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Disappearance and survival of fermented beverages in the biosphere reserve Tehuacán-Cuicatlán, Mexico: The cases of *Tolonche* and *Lapo*

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Traditional fermented products are disappearing from the local foodscapes due to social pressures and ecological changes that affect their production; it is therefore crucial to document local knowledge, which is crucial to maintain and recover local biocultural heritage and to contribute to food security. This study aims to document and foster the production of local traditional beverages by registering recipes of fermented beverages in the Tehuacán-Cuicatlán biosphere reserve in central Mexico, a region recognized for its great biocultural diversity. We conducted a search of peer-reviewed literature. Additionally, we included ethnographic research and participatory methods to engage residents in different steps of the production process. We identified five main fermented beverages in the research area, the most common beverages are those produced by agave species which include, mescal, pulque and an almost extinct beverage known as *lapo* which involves sugar cane as main substrate. We also identified a fermented beverage produced with several cacti fruits known as *nochoctli* and a traditional a fermented beverage produced with fruits of *Schinus molle* known as *tolonche*. We highlight the production of *lapo* and *tolonche* since these involved the incorporation of foreign substrates into the region after the Spaniard conquest and to their restricted distribution and almost extinction. The beverages *tolonche* and *lapo* are nowadays almost lost and only a few producers still prepare them to follow modified versions of the original recipe. *Lapo* and *tolonche* were once important in the research area but almost became extinct until local people started to recently recover them. Traditional fermented beverages in Mexico play an important role in cultural identity and contribute to the local diet; nevertheless, several fermented beverages have not been recorded and have even become extinct. This work is an effort to promote and conserve traditional fermented beverages as valuable biocultural heritage by empowering people to make decisions about the use of locally available resources, which is crucial in times when food systems are highly vulnerable.

KEYWORDS

ethnozymology, ethnomicrobiology, pulque, *Schinus molle*, foodscapes

1. Introduction

Food in all its expressions, preparations, and conceptualizations can be studied as multiple and interrelated complex systems of knowledge, practices, and forms of communication through which people interact and learn from one another to construct their realities (Caplan, 1997; Stross, 2011; Gillespie and van den Bold, 2017). The complexity of different food systems is constructed upon the intimate interaction with the local availability of resources in the surrounding environments (Hegarty, 2005; Ingram, 2011; Gliessman, 2014). One way to study such complexity is by picking food items and tracing relevant aspects of their composition, production, distribution, preparation, and consumption and exploring all food-related behaviors and their meanings within a single community at different points in time (Caplan, 1997; Ashley et al., 2004; Stross, 2011; de Albeniz, 2021). Another way to do this is by performing a detailed characterization of food preparation processes or products and comparing them among societies (Beardsworth and Keil, 2002; Stross, 2011; Atkins and Bowler, 2016). Information on how food and other aspects of culture are interrelated and how food practices are communicated in a community are key aspects of a detailed analysis of a particular food in a region (Stross, 2011; Warde, 2016). Fermentation is an expression of local and regional food systems. It has been historically and globally considered a strategy that allows humans to preserve and improve foods or beverages by transforming edible raw matter into new products with unique sensorial properties with a plethora of final products (Smid and Hugenholtz, 2010; Tamang, 2010).

Traditional fermented beverages are keystone products in local food diets and play important roles in human cultures (Tamang, 2010). Most of these beverages are highly valued by indigenous and non-indigenous societies. Some fermented beverages are sacred and understanding why they are so can shed light on our understanding of different cultural endeavors and their relevance in local diets. Also, these products give identity to the local communities and shape cultures (Albuquerque et al., 2021; Ojeda-Linares et al., 2021). Research programs have recently addressed the production methods, preparation tools, consumption rituals, frequency, and other issues related to fermented beverages. This has led to some outstanding studies that have contributed to the revival of traditional fermented products (Madej et al., 2014; Flachs and Orkin, 2019; Herrera Cano and Suárez, 2020; Kraus et al., 2022), their consideration as part of local biocultural heritage (Chaves-López et al., 2014; Puerari et al., 2015; Puerari et al., 2015; Tamang et al., 2016; Pérez-Armendáriz and Cardoso-Ugarte, 2020) and their relevance for diversifying diets (Chileshe, 2019; Bultosa et al., 2020; Dunn et al., 2021). Nevertheless, several social and economic pressures have promoted changes in values and cultures in the last decades that have resulted in the almost extinction of several of these products. This is a motive of concern since numerous traditional fermented beverages may prevent malnutrition and promote healthy living in local diets (Marsh et al., 2014; Bourrie et al., 2016; Makwana and Hati, 2019; Tang et al., 2022). The loss of these products also implies cultural erosion; culture is dynamic, and it incorporates resources, tools, practices, knowledge, and worldviews. By losing relevant components, fundamental pieces are lost that can enhance a cascade of losses, which include value to certain resources and with it the possible loss of components of the ecosystems transformed into the landscapes themselves (Lazos et al., 2019), as well, the foodscapes.

Latin America displays a wide range of fermented products elaborated from several substrates that are keystone products in local diets, such as maize, agave, cacti fruits, cacao, cassava, and many other substrates (Stross, 2011; Mayorga et al., 2020; Ojeda-Linares et al., 2021; Rebaza-Cardenas et al., 2021). Most of them were consumed before the Spanish conquest and remain until the present; others were introduced and adopted during the centuries following the conquest. For instance, sugar cane (*Saccharum officinarum*) was introduced from Southeast Asia (Paterson et al., 2013), and then incorporated in several regions of Latin America after the Spanish conquest. Indeed, the production of sugar in Latin American countries served as a strategy of domination and enslavement, and its production changed the rural landscapes and local diets (Galeano, 1975). *Schinus molle*, known as pepper tree, or "pirúl" is native from Peru. It has a wide distribution that ranges along water courses and in high regions of Mexico. Its fruits are pink-red when mature and have the size of peppercorns, with a kernel enclosing a single seed. This plant is used in Peru and in some Andean areas to produce a traditional fermented beverage known as *chicha de molle* (Kramer, 1957). To produce it, the seeds are first cleaned with water; then, pedicels and leaves are removed; finally, seeds are soaked for at least 12 h to obtain a sweet brown color liquid. Then, seeds are removed with a clean cloth, and the fermented beverage is placed in a container known as *damajuana* (glass container) or *porongo* (*Lagenaria siceraria* fruits). Finally, sugar and yeast from previous batches is added (Kramer, 1957). Likewise, the use of *S. molle* as a source of fermented beverages was also performed in some regions of Mexico. However, this beverage was prepared by soaking reaped seeds of *S. molle* in warm water and then straining them. Eventually, a healthy wine-like drink is obtained that can also be consumed as a syrup or fermented beverage. If it is over fermented it can also produce vinegar (Bruman, 2000). Finally, a fermented beverage prepared with the fermented mead of agave known as pulque, where the juice of the corn cane, grounded corn, *and S. molle* seeds were also added was recorded in Nahuatl as *copaloetli* or as "quebranta huesos" or bone breaker (Godoy et al., 2003). Nevertheless, there was little information characterizing the

preparation of a fermented beverage with *S. molle* fruits in Mexico nor any data on where it is prepared or consumed until this study.

A significant number of fermented beverages have been lost over time, which makes it even more necessary to collect and maintain data related to these products (Godoy et al., 2003; Stross, 2011; Herrera Cano and Suárez, 2020). Throughout history, people have incorporated and adapted different plant-based products and technologies around the world due to migrations, thus making the foodscapes that comprise them more diverse. However, the core products are interestingly maintained and transformed with these foreign plants and technologies (de Albuquerque, 2006; Ceuterick et al., 2008; Van Andel and Westers, 2010). For example, in Mexico, pulque is a core beverage in different regions. It is a traditional fermented beverage produced with the fermented sap/mead of different *Agave* species that is consumed by several Mesoamerican cultures since pre-Hispanic times (Valadez-Blanco et al., 2012; Escalante et al., 2016; Álvarez-Ríos et al., 2022). Nevertheless, pulque is nowadays mostly consumed by mestizo people, and its consumption has incorporated several fruits, vegetables, and even animal products in beverages called *curados* or *preparados* (Escalante et al., 2016; Álvarez-Ríos et al., 2022). This fact reflects the relevance of a core beverage and the addition of secondary ingredients, thus allowing for the diversification of a central fermented product in Mexican people's diet.

The Tehuacán-Cuicatlán Valley in the states of Puebla and Oaxaca, central Mexico is recognized as the arid zone with the highest biocultural diversity in North America (Valiente-Banuet et al., 2000; Dávila et al., 2002; Blancas et al., 2010). It is inhabited by indigenous people of the Nahua, Popoloca, Mazatec, Chinantec, Ixcatec, Cuicatec, Chocholtec, and Mixtec ethnic groups (Flannery, 1986; MacNeish, 1967; Casas et al., 2001). These peoples have subsisted for thousands of years thanks to their interactions with the surrounding environment of the region (Garcíadiego, 2005; Renard and Thomé, 2016; Vera and García, 2020). Thus, such unique bio-cultural diversity encourages interesting gastronomy that can be seen and tasted in a plethora of unique cuisines (Acuña et al., 2011). Nevertheless, little has been studied to characterize the diversity of traditional fermented beverages in the region, their fermentation practices, and the history of these products. Based on previous research assessing food systems in the region, this study aims to identify and characterize the traditional beverages of the Tehuacán-Cuicatlán Valley, including their main plant substrates and those that have been added as part of the dynamic management practices in the region. We particularly emphasize two beverages that are endangered to be lost and that have not been documented in detail. We performed ethnobiological research to characterize their plant substrates, the causes of their loss, and the mechanisms employed for its current conservation, especially needed when food systems are vulnerable.

2. Methods

We conducted a search of peer-reviewed literature in Scopus, Google Scholar, Google, and the Web of Science databases to identify fermented beverages reported in the region, using keywords such as: fermented beverages and Tehuacán-Cuicatlán Valley. Throughout the peer reviewed literature, we identified beverages prepared from agaves, like pulque and mescal, and the fermented beverages prepared with cacti fruits called colonche or *nochoctli*. Then, we visited the area and conducted ethnobiological research through a qualitative approach. Here different communities of La Mixteca Poblana sub-region and neighboring communities of the Tehuacán-Cuicatlán Valley Biosphere Reserve (UNESCO, 2012), which is one of the most important areas of biocultural heritage in Mexico (Vallejo et al., 2015) were visited. We studied the communities of Los Reyes Metzontla, San Gabriel Chilac, San José Miahuatlán, and Zapotitlán Salinas in the state of Puebla and Santiago Chazumba in the state of Oaxaca (Figure 1). In this region, the annual mean temperature is 21°C, and the average precipitation is 400–450 mm. Rainfall is sparse or random, and torrential rainfall caused by tropical storms or hurricanes can sometimes occur at the end of the rainy season (López-Galindo et al., 2003). The vegetation is predominantly xerophytic (Rzedowski and Huerta, 1978) with predominant columnar cacti forests (Valiente-Banuet, 2009).

For this study, we performed closed interviews through which we mainly asked to the interviewees about which fermented beverages were consumed and produced in the locality. We conducted free listing of local names of those beverages that were prepared in the communities, and we asked to people if these were produced in recent years. Interviews were mainly performed with 30 women and 20 men between 35 to 80 years old. Then, a snowball approach (Albuquerque et al., 2014) was performed to identify possible producers of these products in all the localities. Once key informants were identified, producers were visited and asked if they allowed us to conduct open interviews, 4 with *tolonche*, 1 with pulque, 1 mescal, and 1 with *lapo* producers (7 in total) for a deeper information acquisition of the production of these fermented beverages. We employed participant observation regarding the production of the local traditional fermented beverages in the region. The authors participated in the preparation of *lapo* and *tolonche* beverages, from the harvest of *S. molle* fruits and the obtention of agave sap to the consumption of the beverage and the documentation of the details throughout the production process.

Photographs and video records were taken with the authorization of the interviewees given through oral consent from the local authorities and participants. We also registered data about the economic and socio-cultural roles of the producers of fermented beverages, the production process in previous times, and the tools,

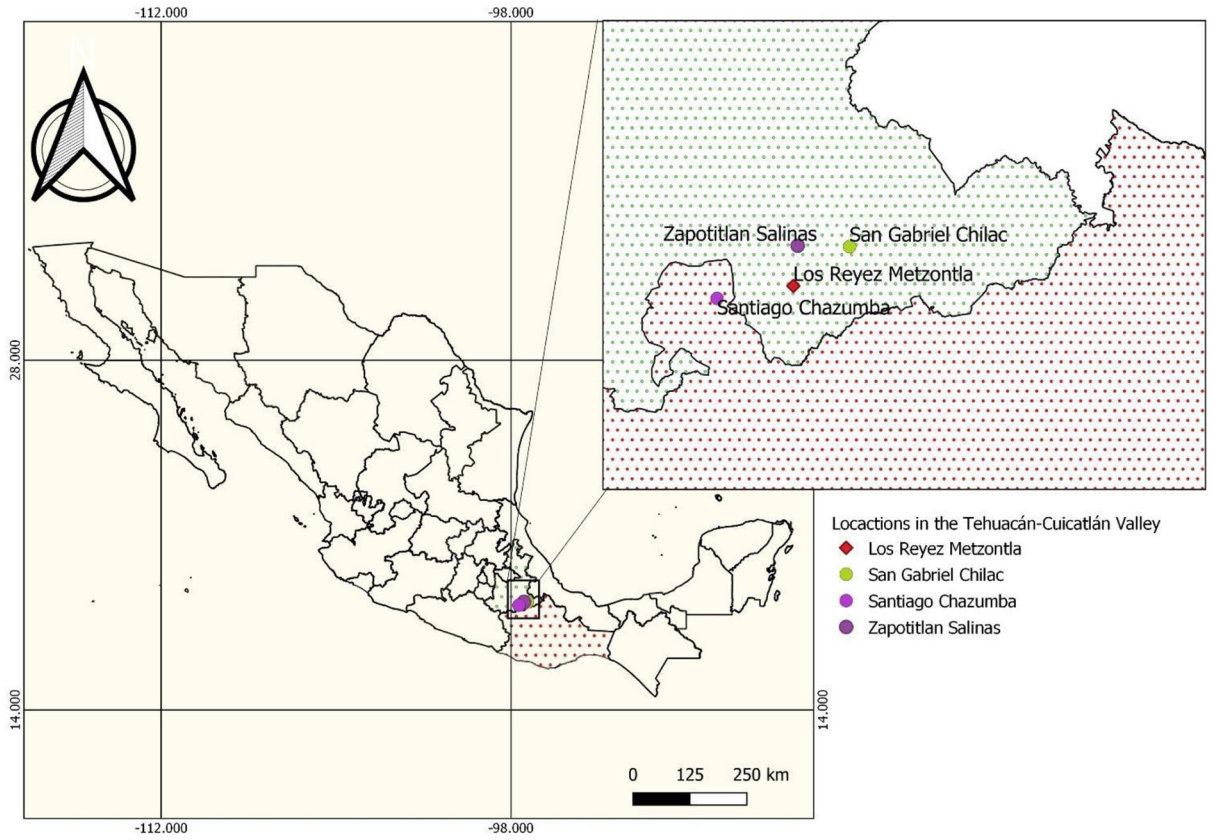

FIGURE 1
Study area in Mexico, doted locations comprise states where the study was performed (red for Oaxaca and green for Puebla). Purple points represent sites where *tolonche* production was recorded, the green point is the locality where *lapo* production was recorded, and the red point represents the locality where pulque and fermentation containers are produced. The map was elaborated with open-source software, Qgis3.4, https://qgis.org/es/site/. Source: INEGI conjunto de datos vectoriales.

instruments, and techniques that they employed. When we identified the production of a traditional fermented beverage prepared with *S. molle*, we also documented other uses of this tree.

3. Results

Throughout this study, we identified five traditional fermented beverages prepared in the Tehuacán-Cuicatlán Valley in which *Agave* species are the main plant substrate to produce fermented beverages. These were mescal, pulque, and *lapo*. We recorded that the production of *lapo* is almost extinct and only one producer remains active. We also identified a fermented beverage produced with different cacti fruits known as *nochoctli*, which is also disappearing, and few producers remain preparing it, but a few mentions were recorded. Finally, a beverage prepared with fruits of the pepper tree (*S. molle*) known as *tolonche* was identified. In the following sections, we will describe the five beverages produced in the region based on their substrates. We particularly emphasize the production of *lapo* and *tolonche* due to their uniqueness in the region, the incorporation of foreign substrates such as *S. molle* and sugar cane (*S. officinarum*), and because of its risk to disappear.

3.1. Agave: The main ingredient in the fermented beverages of the Tehuacán-Cuicatlán Valley

3.1.1. Mescal a distilled beverage prepared from *Agave* stems

Mescal is a distilled beverage prepared from cooked agave stems in several regions of Mexico. The most common species used to produce mescal in the Tehuacán-Cuicatlán Valley are *A. potatorum* and *A. marmorata*, whose local names are *papalometl* and *pichometl*, respectively (Figure 2A), these records confirm previous reports (Delgado-Lemus et al., 2014;

Rangel-Landa et al., 2015; Torres et al., 2015). In this study we identified three producers that distilled on average 180 L of mescal *per* batch, using *A. potatorum* or *A. marmorata*, but they say to have higher yields with *A. marmorata*, depending on plant size. The final product is a spirit with 47–51% of alcoholic volume (Figure 2B). Interestingly, *A. karwinskii* is also distributed in the region but not employed for mescal production because, according to local people, the mescal produced with this specie causes headaches, and its sugar concentrations are too low for the fermentation process. Nevertheless, a recent interaction between mescal producers from the state of Oaxaca (a major mescal state producer) and Zapotitlán has led to the incorporation of the know-how for this mescal. Furthermore, there has been an increasing market demand in recent years for mescal based on *A. inaequidens* that has promoted the cultivation of this species in extensive areas, even when this is an introduced specie in the region.

3.1.2. Pulque a traditional fermented beverage produced with *Agave* sap

In the Tehuacán-Cuicatlán Valley, pulque is produced with different *Agave* species. *A. salmiana* and *A. mapisaga* are the most mentioned species (Figure 5C), but some producers are nowadays acquiring and promoting other species, like *A. americana*. Pulque was an emblematic product in the Tehuacán-Cuicatlán Valley and several other localities in Mexico (Figure 2C). Here, we identified one producer in Zapotitlan Salinas who produces 50 L of pulque per day, but its production varies throughout the year, mainly because of the variable quality of the agave mead during the rainy season. But it produces a beverage with 5–7% of alcoholic content (Figure 2D). Pulque producers in the community have nowadays decreased. They say this activity demands excessive work and causes social stigmas but pays off low economic profit. In contrast, the number of mescal producers has increased, and producers that had historically been pulque producers have now shifted to mescal production. Pulque is prepared by adding a wide diversity of fruits; in the study region, pulque is mixed with cacti fruits, mainly *Pachycereus weberi*, *Opuntia xoconostle*, *Stenocereus stellatus*, *Escontria chiotilla*, and *Myrtillocactus geometrizans*. All these fruits are part of the local landscapes of the region, and most of these species are managed to obtain these fruits.

While pulque production occurs in clay vessels (Figure 5), the maintenance and cleaning of the ship are particularly important for producers. For example, if a new vessel is going to be used for pulque, the producers employ *Agave* leaves. They leave the leaves inside the vessel until they rot and are then removed. Finally, *Agave* mead is added to start the fermentation process. Likewise, another practice to clean and guarantee the optimal status of the final product is to add alcohol and set it on fire to clean possible undesired odors and flavors. The latter practice is performed mainly when the final product is predominantly acidic. It should be highlighted that there is a preference for segmented shapes with wide middle parts and mouths. This allows to contain fermented products and prevent them from spilling. Finally, when pulque production stops, the vessels are kept and sealed in a safe place and cleaned with plain water. We particularly noted that pulque consumers identify differences in the quality of pulque when it is produced in clay containers rather than plastic containers, and preferences are significantly high for clay vessels.

3.1.3. *Lapo*: An almost vanished beverage in the Tehuacán-Cuicatlán Valley

Lapo is the common name for a beverage prepared with pulque and sugar cane juice. In the past, *lapo* was prepared with pulque, mescal, sugarcane juice, or brown sugar. Nowadays, the last producer that remains in the locality of San Gabriel Chilac prepares it with over-fermented pulque and dissolved brown sugar, which is locally known as panela. For its fermentation, 1 L of sugar cane is added to 2 L of pulque. It is then fermented for 8 h until it is ready to serve. Its consumption was mainly for celebrations, such as weddings, birthdays, and religious festivities. Its consumption was important during the celebration of "*la matanza,*" where "*mole de caderas*" (a typical dish prepared with goats) is consumed in the communities of San Gabriel Chilac and San José Miahuatlán. It is served in classic *Cresentia cujete* containers painted in red (Figure 3C).

Lapo is currently an almost lost beverage. Only one woman <60 years old produces *lapo*, and it is mostly considered an ancient beverage even by elder generations (people <60 years old). Younger generations don't even know its name. Two of the main reasons for the decline of *lapo* production are the removal of sugarcane mills known as *trapiche* and the shift from sugarcane cultivation to other products. In the locality of Chilac (Figure 1), sugarcane production was important years ago, but the region has undergone a shift in agriculture due to water scarcity. Nevertheless, some sugarcane fields remain in the locality (Figure 3). *Lapo* was maintained and reproduced for several years. However, it was later produced with brown sugar rather than mescal or sugar cane and has remained like this until present times. Still, people consider that the flavor is different and that the actual *lapo* does not have the flavor that it used to have. Nowadays, the yields for this beverage are low, 5 to 8 L per week and the alcoholic content varies since the volumes of pulque and brown sugar and fermentation duration are heterogenous.

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FIGURE 2
Mescal and pulque production. **(A)** *A. marmorata* cultivars for mescal production closer to the mescal factory. **(B)** Distillation process in Zapotitlan Salinas, Puebla. **(C)** *A. salmiana* cultivar for pulque production. **(D)** Agave mead storage in plastic container for further pulque production.

3.2. *Nochoctli* or *colonche*: Fermented cacti fruits beverages, transitions from spines to foam

Several columnar cacti have been recorded in the Tehuacán-Cuicatlán Valley. Among them, *Stenocereus* spp. *Polaskia* spp., *Myrtillocactus* spp., *Pachycereus weberi*, *Isolatocereus dumortieri*, *Neobuxbaumia* spp., *Pilosocereus chrysacanthus* are the most common species in the region (Valiente-Banuet et al., 1997; Casas et al., 2001; Pérez-Negrón et al., 2014). Most of these species produce edible fruits that are involved in the fermentative process by which a beverage known as colonche or *nochoctli* is obtained (Ojeda-Linares et al., 2020).

Colonche is the common name for a group of traditional, fermented beverages produced from the fermentation of several cacti fruits. In the Tehuacán-Cuicatlán Valley, this beverage is best known as *nochoctli,* which means cactus fruit (*nochtli*) and pulque (*octli*) in Nahuatl. In villages of the Tehuacán-Cuicatlán Valley such as Los Reyes Metzontla, colonche is prepared with fruits of *Opuntia pilifera* and several columnar cacti species such as *Pachycereus weberi*, *Escontria chiotilla*, *Stenocereus* spp., and *Polaskia* spp., *P. chichipe*, *P. chende*, *S. stellatus*, and *S. pruinosus*

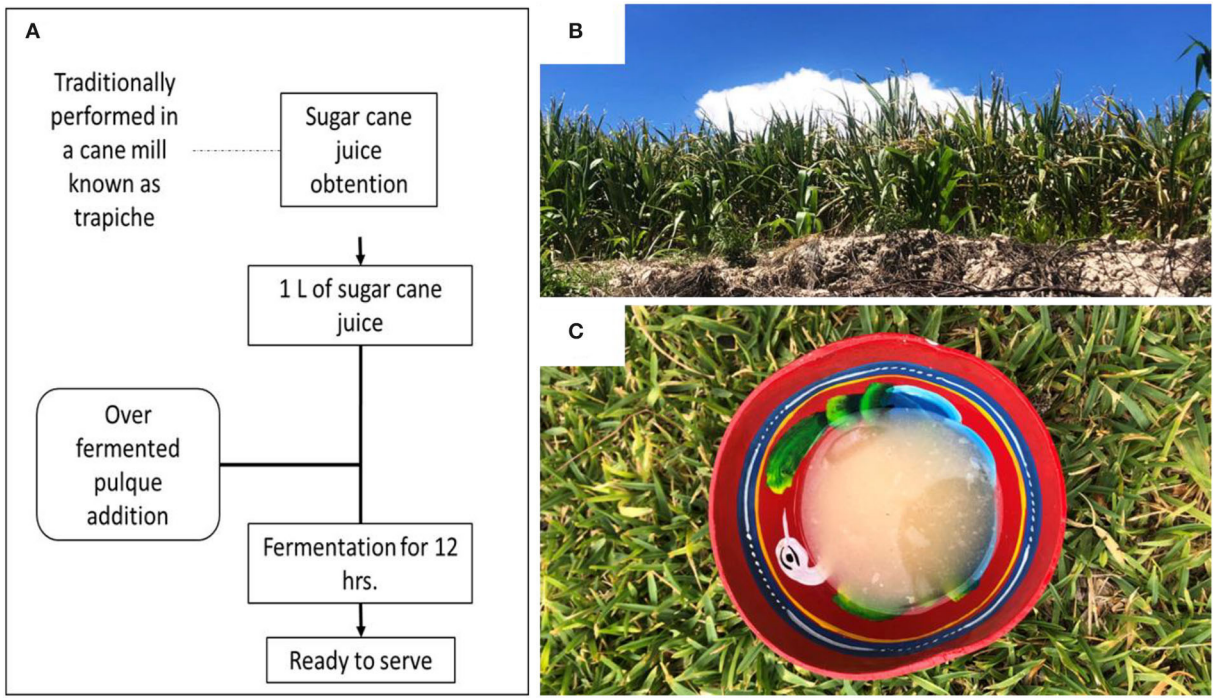

FIGURE 3
Lapo production in San Gabriel Chilac. **(A)** A scheme for its production. **(B)** Sugar cane production in the community of San Gabriel Chilac. **(C)** Actual *lapo* distributed in San Gabriel Chilac.

(Casas et al., 1997, 2001, 2008; Carmona and Casas, 2005; Ojeda-Linares et al., 2020). Additionally, other types of fermented cacti fruit juices have been recorded in other regions and were also consumed by the Aztecs and their tributary peoples from the North to the South of Mexico (Casas et al., 1997, 2001, 2008; Carmona and Casas, 2005).

Nowadays, *nochoctli* production in the region is in decay. Few producers remain, and almost all of them are in Los Reyes Metzontla, the place where traditional producers of fermented beverages such as *tolonche*, pulque, *lapo,* and *nochoctli* obtained their vessels to store and serve these products. Likewise, the containers used for fermentation are currently in disuse and have also been replaced with plastic bowls, glass jars, buckets, or aluminum pots. All these mentioned items were common in the daily lives of residents of the Tehuacán-Cuicatlán Valley and were mentioned as fundamental containers in distinct localities. They are used to improve the sensorial attributes of beverages (Figure 5A). Finally, the gathering of cacti fruits has also changed due to an increase in demand for fruits like *Pachycereus weberi or Hylocereus undatus*. The increase in demand in national and international markets has altered the gathering of these fruits for local consumption and changed the motivation to maintain this beverage. There has also been an increase in migration in the localities that produce *nochoctli*, which might endanger the transmission of the knowledge for producing this beverage to future generations. Several socio-economic pressures threaten the future of this beverage, but perhaps the most important is the low oral transmission about how to produce it, mainly because migration is a common factor affecting the localities studied.

3.3. *Tolonche*: The concurrence in a fermented beverage prepared with *Schinus molle* L. (Anacardiaceae) in the Americas

Among the traditional fermented beverages that we found in the Tehuacán-Cuicatlán Valley, *tolonche*, made from the fermentation of *S. mole* is particularly interesting. *Tolonche* involves the fermentation of *S. molle* fruits in localities of the Tehuacán-Cuicatlán reserve and nearby areas. According to the interviewees, this beverage has a particular fresh flavor that is somewhat spicy and astringent. According to them, this flavor reminds them of the woody flavor they get when *S. molle* seeds are chewed. It also has a particular dark golden color. Figure 4A presents a scheme that illustrates the production of *tolonche* in the research area.

The Peruvian pepper tree was introduced in Mexico during the colonial period. It is thought that this occurred during the

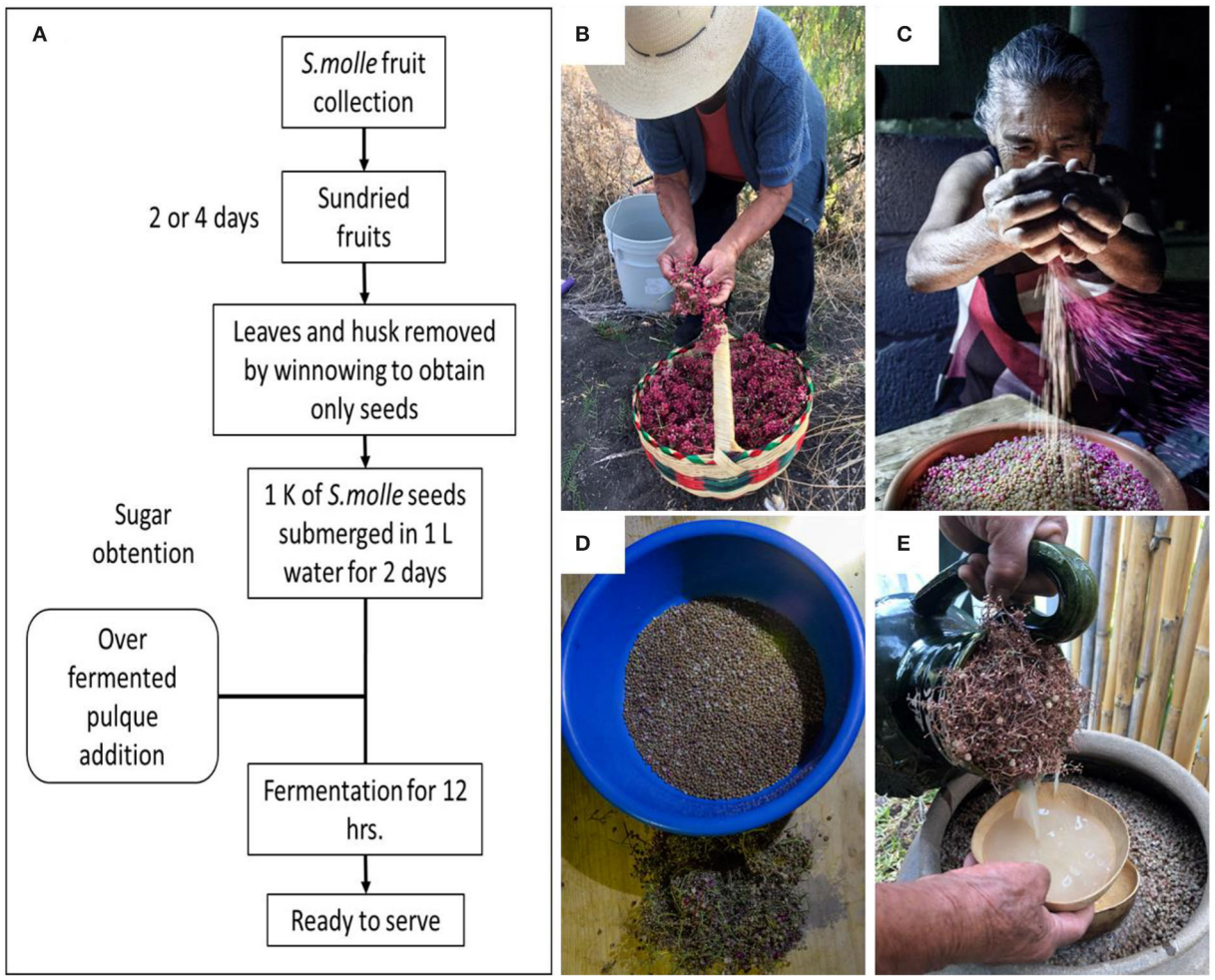

FIGURE 4
A general process for *tolonche* production. **(A)** A scheme for *tolonche* production; **(B)** Recollection of *S. molle* seeds; **(C)** Removing the hull from the seeds; **(D)** Watering the fruits of *S. molle* to obtain the sugar and flavor, and **(E)** Pulque addition for a shorter fermentation time.

viceroyalty of Antonio de Mendoza around 1540 because of the big interaction between the Peruvian regions and Mexico during those years (Kramer, 1957). Then this tree was introduced into the southwestern USA and southern Europe (Emory, 1589). However, in most of these areas, its use was basically ornamental. In contrast, this tree was mainly introduced into Mexico to have available wood in the central zone of the country. No previous records of this plant can be found in the exhaustive botanical work of Francisco Hernández. The Nahuatl name given to the tree is *Pelonquauitl* (*pelon*, "Peru," *quauitl* -tree), which also suggests that it was introduced by the Spaniards (De Sahagún and Monterroso, 1981). The use of this tree for medicinal purposes has vanished throughout the area that goes from the Andean region to Mesoamerica.

When we asked about other uses of *S. molle* in the communities of the Tehuacán-Cuicatlán Valley, we identified other applications. For instance, seeds are used as a substitute for pepper in the regional cuisine. Likewise, we also noticed that the sugary sap obtained when *S. molle* seeds are soaked in water was also used in the past as a substitute for sugar or agave mead when these products were not available. For instance, when people went to work with the cattle, they took the fruits and added them to their water to have a refreshing drink with the flavor of *S. molle* seeds. Nowadays, *S. molle* is used as firewood and in mescal production, where agave stems are cooked (Delgado-Lemus et al., 2014; Rangel-Landa et al., 2015; Torres et al., 2015). It is used because it brings important flavors to the final product. Likewise, it is a highly valued tree in the agroforestry systems (Moreno-Calles and Casas, 2010) rather than medicinal purposes.

Tolonche production starts with the recollection of *S. molle* fruits. To do this, *tolonche* producers in the localities of Chazumba and Zapotitlan make tours along the glens to identify *S. molle* trees with fruits. However, they do not select

FIGURE 5
Traditional vessels from the community of Los Reyes Metzontla for *tolonche* and pulque fermentation. **(A)** Old vessels for *tolonche* production, **(B)** modern vessels for *tolonche* production, also this clay containers are used for pulque production in small batches. **(C)** *Agave salmiana* plantations for pulque production in Los Reyes Metzontla community.

trees near the highway because the vehicles that pass through endanger the quality of the seeds. Furthermore, they only cut the branches with high abundance of pink-red fruits known as *bolilla* and avoid the green ones as color is seen as a sign of maturity (Figure 4B). Besides color, they also use the sounds that the fruits exhibit as another indicator for selection. They only collect the fruits that sound like a rattle when shaken, for they contain seeds that release more sugars and flavors. Once the seeds are removed from the branches and placed in a different container, they are then sun-dried for 2 days, which is especially encouraged by the temperature conditions of the locality. After this, they remove the leaves to avoid flavor affectation and the bitter taste they can give to the drink. *S. molle* contains dominant compounds that are particularly found in their leaves and fruits, such as monoterpene hydrocarbons, namely α-phellandrene, β-phellandrene, β-myrcene, limonene, and α-pinene. Although they exhibit lower toxicity in mice, these compounds have antimicrobial properties that might endanger the microbial community during fermentation. Nevertheless, further studies should be performed (do Rosário Martins et al.,

2014). After taking away the leaves, the fruits are winnowed to separate the husk that covers the seeds, and the rest is stored in another container (Figure 4C).

Once the seeds are collected, *tolonche* producers proceed to make the beverage. However, not all producers follow similar processes, for there are small differences in the production of *tolonche* among the localities of Zapotitlán and Chazumba once the seed recollection is over. For instance, in the locality of Zapotitlán, seeds are separated in a container where 1 kg of seeds is submerged in 1 L of warm water. After this, seeds are then hand-shaken to obtain a sugary liquid known by the producers as dulce de *bollilla* or *S. molle* sweet (Figure 4D). This process takes almost 12 h until they can obtain the flavors and sugars from the *S. molle* seeds. A short fermentation occurs during this time, which is noticed by the producers due to some bubbling. Then, the seeds are filtered, and the sugary water is placed in a container with 1 L of over-fermented pulque known as *fuerte* (strong) due to its high alcohol content. After they are mixed, a shorter fermentation occurs (4 h) before the beverage is ready to drink. In contrast, producers in Chazumba recollect 25 kg of *S. molle* seeds and place them in a fermentation vessel along with 30 L of water. Once everything is mixed, a liter of pulque is added to speed up the fermentation, and the vessel is left covered outside the house for 12 h (Figure 4E). In this sense, producers in Chazumba follow an ancient recipe for *tolonche* in which fermentation takes longer. In the case of Zapotitlán, the fermentation process is accelerated using pulque. As a matter of fact, the first fermentation took more than 72 h in previous times and either brown sugar was added, or another soaking was performed to increase the speed. Nowadays, *tolonche* displays a low alcoholic content (3–5% alcoholic content). Likewise, *tolonche* producers traditionally use ceramics from the locality of Los Reyes Metzontla to perform the fermentation. Prayers were also made as part of the ritual, and those pots were tenderly cared for to produce this beverage. To clean the vessels, producers performed different practices. For instance, *tolonche* producers maintain the vessel sealed and only clean them with plain water when they are going to be used for the next batch of *tolonche* (Figure 5B). Nowadays, this tradition is almost lost, and most producers use plastic containers and add pulque to obtain a more rapid fermentation.

It is important to highlight that most of the producers are women that learned the production process from their mothers. Historically, *tolonche* was a fermented beverage in this region that was mainly produced by women known as *toloncheras*. This product gave the women economic incomes. The current producers that remain argue that it is important that their families know how to produce this beverage, so they are teaching their kids and other interested people in the community. Recently, both producers started the production because of its symbolic association with family relationships and a sense of belonging to the community. On the other hand, they also point out that the main reason for the disappearance of this beverage is the easiness with which they can acquire other beverages that are accessible in the local store such as soda or beer. In contrast, the production of this beverage involves time for its production.

4. Discussion

As we have documented, the most common fermented beverages in the Tehuacán-Cuicatlán Valley are those prepared with *Agave* species. These results are consistent with the many uses that this genus has in Mexican daily life in several regions. For instance, it is commonly used as non-timber forest products and in the production of foods and beverages in most cases (Delgado-Lemus et al., 2014; Rangel-Landa et al., 2015; Torres et al., 2015; Torres-García et al., 2019). The genus *Agave* belongs to the Asparagaceae family, which comprises nearly 300 species most of them distributed in Mexico with high level of endemism (Good-Avila et al., 2006; Mendoza, 2007). The wide distribution of *Agave* and the long history of using its products favor the maintenance of traditional uses, such as preparation of mescal and pulque, which are relevant to semi-arid regions in the country and local communities like the Tehuacán-Cuicatlán Valley. However, the increasing demand of alcoholic beverages in the global markets and the consumer behaviors in alcohol consumption has arisen a demand of spirits as mescal (Jernigan, 2009), but compromising the environment and the culture of people that produce these beverages (Delgado-Lemus et al., 2014; Bowen, 2015; Lira et al., 2022). It is important to highlight the incorporation of other knowledges as the use of *A. karwinskii* for mescal production, although the production of this mescal is not yet expanded it might be gradually incorporated to local knowledge for future productions.

Pulque has become a keystone product for local diets in semi-arid areas. In these areas, pulque is not only consumed as an alcoholic beverage but also as a complement to dietary intake as well (Escalante et al., 2016). Although its production is reducing in several parts of the country, local producers keep and maintain the bodies of knowledge required to produce this beverage. The interaction between pulque producers in the Tehuacán-Cuicatlán Valley and producers outside the region has led them to incorporate new pulque production techniques, new strategies to have a more resilient production, and even foreign *Agave* species like the *A. inaequidens*, which has its distribution in other locations (Figueredo et al., 2014). The attempt to incorporate new substrates is motivated by the search for unique sensorial attributes of their final product, the need to cope with environmental and socio-economic pressures that might endanger the continuity of this product and the effort to maintain diversity in their agroforest systems. The latter has been characterized in different scenarios, including the

Tehuacán-Cuicatlán Valley in particular (Vallejo et al., 2015, 2019; Rendón-Sandoval et al., 2020).

The incorporation of the pepper tree and sugar cane after the Spanish conquest allowed for the production of *tolonche* and *lapo*. In this sense, these plant species helped diversify the fermented beverages in the region. This phenomenon has been seen in different fermented beverages around the country (Ojeda-Linares et al., 2021) and in several medicinal plants around the world (de Albuquerque, 2006). The incorporation of *S. molle* into fermented beverages and some of its other uses exemplify these phenomena from Peru to Mexico. However, these species were also relevant in other areas of the post-conquest economy. During this period, *S. molle* was used to obtain wood, sugarcane was used to obtain and process sugars that would later be taken to other markets, and other fermented beverages known as *aguardiente* were produced (Palomo, 1974; Lemus-Ruiz, 1999; Salvucci, 2010). However, because *S. molle* was not incorporated as a main ingredient in Mexican food, this product did not affect the local diet as significantly as the incorporation of other foods in similar conquests. In these other conquests, food reconfigurations changed drastically due to changes in the carbohydrate intake and the utensils or other pottery involved in the reproduction of local diets just as it happened with the Norman Conquest that changed England's food habits (Jervis et al., 2017). Nevertheless, the incorporation of sugarcane in the Mexican diet promoted changes such as the increasing availability of sweetened beverages or a wide range of products with added sugar that nowadays represent a national health problem in the Mexican population (Sánchez-Pimienta et al., 2016).

The shift in gathering processes due to an increasing monoculture production of species such as *Stenocereous* spp. and *Hylocereus undatus* may affect the continuity of *nochoctli* in different localities. In this sense, the continuity of the ecological traditional knowledge of its production will be limited because of how the production is now being directed to international markets. However, it is still possible that small batches will be produced due to the producers' desire to maintain this product because of its relation to local identity and gastronomic traditions, thus contributing to the preservation of the gastronomic patrimony and the safeguarding of the food security of the local population. These behaviors of the maintenance of certain varieties for homemade production have been recorded in maize production in different localities of Mexico (Arnés and Astier, 2019; Arnés et al., 2022). Nevertheless, other socio-economic pressures might also endanger the continuity of this product. For instance, the easy acquisition of sodas and alcoholic beverages like beer substitutes the consumption and production of these beverages mainly because these products are more easily accessed and produced. Similar results have been identified in different countries where traditional products are substituted with easily accessible industrialized products (Watson et al., 1996; Adams, 1998; Anukam and Reid, 2009; Tamang and Samuel, 2010; Chelule et al., 2014; Rousham et al., 2020). In general, this issue has been a significant pressure in the marginalization of fermented products worldwide.

Another crucial factor for the disappearance of these products is the lack of oral and practical transmission of knowledge that is needed for the production of these beverages. Traditional knowledge is largely transmitted through socialization within the household context. As a result, it requires family wholeness and considerable interpersonal relations to serve as a channel of intergenerational, cultural transmission that is mostly learned along gender lines (Hewlett and Cavalli-sforza, 1986; Ruddle, 1993). However, the production of *tolonche* in Zapotitlán Salinas has been dramatically reduced due to the low communication between parents and children and the decrease in oral and daily practical experiences. Despite this, the last *tolonchera* in Chazumba is trying in recent years to transmit this knowledge and maintain the beverage through different channels such as local festivities. In this sense, the maintenance of this oral transmission might allow the continuity of this product.

In Peru, different uses of *S. molle* have been recorded, such as the use of the leaves to combat ophthalmia (or "eye clouds") and rheumatism. Similarly, the trunk sap is also consumed as a purgative or diuretic remedy, while at the skin level it is used as an ointment for leg pain or swelling. Also, the bark is used as a dye because yellow color is obtained from it, although there is not much information about its production (Kramer, 1957). It might be possible that the loss of all these applications of *S. molle* might be due to the lack of oral transmission from the Peruvian locality through Mexican territory. Nevertheless, the use of *S. molle* seeds as a substitute for sugar in the localities might highlight the knowledge that the locals have of their environment.

Finally, containers also play an important role in the production of different traditional fermented beverages as they affect important sensorial attributes of the final products. For example, in the production of *kimchi,* a traditional fermented dish that is produced from a combination of vegetables in different Asian countries (Han et al., 2013), differences were found in the traditional vessels known as *Onggi* and plastic containers where microbial community change within its production. Likewise, red wine (González-Centeno et al., 2017) undergoes changes in aroma when it is fermented in barrels instead of steel tanks. Furthermore, changes in size and shape of cocoa containers have also been found to change the physicochemical attributes of cocoa during fermentation because they promote different temperatures and lead to pH changes (Indarti et al., 2011). For example, in Mexico, the *olla tesgüinera* (*Tesgüino* is a traditional fermented beverage produced by maize fermentation and olla, which means clay

container, see, Bye, 1980; Lappe and Ulloa, 1989; Ojeda-Linares et al., 2021) is considered fundamental to acquire the final product's unique flavor. Finally, to produce a traditional fermented beverage with prickly pear fruits, producers continue to use clay vessels, and changes in the perception and the microbial community have been recorded (Ojeda-Linares et al., 2020, 2022). Thus, vessels have been relevant in Mexican culture for fermented beverages in different regions. For example, in Mayan iconography, vases were represented with circles to represent the foam surmounting the container (Kerr, 2010; Stross, 2011). Also, in the Dresden Codex, page 35, there is a round-bottom Maya vessel marked with a "moon" sign. A semicircle of dots of foam above the rim suggests that this is a pulque vessel (Lounsbury, 1973).

5. Conclusions

Human cultural groups develop several strategies with the resources surrounding them, and the diversification and incorporation of different substrates to produce traditional fermented beverages in Mexico have been historically common. This can be seen throughout the fermented products of the Tehuacán-Cuicatlán Valley, here a constant exploration of the production of these beverages has maintained keystone products made from agave plants—such as pulque and mescal—and has promoted the incorporation of other species as *S. molle* and *S. officinarum* as a way of diversifying and innovating pulque preparations and promoting a resilient fermented landscape. However, traditional fermented products are silently disappearing from the foodscapes. The lack of reproduction from generation to generation of this knowledge constrains the maintenance of these complex foodscapes. *Tolonche* was a beverage that contributed to regional pride and cultural identity. Local efforts to revive this beverage reflect a strong relationship with the cultural heritage. On the other hand, the beverage known as *lapo* is almost lost, due to the lack of access to the means of sugar cane production, this beverage's revival is compromised. The detailed documentation and description of the preparation of these beverages is an effort to revive traditions around food systems and contribute to the rescuing of the *know-how* for producing of these beverages to help future generations cope with food security and sovereignty.

Author's note

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Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Written informed consent was obtained from the individuals for the publication of any potentially identifiable images or data included in this article.

Author contributions

CO-L conceived, designed, conducted, collected data, and wrote the manuscript. MV funded, conducted, and reviewed all versions of the manuscript. AC conceived, designed, advised, funded, drafted, and reviewed all versions of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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