: clearly defined boundaries, rules adapted to the local context, user participation in decision-making, community monitoring, and conflict resolution mechanisms. These principles are applicable to community water systems operating in many mezcal communities. Recent studies have documented the effectiveness of tequio systems, water committees, and customary rules to regulate water use in contexts of scarcity and external pressure (Lopez-Binnquist, 2020). However, the boom in mezcal production has generated tensions in these systems, such as the increase in extractions and the decrease in groundwater recharge, which poses new challenges for sustainability.

2.5 Socio-technical characterization and multivariate analysis

Socio-technical characterization seeks to identify patterns and profiles of producers based on combined variables that include social, technical, organizational and environmental aspects. This approach makes it possible to go beyond traditional classifications and build typologies that reflect the diversity of production strategies. The use of multivariate analysis techniques, such as correspondence analysis, clusters and principal components, facilitates the identification of homogeneous groups of producers based on significant variables (Hair et al., 2014). These tools are useful for designing differentiated technical and organizational support policies. Tlelo-Cuautle et al. (2022) apply this type of methodology to poblano chile producers, identifying profiles with different

levels of technological adoption, access to resources and market linkages. In the case of mezcal production, these methodologies make it possible to demonstrate the productive rationalities and structural conditions that influence the sustainability of the system.

3. METHODOLOGY

The present study was conducted under a quantitative approach, with a descriptive and comparative non-experimental design. Its purpose was to characterize the profiles of mezcal producers in the municipality of Villa Sola de Vega, Oaxaca, focusing the analysis on three localities: Rancho Viejo, Quialela and Sección Cuarta. The fieldwork was carried out during the months of October and November 2024. For data collection, a structured questionnaire was applied, consisting of 48 items grouped into four thematic blocks: sociodemographic characteristics, technical practices in agave cultivation, traditional knowledge and water management. The sample consisted of 60 mezcal producers belonging to three Sustainable Peasant Learning Communities (CAC's) of the Sembrando Vida program in the municipality of Sola de Vega, Oaxaca. These communities total 75 producers (25 producers per CAC), so the study reached 80% coverage of the target population. Given this high level of inclusion, it was not necessary to apply a statistical formula to calculate the sample size, since the proportion covered was considered sufficient to guarantee the validity of the analysis, methodologically approaching a census.

The selection was made by stratified sampling by community, in order to ensure adequate territorial representation and capture the internal diversity of productive conditions, technical practices and forms of water management. This approach is based on analytical representativeness criteria (Patton, 2015), which prioritize the richness of information and variability of the cases over statistical inference. In research with clearly delimited populations and characterization objectives, this type of strategy makes it possible to generate in-depth and contextualized diagnoses that better guide territorial intervention proposals.

The questionnaire was validated by internal consistency analysis, obtaining an overall Cronbach's alpha of 0.76, indicating good reliability. The data were analyzed using Python 3.11, using three libraries for data analysis: pandas, scikit-learn and matplotlib, each with specific functions in different phases of statistical processing and interpretation.

The panda library was used to clean and organize the data obtained from the database, based on the questionnaires applied to the producers. This tool made it possible to structure the data in table format, filter relevant variables, code categories and prepare the set for multivariate analysis.

Subsequently, the key statistical procedures were performed with scikit-learn. The k-means clustering algorithm was applied to identify typologies of producers based on their socio-technical characteristics, grouping them into three distinct clusters. Principal Component Analysis (PCA) was also used to reduce the dimensionality of the set of variables and facilitate the visualization of patterns, without losing substantive information on the behavior of the data.

Finally, the matplotlib library was essential to generate the graphical representations of the results. Factor planes were designed to intuitively visualize the distribution of producers according to the first two principal components of the PCA, differentiating the clusters by means of colors, labels and visual references. These graphs facilitated a clearer interpretation of the profiles identified and their relationship with variables such as water use, technification and traditional knowledge. At the same time, informed consent was obtained from all participants and the community authorities gave their approval for the application of the instruments.

The methodology was organized in four phases, which are described below:

Table 1: Methodology by phases.

Phase	Description
Phase 1: Territorial characterization and sample selection	Delimitation of the municipality of Sola de Vega, identification of mezcal communities, and selection of a sample of 60 producers through stratified sampling considering community.
Phase 2: Design, validation and application of the instrument	Structured questionnaire with 48 items in four blocks: sociodemographic, technical-productive, traditional knowledge and water management.
Phase 3: Statistical processing and analysis	Descriptive analysis, Chi-square, correspondence analysis, cluster analysis processed in Python.
Phase 4: Interpretation and territorial linkage	Analysis of culturally and environmentally contextualized results. Focus on water sustainability and territorial development proposals.

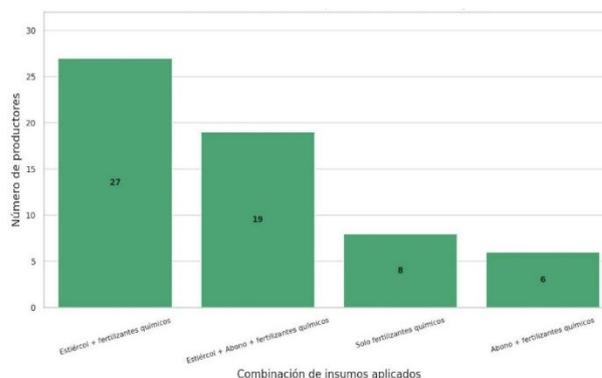Source: Own elaboration, 2025.

4. RESULTS
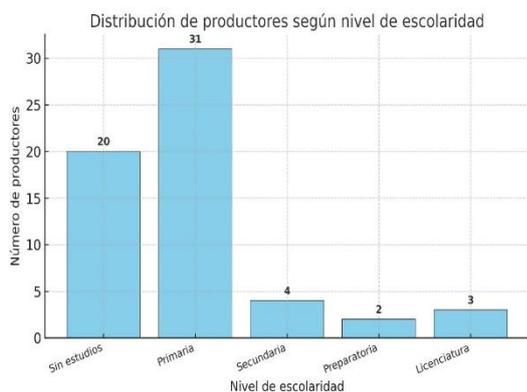
Graph 1: Schooling of mezcal producers.
Source: Own elaboration

Graph 1 shows a clear concentration in basic and middle school levels, which evidences both the educational trajectories of local actors and the structural limitations of access to formal education in rural contexts. The largest group corresponds to those who studied up to primary school, with 31 producers, i.e., slightly more than half of the total surveyed. This data suggests that, although there is a school base that allows some understanding of technical processes, this does not necessarily imply a deep mastery of specialized contents, nor does it facilitate, by itself, the full incorporation of sustainable practices or emerging technologies.

This group is followed by the group of farmers who did not finish primary school or did not have a formal school education, with 20 cases, representing one third of the sample. The presence of this group reinforces the hypothesis that many farmers faced conditions that made it difficult for them to remain in the school system, such as agricultural work, migration or the lack of educational infrastructure in their communities. It is interesting to note that only 3 people have completed undergraduate studies and that most of them belong to a generational transition where the farmers' children are enrolled in higher education and they are the new farmers, although this is limited but the evidence indicates a progress, it is also observed that 2 farmers have reached high school, which indicates a low representation in the universe of farmers. Finally, the group that went to high school is made up of 4 people, which, although it represents a lower percentage, should be considered with attention, as it shows a situation of educational vulnerability that further limits access to certain rights of access to secondary or higher education.

Taken together, these data reveal an unequal educational panorama that should be considered when designing intervention or training strategies in mezcal communities. The limited presence of higher education does not imply an absence of knowledge, but rather a predominance of empirical and community knowledge that, although not validated by the school system, is essential for the continuity of productive activity. From this perspective, it is essential to build training schemes that recognize the diversity of training trajectories, value traditional knowledge and combine accessible pedagogies with technical approaches adapted to local contexts. In addition, promoting spaces for productive literacy and grassroots technical education could contribute to strengthening the organizational and productive capacities of the sector, without disarticulating the ways of learning and transmitting knowledge that exist in the rural world.

Graph 2: Combination of inputs applied for mezcal production.
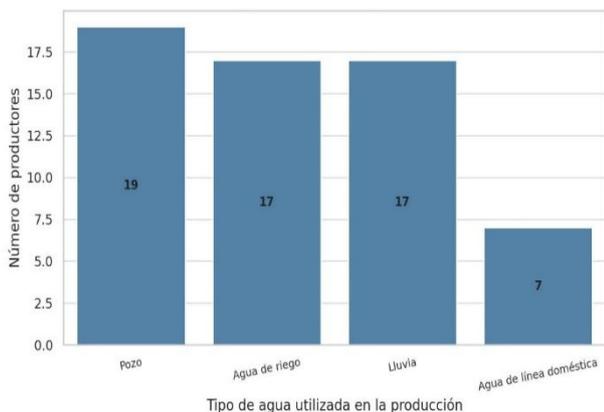Source: Own elaboration

The graph on the combination of inputs applied in the cultivation of maguey by mezcal producers reveals heterogeneous practices that reflect both the availability of resources and local knowledge on fertilization. The majority of producers (27) opt for a mixture of manure and chemical fertilizers, suggesting a management strategy that seeks to balance traditional practices with industrial-type inputs. This combination can be interpreted as a form of transition, where an attempt is made to maintain soil fertility without completely abandoning conventional methods.

Secondly, 19 producers are observed to use a broader combination that includes manure, compost and chemical fertilizers, which can be considered a more diversified and possibly more agroecologically conscious practice. This group represents a profile that, although a minority, denotes an interest in enriching the soil with different sources of nutrients,

possibly as a result of training processes or accumulated experiences.

On the other hand, 8 producers apply only chemical fertilizers, which could be due to lack of access to organic sources, time constraints, or simply a technical preference inherited from more conventional agricultural models. Finally, 6 producers report the exclusive use of organic manure together with chemical fertilizers, a practice that, although less common, may reflect efforts to reduce the chemical load while still guaranteeing crop yields.
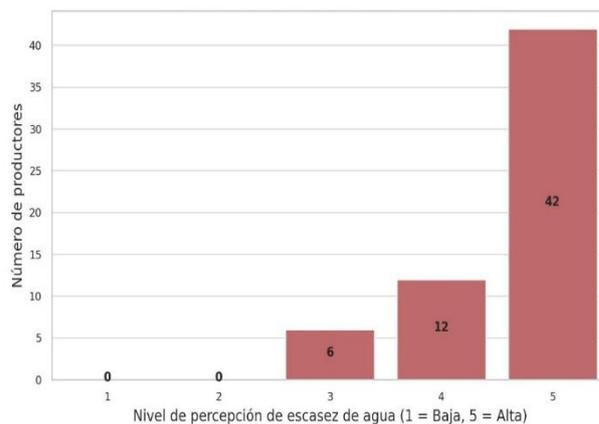
These combinations show that there is no single way to fertilize maguey, but that producers adapt their decisions based on their possibilities, knowledge and experience. In this sense, support policies should recognize this diversity of practices and promote flexible schemes that accompany local processes, instead of imposing uniform models. In addition, there is an opportunity to strengthen knowledge on agroecology and soil management, especially in those producers who already incorporate organic matter, , as a starting point to move towards more sustainable and culturally appropriate systems.

Graph 4: Perception of water scarcity in mezcal production.
Source: Own elaboration

Graph 4 shows a critical perception: 70% of producers rate water scarcity as high and 20% as level 4; the rest rate it as moderate (level 3). The absence of responses in levels 1 or 2 confirms the feeling of generalized water stress, consistent with the projected flow reduction scenarios for the Sierra Sur (CONAGUA, 2023).

Graph 3: Sources of water used for mezcal production.
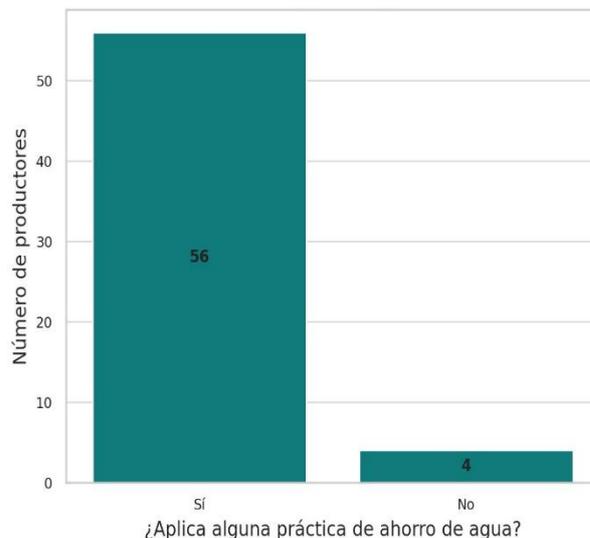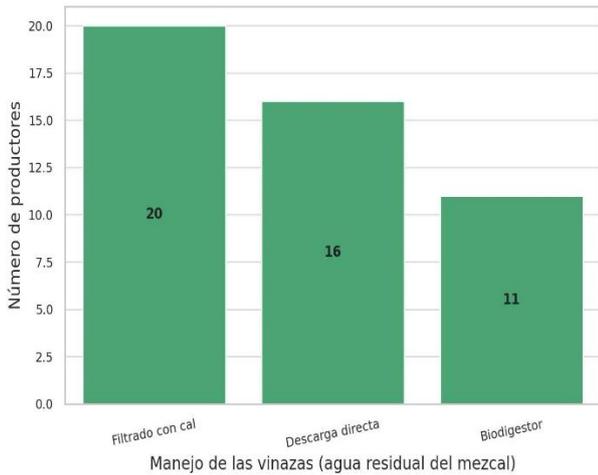Source: Own elaboration

Graph 3 shows that water for mezcal production is dependent, in the first place, on wells (31.7%), followed by irrigation water (28.3%) and rainwater harvesting (28.3%). Only 11.7% report that they produce with water coming from domestic lines, which reveals the limited coverage of public networks in peripheral productive zones. This distribution corroborates the water stratification described by Quiroz-Flores and Garduño-Ramírez (2022), where the availability of infrastructure conditions the sustainability of agroindustrial systems.

Graph 5: Water saving practices in mezcal production.
Source: Own elaboration

Despite the precariousness of the situation, 93.3% reported applying water saving measures (reuse of water for distillation), while only 6.7% did not implement any action, as can be seen in (Graph 5). This result exceeds the values reported by Andrade et al. (2017) for tequila microdistilleries (≈ 60 %), suggesting greater environmental awareness in the local mezcal sector.

Graph 6: vinasse disposal practices.
Source: Own elaboration

Figure 1: Correspondence analysis factorial plane.
Source: Own elaboration, 2025.

Vinazas with high organic load and acid pH are managed in three main ways (Graph 6): Filtering with lime (33.3 %), a traditional practice that neutralizes acidity and facilitates its use in irrigation; Direct discharge into stream beds or soils (≈ 26 %), an option of high environmental impact still prevalent; rustic biodigesters (≈ 18 %), an emerging strategy that allows the generation of irrigation water. Lime filtration coincides with NOM-EM-001-SEDAGRO-2023 recommendations for small producers, while the low adoption of biodigesters reveals investment and technical assistance barriers (Martínez-Rangel & González-Torres, 2021).
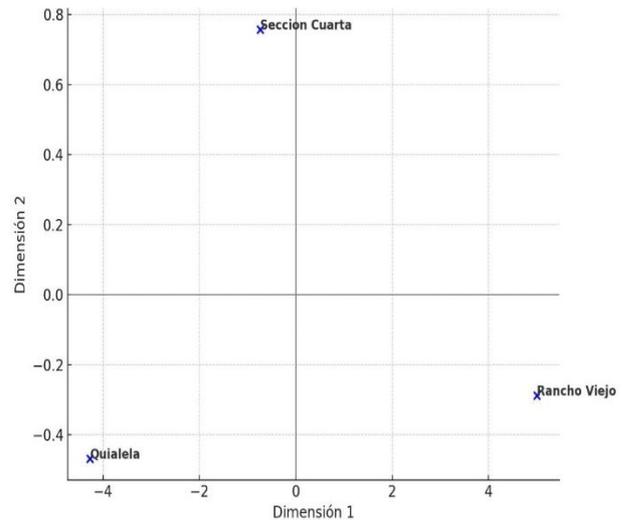
Chi-square

A Chi-square test of independence was used to evaluate the relationship between the community of origin of mezcal producers and the type of water source used. The results show a statistically significant association ($p < 0.05$).

Table 1: Chi-square test.

Chi-square statistic (χ^2)	79.67
Degrees of freedom (gl)	6
p-value	4.173e-15
Significance level	0.05

Source: Own elaboration with Python, 2025.

The result of the Chi-Square test refers to the fact that the type of water used by people to produce mezcal is not the same in all communities, and that difference is not casual. Rather, it reflects the conditions in which each group lives and works. These differences show that each community has been solving access to water as it has been able to, according to what it has at hand and the forms of organization it has built over time.

The correspondence analysis made it possible to identify differentiated associations between the communities studied and the practices linked to water use and management in the context of mezcal production. At the factorial level, Dimension 1 captures most of the variance explained, mainly segmenting the communities according to their predominant relationship with the type of water action reported, while Dimension 2 deepens internal differences between the water strategies implemented. A simple correspondence analysis (SCA) was applied on the contingency table between communities and schooling levels of mezcal producers. The ACS projects the dependency relationships between these two variables in a two-dimensional space, allowing the identification of structural associations.

Dimension 1 (horizontal axis): Formal Schooling Gradient

This dimension concentrates most of the explanatory inertia of the analysis, and can be interpreted as an axis that organizes communities according to the relative concentration of high or low educational levels. Rancho Viejo, being located towards one end of the axis, shows affinity with more basic educational levels, such as primary or secondary. This suggests a historically limited educational trajectory, probably influenced by structural or geographic constraints. Sección Cuarta is located at the opposite end of this axis, indicating a stronger association with middle or higher levels of schooling, such as high school and bachelor's degrees. It is likely that this community has better access to educational infrastructure or greater

intergenerational mobility. Quialela, located at an intermediate point or close to the origin, presents an educationally heterogeneous profile, that is, it is not strongly associated with either low or high schooling, which may indicate internal diversity or recent educational transitions.

Dimension 2 (vertical axis): Gradient of educational homogeneity/heterogeneity

The second dimension explains a smaller proportion of the variance but allows refining the interpretation of the internal positioning of each community: Rancho Viejo, with a more distant position in this dimension, could be reflecting a relative internal homogeneity in schooling levels (e.g., majority with primary/secondary, and few extreme cases). Section Four also shows some internal coherence at higher levels of education, possibly reflecting a more homogeneous community policy or institutional trajectory and Quialela appears closer to the origin in both dimensions, it can be interpreted as an educationally diverse community, with coexistence of producers with no schooling, with secondary schooling, and some with higher education, which points to greater intra-community variability.

The factorial level reveals territorial educational asymmetries between mezcal communities, which suggests that the processes of training, innovation or access to support should be designed with differentiated approaches. Communities with low schooling (such as Rancho Viejo) could benefit from productive literacy strategies, basic technical training and contextualized popular education methodologies. Communities with more schooling (such as Sección Cuarta) have better conditions to integrate specialized training, associativity and territorial governance processes. The educational diversity in Quialela indicates the need for flexible interventions that recognize different levels of formal knowledge and local knowledge, especially in technology transfer and organizational strengthening processes.

Based on the cluster analysis (K-means, k=3), three differentiated groups of producers were identified according to their educational characteristics, perception of water scarcity, type of supply, saving practices and stillage management. This segmentation makes it possible to establish contrasting profiles with respect to the degree of technification, organizational capacity and water sustainability strategies adopted. Figure 2 presents the visualization of the clusters on a factorial plane reduced by principal component analysis, while

Table 2 summarizes the distinctive properties of each group.
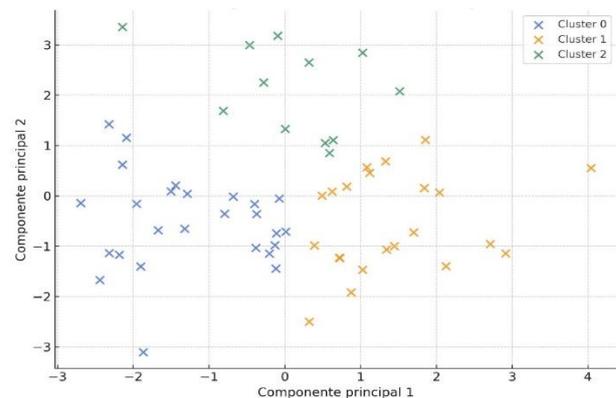
Figure 2: Cluster análisis.
Source: Own elaboration, 2025.

The resulting typology evidences a significant structural diversity in water management within the mezcal production system. Cluster A, a minority but relevant, is characterized by producers with medium-high schooling, access to pressurized water sources (irrigation or well) and willingness to implement emerging technologies such as biodigesters. However, there is a lack of systematic water saving practices, which limits their water efficiency despite the available equipment.

Cluster B groups the majority of respondents, who have a medium educational level, a high perception of scarcity and a favorable attitude towards the incorporation of water efficiency measures, such as storage or recirculation. However, wastewater treatment is still incipient through direct discharge or basic filtration, suggesting an intermediate level of transition towards more sustainable practices.

Cluster C represents producers with a lower level of education and limited access to water (domestic line and rainwater collection), who, despite these conditions, apply low-cost strategies such as filtering with lime for stillage management. These practices reflect a productive rationality based on traditional knowledge and community solutions, which can be strengthened through basic infrastructure interventions and the valorization of local knowledge.

This classification offers key elements for the design of public policies and technical strategies that recognize the heterogeneity of the mezcal territory. Differentiated intervention, based on the real conditions of each typology, would make it possible to promote more equitable, efficient and sustainable processes in water and waste management within this strategic sector.

Cluster Analysis

Cluster	Average schooling	Perception of water scarcity	Main source of water	Water saving practices	Stillage management	Strategic needs
A: Spot treatment with emergent treatment	Medium-high (No education or primary)	Very high (≥ 4.5)	Occasional irrigation / well	Not implemented	Emerging use of biodigester	Integrate water savings and systematize processes.
B: Conventional in transition to efficiency	Medium (No studies or primary)	Very high (≈ 4.5)	Occasional irrigation/ well	Yes implemented (storage, recirculation).	Direct discharge and basic filtration	Scale up treatment technologies and technical training
C: Domestic-traditional resilient	Low (junior high school, high school, bachelor's degree)	High (≈ 4.2)	Domestic line / rainfall	Yes implemented (rational use)	Filtration with traditional processes (low cost)	Infrastructure and valorization of local know-how

Source: Own elaboration, 2025.

5. DISCUSSION

What the data of this study reveal is something that is often perceived from the field work, but rarely documented with clarity, which is that mezcal producers in Sola de Vega live very different realities, even when they share the same territory. Through the multivariate analysis it was possible to distinguish three ways of organizing production and facing the challenges of water: those who have advanced towards certain forms of technification although with environmental limitations; those who are in an intermediate stage, trying to improve their practices without completely abandoning conventional forms; and those who continue to sustain themselves from their traditional knowledge, with few technical tools, but with a strong connection to the environment. This diversity is not only logical, but deeply revealing. It tells us that there is no single path to sustainability, and that any attempt to intervene must begin by listening to these differences.

One of the most troubling findings is the very high perception of water scarcity. Most of the people interviewed clearly expressed that water is insufficient, that it is becoming increasingly difficult to maintain production, that wells are going down, and that rainfall is no longer the same. And although this could be seen only as a perception, the data show that this is a shared reality. This feeling of being at the limit coincides with what institutions such as CONAGUA (2023) have projected for the region. It is not an exaggeration, it is an alert. And an alert that calls for looking towards the community, towards collective ways of taking care of water, as proposed by Ostrom (1990) when speaking of common goods:

when water is scarce, management must be shared.

But the discussion does not end there. When looking at the ways of managing mezcal residues, a range of responses also appear. Some producers have begun to incorporate biodigesters, although still on an experimental basis. Others continue to resort to simpler practices such as basic filtering or, in some cases, direct discharge. Still others, especially in communities with less institutional support, use lime to neutralize waste, a technique that goes back generations. This plurality of responses does not mean improvisation, but rather adaptations to different contexts. What is needed is not to impose a single technology, but to understand how to combine innovation and tradition so that no one is left out.

Something similar occurs with traditional knowledge. They are present in every stage of the process: from the selection of the maguey to the way of distilling. Far from being a remnant of the past, these practices are still alive and have a logic of their own that is not always seen from the outside. As pointed out by Toledo and Barrera-Bassols (2008) and Gliessman (2007), this knowledge is a valuable biocultural memory that allows sustaining a way of life, not just a commercial product.

An important reflection that emerges from the analysis has to do with schooling. Although it would be easy to assume that the higher the level of education, the better the practices, the results show that this is not always the case. There are producers with middle or higher education who have implemented technology, but without applying sustainability criteria or even based on traditional knowledge. On the other hand, there are those who have barely finished primary school, but who take care of water, reuse waste and collectively manage

resources. This observation breaks with the idea that technical knowledge alone is sufficient. As Leff (2004) says, environmental awareness is not an exclusive attribute of formal education, but a situated construction, which also arises from rootedness, experience and community values. All this leads us to think that public policies cannot be designed from a desk. They need to be anchored in the territory and in listening. For the most technified producers, it is necessary to consolidate efficiency and monitoring systems. As stated by López-Binnquist (2020), water management can only be fair if it is built on participation and trust.

6. CONCLUSIONS

This study has allowed for a comprehensive characterization of mezcal producers in the municipality of Sola de Vega, Oaxaca, identifying differentiated profiles that reflect the socio-technical, cultural and environmental heterogeneity of the mezcal production system. Through the cluster analysis, three groupings were defined with different characteristics in terms of educational level, access to water, waste management, technical practices and appropriation of traditional knowledge; the objectives proposed at the beginning of this study have been amply met. We were able to characterize the mezcal producers of Sola de Vega through a socio-technical and multivariate approach, which allowed us to identify three differentiated profiles of water management and productive practices. The community of origin turned out to be a determining factor in access to water, saving strategies and the type of waste generated and managed, thus confirming the hypothesis that territorial conditions have a direct impact on modes of production and local sustainability.

One of the most consistent findings was the high perception of water scarcity in all the profiles, which evidences the fragility of the system in the context of climate change, overexploitation of aquifers and limited infrastructure for sustainable water management. Although some producers have begun to adopt emerging treatment practices such as biodigesters or artisanal filtering, there is still a structural lag that requires immediate attention.

Secondly, it was found that traditional knowledge is not only present in the three clusters identified, but is an active component of the ecological and cultural sustainability of the mezcal system. This supports the importance of revaluing local knowledge as a strategic axis for the design of territorial policies, recognizing its potential to complement modern technologies and adapt to specific contexts.

Likewise, the results indicate that there is no linear relationship between schooling and adoption of sustainable practices: while the most technified producers show a certain degree of innovation, they also reproduce extractivist schemes in the use of water. In contrast, profiles with less schooling, but greater adherence to traditional practices, show higher levels of efficiency and environmental awareness, which challenges the hegemonic narratives on productive development.

Finally, this research demonstrates the usefulness of mixed and multivariate approaches to generate differentiated diagnoses to guide more relevant public strategies. The identification of productive profiles not only contributes to academic knowledge, but also offers practical inputs for the design of specific interventions according to the capacities, needs and contexts of each group.

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